Pergamon

Cement and Concrete Research, Vol. 27, No. 2, pp. 165-170, 1997

0008-8846/97 $17.00 + .00

PII S0008-8846(97)00006-9

EFFECT OF COARSE AGGREGATE TYPE ON MECHANICAL PROPERTIES OF CONCRETES WITH DIFFERENT STRENGTHS

Turan Özturan and Cengizhan Çeçen
Boğaziçi University, Civil Engineering Department, İstanbul, Turkey

(Communicated by F. W. Locher)
(Received November 5, 1996; in final form January 8, 1997)

ABSTRACT

Tests were carried out to study the effect of the type of coarse aggregate on the compressive, flexural and splitting tensile strength on concrete produced at different strength levels. Concretes with 28 day target compressive strengths of 30, 60 and 90 MPa were produced using basalt, limestone and gravel coarse aggregates. The gravel aggregate concrete with 90 MPa target strength was also replicated by using a cement of higher strength, keeping the other parameters same. Twenty eight day test results have indicated that, in high strength concrete, basalt produced the highest, whereas gravel gave the lowest compressive strengths. Normal strength concretes made with basalt and gravel gave similar compressive strengths while the concrete containing limestone attained somewhat higher strength. Higher tensile strengths were obtained with crushed basalt and limestone compared to the gravel aggregate when used in high strength concrete. In the replicate mixture, approximately 30 percent increase in flexural and splitting tensile strengths were obtained as a result of using a stronger cement, while the compressive strength was not affected at all. © *1997 Elsevier Science Ltd*

Introduction

The strength of the concrete is determined mainly by the characteristics of the mortar, coarse aggregate and the interface. For the same quality mortar, different types of coarse aggregates with different shape, texture, mineralogy and strength may result in different concrete strengths. The influence of the type of coarse aggregate on the strength of concrete, however, becomes paramount as the quality of the mortar is improved (1).

In concrete mixtures, having water-cement ratios (w/c) greater than about 0.4, the strength of the mortar and the bonding of mortar and coarse aggregate are limiting the strength of the material. Hence, the influence of the coarse aggregates on the strength of the concrete has not been considered in normal strength concrete. In such a concrete microcracking at the interface and cracking throughout the mortar will lead to failure of the concrete regardless of the strength of the coarse aggregate.

For high strength concrete mixtures, having compressive strengths greater than about 40 MPa, which are usually made with a water-cement ratio less than 0.4, the strength of the mortar and the bond at the interface may be comparable to the strength of the coarse aggregate. In such a case it may be possible to make use of the full strength potential of the coarse aggregate particles. Thus, using a coarse aggregate of higher strength and proper textural and mineralogical characteristics may improve the strength of the concrete. The influence of some of the coarse aggregate characateristics on the strength and the elastic properties of the high strength concretes have been previously reported (2,3,4,5). This paper reports the results of a study undertaken to investigate the effects of three different types of coarse aggregates on the compressive, flexural and splitting tensile strengths of concretes designed to achieve three different strength levels.

Experimental Work

Materials. Cement: The portland cement (PCI) used for the production of the nine concrete mixtures had a 28 day compressive strength of 53 MPa. Another portland cement (PCII) having a higher strength (64 MPa) was used to produce a replicate of the high strength concrete mixture made with gravel coarse aggregate.

Silica fume: The silica fume containing 92–98 percent silicon dioxide was from a ferrosilicon producing plant.

Aggregates: The fine aggregate was a siliceous sand with a fineness modulus of 2.9. Three different types of coarse aggregates; namely, round siliceous gravel, crushed limestone and crushed basalt were used.

Superplasticizer: A sulphonated naphtalene formaldehyde superplasticizer was used.

Mixture Proportions. Three concrete mixtures were designed to have 28 day compressive strengths of 30, 60 and 90 MPa. The water-cement ratios were 0.58, 0.40 and 0.30, whereas the cement contents were 340, 450 and 550 kg/m^3, respectively. At each w/c, three mixtures were produced with gravel, limestone and basalt coarse aggregates. The type of the fine aggregate and cement were not changed in these mixtures. One additional mixture was made as a replicate of the concrete with a 90 MPa target strength and containing gravel aggregate, by using a cement of higher strength while other parameters have been kept unchanged. Mixtures were coded such that letters B, L and G designates basalt, limestone and gravel coarse aggregates, respectively. The number following the letter shows the target strength of the concrete. The mixture proportions are shown in Table 1.

For all concrete mixtures the maximum size of the coarse aggregate was 19 mm. The fineness modulus of the mixture of fine and coarse aggregates varied from 4.26 to 4.53 for all concrete mixtures. Silica fume was used in high strength concrete mixtures only. The workability of the fresh concrete at each strength level was indexed to the slump of the concrete containing gravel coarse aggregate. Superplasticizer was used, if required, to maintain this slump at 200 ± 25 mm. As the type of the coarse aggregate has been changed, the change in the slump was detected. Properties of the fresh concretes are given in Table 2.

Casting, Curing and Testing of Specimens. Three cubes, two cylinders and two prisms were cast from each concrete mixture. Cubes of 150 × 150 × 150 mm, cylinders of 150 × 300 mm and prisms of 100 × 100 × 500 mm were used for compressive, splitting tensile and flexural tests, respectively. Third point loading was used in flexure test. Test specimens were water cured for 7 days followed by laboratory air curing till testing at 28 days.

TABLE 1

Mixture Proportions of Concretes Produced

Mix Code	Aggregate Type	Cement (kg/m^3)	Silica Fume (kg/m^3)	Coarse Aggregate (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Super-plasticizer (kg/m^3)	Water-Cement Ratio
B30	Basalt	340	—	1216	752	198	—	0.58
L30	Limestone	340	—	1123	752	198	—	0.58
G30	Gravel	340	—	1111	752	198	—	0.58
B60	Basalt	450	45	976	865	180	15	0.40
L60	Limestone	450	45	898	865	180	15	0.40
G60	Gravel	450	45	884	865	180	15	0.40
B90	Basalt	550	82.5	864	787	165	19	0.30
L90	Limestone	550	82.5	797	787	165	19	0.30
G90	Gravel	550	82.5	784	787	165	19	0.30
G90-PCII	Gravel	550	82.5	784	787	165	19	0.30

Tests Results and Discussion

Table 2 shows the properties of fresh concrete. The workability of the fresh concrete is affected by the type of the coarse aggregate. Rounded gravel aggregate gives the highest slump for all the concrete mixtures. The use of crushed limestone and basalt aggregates causes a reduction in the slump where the reduction is larger for non-superplasticized mixtures. The unit weights of the concretes are in consistance with the differences in the specific gravities of the coarse aggregates.

TABLE 2

Properties of Fresh Concrete Mixtures

Mix Code	B30	L30	G30	B60	L60	G60	B90	L90	G90	G90-PCII
Unit Weight (kg/m^3)	2490	2400	2400	2490	2400	2400	2500	2420	2380	2380
Slump (mm)	40	40	180	200	190	210	120	130	210	210

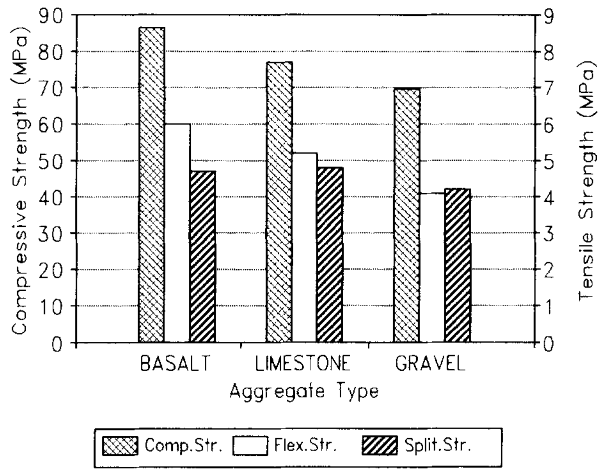

FIG. 1.
Effect of coarse aggregate type on the strength of concrete with target strength of 90 MPa.

In high strength concretes (target strength $\geq$ 60 MPa), crushed aggregates of basalt and limestone produce higher compressive strengths than the rounded gravel aggregate (Fig. 1 and 2). The 28 day compressive strength of concretes made with gravel coarse aggregate are about 10 to 20 percent lower when compared to limestone and basalt aggregate concretes. This may be attributed to the lower expected strength of the gravel aggregate as well as the round and smooth surface of the gravel particles, resulting in lower bonding strength with the matrix. However, in concretes with target strength of 30 MPa (Fig. 3), the compressive strengths pro-

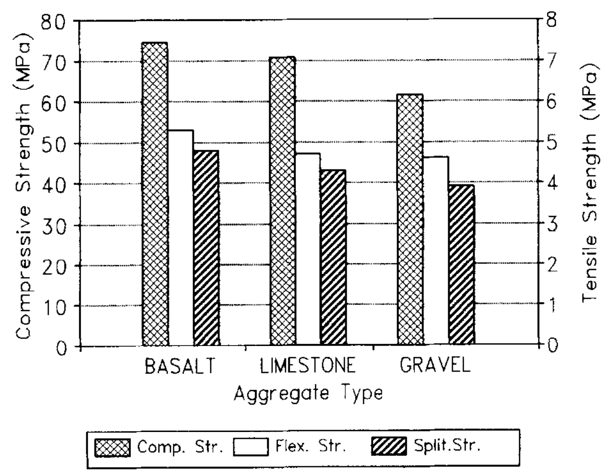

FIG. 2.
Effect of coarse aggregate type on the strength of concrete with target strength of 60 MPa.

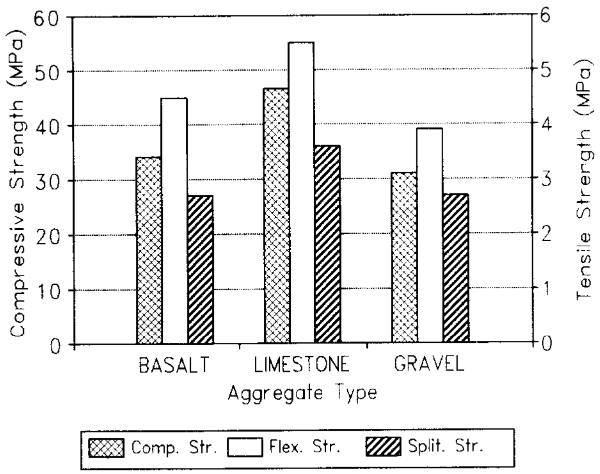

FIG. 3.
Effect of coarse aggregate type on the strength of concrete with target strength of 30 MPa.

duced by gravel and basalt coarse aggregates are comparable. The relatively higher compressive strength of the concrete with limestone coarse aggregate may be due to some interfacial chemical reactions which may improve the bond strength. These results clearly illustrate that the influence of the type of coarse aggregate on the compressive strength of the concrete is more important in high strength concrete than in normal strength concrete.

The tensile strength of the concretes measured through flexural and splitting tests, as shown in Fig. 1 and 3, are higher for crushed basalt and crushed limestone aggregates than for gravel

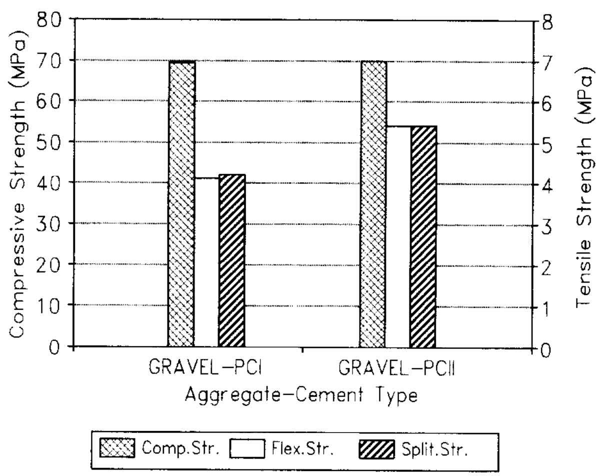

FIG. 4.
Effect of cement type on strength of concrete with target strength of 90 MPa.

aggregate. However, as the target strength of the concrete is reduced, the differences in tensile strength of concretes with different types of coarse aggregates are getting less. The higher flexural and splitting tensile strengths of the normal strength concrete with limestone aggregate are probably due to better bonding of limestone aggregate particles to the mortar. This indicates that the interfacial bond strength depending on the surface characteristics of the coarse aggregates, the strength of the mortar and the quality of the interfacial zone, which may be improved by using silica fume and reducing the water-cement ratio, will play an important role on the tensile strength of the concrete.

The effect of improving the binder quality on the strength of concrete is illustrated in Fig. 4. In concrete with a target strength of 90 MPa, the cement used is replaced by a stronger one, keeping other parameters unchanged. Although the data is limited to the gravel coarse aggregate concrete only, it is noteworthy that improving the mortar strength results in about 30 percent increase in flexural and splitting tensile strengths of the concrete whereas the compressive strength is not practically affected. It may also be observed from Fig. 1 and Fig. 4 that in high strength concretes the compressive strength is determined mainly by the type of the coarse aggregate while the tensile strength is mostly affected from the strength of the mortar as well as the surface characteristics of the coarse aggregate.

Conclusions

The impact of the type of coarse aggregate on the strength of concrete is more significant in high strength concretes. In high strength concretes, about 10 to 20 percent higher compressive, flexural and splitting tensile strengths are obtained with basalt and limestone coarse aggregates compared to gravel coarse aggregate. Basalt produces somewhat higher compressive strengths compared to limestone. However, in concrete with a target strength of 30 MPa, strength differences between concretes made with basalt, limestone and gravel are reduced. The comparatively higher strength of the concrete made with limestone may be due to interfacial chemical reactions between the cement paste and the coarse aggregate particles. Using a cement of higher strength and keeping other parameters unchanged in gravel coarse aggregate concrete with a target strength of 90 MPa results in about 30 percent increase in the flexural and splitting tensile strengths while the compressive strength is not practically influenced. This confirms that in high strength concretes the tensile strength is mainly determined by the mortar strength whereas the compressive strength is influenced significantly by the strength and surface characteristics of the coarse aggregate.

References

1. Neville, A.M., Properties of Concrete, p. 287, 3rd Ed., Longman Scientific, London, 1981.
2. Aitcin, P.C. and Mehta, P.K. ACI Mater. J. 87, 103 (1990).
3. Baalbaki, W., Benmokrane, B., Chaallal, O. and Aitcin, P.C., ACI Mater. J. 88, 499 (1991).
4. Giaccio, G., Rocco, C., Violini, D., Zappitelli, J. and Zerbino, R., ACI Mater. J. 89, 242 (1992).
5. Lingard, J. and Smeplass, S., Proc. 4th Int. Conf. on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, İstanbul, V.M. Malhotra, ed. 2, 1061 (1992).