Original Scientific paper
UDK 620.173.25:691.31
DOI: 10.7251/afts.2019.1121033K
COBISS.RS-ID 8413208

NATURAL CRUSHED ROCK AS AGGREGATE FOR ULTRA HIGH STRENGTH CEMENT CONCRETES

Kekanović Milan[1], Đurić Neđo[1], Pištalo Sreten[1]

[1]*Faculty of Civil Engineering Subotica, University of Novi Sad, Serbia, e.mai: kekec@gf.uns.ac.rs*

ABSTRACT

Because of strong competition and new trends of concrete construction, cement industry is starting to offer cement of high class in world markets (62.5; 72.5; 82.5) with whom production of ultra hard concretes of 100 MPa up to 250 MPa of withstanding is possible. To achieve such withstanding, not only cement of high class are needed but also rock aggregates of at least 30% higher rigidity than the required rigidity of concrete. Technological solutions for this kind of concrete will be highly demanded by the cement industry, civil engineering industry and industry for the exploitation of raw mineral materials. Production of such crushed aggregates will find its use in the production of ultra high rigidity concretes and will open new surroundings.

This paper offers the overview of tests in laboratories conducted on samples of aggregates made of gabbro rock under Nero Zimbabwe's name, as an initial phase of research. In later phases it covers a larger number of above mentioned samples from various excavation sites, with a special accent on these kinds of sites in former Yugoslavia. It is expected that these premises may have reserves of rock aggregate resistant to pressures of 150 MPa to 330 MPa which would open possibilities of constructing ultra high rigidity concretes.

In addition to analyzing the required production of ultra high strength concrete, the authors consciously point out the problem of interpreting the mechanical characteristics of the material. The technical profession does not consider the physical state of the investigated materials, where the compressive strength of concrete is in the form of relative strength. From the aspect of legal sciences, the concept of relative at the construction of large and small objects can cause legal consequences for the constructor and its profession.

Key words: *concretes, ultra, rigidity, cement, rock, aggregate, construction*

INTRODUCTION

Concrete is the basic material for the construction of objects in the world today. After water, in the world concrete is mostly produced. In large cities that have millions of inhabitants, objects of several hundred meters are built, figure 1. The reason for that is the lack of construction sites and infrastructural objects. High objects are extremely expensive and demand concrete of ultra high strength, over 100 MPa.

Price of construction of such objects is very high and time of exploitation considers hundreds of years [1,2]. Concretes, in order to have strength on pressure more than 100 Mpa have to be extremely compact, with low absorbency and high resistance and durability. In the region of ex Yugoslavia there are no large cities and the need for construction of high buildings does not exist. Here, however, exist the need for construction of other large objects such as bridges and viaducts because of the presence of rivers, mountain valleys and islands on the sea, figure 2.

Figure 1 Buildings that are become a trend and need in cities with millions of inhabitants

Figure 2 Large concrete arch bridge near the island Krk in Croatia
whose lifetime should be several hundred of years

In our region exist large hydro technical objects like hydro power plant dams whose construction is extremely expensive and demanding, figure 3. These objects have to have high level of security and durability because any endangerment of stability can have catastrophic consequences for people and material goods in the downstream part.

Figure 3 Hydro power plant on the river Drina

Concretes so far with the strength of several tens of megapascales (MPa) are no longer reliable enough as far as resistance and durability. Because of that exists a justified need for introduction of concrete of ultra high strength into production and on the market at the construction of capital and expensive objects. Authors of this work predict that there are also other reasons that in the near future could have an effect on the use of such concretes and on other objects and those are aggressive chemical environment and corrosion that can impact regular concrete. The most common form of concrete corrosion is carbonation [1]. Today huge amount of funds are used on sanation of concrete objects, all around the world. In particular, this form of corrosion has been present lately as the level of harmful emissions of CO_2increases. Carbonation is a process where CO_2 from air enters into concrete and has a chemical reaction with lime $Ca(OH)_2$ whereby are formed limestone $CaCO_3$ and water H_2O.

$$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O \quad \text{.................} \ (1)$$

This process is harmful because on that way concrete loses lime $Ca(OH)_2$. It means that pH decreases and becomes less than 12. On that way are created conditions for corrosion of armature in concrete and development of microorganisms and fungi that degrade concrete. Authors believe and prove that with this work the process of carbonation would be slowed by larger compactness and „containment”. The best indicators of concrete containment are its volume mass and water absorption size that should be less than 4,5%. On that way approach to the air and change of the air are prevented and with that also the processes carbonation. Carbonation of ordinary, one year old, concrete can be seen on the surface of sample of 10x10 cm, figure 4.

Figure 4 Measured process of carbonation in the size to 5mm
at ordinary, one year old, concrete

Depth of layer that is affected by carbonation is to 5 mm. That presents big value that increases every year with the tendency of introducing armature steel in corrosion processes that can lead to degradation of concrete.

NEW GENERATION CONCRETES – CONCRETES OF ULTRA HIGH STRENGTH

In introduction are clearly listed the reasons for introducing the new generation of concrete with ultra high strength on pressure over 100 MPa and low water absorption, less then 4,5%. In order to be able to make that concrete it is necessary to have cement of the lowest class 52,5 with addition of micro silice in the phase of milling of cement clinker. It is better to have cement of classes 62,5; 72,5 or 82,5. Lately the cement industry has been intensively engaged not only in cement but also in concretes. Competition to cement industry is Chemical industry of construction materials that for years markets additives for concretes and mortars. Certain additives besides improvement of concretes characteristics, also include reducing the amount of water and cement mass with the same or better application and higher strength of concrete, figure 5, [2,3]. The best examples are super plasticizers and lately hyper plasticizers, for concrete application. Cement industry has to protect its product and the cement market and it starts to produce cements of higher classes and better performances by itself. Its is also ready to produce and to add certain additives into cement. However, for new generation concrete of ultra high strength, quality cement of high class is not enough, but is necessary to have the aggregate of high strength and resistance [4].

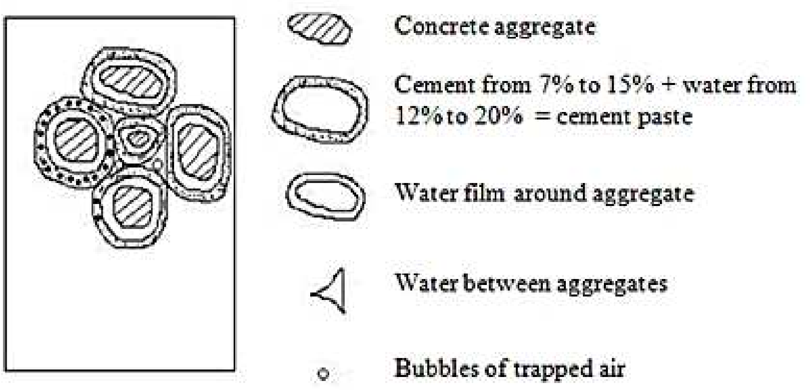

Figure 5 Volume mass of participation of certain components in the concrete

COMPONENTS FOR NEW GENERATION CONCRETES OF ULTRA HIGH STRENGTH

Aggregate is by volume mostly present in concrete and it is about 60 to 80 percentages. If the concrete of high strength is needed, then aggregate have to have at least 30% higher strength than the concrete itself. Sometimes i is very difficult to find that kind of aggregate even for experimental research. To produce concretes of 100 MPa to 250 MPa, it is necessary to have aggregates of compression strength from 150 MPa to 330 MPa [4,5]. It is necessary to conduct detail research on locations where exist sites of eruptive rock of high strength [6]. Within research it is necessary to conduct laboratory tastings on samples of crushed rock, that would include physical – mechanical and chemical - mineralogical characteristics:

- volume weight
- specific weight
- water absorption
- low temperature resistance
- compressive strength
- tensile strength in bending
- abrasion resistance
- chemical-mineralogical composition

Natural rock as aggregate for concretes of ultra high strength must be crushed, with small absorption of 0,5% (1%), without weak grains and with the ability to establish good adhesion with cement stone. Adsorption must be reduced due to higher resistance to low temperatures and lesser concrete shrinkage [7,8]. Authors of this paper consider that adsorption would be optimal for 0,5 % (minimal 0,25 %) due to the possibility of achieving adequate adhesion between aggregate and cement rock. The granulometric curve must be optimal with good "packing" of the aggregate grain, figure 5. The granulometric curve must not contain large aggregate grains which may be the site of stress concentration, slika 6, where the first micro-cracks may appear which extend into the cracks until fracture and total destruction of the concrete. The largest aggregate grain should not be larger than 11,2 mm (8 mm). The method of grinding aggregates by crushing should be controlled in such way that elongated grains do not occur which due to their geometry would not be suitable and they are not allowed by standard for production of concrete. Elongated grains can have micro – cracks that have emerged in the course of crushing. These micro-cracks in the aggregate develop during the loading of concrete into cracks that can cause the destruction of concrete at lower stresses than projected.

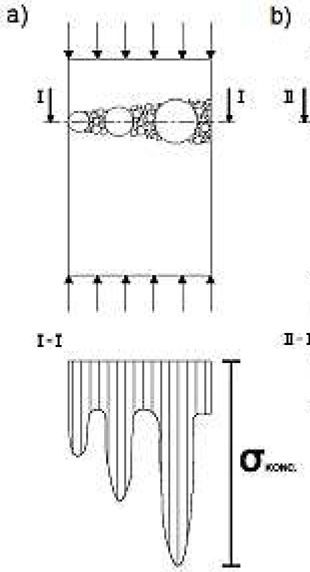

Figure 6 Macrostructure of concrete and state of stress in a given cross section for the case of:
a) classic concrete with large grains and b) concrete with small grains

Granulometric curves of ultra high strength concrete should not contain smaller particles of aggregate of size less than 0,1 mm. Meaning, at new generation concrete with ultra high strength, it is necessary to doze higher amounts of cement from 400 to 800 kg/m^3. On that way there is enough cement for the wrapping of all aggregates and for fulfilling of the smallest cavities between aggregate grains. If too small particles of aggregate, < 0,1 mm, are present increases unnecessarily specific surface of the aggregate that the cement film has to wrap. Accordingly, if the smallest particles of aggregate are dispensed, concentration of cement could be reduced to optimal from 400 to 550 kg/m^3 with which it could get concretes of good compactness and high strength from 100 to 170 MPa. Strengths of new generation concrete depend not only from the amount of cement but also from its class. For certain strength of the concrete with higher class of cement could be used a smallest amount for the same ratio of water mass and cement mass m_v/m_c.

New generation concretes have to have good embeddedness and high volume mass that is a guarantee of compactness and high strength. This can be achieved with as little water cement factor as possible m_v/m_c which should range in size from 0,23 to 0,3. These values tell us that we have extremely small mass of water with which we must obtain good embeddedness with the help of super plasticizers and hyper plasticizers. Small amount of water means that the concrete would not have a lot of capillaries and the ability of large capillary absorption of water. Absorption of new generation concretes that was conducted by the authors of this paper is from 3,05 to 4,33% . Concrete like that is completely closed not only for water but also for air, or CO_2. From this it is logical to conclude that the processes of carbonation in such concrete is not possible or is very slow.

Application of super plasticizers and hyper plasticizers is mandatory for concretes of new generation of ultra high strength due to maximal reduction of water. Author[1] offers new technology of mixing concrete with the help of hyper plasticizers that will be processed with patent where it is possible to reduce the water to the level of water cement factor m_v/m_c = 0,25 (0,23). It is interesting that with this water cement factor obtains plastic consistency with extra good embeddedness and workability of concrete with pores that are smaller than 0,5%.

PRACTICAL RESEARCH OF NEW GENERATION CONCRETE WITH ULTRA HIGH STRENGTH

Research was conducted on Faculty of Civil Engineering in Subotica in the first part of the year 2013. Aggregate for test laboratory production of new generation concrete was done from natural rock of African gabbro under the name Nero Zimbabve which has high strength on pressure that is 286 MPa, figure 7. The measured water absorption of this aggregate is 0,25 %. Volume mass is 2950 kg/m^3.

Figure 7. Concrete sample M15 and rock Gabbro under the name Nero Zimbabwe
From which was made aggregate for concrete

Cement that was used is of class 62,5 that is obtained by experimental way and is not on the market. Water cement factor as ratio of participation of water mass in relation to cement mass is m_c/m_v = 0,28. In the process of making of this concrete was used super plasticizer with participation 0,5 % in relation to cement mass.

New generation concrete recipe:

- Cement + micro silica (m_c), class 62,5
- Water (m_v) with ratio of masses m_v/m_c =0,28
- Super plasticizer 0,5% x m_c
- Aggregate Nero Zimbabwe (Gabbro):
  - 0,1 – 2,0 mm (29,64%)
  - 2,0 – 4,0 mm (8,34%)
  - 4,0 – 8,0 mm (25,98%)
  - 8,0 – 11,2 mm (32,98%)

After the embedment the average mass of fresh concrete was measured, that was $m_{b,sv}$ = 2665 kg/m^3.

The measured compressive strength after twenty eight days is 142 MPa, table 1. To cement was added 6% of micro silice (pepo sa SiO_2) which has a large developed specific surface area S > 20 000 cm^2/g. Micro silica enters into a chemical reaction with $Ca(OH)_2$ which is one of the products of cement hydration. These reactions are intense even after twenty eight days, which can be seen by the increase in strength on the fifty sixth day when this concrete has strength of 153 MPa.

Table 1 Results of measurement of tensile strengths in bending/compressive strength

Tensile strengths in bending/compressive strength MPa							
	1 day	2 day	7 day	28 day	56 day	90 day	180 day
	t.str.bend/ com.str	t.str.bend/ com.str.	t.str.bend/ com.str.	t.str.bend/ com.str.	t.str.bend/ com.str.	t.str.bend/ com.str.	t.str.bend/ com.str.
M15	10,1 /80,9	12,3/88,5	14,2/115	15,2/142	16,2/153	-	-

On figure 8 is seen that the investigation was conducted on small samples 4x4x16 cm. Such small test bodies were chosen for simple reason because laboratory press can produce the force up to 2000 kN that is not sufficient to determine the strength on trial bodies 15x15x15 cm.

Figure 8 Investigation of comprehensive strenght at concretes of ultra high strenght on sample M15

Today the most common presses are with maximal force of 3000 kN. If test bodies would have the size of 15x15x15 cm those presses could not be used for concretes that have the strength stronger than 135 MPa. Choice of smaller test bodies is possible because fractions of aggregates are smaller (to 8 mm) so it satisfies the condition that the size of the largest aggregate grain must be at least four times smaller than the thinnest part of the test body. So, existing presses with forces from 2000 kN to 3000 kN will satisfy new generations for concrete investigations with ultra high strength with the condition that they are used for smaller test bodies, prisms 4x4x16 cm or a bit larger test bodies 10x10x10 cm. If test bodies are used so the bigger prism 10x10x40 cm cuts them to 10x10x10 cm, it is necesery to take care that the load is not deposited over the cut surface. That surface is not flat enough, so it can cause concentration of stress that breaks concrete before time. Load does not always have to be deposited on the opposite surfaces that were in the mold.

When testing materials and determining the compressive strength, the test body is usually a cube with dimensions of 20cmx20cmx20 cm. The compressive strength of any other shape of the test body, that is, a larger or smaller cube relative to the above, is calculated on the strength of the standard cube body of 20cm x 20cm x 20cm [9,10,11]. According to the interpretation of official standards and literature [9,10,11], the same material exhibits higher compressive strengths, the smaller the cube sample is. This, on one hand, can lead to the conclusion that the compressive strength of the material is the relative strength. On the other hand, the question may be asked whether the shape of the body should be different if the compressive strength is determined. The technical profession dealing with the resistance of materials, mechanics and fracture mechanics may not be sufficiently aware of the physical states of behavior of the materials that can affect the compressive strength. Also, the materials are different and have different values of individual strengths, above all the compressive strength and tensile strength on bending. Authors think that relation of tensile strength and compressive strength, at the same material can have an effect on the shape of test body for investigation. In that case, if accurate, compressive strength, at smaller volumes of investigated samples of material and larger volumes of investigated samples of material would have to be similar or the same. Then it could not be concluded that the compressive strength of the material is relative strength. Considering the aforementioned issues from the aspect of legal sciences, the technical profession must urgently determine the actual physical condition of the material, because, technically and legally speaking, the strength of the material cannot be relative strength. The materials are used for the construction of very large and very expensive buildings where people live. Some large constructions are used for crossing and transport of the people. The legal profession states that there must be regulations and rules for the exact examination of material and the determination of its characteristics, as otherwise penal laws could be applied [12,13]. The construction of buildings, large and small, does not suffer from the notion that the conditions in the building and the strength of the materials used may be relative. Human lives and material assets must be taken care of and preserved in all possible conditions, normal and extraordinary, in the event of an earthquake or storm outbursts. The possible occurrence of life threatening consequences or threats is also a basis for criminal liability [13], since the said actions acquire elements of criminal offenses prescribed by the Criminal Code.

Listed very high strengths in table 1 are obtained on small samples of investigated material. This does not mean that the same strengths will not be obtained on larger samples and larger volumes of material, but it is unknown at this time what a universal test body, larger or smaller volumes, should look like. In other words, it is very realistically possible that today by official standards and literature [9,10,11] we do not properly test and determine the compressive strength, especially for concrete as a building material. The economic and legal aspects require that the technical profession must investigate these issues in more detail in order to build economically rational and secure, without legal consequences [12,13].

These new materials with ultra high compressive strength in concrete, allow the construction of much larger and much more expensive objects, and therefore legal laws and regulations [10,11,12,13] should be more accurate and rigorous than for the construction of smaller objects. Large and small objects must be built economically rational, despite the rigorous legal requirements of construction of large objects.

Measured volume mass of concrete in fresh state of 2665 kg/m^3 shows us, in relation to projected volume mass of fresh concrete, that maximally good embeddedness is achieved where the quantity of pulled air is smallest than 1%. Measured water absorption of hardened concrete after twenty eight days is u = 4,35%, figure 9. Water absorption in ordinary concrete is of high quality of 5 to 6% and goes even up to 7% at ordinary concretes of weaker quality.

Figure 9 Measuring of water absorption on concrete of ultra high strenght, sample M 15

The size of the layer that captured the carbonation process on a one-year-old concrete sample was measured. On sample can be seen that the process of carbonation did not affect the concrete of new generation, figure 10, which is a clear proof that these concretes are „closed” considering air entrance. This could be of particular importance to the global concrete construction industry in terms of solving the carbonation problem.

Figure 10 The carbonation process on new generation concrete after one year is not visible

Wear resistance was also measured at new generation concrete, figure 11. It can be seen the trace of worn out part due to wearing (valued as I class) and it is for 40% narrower for ultra high strength concrete (right sample) in relation to trace due to wearing (valued as II class) of sample of ordinary concrete (left sample). Practically, wearing of ultra high strength concrete is only present on cement rock with the finest aggregate grains. This is further evidence of the exceptional strength of this concrete, which has hardness at the level of hardness required for resistant special concrete of industrial floors.

Figure 11 Resistance to wearing of ordinary concrete – left sample and
new generation concrete of ultra high strength – right sample

CONCLUSION

In paper are presented results of the research of concrete of ultra high strength from the aspect of cement as binder, hyper plasticizers as additives for embeddedness and processing, amount of water and crushed aggregate of high physical mechanical performances. All listed components were conditioned so it could produce concrete of new generation with strength higher than 100 MPa in ordinary construction conditions, without special equipment and machines.

Concretes of new generation of ultra high strength are becoming the need in order to construct high buildings from several hundreds of meters in cities that have millions of inhabitants. Other large and expensive objects such as bridges and dams of hydro power plants demand quality of concrete that guaranties also high resilience and durability, of several hundred years.

Authors of this paper consider that new generation concretes of ultra high strength will have to be used also for other types of objects built of concrete due to greater danger of chemical corrosion. Harmful emissions of CO_2 causes also chemical corrosion of concrete known as carbonation that creates conditions for the process of corrosion of armature steel and degradation of concrete. Cement industry is capable to create new cement and additives for such super concretes of new generation. Aim of this paper is to initiate possibilities of using concrete of new generation of ultra high strength in our area, considering that exist significant sites of quality natural crushed aggregates of high physical mechanical performances.

In addition to analyzing the need for the production of ultra high strength concrete, the authors consciously point out the problem of interpreting the mechanical properties of materials, where the technical profession does not fully consider the physical states of the investigates materials. This fact points to the conclusion that the material strength on pressure may be relative. From the stand point of technical and legal doctrine, the concept of relative in the construction of large and small objects, can cause legal consequences [12,13] for constructor and their profession.

(Received September 2019, accepted september 2019)

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