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A COMPARATIVE ANALYSIS OF CONCRETE STRENGTH USING IGNEOUS, SEDIMENTARY AND METAMORPHIC ROCKS (CRUSHED GRANITE, LIMESTONE AND MARBLE STONE) AS COARSE AGGREGATE

Introduction

Concrete is regarded as the most widely used man-made material in the world, second only to water as the world's most utilized substance [1-4]. The other principal constituent of concrete is the binding medium used to bind the aggregate particles together to form a very hard composite material. The most common used binding medium is the product formed by the chemical reaction between cement and water [1, 5, 6]. The future of concrete looks even brighter because for most purposes it offers suitable engineering properties at low cost.

A good knowledge of properties of cement, aggregates and water is required in understanding the behavior of concrete, in ordinary structural concrete the aggregate occupies 70÷75% of the volume of hardened mass and in similar vein it occupies 90% or more in asphalt cement concrete [2, 7, 9]. It is inevitable that a constituent occupying such a large percentage of mass should have an important effect on the properties of both the fresh and hardened product (concrete). Their impact on various characteristics and properties of concrete is undoubtedly considerable.

One of the ingredients for making concrete, as earlier pointed out, is aggregate. Aggregate is a material such as broken stone, slag, gravel or sand which, when held together by a binding agent, forms a substantial part of such material as concrete, asphalt and coated macadam [10, 11]. Aggregate can be classified as fine or coarse aggregate. Fine aggregate is generally natural sand and is graded from particles 5 mm in size down to the finest particles but excluding dust. Coarse aggregate is natural gravel or crushed stone usually larger than 5 mm and usually less than 16 mm in ordinary structure [1, 6, 8, 12, 13]. In this research, the emphasis will be on coarse aggregate.

Aggregate, part of which is coarse, is used primarily for the purpose of providing bulk to the concrete. As economical filler which is much cheaper than cement, maximum economy in the production of concrete can be obtained by using as much aggregate as possible. The use of aggregate also considerably improves both the volume stability and the durability of the resulting concrete. Aggregate provides about 75 percent of the body of the concrete and hence its influence is extremely important. The commonly held view that aggregate is a completely inert filler in concrete is not true, its physical characteristics and in some cases its chemical composition affect to a varying degree the properties of concrete in both its plastic and hardened state [10, 14].

Strength of concrete is commonly considered as most valuable property in Portland cement concrete. Although in many practical cases other characteristics such as durability and permeability may in fact be more important. Nevertheless, strength usually gives an overall picture of the quality of concrete because strength is directly related to the structure of the hydrated cement paste. Moreover, the strength of concrete is almost invariably a vital element of structural design [4].

Compressive strength of concrete is commonly considered to be its most valued property, although in many practical cases, other characteristics, such as durability, impermeability and volume stability, may in fact be more important. Nevertheless, compressive strength usually gives an overall picture of the quality of concrete [15]. Because of the important contribution of aggregate to the strength of concrete, this paper seeks to examine the effect of physical properties of coarse aggregate (igneous rock - crushed granite stone; sedimentary rock - limestone and metamorphic rock - marble rocks) on the compressive strength of Portland cement concrete, and also to compare their concrete strength with the BS.

1. Materials and methods

Physical and mechanical properties such as specific gravity, moisture content, bulk density and void ratio, water absorption, porosity, aggregate impact value, slump and compaction factor, and compressive strength were determined for the various rocks and concretes cubes produced.

1.1. Materials

Constituent materials of concrete: The materials, namely cement, fine and coarse (igneous rock - crushed granite stone, sedimentary rock - limestone and metamorphic rock - marble stone) aggregates and water, used for the purpose of this study were selected and tested according to British Standard Codes of practice or specifications and American Society for Testing Materials (ASTM) standard.

Fine aggregate (sand)

The fine aggregate used was uncrushed type which was obtained locally from the River Bako at Kpankungu along Federal University of Technology, Gidan Kwano main campus, Minna. It was free from organic impurities in form of silt and clay. The fine aggregate was found to be under standard F-classification and falls under the grading limit of zone 3 of [12, 13] after sieve analysis using the method of sieve analysis in accordance to [16]. Specific gravity of sand which is fine aggregate is 2.36.

Coarse aggregates

Coarse aggregates from three different natural parent rock materials were obtained viz igneous - crushed granite stone, sedimentary rock - limestone and metamorphic rock - marble stone [12, 13]. The fractions of different sizes of the aggregates as shown in Table 1 were in the ranges as specified in [13]. The maximum size of the coarse aggregate used falls within 6.3÷25 mm using the method of sieve analysis in accordance with [16]. The aggregate rocks are irregular in sizes, strong and tough with rough surface texture.

Cement

Ordinary Portland cement of Burham brand obtained from local distributors in Minna and of recent supply, free of adulteration, was used as the main binder. The brand of cement used is to [17] specifications. The specific gravity and unit weight of cement are 3.15 and 1440 kg/m^3 respectively.

Water

The water used for mixing and curing of the concrete was potable tap water, free from impurities such as silt, alkaline salt, clay, acid and organic matter. Density and pH value of water are 1000 kg/m^3 and 6.9 respectively.

1.2. Methods

Particle size distribution or grading of aggregates

One of the most important factors for producing workable concrete is good grading of aggregate. Sieve analysis method was adopted for this purpose. Sieve analysis refers to the process of dividing a sample of aggregate into fractions of same particle sizes. The determination of fractions of aggregate particle sizes was carried out in accordance with [16]. The aggregates were all obtained from their natural sources and extremely dried after long exposure to sun. The results of particle size distribution earned out on the aggregates (fine and coarse - crushed granite stone, limestone and marble stone) are presented in Table 1.

Specific gravity

Specific gravity (G_s) is generally defined as the ratio of the mass of a given volume of material to the mass of an equal volume of water at the same temperature. When considering aggregate for Portland cement concrete, the most common definition for specific gravity is based upon the bulk volume of the individual aggregate in a saturated and surface-dry (SSD) condition. The determination of aggregate specific gravity was carried out in accordance with [17].

Bulk density or unit weight and void ratio

Bulk density gives valuable information regarding the shape and grading of the aggregate. Bulk density refers to the mass of material (including solid particles and any contained water) per unit volume, including the voids between the particles. Dry method was employed for the determination of bulk density and was carried out in accordance with [17, 18]. The net weight of the aggregate in the container was determined and the bulk density calculated in kg/m^3. From the values of specific gravity and bulk density in saturated and surface-dry conditions of the aggregates sample, the percentage of void ratio was then calculated.

Porosity

The porosity of aggregates affects the bond between them and the cement paste as well as the specific gravity. For aggregates with pores, these pores vary over a wide range; some of the aggregate pores are wholly within the solid, while others open to the surface so that water can penetrate the pores. The amount and rate of penetration of water however depends on the size, constituents and total volume of pores.

Water absorption

Water absorption refers to the increase in mass of a sample of aggregate due to the penetration of water into the water-accessible voids of the oven-dried aggregate i.e. the ratio of decrease in the mass between a saturated sample and a surface dried aggregate after oven drying for 24 hours to the mass of the oven dried sample expressed as a percentage. Water absorption test was conducted in accordance with [19].

Aggregate impact and crushing values

Aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact and aggregate crashing value gives a relative measure of the resistance of an aggregate to crashing under a gradually applied compressive load. The aggregates were tested in a surface dry condition. Aggregate impact and crushing tests were in a surface dry condition of aggregate and conducted in accordance with [20, 21] respectively.

Slump test

The slump test of fresh concrete mixes was conducted to ascertain concrete workability. This was carried out in accordance with [22].

Compacting factor

This test is to determine the consistency or self compaction of the fresh concrete mixes produced form three different types of coarse aggregate (granite/crushed stone, limestone and marble). The compaction factor test was canied out in accordance with [23].

Compressive strength

The basic properties of hardened concrete are closely associated with its strength. The crushing strength test for the compressive strength was carried out in accordance with [24, 25] using compressive strength test machine as specified by [26]. A proportion mix ratio of 1:2:4 and 1:3:6 (cement, fine and coarse aggregates) at water cement ratio of 0.5 and 0.6 were used to cast the concrete cube of 150x150xl50 mm for 7, 14, 21 and 28-day curing periods respectively. Thirty-six (36) in number concrete cubes were cast, cured in a tank containing clean tap water and crushed for each water cement ratio and curing period. The average compressive strength was then taken. The modes of failure of concrete cubes are normal, that is there are non-explosive failures. The degree of workability, density and compressive strength are the three properties for which concrete is designed [4]. Therefore, absolute volume method was used in the calculation of nominal mix proportion. This method is based on the principle that the volume of fully compacted concrete is equal to the volume of all the ingredients (ignoring air content).

$$\text{Absolute Volume} = (W/1000) + (C/1000\,P_c) + (A_1/1000\,P_1)+(A_2/1000\,P_2) = 1$$

where: W - weight of water; C - weight of cement; A_1, A_2 - weight of fine and coarse aggregates; P_c - specific gravity of cement; P_l, P_2 - specific gravity of fine and coarse aggregate respectively; 1000 = 1000 kg/m^3 $P_c = 3.15$; $P_1 = 2.36$; W/C - water-cement ratio.

The characteristic compressive strength was obtained by dividing the maximum load the cube can sustain by the area of the cube.

2. Results and discussion

2.1. Particle size distribution of fine and coarse aggregates

The result of particle size distribution carried out on the aggregates (fine and coarse) as shown in Table 1, indicates that the fine and coarse aggregate maximum sizes used for the study were 5 and 28 mm respectively. The size of aggregate particles (fine and coarse) normally used in concrete varies from 0.15 to 37.5 mm. The values obtained are in the ranges specified in [12, 13, 16]. The coarse aggregates are irregular in shape. The fine modulus of fine aggregate is 5.27 and that of coarse aggregates (igneous rock - crushed granite stone, sedimentary rock - limestone and metamorphic rock - marble stone) are 72.38, 2.07 and 4.16 respectively.

TABLE 1

Particle size distribution (gradation) of coarse and fine aggregates

Sieve size	Percentage fineness by mass [% passing]			
	Igneous rock - crushed	Sedimentary	Metamorphic rock - marble	Sand - fine

	granite	rock - limestone	stone	
28 mm	100	100.00	100	–
20 mm	99.15	99.5	99.48	–
14 mm	45.66	56.27	54.48	–
10 mm	8.4	21.29	19.22	–
6.3 mm	0.2	6.73	6.23	–
5.0 mm	0.2	0.23	0.23	94.93
3.35 mm	0.00	0.00	0.00	90.42
2.00 mm	0.00	0.00	0.00	84.14
1.18 mm	0.00	0.00	0.00	75.22
850 um	0.00	0.00	0.00	66.68
600 um	0.00	0.00	0.00	40.64
452 um	0.00	0.00	0.00	11.09
300 um	0.00	0.00	0.00	7.11
150 um	0.00	0.00	0.00	2.78
75 um	0.00	0.00	0.00	0.00
Pan	0.00	0.00	0.00	0.00

2.2. Specific gravity of coarse aggregates

The apparent specific gravity of most rocks falls between 2.6 and 2.7 [4, 12, 13, 15, 27]. The values of specific gravity of igneous rock - crushed granite stone, sedimentary rock - limestone and metamorphic rock - marble stone obtained are 2.65, 2.63 and 2.58 respectively. The values obtained indicate that granite and limestone rocks fall within the standard range, and that of marble rock is slightly below the lower limit given above as specified by [12, 13]. This is because the percentage porosity of metamorphic rock is higher than those of granite and riverbed aggregates. The granite, limestone and marble rock aggregates can be use for normal structural concrete works since the specific gravity values are above the minimum values stipulated by [12, 13].

2.3. Bulk density or unit weight of coarse aggregates

The bulk density of the igneous rock - crushed granite stone, sedimentary rock - limestone and metamorphic rock - marble aggregates were found to be 1413 kg/m^3, 1409 kg/m^3 and 1346 kg/m^3 respectively. The bulk density of most natural aggregate varies between 1350÷1800 kg/m^3 according to [11, 17, 28, 29]. Crushed granite and limestone aggregates fall within this range while marble rock aggregate falls below the minimum value given above by [13]. The higher the bulk density, the lower is the void content to be filled by sand and cement [30]. The results obtained from the research indicate that metamorphic rock - marble aggregate is less densely packed.

2.4. Void ratio of coarse aggregates

The results of the void ratio of the three different aggregates are 0.48, 0.49 and 0.52, which shows clearly that metamorphic rock aggregate contains more voids when compared with the other two rock aggregate samples. This means that concrete produce with the metamorphic rock aggregate will be less durable, more porous and consequently water absorption is expected to be high in metamorphic rock.

2.5. Porosity of coarse aggregates

The values of porosity obtained from the research are 11.24, 11.03 and 15.07% respectively. The range of porosity of common rocks varies from 0 to 50 percent [6, 8, 13, 31]. This indicates that the value of porosity of the three rock aggregates obtained falls within the range. The pores in aggregate vary in size over a wide range.

2.6. Water absorption of coarse aggregates

The water absorption value of the three rock aggregates are presented in Table 2. Metamorphic rock - marble aggregate has more percentage water absorption than the other two samples of rock aggregates. This is as a result of the fact that metamorphic rock aggregate contains more pores necessary for water absorption.

2.7. Aggregate Impact Value (AIV) of coarse aggregates

The result of the impact carried out on the three samples of rock aggregates as shown in Table 2, indicates that metamorphic rock - marble aggregate is the weakest of the three samples with an average of 21.91%, approximately 21%. This could be due to the fact that its parent material is of a very weak rock or the process of metamorphism has softened the rock. The maximum aggregate impact and crushing values are 20% when the aggregate is to be used in heavy-duty concrete floor finishes, 30% for pavement wearing surfaces and 45% for other concrete works [10, 13]. The lower the value of AIV and ACV, the stronger the aggregate i.e. the greater its ability to resist impact and crushing.

2.8. Fresh properties of Portland cement concrete

Slump

The concrete produced with igneous rock-crushed granite stone and sedimentary rock - limestone aggregates recorded a medium workability with slump values of

32.5, 30.5 and 32 mm for concrete grade of 20 N/mm^2, and 32, 30.5 and 31.5 mm for 30 N/mm^2 concrete grade, respectively while that of metamorphic rock aggregate recorded a low workability as shown in Table 2. Though the concrete produced a reasonable slump value, but it has the lowest compacting factor value when compared with concrete produced with the other two rock aggregate samples.

Compacting factor

Compacting factor as shown in Table 2 indicates that out of the three samples of aggregates used in producing concrete for this study, metamorphic rock - marble stone aggregate produced the least compacting factor value for the grades of concrete indicating a low level of workability.

TABLE 2

Physical and mechanical properties of various coarse aggregates and Portland cement concrete

Property	Values		
	Granite	Limestone	Marble
Unit weight	1363.75 kg/m^3	1394.74 kg/m^3	1271.38 kg/m^3
Apparent specific gravity	2.65	2.63	2.58
Bulk density	1413 kg/m^3	1409 kg/m^3	1346 kg/m^3
Water absorption	0.46%	0.29%	0.59%
Moisture content	0.70%	0.71%	2.68%
Void ratio	0.48	0.49	0.52
Porosity	11.24%	11.03%	15.07%
Aggregate Impact Value	5.72%	6.08%	12.27%
Slump (20 N/mm^2)	32.5 mm	32.5 mm	32 mm
Slump (30 N/mm^2)	32 mm	31.7 mm	31.3 mm
Compacting factor (20 N/mm^2)	0.92	0.92	0.91
Compacting factor (30 N/mm^2)	0.91	0.91	0.90

Compressive strength

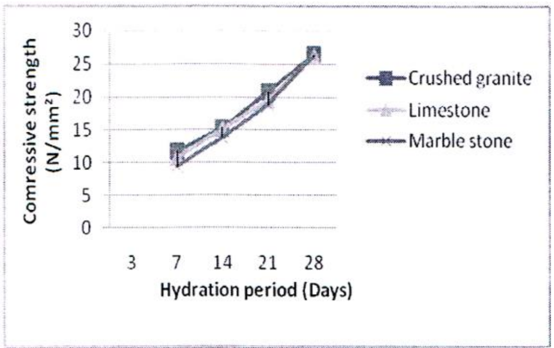
Compressive strength of the concrete produced from the various coarse aggregates at water-cement ratio of 0.5 and 0.6 and design concrete strengths of 20 and 30 N/mm^2 are presented in Table 3 and Figures 1 and 2 respectively. In all of the three coarse aggregates used, the compressive strength of concrete increased with increasing age of hydration, and in other side reduces with increasing water-cement ratio.

TABLE 3

Compressive strength of the concrete produced from the various coarse aggregates at water-cement ratio of 0.5 and 0.6 and design concrete strengths of 20 and 30 N/mm²

Concrete	Compressive strength [N/mm²] at W/C = 0.5				Compressive strength [N/mm²] at W/C = 0.6			
	7 Days	14 Days	21 Days	28 Days	7 Days	14 Days	21 Days	28 Days
Granite	11.74	15.35	20.76	26.45	9.84	13.38	18.79	25.68
Limestone	10.80	15.13	19.55	26.11	9.13	12.76	18.57	25.19
Marble	7.45	13.85	18.83	26.03	7.05	9.85	13.93	24.84
Design strength of 30 N/mm²								
Granite	20.62	21.13	25.69	30.11	16.34	19.98	22.85	27.29
Limestone	17.20	18.94	26.86	29.78	14.99	16.87	20.47	26.81
Marble	17.11	18.45	22.25	29.53	13..03	14.21	18.18	26. 44

a)



b)

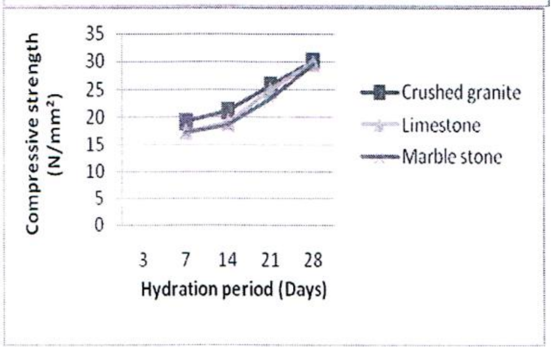


Fig. 1. Compressive strength of the concrete produced from the various coarse at water cement ratios of: a) 0.5 and b) 0.6, and design concrete strengths of 20 N/mm²

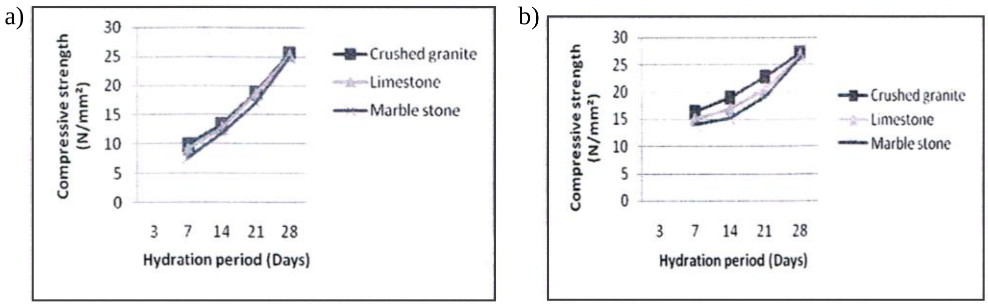


Fig. 2. Compressive strength of the concrete produced from the various coarse aggregate at water cement ratios of (a) 0.5 and (b) 0.06, and design concrete strengths of 30 N/mm^2

The results obtained indicate that igneous rock - crushed granite produced the highest strength followed by sedimentary rock - limestone and metamorphic rock - marble stone the least. This could be due to the fact that the igneous rock - crushed granite aggregate is very strong and tough with rough surface texture which enhances stronger bonding between cement paste and the aggregate particles. The strengths variation could also be viewed from the result of ATV and percentage porosity carried out. Concrete aggregates with higher porosity and absorption factor create internal stresses reducing concrete durability [8, 10]. Sedimentary rock - limestone stone look more roundish and smoother than crushed granite leading to poor bonding between individual particles and cement paste which have negative effect on strength development. The resistance of limestone aggregate to failure by impact is lower than that of igneous rock - crushed granite aggregate as indicated from the AFV test carried out, hence showing the lower average compressive strength recorded by sedimentary rock - limestone aggregate as compared to crushed granite rock aggregate. The weaker aggregate among the three samples of aggregates used in the study was metamorphic rock - marble. This accounts for the least values of average compressive strength recorded by it at all curing ages.

Conclusions

The following conclusions can be drawn based on the results and discussion of the study conducted:

1. Igneous rock - crushed granite stone aggregate gave the highest compressive strength at all curing ages, this is due to the fact that crushed granite stone is very strong, tough and has good surface texture which enhances proper bonding between the aggregate particles and cement paste;
2. Sedimentary rock - limestone aggregate produced higher compressive strength than metamorphic rock - marble stone aggregate. This is so because limestone aggregate is stronger and harder than the metamorphic rock aggregate used in the study. It was also observed that the strength produced by limestone aggregate is lower than that of crushed granite stone. The riverbed aggregate are roundish

in shape and again smoother than the crushed granite rock, this is a major disadvantage in strength developments as the roundish shape lead to poor interlocking of the individual particles which also lead to poor bonding within the particles and cement paste.

3. Of all the three aggregate samples used in concrete production, metamorphic rock - marble stone aggregate produced least compressive strength for all curing ages (hydration periods). This is because the aggregate is weak and less tough in nature.

Recommendations

From the foregoing, the three rocks namely igneous - crushed granite, sedimentary - limestone and metamorphic - marble performs satisfactory as coarse aggregate for structural Portland cement concrete although their strength varies considerably. Similar research should be carried out on the other types of igneous, sedimentary and metamorphic rocks to ascertain their strength variations and to determine where each could be of best use.

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Abstract

This paper presents a comparative analysis of the effect of the physical properties of coarse aggregate (igneous rock - crushed granite stone; sedimentary rock - limestone and metamorphic rock - marble stone) on the compressive strength of Portland cement concrete and compare their characteristic strength. Tests such as sieve analysis, specific gravity, bulk density, void ratio, porosity, water absorption and aggregate impact value were carried out on aggregates to ascertain their physical properties as they affect the strength of concrete. The concrete strength comparison was confined to characteristic concrete strength of grade 20 and 30 N/mm^2 only. Two different mix proportions

of 1:2:4 and 1:3:6, and water cement ratio of 0.5 and 0.6 for both mixes were used to cast concrete cubes which were hydrated for 7, 14, and 28-day periods respectively. The compressive strength tests conducted on the cast cubes was found to be within the stipulated value of concrete strength of 26.0 N/mm^2 for 28-day hydration period by British Standard specification. The 28-day concrete cubes cast with these aggregates shows that, at the low strength of 20 N/mm^2, igneous rock - crushed granite stone c concrete had the highest strength of 26.45 N/mm^2 followed by Sedimentary-limestone with 26.11 N/mm^2 and metamorphic rock - marble stone 26.03 N/mm^2 in that order, and also at the high strength of 30 N/mm^2, crushed granite concrete gave the highest strength to be 30.11 N/mm^2 followed by granite 29.78 N/mm^2 and limestone 29.53 N/mm^2 in that order.

Analiza porównawcza wytrzymałości betonu z kruszywem grubym w postaci skał magmowych, osadowych i metamorficznych (łamany granit, wapień i marmur)

Streszczenie

W artykule przedstawiono analizę porównawczą wpływu właściwości fizycznych kruszywa grubego (skały magmowej - łamany granit, skały osadowej - wapienie i skały metamorficznej - marmur) na ściskanie betonu poprzez porównanie charakterystycznej wytrzymałości. Kruszywo grube poddano badaniom: uziarnienia, gęstości nasypowej, gęstości, porowatości, wskaźnika porowatości, absorpcji wody i współczynnika wpływu kruszywa w celu ustalenia właściwości fizycznych, jakie mają wpływ na wytrzymałość betonu. Porównanie wytrzymałości betonu ograniczono do charakterystycznej wytrzymałości na ściskanie betonu o wartości 20 i 30 N/mm^2. Do wykonania sześciennych kostek betonowych zastosowano dwie różne proporcje mieszanki 1:2:4 i 1:3:6 i dwie wartości stosunku cementowo-wodnego 0,5 i 0,6, które dojrzewały odpowiednio przez 7, 14 i 28 dni. Testy wytrzymałości na ściskanie przeprowadzone na kostkach sześciennych wykazały, że przewidywana wytrzymałość betonu dla próbek 28-dniowych wynosi 26,0 N/mm^2, opierając się na normie brytyjskiej. Badania 28-dniowych betonowych kostek, w których zastosowano analizowane kruszywa grube wykazały, że dla wytrzymałości 20 N/mm^2: beton z granitem miał największą wytrzymałość - 26,45 N/mm^2, beton z wapieniem 26,11 N/mm^2 i z marmurem - 26,03 N/mm^2. Dla wytrzymałości 30 N/mm^2 również beton z granitem miał największą wytrzymałość: 30,11 N/mm^2, następnie z granitem 29,78 N/mm^2 i wapieniem 29,53 N/mm^2.