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A Study on the Batch and Continuous Gradations of Concrete

[Yüksel ESEN]

***Abstract*—In this study, the results of the mechanical and physical tests on the concrete that has batch and continuous granulometrics aggregate have been analyzed. For this purpose, 300-400 doze concrete samples have been produced from streams and crushed stone aggregate. The ratio of water/cement was taken as 0.50 in all of these mixtures. Maximum grain diameter (dmax) of the aggregate was chosen as 32 mm. To create a step gradation, the aggregates that has equivalent (0-4), (4-8), (8-16) and (16-32) mm sieve eye openings were subtracted from the aggregate stack, respectively. Crushed stone aggregate with continuous granulometrics and streams aggregate with batch granulometrics except (8-16) mm has shown high mechanical performance. (Abstract)**

Keywords*—Concrete, step gradation, mechanical properties (key words)

I. Introduction *(Heading 1)*

Aggregates are granular materials which are used to produce concrete by mixing with cement and water. Since they constitute 60-75% by volume of concrete, aggregates are among major constituents of concrete. Because they are generally tough and durable, they contribute significantly to the mechanical properties of concrete. Cement paste is a material which loses its structural water with time so drying shrinkage occurs. Aggregates restrain the volume change in concrete resulting from shrinkage. They also increase the abrasion resistance of concrete [1].

The dispersion of the grains within the aggregate with regard to their size is called gradation, or granulometry. The aim of determination of the gradation is to indicate the size and amount of the grains present within the aggregate. Gradation considerably affects the compactness, mixing water content, strength and durability of the concrete. In case the aggregate mixture includes grains of various sizes, it leads to a less porous structure between the grains for a given volume [2].

In some construction projects, for example in mass concrete, gap grading can be used. Gap-grading is a kind of grading in which the amount of retained material on one or more sieves is 0%. Gap grading is economical in case the material is naturally in gap grading state. Besides, in the experimental studies, it is presented that intentionally used gap grading aggregate rather than continuously grading one does not provide an advantage [3].

Yüksel ESEN
Fırat University
Turkey

Gülşah (2006) indicated that according to the hardened concrete test results, concrete mixtures having gap grading aggregate show better mechanical performance than well graded aggregate including mixtures and according to the fresh concrete test results, mixtures having well graded aggregate show better segregation resistance than the gap grading aggregate including ones [4].

Curves of gap-grading in which some medium size grains are omitted should fall between the lower limit of curve U and curve A (Figure 1). In order to obtain gap grading aggregate, at least two size fractions should be combined. Gap graded aggregate with a maximum grain size of 32 mm may be used in concrete having a maximum strength class of C25 [5]. A type of concrete having no fine aggregate particles is also a particular case. This type of concrete has low strength and is highly permeable. Coarse aggregates are wrapped by cement paste instead of fine aggregate in this concrete type. Advantages of this type of concrete can be listed as its low density, low shrinkage and low coefficient of thermal conductivity. It is generally suggested that this concrete can be used in the non-load-bearing components of the structure [6].

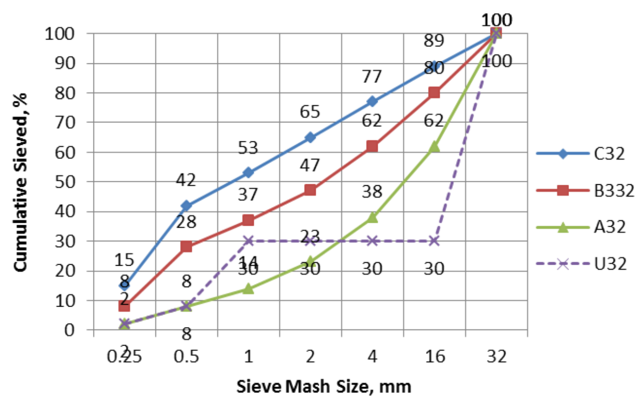


Figure 1. Aggregate gradation curves of maximum grain size of 32 mm [7].

In this study, maximum aggregate size of 32 mm was used. Particles remaining between 0-4, 4-8, 8-16 and 16-32 mm sieves are removed respectively, and concrete mixtures having gap graded and well graded crushed and stream aggregate were produced. Regarding aggregate type, the effects of these discontinuities in aggregate on mechanical and physical properties of concrete were experimentally investigated.

2. Materials and Method

Researches on the concrete indicate that the most proper maximum grain size of aggregate is 25 mm and the maximum grain size of aggregate should not exceed 40 mm [8]. Thus, in this study, aggregate having 32 mm maximum grain size was selected. The physical properties of stream and crushed aggregate used in the study are shown in Table 1. CEM I 42.5 N type cement with physical and chemical properties given in Table 2 was used.

TABLE 1. PHYSICAL PROPERTIES OF AGGREGATES

Aggregate Type	Density (gr/cm^3)	Water absorption (%)	Abrasion after 500 cycles (%)
River aggregate (fine)	2,67	3,46	-
River aggregate (coarse)	2,73	2,00	5,6
Crushed aggregate (fine)	2,64	2,25	-
Crushed aggregate (coarse)	2,70	3,00	21

TABLE 2. PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT

Oxide Composition %	Cement (CEM I 42.5 N)
Chemical Properties	
S($SİO_2$)	21.12
A(Al_2O_3)	5.62
F(Fe_2O_3)	3.24
C(CaO)	62.94
MgO	2.73
SO_3	2.30
Na_2O	--
K_2O	--
Cl	0.009
Loss on ignition	1.78
Physical Properties	
Density (g/cm^3)	3.13
Specific surface area (cm^2/g)	3370
Initial setting time (min.)	168
Final setting time (min.)	258
Compressive Strength	
2 days (MPa)	25.8
7 days (MPa)	41.8
28 days (MPa)	50.7

In this study, for each cement dosages, six different concrete mixtures were produced. Among these, three concrete mixtures were produced with gap graded aggregate and the remaining three concrete mixtures were produced with well graded aggregate. 20 concrete mixtures having two different cement dosages (300-400kg/m^3) and two different aggregate types (river and crushed) were prepared. Water/cement ratio was kept constant at 0.50 for all concrete mixtures. Mix proportions of the concrete mixtures were determined according to the principles of TS 802 standard and are summarized in Table 3. In order to prepare the combined aggregate, Curve B32 which remains between Curve A32 and Curve C32 specified in TS 802 standard was selected (Figure 1). Concrete mixtures were cast and compacted in the molds and after setting, they were standard-cured for 28 days.

In this study, the designations of the series were made as follows: In the first part of the designation, CG and BG show well graded and gap graded aggregates, respectively. In the second part, the number sequence of mixture in the case of continuously graded aggregate or the number sequence of omitted particle sizes for gap-graded mixtures exist. Third part of the designation is allocated for cement dosage (I-II) and in the last part of the designation, CR and ST show crushed and stream aggregate, respectively. [9].

3. Experimental Study

Compressive, splitting tensile and flexural strength tests were applied to concrete specimens at the testing days. Figure 2 represents the change in the compressive strength of 2 different dosaged concrete mixtures including stream or crushed aggregate with either continuous gradation or gap-grading. It is apparent from the figure that for a given aggregate characteristic, strength values increased with increasing dosage.

The maximum strength was obtained in CG1-I-CR coded mixture prepared by using crushed aggregate and having a dosage of 300 while BG1-I-CR coded mixture prepared without 0-4 mm had the lowest strength. The reason for the low strength in this mixture was the deficiency of the fine aggregate that has the ability to fill the voids between coarse aggregate particles. In stream aggregate incorporating mixtures with a dosage value of 300, the maximum strength was obtained in BG3-I-ST coded mixture and as in the case of crushed aggregate incorporating mixtures, BG1-I-ST coded mixture including no (0-4 mm) aggregate showed the minimum strength. In crushed aggregate incorporating mixtures utilization of continuously graded aggregate led to maximum strength in concrete mixture; however, in stream aggregate incorporating mixtures higher strength levels were obtained when the size fraction of (8-16 mm) in aggregate is omitted.

In general, splitting tensile strength values were found to be similar to compressive strength figures. As can be seen from Figure 3, among mixtures including crushed aggregate with a dosage of 300, the maximum strength was reached in BG2-I-CR. BG1-I-CR mixture having no (0-4 mm) aggregate had the lowest value. In mixtures having 300 dosage and stream aggregate, the maximum strength was reached in CG3-I-ST mixture. The maximum and minimum strengths in crushed aggregate incorporating mixtures that have a dosage of 400 were reached in BG4-II-CR and BG1-II-CR, respectively. Among concrete mixtures with 400 dosages and including stream aggregate, CG4-II-ST showed the maximum strength while BG1-II-ST had the minimum strength.

Flexural strength test results are given in Figure 4. Figures related with compressive strength and flexural strength are similar to a large extent.

According to overall results, CG-4-II-ST coded mixture reached the maximum strength in flexural strength test. On the other hand, the mixture with the lowest strength is BG1-I-CR coded one that has 300 dosage and gap-graded aggregate mixture with no 0-4 mm in it.

TABLE 3. CONCRETE MIXTURE PROPORTIONS (1m^3)

Series	Water/cement ratio	Cement (kg)	Water (lt)	Aggregate (kg)			
				0-4 mm	*4-8 mm*	*8-16 mm*	*16-32 mm*
CG1-I-CR	0.50	300	150	930,6	297	356,4	396
BG1-I-CR	0.50	300	150	-	1227,6	356,4	396
BG2-I-CR	0.50	300	150	930,6	-	653,4	396
BG3-I-CR	0.50	300	150	930,6	297	-	752,4
BG4-I-CR	0.50	300	150	1108,8	396	475,2	-
CG2-II-CR	0.50	400	200	826,2	263,7	316,4	351,6
BG1-II-CR	0.50	400	200	-	1089,9	316,4	351,6
BG2-II-CR	0.50	400	200	826,2	-	580,1	351,6
BG3-II-CR	0.50	400	200	826,2	263,7	-	668,1
BG4-II-CR	0.50	400	200	984,4	351,6	421,9	-
CG3-I-ST	0.50	300	150	895,8	285,9	343,08	381,2
BG1-I-ST	0.50	300	150	-	1181,7	343,08	381,2
BG2-I-ST	0.50	300	150	895,8	-	628,9	381,2
BG3-I-ST	0.50	300	150	895,8	285,9	-	724,2
BG4-I-ST	0.50	300	150	1067,3	381,2	457,4	-
CG4-II-ST	0.50	400	200	795,7	253,9	304,7	338,6
BG1-II-ST	0.50	400	200	-	1049,6	304,7	338,6
BG2-II-ST	0.50	400	200	795,7	-	558,6	338,6
BG3-II-ST	0.50	400	200	795,7	253,9	-	643,3
BG4-II-ST	0.50	400	200	948,08	338,6	406,3	-

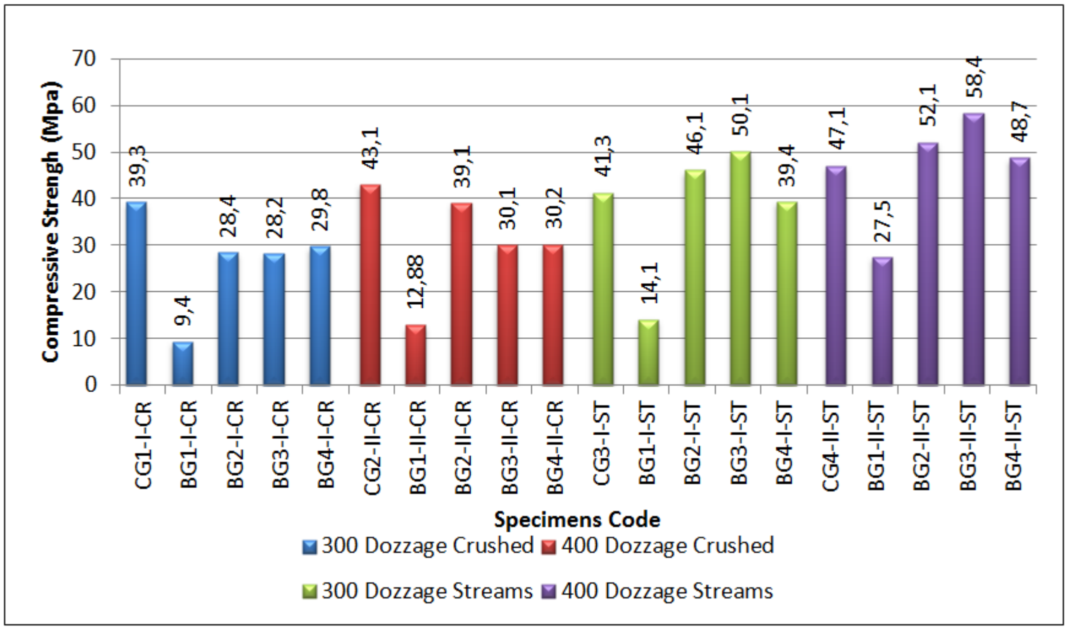


Figure 2. 28-day compressive strengths of mixtures

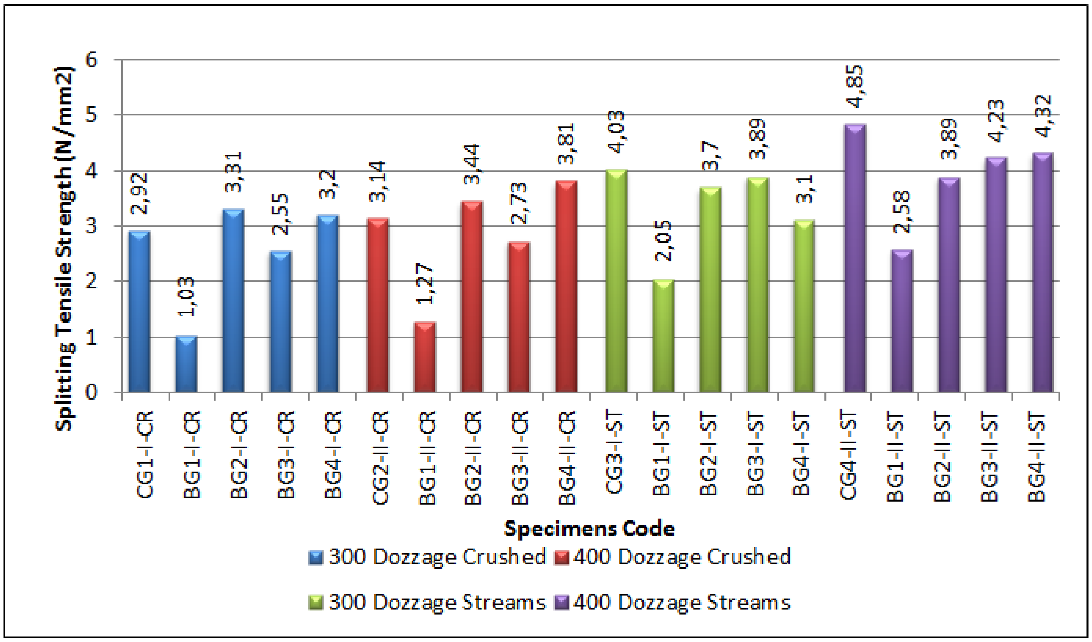


Figure 3. 28-day splitting tensile strengths of mixtures

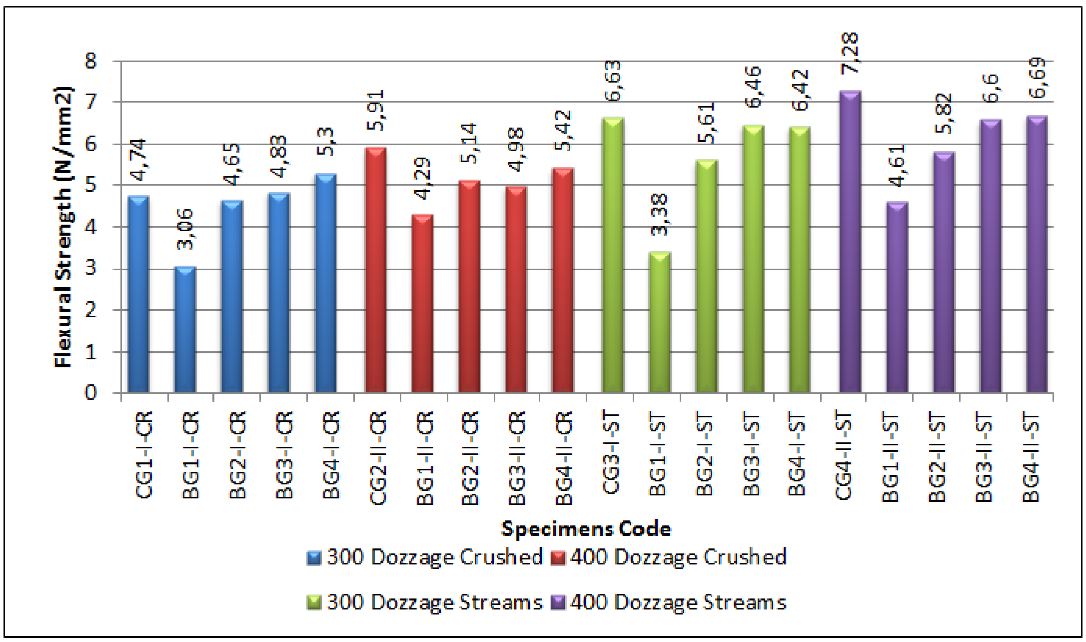


Figure 4. 28-day flexural strengths of mixtures

4. Results and Recommendations

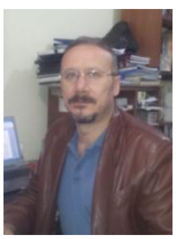
Although there exist various formulas regarding how to obtain a suitable or good gradation developed by many scientists, there is no agreement on the definition of the best (optimum) gradation. In many studies tests were conducted by obtaining granulometric mixtures conforming to specific standards and in general, the authors reached a conclusion that gap-graded mixtures would show a poor performance. However, in this subject there is no experimental study with respect to numerical values about the effect of gradation on results.

According to compressive strength test results, when continuous grading is preferred in concrete mixtures stream aggregate helped to obtain higher values compared to crushed aggregate. Angular aggregates such as crushed stone reduce the flowability of fresh concrete due to friction. Thus, for a given consistency level, water requirement of concrete mixture reduces when rounded aggregate is used as aggregate rather than crushed aggregate. In angular aggregate incorporating concrete mixtures, a higher amount of fine aggregate is required in order to improve workability. The increase in water requirement of fresh concrete leads to a relatively low strength. On the other hand, the bond between the aggregate particles and cement paste improves in concrete mixtures including angular aggregates. In the current study, using a constant W/C ratio caused this result.

It can be observed that CG4-II-ST coded mixture exhibits the maximum splitting tensile strength. Meanwhile BG1-I-CR coded mixture had the lowest strength. According to overall results, CG-4-II-ST coded mixture reached the maximum strength in flexural strength test. On the other hand, the mixture with the lowest strength is BG1-I-CR coded one that has 300 dosage and gap-graded aggregate mixture with no 0-4 mm in it. Results obtained in these tests are in parallel to compressive strength test results. In addition, strength values went up with increasing dosage.

According to the results of this study it can be concluded that it is possible to obtain favorable strength levels by using gap-graded aggregate in concrete mixture. Except the mixtures containing no (0-4 mm) particle size fraction within them, there wasn't any excessive difference in the other series from strength view point. Even, compared to some continuously graded aggregate incorporating mixtures, a significant strength increase was observed in gap-graded aggregate incorporating ones.

About Author :



[Yüksel ESEN is Assocciate Prof. in the Department of Civil Engineering Faculty University of Firat. He is working in the department of mechanics. Strength of Materials his interest.]

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