Original Scientific paper
UDK 624.21.072.336.041(497.6)
DOI: 10.7251/afts.2018.1019.001D
COBISS.RS-ID 7710488

INVESTIGATION OF CORRESPONDANCE CHARACTERISTICS OF CONSTRUCTION STONE FOR REHABILITATION OF ALADZA MOSQUE IN FOCA, BOSNIA AND HERZEGOVINA

Đurić Neđo[1], Đurić Dijana[2]

[1]*Technical institute Bijeljina, Bosnia & Herzegovina. e. mail: nedjo@tehnicki-institut.com*
[2] *Faculty of Civil Engineering, Subotica, University of Novi Sad, Serbia*

ABSTRACT

The Aladza Mosque in Foca was built in the middle of the seventeenth century and it was destroyed during the war in Bosnia and Herzegovina. Given that it is a monument protected by the state and included in the World Heritage by UNESCO, it is necessary to carry out its rehabilitation. It is essential to construct the religion building of the same materials, dimensions and exterior form.

Since the building was demolished in its entirety, there has been damage to some original stone fragments that the mosque was built of. Therefore, it is necessary to provide new supplies of stone matching the original.

Firstly, research were conduscted with the existing original fragments and based on them were overwied the possibilities for finding an appropriate sites of the stone in the immediate vicinity. Based on a certain mineralogical-petrologic and geomechanical characteristics of the original fragments originating from the various structural components of the mosque, six locations were selected for the investigation of possible finding sites in the immediate area. Samples that were taken underwent the same testing procedures. Obtained results indicate that samples from four sites can be used as a material for rehabilitation because their characteristics match the original fragments.

Key words: *The Aladza Mosque, original stone fragments, potential sites of materials, field research, samples of stone and rocks, laboratory testing*

INTRODUCTION

The Aladza Mosque in Foca was built during the middle of the seventeenth century and it belongs to the category of cultural heritage of Bosnia and Herzegovina which is included in the world heritage monuments of UNESCO. It characterized Ottoman architectural style, which was later reflected in the construction of newer mosques. It was built from materials that resisted time

During the war in Bosnia and Herzegovina this religious object was ruined, whereby one part of the material from which it is built was damaged, the other part disappeared, and the most was left next to the property.

Launching the reconstruction of Aladža mosque, required an overview of the real situation on the site. The object was constructed of several types of rocks with a characteristic way of foundation and construction. Previously, all kinds of original fragments - stone located at the site of the mosque were registered, after which was concluded that the piece of material that must be used in order to build a facility in an earlier form was missing. Considering the time distance from the date of construction of the object, as well as today's more modern and stronger method of construction, it was necessary to provide more significant deposits of various building materials.

Since it started from the premise that the material for an object was located some where in the close environment, researching of potential sites of rock material began. Primarily, if the material exists, then the amount of it and whether it petrographycaly matches the rock material located at the site of the demolished mosque.

OVERVIEW OF ORIGINAL FRAGMENTS - STONE ON LOCATION OF THE MOSQUE

The presence of fragments of the original structural elements, gave the opportunity to understand their characteristics from mineralogical and petrographic to physical and mechanical.

It was conducted a selection of the original samples to six (6) characteristic structural elements for laboratory mineralogical - petrographic and physico - mechanical tests [1.2.3]. The appearance of samples from the field and processed in the laboratory is given in figure 1.

Figure 1. Part of the original samples from the field and processed samples of original fragments and rocks from potential deposits for the reconstruction of Aladza mosque in Foca

Mineralogical - petrographic tests covered:

- macroscopic examination with the use of magnifying glasses, cold and diluting (1:3), hydrochloric acid and photographing
- microscopic testing on prepared petrographic preparations with the use of polarizing microscope for transmitted light type Leica DMLSP on which is a digital camera Leica DC 300 and a software program Leica IM 50, which allows the image to be displayed at the monitor as well as the photographing of the preparations.

Macroscopic tests determined the outer appearance of each rock, where are separated observations of color, structure and texture, degree of homogeneity, the presence of porosity and reaction to HCl Microscopic tests clearly defined the presence of certain minerals, their crystalline form, the presence of porosity in a certain percentage and also larger pores, possible presence of various oxides and hydroxides, which emerge in different colors [3,4,5]. Physical - mechanical tests were performed on the same samples. The test results are given in table 1.

Table 1. Mineralogical - petrographic and physical - mechanical characteristics of rocks

Code of the sample	Constructive element	Mineralogical – petrographic regulation	Bulk weight		Water absorption	Uniaxial compressive strength	
			with pores γ_v	without pores γ_s	u_v	dry codition σ_z	water saturated condition σ_z
			kN/m^3	kN/m^3	%	kN/m^2	kN/m^2
T – 1	minaret	limestone	27,77	29,20	5,02	54 777	43 949
T – 2	wall	bigar - travertine	17,80	20,05	15	5 095	3 821
T – 3	wall	bigar - travertine	17,10	20,01	17,10	5 095	3 821
T – 4	foundation	micritic organogenic limestone	34,10	34,15	0,19	80 254	76 430
T – 5	minaret	micritic limestone	25,10	26,10	7,57	30 573	28 025
T – 6	ring beam	micritic limestone	28,20	29,60	4,97	42 675	39 490

Based on field studies of samples and laboratory tests of mineralogical - petrographic and physico - mechanical characteristics of the original fragments, the types of rocks from which the mosque was built were determined. Figure 2 shows the appearance of all analyzed samples.

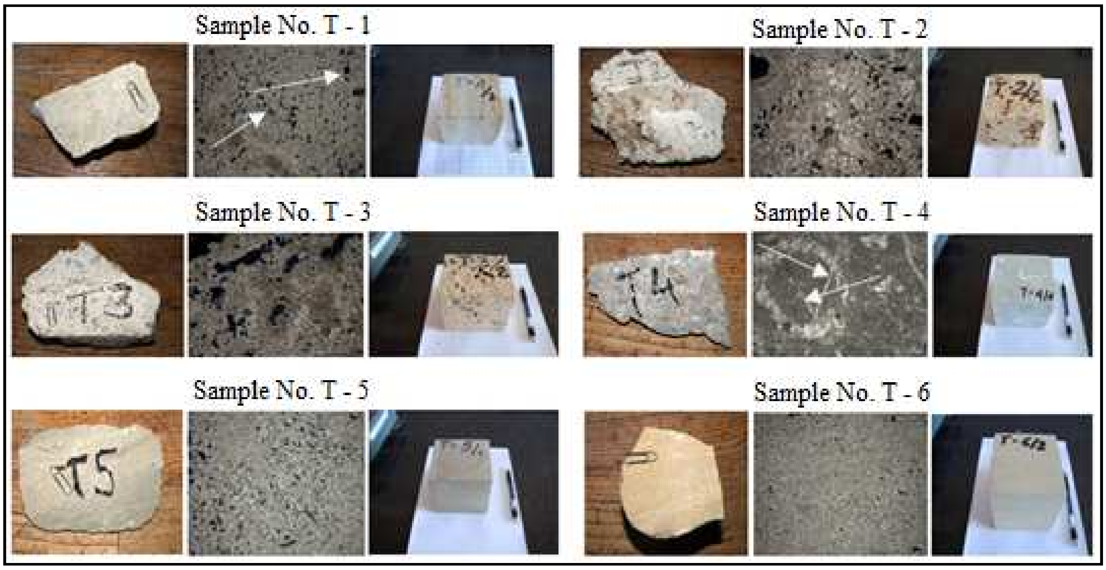

Figure 2. Analyzed samples of original fragments T – 1 to T – 6

Minaret: samples No. T – 1 and T – 5

Sample T – 1 represents the rock of ocher, crystalline structure and massive texture. Macroscopically, rock mass shows a high degree of homogeneity, constructed of grain of relatively equalized size. In the structure of the rock participates calcite which shows anisotropy, and is present in the form of crystals, which by its size is at the transition between the grains micritic and sparitic character. Finely grains of accumulation from hydroxide and oxide of iron are observed. Important place in the context of the rock occupies porosity, up to 30% are pores, shown by arrows in figure 2. According to the characteristics and mineral composition, tested rock is limestone.

Sample T – 5 is a rock of gray-ocher color, crystalline structure and massive homogenous texture, and acts homogeneously in color and size of the ingredients. Per microscopic characteristics the rocks is similar to the sample T – 1, it is made of micritic calcite of equal size and porosity, figure 2. According to the characteristics and mineral composition, tested rock is micritic limestone. Established values of physical - mechanical parameters of the sample T – 1 and T – 5, are given in table 1.

Wall: samples No. T – 2 and T – 3

Sample No. T – 2 ia a rock of light ocher color, crypto crystalline structure and porous texture. It is characterized by the presence of numerous caverns of irregular shapes and different dimensions. It is built of aggregates from crypto crystalline to micro crystalline calcite. Some of them are plate-shaped with a diameter of up to 1mm. The larger crystals clearly demonstrate pseudo polihroism traces of two types of cleavage. Rarely appears the classic component in the form of isolated grains. The porosity of the rocks is up to 45%, and pore size varies widely from submillimeter dimensions, to cavities whose length reaches 2 – 3 cm, (Figure 2). According to the characteristics and mineral composition, tested rock is bigar - travertine.

Sample No. 3. by the macroscopic characteristics of the pattern is very similar to the pattern No. T – 2. The rock is of light ocher color, crypto crystalline structure and highly porous texture. It is built from calcite, and has more prominent straps from sample T – 2 that are coming to the surface of the terrain and wrap cavities, (Figure 2). According to the characteristics and mineral composition, tested rock is bigar – sedra.

Foundation: sample No. T – 4

The rock is of gray color, crystalline structure and massive texture. In the structure participate micritic components of calcite, remains of fossils and crystalline calcite. Cracks are present that goes in two directions. In them is deposited coarse grain calcite, (Figure 2).

Rock mass still contains small dark crystals of dolomite less than 0.1 mm in diameter, then fragments of different shapes shells of microorganisms. Regulation shows that the tested rock is micritic organogenic limestone.

Ring beam: sample No. T – 6

Sample is very similar to sample No. T – 1. Rock is of ocher color, crystalline structure and massive texture, homogeneous with low observable elements of striped texture, crypto crystalline structure and porous texture, (Figure 2).

Rock base is represented with micritic component with tiny pores that are less present. Regulation and mineral composition show that tested rock is micritic limestone.

EXPLORATION OF POTENTIAL DEPOSITS OF ROCKS

On the area near Foca there are no known significant deposits of rocks from which the mosque was built. Smaller sites were not researched except durig the time of making General Geological Map of SFRJ 1:100000, sheet Foca [6], where were only registered. With detailed research were selected the following location of potential deposits of constructional and ornamental rocks around Foca, (Figure 3).

During field research all relevant data necessary for the site selection were analyzed, also the possibility of exploitation [7,8,9]. For each potential deposit samples for laboratory testing were taken, (Table 2). One sample of bigar – tufa was taken from the construction site of the Serbian Orthodox Church, and all needed tests were carried out, even thought it is originating from deposit in Kosjeric, near Uzice, Serbia. Laboratory tests were carried out in the same laboratories, as well as were original fragments. Test results of mineralogical – petrographic and physico – mechanical characteristics of rocks are shown in the table 2 .

Field studies and laboratory tests provided more detailed informations about analyzed potential sites, based on which were allocated sites that can be used for the rehabilitation of the Aladza mosque. Samples that are taken on the field and tested in the laboratory are shown in figure 4.

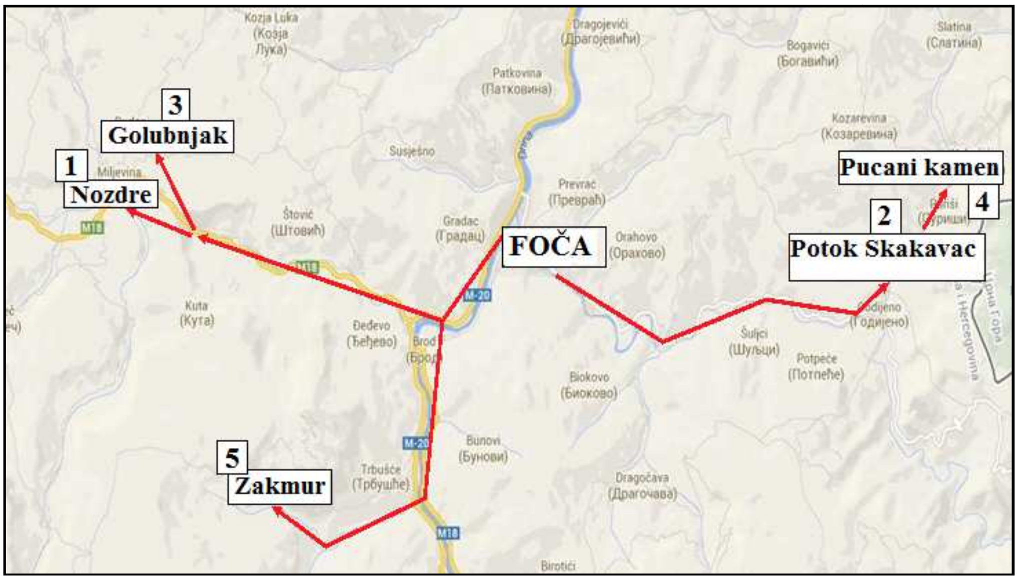

Figure 3. Locations of potential deposits of ornamental rocks. 3.1. deposit of travertine limestone Nozdra, 3.2. deposit of bigar – tufa Potok Skakavac, 3.3. deposit of of marble limestone Golubnjak, 3.4. deposit of marble dolomite Pucani kamen, 3.5. deposit of breccia limestone Zakmur

Table 2. Mileralogical – petrographic and physico – mechanical characteristics of the rocks

Code of the sample	Location of deposits	Mineralogical - petrographic ordinance	Bulk weight		Water absorption	Uniaxial compressive strength	
			with pores γ_v	without pores γ_s	u_v	dry condition σ_z	water saturated condition σ_z
			kN/m^3	kN/m^3	%	kN/m^2	kN/m^2
SK 1 1 – 3	Nozdre – Kapak – Miljevina	micritic limestone	21,90	24,10	12,50	24 203	17 834
S – 2	Potok Skakavac – Vukusic – Slatina	bigar	18,10	20,03	13,42	8 280	7 640
S – 3	Kosjerić – Užice	bigar	14,70	16,10	15,81	3 180	2 929
K – 4	Golubnjak – Miljevina	marbled limestone	33,20	33,21	0,38	69 430	63 060
MDK – 5	Pucani Kamen – Vukusic – Slatina	marbled dolomite	35,60	35,70	0,36	113 380	77 710
ZK – 6	Zakmur – Brod – Foca	breccia limestone	34,10	34,10	0,19	115 920	100 460

Deposits of micricit limestone Nozdra samples No. SK – 1 (1 – 3)

The deposit of architectural - building stone Nozdra is located nearby the area of Miljevina basin, about 2.0 km west of Miljevina, site Golubnjak D. Budanj. It covers the area of around ten (10) hectares and is located nearby the main road Sarajevo - Foca [10].

In geological terms terrain is built of banked and layered limestones of middle Miocene M_2^2 with layers of marl and shale clay. Deposit of limestones represents a small part of the limestone massif. It is Built of banked micritic limestone of gray, greywhite and yellowish color. Today is occasionally exploited and could be used for the purposes of restoring of Aladza mosque. Three samples were analyzed with average values given in the table 2.

Macroscopically observed the rock is of ocher color, crystalline structure and massive texture, permeated with tiny cracks and pores and on the surface is consumed in the form of powder, (figure

4). Observed are "circles" of different sizes of accumulation of iron oxide which are deposited from solution (black arrows). Around them appear halos of iron hydroxide of reddish color, which give a special esthetic effect because they are clearly noticeable.

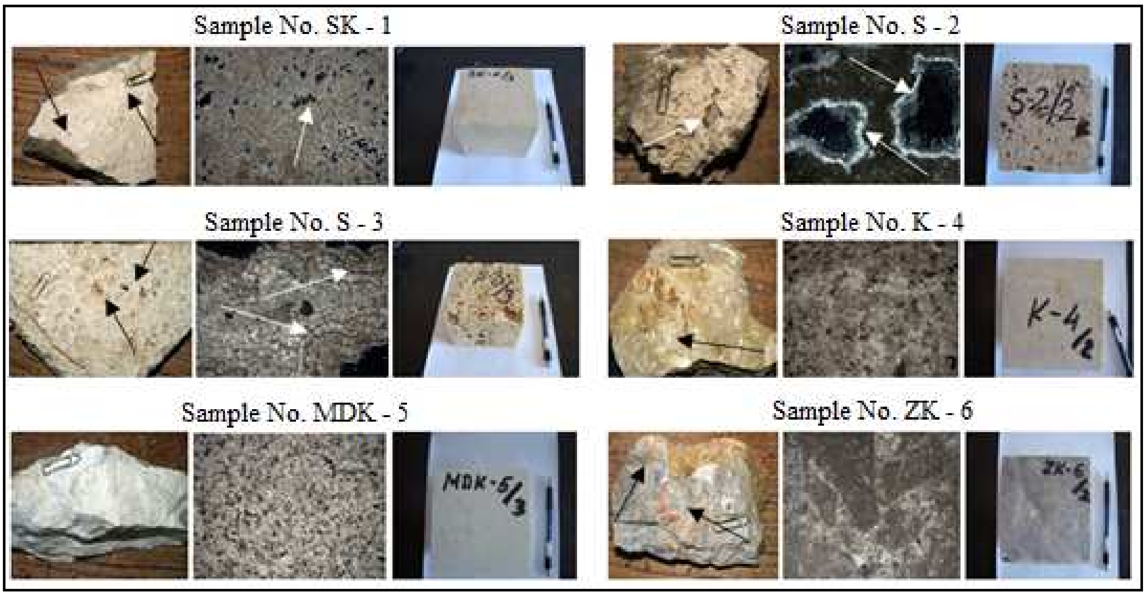

Figure 4. Analyzed samples of potential sites SK – 1 to ZK – 6

Microscopic appearance of the rock is crypto crystalline structure and porous texture, and is made of calcite micricit character, which represents a base of the rock. The rock mass is permeated with cavities usually of elongated and irregular shape of various sizes, about 0.8 mm to under 0.1 mm in length (white arrows). The amount of cavities is over 35-40% of the total volume of the rock mass. Observed macroscopically and microscopically, and according to the characteristics of the set and mineral composition the rocks is a micritic limestone.

Deposits of bigar – tufa Potok Skakavac
samples No. S – 2 (1 – 3)

The deposit of ornamental - building stone bigar - tufa is located in the area of Slatina, area of Vukusic village, about fifteen (15) kilometers east of Foca. There is an inactive marble dolomite quarry of Pucani kamen, by the road Foca – Slatina – Cajnice. Along the stream valley which descends below the Pucani kamen towards the river Slatina, in the upper stream were formed powerful layers of bigar – tufa which made two terraces. Bigar is massive, compact with karstic channels and caverns, and it belongs to Quaternary Q_1 sediments.

The rock is of ocher color, crypto crystalline structure and porous texture. The pores are irregular, of various sizes, most likely interrelated. By its macroscopic characteristics is very similar to the samples of the original fragments T – 2 and T – 3. The rock mass is made of calcite, (Figure 4).

Microscopically observed the rock structure is crypto crystalline rock, and the texture is porous (black arrows). In comparison with already described samples of bigar-tufa, the sample is characterized by the presence of the most finely grained aggregates of calcite, which form the basis of rocks. Cavities are of irregular shape and of wide variation.

The sample is different from previous samples of bigar – tufa which has a specific growth of grained crystals of calcite around the edge of cavities (white arrow). Crystallization of grained calcite along the edges of the cavities most likely occurred by the circulation of solution during diagenetic processes. According to the characteristics of the set and mineral composition, investigated rock is bigar – tufa.

Deposits of bigar – tufa Kosjeric near Uzice, Serbia
samples br. S – 3 (1 – 3)

The samples intended for laboratory tests are taken from the neighboring construction site, and the deposit is proposed as an alternative in case of impossibility of the exploitation from the deposit Potok Skakavac.

Rock is of ocher color, crypto crystalline structure and porous texture (black arrow), (Figure 4). Macroscopic characteristics are very similar to the characteristics of the samples S – 2, as well as to samples of bigar – tufa T – 2 and T – 3, used for the construction of mosque, but this specimen works a bit stronger.

Microscopically observed rock is made of calcite, and the cavities are irregular, varying in size and comprise about 35 – 40% of the total rock volume. The sample is different from previously described samples of bigar – tufa by the presence of striped texture in the rock mass between the cavities (white arrows). Color of the strips are of various shades of brown. According to the characteristics of the set and mineral composition, investigated rock is bigar - tufa.

Deposits of marble limestone Golubnjak
samples No. K – 4 (1 – 3)

Deposit of technical construction rock is located on the area of Miljevina, site Golubnjak. It covers the area around four (4) ha and is located near the main road Sarajevo – Foca. In geological terms deposit represents a small part of the limestone massif of the Middle – Upper Triassic [11,12]. It is of simple geological structure and tectonically is mostly undamaged.

The rock is of ocher color and shows a crystalline structure and massive texture. Observed are cracks and caverns which are mostly elongated in which are deposited milky white crystals of calcite (black arrows), (Figure 4). In some parts of the rocks have been developed a light grimly coating of limonitic composition.

Microscopically observed structure is coarsely crystalline, and texture is massive. It is built from calcite crystals that recrystallized, which gives the elements of granoblastic structure to the rock. Recrystallization is carried out by straight edges that sometimes made an angle of 120º which indicates metamorphic recrystallization in balanced conditions and in steady litostatic pressure. According to the characteristics of the set and mineral composition, investigated rock is marbled limestone.

Deposits of marble dolomite Pucani kamen
samples No. MDK – 5 (1 – 3)

Deposit is located in the area of Slatina, village Vukusic, about fifteen (15) km east of Foca. In the previous period deposit has been exploited. With the termination of the exploitation, the quarry was abandoned, and access was made difficult. White marbled dolomites occur in thick layers, sometimes in over 1.50 m thick and are generaly oriented with the fall towards east - southeast. They are of primary origin, ie were created in the process of sedimentation. The process of marbelisation is linked to a dynamo metamorphism. In the stratigraphic column lie over yellow dolomites and belong to Upper Triassic (T_3) deposits [13,14].

The rock is of milky white color, macro crystalline structure and massive texture (Figure 4). In some parts of the rock are developed large dolomites crystals.

Microscopically observed structure is macrocrystalline, blastic cristalline to granoblastic. Texture is massive and homogenous. It is of monomineral composition and is made of dolomite. Dolomite crystals occur in the form of idiomorfic rhombic shaped crystal that show dual tearing and are of average size of about 0.2 mm. Dolomite grains mutually coalesce whereby the edges of crystals often form an angle of about 120°. Such set indicates the equilibrium conditions during recrystallization. Rock is marbled dolomite.

Deposits of breccia limestone Zakmur
sample No. ZK – 6 (1 – 3)

Deposit of ornamental - construction rock breccia limestone Zakmur has not been exploited so far, although there is an open incision, about 30,0 m along the local road. The rock belong to the Triassic sediments, or Middle Triassic, Anisian floor (T_2^1) [15,16,17,18]. Continuous are precipitated over the Lower Triassic sediments.

Microscopically observed rock is of light gray color and crystalline structure. Inhomogeneity of the rock define the presence of deformed stylolite - cracks that are marked with reddish coating, as well as the existence of lenses filled with milky - white crystals of calcite (black arrows), (Figure 4).

Microscopically observed rock is of crypto crystalline structure and inhomogeneous texture that gives it breccia character. The base of the rock is made of micrites, remains of fossil shells and calcite disposed in stylolitic cracks. The contours of fossils are marked with a bit coarse-grained calcite. According to the characteristics of the set and mineral composition, investigated rock is breccia limestone.

ANALYSIS OF MATCHING CHARACTERISTICS OF ORIGINAL FRAGMENTS AND ROCKS OF POTENTIAL SITES – DISCUSSION

During the research two groups of rocks were analyzed, the original fragments and rocks from potential deposits in the immediate area. Field research gave a review of the original fragments at the site of the object, and based on those data, samples of rocks on the surrounding deposits were collected. On samples were carried out mineralogical - petrographic and physico – mechanical tests. Each type of original fragments or potential sites is included with three samples, and the average value is analyzed.

Comparing the characteristic of their set and composition, as well as the physical - mechanical characteristics (bulk density with and without pores, water absorption, uniaxial compressive strength in dry and water saturated state) similarities and differences between the characteristics of the original stone fragment with rocks from potential deposits of construction - architectural rocks were established, (Table 3).

For the construction of Aladza mosque were used two types of rocks: bigar – tufa, used for walls and varieties of limestone – micritic and micritic organogenic limestone for minaret, foundation and ring beam. The rocks of the potential sites are presented with bigar – tufa, limestone and dolomite.

Bigar, is a rock previously used for the walls, samples are analyzed from two sites of the rock, S – 2 and S – 3. Macroscopic characteristics of used construction stone and samples from quarries are very similar. There are no significant differences in color and texture, ie size of the cavity. Microscopic studies found on a sample of S – 2 occurrence of coarse-grained crystals of calcite on the walls of the cavity, while the sample S – 3 are characterized by the presence of microstrip texture. However, the differences are not significant, given that the mineralogical – petrographic and physical – mechanical analyzes show satisfactory correspondence. The sites are recommended for external cladding of the walls at its reconstruction.

Micricit limestone, with, or without organogenic component, is used for minaret, samples No. T – 1 and T – 5, foundation T – 4, and ring beam T – 6. The samples were compared with samples from potential sites SK – 1 and K – 4. By its macroscopic and microscopic characteristics most similar sample of previously used rocks is the sample SK – 1, which is defined as micricit limestone (Đurić et al., Djuric et al., 2015, 2016). It is a good material for the construction of the object in part of the foundation, ring beam and minaret. Sample No. K – 4, is a marbled limestone which has a different set. The ingredients are densely packed, the porosity is smaller, which can affect the behavior of the stone after installation. However, due to its physical - mechanical characteristics is good for the construction of the internal parts of the building.

Table 3. Correspondence of the characteristics of the analyzed rocks

Original fragment			Potenctial sites		
Code of the sample	Type of rock	Constructive elements	Code of the sample	Type of rock	The possibility of use
T – 2 T – 3	bigar – tufa	wall	S – 2 S – 3	bigar – tufa	wall
T – 1 T – 5	limestone, micricit limestone	minaret	SK – 1	micricit limestone	minaret, foundation, ring beam
T – 4 T – 6	micricit organogenic limestone and micricit limestone	foundation, ring beam			
			K – 4	marbled limestone	interior walls
			MDK – 5 ZK – 6	marbled dolomite, breccia limestone	–

Marbled dolomite and breccia limestone, show the largest mineralogical - petrographic differences in relation to rock that was used in the construction of the mosque. Marbled dolomite, sample No. MDK – 5 the only milky white rock of all twelve samples and at first sight stands out from the other samples. In addition, this rock is built of mineral dolomite which is slightly more resistant to atmospheric influences. Breccia limestone, sample No. ZK – 6 has several characteristics by which is separated from other samples such as emphasized stylolitic cracks, pink scum that give special tone to the color and size of micricit calcite in the basis of the rock. Due to the mentioned characteristics, these two types of rocks should not be taken into account as a potential material that could be used for the reconstruction of the mosque Aladza.

The results of field studies and laboratory tests of characteristics of the original fragments and potential sites, showed that in the immediate environment of the object for rehabilitation of the Aladza mosque, are deposits of rocks that can be used as potential sites for the replacement of damaged or lost original fragments. Deposits of bigar - tufa Potok Skakavac, micricit limestone Nozdre and marbled limestone Golubnjak were allocated. The analyzed sample of deposit of bigar – tufa Kosjeric near Uzice, Serbia, responds as a replacement to the original fragments of breccia, but this deposit is substantially far from the object.

CONCLUSION

Investigation of natural stone's matching with original fragments of previously destroyed Aladza mosque in Foca is conducted on six chosen locations in immediate proximity of the object. On taken samples were determined mineralogical-petrological and geomechanical characteristics of rocks.

Mineralogical-petrological and geomechanical investigations in laboratory showed that results to a satisfactory extent match to the materials of the original fragments, which gives the possibility for their use in planned purposes.

Conducted research on taken samples showed that material from four locations can be used for rehabilitation of object.

(Received May 2018, accepted August 2018)

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