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Faculty of Mining, Geology and Civil Engineering, University of Tuzla

FOR PUBLISHER
Prof.dr.sc. Kemal Gutić

EDITOR-IN-CHIEF
Prof.dr.sc. Rejhana Dervišević
Rudarsko-geološko-građevinski fakultet
Univerzitetska 2, 75000 Tuzla, BiH
Tel. +387 35 320 582
e-mail: rejhana.dervisevic@untz.ba, rdervisevic@gmail.com

TECHNICAL EDITOR FOR ONLINE EDITION
Prof.dr.sc. Tihomir Knežiček
Tel. +387 35 320 571
e-mail: tihomir.knezicek@untz.ba

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CONTENT

Prof. Rejhana Dervišević
Editor in Chief

Dear readers, it is our great pleasure to offer to a scientific and professional public insight at the new issue of "Journal of Faculty of Mining, Geology and Civil Engineering".

In more of six decades of our Faculty's work, besides education was also conducted a research work, achieved through numerous significant domestic, European and international projects that contributed to the development of Bosnia and Herzegovina economy, mining, geological and civil engineering profession and science. Today's organization of our Faculty with five departments emerged from all general departments for scientific and educational work and those are: Mining, Geology, Civil Engineering, Borehole Exploitation of Mineral resources, Safety Studies as well as 15 scientific fields at which scientific work has been carried out (science fields 1.5, 2.1 and 2.7; Frascati).

Work on promoting and raising the quality, as well as affirming this publication, is a great challenge for every editor in chief. To accomplish this goal, current scientific and professional work, as well as systematic work, and successful co-operation of members of the Editorial and Advisory Board, reviewers and authors are necessary.

We would like to thank to the authors that have chosen our Journal for publishing their papers. We expect to continue and extend cooperation in the future, by contributing to the affirmation of the publication, and promotion of scientific thoughts and scientific results as well.

Scientific Paper

CLAYS OF THE BUGOJNO COAL BASIN

Dževad Forčaković[1], Rejhana Dervišević[2],

SUMMARY

This scientific paper presents the results of clay exploration of the Bugojno coal basin, which contains very significant, but still insufficiently explored clay reserves.
Based on the determined boundaries of spatial distribution and on the results of research in the Bugojno coal basin, the presence of significant reserves of quality brick clays is evident.
This paper presents the general geological characteristics of the area, reserves and quality of clays and their spatial perspective. Clays represent the most economically important sediments into bazal zone ($^1M_{2,3}$) and Plio-Quaternary sediments (Pl,Q). In this area, brick clays are quality, fine sandy and semi-plastic, yellowish-brown, brown and gray, which belong to the group of semi-acid clays.
Based on the established qualitative-quantitative characteristics of clays in this area, there is no doubt that there is a real possibility of their quite widespread application in industry and construction.
Considering to the raw material base, brick clays, after coal, represent the most important mineral raw material of the Bugojno basin. It is very important to emphasize that only certain localities have been explored, so it is justified to forecast significantly larger reserves in the basin.

That is why it is necessary to increase the level of research, because the estimated reserves are very modest in relation to the potential possibilities. Due to the favorable geographical position, all the necessary preconditions have been realized for the development of large-scale industrial production with very favorable economic effects. Considering to the raw material potential, as well as the possibility of expanding the existing raw material base, the Bugojno coal basin is also important for the perspective development of clay exploitation.

Keywords: Bugojno coal basin, clays, raw material potential, qualitative-quantitative characteristics, spatial perspective.

1. INTRODUCTION

The Bugojno coal basin (Figure 1), where significant reserves of brick clays are situated, is located in the Vrbas valley between Gornji Vakuf and Donji Vakuf, on the area of about 130 km^2 [1]. The clays in the Ciglana clay pit, at the southeastern foot of the Gradina hill, have been exploited since before the Second World War until the aggression on BiH (early ‘90s), when production was broken. The annual production was about 6 million brick units and between 10-12 x 10^3 m^3 of clay being excavated.

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[1] Mr. Dževad Forčaković, RU Gračanica d.o.o. Gornji Vakuf-Uskoplje, Humac bb, Bosna and Herzegovina, dzevad7@live.com

[2] Prof. Rejhana Dervišević, Faculty of Mining, Geology and Civil Engineering, University of Tuzla, Bosna and Herzegovina, rejhana.dervisevic@untz.ba

Figure 1 Location of the Bugojno coal basin

The exploitation of clay at the Gradina clay pit was performed by the construction company Gorica from Bugojno, which included construction equipment, as well as a brickyard in which bricks, blocks and roof tiles were produced. After the aggression on Bosnia and Herzegovina, the Gorica was privatized and the production of brick products was never restarted.

The regional geological exploration were performed in the period from 1983 to 1987, when samples of clay were examined quantitatively and qualitatively within the projected density of coal exploration works [2], while detailed exploration were performed from 2014 to the end of 2018. In this period significant distribution of clays within the Pliocene-Quaternary sediments were confirmed [3].

2. GEOLOGICAL CHARACTERISTICS

In relation to the spatial distribution of coal deposits, the Bugojno coal basin (Figure 1) is divided into northwestern and southeastern parts [4]. Morphologically, it represents a high intermountain depression, caused by the lowering of the terrain between the northeastern Vrbas-Voljevac fault and southwestern Poric fault. The shape of the basin relief was greatly influenced by the river Vrbas, which flows through the central part of the basin.

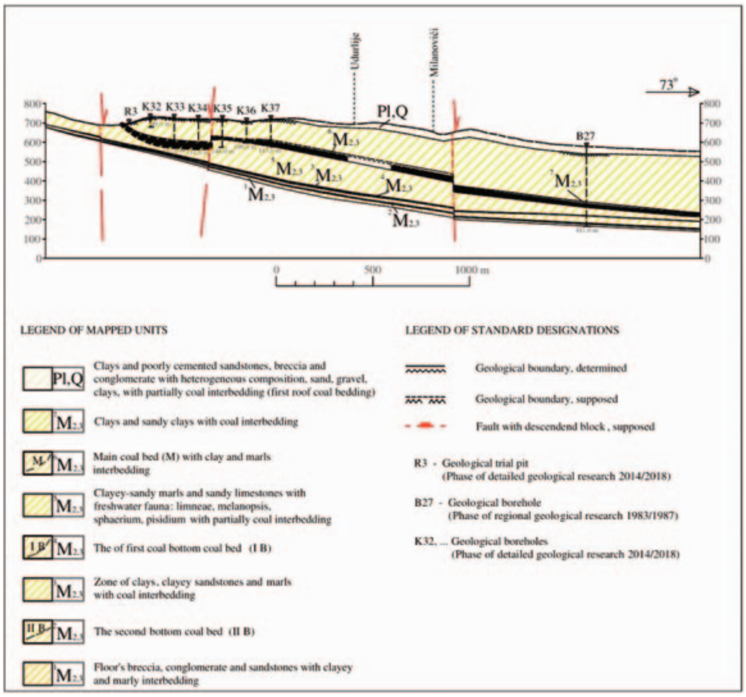

Figure 2 Characteristic geological cross-section A-B, (Forčaković Dž.)

The Bugojno basin is represented by sedimentary rocks of the Neogene and Quaternary. The Neogene sediments of the Bugojno basin represent freshwater lake formations, which lie discordantly over the older basis of mountain. This part of mountain consists of Middle Triassic and partly Upper Cretaceous sediments (northwestern part of the Bugojno basin) [3]. Quaternary sediments are also significantly represented in the eastern part of the basin, northeast of Bugojno.

The Neogene is divided on the Middle and Upper Miocene (Figure 2) and additionally separated into seven lithostratigraphic units/members basal units ($^1M_{2,3}$), the second floor coal bed ($^2M_{2,3}$), units of clays, clayey sandstones and marls ($^3M_{2,3}$), the first floor coal bed ($^4M_{2,3}$), unit of marly limestones and marls ($^5M_{2,3}$), the main coal bed ($^6M_{2,3}$), unit of clays and sandy clays ($^7M_{2,3}$) and Plio-Quaternary (Pl,Q) [2, 5, 6, 7, 8].

Within the basin exists several localities with brick clays: Prusac-Potkraj, Guvna-Karići, Milanovići-Udurlije, Jele-Karalinka-Kotezi, Gradina-Hodžinke (exploitation carried out until 1992), Kopčić, Vejići, Gornji Boganovci and Paloč. In the other localities the exploitation was not carried out.

3. NATURAL INDICATORS OF GEOLOGICAL-ECONOMIC VALUES

3.1. CLAY RESERVES

During the geological research of the Bugojno basin, clays were tested and suitable laboratory tests were performed. The analysis of brick clays within the contoured area of the Bugojno basin, as part of regional and detailed research, several localities were identified (Figure 3), in which about 50x10^6 m^3 of clay was estimated according to the average clay thickness of 16 meters.

In the shallow boreholes B-200 and B-201, south of Prusac, in the part of the terrain between the asphalt road Prusac - Bugojno and the stream Rigavac (Figures 1 and 3) in the floor of the second floor coal bed ($^1M_{2,3}$), gray-yellowish, fine sandy and semi-plastic clays were drilled. Their thickness is about 7.8 m (B-200) and 6.8 m (B-201). Below them there are deposits of gray, gray-ash and gray-green, in some places fine sandy, semi-plastic claystone with 26.7 m thick (B-200) to 60.6 m thick (B-201). In the claystones can be found rare and thin layers of lignite with 0,1-0,4 m thickness; fine-grained conglomerates of heterogeneous composition (magmatic rocks, quartz, shales, etc.) with clay cement; fine-grained breccia sandstones of heterogeneous composition with clay-carbonate cement; coal-marly limestone; rarely gray-ash carbonates (siderite?, ankerite) and limonite-pyrite masses with clay.

Considering the drilled thicknesses of clays and claystones (B-200 and B-201) and their frequent outcrops on the surface of the terrain around them, in this area of about 600,000 m^2, reserves of brick clays of over 4 million m^3 can be expected.

The newly discovered clay masses for bricks industries, which are similar quality with previously described clays, in the area between Milanovići and Karalinka (Figure 3) confirm that in the Bugojno basin exists potential clay reserves, which are significantly better in quality than those have been used in previous production. This perspectives area covers an area of 1,300,000 m^2, where brick clay reserves of over 9.5 million m^3 can be expected.

3.2. QUALITY OF CLAYS

The results of the mineralogical (DTA, TGA and Rö) granulometric and chemical analysis indicated that semi-plastic clays and claystones in shallow boreholes B-200 and B-201 represent a mixture of minerals ilite and kaolinite. Illite is significantly more represented than kaolinite (content varies from 10-15%). Besides of clay minerals, quartz predominates in their structure and in much smaller quantities getite, siderite, chlorite and calcite (only in borehole B-201 in the interval of 35.4-64.4 m) are represented [1].

The composition of individual fractions in these clays and claystones is presented in Table 1.

Table 1

Sample	Place of sampling	Interval of sampling	Composition of fraction (mm) %		
			0,2-0,02	0,02-0,002	ispod 0,002
KPGL-200/1	B-200	0,3-8,0	46	32	22
KPGL_200/2	B_200	8,0_34,7	59	20	21
KPGL-201/1	B-201	0,5-6,8	26	45	29
KPGL-201/2	B-201	6,8-35,0	44	32	24
KPGL-201/3	B-201	35,4-64,4	41	34	20
Average:			oko 43	oko 32	oko 23

From the presented granulometric data, it is noticeable that clays and claystones contain fractions of 0.02 and < 0.002 mm over 50%, which indicates that they belong to clays and claystones of medium dispersivity and plasticity.

The average chemical composition of clays and claystones from boreholes B-200 and B-201 is presented in Table 2.

Table 2

Analyzed components	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	H_2O^+	H_2O^-
Average content (%)	56,63	17,68	7,97	1,31	3,02	0,82	3,1	8,74	1,83

These deposits of clay and claystones are characterized by an increased content of Fe_2O_3 and K_2O, which increases the binding power and strength (Fe_2O_3) during the production of brick products and gives the necessary plasticity to the clay "dough" (K_2O). The content of one of the most harmful components of CaO in clays and claystones is very low. These components are represented in the form of fine particles that are equally represented throughout the mass. Considerting that these clay and claystones contain Al_2O_3 below 30%, these clay sediments belong to the group of semi-acid clays (from 15-30 % Al2O3). The results of the previous mentioned tests of quality of these clays and claystones indicate the possibility of their successful application in the brick industry. Research has shown that in the Bugojno basin exists quality brick and ceramic clays. Those types of clays were drilled on the exploration borehole B-22 (Vejići) at intervals from 5.4 to 16.0 m and from 18.5 to 27.0 m, and also on the borehole B-23 (Gornji Boganovci), at intervals from 4.8 to 11.65 m and from 14.65 to 26.2 m. Chemical analysis of clay from borehole B-23 from the interval of 14.65-26.2 m is showed these contents: SiO_2 44,90 %, TiO_2 1,35 %, Fe_2O_3 12,97 %, Al_2O_3 21,96 %, MnO 0,25 %, MgO 0,39 %, CaO 3,90 %, Na_2O 0,53 %, K_2O 1,61 %, H_2O- 4,14 %, H_2O+ 10,35 % and P_2O_5 1,20 %. The obtained composition shows that the harmful component is very low and that it is a ceramic (pottery) clay of excellent quality [1].

3.2.1. Semi-plastic to plastic clay

Explorations carried out in the following areas: Bijeli put-Ograde (about 1.5 km south of Prusac), north of Karadže, in the road Prusac - Guvna at the site Karići (east of the borehole BP-1); west of the settlement of Milanovići, as well as on the road southeast of Karalinka, a large number of outcrops of semi-plastic to plastic clays were registered. These types of clay were also discovered by the RP-1b trial pit.

Except of the gray-green color of the clay in the BP-3 borehole, the clays of other areas represent a mixture of yellow-brown and gray clays with a higher volume presents of yellow-brown clays. The clays of other areas, as well as in the BP-3 borehole, probably correspond to the oldest parts of the Pliocene-Quaternary (Pl, Q) formations. Considering to the distribution and frequent outcrops of these clays, which are interesting for the ceramics industry, it is reasonable to expect that economically significant reserves can be proven by detailed geological research.

Samples of clay was taken from the following localities: Karići, Milanovići, Hodžinke and from the BP-3 borehole and their chemical and mineral composition (DTA, TGA, Rö) was tested. On the samples from the Karići locality, as well as from the BP-3 borehole, in addition to the examination of chemical and mineral quality, the examination of their granulometric composition was also performed. The results showed the following characteristics:

a) Mineral composition

Semi-plastic and plastic clays from the above-mentioned areas, as well as from the BP-3 borehole, represent a mixture of minerals of the kaolinite or illite-montmorillonite group. The content of illite-montmorillonite is from 35-50 %, and the content of kaolinite is lower: 7-30%. Participation other minerals in their structure: quartz (20-35 %), plagioclase (5-20 %), rarely siderite 3 % (only in the KGP-3/1 sample).

Details about the mineral composition of these clays are in Table 3.

Table 3

Sample	Place of sampling	Interval of sampling	Location	Mineral composition (%)		
				Kaolinite	Ilite-montmorilonite	Other minerals
PGK-1	izdanka		Karići-Prusac	30	35-40	Quartz (20-25) Plagioclase (5-7)
PM-375	izdanka		Hodžinke	5-7	40-50	Quartz (20-25) Plagioclase (10-20)
JS-274	izdanka		Milanovići	7-8	35-45	Quartz (25-35) Plagioclase (10-20)
KGP-3/1	BP-3	115,90-134,00	Kukuruska-Guvna	14	35-45	Quartz (25-35) Plagioclase (7-8) Siderite (?) 3

By comparing the mineral composition of these clays with the mineral composition of known semi-plastic to plastic clays, which are used in the ceramic industry, it can be concluded that their mineral composition is not so different.

b) Granulometric composition

The composition of individual fractions in the clays of the Prusac-Guvna road (Karići locality) and from the BP-3 borehole is presented in Table 4.

Table 4

Sample	Place of sampling	Interval of sampling	Location	Composition of fraction (mm) u %		
				0,2-0,02	0,02-0,002	ispod 0,002
PKG-1	izdanka		Karići-Prusac	15	35	50
PKG-3	BP-3	115,90-134,00	Kukuruska-Guvna	17	38	45

The presented granulometric data show that the clays of these localities contain fractions of 0.02 and < 0.002 mm over 80%, which indicates that these clays belong to a clays with higher dispersivity and plasticity.

c) Chemical composition

The chemical composition of clays from the area in Karići, Hodžinki, as well as from the BP-3 borehole is presented in Table 5.

The presented chemical composition of clays from the Bugojno basin, with the exception of higher content Fe_2O_3 and lower content Al_2O_3 (samples PM-375, JS-274 and KGP-3/1), is not so different from standard semi-plastic and plastic clays which used in the ceramic industry. Considering that these clays contain Al_2O_3 < 30%, they belong to the group of semi-acid clays (from 15-30 % Al_2O_3).

Table 5

Sample	Place of sampling	Interval of sampling	Location	Content (%)								
				SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	H_2O_+	H_2O_-
PKG-1	izdanka		Karići-Prusac	53,66	27,42	3,74	1,08	2,33	1,13	1,63	2,80	-
PM-375	izdanka		Hodžinke (D.Vakuf)	54,40	23,56	6,08	1,37	2,45	0,73	4,57	6,69	1,25
JS-274	izdanka		Milanovići	56,16	20,79	5,61	1,56	1,36	0,83	4,09	6,13	0,97
KGP-3/1	BP-3	115,9-134,0	Kukuruska -Guvna	62,74	21,78	4,99	1,17	1,77	0,73	3,13	6,80	0,70

The quality analyzes of these clays certainly indicate the possibility of their application in ceramics, which should be verified in the phase of detailed geological research and verified by conducting dedicated technological tests, both in laboratory and industrial scope.

3.2.2. Brick clays

Numerous outcrops of yellow-brown and brown, sometimes less, sometimes more fine sandy clays have been registered in the area of Milanović, as well as in the wider area of the inactive clay pit of Ciglana on the Gradina hill in Bugojno. The discovered clay deposits are typical brick clays. These clays belong to the older parts of the Pliocene-Quaternary sediments.

In the area of the village of Paloč, on the periphery of Gornji Vakuf, for the Bugojno construction company Gorica, exploratory geological researches were performed by company from former iron ore mining Radovan (Gornji Vakuf). Clays of good quality were drilled and were used as a brick material until 1992. The sediments that make this part of the terrain are probably Plio-Quaternary.

4. PERSPECTIVE OF THE RESEARCH AREA

Considering to the perspective of clay resources, in the Bugojno basin (Figure 3) three categories can be separated:

- Very perspective areas - the most economically important in the basin,
- Perspective areas - economically significant in the basin, and
- Areas with uncertain perspective - without proven economic significance.

Very perspective areas which have the most economically important in the basin are: Prusac-Potkraj (average thickness tavg. = 7.3 m), Guvna-Karići (tavg. = 7.0 m), Milanovići-Udurlije (tavg. = 49 m), Jele-Karalinka-Kotezi (tavg. = 14.75 m), Gradina-Hodžinke (tavg. = 7.15 m). The average thickness of clay deposits in this category is 17 meters (for the calculation of the average thickness of brick clays were taken about 218 drilled boreholes).

Perspective areas which have economically significant in the basin are: Kopčić (tavg. = 7,5 m), Vejići (tavg. = 20,1 m) i Gornji Boganovci (tavg. = 18,2 m). The average thickness of clay deposits in this category is 15,3 meters.

Areas with uncertain perspective without proven economic significance are located in village Paloč. There are only observed clay outcrops and there hasn't data on the thickness of these deposits.

Considering to the areas where Pliocene-Quaternary deposits (Pl, Q) are presented, which contain clays, except of the narrow belt Prusac Potkraj which belongs to the middle and upper Miocene sediments (1M2,3), it can be confirmed with certainty that is possible to prove balance reserves of over 50 million m^3 of quality brick clays in this area. The isolated areas (Figure 3) represent potential clay pits.

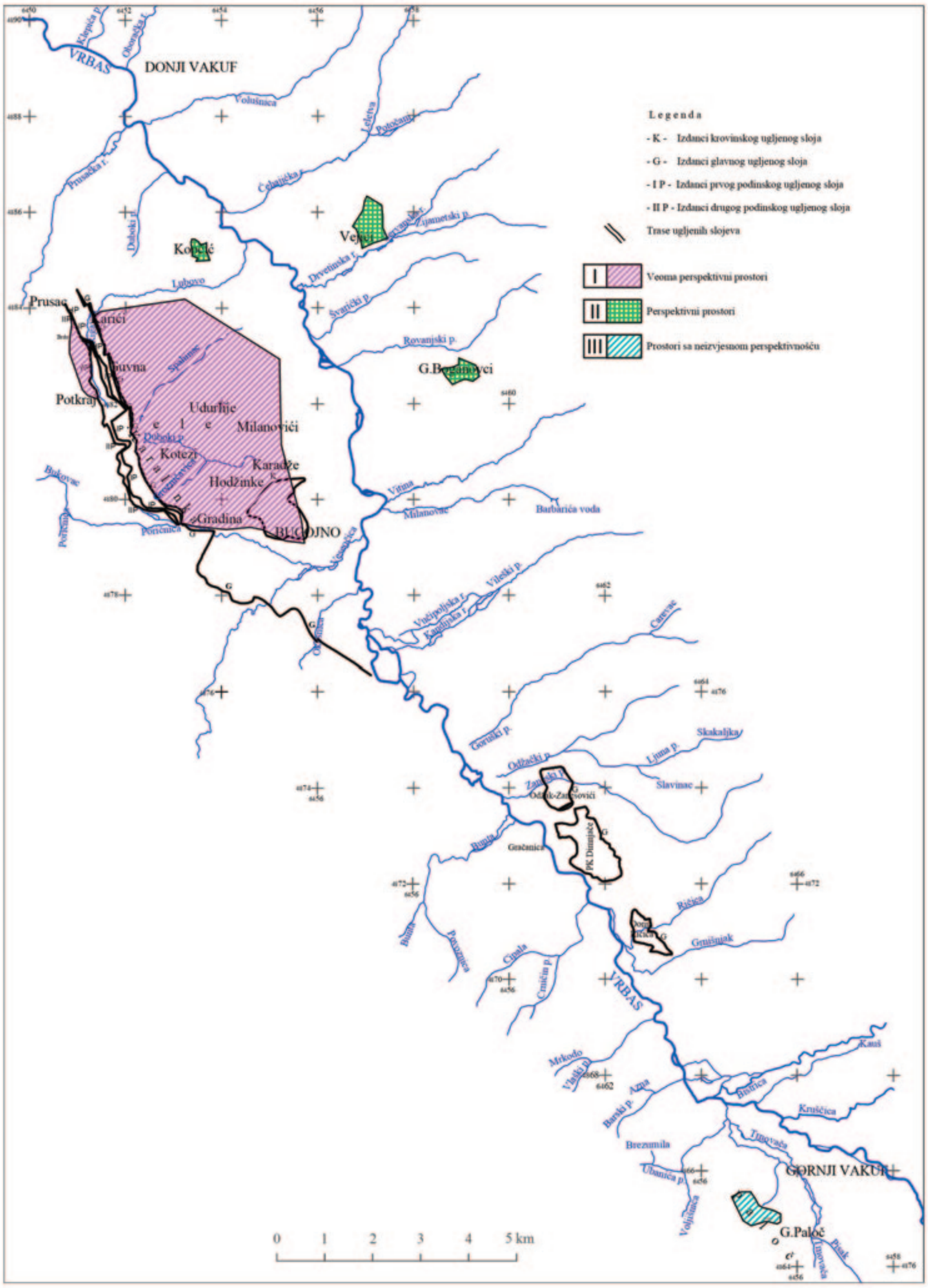

Figure 3 Map of the perspectivity of clays of the Bugojno basin (Forčaković Dž.)

5. CONCLUSION

The analysis of brick clays of the Bugojno basin identified parts of the basin that have extremely high potential and which it is possible to realize open pit exploitation of clays. The explored and verified reserves are very small in relation to the potential possibilities. The qualitative characteristics of the clays obtained by the different type of researches represent a reason to plan detailed geological researches. Geological and mining conditions are favorable, which could indicate the potential and perspective of the entire coal basin.

Proven economic and potentially exploitation reserves of brick clays suppose possible exploitation and opening new mines. It's very important to emphasize that the ore-bearing capacity of the basin is shown at a low level of geological exploration. Besides of the necessary activities for the research of brick clays of the Bugojno basin and the preparation of the necessary mining, technical and investment documentation for the opening of new mining plants, it should be paid attention to the social factor (urbanisation of this area).

Until now, brick clays are not exploited in this basin, although their reserves, after coal, have the greatest economic value in this area. The presented data indicate the great potential and perspective of brick clays of the Bugojno basin, which is the basis for additional research, justified and economical exploitation of clays and the possibility of choosing priority areas for exploitation. Considering to the favorable geographical position of this area, all the necessary preconditions for the development of industrial production have been realized, with high favorable economic effects.

Based on modern views and assessments, comparing with the conditions on similar deposits, it can be concluded that the general geological and technical-exploitation factors are relatively favorable and indicate a possible profitable exploitation of the deposit.

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Scientific Paper

GROUNDWATER AS A GEOMANIFESTATION OF STRUCTURAL-TECTONIC RELATIONS IN THE KRIVAJA RIVER BASIN

Ferid Skopljak[1], Ćazim Šarić[2], Izet Žigić[3], Dinka Pašić-Škripić[4]

SUMMARY

Geomanifestations are distinct manifestations of the current or past geological process. They most often indicate specific geological conditions and therefore can be important sources of information for a better understanding of geological conditions in an area. Some of the most common geomanifestations are seismotectonic activity, horizontal and vertical tectonic movements, gas occurrences, local conditions and differences in the physical and chemical composition of groundwater, thermal anomalies, occurrence of mineral deposits, hydraulic character of aquifers, pressure zones and special geomorphological characteristics.

Geological and hydrogeological studies and research in the Krivaja river basin have identified a number of geomanifestations such as seismotectonic activity, deep Krivaja fault, large-scale coverings, occurrences and deposits of metals, occurrences of thermal and cold water sources in the immediate vicinity, and CO_2 gas occurrences.

Our first assessments during hydrogeological research of these terrains showed that the groundwater in the Krivaja river basin represents a first-class geomanifestation for a better understanding of extremely complex structural-tectonic relations, and the evolution of geological terrain processes that gravitate to the Krivaja river. By analyzing the geological, structural-tectonic and hydrogeological characteristics of the terrain, and examining the chemical and isotopic composition of groundwater, we came to the conclusion that structural-tectonic relations predisposed the overall hydrogeological relations in this area, and that structural-tectonic relations are of paramount importance for thermal and cold waters genesis in the Krivaja river basin. Sources of thermal and cold waters that appear in the Krivaja river basin, as a rule, appear almost in the immediate vicinity, as an important geomanifestation indicate the presence of two structural floors in the terrain, in which Triassic carbonates of lower structural floors are aquifer of thermal waters and Triassic carbonates of upper structural floors are aquifer of cold groundwater.

Keywords: geomenifestations, groundwater, structural-tectonic relations, Triassic, Durmitor overburden, Bosnian flysch, Krivaja fault

1. GEOGRAPHICAL LOCATION OF GROUNDWATER SOURCES

Groundwater sources in the Krivaja river basin appear from Knežina in the southeast through Olovo to Kovačići in the northwest (Fig. 1). The distance between the springs in Knežina and Kovačići is over 30

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[1] Prof. Ferid Skopljak , Geological Survey Federation of the Bosnia and Herzegovina, Ustanička 11, Sarajevo, Bosnia and Herzegovina, fskopljak@yahoo.com

[2] Mr.sci. Ćazim Šarić , Geological Survey Federation of the Bosnia and Herzegovina, Ustanička 11, Sarajevo, Bosnia and Herzegovina, cazim8@gmail.com

[3] Prof. Izet Žigić, University of Tuzla, Faculty of Mining, Geology and Civil Engineering, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, izet.zigic@untz.ba

[4] Prof. Dinka Pašić-Škripić , University of Tuzla, Faculty of Mining, Geology and Civil Engineering, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, dinka.pasic@untz.ba

km, which, in addition to the almost linear layout, indicates a certain regularity of their appearance. The sources of thermal water in this area are Toplik in Knežina, Podlipnik, Zelen vir in Olovo, Terme in Olovo, Solun, Kovačići, Orlja and Očevija, while the sources of cold water are Knežak in Knežina, Vrutak in Podlipnik, Zelen vir in Olovo, Jasen in Olovo, Orlja in Orlja, Vrela in Očevija, Studenac in Solun and Krstac in Kovačići.

Fig 1. Geographical position of thermal and cold springs in the Krivaja river basin, M 1: 200 000

2. GEOLOGICAL STRUCTURE

Paleozoic, Triassic, Jurassic, Jurassic-Cretaceous and Quaternary formations participate in the geological structure of the terrain in the Krivaja river basin (Fig. 2).

Paleozoic rocks have been isolated in only one small area near Brgule northeast of Vareš, where they are represented by quartz-mica-chlorite shales, clay shales, meta-sandstones and lydites. These deposits in the valley of the river Krivaja certainly lie deep below the Triassic deposits.

The Triassic is represented by all the floors of the Lower, Middle, Middle-Upper and Upper Triassic.

The Lower Triassic deposits were developed from Rakova Noga and Podlipnik in the southeast through Krivajević to Očevija in the northwest. The Lower Triassic is divided into two superposition packages; the lower package ($^1T_1$) represented by banked and massive quartz and quartz-mica sandstones with a total thickness of 300-500 m, and the upper package of the Lower Triassic ($^2T_1$) in which the sandstones of older verfen gradually transition into a series of marls, sandstones and limestones with Campil fauna stage). They gradually turn upwards into Anisic limestones. The thickness of this Lower Triassic package is about 200 m.

The Middle Triassic is represented by deposits of Anisiac and Ladinic which are more widespread from Rakova Noga in the southeast through Bijambara to Očevija in the northwest, and subordinate to the right side of Bioštica in the Mangurić region. Anisian, predominantly limestone deposits, about 400 m thick, lie normally over Lower Triassic deposits. Ladinic deposits were developed in two superposition packages; the lower package ($^1T^2_2$) formed by corneas, clays, tuff sands, marls and, subordinately, limestones with a total thickness of about 100 m, and the upper package ($^2T^2_2$) composed of reddish plate limestones, then knurled limestones interlayers of corneas, total thickness about 150 m. Manganese deposits have been formed in limestones with hornblende in the valley of Ljubina, in the region of Ivančići and Čevljanovići.

The deposits of the Middle and Upper Triassic have the greatest distribution on the left side of the Bioštica river above Olovo, from Imamovići to Dolovo, and northeast of Knežina. They are represented mainly by thick packs of bank and massive limestones, which are about 450 m thick.

The Upper Triassic is represented mainly by limestones, which are more widespread in the direction Medojevići - Kruševo - Prgoševo. Numerous occurrences and deposits of cerusite have been registered in the Upper Triassic limestones. The thickness of the Upper Triassic limestones is about 500 m.

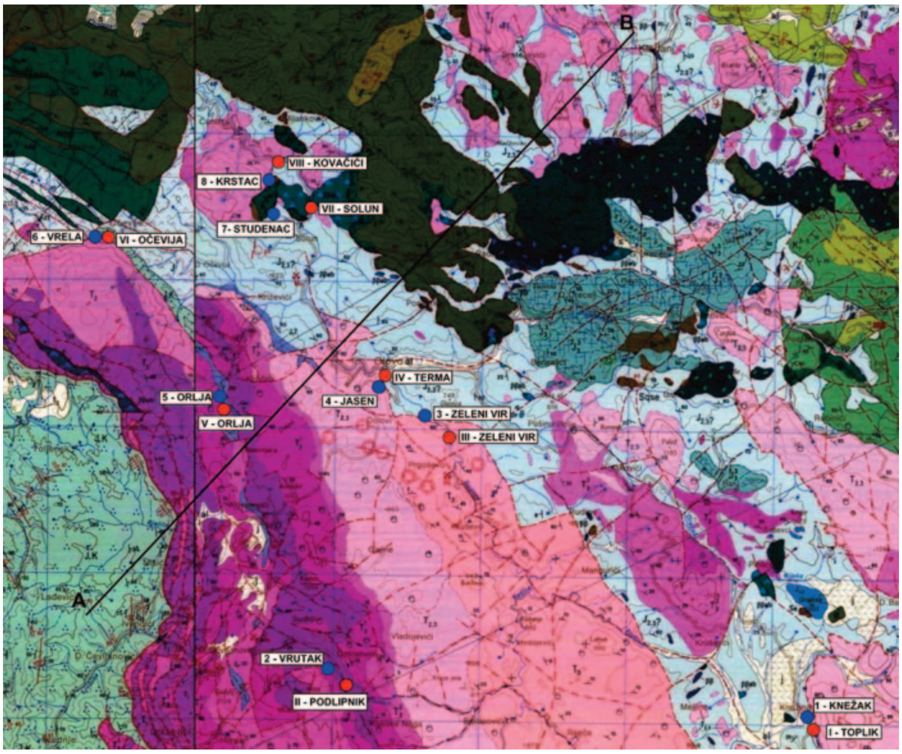


Fig 2. Geological map in the Krivaja River basin (BGM M= 1:100 000, sheet Vlasenica, Strajin, V. et al.,1972.)

Lower Jurassic (J_1)

Lower Jurassic marly-limestone sediments are provided in the form of narrow belts 200-500 m wide; from the river Orlja in the northwest through Krivajevići and Čevljanovići to the river Rača in the southeast. Almost parallel to this belt, somewhat further north, between Očevija and Križevići, there is another belt of these deposits. Superpositionally, these deposits lie between the steep development of the Middle and Upper Triassic and the Jurassic volcanogenic-sedimentary formation, and are assumed to belong to the Lower Jurassic. In addition, apart from radiolarians, no other fauna was found in the sediments of this unit. Their structural position is rather unclear, but it can be reasonably assumed that it was caused by the "Durmitor overburden". The thickness of the Lower Jurassic sediments is about 100 m.

Middle – Upper Jurassic ($J_{2,3}$)

The formations of the Middle-Upper Jurassic are represented by a volcanogenic-sedimentary formation (some authors call this formation a "diabase-hornblende formation") which has a large distribution in the Krivaja river basin; from Knežina in the southeast to Kovačići in the northwest, where they participate in the structure of the Konjuh and Zvijezda mountains. The volcanogenic-sedimentary formation of the Jurassic (Olujić, J. et.all 1978; Strajin, V. Et. All 1978) is built of various sedimentary rocks (sandstones, clays, rarely hornblende and subordinate conglomerates, breccias), and in addition they also contain large masses of igneous rocks (ultramafites with basic companions, the so-called ophiolites, are particularly common), with relatively smaller amounts of metamorphites. The thickness of the volcanogenic-sedimentary Jurassic formation is estimated at over 1,000 m.

Upper Jurassic (J_3)

The Upper Jurassic deposits have been isolated in teh vicinity to Olovo in the Stupčanica basin, where they lie discordantly over the volcanic-sedimentary Jurassic formation. Here the Upper Jurassic is developed into two facies, clastic and carbonate; the clastic facies belongs to the lower (older) package, and the carbonate, to the upper (younger) one. The clastic facies of the Upper Jurassic is 200-250 m thick and the carbonate facies is about 400 m thick.

Jurassic – Cretaceous (J,K)

Jurassic-Cretaceous deposits have the greatest distribution in the wider region of the Nišići plateau, while a narrow belt was discovered between Očevija and Orlja. Jurassic - Cretaceous is represented by thick complexes of flysch sediments ("Bosnian flysch"), which include limestone breccias, calcarenites, sandstones, marls and clays. The thickness of the Jurassic-Cretaceous flysch has not been established in this area, but it is estimated at up to 600 m.

Quarternary

Quaternary deposits have been identified in the Krivaja valley and its main tributaries Bioštica and Stupčanica. They are represented mainly by alluvial deposits (al), which are composed of large rocks, gravel and sands, which are in some places more or less clayey.

4. STRUCTURAL-TECTONIC CHARACTERISTICS

The terrain in the Krivaja river basin is characterized by a very complex tectonic structure that has not been studied in detail and comprehensively. The structural-tectonic relations of this area are covered mainly by regional considerations of the geotectonic structure of Yugoslavia and later Bosnia and Herzegovina, with often diametrically different understandings of individual authors regarding the geotectonic regionalization of this part of the Dinarides; starting with J. Cvijić (1900-1924), L. Kober (1913-1929), F. Kosmat (1924), V. Peković (1931), K. Petković (1961), W .Medwenitsca-B.Sikošek (1965), M.Miladinović (1972), D.Dimitrijević (1974), A.Grubić (1980), M.Andjelković (1982), M.Herak (1991) , S. Čičića (2002), H.Hrvatović (2006), S.M Schmid (2008), M.v. Unen (2019), et al.

In this paper, an analysis of almost all published works was performed, which, through the consideration of geotectonic regionalization and structural-tectonic relations, included the area in the Krivaja river basin. Special emphasis was given to the most important works that were more closely related to the structural-tectonic structure of this and neighboring terrains on the basis of which, with the analysis of the genesis of thermal and cold groundwater, the interpretation of structural tectonic relations in the Krivaja river basin was performed.

According to the BGM sheet Vlasenica (Strajin, V. et.all 1978) and Vareš (Olujić, J. et.all 1970), the space in the Krivaja river basin belongs to the structural-facial units: "Romanija", "Central ophiolite zone" and "Drina-Ivanjica Paleozoic".

The structural-facial unit "Romania" is represented in this area by the " Romanija Tectonic unit ", which can be traced from Romanija through Olovo to Vareš. The southern border of this unit is a cover built mainly of Triassic clasts and limestones, pulled over the tectonic units "Ozren" and "Nišići-Crepoljsko", and partly over the zone "Sarajevo-Banja Luka flysch". The northeastern boundary is mostly faulty and discordant with the volcanic-sedimentary Jurassic formations. This unit represents an anticline limb with a slight sinking to the northeast, which is separated into several smaller blocks with a general fall to the northeast, concordant to the faults of the Dinaric direction and perpendicular to the Dinaric direction.

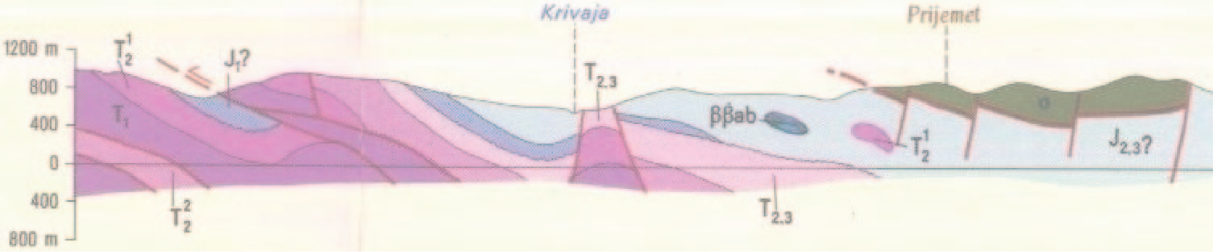


Fig 3. Cross section profile along the Krivaja River (Source: BGM Sheet Vlasenica, M 1:100.000, Strajin.V.et.all 1978.)

The structural-facies unit "Central ophiolite zone" was built mostly from the rocks of the Jurassic volcanic-sedimentary formation. In addition to these, this formation is accompanied by Jurassic-Cretaceous clastic creations ("Pogarska facies", etc.). Triassic sediments are subordinated (northern parts of the Vareš Triassic structure), or they come along fault zones within the Jurassic volcanic-sedimentary formation. The Jurassic volcanogenic-sedimentary formation is highly tectonised, and in some parts it represents a melange formation. Within the "Central Ophiolite Zone", four smaller units have been singled out: "Krivaja-Konjuh Ultramafic Massif", "Southwestern Rim of Krivaja-Konjuh Massif", "Pogar-Ponijeri Syncline" and "North Limb of the Vareš Structure". The "central ophiolite zone" has a complex composition in which the dominant role of sediments is played by sandstones, clays and hornblende, and olistolites of Triassic limestones. Of the igneous rocks, the most common are the ultramafites (peridotites) of Konjuh, followed by basic rocks, most commonly diabases, spilites and hornblende and amphibolites of meta-morphic rocks. On the profile of BGM sheet Vlasenica, it can be noticed that the formations of the "Central ophiolite zone" were isolated in the floodplain of the Middle Upper Triassic deposits without the tectonic character of the contact (Fig. 3).

The structural-facial unit "Drina-Ivanjica Paleozoic" is represented by a lower order tectonic unit "Han Pijesak-Devetak-Knežina". This unit is built of Triassic limestones that lie tectonically across the "Central Ophiolite Zone". Structurally, these are tectonic sheets of the Drina Paleozoic rim, which at the time of the closure of the central Bosnian ophiolite space were torn from the rim and moved over the ophiolite complex as tectonic sheets, and partly incorporated into it as olistolites. Individual blocks of this unit were separated (torn off) by faults and transported longer.

In the wider area of the Zvijezda mountain Miladinović, M. (1972) singles out "autochthonous" terrains and "drawn" masses of sedimentary and igneous rocks .) from the direction of Sarajevo as an extension of the cover (Durmitor, prim. Auth). Indigenous terrains consist of thick series of Jurassic-Cretaceous flysch that are intensively folded and cover the terrains between the upper streams of Ljubina and Misoča River, over Nišić and further towards Vareš, Zgošća and Vranduk. According to Miladinović, the "Durmitor overburden" in these terrains includes layers of the Lower and Middle Triassic, complete Jurassic as well as ophiolites and other igneous rocks. The deposits of the Lower and Middle Triassic are pulled over the Jurassic-Cretaceous flysch, and the Triassic area of Vareš and Borovica is the most protruding northwestern part of the "Durmitor overburden". What is interesting that Miladinović includes the ophiolite massif of Konjuh in the "Durmitor overburden"!

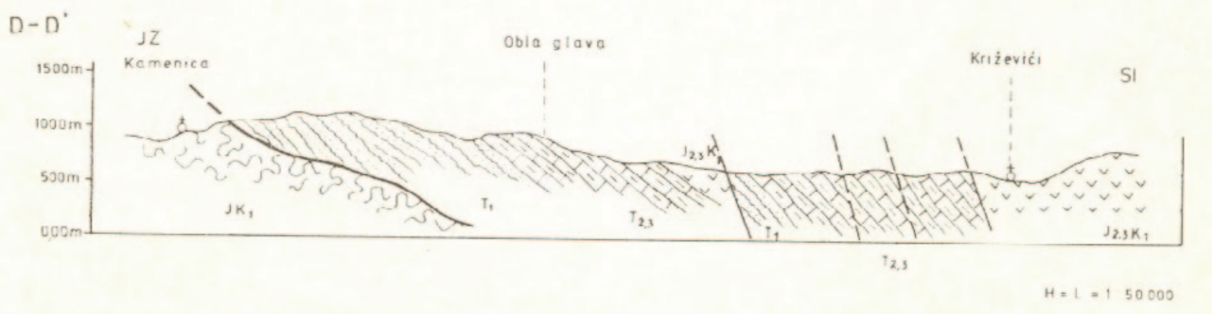


Fig 4. Cross section profile along the Zvijezda mountain and the Krivaja River (Miladinović, M. 1972.)

According to M. Anđelković (1982), the area in the Krivaja river basin is part of the "Ibar zone", "Drina zone", "Lim zone" and "Bosnian zone".

The "Ibar zone", ie the "Ibar mesoshariaz", mostly includes the terrain between Olovo and Kladanj. In their composition, the largest massif of ophiolite is known as the "Krivaja-konjuh massif", which is joined by the creations of the volcanogenic-sedimentary series (middle-upper Jurassic, prim. Auth.) with shelf titon-beria limestones. According to Anđelković, the basis of the ophiolite-radiolaritic complex are Triassic and Liasic-Doger cephalopod limestones, while transgressively and discordantly over them, as molasses formations, lie Maglaj clasts and carbonate-clastic deposits of Barem and Apt, and Upper Cretaceous formations. p.335). Northwest of Vareš, this ophiolite complex is pulled over the "Bosnian zone" flysch.

According to Andjelković (p. 349), parts of the terrain between Kladanj, Olovo, Sokolac and Vlasenica belong to the "Drina zone", ie the "Drina Mesosharia". The "Drina Mesoshariah" is represented by a single carbonate Triassic plate that was pulled over the "Ibar Mesochariah" during the Lower Cretaceous (youth phase). With subsequent tectonic movements, this Sharia plate, built of Middle and Upper Triassic carbonates, was broken into particular blocks that were modified by erosion and represent smaller or larger tectonic clips in the region of Knežina, Olovo and Kladanj, etc.

According to Andjelković (p. 365), the "Lim zone" includes "Vareška navlaka" (Vareš overburden) which stretches from Borovica in the northwest through Vareš, Zvijezda and Ozren further to the southeast through Romanija and Prača to Lim (this overburden is called the "Durmitor overburden" in some papers). prim.auth.). The "Vareška navlaka" includes subordinate Paleozoic, and mostly Triassic creations that were pulled over from the Borovica to Ozren (Sarajevo) to the flysch of the "Bosnian zone". The inner structure of this overburden is represented by the "Vareš anticlinorium" with normal, flat and overturned folds, broken into special cleavages that are pulled over each other in the southwest direction. According to Andjelković, the "Vareš overburden" in the northeast sinks below the "Ibar Mesochariah", which can play a major role in hydrogeological conditions and the appearance of cold and thermal waters in the Krivaja river basin. In some places in the Krivaja river basin, the "Ibar mesoshariah" (ophiolite-radiolaritic complex) is pulled over the "Vareš overburden", as is the case in the region of Zvijezda mountain near Vareš (Fig. 5).

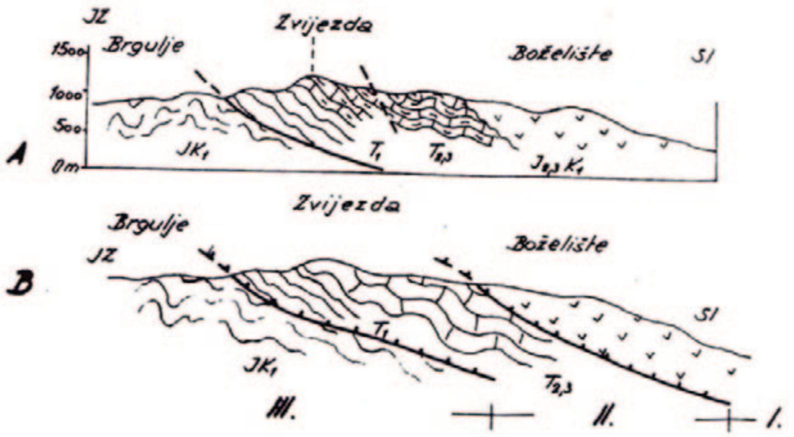


Fig 5. Cross section profile along the Zvijezda mountain; A - according to Miladinović;
B- according to Anđelković (M.Anđelković 1982 p.366)
B I-ibar mesoshariach (ofiolite- radiolarite complex); II -lim zone (triassic Vareš overburden);
III – bosnian zone (bosnian flysch-Vranduk overburden)

According to Andjelković (p. 382), the "Bosnian zone" includes the "Vranduk overburden" which extends in these areas from Zenica to Sarajevo to the southwestern slopes of Ravta and Zvijezda mountain. The composition of "Vranduk overburden" mostly includes "Bosnian flysch" which lies over the volcanic-sedimentary series of the Upper Jurassic, and partly of Triassic formations. In the northeast, from Banja Luka to Borovica, the ophiolite-radiolaritic complex "Ibar Mesoshariah" was pulled over the "Vranduk overburden", and further to the southeast, the "Vareš overburden" was pulled over the "Vranduk overburden". The internal structure of the "Vranduk overburden" is very complex; it is constructed of meter and decameter folds that are normal, curved, or inverted with vergences to the west or southwest. Southeast of Vareš, in the "Vranduk overburden", there are folds with the direction of the NW-SE or NW-SE. The "Bosnian zone" built of impermeable flysch has a great role for hydrogeological conditions, and for the appearance of cold and thermal waters in the Krivaja river basin.

Čičić, S. (2002) locates the area in the Krivaja river basin at the crossing of the central and inner Dinarides of Bosnia and Herzegovina. It is important to note that Čičić shows Triassic carbonate deposits in the bottom of the "diabase-hornblende formation" (volcanogenic-sedimentary series of the Upper Jurassic) on the profile across the Krivaja River (Fig. 6), and that Upper Jurassic and Cretaceous limestones (loc.cit. p.264). Čičić estimates the thickness of the "diabase-hornblende formation" as it is called at approximately 600-1500 m.

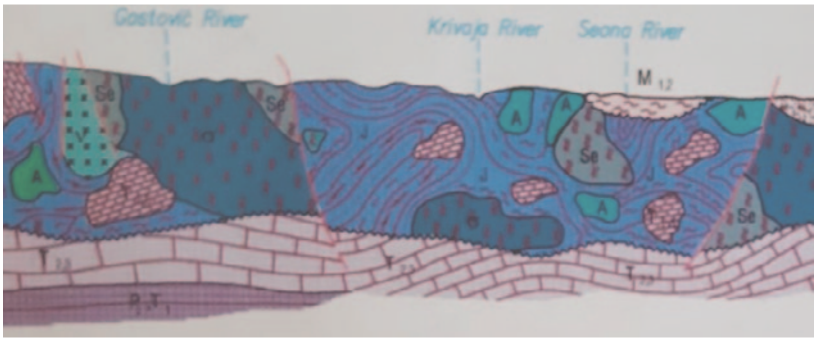


Fig 6. cross section profile along the Gostović and Krivaja and Seona rivers (S.Čičić 2002.)

Hrvatović, H. (2006) singles out four large overburden in the Krivaja river basin; "Golija overburden"; "Ophiolite overburden", "Durmitor overburden" and "Bosnian flysch" overburden..

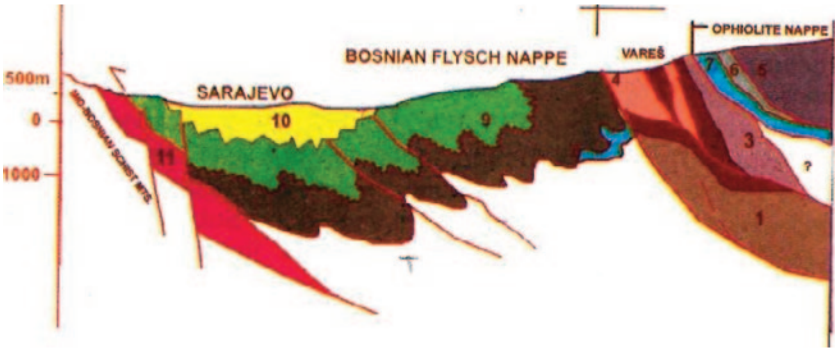


Fig 7. Cross section profile Sarajevo-Vareš (H. Hrvatović, 2006.)
Legenda 1 – East Bosnia Paleosoic; 2 – Lower Triassic slilica-clastic sediments, 3 – Anisic limestonesi, 4 – Ladinic and Anisic cornea, breccia, tuf and limestones; 5 – Opholite melange; 6 - „Wild" flysch; 7 – Bosnian flysch basis; 8 - J,K - paraflysch; 9 – Upper Cretaceous and paleogene flysch; 10 – Sediments of Zenica - Sarajevo basin, 11 – Triassic formation

The "Golija overburden" corresponds to the part of the "inner Paleozoic zone" according to Petković (1961), ie the "Golija zone" according to Obuen (1974) and the "Drina Mesoshariach" according to Andjelković (1982). This overburden includes the Drina Paleozoic (Vlasenica, Bratunac, Srebrenica area) with a Triassic overburden on its southwestern rim, which is pulled over the "Ophiolite overburden". According to Hrvatović, the Goliath overburden is probably part of a large overburden that begins in the northwestern Dinarides with the Pannonian overburden (Miladinović, 1974), which extends to the south into the western Macedonian Paleozoic.

According to Hrvatović, the "ophiolite overburden" is the largest cover structure of the Inner Dinarides. The ophiolite formations of this overburden were best discovered in the valley of the river Bosna and Krivaja, where further in the southeast the "Golija overburden" was pulled over it. Hrvatović divides the "ophiolite overburden" into two floors: the lower floor is built by a "radiolaritic formation", and the upper by an olistostromic ophiolite melange and ultramafics. In the upper and much thicker part of the ophiolite overburden, built of olistostrom melange, in Bosnia he singled out two second-order covers: 1) "Lower Ophiolite overburden" includes ultramafic massifs Borja-Mahnjača-Krivaja and 2) "Upper Ophiolite overburden" which includes ultramafic massifs Ljubić-Ozren-Konjuh. According to Hrvatović, in the area of Vareš, and in the southeast direction, the "ophiolite overburden" was pulled over the "Durmitor overburden", while towards the northwest it was pulled over the overburden of the "Bosnian flysch" (Fig. 7).

According to Hrvatović, the "Durmitor overburden" was built mostly of Triassic, mostly carbonate rocks, with subordinate clastic, silica and volcanic sediments. This overburden can be traced in Bosnia from Vareš through Čevljanovići to Sarajevo further south. The "Durmitor overburden" is attached to the "Bosnian flysch". Andjelković calls this cover "Vareš overburden" which has a decisive influence on hydrogeological relations and the appearance of cold waters, both in the valley of the river Krivaja and in the basin of the river Bosna in the southwest, and from the Lijas to the Lower Paleogene, mostly flysch formations, in this area can be traced from Sarajevo to Banja Luka, where an ophiolite cover lies across it. The "Bosnian flysch overburden" has a specific and complex tectonic structure; represented by a set of folds: upright, overturned, reclined, sunken and curved with general vergence to the southwest with axes of different orientation. The folds were largely formed under the influence of the "Durmitor overburden" by underlining (loc.cit.p.38). The "Bosnian flysch overburden" plays an important role in the overall hydrogeological relations in this part of the Dinarides, both in the "Zenica-Sarajevo basin" and in the Krivaja river basin, because it caused the appearance of thermal water aquifers in these areas.

SM Schmid (2008) and his collaborators in the paper on the correlation and evolution of the tectonic units of the Alps, the Carpathians and the Dinarides give, among other things, a geological profile across the Dinarides (Fig. 8). The fact is that the profile only partially crosses Bosnia and Herzegovina and does not pass through Krivaja, but it can certainly be correlated with the geotectonic structures of this area. In the profile, the area of the "Durmitor overburden", which includes Paleozoic and Triassic deposits, belongs to the internal Dinaric Platform (Interal Dinaric Platform), ie the East-Bosnia-Durmitor unit. The pulling of the western Vardar ophiolite unit (ophiolite-radiolaritic complex) over the Triassic deposits was emphasized, as is the case in the Krivaja river valley.

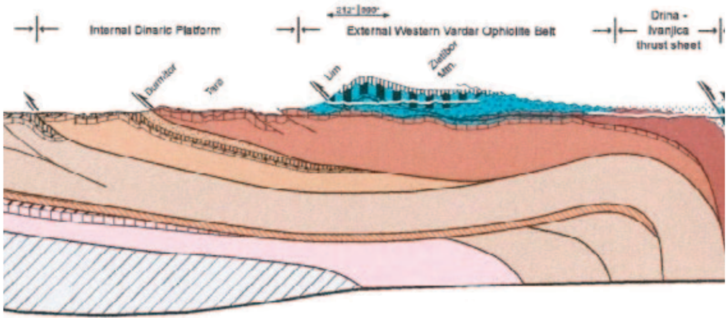


Fig 8. Cross section profile along the dinarides- section (S.M.Schmid, 2008.)

M.v.Unen and co-workers (2019) give a noteworthy geological profile through the Dinarides of Bosnia and Herzegovina which, among other things, intersects the Krivaja valley. In this profile, in the Krivaja river basin, ophiolites and ophiolite melange (Upper Jurassic, prim.auth.) are pulled over Triassic deposits beneath which lie Permo-triassic formations (Fig. 9). According to the mentioned authors, these formations are parts of the "East Bosnian Durmitor" zone pulled over the tectonic unit "High and Pre-Karst", which is an interesting conclusion which, among other things, can contribute to the study of the genesis of thermal waters in the Krivaja river in the southwest and the Spreča valley in the northeast.

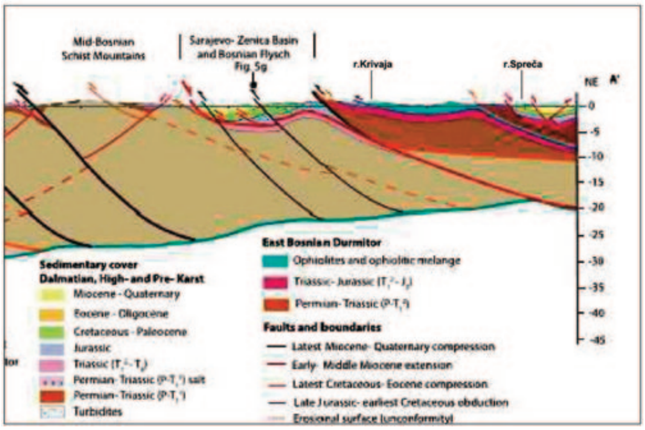


Fig 9. Cross section profile along the Dinarides (M.v.Unen, 2019.)

The most important fault in the Krivaja river basin is the fault that stretches through the canyon and valley of the Krivaja river. According to Hrvatović (2006), it is a deep fault that stretches for hundreds of kilometers from Prijedor and Banja Luka to Žepče and further across Olovo all the way to Višegrad. The recorded epicenters of earthquakes in Prijedor, Banja Luka, Žepče and eastern Bosnia can be connected to this deep fault. The fault according to Hrvatović (2006) reaches the Mohorovičić discontinuity at a depth of 30-35 km. It plays a major role in the inflow of thermal waters from the Triassic carbonate aquifer that lies deep beneath the cover of the Bosnian flysch.

Based on the analysis of structural-tectonic relations in the Krivaja river basin by the mentioned authors, and the study of structural-tectonic relations in correlation with hydrogeological conditions in the Krivaja river basin, conditions and genesis of cold and thermal groundwater sources in Krivaja valley, for this paper a geological and hydrogeological profile was prepared (Fig. 10).

Structural-tectonic relations can also be interpreted on the geological profile, which is characterized by the following:

- The deep base of all Mesozoic, mostly allochthonous deposits are Paleozoic formations (Pz).
- The ophiolite-radiolaritic complex ($J_{2,3}$) is pulled northeast of Krivaja and Bioštica rivers over Triassic formations (T_1-T_3).
- "Ophiolite overburden", ie ophiolite-radiolaritic complex ($J_{2,3}$), in the southwest in the zone of thermal waters between Očevija and Knežina rivers, ends with a deep fault of Krivaja.
- Triassic deposits of the "Durmitor overburden" (T^1, T^1_2, T_2^2, $T_{2,3}$) were torn from Triassic deposits from the floor of the ophiolite-radiolaritic complex northeast of Krivaja and Bioštica and brought to their current position in the area of the Zvijezda mountain,

- The torn off Triassic deposits of the "Durmitor overburden" are attached to the "Bosnian flysch", ie the cover of the "Bosnian flysch".
- "Bosnian flysch" in the direction of the southwest and "Zenica-Sarajevo basin" is pulled over the Triassic formations (T_1-T_3).

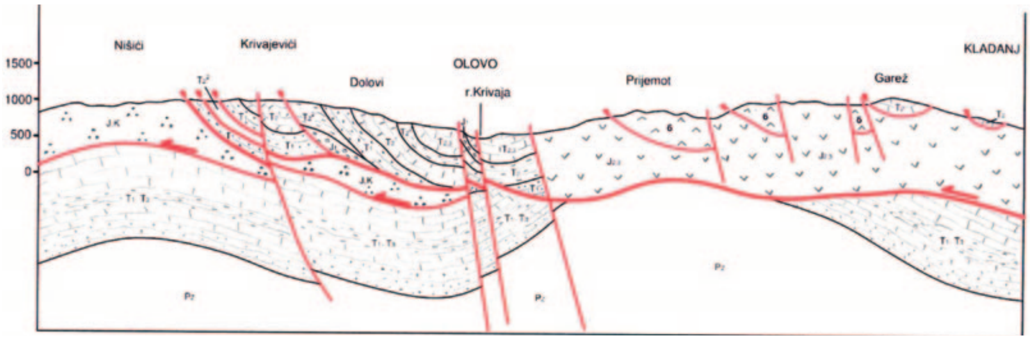


Fig 10. Cross section profile along the Krivaja river

5. HYDROGEOOGICAL TERRAIN CHARACTERISTICS

5.1. HYDROGEOLOGICAL CATEGORIZATION, REGIONALIZATION AND ROCK FUNCTIONS

In the Krivaja river basin, two hydrogeological categories of rocks have been singled out:

- permeable rocks of cavernous-fissure porosity,
- permeable rocks of fissure porosity, and
- impermeable rocks.

Permeable rocks of cavernous-fissure porosity are carbonates of Anisic (T_{21}), middle-upper Triassic ($T_{2.3}$) and upper Triassic (T_3). According to the intensity of karstification, they are separated into a class of well-karstified deposits in which many surface and underground karst forms appear. From the surface karst forms there are numerous sinkholes and dolines, and from the underground karst springs and caves. The carbonates of the Middle and Upper Triassic have the hydrogeological functions of cold water aquifers in the upper structural floor (Durmitor overburden) and thermal waters in the lower structural floor (T_1-T_3). It should be noted that at the current level of research, it is difficult to distinguish whether the Triassic formations of the lower structural floor belong to the so-called "Lim zone" or the zone of the Bosnian flysch.

Permeable rocks of fissure porosity are formations of the volcanic-sedimentary formation of Ladinik (T^2_2). According to the intensity of cracking, plate limestones have a particularly good permeability, as well as knurled limestones and interlayers of corneas located in the upper level of the Ladinic. They have hydrogeological functions of fissure porosity aquifers. It is quite certain that these tectonically strongly disturbed deposits in the zone of the "Durmitor overburden" together with the carbonates of the Middle and Upper Triassic form a unique cold waters aquifer.

Impermeable rocks are classified into: impermeable rocks and predominantly impermeable complexes. The volcanic-sedimentary formation of the Jurassic ($J_{2,3}$) is included in the category of impermeable rocks. There are no aquifers in this watertight formation over 1,000 meters in thicknes, and only in some places, within the igneous members of this formation, there are sources of less abundance. Northwest and southwest of the occurrence of thermal waters in the valley of the Krivaja River (Žepče, Rogatica, Višegrad), and in the northeast in the valley of the Spreča River (Živinice, Gračanica) these deposits form a watertight roof strata with Triassic carbonate deposits and aquifers of thermal and thermal waters.

The Lower Triassic (T_1) and Jurassic-Cretaceous flysch (J, K) deposits have been singled out in the category of predominantly impermeable complexes. The permeability of these deposits is low so that aquifers of higher water abundance are not formed in them. Only in places shallowly below the surface of the terrain, cold-water aquifers of limited distribution appear. The deposits of the Jurassic-Cretaceous flysch (Bosnian flysch) are probably a roof strata barrier to the aquifer of thermal waters formed within the Triassic carbonates, and a floor strata barier to the aquifers of cold waters formed within the "Durmitor overburden".

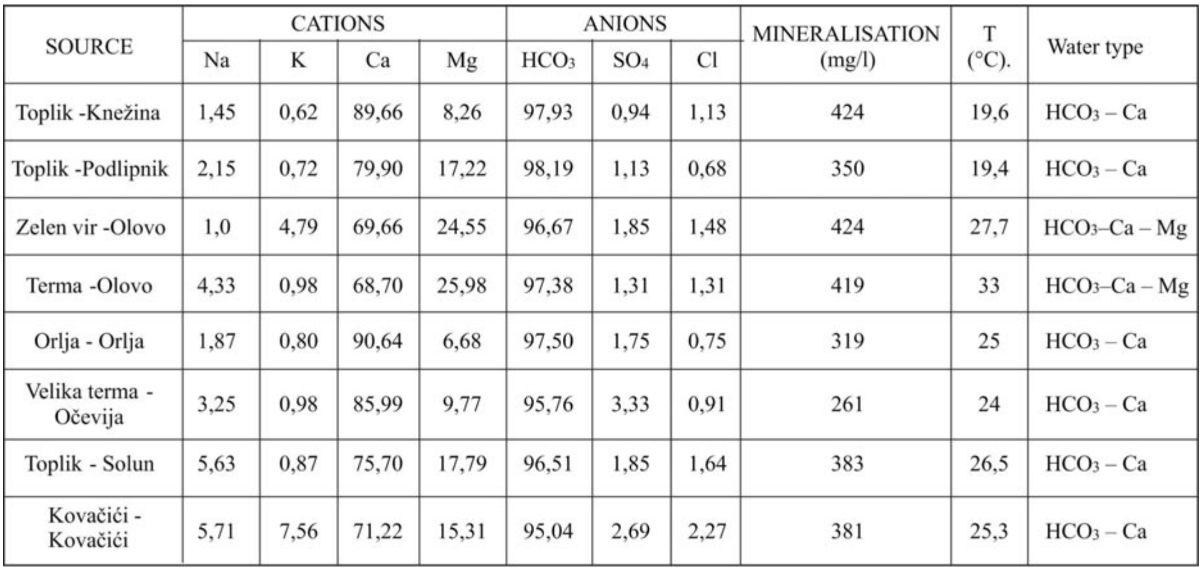
5.2. GROUNDWATER SOURCES

5.2.1. Thermal water springs

There are 8 (eight) springs of thermal water identified in the Krivaja river basin: "Toplik" in Knežina, "Toplik" in Podlipnik, "Zelen vir" in Olovo, "Terma" in Olovo, "Toplik" in Solun, "Kovačići" in Kovačići, "Orlja" in Orlja and "Velika Terma" in Očevije (Table 1). All thermal water sources are of the fissure type porosity and ascending flow mechanism. They appear within the carbonates of the Middle or Upper Triassic and near contact with impermeable rocks, and necessarily in the fault zone.

The waters of the thermal springs in the valley of the Krivaja river have very similar physical and chemical characteristics; mineralization 319-424 mg/l, temperature 19.4 - 33.0 °C, HCO_3-Ca and subordinate HCO_3-Ca-Mg type.

Tabele 1. Physical-chemical characteristics of thermal water in the Krivaja river valley



SOURCE	CATIONS				ANIONS			MINERALISATION (mg/l)	T (°C).	Water type
	Na	K	Ca	Mg	HCO_3	SO_4	Cl			
Toplik -Knežina	1,45	0,62	89,66	8,26	97,93	0,94	1,13	424	19,6	HCO_3 – Ca
Toplik -Podlipnik	2,15	0,72	79,90	17,22	98,19	1,13	0,68	350	19,4	HCO_3 – Ca
Zelen vir -Olovo	1,0	4,79	69,66	24,55	96,67	1,85	1,48	424	27,7	HCO_3–Ca – Mg
Terma -Olovo	4,33	0,98	68,70	25,98	97,38	1,31	1,31	419	33	HCO_3–Ca – Mg
Orlja - Orlja	1,87	0,80	90,64	6,68	97,50	1,75	0,75	319	25	HCO_3 – Ca
Velika terma - Očevija	3,25	0,98	85,99	9,77	95,76	3,33	0,91	261	24	HCO_3 – Ca
Toplik - Solun	5,63	0,87	75,70	17,79	96,51	1,85	1,64	383	26,5	HCO_3 – Ca
Kovačići - Kovačići	5,71	7,56	71,22	15,31	95,04	2,69	2,27	381	25,3	HCO_3 – Ca

Regarding the chemical composition of thermal water in the Krivaja river basin, in addition to the dominant presence of hydrocarbonate, calcium and magnesium ions, which indicate the flow through limestones and dolomites, it is characterized by very low sulfate and chloride content, which indicates that thermal waters do not flow through evaporites, which is important for defining the geological structure and structural-tectonic relations in this area.

Genesis of thermal waters

The study of the genesis of thermal waters in the Krivaja river basin was performed using the method of Sulin, Piper and Schoeller diagrams, and based on the isotopic composition of water by the methods of tritium (^3H), deuterium (^2H) and oxygen 18 (^{18}O).

Genetic types of thermal waters were determined using Sulin graphs based on the values of the main ion ratios: Na/Cl, Na-Cl/SO_4 and Cl-Na/Mg. It can be seen from the graphs that all thermal waters in this area have Na-Cl/SO_4>1, ie that they are of the hydrocarbonate-calcium-magnesium type and originate from the mainland environment (Fig. 11).

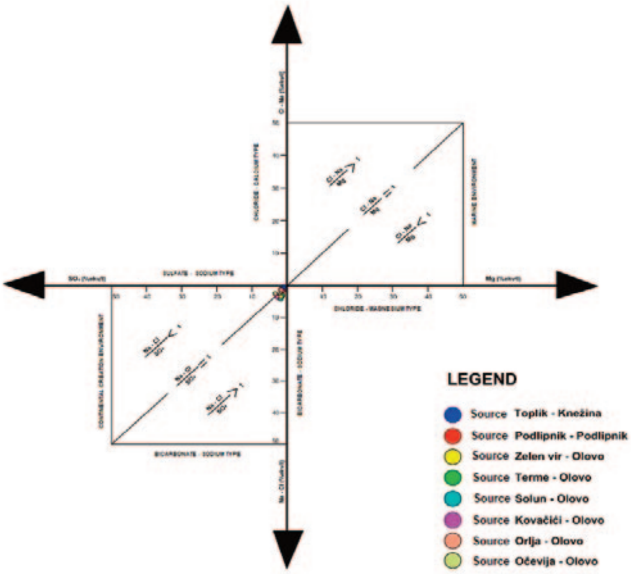


Fig 11. Thermal water diagram in the Krivaja river basin, according to Sulin

Piper ´s diagram shows that all thermal waters in the Krivaja river basin are of the same hydrochemical type, ie hydrocarbonate - calcium - magnesium type (Fig. 12). The formation of the mentioned hydrochemical type of thermal waters in this area is in direct dependence on the chemical composition of the rocks through which their flow takes place, ie origin from limestone and dolomite.

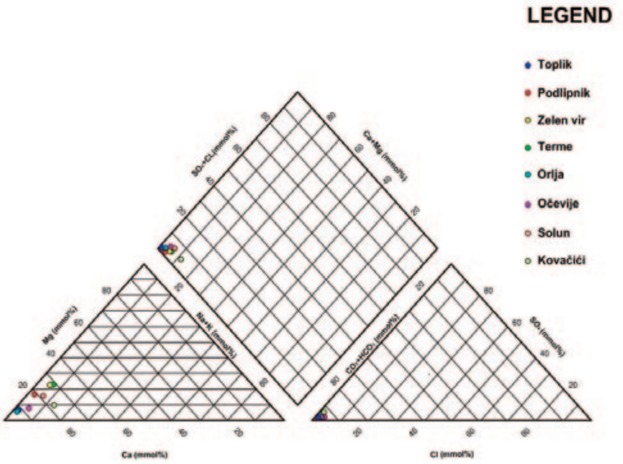


Fig 12. Piper´s thermal water diagram in the Krivaja river basin

The relatively low mineralization of thermal waters is most likely the result of faster water replacement and the absence of CO_2. The absence of CO_2 indicates that thermometamorphic processes are not pronounced in the deeper parts of the terrain of the upper course of the Krivaja river, and that there are no manifestations of younger Tertiary magmatism.

Schoeller's diagram for thermal waters in the Krivaja river basin (Fig. 13) shows that all thermal waters have a very similar ionic composition, which also indicates similar conditions of origin, accumulation, flow and discharge.

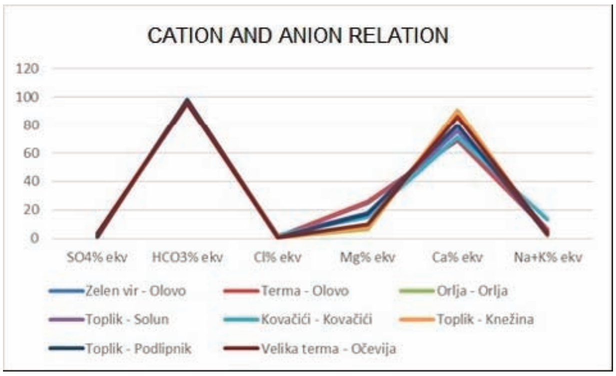


Fig 13: Schoeller's diagram for thermal waters in the Krivaja river basin

Isotopic testing of thermal water samples at the Ruđer Bošković Institute in Zagreb (2019) determined the tritium content in the range of 0.4 to 3.1 TU. The stated tritium content according to Clark and Frieze (1999) show that the thermal waters in the Krivaja River Basin are a mixture of submodern and more recently infiltrated waters. Only the thermal waters at the spring in Podlipnik and the Terma-Olovo well of submodern waters are older than 1952 (before the first nuclear test), which indicates a long retention of water underground (Table 2).

Table 2. Isotopic composition (tritium) of thermal waters in the Krivaja river basin - (Ruđer Boškovič Institute, Zagreb, 2019)

Source/ Lokation	Tritium content in water - **TU**
Toplik – Knežina	**2,8** +/- 0,9
Podlipnik – Podlipnik	**0,7** +/- 0,4
Zelen vir – Olovo	**1,1** +/- 0,5
Terma – Olovo	**0,4** +/- 0,3
Solun – Solun	**1,4** +/- 0,5
Kovačići – Kovačići	**1,9** +/- 0,7
Orlja – Križevići	**3,1** +/- 0,9
Očevija Očevija	**2,1** +/ 0,3

From the correlation diagram of temperature and tritium content in thermal waters (Fig. 14) it can be concluded that with increasing water temperature the tritium content decreases, ie the lower the water temperature, the higher the tritium content, which indirectly indicates mixing of cold and thermal waters in the basin of the river Krivaja.

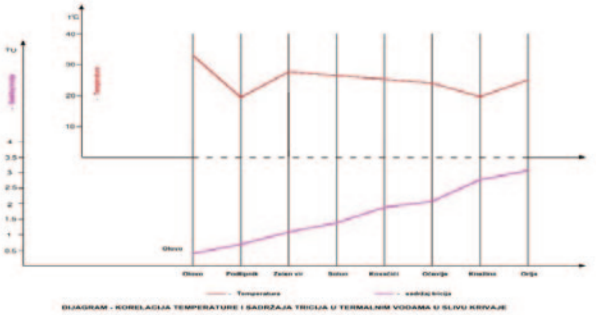


Fig 14. Temperature and Tritium content correlation in Krivaja river basin water

The content of the isotope hydrogen - deuterium ($_2$H) in the thermal waters in the Krivaja river basin ranges from 71.73% δ_2H to 73.90% δ_2H and the isotope oxygen (^{18}O) from 10.42% δ_2O to 10.89% (Table 3). The stated values of hydrogen and oxygen isotopes content indicate the atmospheric origin of water because the contents of ^{18}O and ^{2}H of thermal waters and precipitation lie on the so-called middle line, reproduced by the equation $\delta H = (8x\delta^{18}O) + 10$ (Fig.13).

Izvor / Lokacija	Temperatura vode - T °C	Kisik - (^{18}O)	Deuterij - (^{2}H)
Toplik – Knežina	19,6	-10,60	-73,38
Podlipnik – Podlipnik	19,4	-10,49	-72,89
Zelen vir – Olovo	27,7	-10,68	-73,90
Terma – Olovo	33	-10,64	-72,41
Solun – Solun	26,5	-10,42	-71,73
Kovačići – Kovačići	25,3	-10,59	-72,90
Orlja – Križevići	25	-10,89	-73,62
Očevija – Očevija	24	-10,77	-72,38

Table 3. Isotopic composition (deuterium and oxygen) of thermal waters in the Krivaja river basin - (Croatian Geological Institute, Zagreb 2019)

From the diagram in Figure 13, it can be seen that the thermal waters in the Krivaja river basin were created in the late Pleistocene, at the time of the influence of the cold climate (Fig. 15).

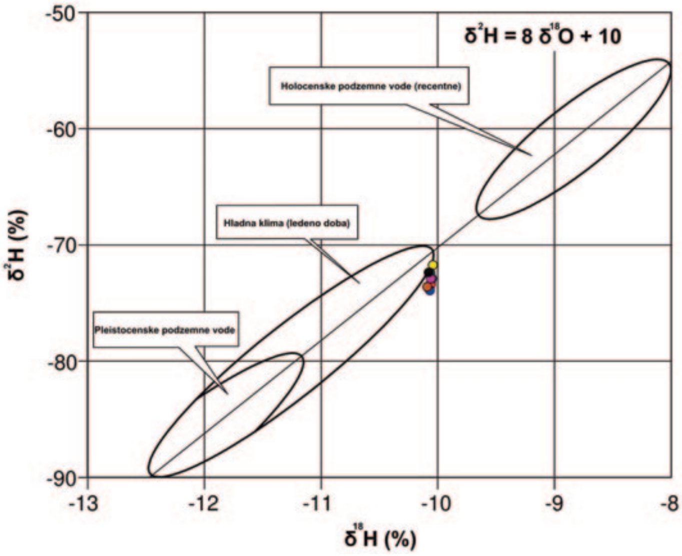
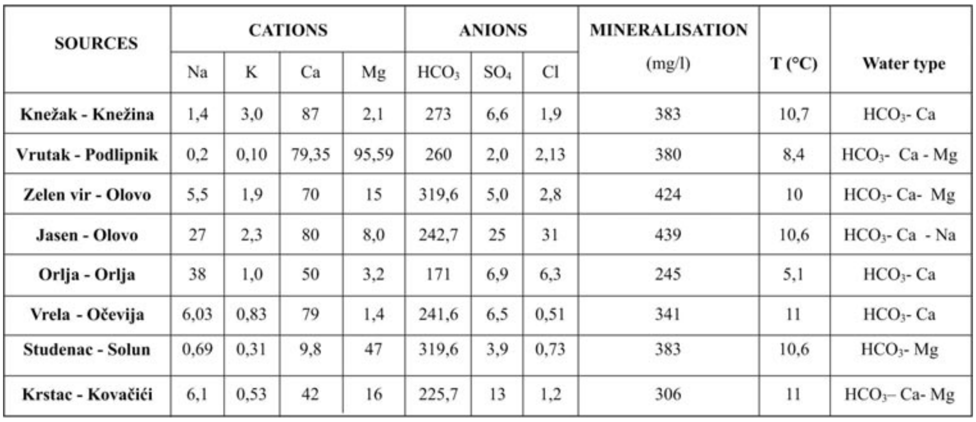


Fig 15: Oxygen and Deuterium izotope content of thermal water in Krivaja river basin

4.2.2. Sources of cold water

In the Krivaja river basin, 8 (eight) major and important sources of cold water were identified and analyzed, such as Knežak in Knežina, Vrutak in Podlipnik, Zelen vir in Olovo, Jasen in Olovo, Orlja in Orlja, Vrela in Očevija, Studenac in Solun and Krstac in Kovačići (Table 4). these cold springs generally occur almost in the immediate vicinity of thermal springs. The sources of cold water are fissure type, mostly descending and in some places ascending flow mechanism. They appear within the carbonates of the Middle or Upper Triassic and close to contact with impermeable rocks, and necessarily in the fault zone.



SOURCES	CATIONS				ANIONS			MINERALISATION (mg/l)	T (°C)	Water type
	Na	K	Ca	Mg	HCO_3	SO_4	Cl			
Knežak - Knežina	1,4	3,0	87	2,1	273	6,6	1,9	383	10,7	HCO_3- Ca
Vrutak - Podlipnik	0,2	0,10	79,35	95,59	260	2,0	2,13	380	8,4	HCO_3- Ca - Mg
Zelen vir - Olovo	5,5	1,9	70	15	319,6	5,0	2,8	424	10	HCO_3- Ca- Mg
Jasen - Olovo	27	2,3	80	8,0	242,7	25	31	439	10,6	HCO_3- Ca - Na
Orlja - Orlja	38	1,0	50	3,2	171	6,9	6,3	245	5,1	HCO_3- Ca
Vrela - Očevija	6,03	0,83	79	1,4	241,6	6,5	0,51	341	11	HCO_3- Ca
Studenac - Solun	0,69	0,31	9,8	47	319,6	3,9	0,73	383	10,6	HCO_3- Mg
Krstac - Kovačići	6,1	0,53	42	16	225,7	13	1,2	306	11	HCO_3– Ca- Mg

Fig 4. Cold water physiochemical characteristics of Krivaja river basin

Cold water springs have similar physicochemical characteristics. Cold waters are low mineralized 245-440 mg/l, temperature 5-11 °C, HCO_3-Ca and HCO_3-Ca-Mg type, depending on whether dolomite deposits are present in the aquifer.

Genesis of cold waters

The cold waters in the Krivaja river basin are of atmospheric origin, caused by precipitation infiltration. Aquifers are carbonates of Middle and Upper Triassic formed within the "Durmitor overburden" in the base of which are impermeable rocks of the Lower Triassic, Jurassic-Cretaceous flysch or, less frequently, ophiolite-radiolaritic complex. The yield of the spring depends on the amount of precipitation and oscillates during the hydrological year.

5. GROUNDWATER AND STRUCTURAL-TECTONIC RELATIONS

Based on the consideration of groundwater genesis in the Krivaja river basin, the following can be concluded:

- Groundwater (cold and thermal) occurs in the zone of the deep fault of Krivaja and faults subparallel to this fault.
- Cold and thermal waters have the same, atmospheric origin but completely different genesis.
- Cold waters are recent waters created by precipitation recharge and under the influence of daily climate change.
- Thermal waters were formed at the end of the Pleistocene, ie at the end of the Ice Age.
- Cold water aquifers are Triassic carbonates of the "Durmitor overburden" in the base, which are deposits of Jurassic-Cretaceous flysch ("Bosnian flysch").
- The primary aquifers of thermal waters are Triassic carbonates (T_1-T_3) that lie below the Jurassic-Cretaceous flysch deposits.
- Thermal waters are generally mixed with cold waters, which means that in the primary aquifer it is possible to capture thermal waters of higher temperatures than those at the springs.
- Mixing of thermal and cold waters happens at greater depths within the Triassic carbonates of the "Durmitor overburden".
- Thermal springs Banja and Podlipnik had no connection with precipitation after 1952, which indicates a slow water replacement; but does not preclude mixing and capturing thermal water of higher temperature.

The genesis of thermal and cold waters indicates the following structural-tectonic relations in the Krivaja river basin:

The key role for the origin and origin of groundwater in the Krivaja river basin (cold and thermal) is played by:

- The Durmitor overburden,
- The Bosnian flysch overburden and
- The Krivaja fault.

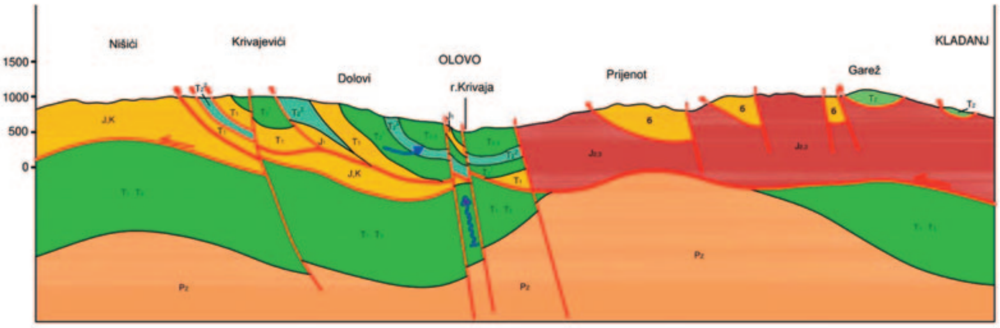


Fig 16. Hydrogeological cross section profile over the Kriva^{j}a river

Having in mind the consideration of structural-tectonic relations, and hydrogeological research and hydrochemical tests, it can be concluded that groundwater (cold and thermal) in the Krivaja river basin as a geomanifestation indicates the formation of two structural floors in this area:

- **the lower structural floor** consisting of Triassic carbonates (T_1-T_3) over which the Jurassic-Cretaceous flysch deposits ("Bosnian flysch" pverburden) are drawn, and
- **the upper structural floor** of the Triassic deposit (T_1-T_3) of the "Durmitor cover" which is pulled over the deposits of the Jurassic-Cretaceous flysch, ie the cover of the "Bosnian flysch",

The presence of these structural floors, which is intersected by the Krivaja fault, is the main cause of the appearance of karst cold water sources in the immediate vicinity of thermal water sources, at almost all localities in the Krivaja river basin.

6. CONCLUSION

Research conducted for the preparation of this paper shows that groundwater (cold and thermal) waters are a first-class geomanifestation for the analysis of structural-tectonic relations in the Krivaja river basin.

The almost linear arrangement of the sources of cold and thermal water that appear almost in the immediate vicinity indicate the regularity of their occurrence and the unique structural-tectonic relations in the Krivaja river basin between Očevija and Knežina.

Cold and thermal waters in the Krivaja river basin have the same, atmospheric origin but different genesis. Cold waters are recent waters that are formed by precipitation recharge and under the influence of daily climate change. Thermal waters were formed at the end of the Pleistocene, ie at the end of the Ice Age.

The aquifer of cold waters are Triassic carbonates of the "Durmitor overburden" in the base which are of Jurassic-Cretaceous flysch deposits. The primary aquifers of thermal waters are Triassic carbonates that lie below the Jurassic-Cretaceous flysch deposits.

Thermal waters are mainly mixed with cold waters at greater depths within the Triassic carbonates of the "Durmitor overburden". Sources of cold and thermal waters in the Krivaja river basin indicate that two structural floors were formed in these terrains: the lower structural floor consisting of Triassic carbonates over which Jurassic-Cretaceous flysch deposits were pulled over, and the upper structural floor composed of Triassic deposits. on Jurassic-Cretaceous flysch deposits. The main role for the origin and origin of groundwater in the Krivaja river basin is played by the "Durmitor overburden", the "Bosnian flysch overburden" and the Krivaja fault.

Hydrogeological and hydrochemical research of groundwater with the analysis of other geomanifestations present in the Krivaja river basin, and conducting additional research using geophysical research methods, can increase the degree of exploration of space, which can be extremely important for research of minerals (metals), CO_2, gas and geothermal energy in the Krivaja river basin.

The use of groundwater as a geomanifestation of geological processes in the Krivaja river basin can be interpolated on neighboring terrains at the crossing of the inner and central Dinarides, which are still insufficiently explored, especially the evolution and position of the ophiolite-radiolaritic complex as the most remarkable formation in this part of Bosnia and Herzegovina.

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Review Paper

AN UTILIZATION OF HIGH-PERFORMANCE CONCRETE IN CONCRETE STRUCTURES

Kemal Zahirović[1], Danijel Ružić[2]

SUMMARY

An utilization of the high - performance concrete in concrete structures has been provided in this paper. During last 30 years, this type of concrete has been in more intensive use, therefore there is a significant base of experience in terms of concrete manufacture and application. In addition, previous research has also allowed the introduction of high - performance concrete recipes. Since high-performance concretes are increasingly utilized, this paper summarizes the previous knowledge in this area. In addition to the utilization of high-performance concrete, it is also interesting to review the research in terms of making recipes and testing the properties of such concrete. Therefore, the review presented in this paper included the production, testing and examples of the utilization of high performance concrete.

Keywords: concrete, cement, material, compressive strength, ductility, durability

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1. INTRODUCTION

Concrete is the most suitable building material, which has its advantages and disadvantages. The main advantages of concrete are the price, applicability to almost all structural elements due to the possibility of forming any shape (shape) and fire resistance. The main disadvantages of concrete include weight, durability and degree of utilization of the cross section. The trend of research in construction industry is to achieve rational structures with high performance in terms of their load-bearing capacity and usability, which will reduce previously mentioned disadvantages of conventional concrete. In other words, "the more performances for as little money as possible" In this sense, research goes in two directions:

- Construction rationalization by reducing the size of structural elements
- Construction rationalization through improving the properties of embedded materials in structural elements

High-performance concrete is the product of research in terms of construction rationalization by improving the properties of embedded materials. During last 30 years began its intensive application and it can be stated that a sufficient database has been formed that enables the efficiency of its application and further development in terms of achieving the best possible performance of the structure.

This article provides an overview of research in the development and utilization of high-performance concrete. A paper included research in the field of formulating recipes, achieving the best possible properties of concrete and optimal application in concrete structures.

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[1] Kemal Zahirović, Master in Civil Engineering, Širbegović Inžinjering, Branilaca grada bb, Gračanica; Bosnia and Herzegovina, kemo_z_92@hotmail.com

[2] Danijel Rožić, Master in Civil Engineering, Tehnograd, Turalibegova 48, Tuzla, Bosnia and Herzegovina, danijelr@hotmail.com

There is a short critical review of the previous research in the field of utilization of high performance concrete and recommendations for modalities of using this type of conCRETE.

2. COMPOSITION AND MATERIALS

A conventional concrete with compressive strength up to 50 or 60 MPa was in use 30 years ago. Development of concrete recipes in terms of the use of additional components and new technologies (plasticizers, binding accelerators, evaporation technologies, the use of silicate dust and fly ash, metakaolin, aramid fibers, etc.) began utilization of high - performance concrete (HPC) whose strength is higher than in those components mentioned above.

The production of such concretes allowed us to produce smaller structural elements, concrete has a better density, and its durability is increased, which allows us to overcome the main disadvantages of concrete as a material that is widely used in the construction industry.During past twenty years, ultra-high performance concretes (UHPC) have also been used, whose strength classes far exceed the strengths of conventional concrete. Any increase in strength harms ductility of the material, therefore these and unconventional materials have higher brittleness.

Many studies have been conducted that have analyzed the possibilities of utilizing other and innovative materials for concrete production. In the paper [1] have been analysed the use of copper slag instead of sand in mixing high-performance concrete. Copper slag is one of the materials that is considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates.

In order to produce every ton of copper, approximately 2.2–3.0 tons of copper slag is generated as a by-product material, which fulfills the basic precondition for the economic justification of this research. It has been experimentally proven that by adding up to 50% of copper slag as sand replacement yielded equivalent strength with that of the control mix. However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix. Mixtures with 80% and 100% copper slag replacement gave the lowest compressive strength value of approximately 80 MPa, which was almost 16% lower than the strength of the control mix.

There was a decrease in the surface water absorption as copper slag quantity increased up to 40% replacement, beyond that level of replacement, the water absorption rate increases rapidly. It is recommended that 40 % of copper slag can be used as replacement of sand in order for the concrete obtain good properties.

It should be noted that further in the paper [2] has been analysed utilization of silica dust and fly ash in mixing high-performance concrete. The experiment was conducted in three groups of concrete mix:

a) Type 1: cement, fine aggregate, coarse aggregate and water
b) Type 2: cement, fly ash, silicate dust, fine aggregate, coarse aggregate and water
c) Type 3: cement, fly ash, silicate dust, fine aggregate and water

By adding fly ash and micro silica and thereby decreasing the content of cement the flexural strength of the concrete beam was seen to be increased by 13.3%. By adding fly ash and micro silica as cement replacement and henceforth reducing the content of cement the seven day compressive strength of cube increases by 2.17%. and 28.35% after 28 days. A results of the research show that mixture of Type 3 has the lowest compressive strength. The authors of this research do not recommend use of such concrete mixture given that this mixture is made without a coarse aggregate.

Also, in the paper [3] has been analysed the use of recycled porous ceramic aggregate for high-performance concrete. Internal curing has been extensively used to reduce shrinkage and consequently mitigate the high risk of early age cracking of high-strength concrete. The main objective of this paper is an efficiency of internal curing system provided by a recycled porous ceramic coarse aggregate (PCCA). Six different mixtures of high-strenght concrete have been examined, thus physical and mechanical development properties have been measured with and without PCCA additives.

The results indicate that the waste recycled porous ceramic aggregate has a great 'potential' for internal curing purposes when it is comes to achieving an internal curing system. An additional benefit of this aggregate is improvement of cement hydration reaction which results in a significant increase of the concrete compressive strength.

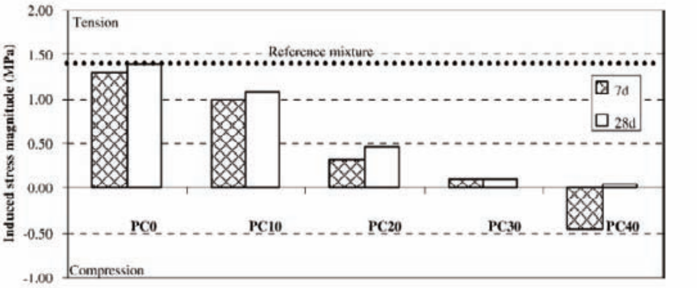

Fig. 1: The PCCA contribution to the capillary stress reduction [3]

An enhancement of the 28-day compressive strength of about 10% to 20% for the concrete mixtures containing the PCCA was achieved. In addition, the use of these aggregates reduces the capillary tension in the concrete mixture.(indicated in the Fig.above) It has been found that when the content of the PCCA changes from 10 to 40% by volume, the obtained magnitude of shrinkage reduces from 30% to 105%.

In the paper [4] has been analysed the use of rice husk ash (RHA), which mainly contains high carbon content in its composition, on to high-performance concrete. The focus of this paper is on the research of different grinding times of RHA in a vibratory mill, in order to improve the properties, which are reflected in utilization of high-strength concrete. The experiment that was carried out is consisted of making four high performance concrete mixes that had 0%, 10%, 20% and 30% cement mass, replaced with ultrafine rice husk ash.

The RHA grinding procedures that were adopted can be used to increase the homogeneity of concrete mix. It is important to emphasize that by using ultrafine RHA instead of cement, the consistency of concrete is reduced, however this problem can be solved by increasing the number of superplasticizers. The use of the ultrafine RHA maintained or increased the mechanical behavior of the reference concrete, while the mixture containing 20% of RHA presented a superior performance.

A research has been conducted related to the production of rice husk ash used in high performance concrete mixtures. In the paper [5], two methods were examined, and those are:

a) A conventional type of RHA (TRHA) - obtained by a thermal treatment of the rice husk
b) A chemical–thermal method (ChRHA)

Experimental analysis showed an increase in the compressive strength of concrete obtained by the ChRHA method. The main cause of this is a high content of amorphous SiO_2 in ChRHA. Compressive strenght of ChRHA concrete is comparable to a SF concrete made with the same replacement level, and these strengths are higher than in the control and TRHA mixtures that have been tested as seen in the figure below. Incorporation of ChRHA in concrete enhances durability properties by refining its pore structure.

A similar topic was presented in the paper [6], by analyzing the possibility of using rice husk ash for the production of ultra high performance concrete (UHPC). The limited available resource and the high cost of silica fume (SF) in producing ultra high performance concrete (UHPC) give the motivation for searching for the substitution by other materials with similar functions. Rice Husk Ash (RHA), an agricultural waste, is classified as "a highly active pozzolan" because it possesses a very high amount of amorphous SiO_2 and a large surface area. Because of that, it has been explored its application in production of ultra high performance concrete.

The possibility of using RHA to produce UHPC was explored in experimental analysis. The result shows that the compressive strength of UHPC incorporating RHA, with the mean size between 3.6 μm and 9 μm, can be achieved in excess of 150 MPa with normal curing regime. The interesting point is that the effect of RHA on the development of compressive strength of such concrete is larger than that of silica fumes, which is usually used for the manufacture of ultra high performance concrete. Besides, the sample incorporating the mixture of cement with 10% RHA and 10% SF showed better compressive strength than that of the control sample without RHA or SF. This mixture proved to be the optimum combination for achieving maximum synergic effect.

The fineness of RHA has a favorable effect on compressive strength when occured in the normal condition compared to the use of RHA for preparation of concrete with the use of silica fumes. The optimum mean RHA particle size for producing UHPC was found to be 5.6 μm and the finer particles of RHA can improve significantly the compressive strength of UHPC. The compressive strength of UHPC using the finest RHA with the mean particle size of 3.6 μ can reach up to 180 MPa and 210 MPa at ages of 28 and 91 days.

In contrast to previous papers, in the paper [7] have been analysed the use of aramid fibre in high performance concrete (AFRC) for the purpose of increasing fire resistence of the structure. Mechanical properties of concrete such as compressive strength and flexural strength are considerably reduced under elevated temperature. It is assumed, that the use of a material with a higher resistance to elevated temperatures, this reduction would be limited. It has been proved a usage of aramid fibers in high-strength concrete.

The compressive, split tensile and flexural strengths of concrete (M100) are increased with the usage of aramid fibers. It was observed that major part of the loss in mechanical properties of concrete is taking place after exposure to temperature more than 300°C and the split tensile value of AFRC at 300°C almost equal to the split tensile value of conventional concrete mix at room temperature. Flexural strength of concrete was noticed to decrease continuously up to 400°C and beyond that, there is a sudden decrease in flexural strength, as see in the Figure below. Measurements have shown that the flexural strength of AFRC at 400 °C is almost equal to the flexural strength of conventional concrete at room temperature.

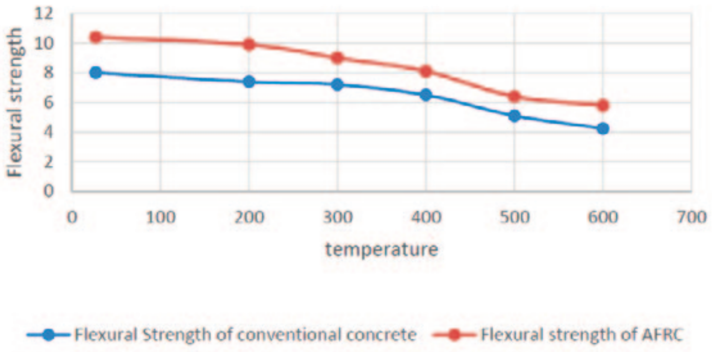

Figure 2: Flexural strength of concrete exposed to temperature[7]

When it comes to the optimal composition of high strength concrete, the paper [8] presents researches of the very high-strength concrete with eruptive crushed aggregate. Very high-strength concretes can have an eruptive crushed aggregate with a smaller grain diameter (usually up to 8 mm), or even more often, a large aggregate is not used for their preparation, so their structure is more similar to the structure of plaster. Such concretes contain particles less than 0.1 μm and up to about 300-600 μm, in order to get the most uniform grain packing and the most uniform mass.

By optimizing the composition of very high-strength concrete, it was found that the amount of cement above 930 kg/m^3 and superplasticizers above 40 kg/m_3 does not affect the further increase in compressive strength, and that heat treatment - steaming achieves not only significantly higher compressive strength, but also higher 28-day compressive strength of concrete, which is regularly 10% higher than samples that were not steamed. The amount of steel fibers in very high-strength concretes does not significantly increase the compressive strength, but significantly increases the tensile strength (up to 30% higher than the strength of the mixture with the lowest percentage of fibers) and increases ductility.

In the paper [9] has been conducted research about utilization of Fine Recycled Concrete Aggregate (FRCA) and Coarse Recycled Concrete Aggregate (CRCA) in High Performance Concrete mixes. Recycling of concrete waste is considered as a viable option, as it reduces the consumption of natural resources as well as minimizes landfill. Even-though, not many studies have been conducted related to HPC, the properties of Recycled Aggregate Concrete (RAC) mix with CRCA and FRCA are found to be acceptable even at 100% replacement levels.

This experimental study has resulted in a general observation, that recycled materials such as CRCA and FRCA recovered from concrete waste can be utilized at 20% replacement levels of natural aggregate in the mixing high-strength concrete. The results showed a satisfactory level of strength and performance of such mixtures.

The test results of HPC mixes with 20% CRCA and 20% FRCA exibits satisfactory performances when it is subjected to sulphate attack, and significant loss in strength is noticed for the same mix exposed to H_2SO_4.

Also, it has been analysed an influence of marble powder on high-strength concrete behavior. The paper [10] shows an experimental study of the influence of marble powder used as a partial substitute for

Portland cement (PC) on the mechanical properties and durability of high performance concretes. Two formulations of concrete were studied for the purpose of analysing an influence of marble powder onto concrete properties. Prepared specimens were stored for one year in an environment containing 5% calcium chloride, (media 1) and drinking water (media 2).

The analysis of the experimental results on concrete at 15% content of marble powder with a fineness modulus of 11500 cm^2/g, in a chloride environment, showed that it contributes positively to its mechanical characteristics. On the basis of this, we can conclude that marble powder is suitable for the production of high-performance concrete.

Effect of Metakaolin Content on the Properties of High Strength Concrete have been explored in the paper [11]. The metakaolin is a mineral supplement with pozzolans activity obtained by production from kaolin clay. It is usually used in an amount from 10 to 25% compared to the cement mass. The environmental acceptability of this supplement is reflected in the fact that metakaolin production produces significantly less CO_2 emissions than cement production. This study presents the effect of incorporating metakaolin on the mechanical and durability properties of high strength concrete for a water-cement ratio of 0.3. In mixtures MK5, MK10 and MK15, cement content was replaced with 5, 10, and 15 % MK.

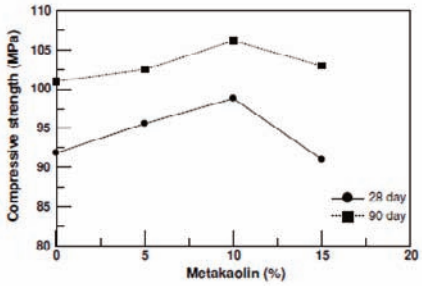

Fig. 3: Compressive strength with respect to metakaolinpercentage[11]

The results shows that by utilizing MK and cement designed for a low water-cement ratio can develop high performance concrete and compressive strengths of more than 100 MPa. The optimum percentage of MK in concrete mixture was 10% which gave the highest compressive strength of 106 MPa as shown in the figure above. This type of concrete exhibited a 28-day splitting tensile strength of around 5.15 % and relatively high values of modulus of elasticity. As far as the durability properties are concerned, concrete with MK have shown to reduce water permeability, absorption, and chloride permeability as the replacement percentage increases.

In the paper [12] is presented a new approach on surface modification of crumb rubber using organoclay composites in order to improve utilization of high-strength concrete properties. There is a decrease in mechanical properties of concrete due to poor adhesion between cement paste and crumb rubber, therefore many efforts have been made in recent years to improve adhesion between the cement paste and crumb rubber.

Results have shown that when rubber content is increased from 0 to 25 % in high strength concrete, the concrete workability also increases due to water repellent nature of rubber. However, the workability decreases in the case of the surface treated rubberized concrete. The surface modified rubber concrete showed higher compressive strength compared to the untreated rubber concrete, and the main reason for that is better bond between cement paste and crumb rubber.

In the previously presented papers, researches have been shown various materials and compositions for the preparation of high-strength concrete mixtures, primarily taking care not to jeopardize its mechanical properties. In addition, the use of local materials in high-strength concrete achieves one of the basic goals in terms of rationalization of construction costs, which results in the economic justification of these studies. It is very important to emphasize the environmental aspect, therefore we pay attention to the possibility of using recycled materials that were obtained from concrete WASTE.

3. PROPERTIES OF HIGH-STRENGTH CONCRETE

It is clear that high-strength concrete requires more attention in the choice of ingredients than normal-strength concrete. The choice of properties that we want to achieve in the fresh and hardened state and type of construction directly influences the choice of the previously listed parameters based on a high-performance concrete structure.

High-property concretes have a wide application in the construction of load-bearing, durable and usable reinforced concrete structures. Due to the reduced porosity, high-strength concretes have significantly improved durability properties compared to normal-strength concretes. This is the main reason for their use in various aggressive environments. In addition to improving durability, high-performance concretes in relation to concretes of normal strength are also characterized by better resistance to chemical substances, improved adhesion to concrete steel and prestressing steel, reduced shrinkage and creep of concrete, etc.

It is known that the compressive strength of concrete is considered the most significant mechanical property of concrete. Due to that, there are a large number of research papers devoted to this topic. In the paper [13] has been conducted analysis of the compressive strength of high-strength concrete and influential parameters on that strenght. The reason for this study is the need to determine the actual influence of silica dust on the compressive strength of concrete about which many researchers seem to disagree. Moreover, we introduce a prediction model of the compressive strength of high performance concrete depending on time, in the form of empirical formulas that were defined by several researchers.

The use of silica fume in combination with a superplasticizer is now a usual way to obtain high-strength concretes. The improvement of mechanical properties of concretes with silica dust accounts for the increasing consumption of this admixture in concrete. Nevertheless various authors point out some drawbacks regarding the use of silica fume in concrete mixtures. Among these, the loss of plasticity during the production of concrete and the great sensitivity to shrinkage during the initial curing are the most important.

It is concluded that the increase of the concrete compressive strength depends much more on the decrease of the water/cementitious materials ratio than on the replacement of silica dust with cement. The compressive strength increases with the silica dust content up to 20% and reaches a maximum for a 10 to 15%sf level.

In the paper [14] has been conducted a research related to flexural strength of reinforced concrete members with ultra high-strength concrete. In order to determine specified strengths, according to various regulations and recommendations (ACI, EC2, CEB / FIP), simplified block diagrams of stress are used, according to which the main parameter of influence on the results is the compressive concrete strength. The main aim of the research is a proposal of flexural strength evaluation model for ultra high-strength concrete. Additional verifications were carried out with previous researches (21 test specimens) on flexural strength of steel fiber reinforced concrete or ultra high strength concrete.

The most accurate model of ultra high performance concrete under compression is triangular. Under tensile stress, stress distribution of concrete can be varied with fiber contents or shape. However, researchers concluded that existing flexural strength calculation models cannot accurately and safely predict the flexural strength of ultra high performance concrete.

A paper [15] represents a research on tensile strength of Ultra High Performance Concrete (UHPC) and Ultra High Performance Fiber Reinforced Concrete (UHPFRC). During direct experimenatal measurements of concrete tensile strength (if it does not contain fibers) it was determined that mean value ranges from 7 - 10 MPa (Japanese recommendation of mean value 5 MPa, and French Guidelines SETRA/AFGC suggest mean value ranging from 8 and 8.1 MPa). On the other hand, the tensile strength of UHPC and UHPFRC that containe steel fiber varies in the range of 7-15 MPa.

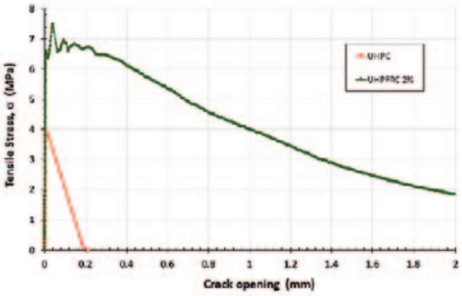

Fig.4: Crack Opening Diagram (UHPC and UHPFRC)[15]

A total of 2 series of mixtures were tested, each consists of UHPC and UHPFRC 2% (2 vol.-% of fiber) Tensile strength tests of UHPC ended with sudden brittle failures and show no falling branch, while on the other hand, the specimens made of UHPFRC containing 2 vol.-% of fibers show ductile behaviors with a gradual falling branch due to the pullout of the fiber.

At the figure below, it can be identified that UHPC and UHPFRC used in the study have mean maximum tensile strengths of 4.0263 MPa (for UHPC) and 6.5851 MPa (for UHPFRC 2%), also having the correlation crack opening lengths of 0.0078 mm (for UHPC) and 0.0068 mm (for UHPFRC 2%).

A study case related to previous testing of internal curing on behavior of high performance concrete was published in the paper [16]. Common materials have been used to produce the internal curing required to reduce therisks of developing cracks in hardened concrete. Furthermore, this study focuses on the behavior of HPC, including density, strength (compressive, splitting tensile, and flexural), shrinkage, etc.

Results indicate that internal curing is more effective at a later age on splitting tensile and flexural strength than on compressive strength. Several studies, analysed in the paper, emphasized that internal curing directly influences areduction in the shrinkage of high-strength concrete, therefore, the cement matrix must be kept volumetrically stable. The pressure strength can be higher in the mixtures with lightweight aggregate than in the mixtures without it. The degree of hydration of concrete mixture depends on the amount of available water in the hydrated cement paste. Many studies report about increased pressure strength of HPC samples with added lightweight aggregates and superabsorbing polymers, and it is believed that this phenomenon is associated with a high degree of hydration. Accordingly, the answer to the question of whether a lightweight aggregate can cause an increase in pressure strength depends directly on whether an increased degree of hydration due to internal curing can replace the low strength of a lightweight aggregate.

It should be mentioned that fire resistance representa significant advantage of the concrete as a bulding material compared to other materials (steel and wood) used in civil engineering structures. Therefore, in the paper [17] has been explored prediction on the fire resistance behaviour of high strength reinforced concrete columns. Structural elements used in civil engineering, taking into account the load-bearing capacity and stability, must meet the required fire resistance. Generally, concrete exibit good performance under fire situations, however studies have shown that the fire performance of high-strength concrete is a bit weaker related to the concrete of normal strength due to the low water-cement ratio.

The computer program presented in this study proved to be capable (compared to experimental studies) of predicting the fire resistance of concrete columns. Using the model, the fire resistance of columns can be evaluated for any value of the significant parameters, such as load, section dimensions, column length, concrete strength, aggregate type and fiber reinforcement, etc without the necessity of testing.

The paper [18] deals with studying shear capacity of ultra-high reinforced performance concrete squat shear walls. To determine the shear load capacity, a cyclic load test was performed on a sample having a width-to-height ratio of 1.0.

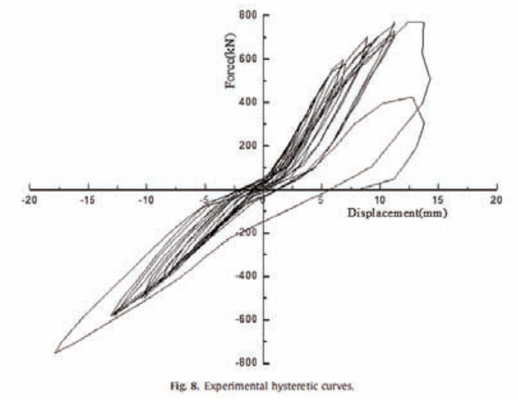

Fig. 5: Hysteresis loop determined experimentally [18]

The number of cracks in the specimen was large, and the specimen did not show a typical x-shaped crack. The cracking load was 65 % of the peak load, and the UHPC shear wall demonstrated a high anti-crack performance and ultimate bearing capacity. It is important to emphasize that the formula for calculating the load that leads to cracking of a UHPC shear wall with an inclined section was conducted. The formula for calculating the bearing capacity of a UHPC shear wall oblique section is proposed. Both formulas demonstrate high precision when compared with the measured experimental results, enabling its use for practical engineering problems.

Paper [19] represents a study of mechanical properties of high-performance concrete reinforced with basalt fibers. This study includes testing of the concrete properties such as strength, elastic modulus, tensile strength for concrete mixtures with basalt fibers. These fibers are relatively cheap and its been used primarly for economics reasons.

In each of the three series the optimum compressive strength at 2% Basalt fibre volume was found to be higher, whereas at 3% fibre volume compressive strength reduced probably due to the presence of voids caused by the use of higher fibre volume of Basalt fibres. Concrete mixes with basalt fiber showed satisfactory ductile behavior, however when it comes to the elastic model results adding of these fibers does not influence it much.

Similar to the previous paper, in the paper [20] have been tested mechanical and durability properties of high-strength concrete containing steel and polypropylene fibers. Results of the experimental study indicate that incorporation of steel and polypropylene fibers improved the mechanical properties of high-strength concrete at each volume fraction considered in this study. This is due to the ability of fibers to restrain the extension of cracks, reduce the extent of stress concentration at the tip of cracks, and delay the growth rate of cracks. Furthermore, it was observed that the addition of 1% steel fiber significantly enhanced the splitting tensile strength and flexural strength of concrete. Among different combinations of steel and polypropylene fibers tested, the best performance was attained by a mixture that contained 0.85% steel and 0.15% polypropylene fiber.

Taken into account requirements for strength and durability, HPC is usually manufactured with a water-cement ration ranging from 0.2 - 0.4. These are the main reasons for frequent shrinkage and cracking of high-strength concrete, therefore shrinkage-reduction admixture (SRA) is being used. Taking into account all the above, experimental study has been conducted [21] on the influence of shrinkage-reducing admixture on mechanical properties of high-strength concrete.On the basis of conducted experiments, results show that SRA effectively reduces strength gain, so the workability of this type of concrete is better. The presence of SRA causes lower early strengths than those found in mixtures without SRA. This strength loss can be offset to some degree by reducing the mixing water content and taking advantage of the water-reducing effects of SRA addition.

In the paper [22] have been tested the effect of pozzolanic additives on the strength, and the main aim of this research is to estimate the effect of pozzolanic substitutes on the temperature generated by the hydration and on the final strength of concrete,and for these purposes has been conducted deferential thermal analysis. It is concluded that silicate fumes (SF) accelerates the commencement of the cement hydration process for approximately 1-2 hours.

When increasing the amount of SF in the composition, beginning of hydration process starts earlier and the hydration process takes longer. All compositions that are being tested reached maximum temperature in 11-13 hour interval. SF leads to increment of mechanical properties (pressure strenght), however, more successful are compositions where no more than 20% of cement are replaced by SF. This paper concludes that pozzolanic reaction can significantly reduce the required amount of cement and make concrete more eco-friendly.

In this paper has been analysed the efficiency of waste glass powder in enhancing the mechanical properties of concrete at high temperature [23]. Chemical composition of this powder reveals that it plays good role as effective inert of a very fine material in concrete strength improvement.

Results demonstrate the great role of waste glass powder in conserving residual strength at high temperature. Mixtures made of silicate dust showed higher degradation of strength at high temperature compared to mixtures produced from glass powder, and consequently the effect of splitting concrete at high temperature is lower for mixtures with such material. Waste glass powder with particle size range of 100–850 μm can be really efficient for high-strength concrete exposed to high temperature.

Paper [24] is based on studying the effects of high temperature on compressive and flexural strengths of normal and high-performance concrete. The mechanical characteristics of the concrete samples were compared with each other and then compared with the samples which had not been heated. On the other hand, strength loss curves of these concrete samples were compared with the strength loss curves given in the codes.

Flexural and compressive strength decreases with the increase of temperature, and such decrease is greater in those cooled in water. The compressive strength of HPC cooled in air and water decreased up to 200 °C, and increased betw^{e}en 200 °C and 400 °C. The compressive strength of normal performances concrete was decreased continuously. The compressive test was not done for normal strength concrete in the temperature above 600 °C, and for high-strength concrete in the temperature ab^{o}ve 800 °C for the, because most of the concrete samples disintegrated. A study indicated that concretes produced using limestone aggregate caused loss of strength in high percentages in those cooled in water after being exposed to high temperature.

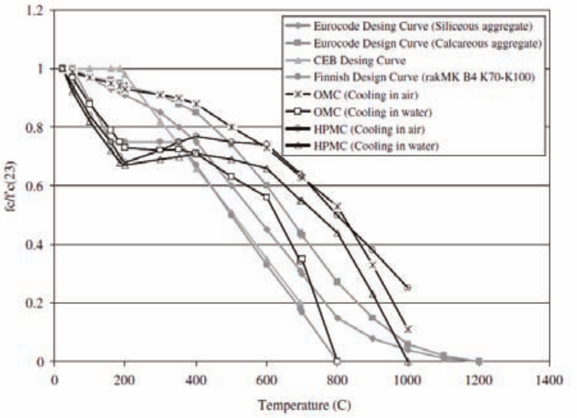

Fig. 6: Comparison of design curves and experimental loss of strength curves [24]

Papers presented in the previous chapter represent a significant database of properties of high-performance concrete, which is very useful both in long-term research and engineering practice. It is important to mention that the compressive strength, as the main mechanical characteristic of concrete, depends mostly on the water-cement ratio. It is also an interesting fact that some authors have proved in their research that existing models for calculating flexural strength cannot accurately and precisely determine the flexural strength of ultra-high performance concrete.

4. UTILIZATION AND DEVELOPMENT

Despite of its superior characteristics, HPC is not widely used at the markets due to its high constituent materials cost. The selection of components, as well as the production, transport, installation and care for these concretes are much more complex than for normal strength concretes, which is directly reflected at the total cost of the material. Generally speaking, high-strength concretes are most often used for the production of precast thin-walled elements reinforced with steel fiber, which are used in highly aggressive environments. However, specific examples of utilization and development of these concretes are provided in the text below.

In the paper [25] have been conducted a research about utilization and development high performance concrete (HPC) for precast/prestressed concrete industry. The main goal of this research is to develop the mechanical properties of HPC using only useful mixing techniques. For industrial use of precast and prestressed concrete, the goal is for the compressive strength of 70 MPa to reach 24 hours, and the final strength of 105 MPa to be reached no later than 28 days.

In order to create HPC mixes it is necessary to use a high energy paddle mixers due to their high binder content and low water-cement ratio. Developed HPC mixes had a minimum 24h compressive strength (after 24h and after 28-days), and the compressive strength is attributed to the high binder content, incorporation of silica fume and fly ash in the mix.

When it comes to Modulus of Elasticity (MoE), a conclusion is drawn that current code equations over-predict the value of the MoE compared to test results as seen at the Fig.7.

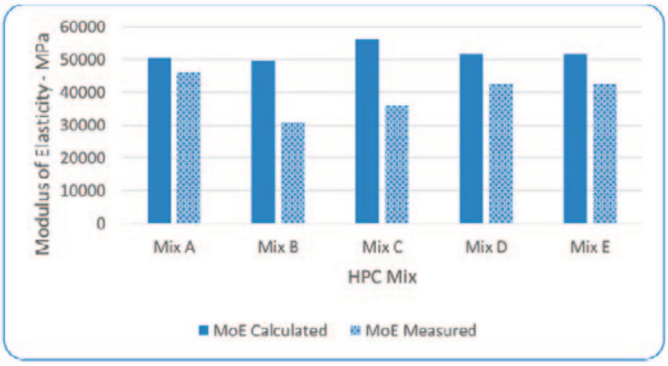

Fig. 7: Modulus of Elasticity: tested and calculated values [25]

The values of tensile strength concrete calculated by using the numerical method are lower than experimental studies. Accordingly, they can be used conservatively if no tests have been performed in the laboratory. Further researches are necessary to determine a more accurate numerical expression of the concrete tensile strength.

An experimental study of the construction of bridges at highways in the United States made of high-performance concrete was shown in the paper [26]. Currently, Federal Highway Administration (FHWA) uses methods to accelerate bridge construction to expedite the construction of new bridges, and minimize material, labor, and equipment cost. This research contains discussions of fabrication of precast/prestressed elements and systems using high performance concrete (HPC).The I-girders cross section demonstrated superior flexural and shear capacities which resulted in smaller girder cross-sections, a larger ratio of span and height of cross-section and increased distances between the girders. It is concluded that the use of such systems in the United States will significantly improve the state of the bridge network in this state in terms of increasing the life of buildings and reducing maintenance and repair costs.

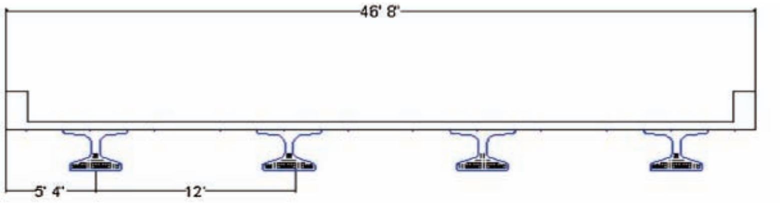

Fig. 8: The alternative bridge construction using HPC and a cables with a large diameter prestressing strands (0.7 in.) [26]

In the paper [27] has been analysed and experimental research of corbels made of ultra-high performance steel fibers (UHPC). In this study, a total of eleven UHPSFC corbels specimens, except one corbel without reinforcement bars, were tested in order to determine the structural behavior characteristics, the ultimate load and the crack patterns, ductility and failure modes of UHPC corbels.

Experimental studies have shown that the first cracks appeared at or vicinity the corbel-column intersection, and the first cracking load increases either with decreasing the shear span-to-depth ratio. Providing secondary reinforcement in the form of steel fibers reduces crack widths, improves corbel stiffness, and enhances ductility. Taking into consideration ACI 318-14 requirements, it is recommended that it is necessary to do more researches in order to establish new limits for the main and secondary reinforcement ratios in the form of steel fibers. The authors of this paper have concluded that expressions recommended by ACI 318-14 are very conservative in terms of shear strength of ultra-high performance concrete brackets with added steel fibers.

The importance of concrete development from an environmental point of view has already been mentioned several times. Accordingly, the paper [28] provides an overview of the experimental study of ultra-high performance concrete (UHPC) taking into account an environmental aspect. Taking into account that UHPC has a significantly higher portion of cement than normal strength concrete (almost twice as much), it is necessary to explore substitution of the cement with hydraulic additives that have CO_2 emissions in order to reduce the harmful impact on the environment. A main focus of this research was use of materials such as granulated blast furnace slag (GBS) or fly ash (FA).

A research has shown that substitution of cement by appropriate less energy intensive cementitious materials is possible up to about 45% by weight without significant degradation of mechanical properties and workability of the concrete. By substitution of cement with mentioned materials it has been made only a first step towards improving the sustainability of UHPC from the ecological point of view. However, if you take into account the reduced material consumption, as well as increased durability, the overall picture is significantly improved. Further steps to optimize the amount of cement, in order to make UHPC more competitive from an environmental point of view, were taken by using fibers in concrete mixes.

In the paper [29] the authors present the possibility to utilize two waste materials to produce high performance concrete (HPC) for the purpose of improving use of such concrete from an environmental point of view. Recycled Concrete Aggregate (RCA) of 4-16 mm fraction and Class F fly ash (from coal burning power plant) were used for preparation of tested mixes in combination with different types of cement. Therefore, on the basis of results, authors believe that the 5% water absorption limit is impossible to achieve. Replacing 2-4 mm fraction of natural aggregate with RCA caused slight worsening of most of the concrete durability properties with the exception of absorption which worsened significantly (20%

increase). This leads to the conclusion that it is safer to use RCA fractions above 4 mm and this conclusion is consistent with the provisions of the standards and recommendations in the literature. It is assumed that by doing further research this effect will be compensated.

In the paper [30] are included principle approaches to high performance concrete application in civil engineering structures. In the article has been discussed research, designing high performance concrete compositions, optimal application of this material as in the field of erecting unique prefabricated structures, so in high-risebuildings. In addition, the main requirements for high-performance concrete were established and the existing practice of application in modern construction practice was described.

In particular, concrete mixtures for various maintenance conditions and different targets set by clients have been designed and successfully implemented: building mixtures providing high strength to concrete structures as well as increased chemical resistance and water-proof characteristics of concrete structures, high performance concrete for entertainment and sport constructions undergoing significant acoustic and vibration dynamic impact; high performance concrete types for industrial buildings and facilities undergoing high temperature, acid and saltthreat; effective concrete types considering special requirements of building hydroelectric power plants and other energetic facilities have been created;etc.

5. CONCLUSION

High-property concretes have a wide application in the construction of load-bearing, durable and usable reinforced concrete structures. Due to the reduced porosity, high-strength concretes have significantly improved durability properties compared to normal-strength concretes. This is the main reason for their use in various aggressive environments. In addition to improved durability compared to normal concretes, they are also characterized by better bonding between cement stone and aggregate, reduced shrinkage and creep, improved adhesion to concrete steel and prestressing steel, etc.

When it comes to the disadvantages of high-performance concrete, it is necessary to emphasize the uncanny brittle behaviour and reduction of plasticity. Improvement of ductility and other properties (Flexural strength, strength, resistance to crack formation and propagation, dynamic behavior) of concrete in the hardened state is achieved mainly through the use of steel fibers. Polymer fibers are used to prevent the cracking of early-age concrete and improve fire resistance.

By studying the most important mechanical properties and understanding their results, the superiority of high-strength concrete over ordinary strength concrete has been proven. The influence of various composite materials, such as waste glass powder, steel and propylene fibers, basalt fibers, etc., has improved the individual mechanical properties and durability of high-strength concrete. All of the above is the main reason for the recommendation to use high-strength concrete.

High and ultra-high performance concrete is a very successful material that provides a high standard of modern construction, not only due to the strength and stability of the structure, but also in terms of ensuring the quality of life by reducing all standards (energy, material, financial, etc.) at the construction stage, especially at the stage of maintenance of objects.

Note: The paper was carried out as part of the research conducted at the doctoral study at the Faculty of Mining, Geology and Civil Engineering, a narrower scientific field of Civil Engineering Structures.

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Scientific Paper

PROBLEMS OF CHOOSING DRILLING RODS FOR MINE DRILLING ON THE LIMESTONE QUARRY ″VIJENAC″ LUKAVAC

Sanel Nuhanović[1], Adnan Hodžić[2], Muhidin Brčaninović[3], Muamer Muratović[4]

SUMMARY

This paper presents an analysis of the causes and factors that lead to the fracture of a series of drilling tools in the part of threaded joints of drill rods during the construction of blastholes, for the needs of limestone exploitation on limestone quarry ″Vijenac″ Lukavac. Geological and technical-technological factors are listed as possible causes, most of which are analyzed in this paper. Since geological factors are treated as immutable and cannot be influenced, attention is paid to the causes of hole inclination, the quality of the drilling tool set, and the applied parameters of rotary-percussion drilling, primarily the applied axial load on the drill bit. Based on the conducted analyzes and extensive discussion, certain conclusions were made, the implementation of which can eliminate the side effects of inclination of the blasthole axis and the consumption of drill bit cutting structures, reduce the time required to make a single hole and limit or completely eradicate drilling tool breakage in the part of the threaded joints of the drill rods during the construction of blastholes on this deposit.

Keywords: drilling, drill rod, drill rod thread, drill rod fracture

1. INTRODUCTION

The need for continuous production at the ″Vijenac″ Limestone Mine in Lukavac leads to constant demands for the construction of blastholes, with the aim of blasting and obtaining predetermined quantities of this non-metallic mineral raw material. Limestone is exploited, crushed and separated at the mine. With the aim of exploiting limestone by blasting from production benches, blastholes with an effective depth of up to 25 m are being drilled. Blastholes are made by self-propelled drilling rigs of the company ″Atlas Copco″, using the rotary-percussion drilling method, with a hammer on the surface (″Top Hammer″). During the construction of a certain number of blastholes, a series of drilling tools broke in the part of the drill rods, ie their threaded joints. The possible causes of these fractures will be discussed in this paper.

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[1] Prof. Sanel Nuhanović, Faculty of Mining, Geology and Civil Engineering, University of Tuzla, Urfeta Vejzagića 2, Tuzla, sanel.nuhanovic@untz.ba

[2] Prof. Adnan Hodžić, Faculty of Mining, Geology and Civil Engineering, University of Tuzla, Urfeta Vejzagića 2, Tuzla, adnan.hodzic@untz.ba

[3] Assistant Prof. Muhidin Brčaninović, Faculty of Mining, Geology and Civil Engineering, University of Tuzla, Urfeta Vejzagića 2, Tuzla, muhidin.brcaninovic@untz.ba

[4] Muamer Muratović, Bachelor – Mining Engineer for well exploitation

2. LOCATION AND GEOLOGY OF LIMESTONE DEPOSIT "VIJENAC"

The ″Vijenac″ limestone mine is located 23 km southwest of Lukavac, with which it is connected by an asphalt road. The second asphalt road to the mine leads from Banovici in the length of 12 km.

These two roads merge and together lead to the ″Vijenac″ mine. The nearest populated area is the village of Gornje Jaruške, and it is located west of ″Vijenac″ at a distance of about 2 km by air.

The area of limestone quarry ″Vijenac″ is located between the Neogene basins of Tuzla and Banovici, ie southeast of the ophiolite complex Ozren-Uzlomac. To the north, the area of ″Vijenac″ borders the Tuzla basin, and on the south side is the Banovici basin. It is a slightly undulating, wooded terrain on which precipitous limestones protrude among flattened metamorphic and igneous rocks. The first data on the geological structure of this area date from the second half of the XIX century, and were presented by Austrian and Hungarian geologists: Rzhak, A. (1879), John, C. (1880), Walter, B. (1887). and Radinski, W. (1889), and data given by E. Mojsisovics, E. Tietze, and A. Bittner (1880) can also be found. By detailed geological mapping [1], the following stratigraphic units have been singled out:

- Volcanogenic-sedimentary formation, Jurassic age, represented by serpentinites, which occupy the entire northern part of the exploration area. They appear as a large mass that surrounds the ″Vijenac″ limestone deposit from the north and east.
- Limestones of the Upper Jurassic and Lower Cretaceous represent the most important lithological member in this area. Contact with serpentinites is tectonic, morphologically clearly differentiated. According to the geological map, the deposits occupy the central and southern parts. A significant feature of these limestones is the pronounced carstification and fissure cracking that is the result of exogenous factors and multiphase tectonic processes.

Figure1. Geological map of the wider area of limestone quarry ″Vijenac″ [2]

The geological reserves of limestone are estimated at 350 to 400 million tons. The projected capacity of the mine is one million tons per year, and the projected capacity of the ″wire″ transport system is 150 t/h.

3. DRILLING CHARACTERISTICS ON LIMESTONE QUARRY "VIJENAC"

Mass blasting operations are being carried out on limestone quarry ″Vijenac″ in order to obtain mineral raw materials. Drilling for blasting is performed by self-propelled drilling rigs, which use the principle of rotary-percussion drilling with a hammer on the surface (″Top Hammer″). The drilling process takes place in such a way that the hammer, driven by compressed air or hydraulic oil, generates impact and rotation (Figure 2). The impact pulse is achieved by accelerating the piston in the hammer drill, which strikes the piston of the drill rod.

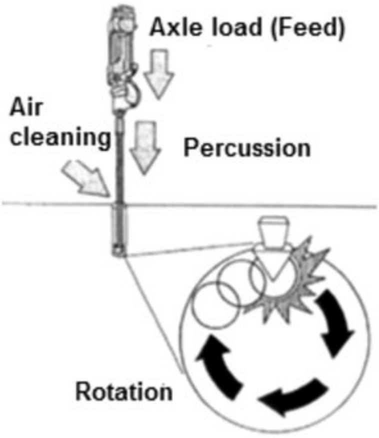

Figure 2. Working scheme of a drilling rig with a hammer on the surface [3]

A series of drill rods transmit percussive energy at a speed of approximately 5000 m/s, all the way to the drill bit, which, via very hard alloy inserts, destroys the rock mass at the bottom of the hole.

During this process, the entire amount of energy is not expended on the destruction of the rock, but, in part, it is reflected in the form of a return wave. The drill rods also transmit the rotation by which the piston rotates on the hammer. The load on the drill bit is provided by the guide in such a way that the system of steel ropes, chains or hydraulically pulls or pushes the hammer to which a series of drill rods (drill pipes) is attached, in the direction of drilling. In this case, it is a hydraulic energy transfer.

What is important is that, in these versions of drilling rigs, all three necessary components for rock destruction (load, rotation and hydraulics) are generated on the surface. The removal of drilled rock particles from the hole takes place using compressed air. Drilling rigs with a hammer on the surface, in general, are suitable for use in medium to hard rocks, which corresponds to the bearing profile, but also for holes with a diameter of 127-140 mm and a depth of 20 m [4], with a drilling diameter does not meet drilling standards and equipment manufacturers.

3.1. DRILLING RIGS ON LIMESTONE QUARRY "VIJENAC" LUKAVAC

For the construction of blastholes on limestone quarry "Vijenac", self-propelled drilling rigs are used, with a rotary-percussion drilling system using an external hammer from the Swedish company "Atlas Copco", of different characteristics, depending on the type of drilling rig.

In general, the basic characteristics are presented in Table 1.

Table 1. Basic characteristics of the drilling rig ROC D7

Characteristics of the drilling rig ROC D7	
Manufacturer	Atlas Copco
Type	ROC D7
Powertrain power	168 (kW)
Compressor operating pressure	6 – 7 (bar)
Air flow	105 (l/s)
Maximum hydraulic pump pressure	250 (bar)
Weight	14 200 (kg)
Maximum rig transport speed	3,6 (km/h)
Traction force	110 (kN)
Maximum slope	20 (°)
Lenght of drill rods	3660 (mm)

This type of drilling hammer, except of rotation and impact in the direction of drilling, has the ability to generate an impact force opposite to the direction of drilling, regarding pulling the drill rods.

In this way, jamming of the drill bit and its loss in the hole is avoided, which is important to emphasize, because this is the manufacturer's recommendation.

4. PROBLEMS OF FRACTURE OF DRILL RODS ON LIMESTONE QUARRY "VIJENAC"

The current condition of the drilling rig on limestone quarry "Vijenac" speaks of its long-term use and fraying, and small investments, with the expectation of high efficiency.

A drilling rig is currently in operation, with the available tools, with the following parameters:

- I set of drill rods - 8 pieces of drill rods - drilled 12 100 m,
- II set of drill rods - 8 pieces of drill rods - drilled 6 550 m,
- III set of drill rods - 8 pieces of drill rods - drilled 1 425 m,
- IV set of drill rods - 8 pieces of drill rods - drilled 3 150 m.

4.1. PROBLEMS OBSERVED

During the construction of blastholes on limestone quarry "Vijenac", drill rods break, most often on the second bit drill rod, ie on the threaded connection between two drill rods, at drilled depths of 8,0 m and 12,7 m.

In this way, three drill rods of the MF T51 rod were "damaged", which can be seen in Figure 3.

Figure 3. Appearance of the drill rod after fracture (limestone quarry "Vijenac")

The basic drilling parameters are presented in Table 2.

Table 2. Values of basic parameters of drilling blastholes on limestone quarry "Vijenac"

Drilling parameter	Parameter value
Effective drilling depth	25 (m) (drilled 8 – 18 m)
Dip angle	70 (°)
Drilling duration	25 (min)
Oil pressure in rotation	50 (bar)
Air pressure in the hammer	6 (bar)
Compressed air pressure	12 (bar)
Drilling diameter	89 (mm) (3,5")
Hole depth	14,30 (m)
Drill rods (drill pipes)	4 x 3,66 (m) (in total 14,64 m)

Terrain geology and drilling conditions are presented in Figure 4.

Figure 4. Drilling conditions and limestone discontinuity on limestone quarry ″Vijenac″

In order to better analyze the problem, it is necessary topoint out the existence of interlayers in the layers of limestone, as a consequence of their carstification, which is shown in Figure 5.

Figure 5. Limestone interlayers at the limestone quarry ″Vijenac″

The theory, but also the practice of drilling, recognizes a number of problems related to the construction of hole channel in rocks of different hardness, with regular occurrence of inclination, ie diversion of the projected trajectory of the hole, which can lead to breakage of drilling tools (Figure 6).

Considering the existing problem, it is realistic to come to the following assumptions:

1. Fracture of drill rods, at such ″small″ depths, is a consequence of encountering harder interlayers in the limestone layer, encountering fault zones, or is a consequence of discontinuity of the working environment (RQD);
2. The breakage of drill rods is a consequence of the ″fatigue of the material″ from which the drill rods are made, all due to excessive use and ″fraying″ of the same;
3. Fracture of drill rods is a consequence of less optimized drilling ″regime″ (ratio of load on the drill bit, speed of rotation and number of strokes, and the amount of flushing fluid - air).

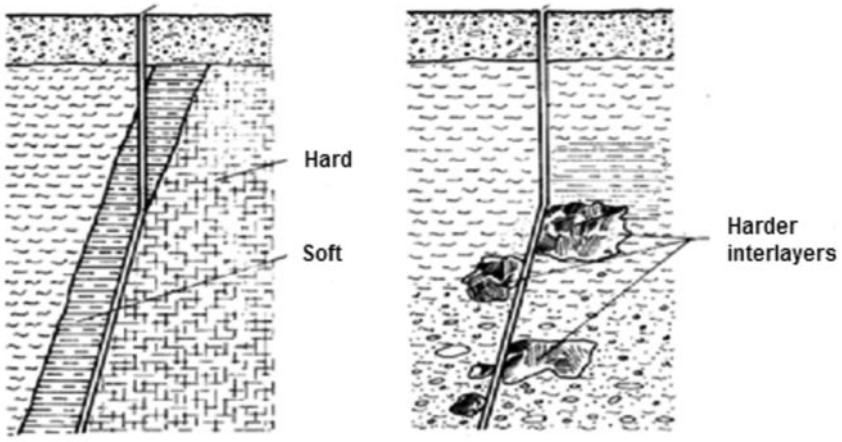

Figure 6. Inclination of hole channels when passing through layers of different hardness and when passing through deposits with hard interlayers

From the assumptions defined in this way, the expected conclusion is that the breakage of the drill rods occurs by a combination of all three mentioned cases.

5. DISCUSSION

The presented images (Figure 4 and Figure 5) show the geology of the terrain in the profile of the working benches. They clearly show the stratification of limestone, its discontinuity and the existence of ″harder″ interlayers. According to the first assumption, in such zones there may be inclination of the hole channel (Figure 6) and breakage of a series of drilling tools (in this case a series of drill rods), where the threaded joints are, in mechanical terms, the weakest part of that series, as shown in Figure 3. Any ″deflection″ of the axis of the hole channel from the designed direction leads to the possibility of excessive consumption of the drill rods, due to their constant contact with the wall of the hole channel, as well as to breakage due to tool jamming during its maneuvering.

Such fractures are more common if the inclination angle of the hole channel is greater at a shorter distance, or if the drill rods do not meet the manufacturer's standards, or if their factory characteristics are reduced to class III or lower and inadequate GRAD quality [5].

The appearance of harder interlayers or cracks in the rock can lead to such a development (Figure 6).

In this case, by looking at the available sets of drill rods, you can see the total drilled length of the same (Chapter 4), which is, sometimes, several thousand meters.

So, it is mostly done in old and ″well-worn″ drill rods and their threaded joints.

It should be noted that the contractor sent the manufacturer two drill rods for testing, 3,0 m long, and according to the manufacturer's results, and based on laboratory tests, they fully met the needs of the manufacturing process. This was shown by X-ray analysis of the structure of the material from when the drill rod was made. This method did not determine the existence of an error in the structure of the material in the technological process of production. Namely, according to the test results, the manufacturer pointed out the doubt in the manner of ″exploitation″ of the drill rod.

Two drill rods sample, of the four existing sets of drill rods, certainly does not represent a ″representative″ sample, and the obtained laboratory results of testing the quality of drill rods cannot be considered too relevant, because we do not have data on drill rods ″selected″ and sent for analysis.

If the test results of drill rods were accepted as correct, then it would return us to the first assumption, or lead us to the third assumption, which leads us to poor optimization of the basic parameters of rotary-percussion drilling, which would mean that the load ratio on the drill bit and the speed of rotation (assuming quality removal of drilled debris by air) is not well matched by the contractor.

Achieving the optimal drilling ″regime″ is, in general, a difficult problem in the technology of hole channel construction, because it depends on a number of geological and technical parameters (lithology of the working environment, physical and mechanical properties of rock, quality of drilling tools, drilling experience, etc.).

In this case, we have the influence of all these parameters, although, in the technology of drilling hole construction, as the most common cause of breakage of a series of drilling tools, inappropriate applied load on the drill bit is considered, and it is pointed out that breakage occurs in the following cases [6]:

1. Case of too little axial load on the drill bit ("Underfeed") - when strong tension (return) waves are created, which lead to the movement of the point of impact of the hammer piston forward, resulting in:

a) high tensile stresses - lead to a reduction in the service life of the drill rod (steel),

b) low tool rotation pressures (torsional moment) - leads to easier unscrewing of drill rod threads and their earlier damage.

2. Case of excessive axial load on the drill bit ("Overfeed") - when too strong compression waves occur, which lead to the movement of the point of impact of the hammer piston back, resulting in:

a) bending (kneading) a series of drilling tools - leads to the creation of inclination of the hole channel,

b) high rotational pressures - lead to more difficult unscrewing of rods on threaded joints,

c) high friction at the "drill bit-rock" contact - leads to increased consumption of the drill bit carbides.

The influence of all the above drilling parameters (axial load, rotation speed and hydraulics) is expressed by the mechanical drilling speed (v_m), in relation to the determined drillability of rock material (in this case limestone), which can be shown in the diagram (Figure 7).

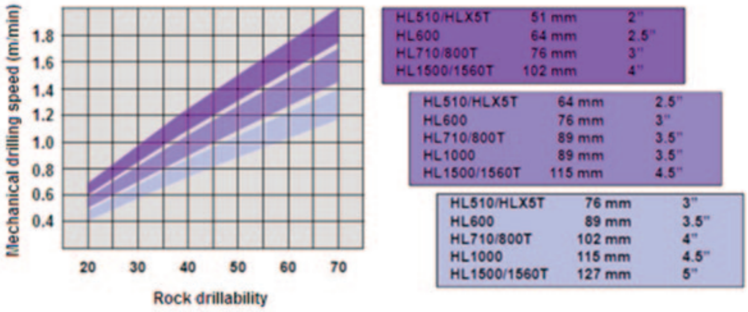

Figure 7. Dependence of mechanical drilling speed on rock drilling values

The drilliness of limestone ranges from 40-60 [7]. For the drilling diameter used on limestone quarry "Vijenac" (Φ 3 ½"), the diagram shows that the mechanical drilling speed should be in the range of 1.0 - 1.6 m/min. This would mean that it would take about 9-15 minutes to drill a 15 m hole. From the table presented above (Table 2), it can be seen that the drilling time of one blasthole on limestone quarry "Vijenac" is about 25 minutes, which is almost twice the required time.

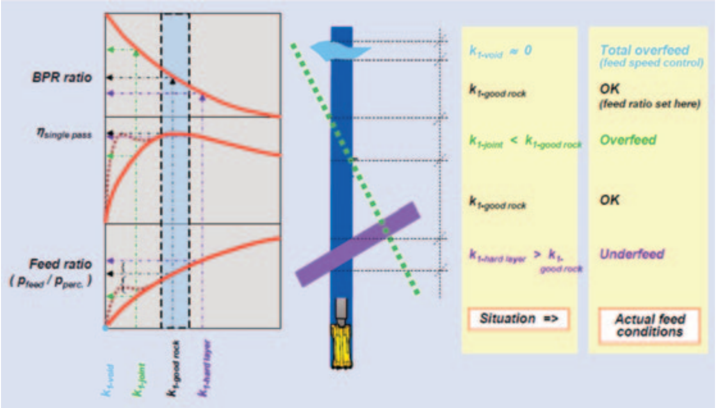

Figure 8. Relationship between axial load and mechanical drilling speed depending on rock hardnes (k_1)

From the diagram in Figure 8, it can be seen that there is a very narrow belt (k_1 optimal) in which the applied drilling parameters give optimal results for rocks of adequate strength and resistance to drilling. Total overload occurs in loose and soft rocks, when due to the possible applied axle load, its value must be taken into account, in order to avoid "deterioration" of the drilling tool through such a layer. As long as the strength of the rock, ie its resistance to drilling (k_1) is less than optimal, it is actually done in the zone of excessive axial load, because the carbides of the drill bit more easily destroy such rock material. In these cases, the applied axial load is higher than required (″overfeed″), and the mechanical drilling speed is higher than optimal. Then the applied axial load must be controlled, in order to avoid the unwanted occurrence of ″kneading″, ie bending of the drilling tool string, due to excessive compression, which can lead to breakage of the drilling tool string.

Only in conditions when k_1 is optimal, ie when the axial load is completely adapted to the conditions of rock strength and its resistance to penetration of the drilling tool, we have optimal conditions for drilling. In the case when the rock strength is higher than optimal, it happens that the applied axial load on the drill bit is insufficient (″underfeed″) for the optimal drilling speed, which then decreases. Then, it is also necessary to correct the applied axial load, in order to prevent stretching of the drilling tool string and its breakage. Since, in the case of drilling on limestone quarry ″Vijenac″ it is drilling in limestone formations, and that the drilling itself lasts, as we have already stated, much longer than is the case with the optimal drilling parameters, it is to be assumed that the axle load parameter on the drill bit is not well set, ie selected. This is usually an excessive axial load on the drill bit, which in such cases leads to increased wear of the drill bit carbides, the occurrence of deviation of the hole channel and, finally, to the breakage of the drill rods. Sometimes the reason for that is the overwork of the drilling staff, that is, the desire to get the job done ″on time″, regardless of the consequences.

Technical-technological causes (primarily bending of a series of drill rods due to drill bit overload) lead to changes in the shape and cross-section of the hole, and the appearance of eccentricity of a series of drill rods and drill bits. With the loss of the cutting structures of the drill bit and the deviation from the projected axis of the hole, the drill rod bends with increasing stress, which leads to breakage of the drill rod, partly caused by intense friction of the rod against the hole.

Due to that, there are problems when maneuvering (lowering and pulling out) a series of drilling tools, which also affect its loss during the performance of drilling works. As a consequence of all this, largely due to the distortion of the drill rod, it was impossible to complete the hole at the predicted depth, which results from the Report of the depths reached during the operation of the drilling rig.

Based on the above, it is necessary to harmonize the drilling regime against the established characteristics of the working environment (″RQD″), with the correct choice of drilling tools.

One of the possibilities of reducing the observed problems in the continuation of works is the introduction of a heavy drilling rod (″Heavy Weight Drill Pipe″), of appropriate quality, which will reduce the possibility of deviation of the hole channel axis, especially when passing through cracked and fault zones.

6. CONCLUDING REMARKS

In order to continuously produce limestone on limestone quarry ″Vijenac″ by blasting, blastholes with an effective depth of up to 25 m are being built, with the rotary-percussion drilling method, using a hammer on the surface (″Top Hammer″). At a certain number of holes, a series of drilling tools break in the part of threaded joints of drill rods, most often between the second and third, or third and fourth bit drill rods (depth 8,0 – 12,7 m). Threaded joints are, in general, the weakest part of any range of drilling tools. The drilling process is greatly complicated by the geological characteristics of the deposit itself, the angle of the layers, the existence of numerous layers of harder material, the discontinuity of limestone, and the existence of numerous, smaller or larger, fault zones.

All this can be the cause of the breakage of the drill rods, caused by the deviation of the hole channel, as a consequence of one of the stated geological factors. However, the geological characteristics of the deposit cannot be influenced, so these are factors that belong to the group of invariants, when analyzing the optimization of parameters and overall drilling results.

As pointed out in the paper, the breakage of drill rods at their threaded joints usually occurs due to the action of one or more common causes, which are, in this case:

- encounters with harder interlayers, discontinuity in the working environment or encounters with a fault zone,
- fatigue of the material from which the drill rods were made (together with them and threaded joints) and
- inadequate drilling parameters (drill bit load, rotation speed and number of strokes, and the amount and speed of air for the removal of drilled debris from the hole channel to the ground surface).

Since it is practically impossible to avoid encountering harder interlayers, fault zone or limestone discontinuity as a working environment, it remains to analyze the degree of material fatigue and applied drilling parameters on limestone quarry ″Vijenac″ Lukavac, in correlation with the stated causes.

Fatigue analysis of drill rod materials showed that (on two drill rods, as many as were analyzed), based on laboratory tests, they fully meet the needs, and that no error in the structure of materials in the technological process of production. This was shown by X-ray analysis of the structure of the material from when the drill rod was made. According to the test results, the manufacturer expressed doubts about the way the drill rod was ″exploited″.

We point out that the analysis of only two, arbitrarily selected drill rods, out of a total of 32 drill rods, as many as there are in 4 drill rod sets, is insufficient and cannot be considered relevant, because some drill rods (first set) drilled over 10 000 m the total length of the hole channel for its service life so far, while some others (for example, the third set) have drilled ″only″ about 1 500 m.

We have no data on which two drill rods were on analysis and how they were determined and selected for analysis.

Consideration of the applied drilling parameters (primarily the applied axial load on the drill bit, assuming a valid rotation speed and the number of strokes applied, as well as an adequate amount of flushing fluid or air) leads us to the conclusion that the applied axial load is not optimal. greater than the required optimal values.

Therefore, in combination with the mentioned geological factors, inclination of the hole channel occurs as well as excessive wear of the drill bit cutting structures, which results in reduced mechanical drilling speed, ie increased time required for drilling hole construction and, finally, breakage of the drilling string tools in the part of the threaded joints of the drill rods.

Wear of drill bit cutting structures and difficulties with maneuvering a series of drilling tools are loaded in the required time of drilling, which is almost twice as long as the prescribed norms for new drilling tools, and all this, with the inclination of the hole axis, leads to inability to reach the designed depth of holes, drilling tool wear and breakage.

It is possible that the so-called organizational causes also participate in all this, ie that some work must be completed within the foreseen time frame, although there are no technical conditions for that, so the drilling rig is exposed to unwanted parameters.

It is necessary to adjust the basic parameters of rotary-percussion drilling to the conditions of the working environment and, if possible, to replace the ″worn out″ drilling rods with newer ones.

If there is a possibility, in one row of drilling tools, just above the drill bit, it is necessary to insert one heavy drill rod (″Heavy Weight Drill Pipe″), in order to reduce the possibility of inclination of the axis of the hole channel.

The investor should also consider the possibility of procuring and introducing into the technological process of drilling a plant for rotary-percussion drilling with a hammer at the bottom (″Down The Hole″ - DTH), because this method of rotary-percussion drilling gives much better results in relation to the existing one (″Top Hammer″), especially in terms of maintaining the axis of the hole channel and, in general, the quality of the built blastholes in complex working environments, as is the case with the limestone deposit ″Vijenac″.

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Scientific Paper

ENGINEERING GEOLOGIGAL RESEARCH FOR THE RESIDENTIAL SETTLEMENT CONSTRUCTION AT SUBSIDENCE ZONE IN THE URBAN AREA OF TUZLA

Jasenko Čomić[1], Rejhana Dervišević[2]

SUMMARY

In the narrower area of Tuzla City, that is within the subsidence boundary of the terrain, where the boundary of the so-called "Zone of expressed deformations" has been defined, the investor "Dženex doo" Tuzla, plans to build five residential buildings of different horizontal dimensions, with the same number of floors.

In the previous period, the study area was significantly degraded by the subsidence process, which occurred as a result of uncontrolled brine leaching. This was also as a result of which the leveling characteristics of the terrain were significantly changed in relation to the conditions before intensive salt exploitation. The competent city services, in the process of determining the possibilities, manner, type and defining the dynamics of possible construction on the subject location, also demanded implementation of geodetic monitoring of the subsidence process. This paper considers very complex construction project in relation to the investigated locality, the engineering geological, hydrogeological and geotechnical characteristics of the area, as well as the data of detailed geodetic monitoring. Twelve geomechanical wells were drilled for the purpose of field and laboratory tests.

Keywords: engineering geological research, geological structure, subsidence, bearing capacityo coal basin, qualitative-quantitative characteristics, spatial potentiality of the deposit, categorization of coal layers.

1. INTRODUCTION

At location of the narrower city center which has been defined as "construction land", the gradual construction of five residential buildings of different horizontal dimensions is planned. This location is located in the former circle of "Amos", on cp no. 256/4, 256/10 and 256/11, K.O. Tuzla I, in Kojšino Street, Local community Center, city of Tuzla.

The study area is located within the zone of pronounced subsidence deformations as a consequence of salt exploitation, and the boundary of the zone with pronounced subsidence scars and the boundaries of subzones with different degrees of terrain consolidation cross this spatial unit, which indicates complex engineering geological characteristics of the area. Planned objects, marked as A1, B1, B2, B3, C1, floors G + 3, are situated between, or tangent to the boundary of three defined subsidence scars.

The research aimed to define the foundation conditions of the buildings that are planned for construction. Data were collected by field measurements and laboratory research, interpreted and applied to the foundation soil in the impact zone of the building. In addition to the reference parameters, calculations were performed aiming to define the conditions and methods of the building foundation. Parameters depending on regional character, such as seismic impacts or water regime in groundwater releases, are taken from the results of regional surveys and applied to the survey site in accordance with its position at the site.

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[1] Mr. sci. Jasenko Čomić, Georad, d.o.o. Tuzla, jasenkocomic@gmail.com

[2] Prof. Rejhana Dervišević, University of Tuzla, Faculty of Mining, Geology and Civil Engineering, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, rdervisevic@gmail.com

The paper presents the engineering geological, geotechnical and hydrogeological characteristics of the research area based on the results of different research methods. Based on the obtained results of field and laboratory tests, the necessary calculations were performed to define the conditions for the foundation of the facilities planned for construction, as well as the landscaping.

2. GEOGRAPHICAL AND GEOMORPHOLOGICAL SETTING

The construction of the facilities is planned in the urban area of the local community Center. On the south side, this site boders with the spatial unit ZBR Slatina 1, which is defined as a residential and business zone with a regime of construction of the first degree [5].

The geographical position of the site is determined by the coordinates 44 ° 32′33.40 ″north latitude and 18 ° 40′23.52″ east longitude according to Greenwich. Morphologically, the site is located in a sunken, flat part of the terrain (Figure 1) where the objects of typical old construction with visible deformations caused as a result of uncontrolled exploitation of the salt deposit, are placed To the east and west of the study area, the slope relief is represented and no traces of destruction and landslides are observed. The average absolute elevation of the investigated terrain is about 240.00 m above sea level. The configuration of the study area was observed and presented by topographic basis (R 1: 25 000) and a georeferenced map (R 1: 2 500) in a 3D model (Figure 1).

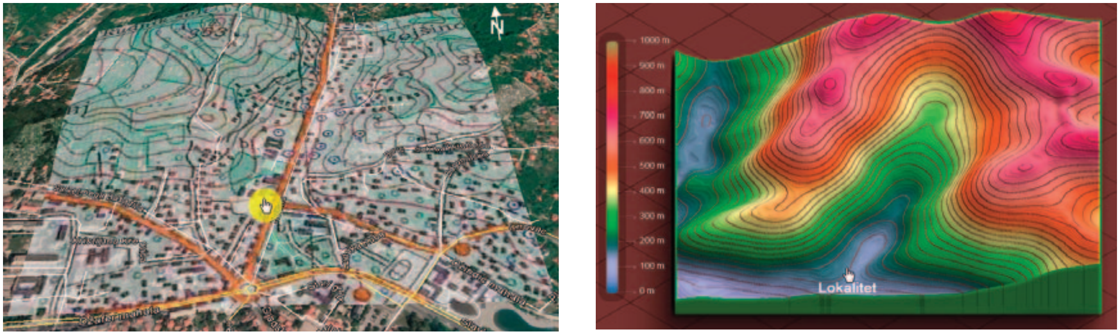

Figure 1. Geographical and morphological location of the research site

In the wider area, an exogenous type of relief is present, within which slope, fluvial and artificial-anthropogenic ones have been distinguished.

The slope type of relief represents only the foot of the southern part of the Kicelj hill. The average slope of the sloping part of the terrain is about 5 °, and the milder slope of this part of the terrain was influenced by its geological structure [1]. Namely, a thicker deluvial cover appears in this zone, which makes a gradual transition between the slope with a higher slope (higher parts of the Kicelj hill) and the flattened river plateau. The fluvial type of relief is represented by two special morphological units: the classical alluvial plateau, and the river terrace and lake-swamp deposits, due to which a slightly sloping terrain was formed in the southwest direction, and this part is about 3.0 m hypsometrically higher than the flat alluvial plateau.

Relief shape of the site represents the slope transition (eluvial-deluvial cover) while the sloping part of the terrain is covered with deluvial sediments. The terrain is generally slightly sloping to the south followed by a fluvial floodplain of terraced flow. Due to the subsidence, a change in the leveling characteristics of the terrain in relation to the initial one is evident. A significant anthropogenic impact is also noticeable, because this area is located in the urban part of the City.

The geological substrate consists of Miocene formations, represented by brown-gray and gray marls, which are covered with quaternary formations. The wider southern area consists mainly of alluvial and terrace sediments of the river Jala.

3. GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The geological substrate in this part of the terrain consists of the Miocene sed^{i}m$_{e}$^{nt}s (1M22 - unstratified brown-gray, gray marls) covered with quaternary formations. Sediments of the Tušanj salt deposit and its immediate bottom participate in the geological structure (Figure 2) of the narrower area of research. The study area is located in the southeastern peripheral area of the strip (M12-M21) and red series (1M12) in its base [2]. Quaternary sediments are represented by alluvial deposits of Jale, as well as stream sediments of larger and smaller streams.

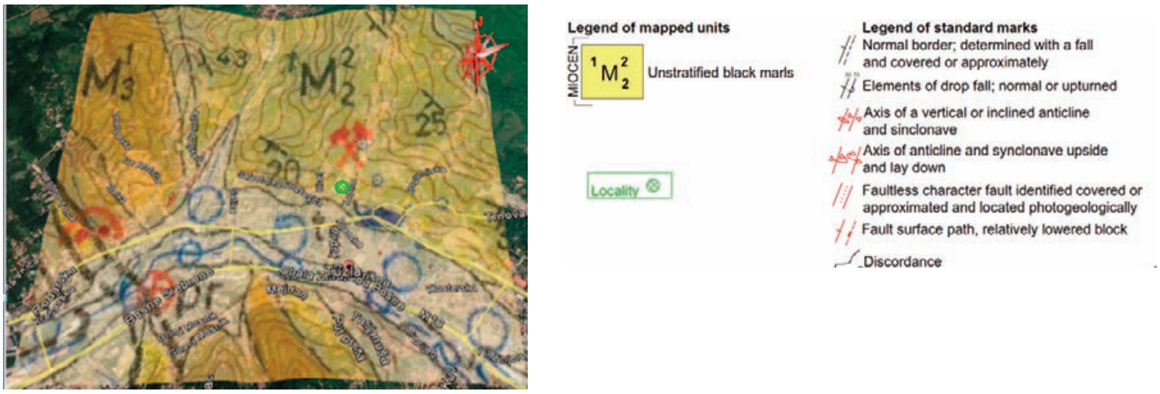

Figure 2 Enlarged detail of OGK R 1: 100 000, (sheet Tuzla) with satellite lining (ground-level view).

The depth of the deposit from the surface is 150 meters in the southeastern part, up to over 600 m in the northwestern position of the deposit. The investigated locality is located on the part (crossing) of the terrain between the represented eluvial-deluvial and deluvial formations of considerable thickness.

In the hydrogeological sense, the impermeable base at the investigated locality is marl brown-gray and gray, which behaves as an insulator. According to the hydrogeological function, the anthropogenically formed embankment and the formations of the cover (ed-d) have the role of a hydrogeological conductor. Hydrogeological collectors (aquifers) of intergranular porosity are mainly present in the valley of the river Jala (wider zone of the Skver), and can be distinguished as alluvial sediment (al) and terrace sediments (t_1).

Alluvial deposits belong to the subrecent type and two facies can be distinguished: one built of clay gravel and sand in the lower profile of the alluvium and second one built of dusty clays, in the upper part of the profile. The gravelly-sandy part of the river sediment has reservoir properties, so that in conditions when the reservoir layer is located between two insulator layers, a groundwater outcrop with subartesian characteristics is usually formed.

The alluvial sediment of the river Jala in terms of composition, spatial parameters and filtration characteristics of the clay-sandy-gravel complex, does not represent a significant aquifer of this type, although it has a continuous spread along the entire flow. In the wider zone of the Skver the occurrence of lake-swamp gray-black soft clays, with poor geotechnical properties, was determined by earlier research (exploratory drilling).

During the geomechanical tests, the investigation determined the occurrence of groundwater and static groundwater levels, which were measured after 24 and 48 hours from the end of the test. The position and water level in each geomechanical well were determined

Measurements showed that the NPV in the study area is in the interval from 1.00 to 4.50 m from the terrain surface, which is also shown on the longitudinal engineering geological profiles (Figure 3).

4. ENGINEERING GEOLOGICAL CHARACTERISTICS

According to the data of the spatial plan of the Tuzla city and the performed zoning of the zones of pronounced subsidence deformations caused by salt exploitation, the site locality belongs to the area of the transition of the zones marked as (B2)-(B3)[1].

Category (B2) includes the area with fractures in the soil (subsidence scars) formed on the Trnovac district, and according to the currently estimated degree of consolidation of the terrain, this category is characterized by different degrees of consolidation: subzone PZ4 (degree of consolidation <50%), PZ3 (50-75%), PZ2 (75-90%) and PZ1 (> of 90%).

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[1] Area B - part of the terrain where the subsidence process that occurred as a result of uncontrolled pumping of brine through deep wells in the Hukalo and Trnovac districts is pronounced [5]. In the defined area B, terrain categories with different influence of subsidence parameters and different current degree of terrain consolidation in the conditions of completed salt exploitation and establishment of quasi - natural regime of groundwater levels B2 and B3 are singled out.

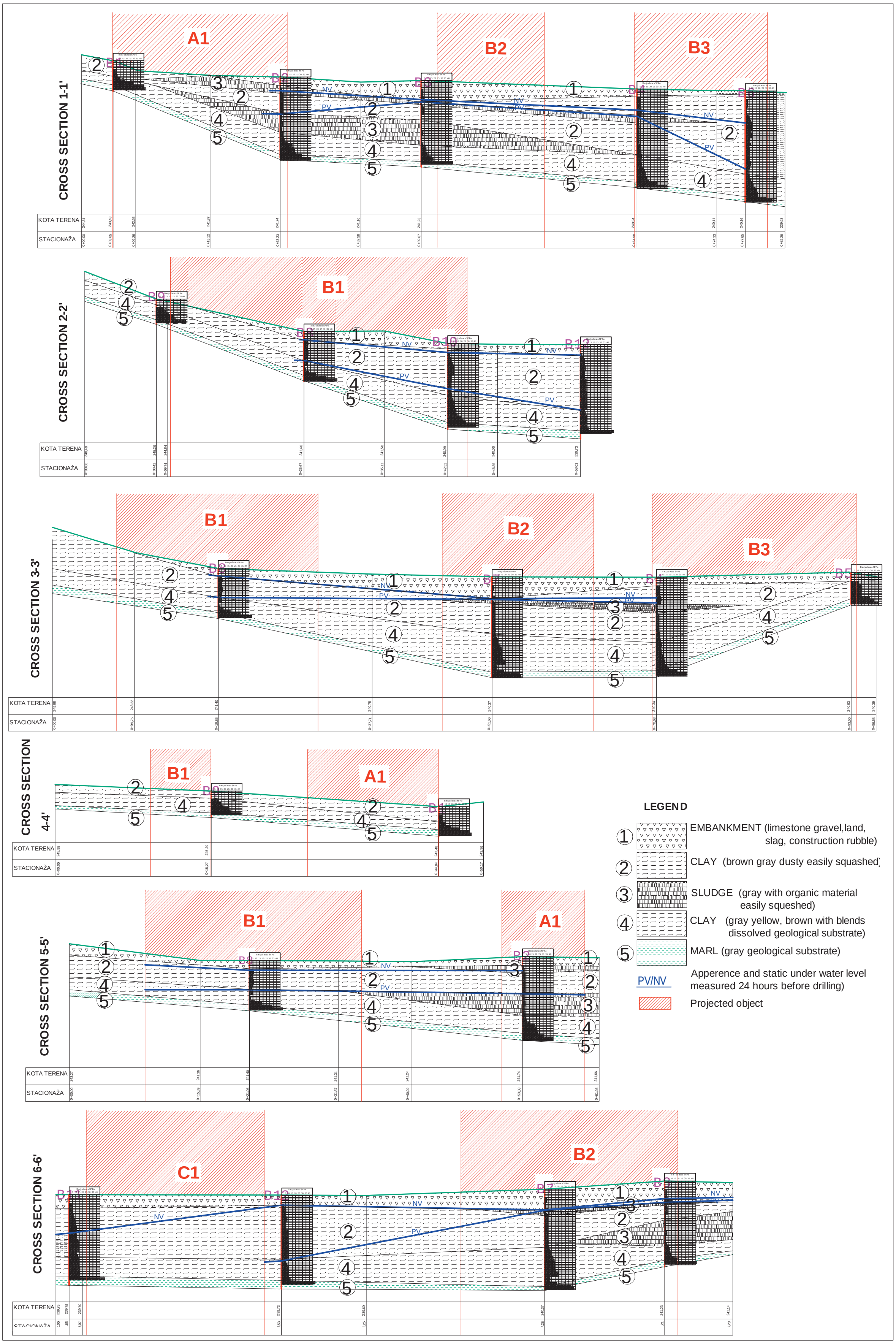


Figure 3 – Engineering geological profiles at the subject site.

Category (B3) represents the parts of the terrain that are outside the fault zone in the Trnovac district and the defined boundaries of the zone of pronounced subsidence deformations. According to the degree of consolidation in this part, subzones PZ3 (degree of consolidation ranges from 50-75%), PZ2 (75-90%) and PZ1 (> 90%) were singled out. There are no pronounced faults in this category of terrain, but the occurrence of compaction, stretching and elevation of the terrain can be expected, as well as the variable behavior of the terrain in the process of terrain consolidation.

According to the latest available data (2012-2015), this part of the terrain belongs to the zero subsidence zone with a degree of consolidation of 50-75% and the expected subsidence of up to 5 cm.

Geological substrate

One lithological type (LT) marl brown-gray clayey stands out as the basic substrate on the part of the investigated site. Marl is recognised in all geomechanical boreholes. These rocks have a weakly layered texture. Under the influence of exogenous-geological processes, they are very susceptible to the decomposition process. Through the recent geological past, a thicker clay cover was formed on them. During drilling, it was found that marls lie in the horizon 2.8 m (B1) to 12.40 m (B6) from the ground surface and have good geotechnical properties. From a hydrogeological point of view, marls represent a hydrogeological barrier. According to the construction norm on the classification of rock masses, given the possibility of digging (GN-200), the rocks of this complex belong to the IV, and fresher rocks to the V category.

Cover

The eluvial-deluvial (ed) cover was formed in the recent geological past as a consequence of surface decomposition of geological substrate formations and partial leaching and accumulation of decomposed material from higher parts of the slope in the central and foot part of the slope. In lithological terms, these are marly clays, medium squashed. The weather product of marl is the crust that created the cover, the weathering zone of decayed marl, the marly clay.

Eluvial-deluvial (ed) cover is most present on the marginal western slope of the microlocality (geomechanical boreholes located and shown situationally B1, B8, B9), as well as on the eastern part (B5).

Deluvial type

The deluvial deposit (dl) of considerable thickness is most present in the central part of the site locality. It was created by washing away the products created by the influence of surface waters that flow down the slopes. The movement of this type of cover is expressed during heavy atmospheric precipitation or melting snow and the transport of these products at the foot of the slopes. The lithological composition of this cover consists of dusty clays with small crumbs, of considerable thickness. The deluvial cover makes a gradual transition between the slope sediments and the foot of the slope, so that they build terrains with a gentle slope of up to 5o. This cover is characterized by the content of dusty clays and with a very small content of crumbs. In general, the deluvial cover is characterized by a higher content of natural moisture in certain zones, so that this cover has variable geotechnical properties according to the vertical profile of the terrain. Groundwater, which has subartesian characteristics, can also be expected in this area. According to GN-200, this type of cover belongs to the III category.

Embankment (e)

In addition to technogenic processes (uncontrolled exploitation of the salt deposit), a layer of unselected embankment - construction waste up to 2.5 m thick from the terrain surface was determined by geomechanical wells (B3 and B7) in the central part of the site locality. The embankment is characterized by variable thickness, and it was formed in several phases, during various technical interventions during the earlier construction of facilities and supporting infrastructure in this area. These are poorly consolidated materials of heterogeneous composition, with poor geotechnical characteristics.

5. SEISMIC CHARACTERISTICS

According to the valid map of microseismic regionalization of the Tuzla city area, made in 1990 by "Institute for Earthquake Engineering and Engineering Seismology" from Skopje, the entire urban area of Tuzla is in the zone of VIII degree MCS scale (Marcali-Cancani-Sieberg).

Based on the local seismogeological characteristics of the terrain, the VIII degree zone is divided into appropriate subzones. The investigated location belongs to VIIIc subzone (terrains built of Quaternary and Tertiary sediments, affected by subsidence and deformation of the soil due to salt exploitation. Seismic parameters for design are defined in this subzone, so the construction of facilities in this area should be adjusted to VIII degree MCS scale, considering the seismic parameters of VIII c subzone and local geological conditions.

6. FIELD AND LABORATORY TESTS

At the study area geodetic surveying was performed in the state coordinate system of scale R 1: 250, as well as locating and determining the coordinates and elevations of geomechanical exploration works (boreholes).The competent city services required preparation of a study of the data of the process of subsidence resulting from the exploitation of salt [6] in the process of determining the possibilities, methods, types, and defining the dynamics of possible construction at this location. In the Study, an analysis of the subsidence process at the investigated site (period 30.07.2017 to 12.11.2018) was performed on the basis of auscultation benchmarks marked (R1 to R16) installed on newer and older buildings (Figure 4) with four series of geodetic monitoring vertical displacements.

Figure 4. Left: Polygon point AM3 with the route of the scar perpendicular to the destroyed object "Amos". Pronounced deformations (orientation and slope of the fracture in the southern direction) on the foundation wall. Right: Display of the built-in benchmark. "Settling scars" in the form of cracks in the asphalt with clearly expressed elements: the width of the impact and the direction of stretching. (Photo by J. Čomić).

After the geodetic monitoring of subsidence at this location, a trend of constant decrease in the value of vertical and horizontal displacements of subsidence was determined, but also the elevation of individual points, which is a feature of parts of the terrain that is in the so-called phase of consolidation. In adition, the subsidence rates have become very small (Figure 5) namely, within – 3 mm/year (less than – 1 mm/year at most points) from 2014 to 2019 [7].

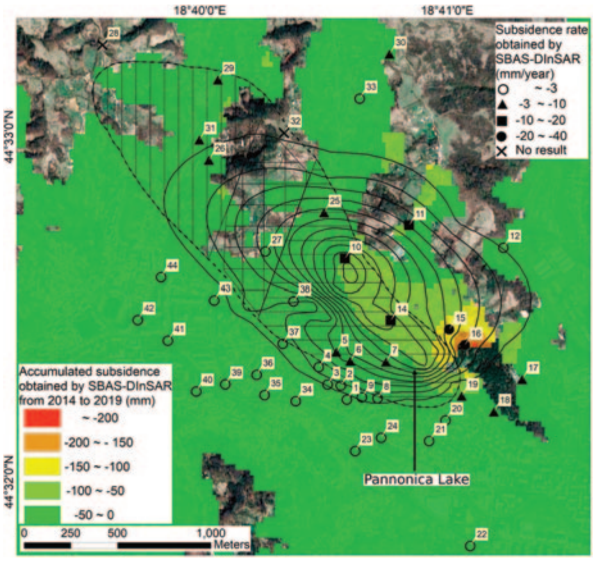


Figure 5. Location of GPS survey points .The symbols of the points indicate the subsidence rate (mm/year) obtained by SBAS-DInSAR (2014–2019)

In order to define the manner and depth of the foundations of the objects, adjusted to their dimensions, detailed geomechanical tests were performed [4], ie drilling of twelve (12) boreholes (Figure 6). The scope of the test was sufficient to profile the ground below the planned objects.

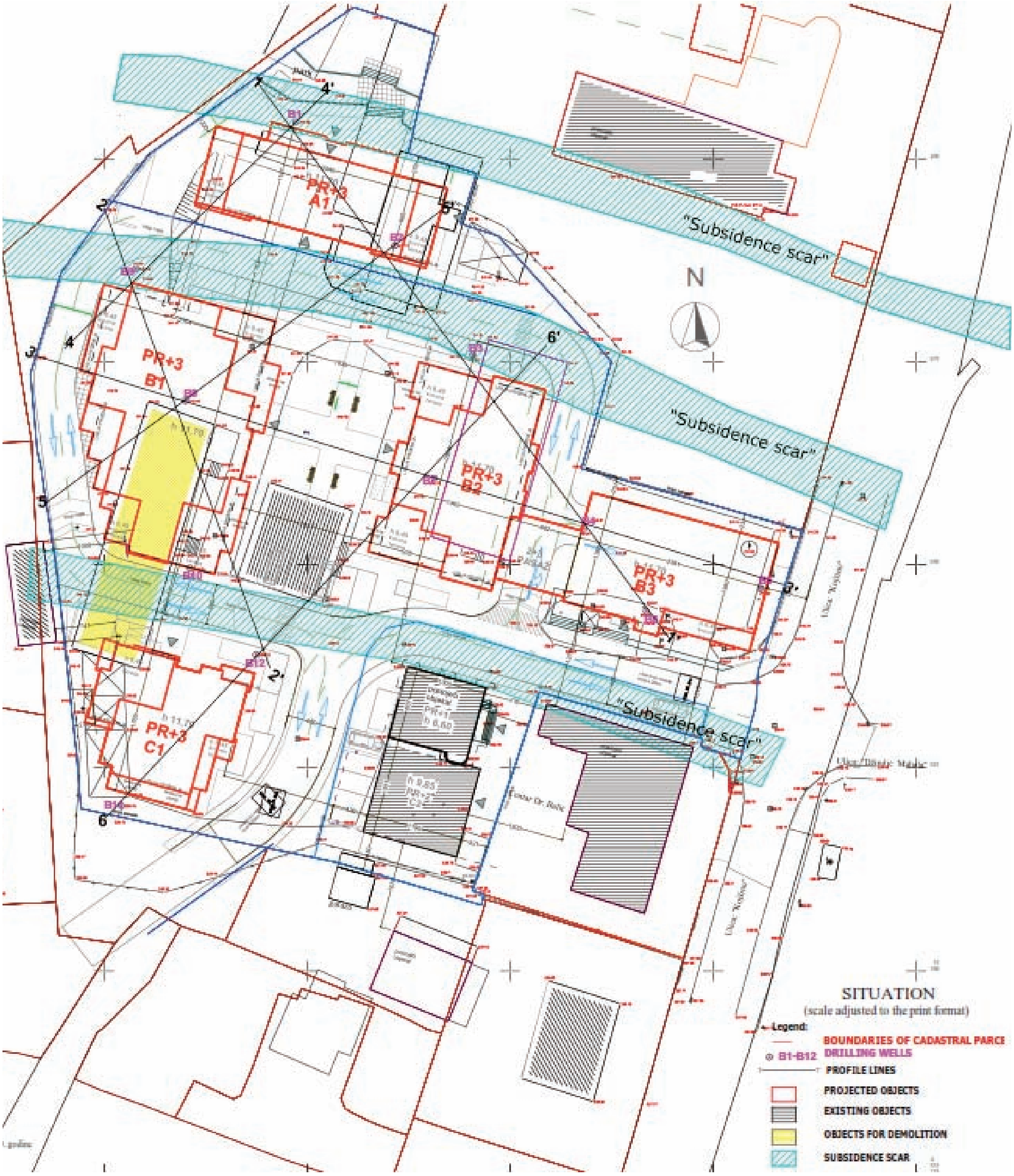


Figure 6. Situation map R 1: 250, with the position of exploratory geomechanical wells (Scale adjusted to the print format).

The results of the standard penetration test were interpreted using the known correlation between static and dynamic penetration. Compaction of coherent and incoherent material as well as the compressibility modulus were determined (Figure 7).

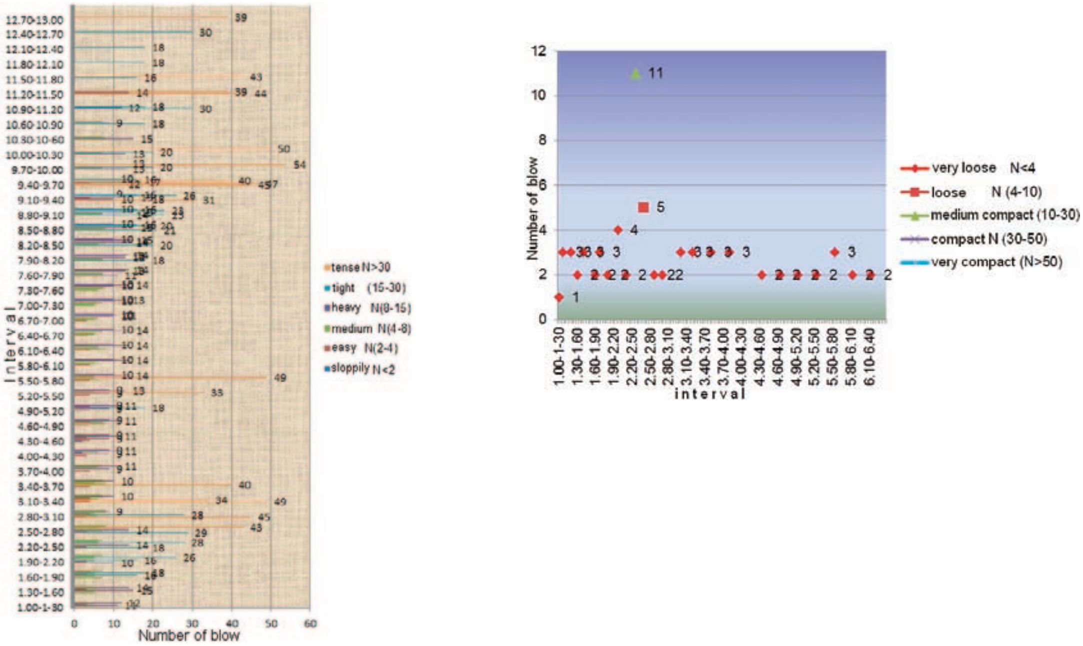


Figure 7. Results ("in situ" of field testing) of the summary standard penetration test. Left: SPP for coherent soil. Right: (SPT) for single grain structure soil.

7. CAPACITY AND SUBSIDENCE CRITERIA

Considering the fact that the investigated location is located in a specific engineering-geological environment, it was necessary to achieve the first identification of the risk of the location, ie consideration of the geotechnical context of the site. Due to the poor physical and mechanical characteristics of the lithological members of the cover in the foundation zone, the use of reinforced concrete piles of different diameters and lengths has been proposed.

Taking into consideration the heterogeneity of lithological members, and the thickness of the compressible layer of clay and sludge, and the high level of groundwater, the allowable bearing capacity on drilled piles 6.0 m, 12.0 m and 14.0 m long was analyzed, which would be based on the geological substrate layer.

The foundation to replacement of the gravel material and deep foundation in order to equalize differential subsidence was considered.

Table 1 – Calculation of pile bearing capacity

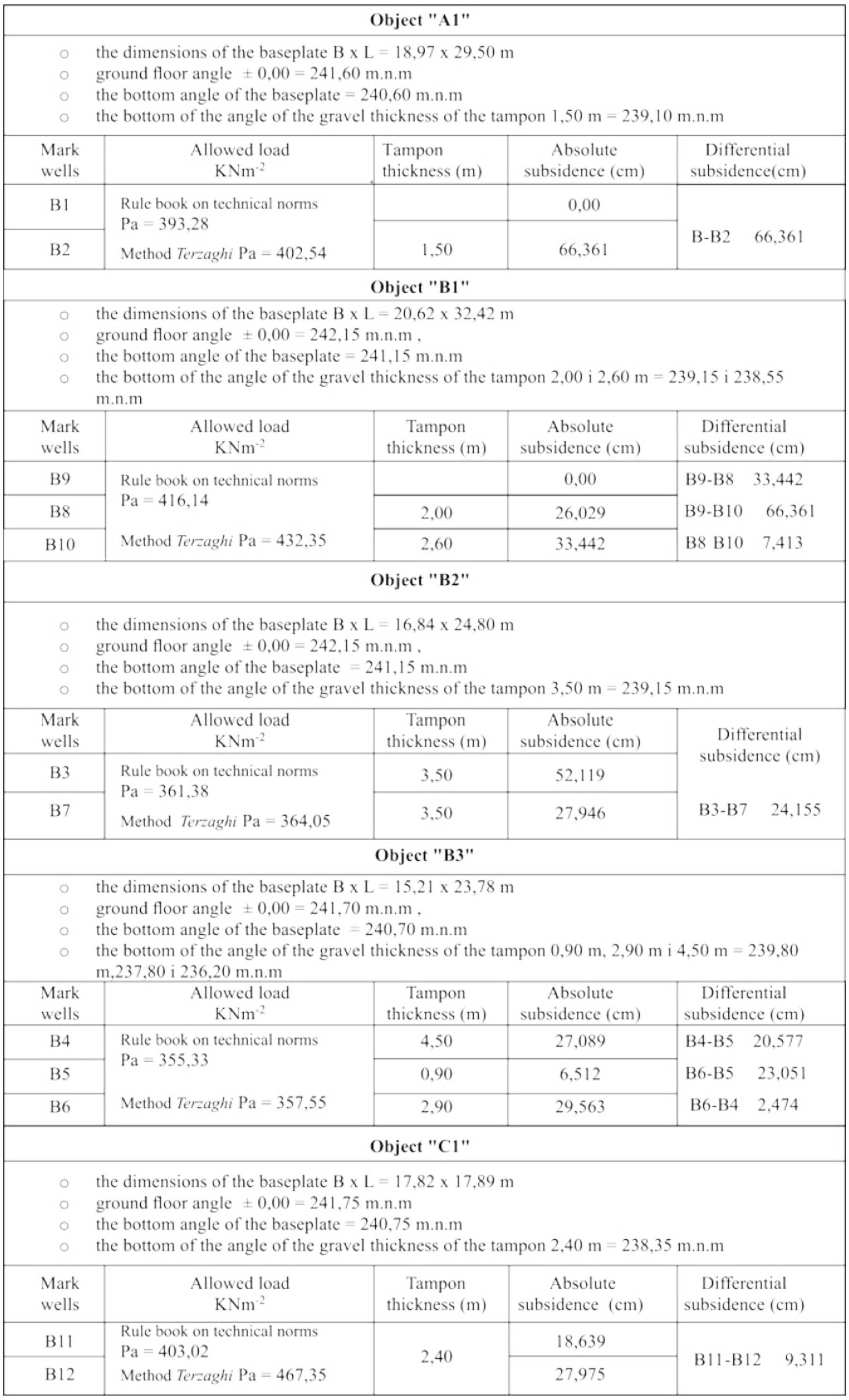
Method	Pile diameter ?600mm (kN)	Pile diameter ?800mm (kN)	Pile diameter Ö900mm (kN)	Pile diameter ?1000mm (kN)
Allowable Bearing Capacity of a pile D = 6,0 m				
Terzaghi	472,33	761,03	930,35	1.116,43
Meyerhof	874,90	1.476,80	1.889,85	2.302,90
Brinch Hansen	399,40	645,50	789,70	948,00
Allowable Bearing Capacity of a pile D = 12,0 m				
Terzaghi	714,71	1.109,80	1.337,12	1.548,40
Meyerhof	1.065,30	1.878,20	2.370,00	2.919,90
Brinch-Hansen	598,00	996,80	1.010,00	1.495,40
Allowable Bearing Capacity of a pile D = 14,0 m				
Terzaghi	788,65	1.216,20	1.461,21	1.727,16
Meyerhof	1.221,90	2.123,90	2.667,70	3.273,30
Brinch-Hansen	863,00	1.384,90	1.689,70	2.023,90

Analyzed were the individual capacity of piles loaded by vertical force, which transfers load to the ground voltage based on the vertical and shearing stress of the pile surface of the timber. Calculations (Table 1) were performed by Terzaghi, Meyerhof and Brinch-Hansen methods, at depths of 6, 12 and 14 m at diameters **Φ** 600, 800, 900 and 1000 mm.

From the calculation (Table 1) it can be concluded that the Meyerhof method gives high values and is not representative for the dimensioning of the pile in the static calculation.

Furthermore, the foundation analysis was performed with the replacement of the material with a plug of gravel layer of different thickness, which is necessary to compact to the compressibility modulus Ms = 60 MPa, for the base rate of the slab for each building. When replacing materials, it is necessary to lower the groundwater level.

Table 2. Subsidence rates



Object "A1"

- the dimensions of the baseplate B x L = 18,97 x 29,50 m
- ground floor angle ± 0,00 = 241,60 m.n.m
- the bottom angle of the baseplate = 240,60 m.n.m
- the bottom of the angle of the gravel thickness of the tampon 1,50 m = 239,10 m.n.m

Mark wells	Allowed load KNm^{-2}	Tampon thickness (m)	Absolute subsidence (cm)	Differential subsidence(cm)
B1	Rule book on technical norms Pa = 393,28		0,00	B-B2 66,361
B2	Method *Terzaghi* Pa = 402,54	1,50	66,361	

Object "B1"

- the dimensions of the baseplate B x L = 20,62 x 32,42 m
- ground floor angle ± 0,00 = 242,15 m.n.m ,
- the bottom angle of the baseplate = 241,15 m.n.m
- the bottom of the angle of the gravel thickness of the tampon 2,00 i 2,60 m = 239,15 i 238,55 m.n.m

Mark wells	Allowed load KNm^{-2}	Tampon thickness (m)	Absolute subsidence (cm)	Differential subsidence (cm)
B9	Rule book on technical norms Pa = 416,14		0,00	B9-B8 33,442
B8		2,00	26,029	B9-B10 66,361
B10	Method *Terzaghi* Pa = 432,35	2,60	33,442	B8 B10 7,413

Object "B2"

- the dimensions of the baseplate B x L = 16,84 x 24,80 m
- ground floor angle ± 0,00 = 242,15 m.n.m ,
- the bottom angle of the baseplate = 241,15 m.n.m
- the bottom of the angle of the gravel thickness of the tampon 3,50 m = 239,15 m.n.m

Mark wells	Allowed load KNm^{-2}	Tampon thickness (m)	Absolute subsidence (cm)	Differential subsidence (cm)
B3	Rule book on technical norms Pa = 361,38	3,50	52,119	B3-B7 24,155
B7	Method *Terzaghi* Pa = 364,05	3,50	27,946	

Object "B3"

- the dimensions of the baseplate B x L = 15,21 x 23,78 m
- ground floor angle ± 0,00 = 241,70 m.n.m ,
- the bottom angle of the baseplate = 240,70 m.n.m
- the bottom of the angle of the gravel thickness of the tampon 0,90 m, 2,90 m i 4,50 m = 239,80 m,237,80 i 236,20 m.n.m

Mark wells	Allowed load KNm^{-2}	Tampon thickness (m)	Absolute subsidence (cm)	Differential subsidence (cm)
B4	Rule book on technical norms Pa = 355,33	4,50	27,089	B4-B5 20,577
B5		0,90	6,512	B6-B5 23,051
B6	Method *Terzaghi* Pa = 357,55	2,90	29,563	B6-B4 2,474

Object "C1"

- the dimensions of the baseplate B x L = 17,82 x 17,89 m
- ground floor angle ± 0,00 = 241,75 m.n.m
- the bottom angle of the baseplate = 240,75 m.n.m
- the bottom of the angle of the gravel thickness of the tampon 2,40 m = 238,35 m.n.m

Mark wells	Allowed load KNm^{-2}	Tampon thickness (m)	Absolute subsidence (cm)	Differential subsidence (cm)
B11	Rule book on technical norms Pa = 403,02	2,40	18,639	B11-B12 9,311
B12	Method *Terzaghi* Pa = 467,35		27,975	

According to the performed calculations, and in accordance with the norms, the criterion of soil fracture at all planned facilities was met, because the allowed soil load is higher than the adopted specific load from the facility δ = 170 KNm^{-2}.

The subsidence critera was not met for any building facility. In accordance with the performed calculations and adopted parameters (Table 2), the following subsidence values were obtained for each of the objects.

8 .CONCLUSION

The conducted research was aimed at defining the foundations of buildings of different dimensions at the location located in the subsidence zone created as a result of salt exploitation, as well as in the so-called. The zone of subsidence scars, which in the previous period was degraded by the subsidence process.

Geological, engineering geological, hydrogeological and geotechnical characteristics of the investigated area are considered, as well as analyzes of detailed geodetic monitoring. The research included the construction of twelve geomechanical wells with the performance of a continuous penetration test, field and laboratory tests of the investigated location, and geotechnical calculations with the definition of foundation conditions for each planned facility. Field investigation works and laboratory tests of samples enabled the selection of input parameters for further analysis of bearing capacity and soil subsidence.

Based on the lithological and physical-mechanical characteristics of the foundation soil, as well as the determined groundwater level, a combined method of foundation has been proposed. Taking into account the permissible load-bearing capacity and subsidence of the foundation soil from its own and additional load, a proposal for how to improve the bearing capacity of the foundation soil is given. In this regard, technology and choice of foundation method must be defined by static calculations within the Main project.

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Scientific Paper

POSSIBILITES OF ALTERNATIVE USE OF COAL FROM KREKA DEPOSIT

Nedžad Alić[1]

SUMMARY

The tendency to eliminate coal as a heat source with the goal to reduce pollution leads to closing of coal mines. The alternative heat source, especially from the aspect of heating smaller living areas, wood pellets, although ecologically acceptable, has its shortcomings, if the quantity of needed energy and the role of forests in air purification are taken into account. That being said, in this paper was explored the possibility of producing energy from the mixture of these energents: wood and coal, and its influence on the environment, from the aspect of sulfur participation. The mixture was subjected to the process of briquetting, and obtained samples were examined and tested with relevant parameters, most important being higher heating value and percentage of sulfur in these products.

Results of this research are indeed optimistic considering both parameters and can be a guide for future research of this idea.

Key words: coal, sawdust, briquette, heating value, ecology

INTRODUCTION

Environmental pollution, especially air pollution, and its influence on life sustainability on Earth is one of the primary goals of research in the scientific and generally social community, due to upsetting the natural balance, which is reflected through a series of indicators. Consequences of rapid development of various process industries and imposing a style of life through the phrase „consumer society", are clearly visible through various macro and micro influences, starting from climate change and onwards. Mining has a significant contribution in these influences by an increased exploatation of energents and other mineral resources. A special role in this is played by fossil fuels, which are claimed to be one of the most important resources that affect the enormous pollution and global changes in living conditions on the planet. From this category of energy sources, coals and their use as energy sources have a special impact on the environmental pollution. Recently, attempts have been made to find an alternative to this energy source, and various studies have been launched concerning the use of other energy sources as well as the development of acceptable technologies for these purposes. The success of some new alternative and ecologically acceptable energy sources is very diverse for all human needs. One of the important characteristics of modern life is the comfort of living, which includes certain norms of heating the space in which one lives. Housing is provided in collective and separate units in urban or rural areas. The problem of introducing new energy sources, from this aspect, is related to individual housing units to which is very difficult to supply energy, due to poorly developed distribution networks or various other reasons, and at the same time, from an economic point of view it is very difficult to apply alternative energy sources. The

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[1] Prof. Nedžad Alić, Faculty of Mining, Geology and Civil Engineering, University of Tuzla, nedzad.alic@untz.ba

most common solution offered as a replacement for coal in the above category, is primarily wood or its pellets as a refined product. Although this mass during combustion has a significant reduction in the emission of primary gases that affect the reduction of air pollution, one should take into account the fact that the primary improvement in the long run could have a completely different result. Excessive exploitation of timber reduces the total amount of forest wealth, which in turn is a natural "filter" of air, so the forest is said to be the lungs of the Earth. Thus, the hypothesis of substituting the type of energy source set in this way does not provide certainty in obtaining a good result. Ovo istraživanje nema za cilj ustanovljenje argumenata naprijed navedenog stava, već inicijalno istraživanje alternativnog rješavanja energenta u naprijed navedene svrhe s akcentom uticaja sagorijevanja na ekologiju.

The research of the possibilities of production of ecological pellets based on lignite from the Kreka coal deposit is basically an improvement of the energy utilization obtained in the current production in this mine.

The basis for this research lies in the significant differences in data: geological research of coal quality and daily laboratory monitoring of basic parameters, namely lower calorific value, moisture and ash. On the other hand, the quality of coal from the aspect of sulfur content is such that it meets the standards of the European Union, which makes this coal a suitable energy source from the environmental aspect. Furthermore, the fact that a significant amount of wood residue is produced in Bosnia and Herzegovina through processing in the wood industry, as well as that a significant amount of this residue is not used, tells us that the basic preconditions for the possibility of pellet production for smaller heat units are realistically fulfilled. The above points to the conclusion that the research has a well-founded basis.

The research implies the application of scientific and professional knowledge obtained in this field, with the obligatory laboratory examination of each statement, ie. the parameter important for achieving the primary goal. Exploration of the possibility of producing coal pellets from the Kreka lignite deposit aims to increase the energy efficiency and reduce the negative effects of combustion on the environment. Unlike previous research, the idea is to add wood shavings created as a by-product in wood processing or as an unused residue in the "cutting" of wood to certain classes of coal in the pelletizing (or briquetting) phase.

The program task of the research is to determine:

- possibilities of obtaining pellets or briquettes with research of the mixture recipe,
- research of agglomeration technology of this mixture,
- determination of key parameters of the product, those being thermal value and harmfulness to the environment through the sulfur content in coal and the obtained agglomerate

The expected results will provide a higher amount of energy for the same individual mass of the energy source, which results in a more efficient use of non-renewable energy sources. The total emission of harmful gases into the atmosphere will be reduced for two reasons: more efficient combustion and less fuel consumption for the same unit of energy.

2. RESEARCH METHOD

The method, or research model, is based on the following principle:

- determination of characteristic or representative (key) indicators of the research;
- determination of sample processing methods, as follows:
  a. method of sample preparation for experiments,
  b. selection of laboratory test methods,
- interpretation and processing of research results
- research conclusion.

2.1. REPRESENTATIVE RESEARCH INDICATORS

Basic factors which define the quality of an energetic resource are the amount of available and released energy and the combustion products from an ecological point of view. When it comes to coal, the first factor is defined through determination of: higher (HHV, Q_g) and/or i/ili lower heating value (LHV, Q_d). The higher heating value (HHV) is the amount of heat that is released during the complete combustion of 1 kg of fuel, where the total amount of moisture is taken in the liquid state (condensed) during the calculation, and its value is determined in the laboratory in the calorimeter [1, 5, 10]. In contrast, the lower heating value (LHV) is calculated provided that all the moisture in the combustion products is in the form of water vapor. Therefore, LHV is calculated from the obtained value of HHV according to the following pattern [10]:

$$Q_d = Q_g - 25\,(w\text{-}9H),\ \ (\mathrm{kJ/kg})$$

Q_d – lower heating value, kJ/kg,
Q_g – higher heating value, kJ/kg,
w – moisture content in the sample, (%),
H – hydrogen content in the sample, (%).

Indicators of coal combustion products are reflected through the emission of gases, namely: COx, NOx and sulfur compounds, and the amount and type of solid particles in the form of ash. The value of these factors is influenced by the content of chemical compounds in coal, moisture content and combustion conditions. From this aspect, the sulfur content in coal and obtained pellet samples was determined as a representative research indicator [3, 5, 7,11].

In these tests, of the relevant research parameters, only the results that gave insight about the qualitative indicators of the obtained pellets were examined, and they are [1, 10] :

- upper and lower heating value of the obtained pellets (HHV and LHV),
- total moisture,
- content of ash, combustible and volatile substances,
- coke and C-fik content,
- sulfur content (combustible, non-combustible and total).

2.2. TESTING METHODS

2.2.1. Sample and its preparation for testing

Coal

The basic material used in this research is coal of 0/40 mm size. Coal was sampled in the technological production chain at the open pit mine in Dubrave, RU Kreka Tuzla. The task in taking the sample was to select the one that has below average coal quality from this deposit. This value for the selected relevant parameters, in this study, was obtained by statistical analysis of two years of production at this mine. For the analysis, 2011, 2012 and 2013 were taken, and the results obtained in the laboratory of RU Kreka were used. The analysis of the average quality was performed on 9350 laboratory test results. The sample defined in this way, was taken in the amount of 50 kg (PK Dubrave, location: I roof layer, mixed 0-40 mm), was laboratory processed and divided into two separate, by weight identical quantities.

Sawdust

The basis of the idea for this research is the use of wood residues from the processing industry of this material. For this, preliminary research, wood sawdust was used as a residue of fir tree processing. Since this is a preliminary research, a detailed laboratory analysis of this material has not been done.

Binder

The production of pellets by pelletizers and extruders almost always requires some kind of binder, which will provide the conditions for preserving the obtained forms of pellets. Only those types of materials that are essentially binders themselves can be exempted from this rule. Given that previous research has shown that the humic acids contained in the lignite of this deposit also act as a possible binder, and that to some extent lignins and resins from timber are also showing similar characteristics it is to be expected that the agglomeration technology of this briquette mixture, without the use of an additional binder mixture is indeed possible. However, given the aim of this paper, the previous possibility has not been explored. In this regard, pellets were made with the use of additional binder in their production. In addition to the need to use a binder, the goal was that the selected binder has no impact on the qualitative properties of the pellets (HHV, LHV, sulfur content, etc.), or at least to minimize its impact, so that in the conclusion on the obtained results, the emphasis would be on the basic materials used in these trials. From this aspect, the most favorable form of binder is a suspension obtained from a starch binder manufactured by Helios, Domžale, R. Slovenia. In all samples, 10% starch concentration in water was used.

2.2.2. Laboratory procedures (tests)

The methodology of laboratory research, according to the set goal of the research, had two separate units. The first of them involved performing a series of operations in the preparation and production of pellets or briquettes - samples, and the second involved determining the relevant parameters on the obtained samples. Therefore, in the first phase of laboratory procedures, the following operations were performed:

- determination of characteristics of samples of components from pellet preparation (humidity and granulometric composition of coal and wood sawdust),
- sample preparation by milling to the required granulation for the selected agglomeration method,
- making agglomerate recipes,
- homogenizing of components - pellet builders and
- making agglomerates for different recipes in laboratory devices.

In the second group, ie. in the measuring part of laboratory procedures, the following procedures were performed [8, 9, 10] :

- determination of pellet moisture,
- determination of bounded sulfur (combustible and total),
- determination of HHV of the obtained pellets in a calorimeter,
- determination of ash content, coke residue, volatile and combustible substances.
- Tests of parameters from this group were performed according to our currently valid standards in the laboratory of RU Kreka from Tuzla (BiH).

2.2.3. Agglomerate preparation procedure in this study

For agglomeration of bulk, granular materials (mineral raw materials), the possibility of agglomeration is reflected in the application of several devices, ie. models of agglomerate production, and in this research two different methods were singled out. One is in a plate pelletizer, which basically gives, according to the professional definition, a product defined by the term - pellet. The second is essentially an extruder that produces a product that in commercial terms has the name pellet, but in the professional sense, it has, above all, the characteristics of briquettes, because its production is primarily done by pressing [8, 9]. However, technologically more demanding way of pellet production is in a plate pelletizer. For this reason, the research for all produced pellets was done in a laboratory extruder, with the same device parameters for all briquettes, which limited the impact on individual obtained results, in terms of less variable sizes. The process of mixing the coal and sawdust into a homogeneous mixture was performed in such way that individual quantities were added from two separate vibrating dispensers, and then placed in a circular path in a plate pelletizer with simultaneous addition of binder in the predefined amount, thus preventing grain segregation. The prepared mixture was dosed directly into the laboratory extruder. After that, the briquettes were dried to a certain amount of moisture, and the analysis of the above mentioned parameters was performed. At the same time, a certain amount of pellets in a plate pelletizer was made for the same recipe conditions. The purpose of this part of the research is to determine the characteristics of pellet production on this device and a comparative analysis of the structure of the obtained agglomerates in two different methodologies with identical recipes.

2.2.4. Recipe

From this aspect, the goal was to assume the characteristic relationships between the materials that are the basis for the production of agglomerates, with an emphasis on coal, so from that point of view the recipe is essentially only an indicative value which is necessary to obtain the possibility of quality parameters of pellets.

Therefore, pellets were produced with the following ratio of basic materials:

- sample 0 : coal sample,
- sample 1 : coal : sawdust = 60 % : 40 %,
- sample 2 : coal : sawdust = 40 % : 60 %,
- sample 3 : coal : sawdust = 80 % : 20 %,
- sample 4 : coal : sawdust = 100 % : 0 %,.

3. RESULTS OF THE RESEARCH

The obtained briquettes and pellets according to the above conditions are shown in Figure 1.

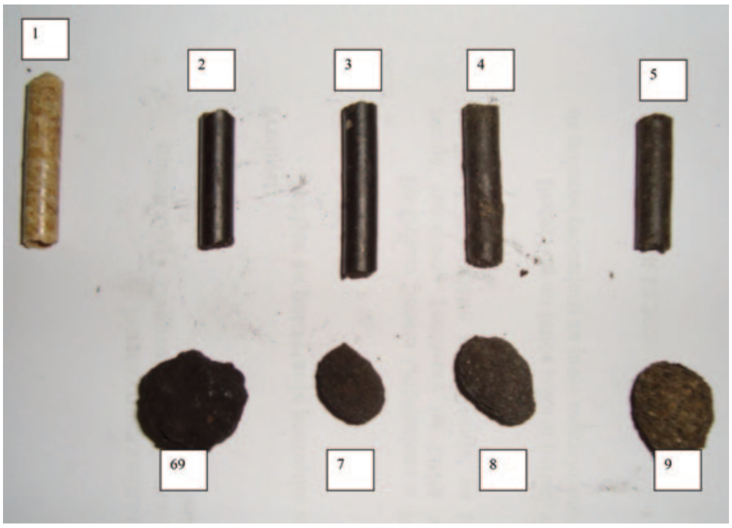

Figure 1. Obtained briquettes and pellets:
1. wood briquette ; 2. briquette of sample 1.; 3. briquette of sample 2.; 4. briquette of sample 3.; 5. briquette of sample 4. ; 6. pellet of sample 1.; 7 pellet of sample 2. ; 8. pellet of sample 3. and 9. pellet of sample 4.

For the previously established relevant and representative research indicators, the obtained results are given in Table 1. The coal sample indicators are given in Table 1.

Table 1. Results of the relevant and representative research indicators

Analytical data	Coal sample	Sample briquette 1.	Sample briquette 2.	Sample briquette 3.	Sample briquette 4.
Total moisture %	25,66	6,30	7,69	5,73	5,73
Ash %	39,12	16,41	22,14	30,55	39,73
Volatile mat. %	21,96	58,40	45,78	46,63	34,87
Combustible mat. %	35,22	77,29	70,17	63,72	54,54
C-fix %	13,26	18,89	24,39	17,09	19,67
Coke %	52,38	35,30	46,53	47,64	59,40
Combustible sulfur %	0,38	0,10	0,40	0,49	0,56
Bounded sulfur %	0,25	0,44	0,38	0,42	0,42
Total sulfur %	0,63	0,54	0,78	0,91	0,98
HHVkJ /kg	8.349	16.249	16.541	14.607	13.388
LHVkJ/kg	7.161	15.413	15.671	13.785	12.566

4. DISCUSSION

As a review of the assumed idea, preliminary research was performed in which arbitrary values of the mixture were taken as a basis, and the results of these tests were emphasized on the higher heating value and the sulfur content of laboratory samples. The obtained results indicate a significant potential of this fuel for the purpose of providing thermal energy for small consumers, etc.

According to these results (Table 1), a significant increase in the calorific value of briquettes is visible in relation to the initial value of coal. The growth of the calorific value in the briquette is related to the reduction of the amount of moisture present, as well as the fact that the share of combustible mass in the unit of energy increases through briquetting. This influence of moisture, in relation to the values from Table 1, can be approximately recalculated, and by reducing the moisture to the same amount (5.73%), Table 2 gives the values of other indicators.

Table 2. Recalculated values of relevant parameters at the same humidity

Sample	Sulfur, %	HHV, kJ/kg	Ash, %	Moisture, %	Combustible mat., %
Wood briquette	0	16660,3	0,7	5,73	93,6
4	0,98	13388,0	39,73	5,73	54,5
3	0,91	14607,0	30,55	5,73	63,7
2	0,78	16593,1	22,61	5,73	71,7
1	0,54	16264,2	16,51	5,73	77,8
0	0,80	8879,1	49,61	5,73	44,7

The obtained data clearly indicates a growth in calorific value by briquetting, which can be directly related to the increase of the combustible mass in zhe briqutte unit. At the same time, with the constant mass, the percentage of ash is reduced by pressing in the briquetting. The growth of the calorific value, depending on the amount of carbon substance in the briquette has an anomaly, which can be seen in the following graph.

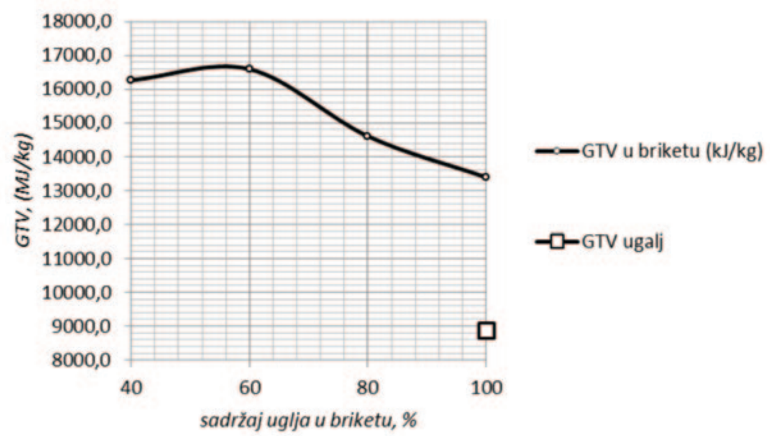

Figure 3. Relation of calorific value and coal content in briquette

The obtained results provide an insufficient amount of information for the accurate detection of the observed anomaly, but they are very interesting and should be paid attention to in future research. However, taking into account the goal of the research, it is clear that the methodology of coal briquetting with the addition of wood sawdust greatly increases the thermal value of coal as an energy source.

Let us now consider the results of testing the sulfur content in the obtained briquettes, including the division of sulfur into combustible and non-combustible, reduced to the same amount of moisture by the same principle [11], as was done in the calculation presented in Table 2. Sulfur content values are given in Table 3.

Table 3. Recalculated sulfur content in the samples

Sample	Sulfur, comb.	Sulfur, non-comb.,	Sulfur, total
Wood briquette			
0	0,48	0,32	0,80
4	0,56	0,42	0,98
3	0,49	0,42	0,91
2	0,30	0,48	0,78
1	0,10	0,44	0,54

The following figure gives a graphical representation of the dependence of sulfur content in the briquettes according to the coal mass present in the briquette sample.

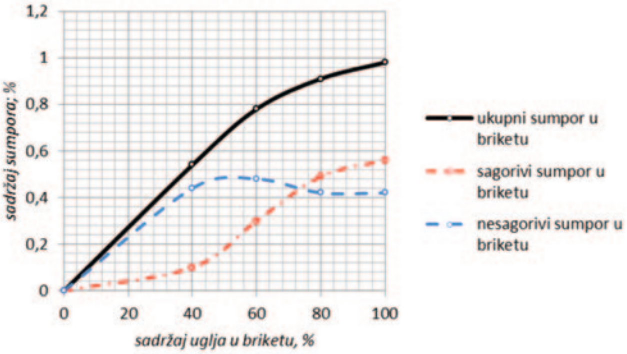

Figure 5. Sulfur content depending on the share of coal mass in the briquette

It is clear from the diagram that as the percentage of coal decreases, the total amount of sulfur decreases, which is normal. It is also observed that as the coal substance decreases, so does the amount of combustible sulfur. It is an interesting phenomenon for the amounts of incombustible sulfur in briquettes, but it can be explained by analyzing the mass share of ash and its variation for these different ratios of coal and sawdust. Of course, this implies a justified, more detailed analysis, but since the goal of this research is to establish the ecological aspect of usage of the obtained mixture from the aspect of sulfur content in it, it is necessary to consider the sulfur content per unit of energy obtained in briquettes. In considering this aspect, the ratio of the percentage values of: combustible (Xi), non-combustible (Yi) and total sulfur (Zi) in coal and briquettes is considered with a unit of obtained thermal energy according to the following relations:

$$Xi = \frac{Ssa\acute{g}}{GTV}\left[\frac{\%}{MJ/_{kg}}\right], \quad Yi = \frac{Sne\acute{s}}{GTV}\left[\frac{\%}{MJ/_{kg}}\right], \quad Zi = \frac{Su\acute{k}}{GTV}\left[\frac{\%}{MJ/_{kg}}\right]$$

The results of this calculation are given in the following table.

Table 4. Sulfur content per unit of heat obtained

Sample	Sulfur, comb., %	Sulfur, non-comb. %	Sulfur, total, %	HHV, MJ/kg	X_i, (%/MJ/kg)	Y_i, (%/MJ/kg)	Z_i, (%/MJ/kg)
Wood briquette	0	0	0	16,660	0	0	0
1	0,10	0,44	0,54	16,264	0,033	0,0061	0,027
2	0,30	0,48	0,78	16,593	0,047	0,0180	0,029
3	0,49	0,42	0,91	14,607	0,062	0,0337	0,029
4	0,56	0,42	0,98	13,388	0,073	0,0418	0,031
0	0,48	0,32	0,80	8,879	0,090	0,0541	0,036

A clearer view of these obtained results can be seen from the diagram given in the following figure.

Therefore, the tendency to reduce sulfur in all its forms is expected and it is clearly visible with the reduction of coal share in the briquette.

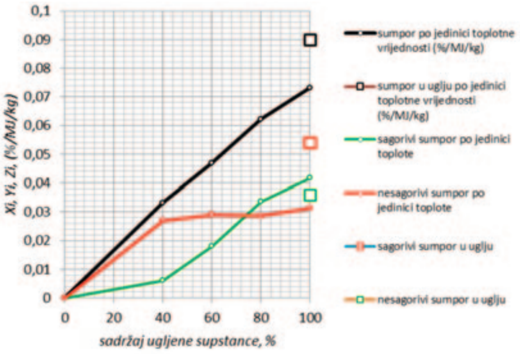

Figure 6. Sulfur content in the coal and briquettes

5. CONCLUSION

In this research, the following claims are clearly proven:

The method of coal briquetting increases HHV and at the same time reduces the sulfur content per the amount of heat released,

By adding wood sawdust to coal and by briquetting such mixture, the increase in the amount of heat released is significant and gets its maximum at values of approximately equal participation of these two substances.

There is a significant reduction in the sulfur content in the products themselves according to the values presented in this paper,

The research was conducted on a coal sample with significantly lower characteristics than the average quality in this deposit. This further suggests that an increase in the amount of heat released in this mixture would have had more significant values if coal with better characteristics was taken, primarily with a more favorable ratio of combustible and non-combustible substances in it.

Although the tendency is to completely eliminate the production of energy from coal, due to the significant amount of harmful substances in the combustion products, the question remains for certain areas, such as households, of realistic alternative heat sources. Very often mentioned alternative and recently very present, the substitution of coal with wood pellets (energy source) for this purpose, is from the aspect of obtaining clean energy an adequate solution. However, a significant amount of application of this type of energy source significantly affects the reduction of wood stock (forest), which in turn is a natural regenerator of pollution. In this sense, the production of fuel with a mixture of coal and wood sawdust seems to be an interesting solution at the moment.

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Scientific Paper

DRILLING BITS DAMAGES DURING OF BLASTHOLE DRILLING ON LIMESTONE QUARRY "DUBOKI POTOK"

Adnan Hodžić[1], Sanel Nuhanović[2], Muhidin Brčaninović[3], Muamer Muratović[4]

SUMMARY

Company "INGRAM" p.l.c. Srebrenik exploits the stone aggregate – limestone, with the technology of drilling and blasting on limestone quarry "Duboki potok". There are thre drilling rigs of the company "Atlas Copco" used to make blastholes, namely: ROC 301, ROC 406 and ROC F6. This paper analyzes the conditions of drill bits "exploitation", the lifetime of the drill bits, or the causes of excessive wear of the drill carbides, as well as their loss from the bearing (groove) in which they are installed, with partial damage to the bits matrix face.

The influence of basic drilling parameters and the influence of physical and mechanical properties of the working environment on the penetration rate, i.e. on the wear and loss of cutting structures (carbides) of the drill bits on the AC ROC F6 drilling rig, was analyzed, with the aim of finding and defining their interconnection. problems in future works on the construction of blastholes on this limestone deposit.

Keywords: drilling, drill bit, carbides loss, geological conditions, drilling variables

1. INTRODUCTION

Initially (1961) the range of limestone quarry "Duboki potok" was based on the production of crushed stone, needed for the construction and maintenance of railway and road infrastructure in the municipality of Srebrenik and beyond, and in the early 70's of XX century, INGRAM dd Srebrenik opened a lime kiln plant and a concrete products factory. Today, the exploitation of limestone at "Duboki potok" is carried out by benches blasting of stone aggregate, which is preceded by the drilling of blastholes, using three active, self-propelled drilling rigs, the Swedish company "Atlas Copco", namely: ROC 301, ROC 406 and ROC F6. After exploitation, limestone is crushed and separated.

The effective depth of blastholes on the production benches of the limestone quarry is up to 25 m, and they are made with a drilling diameter of 89 mm (3 ½ ").

During the drilling works, increased wear of the working part of the DTH hammer was noticed, i.e. deformation and loss of working carbides of the drill bits type "Ballistic RocketBit", followed by partial damage to the bits matrix face, although the considered drill bits were drilled relatively small, only 500 drilled meters or less. Gradual wear of the drill bit carbides or their ejection from the grooves in which they

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[1] Prof. Adnan Hodžić, Associate Professor, University of Tuzla, Faculty of Mining, Geology and Civil Engineering Tuzla, adnan.hodzic@untz.ba

[2] Prof. Sanel Nuhanović, Associate Professor, University of Tuzla, Faculty of Mining, Geology and Civil Engineering Tuzla, sanel.nuhanovic@untz.ba

[3] Assistant Prof. Muhidin Brčaninović, University of Tuzla, Faculty of Mining, Geology and Civil Engineering Tuzla, muhidin.brcaninovic@untz.ba

[4] Muamer Muratović, Bachelor – mining engineer of well exploitation

are installed is not an unusual appearance, and is regularly associated with the physical and mechanical characteristics of the working environment (rock) being drilled and applied parameters of rotary percussion drilling which, in this case, deviate from optimal values.

In contact with the rocks, the working elements of the drilling tool are exposed, not only to mechanical stresses, but also to high friction between the cutting structures of the working element (bits, carbides) and the surface of the rock being drilled.

As a consequence of increased friction between these surfaces, there is a gradual consumption of the cutting structures (carbides) of the drill bit, so that, in a certain period of time, the original geometric shape and dimensions of the entire working part of the drilling hammer going to change, that is, the carbids and drill bits blunting and reducing the diameter of the working part of the drili bits, which causes decreasing in its working capacity.

In order to improve the drilling effects, in addition to increasing the penetration rate, the aim is to reduce the wear of the drilling tool and increase the durability of the cutting elements of the drill bit. One of the basic conditions for optimal operation of drilling equipment is knowledge of the properties and quality of cutting elements of the drill bit and their durability, especially in the case of drilling in hard, abrasive and cracked rock environments.

2. SPATIAL POSITION AND GEOLOGY OF LIMESTONE QUARRY "DUBOKI POTOK"

Limestone deposit and limestone quarry "Duboki Potok" is located in the local community of the same name, which belongs to the municipality of Srebrenik, and is located about 7 km south of the center of Srebrenik, next to the main road M-18, on the right, viewed from the direction of Srebrenik to Tuzla. It is located next to the river Tinja, and belongs to the extreme slopes of the NW edge of the mountain Majevica. In the relief it stands out strongly with its almost vertical sections, which are very expressed on the north side. The massif is mostly forested, under crops, especially orchards, and is not inhabited.

Figure 1. Spatial position of the " Duboki potok " limestone deposit [11]

Morphologically, the wider area of the limestone massif is built of solid and compact limestones representing prominent relief forms, with steep slopes and sections, into which the Tinja River has cut, delimiting the deposit on its northern side. The river Bijela rijeka represents the natural border on the west side, and the nameless stream on the east side. The positive relief of this area is caused by the branched hydrographic network of the river Tinja, its tributaries and surrounding streams.

2.1. GEOLOGICAL STRUCTURE OF THE LIMESTONE DEPOSIT "DUBOKI POTOK"

The geological characteristics of the wider environment were processed on the basis of data from the BGM (Basic Geological Map) of the Tuzla newspaper and the interpreter of the map of the same name [3, 4] and are presented in Figure 2.

The geological structures of the "Duboki Potok - Bijela rijeka" deposit includes marls and Eocene limestones, then alluvial-deluvial clays and alluvium of the Tinja river.

The limestone roof is a humus-clay material, of various thicknesses, mixed with fine limestone material in deeper parts. Marls regularly appear in the limestone floor. On the surface of the terrain, they occur in the bed of an unnamed stream, on the eastern border of the deposit and in the bed of the river Tinja. These are marls in which intercalations of fine-grained sandstones and marly, sandy to breccia limestones occur.

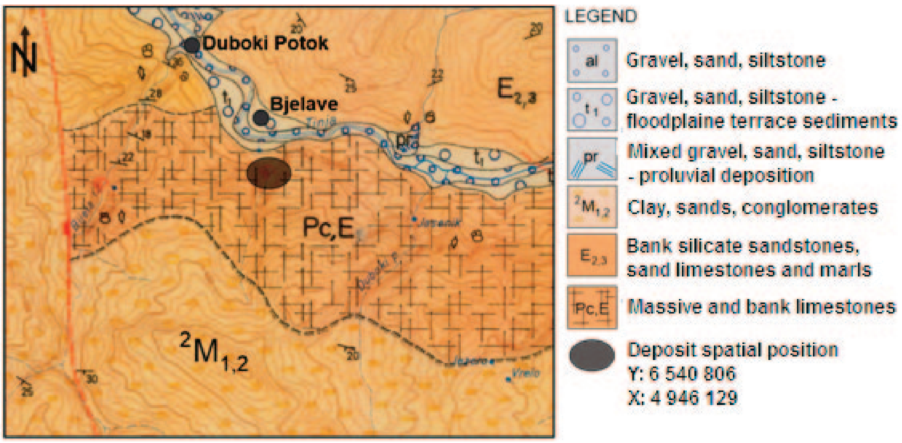

Figure 2. Geological map of the limestone deposit area "Duboki potok"

Limestones are the same age as marls and gradually move from these marls to massive to bank limestone deposits. This limestone mass has the shape of an elongated lens, deformed under the influence of tectonic and erosive factors. The maximum thickness of the limestone, determined by exploration drilling, is over 130 m.

The lower parts of the limestone mass are built of a variety of limestone, usually lighter in color and richer in fossil species, most commonly foraminifera of simpler build. The higher parts are usually brownish to gray in color. Among fossils, foraminifera are the most common, sometimes of quite complex structure and larger dimensions (nummulites).

The Quaternary, as the youngest geological member, is represented by alluvial-deluvial clays. In the Tinja valley, alluvial deposits with gravel, sand and clay appear.

The limestone deposit extends in the EW direction, at a length of over 1000 m. On the right bank of the nameless stream, towards the east, this limestone massif extends for another 1500 m. Previous research on the massif has determined its width of over 300 m.

In the genetic sense, the productive series of massive limestones is of monomineral composition, of organic origin, formed from zoogenic and phyto sediments in the Eocene, with a high content of the $CaCO_3$ useful component.

The limestones of the "Duboki Potok - Bijela rijeka" deposit are extremely organogenic. Of the fossils, the most numerous are various species of foraminifera, much less often bryozoa and corals, and subordinate algae, crinoids and gastropods.

Analyzes of these limestones showed that limestone was formed in a shallow water environment with a pronounced dynamics of sea water, which was reflected in the uneven distribution of constitutive elements (intraclasts, fossils).

This, together with subsequent tectonic damage, led to a significant disturbance of the homogeneity of limestone, i.e. to their pronounced anisotropy when it comes to physical and mechanical properties.

From the hydrogeological aspect, the following can be singled out in the geological structure of the deposit:

- bottom marl sediments, which act as insulators and
- limestone masses with developed crack microporosity, as collectors [5, 6].

3. DRILLING RIG CHARACTERISTICS

The AC ROC F6 drilling rig is equipped with a Down The Hole hammer (DTH ROCKMORE 300-001), with a maximum drilling depth of 36.0 m. The drilling rig has 8 drill rods, each is 4.0 m long. The diameter of the drill rods is 76 mm. Screw compressor, operating pressure of 14 bar has a capacity of 230 l/s, rotation speed is 77 min^{-1} and maximum torque is 1600 Nm [10].

The operating characteristics of the ROC F6 drilling rig are shown in Table 1.

Characteristics of the drilling rig ROC D7	
Manufacturer	Atlas Copco
Type	ROC D7
Powertrain power	168 (kW)
Compressor operating pressure	6 – 7 (bar)
Air flow	105 (l/s)
Maximum hydraulic pump pressure	250 (bar)
Weight	14 200 (kg)
Maximum rig transport speed	3,6 (km/h)
Traction force	110 (kN)
Maximum slope	20 (°)
Lenght of drill rods	3660 (mm)

Table 1. Basic characteristics of the drilling rig ROC F6

The operating pressure of the compressor, during the drilling of blastholes on limestone quarry "Duboki potok", on the drilling rig AC ROC F6, is set to 11-12 bar.

3.1. BASIC WORKING PRINCIPLE OF DTH HAMMER

Drilling existence for the driling of blastholes on limestone quarry " Duboki potok " (AC ROC F6) in its work uses a DTH hammer (ROK 300-001, IR 3.5, 2-3/8" API Reg Pin), with a drill bit type "Ballistic RocketBit " (convexe face 3 ½ "). The typical appearance of a DTH hammer drill is shown in Figure 3, and its basic characteristics in Table 2.

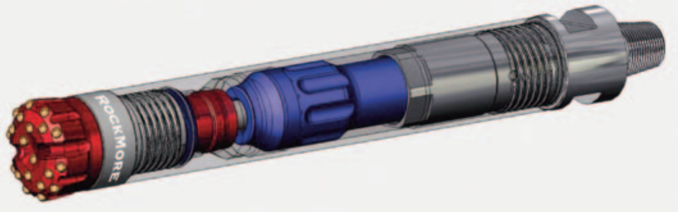

Figure 3. The typical look of a DTH driling hammer [9]

Table 2. Basic characteristics of DTH hammer applied to limestone quarry " Duboki potok " [9]

Drilling parameter	Parameter value
Effective drilling depth	25 (m) (drilled 8 – 18 m)
Dip angle	70 (°)
Drilling duration	25 (min)
Oil pressure in rotation	50 (bar)
Air pressure in the hammer	6 (bar)
Compressed air pressure	12 (bar)
Drilling diameter	89 (mm) (3,5")
Hole depth	14,30 (m)
Drill rods (drill pipes)	4 x 3,66 (m) (in total 14,64 m)

During rotary percussion drilling with the use of a hammer at the bottom of the hole (DTH), the working part of the drilling hammer, i.e. the drill bit, with its cutting structures (carbides), is in constant contact with the rock being drilled. The impact on the rock provides the flow of compressed air, which is a suitable working piston of the hammer, the movement of which transmits the impact to the drill bit. At the same time, the higher capacity of the compressor determines the higher efficiency of the drilling itself.

The rotation of the drilling tools is provided hydraulically, on the surface, i.e. on the carriage of the drilling rig (Figure 4). Drilling diameters usually range from 89-165 mm, although they can be significantly larger. Depths of wells made by this drilling method go up to 60 m.

The use of DTH hammers in the drilling of blastholes reduces the possibility of deviation of the hole and the basic limitations are lower penetration rate (compared to the method of drilling with a hammer on the surface - "Top Hammer"), and lower rig mobility (due to compressor dimension) as well as higher power consumption.

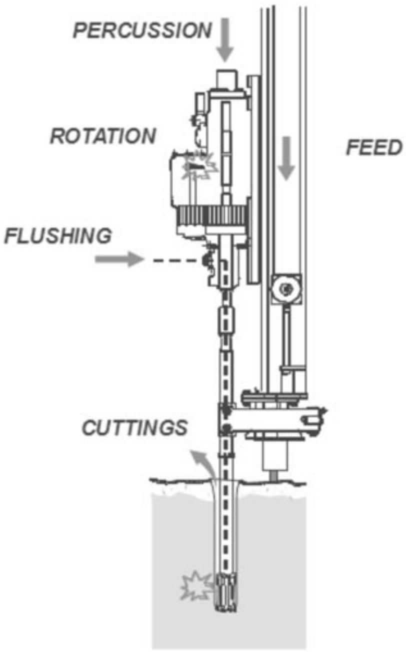

Figure 4. The operation principles of the drilling rig with a DTH hammer [7]

During the works in the hole, different forces act on the operating part of the DTH hammer:
- the percussion force,
- the pushing force of drilling equipment on the bottom of the hole (feed, axial load),
- the force of rotation (torque),
- the force of friction of the carbides against the rock being drilled.

The percussion force ensures the penetration of the drill bit carbides into the rock, and is ensured by the pressure of compressed air from the compressor, from the surface. The impact itself is provided in the hammer drill, i.e. at the bottom of the hole. During the transmission of the impact from the piston of the hammer to the drill bit, air is released, which additionally serves for cleaning (blowing out) the broken rock fragments from the bottom of the hole. The percussion force is directly proportional to the air pressure, so it is controlled.

In the case of softer rocks, the air pressure should be lower, but sufficient to effectively remove the broken rock fragments from the bottom of the hole after performing work in the hammer.

Poor cleaning of the bottom of the hole results in a reduction in the penetration rate, shortening the service life of the drill rods, increased wear of the drilling hammer and drill bit (carbides and bit face), and increases the possibility of jamming drilling tools.

The f*orce of pushing the drilling equipment to the bottom of the hole (feed, axial load)* has the function of maintaining constant contact of the working part of the drilling hammer, or drill bit, with the rock at the bottom of the hole, and maintaining the projected trajectory of the hole.

The intensity of the pushing force of the drilling equipment (Figure 5) depends on the pressure of the compressed air which controls the impact force, then on the type of rock being drilled, on the depth of the hole, and on the type and characteristics of the drilling equipment.

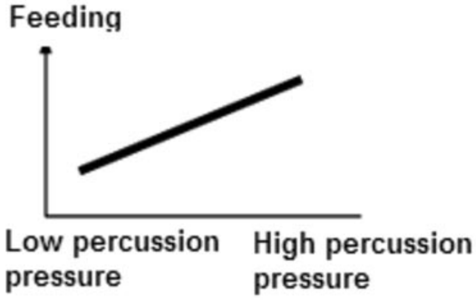

Figure 5. Dependence of the pushing force of drilling accessories on the pressure of compressed air

Excessive feed (axial load) does not increase the penetration rate. On the contrary, there is an increased wear of the drilling hammer and drill bit (carbides), and the occurrence of deviation of the borehole trajectory and distortion of the drill rods. Too much pushing force of the drilling tool does not allow optimal transfer of impact energy from the drilling tool to the rock, which causes damage to the drill rods and the drililng hammer. Modern drilling rigs have automatic adjustment of the optimal pushing force, while when drilling with older drilling rigs, the experience of the person operating the drilling rig is very important.

The force of rotation provides the torque of the drill bit, so that each new impact of the drill bit is performed at a new position in the rock material. The optimal rotation speed depends on the type, geometry and size of the drill bit, and the physical and mechanical characteristics of the rock being drilled.

If the applied rotation speed is higher than the optimal one, it can cause increased wear of the drill bit, i.e. its carbides, because then the breakage of the rock occurs due to the rotation, and not due to the force of the percussion. On the other hand, a rotation speed that is less than optimal will cause a lower penetration rate and excessive, unnecessary shredding of broken rock fragments.

4. PROBLEMS OBSERVED DURING THE BLASTHOLE DRILLING ON LIMESTONE QUARRY "DUBOKI POTOK"

During the drilling of blastholes on limestone quarry "Duboki potok", mechanical damage was found on the carbides of the drill bits (working part of DTH hammer), i.e. the loss of the carbides of the drill bits (inserts) from the grooves in the body of the drill bits, 2 teeth per to any drill bit. The body of the drill bits, in which the cutting structures (carbides) are built, is made of resistant, chrome (Cr) alloy tool steel.

The carbides are made of an alloy of tungsten carbide, i.e. an alloy of tungsten (Wf) and carbon (C), which is characterized by high hardness and wear resistance. The hardness of such a material is 8.5-9.0 on the Mohs hardness scale, and its usual practical name is "Widia" (German: Wie Diamant – "like a diamond"). However, in addition to all the above, during the drilling works on limestone quarry "Duboki potok" there was a loss of carbides, i.e. their flying out of the grooves through which they were installed in the body of the dril bits.

The photographs in Figures 6 and 7 show the appearance of a damaged DTH hammer drill bits, which occurred during the drilling of blastholes at "Duboki potok" limestone quarry.

From Figures 6 and 7, it can be seen that the carbides of the drill bits were torn (broken off) from their bearing (groove) on the spherical part of the bits, which also caused damage to the bits face. Only the peripheral carbides (Gauge Carbides) and part of the matrix around them were damaged.

The issue of this type of DTH drill bits damage is known and is elaborated in more detail in the discussion section.

It is interesting that the loss of the carbides during the drilling occurred in the early phase of their "exploitation", i.e. after a small drilled metrage (the pictures show the length of 182 m and 384 m, respectively).

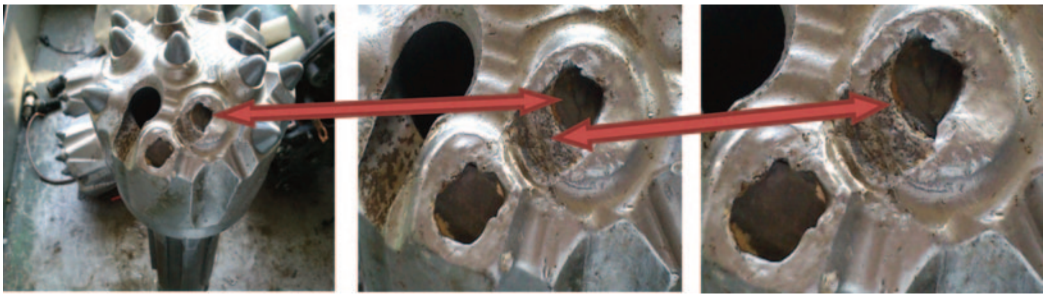

Figure 6. Appearance of a DTH hammer drill bit, with carbides loss points, after drilling 384 m

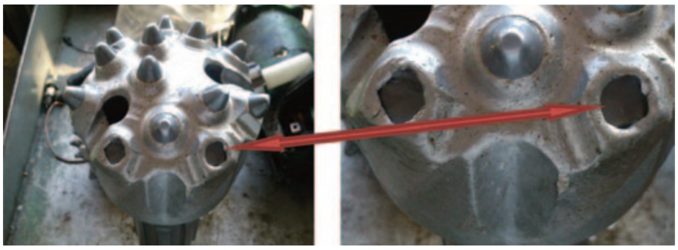

Figure 7. Appearance of a DTH hammer drill bit, with carbides loss points, after drilling 182 m

With all the above characteristics of the hardness and durability of the material from which the drill bits body is made, as well as its inserted teeth (carbides), it is to be expected that the operating lifetime of these drill bits will be much longer and that these problems should not occur at this stage.

Namely, these drill bits are also intended for drilling in medium hard to hard rocks (primarily shales and limestones) with a lower content of SiO_2. The arrangement of carbides on the selected type of drill bits (Figures 6 and 7) indicates a choice that brings a lower penetration rate, but therefore increased operating lifetime of cutting structures, as well as the drill bits as a whole [9].

5. DISCUSSION

In order to reach qualitative conclusions about the causes of damage and loss of drill bit carbides (DTH hammer), when making blastholes on limestone quarry "Duboki potok", it is necessary to analyze the possible parameters that led to such damage to the drilling tool. They can be divided into two groups, represented by geological and technical and technological parameters.

Geological conditions include physical and mechanical properties of the working environment (hardness and strength of rock material and possible presence of layers of harder material), and engineering geological conditions (cracking level, faults, crushed zones, etc.). Technical, technological and organizational causes can include: selection of an adequate drilling tool (in this case, primarily, a drill bit), selection and application of the optimal drilling variables, and training and concentration of personnel performing drilling operations.

Geological parameters, in general, can not be controlled but, to some extent, we can predict them by conducting quality exploration works. Technical and technological, as well as organizational parameters, can be fully controlled.

5.1. ANALYSIS OF GEOLOGICAL PARAMETERS

The limestones of the "Duboki potok" deposit are massive intrasparites and oosparites of Paleocene-Eocene (Pc, E) age. Due to tectonic fragmentation and subsequent erosion, they have been preserved in larger or smaller blocks, up to 300 m thick. They pass laterally into Paleocene clasts, which are represented by sandstones, marly siltstones and calcarenites. Concordant over them lie fine-grained to medium-grained, yellow to red sandstones, which are subsequently destroyed.

Due to the pronounced tectonic activities, it can be concluded that the limestones exploited in this deposit are disintegrated (their physical and mechanical characteristics are variable due to the high level of cracking) and decomposed (there are frequent changes in their chemical and mineralogical and petrological composition).

In such heterogeneous environments, it is important to know the geological characteristics of the formations (especially in depth) in order to, according to them, apply the optimal drilling variables. Therefore, the rotation speed of the drilling hammer, the applied feed and the amount of compressed air per to blow the drilled rock fragments on the ground surface, it is necessary to adjust the micro working environment. The existence of harder layers or inclusions of rock material of higher hardness can be the cause of the drill bit cutting structures loss.

5.2. ANALYSIS OF TECHNICAL AND TECHNOLOGICAL PARAMETERS

5.2.1. Drilling variables

a) Driling feed (Axle load)

When performing DTH drilling, the determining factor of rock destruction at the bottom of the hole is not the mass of the drilling tool, but the percussive action of the drill bit on the rock, caused by compressed air pressure driving the hammer, with a certain degree of applied torque.

However, too much feed (axial load) on the drill bit, most often applied with the aim of increasing the penetration rate, can lead to damage to the carbides and drill bit face.

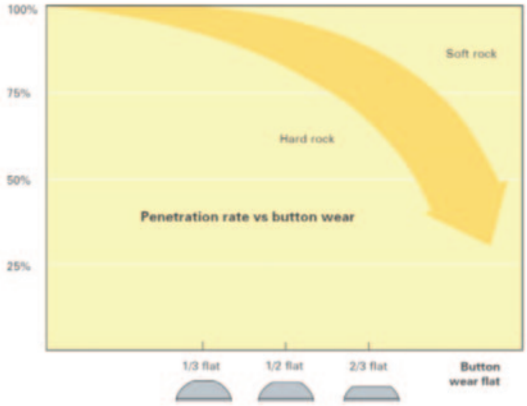

Figure 8. Dependence the penetration rate on the degree of carbides wear

It can be seen from Figure 8 that the penetration rate decreases with increasing wear of the cutting structures of the drill bit. This change is more pronounced in harder formations. The decrease in penetration rate often causes the need to increase the feed and the rotation speed of the drilling tool, which should be accompanied by an increase in the amount of compressed air, so that the drilled rock fragments are brought to the surface.

In practice, it often happens that the optimal size of the applied feed is "controlled" by the driller's hearing.

At the same time, the clear percussion sound of the drill hammer, which comes from the bottom of the hole, means that the drill hammer is working properly. Reliance on the experience and hearing of drillers often leads to unnecessary and unwanted accidents in the drilling process.

Modern drilling rigs have an automated system for regulating the optimal feed on the drill bit (as well as, after all, the optimal roatation speed of the drilling tool, and the optimal amount of compressed air for blowing the borehole).

The feed, in this case, is realized by the mass of a series of drilling tools (mass of drill rods in the hole increased by the mass of the DTH hammer itself), so it is difficult to assume that it is the cause of drill bit cuuting structures (carbides) loss.

b) The rotation speed

Rotation of the drilling tool in DTH drilling does not have a direct impact on the destruction of rock material at the bottom of the hole, but can be one of the main causes of wear and damage of the drill bits and its cutting structures (carbides).

Namely, by increasing the rotation speed, it is necessary to significantly remove the drilled fragments of rock material from the bottom of the hole. Otherwise, the tool gets stuck at the bottom of the hole and the cutting structures (carbides) of the drill bit are lost.

Drilling parameters, including the rotation speed, in cases of the blasthole drilling at limestone quarry "Duboki potok", are set for an ideal working environment, which probably leads to problems in the drilling process, because the carbonate rocks in the deposit are disintegrated, cracked and decomposed, or heterogeneous.

c) Removal of drilled debris from the bottom of the hole

The removal of drilled rock fragments from the bottom of the hole, during the drilling of blastholes, is achieved by constant air circulation, which is provided by the compressor, from the surface. In the process of removal, the "unused" air, remaining by driving the operating piston of the DTH hammer, also helps. The compressor is, therefore, the one that provides the impact energy of the drill bit (and thus its cutting structures) against the rock at the bottom of the hole. The rule is that higher impact energy on the drill bit increases the penetration rate and improves its working performance.

On the other hand, increasing the penetration rate means a larger amount of drilled material that needs to be brought to the surface, so the operating compressor pressure and the amount of compressed air in the circulation must be optimized (air consumption range for the applied DTH drilling hammer ranges from 4.1 - 9.0 m^3/min, which can be seen from Table 2).

The operating pressure of the compressor on the ROC F6 set, during the drilling of blastholes at limestone quarry "Duboki potok" is set at 11-12 bar, which generally satisfies the working environment, without taking into account the problems related to its disintegration, and the possible presence of interlayers and fragments of material of higher hardness.

In case the amount of air in the circulation, as well as the achieved velocities of its flow in the hole are not sufficient, there is a possibility of poor cleaning of the bottom of the hole from drilled material, and the drilling bit is forced to "re-drill" there is often rapid wear of the bit carbides or their damage and loss, as in this case.

In general, it can be concluded that, due to the geological conditions of the working environment, in the case of drilling blastholes at limestone quarry "Duboki potok", constant parameters of the drilling variables are not recommended, because the working environment is not ideal.

5.2.2. Drill bit selection

During the destruction process of rock material at the bottom of the hole, there is a gradual wear in the cutting structures (carbides) of the drill bit, in height and diameter, which increases the operating surface area of the carbides.

Increasing the operating surface of the carbides requires the need for additional drilling feed on the drill bit, which is often the cause of the fracture of the carbides or the whole drill bit body.

The drill bit carbides are considered "sharpened" if the diameter of their tip is ¼ of their basic diameter (base). By wearing their operating surface, the carbides become dull, drill more slowly, and material fatigue occurs, which together causes the carbides and matrix of the drill bits to break. [8].

As already mentioned, due to the known characteristics of the working environment, i.e. limestone, the selection of drill bits which is used on drilling process at limestone quarry "Duboki potok" (Conwexe Face, Ballistic Type), was made with quality, because the selection of drill bits the existence of interlayers or inclusions of harder material in the layer, unless this is defined by previously performed detailed geological and geophysical surveys.

Selected drill bits, with their cutting structures (carbides), are designed for drilling in medium to hard rocks (primarily shales and limestones) with lower SiO_2 content [9].

The quality and arrangement of cerbides on the selected type of drill bit (visible from Figures 6 and 7, and from catalog copies) indicates the selection of drill bits that brings lower penetration rate, but therefore increased operating lifetime of cutting structures, i.e. carbides, as well as operating lifetime of drill bit and a driling hammer, as a whole.

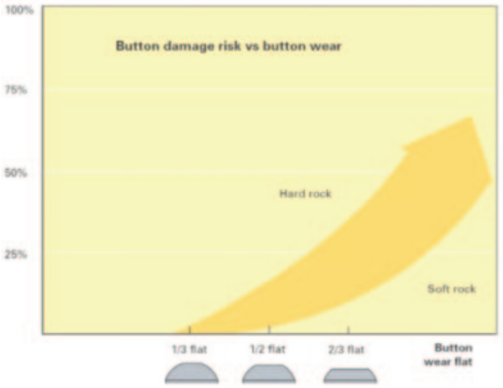

Figure 9. Risk of damage to the drill bit in rocks of different hardness, depending on the degree of carbides wear

However, it turned out that the cutting structures (carbides) of the drill bits used in this case had a significantly shorter service life than expected. Namely, the mentioned drilled metrage (in our examples 384 m and 182 m, respectively), after which the drill bits failed due to the loss of their cutting structures (carbides), is completely unexpected, for the stated characteristics of the selected and applied drill bits.

Practice has shown [8]. that the most common causes of damage shown in Figures 6 and 7, which occurred during the drilling of blastholes at limestone quarry "Duboki potok", are the following:

- excessive use of drill bits (too large drilled "metrage"),
- drilling with use up bit carbides,
- drilling where cutting structures of the drill bits have already been lost,
- inadequate intervals of crushing of rock material, caused by layers of harder material or poor cleaning of the bottom of the hole.

The recommended ways to prevent and solve this problem (given by the manufacturer) are as follows:

- more frequent inspection of the cutting structures of the drill bit,
- periodic sharpening of bit carbides,
- removal and replacement of damaged carbides,
- arranging the drilling interval.

The data we have indicate that we cannot talk about drill bits that drilled a large metrage, because in no case did the bit drill more than 400 m, which is a negligible number, in relation to its quality and factory specifications.

Also, before the mentioned problems, no losses of cutting structures (carbides) were noticed or reported, which excludes the cause of the accident that would occur with the use of drill bits in which the cutting structures have already been lost.

A closer look at Figures 6 and 7 shows that the remaining cutting structures of the drill bits are worn out, but not to such an extent that it can be determined that they are blunt and unusable, i.e. it can be concluded with certainty that the cause of carbides loss, in this case, is not even drilling with worn carbides.

Based on all the above, as the main cause of bit carbides loss, with partial damage to the bit face (matrix) remains inadequate drilling interval, i.e. crushing of rock material, most likely caused by geological conditions in the deposit (disintegration and decomposition of rock material, and the presence of interlayers or inserts), with unsuitable parameters of drilling variables (applied feed, rotation speed and poor cleaning of the bottom of the wellbore).

Therefore, the failure of the applied DTH drilling bits on limestone quarry "Duboki potok", i.e. the loss of cutting structures of the drill bits in their peripheral part, followed by partial damage to the drill bits matrix, probably occurred due to the cooperation of two basic causes, namely:

- existence of interlayers or inserts of rock material of higher hardness and
- insufficient removal (blowing out) of drilled material from the bottom of the hole, due to inadequate operating pressure on the compressor, or damage to the check valve into the drilling hammer body.

In the first case, more detailed geological research is needed, with the aim of defining the zones of such interlayers and inserts and preventing further identical problems that may occur during the next works on the construction of blastholes on this deposit.

In the second case, it is necessary to increase the working pressure of the compressor (possible increase of working pressure up to 14 bar) and the amount of air in the circulation, in order to bring the drilled fragmentss to the surface more efficiently and thus free the bottom of the borehole channel.

In any case, it is necessary to periodically check the quality of the check valve in the drilling hammer budy and adjust it so that it lets the appropriate amount of air to the operating piston of the DTH hammer, and directs the rest of the air to clean the bottom of the hole.

6. CONCLUDING REMARKS

By making blastholes on limestone quarry "Duboki potok", the aggregate - limestone is exploited. Three drilling rigs of the company "Atlas Copco" are used for the blastholes drilling, namely: ROC 301, ROC 406 and ROC F6. The effective depth of blastholes on the production benches of the quarry is up to 25 m, and they are made with a drilling diameter of 89 mm (3 ½ ").

During the drilling works, the loss of peripheral cutting structures (carbides) of the ROCKMORE drill bits, type 300-001, with insert teeth "Ballistic RocketBit", convexe face 3 ½ ", was noticed, two carbides on each used drill bit.

The loss of the carbides was accompanied by partial damage to the drill bit face (matrix), as can be seen from Figures 6 and 7.

The data point to the fact that the mentioned damage to the cutting structures and dril bits faces occurred in the early phase of their use, i.e. after drilling several hundred meters (in our example, the drilled length is 182 m and 384 m, respectively).

Gradual wear of the carbides, their ejection from the grooves in which they are installed, as well as other types of damage to the carbides or drill bit matrix, are not uncommon, and is regularly associated with physical and mechanical characteristics of the working environment (rock characteristics) drilled and values applied parameters of rotary percussion drilling which, in that case, deviate from the required, optimal values.

Analyzing the damage, seen in Figures 6 and 7, and consulting the manufacturer of used drill bits for the most common problems encountered in their use, and ways to solve them [8], several conclusions can be drawn:

- These are not drill bits that have had excessive use, because the drilled length, which caused the loss of the drill bit carbides and damage to its matrix, is relatively small compared to the expected operating lifetime of drill bits, when used in "normal" working environments;
- Regardless of the degree of utilization, it is necessary to continuously (in this case more often) check the condition of the cutting structures (carbides) of the drill bits and their occasional sharpening, because their work on the destruction of hard rock material, as well as due to friction, their constant wear occurs, by diameter and height;
- Prior to the observed problems, no carbides losses or damage to the drill bits faces were registered or reported, and the cause of their loss and damage cannot be considered the use of a drill bits in which certain losses of carbides or cracks of the bits faces have already occurred;
- All damages and losses of drill bit carbides are related to their peripheral part, which can be related to the conditions of poor cleaning of the bottom of the hole and too low rotation speed of drill bits. Since in the case of rotary percussion drilling, the rotation speed is not crucial, it can be assumed that the insufficiently removal of drilled rock fragments from the bottom of the hole caused difficult operation of the drill bit at the bottom, damage carbides and drill bit matrix on its peripheral part;
- In order to prevent future accidents of a similar type, it is necessary, when performing drilling operations, to increase the operating pressure on the compressor (maximum allowable operating pressure is 14 bar), which would accelerate the flow of compressed air in the hole and provide conditions for better cleaning of its channel, that is, more efficient removal of drilled material;
- It is necessary to periodically check the quality of the check valve in the drilling hammer budy and adjust it so that it lets the appropriate amount of air to the operating piston of the DTH hammer, and directs the rest of the air to clean the bottom of the hole;
- The working environment (limestone) is tectonically fragmented and heterogeneous, so the

possibility of sporadic interlayers and inserts of higher hardness material should not be ruled out, which, with the presence of cracked limestone blocks, could cause damage to the drill bit carbides and its matrix (face);

- In order to get better acquainted with the engineering and geological conditions prevailing in the limestone deposit "Duboki potok" and to reduce the same or similar problems in the continuation of blastholes drilling, it is necessary to conduct more detailed geological and geophysical research on this deposit, in order to determine more precisely zones of boundaries between the blocks, and the presence of the mentioned interlayers and fragments of harder materials in the limestone massif.

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Scientific Paper

POSSIBILITY OF USE OF THE VIJENAC' LIMESTONES IN PRODUCTION OF CEMENT AND SODA

Elvir Babajić[1], Medina Nuhić[2], Zehra Salkić[3]

SUMMARY

The limestones of Vijenac near Lukavac have been used for a long time as raw material for the production of cement and soda.

Petrographically, they are defined as intrabiomicrites, oobiomicrites and biomicrites. These limestones have brecciated structure and microcrystalline to fine-crystalline textures. In terms of mineral-petrographic composition, harmful components in limestone in the production of cement and soda have not yet been defined. For this reason, a correlation was made in accordance with the internal standards of chemical composition in soda and cement factories.

In soda production, minor deviations from the internal standard were noted in SiO2, Al2O3 i CaCO3. Elevated values (above the limit) are characteristic for Ca sulfate. In cement production, deviations from the internal standard were noted in Al2O3 and Fe2O3 (low values) and CaCO3 (elevated values).

Analyzing the spatial distribution of carbonate lithotypes of the Vijenac quarry, by selective exploitation and through preparation processes (crushing and grinding), the chemical composition of rocks can be influenced and adjusted to internal standards in the production of soda and cement.

Keywords: Vijenac, carbonate rocks, soda production, cement production.potentiality of the deposit, categorization of coal layers.

INTRODUCTION

Carbonate rock deposit Vijenac is located southwestern of Lukavac at a distance of about 23 kmIt is approximately the same distance from the railway stations in Banovići and Lukavac. The soda and cement factories in Lukavac use over 80% of the total annual production, and the transport of limestone is done by a cable car about 12 km long (Fig. 1a). Several exploitation benches have been developed at the Vijenac quarry. The exploitation bench (E 604) was cut into limestone at the highest elevation, and the lowest bench was formed at an elevation of 500 m (Fig. 1b).

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[1] Prof. Elvir Babajić, Faculty of Mining, Geology and Civil Engineering, University of Tuzla, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, elvir.babajic@untz.ba

[2] MSc Medina Nuhić, bach.ing. geol., Geomet doo Olovo, Huseina kapetana Gradaščevića bb, Olovo, Bosnia and Herzegovina, medina.nuhic@geomet.ba,

[3] Prof. Zehra Salkić, Faculty of Mining, Geology and Civil Engineering, University of Tuzla, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, zehra.salkic@untz.ba

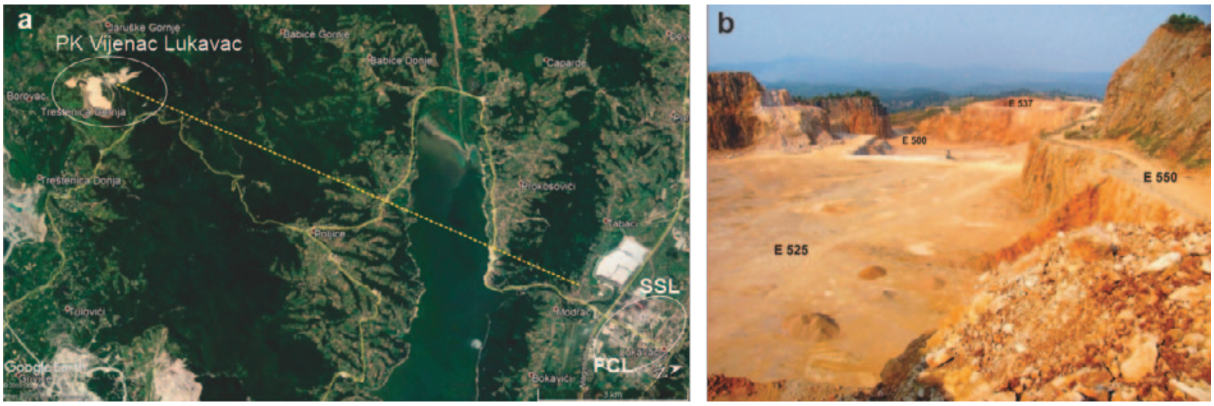

Figure 1. a) position of the Vijenac quarry, b) developed benches

GEOLOGICAL CHARACTERISTICS

The wider area of the Vijenac limestone deposit near Lukavac is formed by ophiolite melange formations with amphibolites and amphibolite shales, peridotites, serpentinites and dolerites. This is followed by undefined coarse-grained clastic sediments of the Upper Jurassic and Lower Cretaceous, as well as massive shelf limestones of the same age.

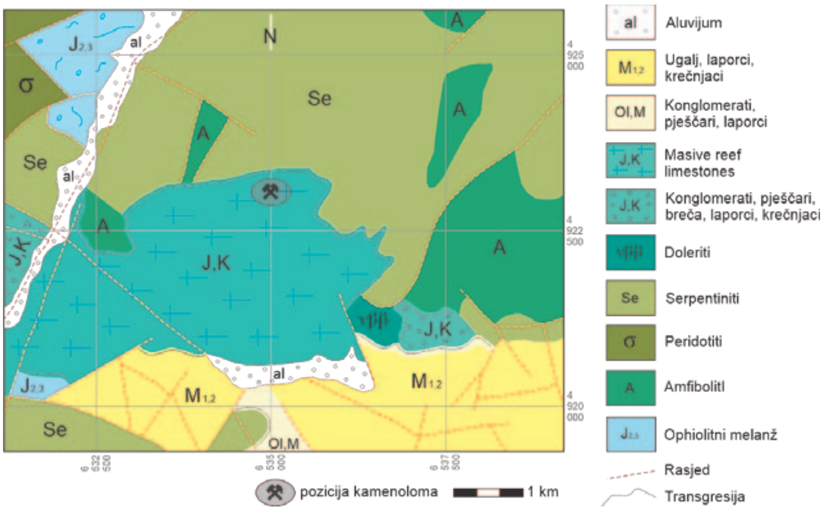

Figure 2. Geological map of the Vijenac limestone deposit wider area [9]

Tertiary deposits with coal in the area of Banovići have a smaller share (Fig. 2) [10, 7]. Serpentinites appear as a large mass that surrounds the Vijenac limestone deposit from the north and east. Serpentinization process did not cover the whole mass with the same intensity, so that there is also the appearance of serpentinized peridotites [6, 7, 8].

Limestone mass represents the horst with lowered east and west wings. The southern boundary of the massif is marked by a series of sinkholes in an east-west direction. Stratification is not clearly expressed, and dip elements of the deposit often cannot be separated due to the different cracks of the limestone. A significant feature of these limestones is the particular karstification and cracking that is the result of exogenous factors and multiphase tectonic processes. Debris material, as a slope sequence of the Quaternary, is present on the steep sections of the mine and under the administrative building of the quarry and mainly corresponds to artificial formations [10, 6].

Limestones of the Vijenac lie on serpentinized peridotites and serpentinites disintegration crusts. This is followed by basal fine-grained breccias (lithoclasts of gabbro, serpentinite, diabase and cherts). The breccia binder is ferrous-carbonate. Thickness of this series is 2 - 4 m. Over these breccias lie limestone breccias 2 - 3 m thick, followed by massive limestones (lower level) and reef limestones (upper level) [4, 9].

RESEARCH AND TESTING METHODS

Through field activities on the benches of the Vijenac quarry, macroscopic visualization revealed several lithological varieties isolated on the basis of color, mineral composition, structures and textures. In addition to the characteristic lithotypes, the sampling network was formed to provide insight into the spatial lithological structure. Special attention is paid to the processes of decomposition and disintegration of the rocks in question.

Laboratory methods included testing the chemical composition of rock samples by the ICP / OES method). Mineral-petrographic tests were performed in transmitted polarized light. The mean value and median value were statistically defined [2, 10].

TEST RESULTS

MINERAL-PETROGRAPHIC TESTS

Based on mineral-petrographic analyzes the examined limestone samples to the largest number match to the precipitated breccias of intrabiomicritic, biomicritic and sparit character [3]. In terms of structure, the limestones of Vijenac match to breccias with different sizes of incorporated clusters - fragments. Textural varieties most often match to microcrystalline to fine-crystalline, less often to clastic and cryptocrystalline varieties (Fig. 3 and Fig. 4).

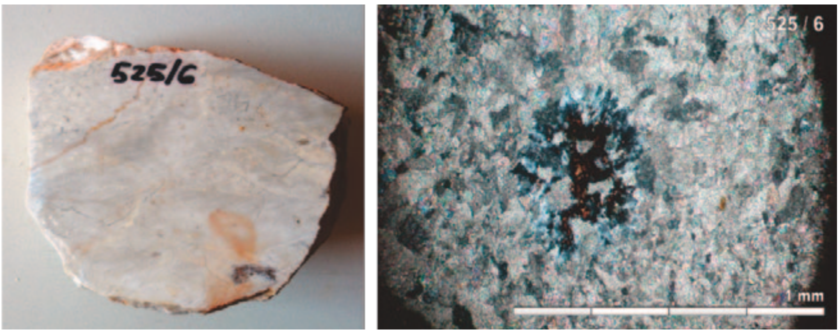

Figure 3. Macro and micro photographs of dominant limestone type of the Vijenac limestone deposit [1]

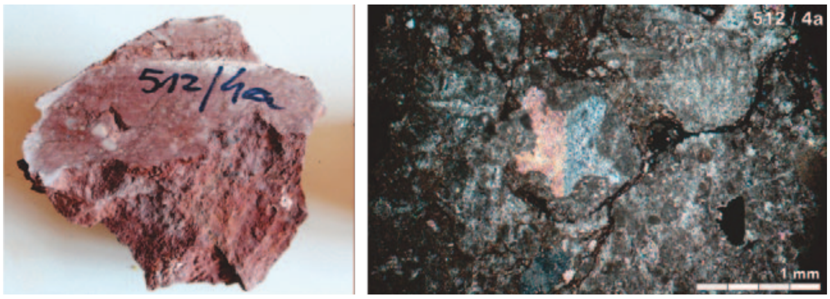

Figure 4. Macro and micro photographs of limestone in the top part of the Vijenac limestone deposit [1]

The main petrogenous mineral is calcite, with different textural type (micrite, sparite). It builds over 95% of the rock (when it comes to gray rocks, Fig. 3) and about 85% (when it comes to red pigmented, brecciated rocks, Fig. 4). A total of 60 samples were examined (Table 1) [1].

CHEMICAL ANALYSIS OF LIMESTONE

Due to the large number of data, the results of limestone chemical analyzes are presented for 2018 (Table 2) and the first seven months for 2019 (Table 3), as mean values (mean v.) and median values (median) [5].

Table 1. Mineral-petrographic analyzes of the Vijenac carbonate rocks [1]

Bench	Number of samples	Petrographic determination
500	13	Precipitated biosparite and intrabiomicritic breccia, red pigmented in places.
512	13	Breccia, biomicritic (with the effects of recrystallization of primary biomicritic clusters), biosparite, intrabiomicritic (red pigmented in places, with abundant pigmentation with limonite and terrigenous serpentinite, subordinate to quartzite).
525	14	Precipitated intrabiomicritic, biomicritic and sparite breccia. Intrabiomicrit breccia is with a binder of secondary oxides and hydroxides of Fe. Biomicrit breccia is with resorption effects.
537	4	Precipitated intrabiomicritic breccia.
550	8	Precipitated biomicritic, intrabiomicritic (with abundant pigmentation of Fe oxides and frequent concretions of Fe oxides) and biosparite breccia.
562	3	Precipitated biomicritic and oobiomicritic breccia.
580	2	Intramicritic breccia and precipitated biosparite breccia.
604	3	Precipitated biomicritic breccia with abundant metallic mineralization.

Table 2. Chemical analyzes of Vijenac limestone for 2018 year.

Month	%	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$CaSO_4$	LOI
01	mean	1.05	0.29	0.23	54.01	0.61	0.39	42.84
	median	1.26	0.18	0.22	54.57	0.46	0.34	42.80
02	mean	0.62	0.55	0.26	54.25	0.47	0.35	43.01
	median	0.43	0.60	0.18	54.41	0.29	0.35	43.05
03	mean	0.62	0.27	0.35	54.27	0.45	0.32	43.06
	median	0.46	0.24	0.30	54.35	0.44	0.29	43.10
04	mean	0.63	0.23	0.23	54.25	0.48	0.34	43.14
	median	0.59	0.22	0.23	54.23	0.35	0.34	43.09
05	mean	0.54	0.29	0.33	54.27	0.42	0.37	43.16
	median	0.44	0.23	0.30	54.55	0.43	0.31	43.18
06	mean	0.51	0.26	0.31	54.21	0.50	0.39	43.09
	median	0.46	0.23	0.27	54.20	0.57	0.37	43.10
07	mean	0.81	0.28	0.42	54.08	0.44	0.36	43.06
	median	0.64	0.21	0.30	53.01	0.41	0.34	43.10
08	mean	0.98	0.35	0.39	53.96	0.51	0.38	42.64
	median	0.68	0.24	0.26	54.29	0.42	0.37	42.88
09	mean	0.58	0.23	0.31	54.21	0.51	0.50	42.76
	median	0.66	0.21	0.27	54.20	0.49	0.41	42.78
10	mean	0.38	0.18	0.32	54.43	0.41	0.38	40.85
	median	0.29	0.18	0.29	54.43	0.40	0.38	43.18
11	mean	0.47	0.21	0.38	54.30	0.46	0.36	43.12
	median	0.42	0.18	0.29	54.43	0.47	0.38	43.14
12	mean	0.43	0.23	0.42	54.29	0.50	0.35	43.41
	median	0.42	0.22	0.38	54.33	0.50	0.34	42.96

Table 3. Chemical analyzes of Vijenac limestone for 2019 year.

Month	%	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$CaSO_4$	LOI
01	mean	0.51	0.24	0.46	54.26	0.44	0.32	43.05
	median	0.48	0.21	0.40	54.15	0.51	0.32	43.07
02	mean	0.52	0.22	0.35	54.26	0.48	0.35	42.97
	median	0.51	0.20	0.29	54.37	0.41	0.34	43.02
03	mean	0.47	0.26	0.38	54.40	0.39	0.32	43.00
	median	0.43	0.21	0.30	54.46	0.38	0.33	43.10
04	mean	0.49	0.23	0.32	54.35	0.45	0.37	42.93
	median	0.40	0.20	0.30	54.43	0.45	0.35	43.11
05	mean	0.42	0.27	0.27	54.45	0.38	0.36	43.08
	median	0.43	0.26	0.24	54.44	0.39	0.36	43.22
06	mean	0.42	0.30	0.33	54.29	0.43	0.35	42.92
	median	0.40	0.27	0.30	54.45	0.43	0.38	42.91
07	mean	0.35	0.22	0.25	54.55	0.36	0.39	43.17
	median	0.33	0.19	0.22	54.60	0.35	0.38	43.20

The content of Ca and Mg carbonates was calculated based on the values of Ca and Mg oxides and is shown in Table 4, [5].

Table 4. Content of Ca and Mg carbonate in the Vijenac limestones

$CaCO_3$ content (%), 2018. year												
month	1	2	3	4	5	6	7	8	9	10	11	12
mean	96.5	96.9	96.9	96.9	96.9	96.8	96.6	96.4	96.8	97.2	96.9	96.9
median	96.7	97.2	97.0	96.9	97.0	97.0	96.8	96.9	96.8	97.2	97.2	97.0
$CaCO_3$ content (%), 2019. year												
month	1	2	3	4	5	6	7					
mean	96.9	96.9	97.2	91.6	97.2	96.9	97.4					
median	96.9	97.1	97.3	97.2	97.2	97.2	97.5					
$MgCO_3$ content (%), 2018. year												
month	1	2	3	4	5	6	7	8	9	10	11	12
mean	1.26	0.98	0.93	1.00	0.87	1.03	0.92	1.07	1.07	0.84	0.96	1.04
median	1.07	0.95	0.92	0.95	0.89	0.98	0.86	0.96	1.02	0.84	0.90	1.05
$MgCO_3$ content (%), 2019. year												
month	1	2	3	4	5	6	7					
mean	0.92	1.01	0.82	0.93	0.79	0.89	0.76					
median	0.90	0.89	0.79	0.93	0.81	0.89	0.73					

DISCUSSION

THE SODA INDUSTRY

The required limestone quality in the Lukavac soda factory (SSL) is determined according to the internal standard (Table 5):

Table 5. Internal standard for carbonate rocks in SSL

$CaCO_3$	min. 96,0 %	SiO_2	max. 0,80 %
$MgCO_3$	max. 2,0 %	Fe_2O_3	max. 0,40 %
$CaSO_4$	max. 0,2 %	Al_2O_3	max. 0,30 %
netopivo	max. 0,3 %		

Concentrations of Si, Al, Fe oxides and Ca-sulfate of the Vijenac limestones are shown through mean and median values (Fig. 5). Elevated content of mean SiO_2 values (above 0.80%) was recorded in the first, seventh and eighth months of 2018. In the other months of 2018 and 2019, SiO_2 contents are below the value that limits the use in the soda industry. The concentration of mean SiO_2 values ranges from 0.35 to 1.05%, averaging 0.57%. Increased content of mean values and medians for Al_2O_3 (above 0.30%) was recorded in the second month of 2018 and slightly in the eighth month of the same year. The concentration of mean values of Al_2O_3 ranges from 0.18 to 0.55%, on average 0.27%. Fe_2O_3 concentrations are in the limit values, with very small deviations, the mean values range from 0.23 to 0.46%, on average 0.30%. For all $CaSO_4$ values, a characteristic increase in values is above the limit values (0.20%), mean values range from 0.32 - 0.56%, on average 0.36%.

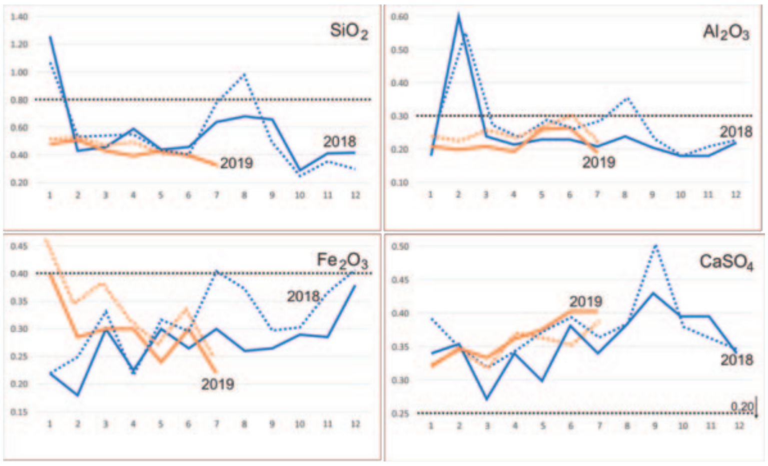

Figure 5. Mean values (dashed line) and medians (solid line) for oxides and sulfates in the Vijenac limestones, according to SSL standards

Ca and Mg carbonate content was calculated stoichiometrically from CaO and MgO concentrations (Fig. 6). The concentration of mean $CaCO_3$ values ranges from 88.20 - 98.00%, on average 96.56%. $MgCO_3$ ranges from 0.76 to 1.26%, averaging 0.94%. Content of caronates satisfies the application conditions in the production of soda. In April 2019, the mean value of Ca carbonate was 91.61%, which is below the limit value (96%).

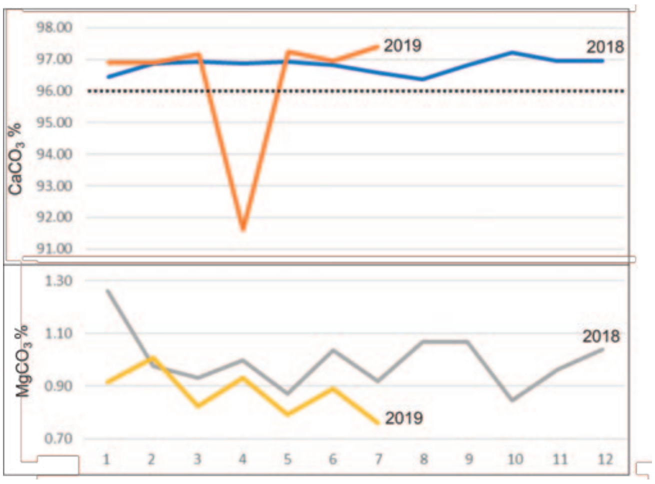

Figure 6. Mean values of Ca and Mg carbonates in the Vijenac limestones

CEMENT INDUSTRY

Several types of mineral raw materials are used for the production of cement. The primary ones are limestone and marl, then clay, sand, tuffs, bauxite, iron ores, gypsum, etc. Industrial waste such as smelter slag and fly ash can also be used.

Factory of Cement Lukavac (FCL) has an internal quality standard for the input of limestone raw material (Table 6).

Table 6. Internal standard for carbonate rocks in FCL

SiO_2	0,5 – 3,0 %
Al_2O_3	0,5 – 1,5 %
Fe_2O_3	0,3 – 1,5 %
CaO	52,0 – 55,0 %
MgO	do 0,75
$CaCO_3$	do 92,0 %

Lower values of SiO_2 than the limited ones (below 0.50%) were recorded in the first six months of 2018 and almost for the next seven months of 2019 (slightly reduced). Concentration of mean SiO_2 values ranges from 0.35 to 1.05%, with an average of 0.57%. Limited content of mean values and medians for Al_2O_3 (above 0.50%) was recorded only in the second month of 2018. Concentration of mean Al_2O_3 values of ranges from 0.18 to 0.55%, on average 0.27%. Concentration of mean Fe_2O_3 values ranges from 0.23 to 0.46%, with an average of 0.30%. Lower values refer mainly to 2019. All CaO concentrations are within the internal standard for FCL (Fig. 7).

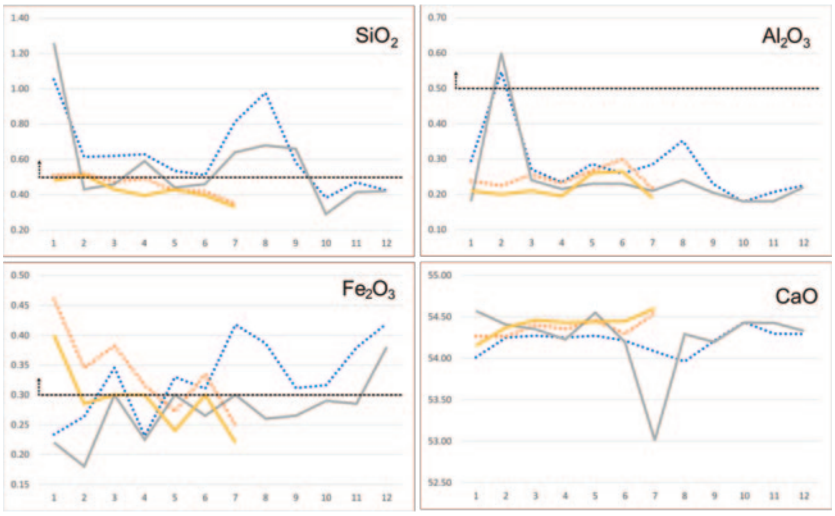

Figure 7. Mean values (dashed line) and medians (solid line) for the Vijenac limestone oxides according to internal FCL standard

The average content of Ca carbonate does not meet the conditions of application in cement production, it is elevated. Only in April 2019, the mean value of Ca carbonate was 91.61%, which meets the limited values (up to 92%), Fig. 8.

Figure 8. Mean values (dashed line) and medians (solid line) for $CaCO_3$ in the Vijenac limestones according to internal FCL standard

CONCLUSION

Based on mineral-petrographic analyzes, the Vijenac limestones can be defined as precipitated intrabiomicrites to oobiomicrites and biomicrites. These rocks are structurally brecciated and texturally microcrystalline to fine-crystalline.

Definition of harmful components in the production of cement and soda, regarding the mineral-petrographic composition of limestone, has not yet been defined by any legal act. It is mainly correlated with the chemical composition that limits certain oxides, carbonates and sulfates through internal standards, as is the case in the soda (SSL) and cement factory in Lukvac (FCL).

By analyzing the results of the limestone chemical analyzes, in terms of soda production, minor deviations from the internal standard were recorded for SiO_2, Al_2O_3 and $CaCO_3$. Elevated values (above the limit) are characteristic of Ca sulfate. For cement production, deviations from the internal standard were recorded for Al_2O_3 and Fe_2O_3 (low values) and $CaCO_3$ (elevated values).

By analyzing the spatial distribution of the Vijenac carbonate lithotypes, by selective exploitation and through the processes of mineral raw material preparation, the chemical composition of these rocks can be influenced and brought closer to internal standards in the production of soda and cement. Elevated contents of Fe_2O_3, Al_2O_3 and Si mineralization are characteristic of breccoid rocks, reddish in color. Such lithotypes of carbonate rocks are spatially distributed in the peak parts of the quarry, in fault zones and karstification zones.

Based on these observations, it is necessary to adjust the exploitation process, which is reflected in the "dilution" or "enrichment" of the mineral raw material with these components, ie adjusting it to the needs of the soda or cement factory. It is also necessary to take into account the season and precipitation. Namely, during precipitation and in the colder period, tailings-clay material is difficult to separate from the parent rock, and this is one of the reasons for the contamination of limestone with aluminosilicates.

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Naučni rad

WATER FLOW IN TRAPEZOIDAL CHANNEL IN THE FUNCTIONS OF THE DIFFERNET ROUGHNESS

Nedim Suljić[1]

SUMMARY

The paper presents hydraulic analyzes of the water flow of a trapezoidal open channel under the influence of different roughness values. A trapezoidal cross-section of an open channel with a slope of 45o and a channel bottom width of 1.0 m was considered. Three cases of canal finishing as a function of Manning's roughness coefficient (n) were analyzed for a concrete canal, a canal made of compacted clay covered with a broken layer of mud, and a canal in very poor condition with large stones on the bottom overgrown with vegetation. The longitudinal channel drop for all analyzed cases is 1%. For the needs of this work, a hydraulic calculation was made for a uniform stationary flow of the trapezoidal cross-section of the channel. Lower pro-accuracy in the channel is given by higher roughness coefficients and vice versa. When dimensioning the canal, it is neces-sary to choose the appropriate finish of the canal from the aspect of throughput as well as the speed of water flow.
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Key words: trapezoidal channel, water flow, channel roughness, stationary flow.

1. INTRODUCTION

In hydrotechnical practice, flow in open channels is observed in relation to the change in the shape of the water face as well as changes in the speed and depth of water over time. As a function of the shape of the water face, the flow in open riverbeds is divided into uniform and non-uniform, and in relation to the change in speed and depth of water over time, we distinguish between stationary and non-stationary flows. If the flow rate of water does not change as a function of time, then the flow is stationary, otherwise it is a non-stationary flow. Stationary flows can be uniform or non-uniform. Uniform flow is a flow that has the same characteristics along its entire course. Uniform flow can occur only in prismatic channels, that is. in channels having a constant drop and a constant cross-section. This paper analyzes a stationary uniform flow of a trapezoidal open channel with the same channel cross-sectional geometry, the same longitudinal channel drop, and with three different roughnesses. Based on the hydraulic calculation, water flows and velocities and their functions were obtained, which show the ratios of water flow and velocity in the trapezoidal channel of different roughnesses [2] [4].

2. STATIONARY UNIFORM FLOW AND CHANNEL ROUGHNESS

In order to achieve a uniform stationary flow, it is necessary to have a constant flow of water in the channel (Q = const), the same cross section of the channel (A = const), the same hydraulic drop (I = const), the same roughness of the channel processing (n = const) and flow without local resistance. A channel with an un-changed cross-section on the observed section is called a prismatic channel, and the depth of water that is realized in the channel with a constant flow and a given longitudinal drop is called normal depth [1].

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[1] Prof. Nedim Suljić, University of Tuzla, Faculty of Mining, Geology and Civil Engineering, Univerzitetska 2, Tuzla, Bosnia and Herzegovina, nedim.suljic@untz.ba

In stationary flow, as discussed in this paper, we can write:

$$\frac{\partial A}{\partial t}=0 \qquad \frac{\partial v}{\partial t}=0 \qquad \text{Q=const.} \tag{1}$$

In uniform flow, the mean velocity as well as the flow are constant, and the energy line is parallel to the free surface of the liquid in the open channel and parallel to the bottom of the channel. That is, all the drops between the two cross-sections in the open channel are equal to each other (Id=I =IE) [1] [6].

For open channels, we can use the Bernoulli equation to describe uniform flow in almost exactly the same way as for pipe flow. The difference is that with uniform flow in open channels there are no local losses but only friction losses during flow, ie:

$$\Delta H_{lin}=\Delta H_{trenje}=I_E\cdot\Delta L=c_f\,\frac{\Delta L}{R}\cdot\frac{v^2}{2g} \tag{2}$$

$$I_E=\frac{\Delta H_{trenje}}{\Delta L}=\frac{c_f}{2g}\cdot\frac{v^2}{R} \tag{3}$$

The value of cf is the coefficient of friction resistance. Based on expression (3), the velocity in an open channel with uniform flow can be determined:

$$c_f\cdot v^2=2gRI_E \Rightarrow v^2=\frac{2gRI_E}{c_f} \tag{4}$$

$$v=\sqrt{\frac{2gRI_E}{c_f}} \tag{5}$$

$$\sqrt{\frac{2g}{c_f}}=C \tag{6}$$

$$v=C\sqrt{RI_E} \tag{7}$$

The expression (7) represents the formula Chezyevu speed in an open channel in the case of uniform flow. The number C is a Chezy number that depends on the surface roughness of the open channel and on the Reynolds number. Since the number C is not a constant quantity, various researchers have given its approximations using some mostly simple functions. Based on experience, some researchers have given empirical expressions for Chezy's number C, so that these expressions are still used today in fluid mechanics with uniform flow in open channels [1] [3]. The term proposed by Manning (1890) is still mostly used today in the following form:

$$C=\frac{1}{n}R^{\frac{1}{6}} \tag{8}$$

where is;
n - Manning roughness coefficient (m-1/3s),
R - hydraulic radius (m).

Natural riverbeds have irregular cross-sectional shapes, changes in bottom slope and meandering axis of watercourses. In natural riverbeds, the longitudinal profile of the water surface is constantly changing. Also, changes in hydraulic parameters along the river flow are frequent [2] [5].

The usual values of Manning roughness coefficient are given in the table in the literature in the field of open channels, and it is important to note that the error in measuring and calculating the flow is directly proportional to the error in selecting Manning roughness values for certain open channels.

3. FLOW IN THE TRAPEZOIDAL CANAL OF DIFFERENT ROUGHNESS

Using Manning's expression, a hydraulic calculation was performed to determine the flow in the channel of a trapezoidal cross-section of the channel bottom width of 1.0 m and a longitudinal channel drop of 1%, while the roughness coefficient was variable. Three cases of trapezoidal channel finishing were analyzed, as fol-lows: concrete lining (n = 0.014 m-1/3s), channel in compacted clay covered with a broken layer of sludge (n = 0.0225 m-1/3s) and channel in very poor condition overgrown with vegetation and with large stones at the bottom (n = 0.055 m-1/3s). In the performed calculations, the water depth in the canal ranged from 0.5 m to 1.5 m with a step of 0.1 m. For all analyzed cases, the water flow rate and water flow in the trapezoidal channel changed. The results of the hydraulic calculation are shown in the following tables:

Table 1: Results of hydraulic calculation of trapezoidal channel for Manning roughness coefficient n = 0.014 m-1/3s (concrete lining)

h_i (m)	F_i (m^2)	O_i (m)	R_i (m)	vi (m/s)	Q^i (m^3/s)
0,50	0,75	2,41	0,31	3,28	2,46
0,60	0,96	2,70	0,36	3,59	3,44
0,70	1,19	2,98	0,40	3,87	4,61
0,80	1,44	3,26	0,44	4,14	5,96
0,90	1,71	3,55	0,48	4,39	7,51
1,00	2,00	3,83	0,52	4,63	9,27
1,10	2,31	4,11	0,56	4,86	11,24
1,20	2,64	4,39	0,60	5,09	13,43
1,30	2,99	4,68	0,64	5,30	15,85
1,40	3,36	4,96	0,68	5,51	18,51
1,50	3,75	5,24	0,72	5,71	21,42

Table 2: Results of hydraulic calculation of trapezoidal channel for Manning roughness coefficient n = 0,0225 m-1/3s (channel in compacted clay covered with a broken layer of sludge)

h_i (m)	F_i (m^2)	O_i (m)	R_i (m)	vi (m/s)	Q^i (m^3/s)
0,50	0,75	2,41	0,31	2,04	1,53
0,60	0,96	2,70	0,36	2,23	2,14
0,70	1,19	2,98	0,40	2,41	2,87
0,80	1,44	3,26	0,44	2,58	3,71
0,90	1,71	3,55	0,48	2,73	4,67
1,00	2,00	3,83	0,52	2,88	5,77
1,10	2,31	4,11	0,56	3,03	6,99
1,20	2,64	4,39	0,60	3,16	8,35
1,30	2,99	4,68	0,64	3,30	9,86
1,40	3,36	4,96	0,68	3,43	11,52
1,50	3,75	5,24	0,72	3,55	13,33

Table 3: Results of the hydraulic calculation of the trapezoidal channel for the Manning roughness coefficient n = 0.055 m-1 / 3s (channel in very poor condition with large stones at the bottom and overgrown with vegetation)

h_i (m)	F_i (m²)	O_i (m)	R_i (m)	vi (m/s)	Q^i (m³/s)
0,50	0,75	2,41	0,31	0,83	0,63
0,60	0,96	2,70	0,36	0,91	0,88
0,70	1,19	2,98	0,40	0,99	1,17
0,80	1,44	3,26	0,44	1,05	1,52
0,90	1,71	3,55	0,48	1,12	1,91
1,00	2,00	3,83	0,52	1,18	2,36
1,10	2,31	4,11	0,56	1,24	2,86
1,20	2,64	4,39	0,60	1,29	3,42
1,30	2,99	4,68	0,64	1,35	4,03
1,40	3,36	4,96	0,68	1,40	4,71
1,50	3,75	5,24	0,72	1,45	5,45

The following figures show the water flow curves in a trapezoidal channel with a bottom width of 1.0 m and a longitudinal drop of 1% for different values of the Mannig coefficient of roughness and water depth from 0.5 m to 1.5 m. Of special importance are the quadratic functions of the obtained curves - the ratio of water flow depending on the depth of water in the trapezoidal channel, which is a mathematical function of the trapezoidal channel of the given characteristics and the corresponding roughness, ie Mannig's roughness coefficient. The obtained quadratic functions are polynomial functions of the second degree.

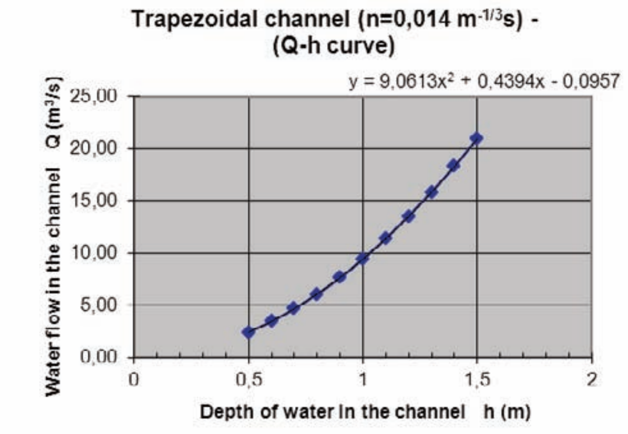

Figure 1: Flow curve in trapezoidal channel for n=0,014 $m^{-1/3}$ s

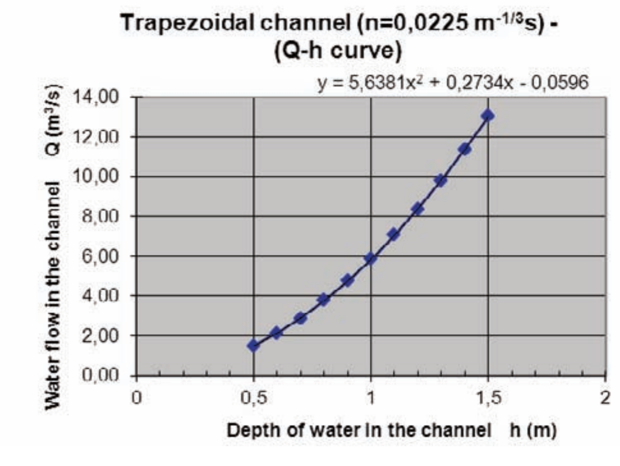

Figure 2: Flow curve in trapezoidal channel for n=0,0225 $m^{-1/3}$ s

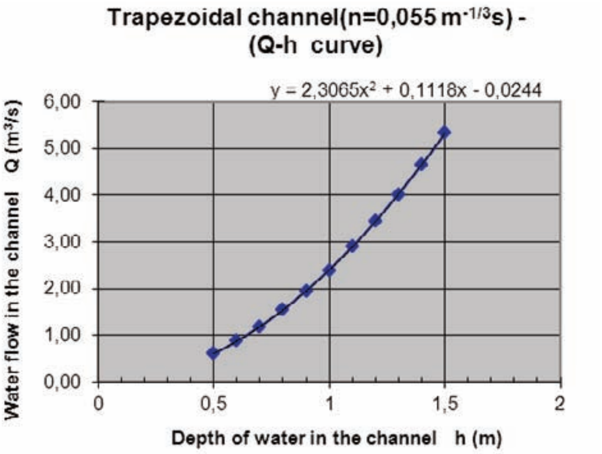

Figure 3: Flow curve in trapezoidal channel for n=0,055 $m^{-1/3}s$

CONCLUSIONS

The paper analyzes the water flow in the open channel of the trapezoidal cross-section depending on the roughness of the channel lining. Three cases of channel roughness were considered taking into account the Manning roughness coefficient. In all analyzed cases, the geometry of the cross-section is the same and the same longitudinal slope of the trapezoidal channel (I=1%). For three different cases of canal roughness (concrete lining, canal in compacted clay covered with a broken layer of silt and canal in very poor condition with large stones at the bottom overgrown with vegetation) values of water velocity and flow were obtained. The water depth in the canal from 0.5 m to 1.5 m with a step of 0.1 m was considered. Due to the same cross-sectional geometry of the trapezoidal channel and the same water depths, in the analyzed examples we have the same channel cross-sectional area, the same wet volume and the same hydraulic radius, and the speed and water flow are variable.

Based on the performed calculations, it can be concluded that for the given flow conditions and the given parameter of the trapezoidal channel, the water flow in the channel with concrete lining is 60.7% higher than in the case of compacted clay channel covered with a broken layer of sludge. This ratio is the same for all analyzed water depths in the trapezoidal channel. Also, the water flow in the canal with concrete lining is 3.9 times higher than the water flow in the canal, which is in a very bad condition with large stones at the bottom. The paper presents the mathematical functions of the flow change in relation to the water depth in a trapezoidal channel with a channel bottom width of 1.0 m, a slope of 45o and a longitudinal drop of 1%.

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Scientific Paper

MINIMUM IGNITION ENERGY OF LIGNITE AND BROWN COAL DUST CLOUDS IN COAL WITH AND WITHOUT INTERLAYERS

Jelena Marković[1], Snežana Mičević[2], Mevludin Delalić[3], Edisa Nukić[4]

SUMMARY

This paper summarizes research on the minimum ignition energy (MIE) of brown coal and lignite dust clouds, as well as the impact of all relevant parameters on the ignition energy of coal samples collected from Bosnian-Herzegovinian mines. The tests were performed for two types of test samples, namely: coal samples from the entire profile of the room (coal from the layer) and samples of pure coal without interlayers (pure coal).

Experimental results show that the degree of coal carbonization significantly affects the energy value required for dust cloud ignition, and that MIE values of samples from the same coal seam vary from one location to another due to uneven chemical and mineral-petrographic composition of coal from one deposit.

Tests on dust samples in "as received" state have shown that with a moisture content ≥ 33% m/m it is very difficult to achieve suspendability, and thus obtain energy at which the dust cloud would ignite. For this reason, tests were also performed on dried samples.

The lowest values of MIE in "pure coal" and "coal from the layer" test samples, with moisture in "as received" state are between:

- 30.2 mJ <MIE <35.4 mJ; or 55.7 mJ <MIE <77.3 mJ for lignite dust, and
- 1650 mJ <MIE <1870 mJ; or 2030 mJ <MIE <2304 mJ for brown coal dust.

A variation of MIE reduction was found with a decrease in humidity in the test samples up to 15% m/m, after which the influence of humidity was significantly weakened.

Keywords: minimum ignition energy (MIE), brown coal, lignite, test sample, moisture content

INTRODUCTION

The minimum ignition energy of a coal dust cloud is an important parameter for assessing the risk of its explosion. The importance of this parameter is in ability to assess explosive mixture ignition by a spark of a certain energy that can be caused by installed electrical or mechanical devices in a given technological process where explosive mixtures of mine gas and/or coal dust in a mixture with air appear.

The MIE value required for coal dust ignition affects explosion flow and development. There are a number of important parameters that affect its value: the degree of coal carbonization, moisture content, inert matter content, volatile content, mineral petrographic composition of dust, dust concentrations and particle size distribution, etc. [1] [3] [6] [9] [10].

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[1] Prof. Jelena Marković, University of Tuzla, Faculty of Mining, Geology and Civil Engineering, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, jelena.markovic@untz.ba

[2] Prof. Snežana Mićević, Association- AtEx, Tuzla, Bosnia and Herzegovina, snezana.micevic@atex.ba

[3] PhD Mevludin Delalić, Association- AtEx, Tuzla, Bosnia and Herzegovina, dine.delalic@gmail.com

[4] Doc. Edisa Nukić, University of Tuzla, Faculty of Mining, Geology and Civil Engineering, Urfeta Vejzagića 2, Tuzla, Bosnia and Herzegovina, edisa.nukic@untz.ba

Wang et al. [10] examined differences in ignition sensitivity and explosion severity characteristics among different ranks of coal dust. Considering results obtained by this research, authors found that the main causes of these differences are volatile content and pyrolytic properties of the coal. A coal sample that has a high volatile content and pyrolyze easier has a lower MIE and minimum ignition temperature (MIT), a dust cloud ignites more easily, and a flame develops faster at the onset of an explosion. If we consider the content of volatiles in lignites and brown coals in B&H, it can be seen that it is high in both as over 50% and more. The influence of dust inertization on MIE and MIT for different flammable dusts was investigated by Addai et al. [1]. The authors express opinion that by increasing concentration of inert matter in the inert-combustible dust mixture, both parameters are increasing until a threshold (between 60 and 80%) is reached in which ignition fails to occur. Experimental investigations of ignition sensitivity of hibrid mixtures of oil shale dust and syngas were performed by L.F.Yu et al. [6]. Norman et al. [9] examined the characteristics of ignition sensitivity and the characteristics of the explosion severity of coal dust in the air and oxygen-enriched atmosphere. Considering the results of the research, the authors found that the ignition sensitivity in a 30 vol.% O_2 in CO_2 mixture was in good agreement to the ignition sensitivity in air, while in a 50 vol% O_2 in CO_2 mixture the ignition energy decreased significantly.

MATERIALS AND METHODS

Testing methodology

Tests of the minimum ignition energy of a coal dust air mixture (dust cloud) were performed in accordance with ISO/IEC standards, on a Hartmann apparatus, according to the prescribed procedure [4] [5].

The Hartmann tube is a vertical glass tube with a volume of 1.2 l and an internal diameter of 70 ± 5 mm, closed at the bottom with a dust dispersion cup. The test procedure is that the test sample (concentrations usually 250 g/m^3, 500 g/m^3, 750 g/m^3, 1000 g/m^3 and 1500 g/m^3) is placed on a tray and dispersed in an explosion with compressed air (volume 50 cm^3 and a pressure of 700 to 800 kPa). During the test, the magnitude of ignition energy, the mass of the tested dust and the time interval between the dust dispersion and the formation of a spark vary. The maximum energy that the test apparatus can achieve in the experiment is 7220 mJ.

In determining dust concentration for optimal ignition conditions for a given test sample, the range of concentrations close to the observed maxima pmax; (dp/dt)max was taken into account, determined by previous tests in a 20 l spherical vessel (Marković et al. 2015; 2017) [7] [8].

During the testing of lignite and brown coal test samples, differences in flame intensity and duration, ie the speed of flame transfer after initiation by an electric spark were observed. In lignite dust, the flame is in principle more intense and is usually transmitted to a complete cloud of dispersed dust, which is not the case with brown coal dust.

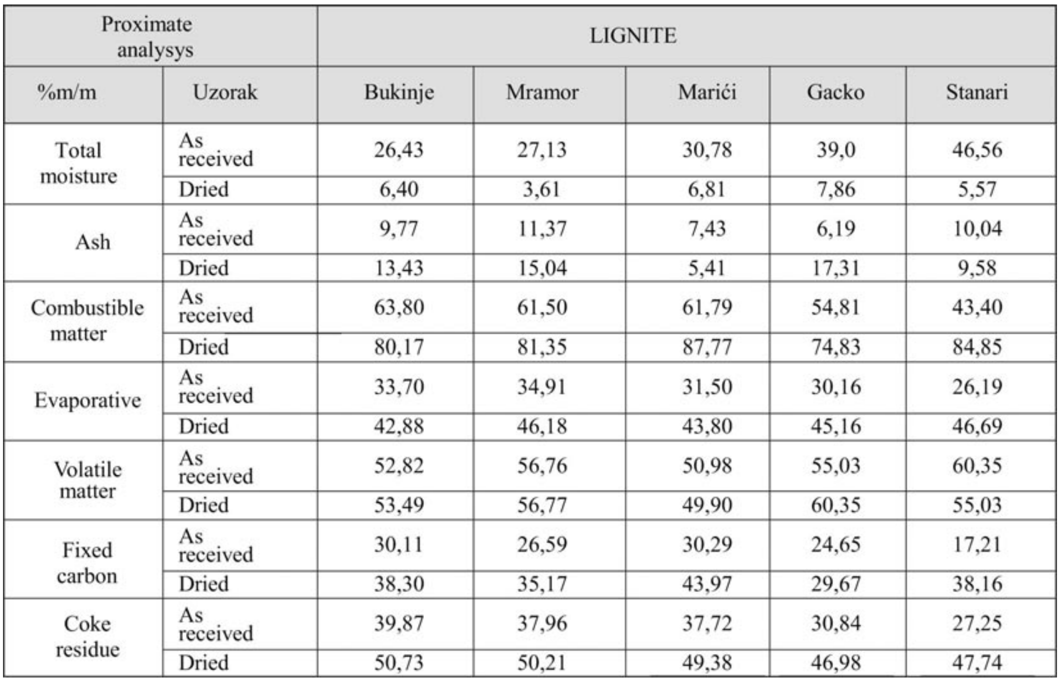
Characteristics of tested dust samples

Coal samples for MIE testing were taken in accordance with standard [2], from five coal seams in a lignite mines and eight coal seams in a brown coal mines. In addition to composite samples taken by the furrow method (label "coal from the layer"), tests were also performed on coal samples without intermediate layers (label "pure coal"). Prior to testing samples were prepared (grinding, sieving, drying, Proximate analysis, ultimate analysis, mineral petrographic analysis).

The minimum ignition energy, among other parameters, is conditioned by dust particles size and the moisture content. The tests were performed on samples <63 µm with original moisture content ("as received" condition) and without coarse moisture, since it is difficult for dust samples to float and the formation of a fine dispersion system with delivered moisture content, Figure 3.

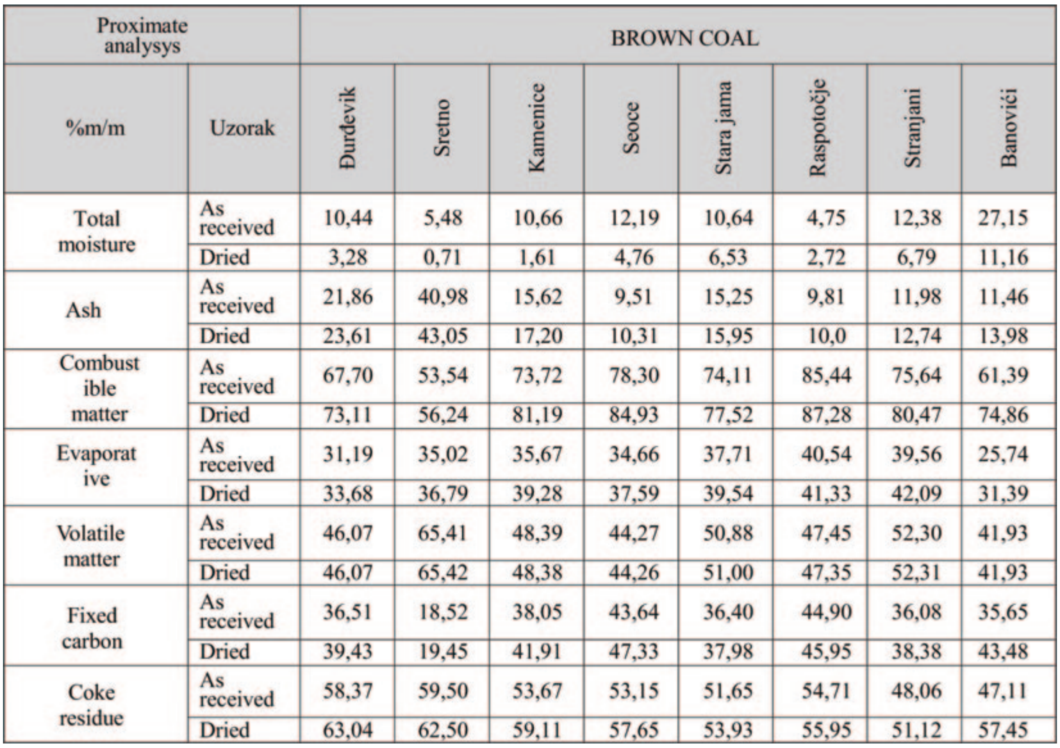
The calorific value of the sampled coal is for lignite from 9,887-16,827 kJ/kg, and for brown coal from 12,304 to 23,996 kJ/kg.

Table 1. Proximate analysis of lignite dust sample [3]



Proximate analysys		LIGNITE				
%m/m	Uzorak	Bukinje	Mramor	Marići	Gacko	Stanari
Total moisture	As received	26,43	27,13	30,78	39,0	46,56
	Dried	6,40	3,61	6,81	7,86	5,57
Ash	As received	9,77	11,37	7,43	6,19	10,04
	Dried	13,43	15,04	5,41	17,31	9,58
Combustible matter	As received	63,80	61,50	61,79	54,81	43,40
	Dried	80,17	81,35	87,77	74,83	84,85
Evaporative	As received	33,70	34,91	31,50	30,16	26,19
	Dried	42,88	46,18	43,80	45,16	46,69
Volatile matter	As received	52,82	56,76	50,98	55,03	60,35
	Dried	53,49	56,77	49,90	60,35	55,03
Fixed carbon	As received	30,11	26,59	30,29	24,65	17,21
	Dried	38,30	35,17	43,97	29,67	38,16
Coke residue	As received	39,87	37,96	37,72	30,84	27,25
	Dried	50,73	50,21	49,38	46,98	47,74

Table 2. Proximate analysis of a brown coal dust sample [3]



Proximate analysys		BROWN COAL							
%m/m	Uzorak	Đurdevik	Sretno	Kamenice	Seoce	Stara jama	Raspotočje	Stranjani	Banovići
Total moisture	As received	10,44	5,48	10,66	12,19	10,64	4,75	12,38	27,15
	Dried	3,28	0,71	1,61	4,76	6,53	2,72	6,79	11,16
Ash	As received	21,86	40,98	15,62	9,51	15,25	9,81	11,98	11,46
	Dried	23,61	43,05	17,20	10,31	15,95	10,0	12,74	13,98
Combustible matter	As received	67,70	53,54	73,72	78,30	74,11	85,44	75,64	61,39
	Dried	73,11	56,24	81,19	84,93	77,52	87,28	80,47	74,86
Evaporative	As received	31,19	35,02	35,67	34,66	37,71	40,54	39,56	25,74
	Dried	33,68	36,79	39,28	37,59	39,54	41,33	42,09	31,39
Volatile matter	As received	46,07	65,41	48,39	44,27	50,88	47,45	52,30	41,93
	Dried	46,07	65,42	48,38	44,26	51,00	47,35	52,31	41,93
Fixed carbon	As received	36,51	18,52	38,05	43,64	36,40	44,90	36,08	35,65
	Dried	39,43	19,45	41,91	47,33	37,98	45,95	38,38	43,48
Coke residue	As received	58,37	59,50	53,67	53,15	51,65	54,71	48,06	47,11
	Dried	63,04	62,50	59,11	57,65	53,93	55,95	51,12	57,45

RESULTS AND DISCUSSION

The MIE research results according to the established program [3] are shown in the diagrams, Figures 1 and 2.

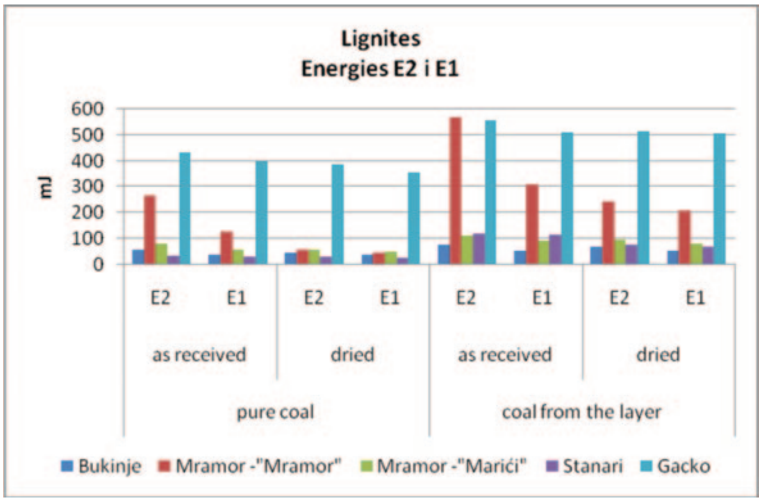


Figure 1. E1 and E2 values for lignite dust

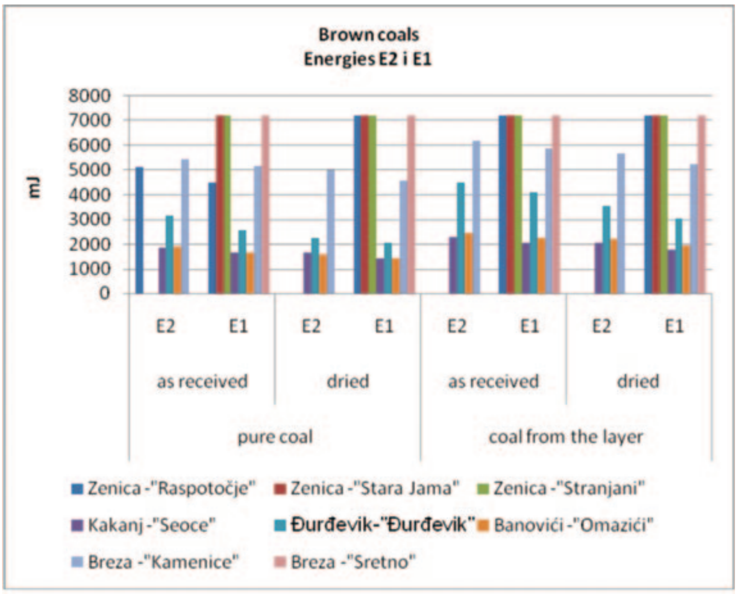


Figure 2. E1 and E2 values for brown coal dust

It was found that the values of the highest energy without ignition (E1), or the lowest with ignition (E2) start from:

- 55.7 mJ ≤ E1 ≤ 512.9 mJ; 30.3mJ ≤ E2 ≤556.5 mJ for lignite dust
- 1408mJ ≤ E1≤ 7220 mJ; 1560 mJ ≤ E2 ≤7220 mJ for brown coal dust.

The research indicates that the higher the degree of coal carbonization, the higher the values of MIE, with the main rule:

- "pure coal" <MIE <"layer coal" (significantly larger range observed for lignite dust) and
- "dried sample"<MIE <"as received" (observed variation of reduction to moisture content 15% m/m).

In addition, tests of samples from the same coal seam taken at different locations (Mramor and Marići) show significant differences in MIE values. This inconsistency in the values of energy required for the ignition of dust clouds of the same coal seam can be explained by the uneven chemical and mineral-petrographic composition of coal in one deposit. The coal seams, both in terms of extension and vertical cross-section, are interwoven with the uneven presence of basic plant matter and tailings admixtures. The share of plant matter is also uneven in terms of the quality and quantity of a particular biomass.

Having in mind the known and then possible factors influencing the results of the MIE test of coal dust clouds, the following was analyzed:

- Influence of dust concentration
- Influence of moisture in the sample
- Influence of delay time between cloud dispersion and spark ignition
- Influence of dust particle shape
- Influence of chemical composition of coal
- Influence of petrographic composition of coal

Influence of dust concentration

All types of samples were tested in the range of optimal concentrations for ignition: 250 g/m^3, 500 g/m^3 and 750 g/m^3, which corresponds to a sample weight of 0.3-0.9 g. In most cases MIE, for both lignite and brown coal, corresponded to the mass of the sample between 0.5-0.8 g, ie the mass concentration of 417 g/m^3 - 667 g/m^3.

Influence of moisture in the sample

The experiments were performed on samples in "as received" state and dried samples where coarse moisture has been completely removed, and the content of hygroscopic moisture in the samples was below 10% m/m.

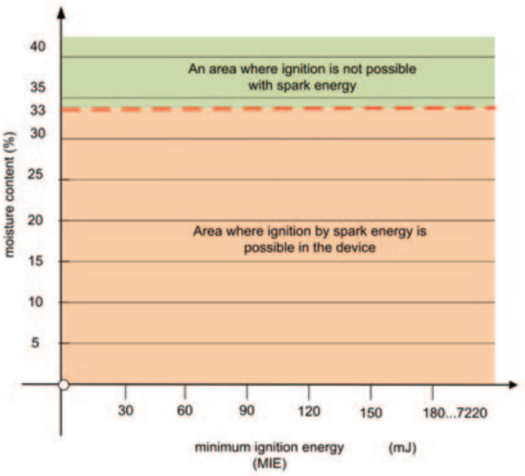


Figure 3. Areas where dust clouds ignition is possible/impossible depending on the moisture content and maximum spark energy that can be achieved in the device [3]

By reducing the humidity in sample to 15% m/m, the MIE moves towards lower values, after which the influence of moisture reduces considerably. The same MIE value was found on some samples with a moisture content of 15% m/m and below 10% m/m. This suggests that a naturally dried sample can achieve optimal moisture content just like a sample that is dried under laboratory conditions. The low moisture content (below 10% m/m) ensures the dispersion of dust particles over a wide area, while the samples in "as received" state achieve a small effective area and flame transfer is difficult. The moisture content in the samples ~ 4 - 5% m/m has no effect on MIE value, which is explained by the fact that evaporation of this amount of hygroscopic or capillary water does not consume a large amount of energy (insufficient to avoid ignition). The above indicates that the MIE test of coal dust clouds should be performed at the optimal moisture content in the sample, which for lignite and brown coal used in the experiment is about 10% m/m.

Influence of delay time between cloud dispersion and spark ignition

MIE is a function of turbulence of the dust/air mixture and dust concentration. MIE should be measured at the optimal dust concentration and the lowest level of turbulence that can be achieved experimentally. The level of turbulence is reduced by prolonging the ignition delay time.

Figure 4 shows all delays that occur in Hartmann apparatus.

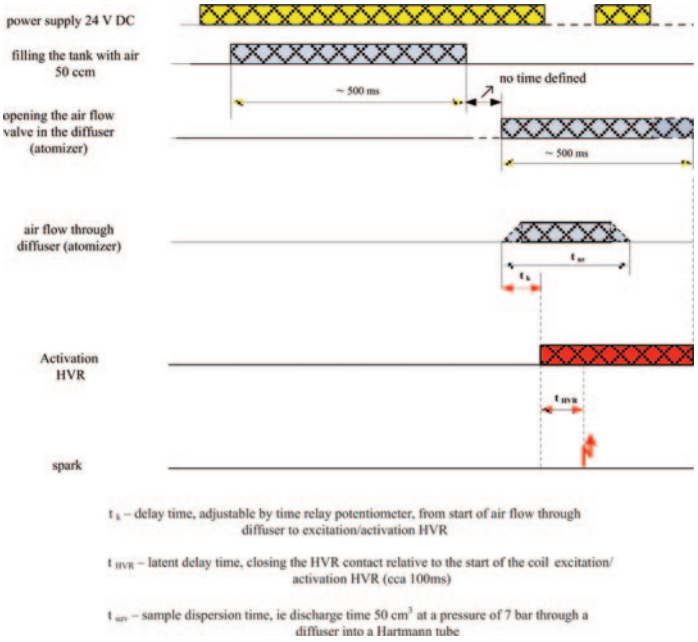


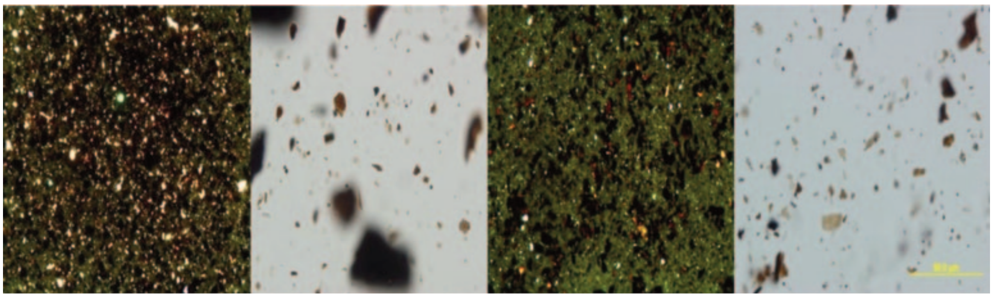
Figure 4. Delay in Hartmann apparatus [3]

By varying the delay time of spark initiation after dust dispersion (30, 60, 120, and 180 ms) in a glass tube, the optimal time at which ignition occurs most easily was determined. For lignite dusts, a slightly longer time interval to achieve the most suitable time to ignite the spark after dust dispersion has been observed. The test results show approximate values of this parameter for lignite and brown coal, provided that the moisture content, granulation and dust concentration are identical. At a dust concentration of 400 g/m3, moisture content below 10% m/m and granulation <63 µm, the optimal time interval between dispersion and spark initiation of 30-60 ms was determined.

Influence of particle shape

The difference between the dispersion of lignite and brown coal dust is a consequence of unequal physical and chemical properties of these coals, which depend on the mineral-petrographic composition and carbonization, but mostly on the ash and moisture content and uneven shape of coal dust particles. Namely, the shape of the lignite dust particle deviates from the spherical shape and has an irregular elongated or flat shape, which has the ability to stay longer in the dispersed system.

Figure 5 shows the microscopic appearance of brown coal and lignite dust, where spherical grains of brown coal particles with mineral matter of epigenetic character are observed, with a dominant presence of silicates, carbonate components, iron minerals and clay minerals (a), and plate and splinter grains of lignite particles also with epigenetic mineral admixtures with the dominant presence of quartz, clay minerals and the sporadic presence of minerals of carbonate origin (b).



a) b)

Figure 5. Microscopic view of coal dust particles <63µm (a) brown coal and (b) lignite. Magnification x100

The influence of the dust particle shape is reflected in the occupation of the effective area in the dust cloud, where the speed of flame transfer from particle to particle is important, ie the speed of flame acceptance of each particle separately. In fluffy, leafy and fibrous forms, flame is more easily transmitted from particle to particle than in granular forms.

The experiments proved the theoretical assumption that spherical particles are more difficult to ignite than other geometric shapes of dust particles, so this is another parameter that influenced the high value of MIE of brown coal dust. In contrary, in plate-shaped lignite, due to the more favorable contact surface between the dust particles dispersed in Hartmann apparatus tube, and the required lower activation energy, the MIE values of the dust clouds are significantly lower.

Influence of chemical composition of coal

The influence of chemical composition on MIE dust clouds is manifested in the content of combustible (carbon, hydrogen and sulfur) and inert (nitrogen and oxygen) elements in the organic part of coal, and in the content of mineral matter in coal, which consists of minerals silicon, iron, aluminum, calcium, magnesium, titanium, phosphorus, alkaline elements, sodium and potassium and other trace elements, such as: beryllium, nickel, zinc, manganese, molybdenum, lead, uranium elements, etc.

Based on analysis results (Table 2), it can be seen that the content of combustible matter in brown coal dust ranges from 53.54 to 85.63% m/m and changes slightly by drying, since the natural moisture content in coal is low. In the dried sample, the amount of combustible matter ranges from 56.24 to 87.28% m/m.

In lignite dust, the natural content of combustible matter is from 43.4 to 63.8% m/m, while in the dried sample it is significantly higher (74.83% m/m to 87.78% m/m), due to the loss of a large amount of coarse moisture found in the natural sample and which evaporates during coal drying, Table 1.

Due to the high content of combustible matter in both types of test samples, significantly lower MIE values were expected than determined. Despite the high content of combustible matter in brown coal dust, MIE dust clouds are many times higher for almost the same content of combustible matter in lignite on both the "as received" sample and the dried sample.

Mineral matter in coal has an inhibitory effect because during the combustion of organic matter in coal it absorbs thermal energy, necessary for endothermic reactions such as: thermal dissociation of limestone, phase transformations, dehydration, dissociation and reduction. These processes are favored in relation to the composition of the mineral matter in coal, and the exothermic ones that occur during crystallization, dissociation and oxidation are mostly subordinated. Based on the above, it can be stated that the presence of mineral matter in coal dust causes an increase in MIE required for dust ignition.

Figure 6 shows the chemical composition of the ash that is formed in coal burning process, or organic matter in coal.

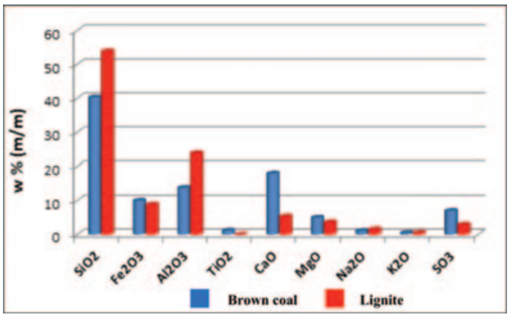


Figure 6. Chemical composition of test coal ash

The ash produced by both types of coal burning has a uniform content of iron minerals and alkaline oxides. The dominant presence of silicate minerals and clay minerals (aluminosilicates) is less in brown coal than in lignites. A high content of carbonate minerals is observed in brown coal, which strongly absorbs heat during thermal changes, as much as 1207.0 kJ/mol, for thermal dissociation of limestone to calcium and magnesium oxides. These data partially shed light on the reason for the high MIE value of brown coal dust. Thus, the chemistry of the combustion process, which occurs in coal dust particles, when the mineral substance is an inhibitor of the reaction, reduces the activation energy of the dust particles and slows down the reaction kinetics. In addition, the mineral matter due to endothermic reactions takes away part of the spark heat.

Influence of petrographic composition of coal

Lignite, which is xylitol coal, with an average density of 1.2 kg/m^3 contains a larger amount of macerals such as texto detrit and gelo detrit, whose density is below 1.3 kg/m^3, while brown coals contain maceral components such as texto gelo with microlithotypes vitrinite, durite and fusinite with semifusinite with an average density of 1.3 to 1.45 kg/m^3.

In relation to the maceral composition of coal, it is clear that maceral texto detrit and gelo detrit have a chemical structure that corresponds to a lower number of aromatic nuclei in the coal structure. The metamorphosis of the original plant matter in younger coals is not complete in terms of ending the carbonization process. This statement was confirmed for the analyzed samples of lignite coals, in which no microlithotype texto gelo was found. This specifically means that the absence of "heavy" aromatic groups in the lignite coal molecule resulted in easier ignition of coal dust, ie lower MIE.

CONCLUSION

Minimum Ignition Energy (MIE) of flammable dusts is an important parameter for efficient planning and implementation of fire and explosion protection measures.

MIE tests were performed on samples of lignite and brown coal dust for two types of test samples: samples of pure coal without interlayers and coal samples from the entire coal mine profile. According to propositions of the standard [5], tests were performed on test samples in "as received" condition and dried samples (coarse moisture removed).

It is determined, by conducted MIE testing, that the lignite dust is generally more prone to ignition at low energies (30 to 5x10^2 mJ) compared to brown coal dust (1.5x 10^3 to ≥7220 mJ), which is explained by differences in physico-chemical and mineral-petrographic composition of tested samples.

Since a large number of tests were performed, differences in flame intensity and duration were observed, ie the speed of flame transfer after initiation by an electric spark. In lignite dust, the flame is generally more intense and is usually transmitted to a complete dust cloud dispersed in the Hartmann apparatus tube. In brown coal dust, ignition sometimes occurred in the area around electrodes, ie in the immediate vicinity of the spark, which confirms the rule of more difficult ignition transmission to a complete cloud of dispersed dust. Tests have shown that with a moisture content above 33% m/m, ignition cannot be achieved regardless of the spark energy.

The research results are aplicable and, along with other parameters that define combustibility and explosibility of coal dust, contribute to a more detailed definition of preventive measures in coal mines, in mining surface facilities as well as in energy facilities.

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