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Full Length Research Paper

Investigation of mechanical properties of concrete produced with waste granites aggregates

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The purpose of this study is to determine the mechanical properties of waste block granites as crushed stone aggregates for concrete production. The granite aggregates were obtained from granite pits around the Kaman town of Kırşehir province in Turkey. The aggregates were tested in terms of density, water absorption, compressive strength, splitting tensile strength, and static modulus of elasticity with the hardened concrete specimens. According to the study results, the mechanical properties of concrete specimens produced with the waste granites were found to comply with the Turkish and European concrete production standards.

Key words: Granite, aggregate, crushed stone, concrete.

INTRODUCTION

Aggregates are used in concrete production as they are economical and robust. Adequate adherence is important for the short and long-term performance of the concrete. In the case of a suitable aggregate granulometry, it is known that less cement will be required in the mixture. In addition, the mineral structure, granular shape, granular distribution, freeze and thaw strength, abrasion strength, unit weight, density, void ratio, water absorption, hardness and the strength to chemical effects of the aggregates used in the concrete production are also important factors that have an effect on the concrete durability (Erdoğan, 1995).

Approximately 60% of the granite blocks produced in the pits of Kırşehir-Kaman regions in Turkey is thought to be waste granites. Identifying a use for this waste has important economic benefits and at the same time provides an alternative aggregate source by their evaluation as aggregate transformation in the crusher workshops.

Knowledge of rock characteristics is of great importance for the production of high-quality crushed stone aggregates. For instance, minerals such as tridymite and andesite, which contain silisium, are not appropriate for concrete production as they may initialize an alkali aggregate reaction. On the other hand, black and white limestone, basalt and syenite may be effectively used in the production of high-quality concretes (Akman, 1984; Erdoğan, 1995). Aggregates may introduce some variability to concrete production according to their chemical and petrographical structures. This can affect critical performance criteria including the abrasion of the internal structure of the concrete or deformation of the concrete due to reduced strength to external forces. In this respect, the mineralogical structures, form and surface textures and water absorption properties of the aggregates used in the concrete production should be taken into consideration (Akman, 1984).

Ajdukiewicz and Kliszczewicz (2002) used recycled aggregates obtained from 2-7 years old moderate-or high-strength concrete with original granite or basalt aggregates. The authors showed that the recycled aggregates can be useful for high performance concrete.

Beshr et al. (2003) found that the type of coarse aggregate influences the modulus of elasticity of concrete. They also proved that weaker aggregates tend to produce a more ductile concrete than stronger aggregates do.

Padmini et al. (2009) investigated the properties of recycled aggregates from parent concrete (PC) of three strengths, each of them made with three maximum sizes of aggregates. They produced recycled aggregate concrete (RAC) using these recycled aggregates. They found that RAC required relatively lower water-cement ratio as compared to PC to achieve a particular compressive strength. They also determined that the difference in strength between PC and RAC increased with strength of concrete.

Pereira et al. (2009) performed an experimental study using a number of coarse aggregates from different geo-

Table 1. Physical and chemical properties of the aggregates.

Groups	1	2	3	4	Limit value
Coarse aggregate, saturated, dry surface density	2.61	2.68	2.68	2.68	2.40
Fine aggregate, saturated, dry surface density	2.65	2.66	2.68	2.67	2.40
Coarse aggregate water absorption (%)	0.51	0.48	0.50	0.48	1.00
Fine aggregate water absorption (%)	0.32	0.24	0.60	0.28	1.00
Loose unit weight (g/cm³)	1.66	1.76	1.78	1.76	1177
Tight unit weight (g/cm³)	1.82	1.91	1.96	1.91	1.177
Freeze loss (%)	1.11	0.74	1.17	0.84	15
Abrasion rate (%)	37.11	30.01	31.64	30.59	50
Sulphate amount (%)	0.014	0.019	0.021	0.019	1.0
Chloride amount (%)	1.13	1.20	1.28	1.21	0.2
Rc alkali reduction M mol/l	60	70	80	70	
Sc dissolved silica M mol/l	12.34	10.15	10.87	10.05	

Table 2. Granular distribution data of the used aggregate specimens.

Sieve size (mm)	Passed (%)			
	1	2	3	4
31.5	100	100	100	100
16	80.54	77.51	79.54	81.82
8	61.78	57.86	59.06	60.44
4	45.1	40.54	41.02	44.06
2	36.44	32.23	32.51	37.58
1	28.11	21.9	22.28	27.34
0.5	16.64	12.99	13.23	17.78
0.25	7.47	2.43	4.87	6.85

logical sources including granite, basalt, limestone and marble. They produced concretes in specific mix proportions and laboratory controlled conditions. They explored that concrete durability properties were not affected by aggregates mineralogy, but in turn were significantly affected by the aggregate size and its water content.

The concretes produced from the various aggregates were determined to be more resistant than those using stream aggregates according to the petrographical, physical and mechanical properties of the aggregates, where as they were determined to be less resistant than limestone and basalt (Giaccio, 1992; Tokyay, 1998).

Although aggregate may make up three fourths of the content of concrete, the quality of the aggregate is much more important than volume in determining the performance of the concrete. Aggregates are known to be sufficient for the specified strength limits of concrete but they may also negatively affect strength and structural performance if they include unwanted properties. Minerals such clay, mica, feldspar, sulphate or iron oxide may reduce strength of the concrete and directly affect the physical and mechanical properties of rocks (e.g. magmatic, metamorphic and sedimentary rocks) used as aggregates in terms of the ultimate load-bearing capacity via the dissolution of these minerals (Neville, 1996).

The purpose of this study is to determine the mechanical properties of granite wastes obtained from granite pits as waste materials as an alternative to basalt and stream aggregates. The identification of alternative sources of aggregates is important to the long-term sustainability of the construction sector due to the constant increase in demand for concrete production and crushed stone aggregates.

MATERIALS

Granite aggregate

Waste granite blocks obtained from the granite pits in the Yelek (I), the northwest of Savcılı I (II), the Ömerhacılı (III), and in the southeast of Savcılı II (IV) villages of Kırşehir-Kaman region in Turkey, were used as the basis for crushed granite aggregates. The whole block waste granites were broken into pieces as aggregates by stone crushers.

The physical and chemical properties of the aggregates used in this study were previously examined (Demir and Uzun, 2007). As a result of the petrographical examination of the aggregates used in the study, it was found that they mostly include quartz, feldspar and plagioclase minerals in their composition (Figure 1). In addition to this, the granites of Yelek region include a slight amount of muscovite. The physical and chemical properties of the aggregates are given in Table 1 as taken from Demir and Uzun (2007). The granular distribution of the aggregates is given in Table 2.

Cement

The Portland cement of CEM I 42.5 was used in the preparation of the concrete mixture. The chemical composition and physical properties of the Portland cement used are given in Table 3. Domestic water of the Kırşehir Municipality was used as the mixing water in the mixture.

Method

The experimental studies were carried out in two stages in accordance with the relevant Turkish Standards (TS) and European Union Standards (EN). In the first stage, aggregate tests were conducted on the aggregate specimens (Table 1). Aggregates were classified into three as 0/4, 4/8 and 8/32 mm. In the second stage, concrete

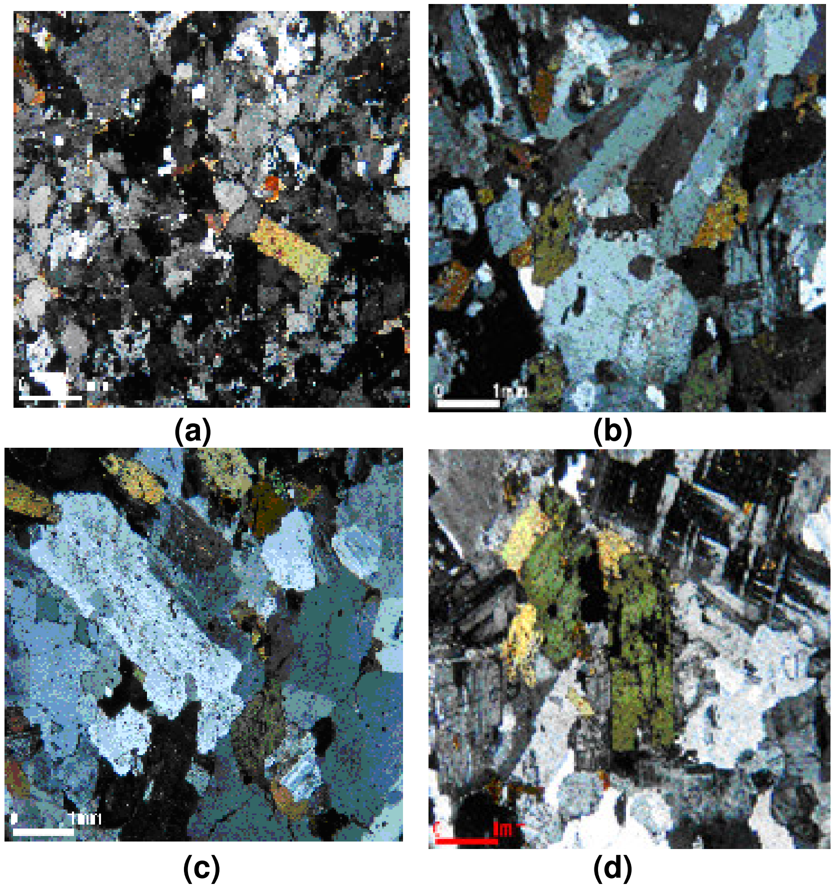

Figure 1. Photomicrographs of granites obtained from Yelek (a), Savcılı I (b), Ömerhacılı (c) and Savcılı II (d) regions.

Table 3. Physical properties and chemical composition of CEM I 42,5 Portland cement.

Physical properties		Chemical composition	%
Residue in the 90-micron screen (%)	1.72	SİO$_2$	19.59
Setting time (min)	188	$A1_2O_3$	5.33
Final set (min)	252	Fe_2O_3	3.11
Blaine specific surface (cm^2 /g)	3092	CaO	62.89
Density (g/cm^3)	3.12	MgO	2.39
Total aperture of Le Chatelier rings (mm)	1.0	SO_3	2.92
		C1	0.0088
		Ignition loss	2.35
		Insoluble residue	0.75

mixtures were prepared in accordance with the design concrete mixes complying with TS 802 (C30 concrete class) as given in Table 4 (TS, 1985). The preparation of the fresh concrete specimens was tested in accordance with TS EN 12390-2 Concrete, Testing Hardened Concrete – Part 2: Making and Curing Specimens for Strength Tests (TS, 2002). In the study, lignosulphonate was used as the plasticizing agent at a concentration of 0.7% with a density range of 1.16 - 1.20 kg/l. The aggregate granulometry was kept stable in the concrete groups. The maximum aggregate size was 31.5 mm. The effective water content was kept stable in each concrete group. As the water amount absorbed by the aggregate was added to the mixing water, the rates of total water/cement (W/C) changed between 0.58 and 0.6 (Table 4). The mixtures were prepared in the same dosage of 350.

The slump test, air content and unit weight on the fresh concrete were carried out in accordance with TS EN 12350–2 (TS, 2002), TS EN 12350–7 (TS 2002) and TS 2941(TS, 1978) standards, respectively. Cylindrical specimens of 150 x 300 mm dimensions were prepared. 90 specimens for three strengths were obtained from each concrete group (30 specimens for each strength experiment). The

Table 4. Mixture rates of concrete groups.

Concrete group	W/C	Water (L)	Cement (kg/m^3)	Aggregate (kg/m^3)		
				0/4 (mm)	(4/8) (mm)	8/32 (mm)
1	0.60	210	350	876	438	371
2	0.58	203	350	838	419	419
3	0.60	210	350	853	427	427
4	0.59	206.5	350	870	489	453

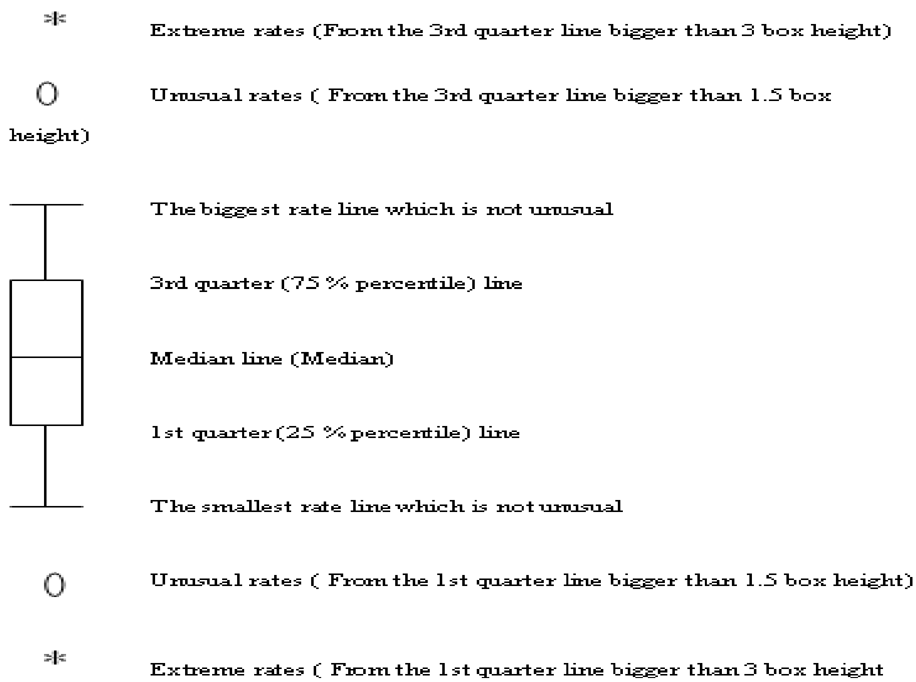

Figure 2. The structure of box plot and properties. The relationship between the central line and quarter line (if the central line is in the axis of the box, the distribution is normal; if the central line is closer to the first quarter line, the distribution was positively skewed; and if the central line is closer to the third quarter line, the distribution is negatively skewed). The variability of the data spread and the box size (50% of the observations take place within the box and thus it is stated that the box size is higher and the variability is greater) are determined (Norusis, 1993).

The specimens were kept in the standard cure pool at 20ºC (±2ºC). After 28 days of cure they were tested after for splitting tensile strength, compressive strength and static modulus of elasticity under 13.5 kN/s constant loading speed with an automated controlling compressive machine. Water absorption rate and density were determined using the same specimens in accordance with TS EN 12390-6 (TS, 2002), TS EN 12390–3 (TS, 2003), TS 3502 (TS, 1981) and TS 3624 (TS, 1981) standards. The material amounts of 1 m^3 concrete mixtures are given in Table 4.

Statistical analysis

The statistical data for different 4 groups for 3 different experiment types were obtained for the hardened concrete specimens (360 specimens in total). Analysis of variance (ANOVA) was employed to identify statistic-cally significant differences between groups followed by the Duncan's multiple comparison tests. The margin of error (significance level) was determined as α = 0.05 at most ("Type 1" error, false-positive) (Neter et al., 1988). Figure 2 shows the distribution of the experimental test results for groups.

RESULTS AND DISCUSSION

Fresh concrete properties

The slump air content and unit weight of the fresh concretes are given in Table 5. According to these results, the slump of the specimens varies between 100 and 110 mm. The slump between 75 and 150 mm is evaluated as plasticizing and is determined as an appropriate concrete type for use in the multi-equipment media and vibration compaction process in accordance with TS 500 standard (TS, 2000). The slumps of the groups are found to be in the standard interval with values ranging from 100 to 120 mm (Table 5). The unit weights of the fresh concrete in all groups are found to be between 2290 and 2370 kg/m^3 (Table 5). The unit weights of the fresh concretes are between 2200 and 2450 kg/m^3 for the concretes used by the normal-weight aggregates (Erdoğan, 2003). The air content of

Table 5. Experimental results of fresh concretes with plasticizing agents.

Concrete group	Unit weight (kg /m³)	Air content (%)	Slump (mm)
1	2290	1.6	100
2	2320	1.8	110
3	2370	2.0	100
4	2300	1.9	110

Table 6. Density and water absorption rates of concrete specimens.

Concrete Group	Density (kg/m³)	Water absorption rate (%)
1	2.21	3.69
2	2.27	2.85
3	2.23	3.19
4	2.19	3.05

Table 7. Specimen statistics of splitting tensile strength (MPa).

Concrete group	Arithmetic average	Standard deviation	Maximum	Minimum
1	3.40	0.243	3.85	3.05
2	4.54	0.207	4.87	4.07
3	4.27	0.414	4.67	3.35
4	4.64	0.228	4.98	4.12

the fresh concretes belonging to each group is given in Table 5. The air content was found to vary between 1.6 and 2%. The air content changes according to the aggregate size and cement ratio not exceeding the 6% limit as suggested by Neville (1996).

Hardened concrete properties

The concrete groups were tested in terms of their density, water absorption rates, splitting tensile strength, compressive strength and static modulus of elasticity.

Density and water absorption rate

The experiment data of density and water absorption rate of hardened concrete are given in Table 6. According to the results, the density values of the concrete specimens varied between 2.21 and 2.29 kg/m³. The concretes, which have oven dry concentration between 2000 and 2600 kg/m^3, were defined as normal concretes according to TS EN 206 standard (TS, 2002). In parallel with this result and data, all of the groups in this study are in the normal concrete group.

The water absorption rates of the specimens varied between 2.85 and 3.69% which are relatively lower than the rates found by Lea (1970) (they change between 6.9 and 12.9%).

Splitting tensile strength

Specimen statistics of splitting tensile strength experiments were given in Table 7. Anova (analysis of variance) and the Duncan multiple comparison test results were presented in Tables 8 and 9, respectively. According to the Anova test results (Table 8), there exists a statistically significant difference in variances of groups.

According to the results obtained, the lowest splitting tensile strength value belongs to the group 1 with a value of 3.40 MPa, while the highest splitting tensile strength value belongs to group 4 with 4.64 MPa value (Table 7).

It was found out that there was a significant difference between split tensile strength data of the groups 1, 3, 2 and 4 at $\alpha = 0.05$ significance level (Table 9) while there was no significant difference between split tensile strength data of groups 2 and 4 at $\alpha = 0.05$ significance level. It was determined that the data distribution of the splitting tensile strength values of the groups 1 and 4 were positively skewed, and the data distribution of the splitting tensile strength value of the group 3 was negatively skewed while the data for group 2 was normally distributed (Figure 3).

The splitting tensile strength of the concrete is 9 and 10% of the compressive strength of the concrete. This rate may vary between 7 and 17% depending on the quality of the concrete (Erdoğan, 2003). Therefore, the splitting tensile strength values of all the groups are above 10% of their compressive strength.

Concrete compressive strength

Specimen statistics of the compressive strength experiments are presented in Table 10 and Anova (analysis of variance) the Duncan multiple comparison tests are tabulated in Table 11. According to the Anova test results (Table 8), there exists a statistically significant difference in variances of groups.

According to the results, the minimum concrete compressive strength was observed in group 1 (34.42 MPa) while the maximum concrete compressive strength was observed in group 2 (36.06 Mpa) (Table 10). A significant difference was observed between the concrete compressive strength values of group 1 and groups 2, 3, and 4 at 5% significance level (Table 11) due mostly to low unit weight and high water absorption ratio. On the other hand, no significant difference was found between the concrete compressive strength values of groups 3 and 4 at the determined significance level (Table 11). Also, it was determined no significant difference between concrete compressive strength values of groups 2 and 4 at the same significance level (Table 11). The specimen data distribution of the concrete compressive strength of group 1 was observed to be positively skewed and that of group 3 was observed to be negatively skewed. However, the specimen data distribution of the concrete compressive

Table 8. Analysis variance (Anova) of splitting tensile strength, concrete compressive strength and static modulus of elasticity.

Groups	Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F-Test	Significance level p≤0.05
Splitting tensile strength	Between groups	28.419	3	9.473	116.484	0.000
	Within groups	9.434	116	0.081		
	Total	37.853	119			
Compressive strength	Between groups	236.143	3	78.714	29.753	0.000
	Within groups	306.892	116	2.646		
	Total	543.036	119			
Static Modulus of elasticity	Between groups	649.420	3	216.473	58.527	0.000
	Within groups	429.047	116	3.699		
	Total	1078.467	119			

Table 9. The Duncan test results of splitting tensile strength (MPa).

Concrete groups	α = 0.05 (*)		
	1	2	3
1	3.40		
3		4.27	
2			4.54
4			4.64

(*) 5% significant difference

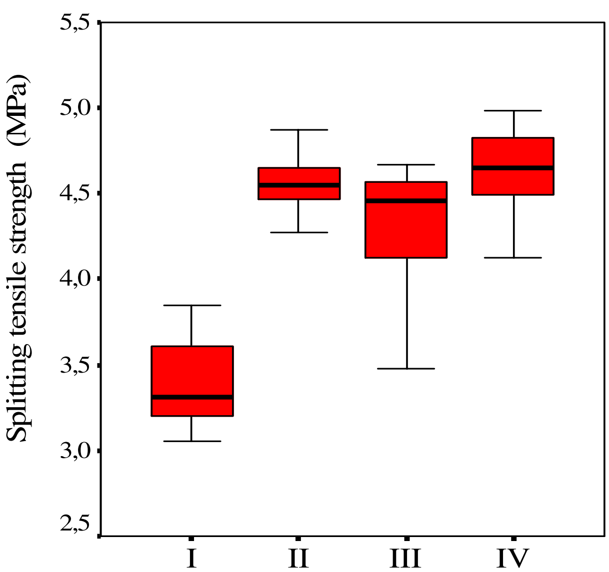

Figure 3. The box plot of concrete splitting tensile values.

strength of group 2 was found to be normally distributed (Figure 4).

In accordance with TS 5893 ISO 3893 (TS, 1999), group 1 specimens with a mean value of 32.42 MPa were within the C30 concrete compressive strength class, whereas group 2 specimens with a mean value

Table 10. Distribution of data on the Concrete Compressive Strength (MPa).

Concrete groups	Arithmetic average	S.d	Maximum	Minimum
1	32.42	1.07	34.05	29.80
2	36.06	1.76	39.40	33.60
3	35.05	1.95	38.15	32.40
4	35.55	1.60	39.84	33.50

Table 11. Duncan test of concrete compressive strength data (MPa).

Concrete groups	α = 0,05 (*)		
	1	2	3
1	32.42		
3		35.05	
4		35.55	35.55
2			36.06

(*) 5% significant difference.

of 36.06 MPa, group 3 specimens with a mean value of 35.05 MPa and group 4 specimens with a mean value of 35.55 MPa were found to be in the C35 con-crete class.

Concrete static modulus of elasticity

Specimens statistics of the concrete static module of elasticity experiments are given in Table 12 and Anova (analysis of variance) the Duncan multiple comparisons test are provided in Table 13. According to the Anova test results (Table 8), there exists a statistically significant differrence in variances of groups.

According to the results shown in Table 12, the minimum concrete static modulu of elasticity was found in group 1 (25.27 GPa) while the maximum value was obtained in group 2 (31.63 GPa). A statistically significant difference was observed between the concrete static module of elasticity values of groups 1 and 3 while there was no sig-

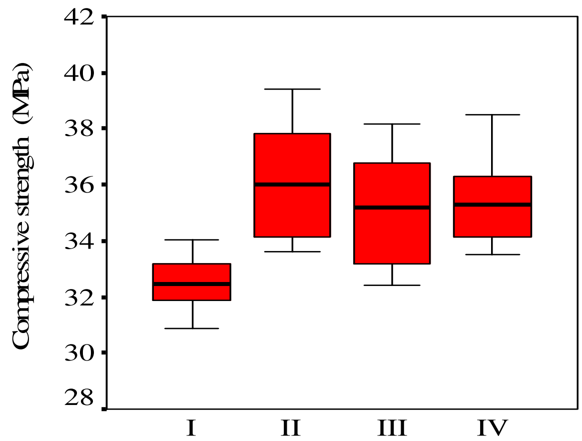

Figure 4. The box plot of concrete compressive strength values.

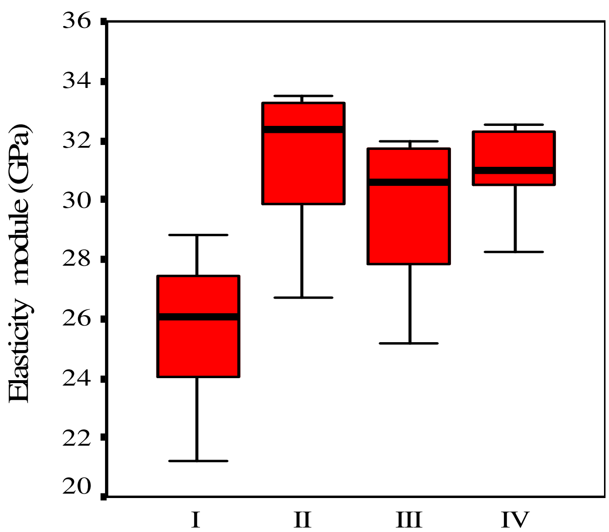

Figure 5. The box plot of concrete static modulus of elasticity values.

Table 12. Specimen statistics of the concrete static modulus of elasticity experiments (GPa).

Concrete groups	Arithmetic average	S. d	Maximum	Minimum
1	25.72	2.06	28.79	21.22
2	31.63	1.94	33.50	26.74
3	29.53	2.32	31.99	25.15
4	31.17	1.17	32.50	28.26

nificant difference between groups 2 and 4 at 5% significance level (Table 13). The distribution of the concrete static module of elasticity data was found to be positively skewed while that of groups 1, 2 and 3 was found to be negatively skewed (Figure 5).

The TS500, (TS, 2000), elasticity limits for concretes

Table 13. Duncan test of concrete static modulu of elasticity data (GPa).

Concrete groups	α = 0.05 (*)		
	1	2	3
1	25.72		
3		29.53	
4			31.17
2			31.63

(*) 5% significant difference.

after 28 days are 28, 30 and 32 GPa for C20, C25 and C30 concrete classes, respectively. The elasticity values of groups 2 and 4 were found to exceed these limits indicating better performance in elasticity.

Conclusions and Suggestions

This research presented an experimental study on the potential use of different granites obtained from Kırşehir-Kaman region in Turkey as concrete aggregates prepared in accordance with the standards. Concrete specimens were studied in four different groups namely 1, 2, 3 and 4 according to the granite type used in concrete as aggregate. The specimens were tested to determine their compressive strength, splitting tensile strength and elasticity module values. Generally, strength and elasticity characteristics of all hardened concrete specimens were determined to comply with the Turkish and European standards very well. However, the density, compressive and splitting tensile strengths, and elasticity module values of group 1 specimens were relatively lower than those of other groups. On the otther hand, the water absorption rate of group 1 specimens was relatively higher than those of other groups.

The evaluation of experimental results showed that the maximum value of the splitting tensile strength was obtained from group IV (4.64 MPa). The maximum compressive strength and the maximum static modulu of elasticity values were determined in group 2 (36.06 MPa and 31.63 GPa, respectively). Also, the study results revealed that the specimens with the maximum compressive strength, splitting tensile strength and elasticity module had relatively higher density, but lower water absorption rates.

In conclusion, the study results indicate that the mechanical properties of concrete specimens produced using the waste granite were found to comply with the Turkish and European concrete production standards.

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