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Chemical-Technological Characterization of Some Georgian Medieval Arch Bridge Mortars

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ABSTRACT

Medieval archaeological bridges located in the region of Adjara (Georgia) have been studied. It is shown that the mineralogic-petrographic composition of the fog is almost uniform. The carbonate part of the mortar equals is 20-25%, and the aluminosilicate part reaches 70-80%. The exception is the bridge of Varjanauli, where the carbonate part is more than 40%. It is recommended to use a high quality cigar to keep the brushes in the rehabilitation and restoration of bridges.

Introduction

The deterioration of the historical and cultural monuments is caused by natural and anthropogenic factors. Out of natural factors it's important to mention climate conditions, dangerous geodynamic phenomena, biological factors and natural disasters. Out of anthropological factors - emissions, vibrations, polluted wastewaters, construction and land works, architectural landscape changes etc. Damages to stone built monuments are mainly caused by above mentioned ecological factors and by using low quality building materials. Damages can also be caused by constructor's and architect's low qualification as well [2,3].

Early and late medieval arch bridges that are being called "Tamaris Khidebi" by locals, hold a special place in Georgian architecture [4-6]. These bridges mainly connect the banks of the mountain rivers and facilitate the movement of the locals. At the same time, they are distinguished with architecture and are perfectly intertwined with the environment.

The binding substances have an important role among construction materials [7]. These substances have a valuable feature: they can binds and, gravel or crushed stone particles as well as stone and brick building materials. They make a dense mortar-mass which gradually gets harder over time and remains strong for centuries [8-10]. The lime as a binding substance has been successfully used for tens of centuries in Georgia [11].

The lime in its original form is almost never used in construction. Mainly, they use the so called lime mortar which is a mixture of lime solution with sand and water. As a rule, they mix one share of the lime and three shares of sand. The water is added accordingly [9]. Such a mixture is used only in above the ground constructions. Other components are added to this mixture while constructing underwater.

Chemically unbounded water is evaporated during the mortar strengthening process; At the same time, under the action of carbon dioxide contained in the air, calcium hydrate gradually loses chemically bound water and, as a result, calcium carbonate - a solid limestone salt - is formed. Meanwhile, calcium hydrate interacts with sand (SiO_2) and solid salt of calcium silicate is formed [7,8].

The mortar formed as a result of obtained salts firmly links stones or bricks and forms a strong monolithic mass. These reactions (especially the formation of limestone) are very slow and last for decades. In some cases they may last for centuries [9]. The low speed of the reaction is caused by the formation of $CaCO_3$ from the outer surface, resulting in the formation of a thick crust of the mortar that prevents water evaporation as well as penetration of CO_2 from the air into the construction system.

The attempt to accelerate mortar strengthening by intensive drying is not giving us a positive result since artificial drying causes a fast evaporation of the water. As a result, the formation of calcium carbonate (limestone, $CaCO_3$) is stopped as carbon dioxide (CO_2) joins the lime only with non-aqueous solution. Because of this, the solution does not have sufficient sticking ability and hardness and does not meet the necessary requirements [9]. The firmness of lime mortar, apart from precisely mixing a certain amount of components, strongly depends on the quality of lime. The quality of lime mainly depends on precisely following the rules of limestone burning technologies which itself depends on the chemical composition and physical structure of the limestone.

The hard limestones which contain a large amount of $CaCO_3$ are difficult to burn and those with the low level of $CaCO_3$ and soft rocks are burnt more easily.

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Burning temperature range of all kinds of limes varies between 1000-11000^{0}C [10]. In addition to the quality of limestone, the impurities that accompany the ore during its removal is also very important. These are mainly clays and sand that can be melted during the burning process and be formed in vitreous crustymass. This mass is either partially dissolved in water or not dissolved at all when used in lime mortar and sharply reduces the quality of lime. Therefore, it is important to mechanically remove these impurities before using the lime.

The chemical composition of high-quality lime obtained according to all necessary requirements is as follows [10]:

$CaO \cdot MgO \cdot 2CaO \cdot SiO_2$, $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$, $12CaO \cdot 7Al_2O_3$

Before conducting the reconstruction and rehabilitation works on historical and architectural monuments, besides other factors it is important to study the construction materials including binding materials (lime mortar in our case) in order to provide the constructor with all the data regarding the mortar as a whole as well as its separate components so that the new mortar composition is as close as possible to the composition of mortar used during the construction.

The chemical and mineralogical-petrographic composition of mortar of several arch bridges (Makhuntseti, Varjanauli, Machakhela, Dandalo and Tsoniarisi) in Adjara region (Georgia) has been studied. Chemical, petrographic and X-ray diffractographic analysis methods were used for the research.

Results and Discussion

The Makhuntseti bridge is located in the village of Makhuntseti in Keda region.

Figure 1.The stone bridge in Makhuntseti.

The bridge is quite big and rests on the original mountain abutments. The bridge is constructed of torn stones on the lime mortar. On both sides of the bridge the torn stones of acingarch is used. Among these rocks there are uneven stones and mortar solution. The facing stones are vertically arranged on both sides of the bridge over the entire length [5,6].

The mineralogical-petrographic and chemical analysis of the bridge mortar showed that the mortar is composed by black and less light particles. In the black color material clasts of plagioclase porphyritic, pyroxene gabbro, trachyte and basalt are petrographically presented. Relatively light particles are lime stones.

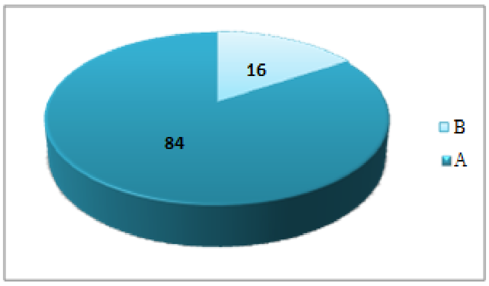

Diagram 1. A - limestone and B-aluminosilicate composition (%) of the mortars of studied Makhuntseti bridge.

Minerologically, in the form of separate grains quartz, feldspar, pyroxene, magnetite and limestone pieces can be found in the material.

The complete chemical analysis of the Makhuntseti bridge is presented in the Table 1.

Table 1. The chemical composition of the mortars of arch bridge are given in a form of oxides.

Arch Bridges	Chemical Composition (%)
Humidity	1.37
Weight loss due to heating	6.17
SiO_2	54.20
TiO_2	0.84
Al_2O_3	15.30
Fe_2O_3	5.00
FeO	1.90
CaO	9.50
MgO	3.10
Na_2O	0.70
K_2O	0.80
SO_3	0.44
CO_2	7.50

According to chemical analysis, the composition of the mortar is distinguished by a small amount of limestone in it (about 15%). Part of the CaO was found in the silicate part as well; Accordingly, the sample is distinguished with a high amount of aluminosilicate. Sample consists with a high amount of iron, titanium and magnesium. It is not of a limestone composition (by petrographic researches dolomite could not be found in the sample) but they are in the aluminosilicate.

The Varjanauli bridge is located in the Kintrishi river gorge.

Figure 2.The stone bridge in Varjanauli.

The bridge is quite large, wide and high with a semicircular shape. It is built with chisel square stone and fence stones on the mortar. The torn stones of ledge facing arch are used for the construction. The lime solution is between the stones. The facing stones are vertically arranged on both sides of the bridge over the entire length. The same arrangement follows the bridge arch near the abutments [5,6].

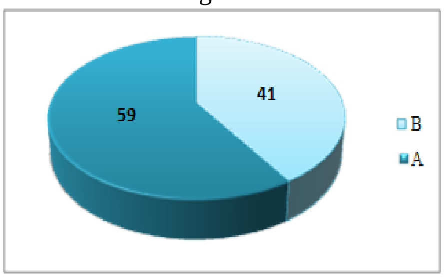

Diagram 2. A - limestone and B-aluminosilicate composition (%) of the mortars of studied Varjanauli bridge.

The chemical and mineral-petrographic research of the bridge mortar showed that the test material differs from all other research materials both with color and composition.

The mortar is mainly composed by light (brownish) clasts. Very small quantities of dark clasts can be found in it; These are plagioclase, porphyrites, trachyte (trachyte-basalt);

Apart from the limestone, pyroxene grains and a small amount of magnetite can be found in the light color masses.

Accordingly, there is a difference in chemical compositions as well.

Table 2. The chemical composition of the mortars of arch bridge are given in a form of oxides.

Arch Bridges	Chemical Composition (%)
Humidity	2.14
Weight loss due to heating	19.94
SiO_2	32.70
TiO_2	0.54
Al_2O_3	11.60
Fe_2O_3	4.17
FeO	1.87
CaO	22.80
MgO	3.24
Na_2O	0.40
K_2O	0.50
SO_3	0.10
CO_2	2.00

The calcium carbonate content of the sample reaches 41% approximately, which is almost twice as high as in other samples; Therefore, the humidity of the sample has also increased. The composition of aluminosilicate has decreased accordingly but its composition is almost unchanged. It should be noted that in this case mainly the percentage of SiO_2 is reduced and the rest of the components remain unchanged. Apart from carbonate, along with silicate, there is a crystallization water in the mineral.

The Machakhela bridge is located in Khelvachauri region in the Machakhela river gorge near the village Machakhela.

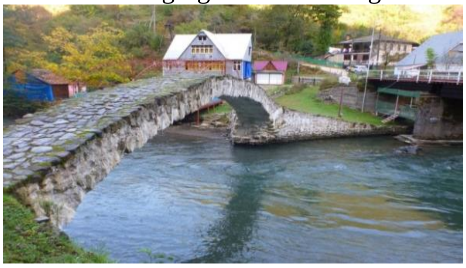

Figure 3.The stone bridge in Machakhela.

Quite a narrow, semi-circular arch bridge is constructed using fence stones and tornstones on lime mortar. On both sides of the bridge two rows of thetornstones of acingarchis used. Among these rocks there are uneven stones and lime solution. The facing stones are vertically arranged on both sides of the bridge over the entire length [5,6].

Chemical and mineralogical-petrographic analysis of the Machakhela bridge mortar showed that unlike Makhuntseti mortar, Machakhela bridge is of lighter color (greyish) and less pieces of darker colors can be found in its structure.

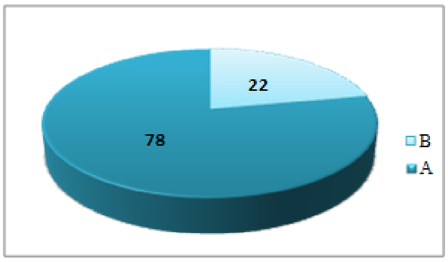

Diagram 3. A - limestone and B-aluminosilicate composition (%) of the mortars of studied Machakhela bridge.

Dark rock clasts petrographically belong to undamaged basalts, olivine basalt -diorite-porphyrites; insertions of quart zedrock clasts with jarosite and iron rust can also be found. The diorite-porphyrites is soaked with epidotes.

White clasts are carbonated. They contain grains of quartz, pyroxane, feldspar and magnetite. Chemical composition of the mortar.

Table 3. The chemical composition of the mortars of arch bridge are given in a form of oxides.

Arch Bridges	Chemical Composition (%)
Humidity	1.86
Weight loss due to heating	2.36
SiO_2	47.80
TiO_2	0.68
Al_2O_3	14.40
Fe_2O_3	4.90
FeO	2.48
CaO	12.90
MgO	3.28
Na_2O	0.80
K_2O	0.80
SO_3	0.10
CO_2	11.00

The table shows that as in case of other samples, the amount of limestone (carbonate rocks) is small but more than in the Makhuntseti Bridge mortar (about 22%); It is noteworthy that the slightest part of CaO is in silicate part as well.

The rest, like in other cases is a mixture of aluminosilicate of different composition.

Figure 4.The stone bridge in Dandalo.

Bridge is located in the village Dandalo in Keda region, in Adjaristskali river gorge, in the narrowest part of the river.

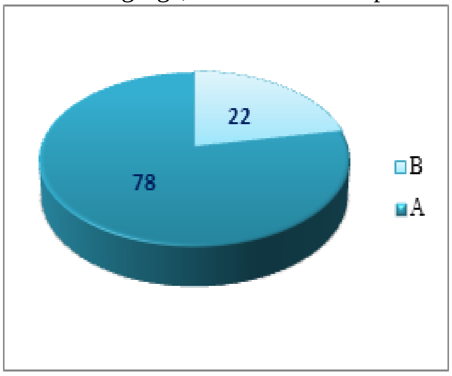

Diagram 4. A - limestone and B-aluminosilicate composition (%) of the mortars of studied Dandalo bridge.

A wide bridge is constructed on limestone mortar. The facing arch torn stone is used for the construction among which areunevenstones and lime sulfide. The facing stones are vertically arranged on each side of the bridge over the entire length [5,6].

Table 4. The chemical composition of the mortars of arch bridge are given in a form of oxides.

Arch Bridges	Chemical Composition (%)
Humidity	1.70
Weight loss due to heating	9.45
SiO_2	49.60
TiO_2	0.90
Al_2O_3	14.00
Fe_2O_3	4.94
FeO	1.36
CaO	12.40
MgO	3.20
Na_2O	0.60
K_2O	0.80
SO_3	0.40
CO_2	11.20

The mineral-petrographic and chemical analyzes of the bridge mortar showed that the material color is similar to Tsoniarisi bridge mortar material.

Figure 5.The stone bridge in Tsoniarisi.

Dark clasts consist of olivine basalt, basalt and plagioclasic porphyrites. Quartzite and limestone clasts as well as quartz pyroxene and feldspar in the form of grains can be found. Light color mortar consists of quartz, pyroxene grains and lime stones clasts.

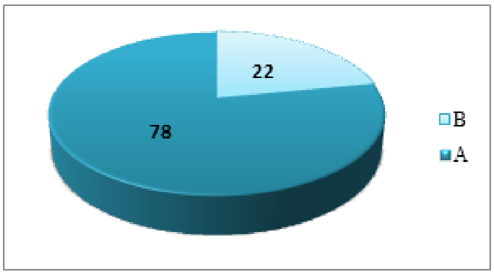

Diagram 5.A - limestone and B-aluminosilicate composition (%) of the mortars of studied Tsoniarisi bridge.

Table 5. The chemical composition of the mortars of arch bridge are given in a form of oxides.

Arch Bridges	Chemical Composition (%)
Humidity	1.60
Weight loss due to heating	9.74
SiO_2	46.70
TiO_2	0.64
Al_2O_3	16.30
Fe_2O_3	5.60
FeO	2.20
CaO	12.30
MgO	3.00
Na_2O	0.60
K_2O	0.50
SO_3	0.22
CO_2	11.10

The chemical analysis of mortar showed that in this case as well as in the previous one limestone content is~ 22%. Accordingly, the share of silicates is also significant.

Here, as in case of other bridges, content of aluminum, iron, magnesium and titanium is big. In this case as well, magnesium is a component of aluminosilicate, not of carbonates in the form of dolomite. Here, as in previous cases, sulfate ions leave at raceindicating the absence of gypsum in the mortar.

The Tsoniarisi bridge is located in the village Tsoniarisi in Keda region where the Tsoniarisi joins the Acharistskali river. The bridge collapsed in April, 2007; Only the abutments of the bridge are retained [5,6].

The mineralogical-petrographic and chemical analyzes of the abutments of the bridge show that the material is grey that is represented by plagioclasic porphyrites, basalt, diuret-porphyrites, traction and zeolite contained basalt clasts. Magnetite rocks are drawn in the main mass of the rocks.

In the light colored limestone mass, quartz and pyroxene grains can be found.

The chemical composition of the mortar is almost similar to the chemical composition of the Machakhela bridge mortar.

Here, as in case of the Machakhela bridge, the carbonate mass ($CaCO_3$) is about 22%; There was no dolomite here too. The aluminosilicates contain a large amount of magnesium. Their chemical composition is approximately the same as that of other materials studied. The content of silicon, as well as aluminum, iron, magnesium and titanium is also great here. It is noteworthy that out of all studied bridges only Tsoniarisi bridge was collapsed. This can not be explained only by discussing the quality of the mortar.

Conclusion

The conducted researches allow us to state that in almost all cases the mineralogical-petrographic composition of mortar is practically homogenous; Mainly, porphyrites, basalt, diorete-porphyrites, trachyte, olivine basalt, gabbro and carbonate particles are represented.

Accordingly, the chemical compositions of all mortars are more or less homogenous; The carbonate part reaches 20-25% while the rest is aluminosilicate. The Varjanauli bridge mortar is an exception where the carbonate share reaches 41%.

During the reconstruction and rehabilitation of each bridge, the composition of the mortar should be as close as possible to the composition of the mortar during the construction of the bridge; Therefore, it is necessary to use chemically and petrographically tested aluminosilicate part (sand) and lime.

The quality of lime is extremely important; Therefore, the technological procedures of limestone burning should be followed strictly. Furthermore, the chemical composition of lime as well as its mechanical characteristics should be studied. Only then should it be used for reconstruction or rehabilitation.

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