AGGREGATE AS A COMPONENT IN THE PROCESS OF CONCRETE MAKING

Zlatica Kuliš[1], Dževad Avdić[1]
[1]Internacionalni univerzitet Travnik u Travniku

Review Article
https://doi.org/10.58952/nit20231101088

Abstract

By modern design of the concrete system, proper selection of cement and aggregates with appropriate additives as well as other concrete production procedures, satisfactory properties of the finished concrete mass can be achieved. When making concrete, aggregate makes up approximately three-quarters of its volume, which has a great influence on the properties of fresh and hardened concrete. Due to its significantly greater stiffness than that of cement stone, large aggregate grains form the basis of concrete through which forces are transmitted. Small aggregate grains together with cement paste make up the mortar. Although the role of coarse grains and sand in fresh and hardened concrete is different, they are observed together in all tests. The choice of aggregate depends on several factors, where we would especially emphasize its availability. Its characteristics such as: plasticity, workability, strength, density, durability, permeability, texture and color largely depend on the type and quality of the aggregate used in the process of making concrete. It is available to everyone because it is actually a composite material whose basic ingredients are aggregate, cement, water and other necessary additives. This paper will deal with the division of aggregates as well as the most frequently investigated properties of aggregates.

Keywords: *concrete, aggregate, components, properties, tests*

This work is licensed under a Creative Commons Attribution 4.0

1 INTRODUCTION

Concrete is an indispensable material in all forms of construction today, favorable for the construction of both simpler and more complex buildings. According to its consumption (from a material point of view), it ranks first after water, because between 21 and 31 billion tons of concrete are used annually for various types of construction. The main reason for the widespread use of concrete in today's modern world is the easy availability of loose materials, which are relatively cheap compared to other materials with similar properties. It is available to everyone because it is actually a composite material whose basic ingredients are aggregate, cement, water and other necessary additives. 65-75% of the volume of concrete consists of rock grains, while the amount of cement in 1 m^3 of concrete is 200 to 400 kg, depending on the requirements of the concrete. By mixing cement and water, a paste is obtained, while in the further course of the process, the cement stone binds to the aggregate grains, with the action of the air created during the mixing of concrete.

Harmful components of aggregates are reflected in:

1. Enveloped grains - sometimes there are healthy grains in the aggregate that are enveloped by a thin layer of clay, mud or fine particles that are weakly or insufficiently bound to the grain by carbonates and oxides. This grain composition prevents contact between the paste and the healthy material of the grain, and the bond between the grain and the cement stone is determined by the quality of the weaker coating of the material.
2. Soft, friable and weak grains - there are often grains in the aggregate that disintegrate or become friable under the influence of water. Such materials are found in lumps of clay, marls, coal shale and certain types of plant particles. However, one should bear in mind the fact that decomposed and worn grains have little or no strength, which is why they appear in the form of voids in the volume of concrete itself.
3. Organic admixtures - What makes concrete porous are certain organic substances that create air bubbles due to their properties. For example, hummus acid has a detrimental effect on the hydration of cement, while sugar slows down or completely prevents the binding of substances, and fats and oils weaken the bond between cement stone and aggregate. All of the above can be partially removed by washing aggregates in specialized facilities. If it is a dry aggregate, small particles can be removed by air flow.

2 DIVISION OF AGGREGATES

The basic division of aggregates is into natural, artificial and special aggregates. According to the rock type, the aggregates can be of volcanic, sedimentary and metamorphic origin. In the case of natural aggregates, all three types are most often represented, and in the case of crushed aggregate, it is usually crushed rock in terms of mineral composition.

Sand, gravel and crushed stone are naturally unbound rocks that were formed by the natural decomposition and pulverization of the rock mass, with the fact that the sand and gravel were rounded due to friction during movement, while the crushed stone on the other hand consists of irregularly shaped pieces with sharp edges created by the decay of rocks which did not move after that process. Gravel and sand are most often found in riverbeds. The difference between them is that gravel is more heterogeneous than sand and has larger grains, from 4mm to 125mm. The sand has a slightly more homogeneous composition, i.e. the grains are approximately the same and are mostly up to 4 mm in size.

Artificial aggregates are created by crushing and grinding rocks such as: granite, porphyry, quartz, limestone, etc., and they can also be obtained by crushing sand, gravel or crushed stone. Crushed stone is most often used to make roadbeds or curtains on railway tracks and is most often called breakstone. Breakstone must be obtained from rock mass with satisfactory strength and wear resistance.

Among the most famous special types of aggregates are light aggregates (naturally light and artificially light aggregates), heavy aggregates, recycled aggregates. Light aggregates are aggregates of cellular or microporous microstructure with a density of less than 1200 kg/m^3. These include alumina (expanded and baked clay), fly ash aggregate, slag, EPS expanded polystyrene, vermiculite, perlite, crushed brick. Combustion slag and fly ash are special aggregates that are a direct by-product of industrial processes. The most common application of heavy aggregates is in the process of making concrete with a density of 2900-6100 kg/m^3. Examples of the above are, for example, barite, magnetite, hematite and the similarly. And finally, recycled aggregate as a special type is an aggregate that consists of crushed and sorted particles obtained from materials that have already been used in construction and constructions, and is increasingly used in making concrete.

3 PRODUCTION OF AGGREGATES FOR CONCRETE

Aggregate for concrete is obtained by fractionation of natural aggregate or by stone crushing and fractionation. The most important parts of the plant are the stone crusher and the separation unit for aggregate fractionation. This process is most often done with washing. If it is a dry process, then instead of a water separator there is another silo for the 0-4 mm fraction. The crushing process itself begins in the primary crusher where large pieces of stone are crushed to the size that corresponds to the next level of crushing. Partially crushed material is further crushed in an impact crusher to the second level of comminution, and this is called a secondary crusher. Fractionation of aggregates is done by sieving on vibrating sieves.

Crushed material can be successfully sieved on vibrating sieves only if it is in a dry state. If the stone material is wet, it is sifted only with the use of a sufficient amount of water, which constantly washes the mesh and pushes the grains through the openings. During washing, water collects under the net with the smallest openings, 4 mm, which is located at the lowest point. The other fractions are separated from the water and partially drained already on a sieve, which is done in a water separator. Large particles sink to the bottom, and the spiral device (auger) pulls them towards the upper end, pulls them out of the water and pushes them out of the separator. The water goes into the overflow and takes small particles with it.

4 PROPERTIES AND TESTING OF AGGREGATES

For the production of concrete, only aggregates that have certified quality documentation may be used. This is done by authorized institutions for issuing certificates on the quality of concrete aggregates at the place of production. Sampling of each aggregate fraction is done at least once a month for a period of 6 months. The tested properties of aggregates are: water absorption, volume mass in loose and compacted state, compressive strength, mineralogical petrographic composition, ingredients that prevent cement hydration, volume mass of grains, frost resistance after 5 cycles in saturated Na2SO4 solution, sulfur content expressed as SO3 , chloride content expressed as CI, content of organic substances, volume coefficient of grain shape, content of clay lumps, content of friable grains, covering of grain surface with loosely bound particles, resistance against crushing, small particles. In this paper, the most frequently investigated properties of aggregates will be discussed.

According to our Rulebook on technical regulations for construction products that are installed in concrete structures (Official Gazette of FBiH 86/2008), the technical properties and other requirements for aggregates for use in concrete are prescribed, as well as the method of confirming the compliance of aggregates depending on the type of aggregates, according to norms : BAS EN 12620:2004 Aggregates for concrete (EN 12620:2002) and BAS EN 13055-1:2006 Light aggregates - Part 1. : Light aggregates for concrete, mortar and grout (EN 13055-1:2002), in in accordance with the provisions of the Ordinance on Certification. Here we mean aggregate and fillers with a grain density greater than 2000 kg/m3 and light aggregate and light fillers with a grain density not greater than 2000 kg/m3 or a bulk density not greater than 1200 kg/m3 obtained by processing natural, industrially produced or recycled materials and a mixture of these aggregates in plants for the production of aggregates.

Table 1: Minimum frequency of testing the general characteristics of aggregates for concrete

Property	Remark	Method examinations	Minimum frequency
Granulometric composition	–	BAS EN 933-1 i BAS EN 933-10	1 x per month or 1 in 2 months (depending on production)
The grain shape of the coarse aggregate	– gravel – crushed	BAS EN 933-4	1 in 6 months 2 in 6 months
Content of small particles	–	BAS EN 933-1	1 x per month or 1 in 2 months (depending on production)
Quality of fine particles	– sand equivalent SE – methylene blue test	BAS EN 933-8 BAS EN 933-9	1 x per month or 1 in 2 months (depending on production)
Bulk density, grain density and water absorption	–	BAS EN 1097-3 BAS EN 1097-6 BAS EN 1097 - 6/AC:2004	1 x a year
Petrographic description	–	BAS EN 932-3	1 in 2 years

Table D.2: Minimum frequency of testing the characteristics of aggregates for concrete essential for the final purpose

Property	Remark	Method examinations	Minimum frequency
Resistance to crushing	–	BAS EN 1097-2	2 times a year
Abrasion resistance	Only for aggregates exposed to abrasion	BAS EN 1097- 8, Addition A	1 x a year

Resistance to freezing and defrosting	–	BAS EN 1367-1	1 x a year
Chloride content	–	EN 1744-1, t. 7	1 x a year

4.1 GRANULOMETRIC COMPOSITION AND MAXIMUM GRAIN OF AGGREGATE

Granulometric composition of concrete is the composition of aggregates by grain size, expressed through data obtained by sifting particles through sieves of different types. This composition of concrete is expressed in a tabular representation or diagram, that is, in the granulometric curve of the aggregate. It is important to point out that each aggregate does not have a granulometric composition that would be favorable for making concrete. In addition to this, an aggregate that is composed of grains of different sizes is much more prone to segregation. In order to avoid this threatening problem, the aggregate must be separated into several parts according to grain size. Accordingly, a fraction is the part of the aggregate that contains grains of certain sizes. The limits of separation, or fractionation, are chosen so that one fraction contains only as many different grain sizes, which reduces the segregation of individual fractions to an acceptable level. Generally speaking, smaller fractions are less prone to segregation, and the boundaries of separation in that area are also wider. The number of fractions depends on the maximum aggregate grain. Fraction separation limits are called the lower and upper nominal size of the fraction. The upper nominal size of the largest fraction in concrete represents the maximum aggregate grain. So, for this limit, it is necessary to determine the mass of the aggregate that passed through each sieve, and it is then expressed as a percentage of the total mass of the cause. The resulting data is called a pass. The sieves through which the particles pass are made of a special mesh or perforated sheet with square openings, and the size of the sieve openings is determined by the side of the square. In contrast, the diameter of the wire of the net and the dimension of the sheet are prescribed by special standards. A standard series of sieves with the following openings in millimeters 0.063 0.125 0.25 0.5 1 2 4 8 16 31.5 63 125 is used for aggregate testing. In all calculations for the last sieves in the series, values of 32, 64 and 128 mm are taken.

This principle originated from the works of American researchers Fuller and Thompson, which were published in 1907. Based on the results of the works, the Fuller curve, i.e. the continuous line in the sieving diagram, was constructed. In these analyses, Fuller also provided data for three types of aggregates, namely sand and gravel, sand and crushed stone, and only crushed aggregate. These 3 lines have only minor differences. Therefore, in this line, which is elliptical at the beginning and then extends tangentially, the law is expressed according to which a good concrete mixture must contain all aggregate fractions, from zero to grains of maximum coarseness. The objection to Fuller's line is that it contains cement grains in addition to aggregates, and since the amount of cement in concrete can vary considerably, a corresponding line of aggregates is constructed for each possible amount of cement. In addition to this, this line is criticized for being too strict a criterion established in construction practice.

The established practice of our system has taken the middle ground, which is that the composition of the aggregate lies in the area between the Fuller curve and the curve called EMPA (Eidgenössisches Materialprüfungsamt, Institute for Materials Testing at the Technical

University of Zurich). Nevertheless, preference is given to the EMPA curve, because if you want to achieve the strongest possible concrete, its composition must be as close as possible to the EMPA curve. In contrast to the above, if one wants to achieve the most perfect incorporation of concrete, in order to overcome the difficulties with dense reinforcement, a line as close as possible to Fuller's is recommended. Changing the diagram is directly related to changing the maximum grain. We will get the corresponding diagram by drawing it in such a way that the values on the abscissa of the axis are entered in the form of logarithmic scales, because of the small fractions that represent a really big problem in the technology of good concrete.

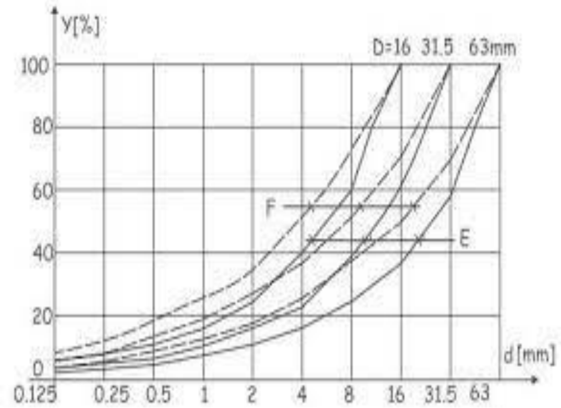

Fig. 1. Fuller and EMPA line

The issue of discontinuous granulation of mortar was much discussed by Feret, who proved through numerous experiments that the maximum compactness of mortar with sand of grain size up to 5 mm is achieved by mixing 38% of fine grains of fraction 0/0.5 and 62% of larger sand grains of fraction 2/5. Bolomey generalized this rule for the entire aggregate, so according to it, the best discontinuous granulation is the one that contains 38% of grains from zero to 0.1 D and 62% of grains from 0.4 D to 1.0 D (D is the diameter of the maximum grains). The basic rule regarding the size of the maximum aggregate grain is that reinforced concrete with an averagely dense reinforcement should not exceed the grain size of 25-30 mm, and in the case of very dense reinforcement or very thin structural elements, this diameter should only be reduced. It is recommended to use coarse aggregate in concrete, which is massively incorporated into large foundations and walls of a similar character. The benefit of coarse aggregate is greater for elements stressed in compression compared to elements stressed in bending. The average grain size for most concrete works is 20 mm. Granulometric principles, according to the system of analogy, are also applied to the aggregate for the production of heavy concrete. Seen from the point of view of hydrotechnics, it is often required to have as little water permeability as possible, sometimes even absolute impermeability. Other requirements are usually related to concrete's resistance to frost or similar properties. Lightweight concretes are not made according to granulometric principles because they absolutely do not need to be compact, on the contrary, they should be as porous as possible.

4.2 TEXTURE OF GRAIN - SHAPE AND SURFACE OF GRAIN

What has the greatest influence on the strength of the bond between aggregate and cement is the texture of the aggregate grains. If it is a smooth texture, such as gravel, then the bond between the grain and the cement will be weaker. On the contrary, in broken aggregates with a stronger texture, this mechanical connection is significantly stronger. However, gravel is used to make concrete and these concretes do not have the problem of a weak bond between the grains and the cement. In fact, the most important thing is that the gravel is clean, i.e. that there are no impurities.

There are several forms of aggregate grains. Thus, we are talking about rounded, irregularly rounded, cubic, fluffy, elongated, and other shapes of aggregate grains. The importance of the shape of the aggregate grain is particularly important and affects the amount of water needed to make concrete, which directly affects its strength. Thus, rounded and irregularly rounded grains have a minimum surface area in relation to their mass, and therefore require a smaller amount of cement paste for bonding compared to other grain shapes. In contrast to the above, fluffy and elongated grains require more cement paste due to the fact that their surface area ratio is higher than that of rounded and irregularly rounded grains. There is a greater risk of segregation if the concrete is made with fluffy and elongated grains, because then the texture of the concrete is rough and a larger amount of sand and cement is required. Therefore, for making concrete, rounded and irregularly rounded grains are more favorable. The surface of the grains should not be too rough, as this requires excess water, nor should it be too smooth or glassy, as this reduces the adhesion of the cement adhesive to the stone.

4.3 CAVITIES IN AGGREGATE AND VOLUME MASS OF AGGREGATE

Aggregate mass depends on the density or volume of aggregate grain mass, but also on the amount of grains between aggregate grains. The amount of voids depends on the granulometric composition, shape and texture of the grains, and on the degree of compaction. The porosity of the aggregate is defined as: š=100 * (ρzps – ρs) (%), where: ρzps - volume mass of compacted saturated, surface-dry aggregate ρs - volume mass of compacted aggregate. What further increases the voids inside the concrete is the irregular shape of the grains and the roughness of the surface of the aggregate, which clearly results from the fact that the volume concentration of voids decreases as the volume concentration of the aggregate increases. For example, one normal fraction of crushed aggregate of 4-8 mm has a volume concentration of aggregate of 0.57. Because of such a low volume concentration, there are still a lot of voids in the concrete. If more than one aggregate fraction were used for the preparation of concrete, the volume of aggregate concentration would increase, while the pore content would decrease.

4.4 PETROGRAPHIC CHARACTERISTICS OF THE AGGREGATE

Various sulfates, as well as various sulfides such as pyrite or marcasite, are harmful minerals. Concretely, there must not be more than 1% of the mentioned minerals in the concrete. Recent research has established that certain aggregates, such as granite and andesite, or phyllite, rhyolite, selenite and similar to that, can be expanded in ready-made concrete. This is actually an expansive reaction of certain minerals, especially silicon-magnesium alkalis. For this reason, it is recommended that in such cases the content of alkali (K20+Na20) does not exceed a concentration of 0.5%. This expansive action of alkali only becomes apparent after a certain time, sometimes even after several years, and can be manifested in the form of swelling of concrete or the formation of visible cracks, especially on massive structures such as high dams. Also, the aggregate must not contain a large amount of stone grains in a state of disintegration, as well as iron components.

4.5 AGGREGATE CLEANLINESS

When we talk about the cleanliness of aggregates, it is necessary to set three requirements:

1. Organic impurities such as humus should not be in the composition of sand to a greater extent. Testing the suitability of sand in this case is done according to the Abrams-Harder method. Therefore, sand is placed in the glass bottle up to the line indicating the content of 130 cm^3, then 3% NaOH solution is added to 200 cm^3. After that, the bottle is shaken vigorously and left for 24 hours. If there is humus in the content, the sodium alkali solution will be colored, and the intensity of the color

that appears serves as a criterion for determining the value. In particular, the aggregate is clean if the liquid is colorless or light yellow, it is usable if it is yellow to brownish-yellow, and it is suspicious or unusable if it is darkly colored.

2. Impurities in the form of a membrane that prevents the joining of individual particles into a technical whole must not surround grains of sand and gravel.

3. The unit must be clean, so it must not be cloudy. What makes it cloudy is all the dusty material that passes through the standard 4900 cm^2 change screen. In order to obtain the finest aggregate grains, a larger amount of cement and water must be used, but they can also significantly reduce the concrete's strength compared to adequate mixtures of larger grains. Fine clay powder prevents cement grains, that is, cement and aggregate, from joining each other, which is why the amount of cement powder is not allowed to exceed 2% in relation to the weight of the entire aggregate. The question of the permissible amount of sludge in the composition of concrete represents a significant problem in modern concrete technology, especially when it comes to concrete of large, massive constructions. Muddiness is tested using the method of washing aggregates, which is best achieved with hot water. Then, the percentage of sludge is determined by weight measurement after settling or filtering the cloudy water, while the sediment is then dried and sieved through a sieve of 4900 holes/cm^2. If there is a large percentage of sludge in the aggregate, it must be washed in suitable machines before use. In any case, unprofessional washing of aggregates significantly damages the composition and quality of concrete. The fact that modern machines can also carry out the process of sieving aggregates through a certain number of fractions testifies to how much science has progressed in general. The modern way of removing sludge with certain fractions is carried out according to the method discovered by the Austrian engineer Eder, which in construction science is called the Rheax method. The procedure of this method is based on the combined vertical and horizontal washing of sludge and powder with water, and it is suitable for separating individual fractions with a grain size of 0.15 or 0.4 mm.

4.6 POROSITY AND WATER ABSORPTION

Aggregate porosity, water permeability and water absorption are important properties that affect the adhesion of cement stone and aggregates in concrete, the resistance of concrete to the effects of frost, and the chemical and erosion resistance of concrete. Water permeability depends on the total volume of pores and their connection. Considering the moisture content, there are four aggregate states:

1. Completely dry aggregate - aggregate that has been dried at temperatures of 100 ^{o}C to 110 ^{o}C to a constant weight.

2. Naturally dry aggregate - aggregate that contains a small amount of moisture in the aggregate, but has a dry surface.

3. Saturated, surface dry aggregate (ZPS) - aggregate that has no free moisture on the surface, but all pores are filled with water.

4. Wet aggregate - aggregate whose pores are filled with water and there is free water on the surface.

Reduced fluidity of concrete occurs when naturally dry aggregate is dosed into the concrete mix when it gradually absorbs part of the water from the cement paste. Therefore, when calculating the concrete mix, the part of the water absorbed by the aggregate should always be subtracted from the total amount of water for the concrete mix and thus arrive at an effective water-cement factor that is relevant for workability, strength, durability and other properties of hardened concrete. Depending on the weather conditions, the humidity of the aggregate is constantly changing, and knowledge of this characteristic is essential when determining the amount of water needed to make the concrete itself. In addition, humidity can be determined by drying a certain amount of average material (in this case at least 5 kg) in a furnace, dryer or in strong sunlight, until it is determined by weight measurement that the weight does not change anymore. Thus, aggregate moisture is the difference between the weight of the material before drying (Tvl) and after drying (Ts) expressed as a percentage in relation to the dry material.

CONCLUSION

The loose material that is used in combination with binding materials, usually cement, to obtain mortar and concrete, is called aggregate in construction. We divide them into natural, artificially crushed and special aggregates. There are many types of aggregates, sand and gravel are the most commonly used in practice, and they represent naturally unbound rocks. The need to determine the composition of aggregates stems from the fact that stone aggregates do not reflect a uniform or constant composition in terms of grain size, and especially not one that provides optimal concrete strength or any other optimal properties. This fact, at the beginning of the stronger development of reinforced concrete, led to the realization that it is necessary to artificially improve the composition of the aggregate in terms of grain size and the relative amount of individual fractions, all in order to achieve optimal strength of the finished concrete. Testing of the aggregate itself is carried out according to its purpose, where, in addition to basic, physical and geometric properties, simulated phenomena in application are often tested. The importance of the properties can be seen from the prescribed frequency where the most common tests are such as granulometric composition, then the proportion of fine particles, flatness index and shape index. The rarest tests are petrographic analysis, resistance to freezing/thawing and resistance to abrasion.

The goal of making good concrete is not always the creation of concrete with the highest possible strength, but its better workability, that is, the possibility of embedding. In accordance with the above, we can conclude that more fractions of aggregate should be used, that is, more different grain sizes, in order to obtain better embedding, workability and, therefore, better quality of concrete.

LITERATURE

1. C.Lian, Y.Zhuge: Optimum mix design of enchanced permeable concrete – An experimental investigation, Australija, 2010.
2. L.K. Crouch, P.E.;Jordan Pitt, Ryan Hewitt: Aggregate effect on pervious portland cement concrete static moduls of elasicity, Journal of Materials in Civil Engineering, 2007
3. M. Vujica: Samozbijajući ekološki odrţivi beton; Diplomski rad, Gradjevinski fakultet sveučilišta u Zagrebu, Zagreb, 2009
4. P. Krstulović: Svojstva i tehnologija betona, Građevinski fakultet sveuĉilišta u Splitu i Institut građevinarstva Hrvatske, Split, 2000.
5. Pravilnik o tehničkim propisima za građevinske proizvode koji se ugrađuju u betonske konstrukcije (Sl.novine FBiH 86/2008)
6. S. Mrakovčić, N. Čeh, V. Jugovac: Utjecaj granulometrijskog sastava na svojstva procjednog betona, Građevinar 66 (2014) 2 pp. 107-113.
7. Thn Chi Fu, Weichung Yeih, Jiang Yu Chang, Ran Huang: The influence of aggregate size and binder material on

the properties of pervious concrete, Taiwan, 2014.
8. V. Ukrainczyk: Beton, Struktura, svojstva, tehnologija, Građevinski fakultet sveučilišta u Zagrebu, Zagreb, 1994.

INTERNET SOURCES

- http://www.cemex.com/
- http://www.ekokuce.com/materijali/beton-sa-letecim-pepelom
- https://www.gradnja.me
- http://info.grad.hr/
- https://www.scribd.com
- https://tehnika.lzmk.hr/tehnickaenciklopedija/beton.pdf
- http://www.quarzwerke.at/downloads/DE_Katalog_2014.pdf