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Dependence of Impact Resistance of Steel Fiber Reinforced Concrete on Aggregate Origin

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In this study, the effect of aggregate origin on impact resistance of steel fiber reinforced concrete was investigated. Using gravel-sized limestone, basalt and natural aggregates of 20 mm of maximum size, normal and steel fiber reinforced concretes were produced. Water/cement ratio and cement dosage of concrete mixtures were 0.5 and 400 kg/m^3, respectively. It should be noted that superplasticizer and steel fibers were used in concrete production. Hooked-end bundled steel fibers with l/d ratio of 65 and 1.0% fiber volume were used. After 28 days standard curing, compressive strength, split tensile strength and ultrasonic pulse velocity tests were performed on $150 \times 150 \times 150$ mm^3 cube specimens. Additionally, impact resistances of concrete specimens were determined using impact test apparatus described in ACI Committee 544. $\Phi 150 \times 300$ mm^3 cylinders were prepared for impact resistance tests. After 28 days curing, these specimens were cut into $\Phi 150 \times 64$ mm^3 dimension. Impact resistance tests were performed on these specimens. Experimental results were evaluated in terms of steel fiber presence and aggregate origin.

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1. Introduction

Impact resistance of traditional concrete is remarkably low due to its stiff nature. This aspect can be improved by fiber inclusion. Cracks may occur in concrete subjected to dynamic loading, and their formation as well as propagation can be controlled by fiber inclusion which subsequently leads to an increase in impact resistance [1–8]. Behaviour of fiber reinforced concrete under impact loads can be investigated by different test methods. One of these methods is the drop weight test. This test is simple, inexpensive and easily applicable. During the test, a 4.54 kg hammer is repeatedly dropped from a constant height (457 mm) on a concrete specimen of $\Phi 150 \times 64$ mm^3 size. It is to be mentioned that a guide is used to aligne the center points of disk and hammer during impact. Afterwards, numbers of blows to failure and formation of initial crack were determined, along with the corresponding impact energy levels. The outcomes of this test are beneficial to evaluate the effect of fiber inclusion on impact resistance of concrete [6, 9–11].

In this study, the effect of aggregate origin on impact resistance of fiber reinforced concrete was investigated. Using limestone, basalt and natural aggregates with 20 mm of maximum size, fiber reinforced concretes were produced. After 28 days standard curing, compressive strength, split tensile strength, ultrasonic pulse velocity and impact resistance tests were performed on concrete specimens. Experimental results were evaluated taking the presence of steel fiber and aggregate origin into consideration.

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2. Experimental study

In preparation of concrete mixtures, CEM I 42.5 R type normal Portland cement was used. 28 days compressive strength and specific surface of cement is 58 MPa and 3670 cm^2/g, respectively. Initial and final setting times of cement are also 170 and 260 min, respectively. C_3S, C_2S, C_3A, and C_4AF contents of cement are 61, 8.82, 7.57, and 10.68%, respectively. Crushed limestone fine aggregate with size of 0–5 mm and three different coarse aggregate types (limestone, basalt and natural aggregate) with maximum size of 20 mm were used in concrete mixtures. The origin of the limestone aggregate is a sedimentary rock composed primarily of calcium carbonate ($CaCO_3$) in the form of the mineral calcite. Basalt aggregates are derived by crushing an extrusive igneous rock composed mainly of plagioclase and pyroxene. The natural crushed aggregate is based on various geological formations, and is obtained from a local riverside quarry. The origin of the natural aggregates is dominated by andesite and limestone formations. Several physical properties of aggregates were given in Table I. 55 and 45% of total aggregate weight in specimens were fine and coarse aggregates, respectively.

TABLE I

Some physical properties of aggregates.

Aggregate type	Properties	Aggregate size	
		0–5 mm	5–20 mm
limestone	specific gravity (SSD)	2.61	2.648
	water absorption [%]	1.18	0.56
basalt	specific gravity (SSD)	–	2.71
	water absorption [%]	–	0.39
natural	specific gravity (SSD)	–	2.515
	water absorption [%]	–	0.93

Hooked-end bundled steel fiber with l/d ratio of 65, tensile strength of 1000 MPa, and 1% inclusion level (by volume of concrete) was used in steel fiber reinforced concrete specimens. Additionally, 1% (by weight of cement) superplasticizer was used in all concrete mixtures. Water/cement ratio and cement dosage of concrete mixtures are 0.5 and 400 kg/m^3, respectively. Mixture compositions of concrete mixtures are summarized in Table II.

The uniaxial compressive strength, tensile strength and ultrasonic pulse velocities of 28 day cured cubic concrete specimens of 150 mm dimension were determined in accordance with TS EN 12390-3, TS EN 12390-6 and ASTM C 597 standards, respectively. Furthermore, impact resistance tests were carried out on concrete disks at the end of 28 days curing period. These disks were prepared by cutting $\Phi 150 \times 300$ mm^3 cylinder concrete specimens using a stone cutter. Impact tests were performed in accordance with proposed test methods by ACI Committee 544. Using this method, number of blows and corresponding energy levels leading to failure and formation of initial crack were determined.

TABLE II

Mix proportions and description of concrete mixtures.

Mixture code	Cement [kg/m^3]	Water [l]	Fine aggregate [kg/m^3]	Coarse aggregate [kg/m^3]	Steel fiber [kg/m^3]	Superplasticizer [kg/m^3]	Unit weight [kg/m^3]	Slump [mm]
LC	400	200	942	782	0	4	2327	120
LFRC	400	200	927	770	78.1	4	2379	108
BC	400	200	942	800	0	4	2346	126
BFRC	400	200	927	788	78.1	4	2397	115
NC	400	200	942	742	0	4	2288	145
NFRC	400	200	927	731	78.1	4	2341	131

TABLE III

Mechanical and dynamic test results.

Mixture code	Compressive strength [MPa]	Tensile strength [MPa]	Ultrasonic pulse velocity [m/s]	Impact resistance (blows)		Impact energy [kN mm]		F–FC
				First crack (FC)	Failure (F)	FC	F	
LC	34.8	3.68	4456	34	37	6877	7626	3
LFRC	36.8	4.14	4385	243	315	49572	64416	72
BC	36.9	3.67	4448	35	37	7218	7558	2
BFRC	38.8	4.13	4410	248	315	50729	64348	67
NC	32.3	3.39	4448	33	34	6809	6877	1
NFRC	35.7	3.65	4393	232	296	47393	60535	64

3. Results and discussion

The results of mechanical and dynamic tests were summarized in Table III. Compressive strength of concrete specimens using basalt aggregate were higher than the specimens prepared using limestone and natural aggregates. Minimum compressive strength value was obtained by testing concrete specimens prepared using natural aggregate.Use of basalt or limestone aggregates instead of natural aggregate led to increases in compressive strength values at rates of 8–14% and 3–9% for normal and steel fiber reinforced concrete, respectively. Maximum tensile strength values were generally obtained at concretes prepared using basalt and limestone aggregates. Minimum tensile strength values were also obtained at concretes prepared using natural aggregate. Tensile strength values of concretes were increased by the use of basalt aggregate instead of natural aggregate by 8% and 13% for normal and steel fiber reinforced concrete, respectively. Ultrasonic pulse velocities of concretes varied between 4385 and 4456 m/s. These results revealed that aggregate type in both normal and steel fiber concretes were not significantly affective on ultrasonic pulse velocities of specimens.

As shown in Table III, impact resistance of ordinary concrete specimens were close. However, inclusion of steel fiber remarkably improved the impact resistance of concretes. First crack blows and failure blows were approximately increased 7 to 8.5 times by inclusion of steel fiber. Change in aggregate type is not significantly effective on impact resistance of steel fiber reinforced concretes. No changes in number of blows causing formation of first crack and failure was recorded on specimens prepared using different types of aggregates. Table III also shows the calculated impact energy values required to formation of first crack and failure. Besides, impact performances of concretes were given for all concrete mixtures. Impact performance was calculated as number of blows from first crack to failure (F–FC). Impact performance of steel fiber reinforced concretes were increased by 24, 33.5, and 64 times for limestone, basalt, and natural aggregate concretes, respectively. This result indicates that fiber inclusion is significantly effective on impact resistance of natural aggregate concrete. Impact performance of concrete was increased approximately 3 times by use of natural aggregate instead of other aggregate types.

The reason of the increase in mechanical and impact properties of concrete prepared using limestone and basalt originating coarse aggregates, in comparison with those prepared using natural coarse aggregates can be explained by greater specific surface area and surface roughness provided by limestone and basalt aggregates, in comparison with those of natural aggregates. Eventually, concrete produced using limestone and basalt aggregates provides a stronger bonding in transition zone between coarse aggregate and cement paste. Several studies in the literature support the findings of this study related to variations in mechanical properties [7, 8, 12–14].

It should be emphasized that the reason of the increase in impact resistance of steel fiber concretes can be due to prevention of crack formation and propagation in mortar phase. Additionally, many studies in the literature underline that presence of steel fiber in concrete improves tensile strength and impact resistance [7, 8, 15–18].

4. Conclusion

In this study, the effect of aggregate type on impact resistance of normal and steel fiber reinforced concrete specimens were experimentally investigated. In normal concrete prepared without fiber, it was observed that aggregate type is effective on compressive strength, split tensile strength, first crack and failure blows of concrete. Maximum compressive strength was obtained in concrete specimens composed of basalt aggregate, whereas minimum compressive strength was obtained by testing concrete specimens including natural aggregate. Concretes composed of basalt and limestone have approximately the same tensile strength values, whereas concrete containing natural aggregate shows lower tensile strength. Blows to initial crack and failure of all concretes were close to each other.

Compressive and tensile strength of concretes were increased by inclusion of steel fiber in concrete mixtures; however this increase is not significant. Effect of steel fiber is clearly observed in impact resistance of concrete specimens. Blows from first crack to failure were improved up to 64 times by fiber inclusion. Highest increase was observed in natural aggregate concretes. Impact performance of concrete was increased 3 times by use of natural aggregate, compared with specimens including other aggregate types.

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