Using the Plate-Creep test to determine the impact strength properties of concrete

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ABSTRACT

The paper aims to design a concrete against repetitive impact and abrasion resistance. Macro/micro steel fibers and two types of crushed stone based on limestone and corundum as aggregate were used in concrete mixtures. Impact test device has been modified, designed and used for impact strength testing of concrete. The usability of the plate creep test in determining the impact strength of concrete was also investigated.

According to the test results, a high correlation was found between the abrasion, impact resistance tests and the creep test.

Key words: Impact resistance, energy absorption capacity, corundum and limestone aggregates, abrasion strength, macro-micro steel fibers.

INTRODUCTION

Fiber reinforced cement composite has become a widely applied versatile material in the construction industries due to its various advantages (Bentur and Mindess 2006; Wongprachum et al., 2018). These include, but are not limited to, bridging and sealing cracks, toughness and tensile stress capacity, reducing the need for steel reinforcement and workers, repairing concrete structures, and providing a durable and permanent solution (Wongprachum et al., 2018; Banthia et al., 2014; Banthia and Sappakittipakorn 2007; Banthia and Gupta

2006). Due to these benefits, the fibers prevent degradation of cementitious matrices (Wongprachum et al., 2018). Ultra-high performance fiber-reinforced concrete developed in the mid-1990s has been recognized as one of the most promising building materials for architectural or individual structures subjected to earthquakes, shocks and extreme loads (Yoo and Banthia 2017). The fiber-reinforced cement composite is suitably used for structures under flexibility or stress, as it prevents crack propagation and can expand the crack by fiber bridging (Yoo et al. 2017). Various types of fiber-reinforced cement-based materials, including metallic, polymeric, carbon, glass, nylon, and waste rubber fibers, have been successfully developed and effectively applied for infrastructure (including buildings, tunnels and bridges) due to the benefits of limiting crack propagation and widening through fiber bridging (Yoo et al. 2019). In addition, increasing the static tensile and bending performance of ultra-high performance fiber reinforced concrete has been successfully achieved by using deformed steel fibers (hooked or twisted) or by increasing the aspect ratio of plain steel fibers without increasing the fiber volume content (Yoo et al., 2017; Richard and Cheyrezy 1995; Wille et al., 2011; Yoo et al., 2015). Concrete and fiber-reinforced concrete are very sensitive to loading speeds (i.e. strain or strain rates) that exhibit completely different behavior under impact loads compared to static loads, so the technology needs a new study on impact strength (ACI 201).

In this study the use of slab creep test to determine the impact strength of concrete was investigated.

MATERIALS AND METHOD

Materials

Aggregate

In the study limestone and corundum aggregates with a maximum granule size of 12 mm, whose physical properties are shown in Table 1, were used as aggregates. The density of limestone-based aggregate is 2.70 g/cm^3 and the density of corundum aggregate is 4.55 g/cm^3.

Table 1 Physical properties of limestone aggregate and corundum aggregate

Physical properties	Limestone Aggregate		Corundum Aggregate	
	Fine Aggregate	Coarse Aggregate	Fine Aggregate	Coarse Aggregate
Sieve Diameter	0-4 mm	4-8 mm	0-4 mm	4-8 mm
Density (g/cm^3)	2.65	2.65	4.10	4.10
Water Absorption (%)	1.80	0.75	0.10	0.05

Chemical Additive

In this study, a polycarboxylate-based hyper plasticizer admixture has been used to preserve the consistency of the fresh concrete for 60 minutes and to settle in the mold with its own weight, considering the application conditions. The density of polycarboxylate-based superplasticizer is 1.11g/cm^3 and pH 5.7 and solid matter 29%.

Blast Furnace Slag (BFS)

The blast furnace slag with a density of 3 gr/cm^3 and a specific surface area of 4785 cm^2/gr was used in this study. Chemical analysis of blast furnace slag is shown in Table 2.

Calcite (Ca)

The maximum grain size of calcite use in the study is 75 microns. Calcite has a density of 2.72 g/cm^3 and a surface area of 4760 cm^2/g. The chemical properties of calcite are given in Table 2.

Table 2 Chemical properties of Blast Furnace Slag and Calcite

Properties	SiO_2	CaO	Al_2O_3	MgO	MnO	S	Fe	K_2O	Na_2O	TiO_2	Fe_2O_3	SO_3	Ca
BFS (%)	38.5	36.31	9.98	7.8	2.92	0.63	0.66	1.38	0.23	1.31	-	-	-
Ca (%)	0.01	53.94	0.07	1.93	-	-	-	0.13	0.06	-	0.05	0.01	44.54

Cement

The properties of the cements CEM I 42.5 and CEM I 52.5 are given in Table 3.

Table 3 Physical and chemical properties of CEM I 42.5 and 52.5 cement

Physical Properties	CEM I 42.5	CEM I 52.5	Chemical Properties		
			Content (%)	CEM I 42.5	CEM I 52.5
Density (g/cm^3)	3.1	3.15	SO_3	2.8	2.57
Blaine (cm^2/g)	3355	4654	SiO_2	20,5	21,6
2 days strength (MPa)	27.3	29.5	Al_2O_3	5.27	4,28
28 days strength (MPa)	51.7	61.5	CaO	62.2	65,8
Volume expansion (mm)	1	1	Na_2O +K_2O	0.82	0.49

Macro and Micro Steel Fibers

In concretes produced using limestone aggregates, the total fiber amount was kept constant as 110 kg/m^3 (macro + micro steel fiber). The fiber amount in concretes produced with corundum aggregate was kept constant as 100 kg/m^3 (macro + micro steel fiber). Brass coated micro steel fiber with a diameter of 0.25 mm, a length of 6 mm and a tensile strength of 2100 N/mm^2 was used to strengthen the surface of the fine material paste and prevent micro cracks (Figure 1a). Macro steel fiber of 35 mm in length, 0.75mm in diameter and 1200 N/mm^2 tensile strength was used (Figure 1b) in this study.

Figure 1 (a) Brass coated micro steel fiber and **(b)** macro steel fiber

Metot

In order to solve the segregation problem and increase the viscosity of self-compacting concrete prepared by using polycarboxylate-based plasticizer additive, the amount of materials smaller than 100 microns was taken as at least 700 kg (cement + calcite + blast furnace slag) in 1 m^3. In concrete mixtures made with limestone aggregate, cement type was chosen as CEM I 42.5 and cement dosage was taken as 520 and 560 kg/m^3. In concrete mixes made with corundum aggregate, the cement type is CEM I 52.5 and the cement dosage is 475 kg/m^3. The amount of calcite and blast furnace slag in all concrete mixtures was kept constant as 150 kg/m^3 and 120 kg/m^3 respectively. The amount of water in concrete mixes is adjusted to have a spread of at least 650 mm. The amount of polycarboxylate-based admixture has been fixed as 3% of the cement dosage in all concrete mixtures.

Concrete Mix Ratios

The concrete mix proportions prepared in this study are given in Table 4. 0-4 mm limestone-based aggregate was added to corundum aggregate concrete in order to solve the problem of high density of corundum aggregate and segregation that may occur in concrete

Table 4 Concrete mix ratios produced with limestone aggregates and corundum aggregates

Materials	Limestone 1 (kg/m^3)	Limestone 2 (kg/m^3)	Corundum 1 (kg/m^3)	Corundum 2 (kg/m^3)
Cement Type	CEM I 42.5	CEM I 42.5	CEM I 52.5	CEM I 52.5
Dosage of the cement	520	560	475	475
Water	190	197	175	175
0-4 mm fine aggregate (limestone)	750	700	580	580
0-4 mm fine aggregate (corundum)	--	--	600	600
4-8 mm coarse aggregate	600	602	530	530
Calcite	150	150	150	150
Blast furnace slag	120	120	120	120
Macro steel fiber	70	80	40	60
Micro steel fiber	40	30	60	40
Chemical additive	15.6	16.8	14.2	14.2
Spread diameter for t=0 min (cm)	67	66	68	67
Spread diameter for t=60 min (cm)	68	68	68	69
Theoretical unit volume weight	2455.6	2455.8	2744.2	2744.2

Compressive Strength Test

The prepared concrete cubes of 150x150x150 mm were subjected to the compressive strength test in accordance with EN 12390-3 (EN 12390-3 2019).

Flexural Strength Test

Concrete beam samples were tested in accordance with EN 12390-5 (EN 12390-5 2019). Beam samples with dimensions of 100x100x500 mm were tested by loading at a speed of 1 kN/sec.

Abrasion Resistance Test

Concrete specimens of 100x100x100 mm dimensions are subjected to abrasion test. Abrasion resistance was carried out on concrete samples on the 28th day in accordance with the principles specified in ASTM C944/C944M (ASTM C944 2019). The samples were exposed to the abrasive wheels at 200 rpm under the weight 3 times at 2 minute intervals. At the end of the experiment, the weight loss by mass in the samples was measured and the results were calculated as "% weight loss".

Creep Test

The creep test was conducted to determine the energy absorbed in concrete. The toughness energy was found from the area under the curve by drawing load-deflection graphs of the slab samples. The test was carried out according to EN 14488-5 (EN14488-5 2006) standard on 600x600x100 mm concrete slabs.

Figure 2 shows the testing of slab samples. Slab samples were loaded with 100x100 mm dimensions from the middle point and the deformation up to 10 mm at the bottom of the slab was measured. Load-deflection graphs of the slab samples were drawn and the toughness energy was found from the area under the curve.

Figure 2 The testing of slab samples

Energy Absorption Capacity

In this study the energy absorption capacities of fiber reinforced concrete were determined by testing according to EN 14488-5 (EN14488-5 2006) standard on 600x600x100 mm concrete slabs. The energy absorption capacity was found from the area under the curve by drawing the energy-deflection graph with the amount of the energy found (Figure 8). The EN 14487-1 (EN14487-1 2006) standard divides the energy absorption performance of the slab into 3 groups as 500 J, 700 J and 1000 J for the deformation of the slab up to 25 mm.

Impact Resistance Test

The impact test device has been modified and built according to The South African Bureau of Standards (SABS 541) Impacting Steel Balls Abrasion Test standard (South African Bureau of Standards 2012). Concrete samples with a surface area of 270x270 mm and a height of 100 mm were prepared for the impact test. Before the test, each sample was weighed and its weight recorded. 25 iron balls with a total mass of 12500 gr and a diameter of 45 mm were placed in the impact test device. The prepared concrete samples were tested for 12 hours in the impact test device with a speed of 60 ± 2 rpm (Figure 3). The test device was rotated 6 hours on the right axis and 6 hours on the left axis. Then, the weight of each sample was weighed after the experiment and recorded. The weight loss before and after the test was found in percent and defined as the percent weight loss.

Figure 3. Impact Resistance Test Device

EXPERIMENT RESULTS

Compressive and Flexural Strength Test Results

Compressive strength test results of concrete samples are given in Table 5. Compressive strengths of prepared concretes are between 80-93 MPa. As a result of the use of CEM I 52.5 cement in concretes produced with corundum aggregate, the low water/cement ratio and the density of the concrete being approximately 2744 kg/m^3, the compressive strength results were higher than the concretes produced with limestone-based aggregate. Beam flexural test results (Table 5) are very close for concrete with limestone and corundum aggregates.

Table 5 Compressive and flexural strength results of concrete samples on 28 days

Mixtures	Compressive Strength (MPa)	Flexural Strength (MPa)
Limestone 1	80.15	11.23
Limestone 2	84.30	11.69
Corundum1	90.80	11.65
Corundum 2	93.58	11.88

Abrasion Test Results

When the abrasion test results were made according to the ASTM C944 (ASTM C944 2019) standard (test period 2 minutes for one side of the sample), it was observed that the abrasion was only on the cement paste surface. There was a mass loss in concrete samples between 0.5 and 1 g as a result of abrasion. These values did not give correct results because the abrasion could not reach the aggregate surface. The duration of the test has been increased to 12 minutes in order to create abrasion on the aggregate surface. Abrasion was observed on aggregates after 12 minutes. Abrasion test results of the samples are given in Table 6. The weight loss was 0.38-0.36% for concretes produced with corundum aggregates, while it was found to be 0.65-0.60% in concretes containing limestone aggregates. It has been determined that concrete produced with corundum aggregates has high resistance to abrasion.

Table 6 Results of the Abrasion Test

Mixtures	Limestone 1	Limestone 2	Corundum 1	Corundum 2
Weigth loss (%)	0.65	0.60	0.38	0.36

Results of The Creep Test and Energy Absorption Capacity Test

In the energy absorption capacity test, it was observed that there was a significant increase in energy absorption capacity as the macro steel fiber dosage increased in concrete mixtures produced with limestone and corundum aggregates. In concretes produced with limestone aggregate, an increase of 192 joules in toughness energy was created with the increase in the volume of cement paste and macro steel fiber for the creep test. In concretes produced with corundum aggregate, the volume of cement paste was kept constant, and the toughness energy of 12 joules increased with the increase in the rate of macro steel fiber. The limestone 2 concrete mix design made with limestone aggregate with the highest macro steel fiber content (80 kg/m^3) has the highest toughness energy with 955 joules. As can be seen from the results, the increase in the rate of macro steel fiber has led to an increase in toughness energy in concrete. The deformation measurement that occurs in concrete slabs is shown in Figure 4.

Figure 4 Measurement of deformation in slab samples

Load-deflection graphs of concretes produced with limestone and corundum aggregates are given in Figures 5-6-7 and 8. The toughness energy was found from the area under the load-deflection curve (Table 7).

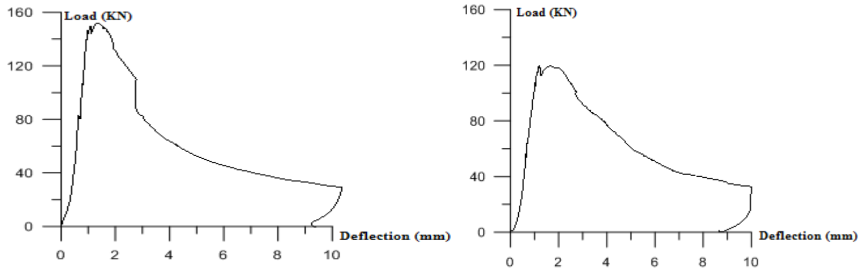


Figure 5. Load-Deflection graphs for concrete slabs of Limestone 1.

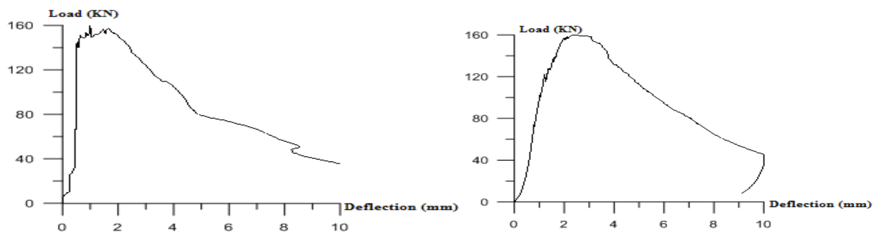


Figure 6 Load-Deflection graphs for concrete slabs of Limestone 2.

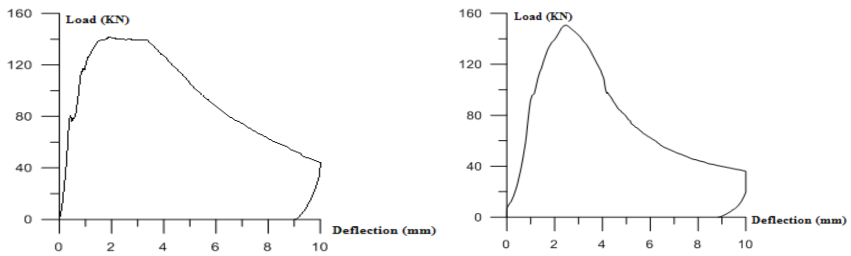


Figure 7 Load-Deflection graphs for concrete slabs of Corundum 1.

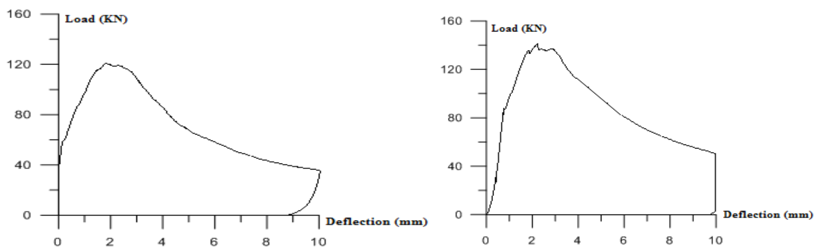
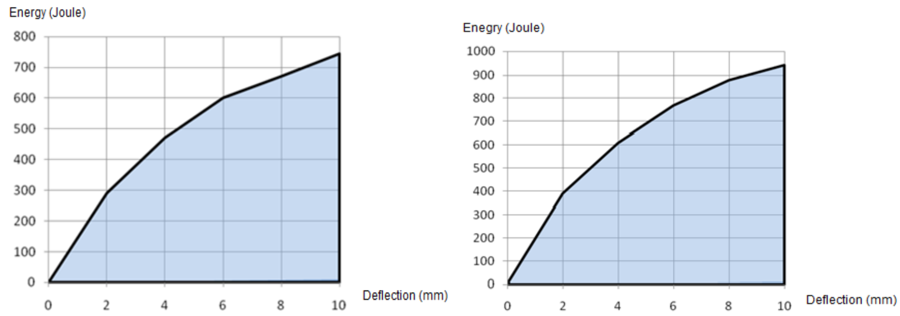


Figure 8 Load-Deflection graphs for concrete slabs of Corundum 2

Table 7 Toughness energy of concrete slabs

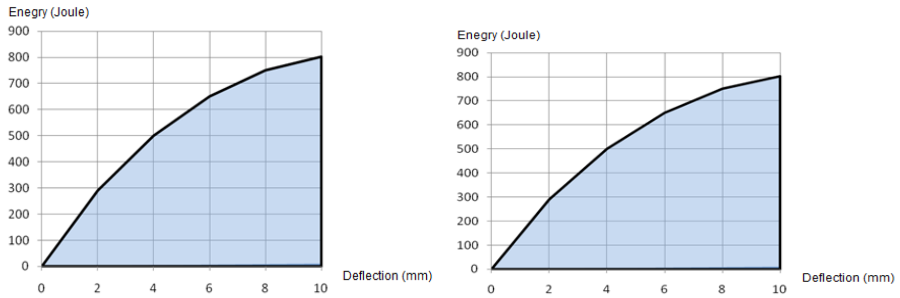
Mixtures	Limestone 1	Limestone 2	Corundum 1	Corundum 2
Toughness Energy (Joule)	763	955	800	812

Energy-deflection graphs were drawn with the toughness energy found. Energy absorption capacities from the area under the energy-deflection curve were found in Figures 9 and 10.



Limestone 1 Limestone 2

Figure 9 Energy-deflection graphs of limestone aggregate concretes



Corundum 1 Corundum 2

Figure 10 Energy-deflection graphs of corundum aggregate concretes

As can be seen in Table 8, it was determined that the concrete with the highest energy absorption capacity with the Limestone 2 concrete mixture with 6296 joules.

Table 8 Energy absorption capacity of concrete slabs

Mixtures	Limestone 1	Limestone 2	Corundum 1	Corundum 2
Energy absorption Capacity	4873 J	6296 J	5190 J	5212 J

Impact Resistance Test

Less weight and volume loss occurred in limestone aggregate concretes with a macro steel fiber amount of 70 and 80 kg/m^3 in the impact resistance test. When limestone and corundum aggregate concretes were subjected to impact resistance test at the same time, 4 and 2.9% weight loss occurred in limestone 1 and limestone 2 concretes, respectively, while 7.5 and 6.3% weight loss occurred in corundum 1 and corundum 2 concretes (Table 9).

The macro steel fiber dosage used in limestone aggregate concretes was kept higher than concrete with corundum aggregate. The high macro steel fiber content has absorbed the energy resulting from the impact on the surface of the concrete by spreading it more homogeneously throughout the concrete. Less weight loss occurred in concretes prepared with limestone aggregates as a result of the impact test. It was determined that the least weight loss (2.9%) occurred in the concrete with 80 kg/m^3 macro fiber content and limestone aggregate. When concretes produced with corundum and limestone aggregate are evaluated together, the weight loss occurred less in concrete with a high amount of macro steel fiber. According to the impact test results, it was concluded that the compressive strength does not have much effect on the impact strength after a certain strength limit, and the impact strength increases with the increase of fiber content. It has been determined that the increase in the amount of macro steel fiber has a direct effect on the impact effect.

Table 9 Impact resistance test results of samples

Mixture	First Weight (gr)	Weight after 12 hours (gr)	Total weight loss (gr)	Weight percent loss (%)
Limestone 1	16722	16053	669	4.0
Limestone 2	16664	16181	483	2.9
Corundum 1	18848	17434	1414	7.5
Corundum 2	19671	18432	1239	6.3

CONCLUSIONS

In this study, the spread of the self-compacting concrete produced by using polycarboxylate-based plasticizer additive was adjusted to be at least 650 mm. The segregation problem that may occur due to the high spread was solved by adjusting the amount of powder material (cement + calcite + blast furnace slag) to 700 kg/m^3. Compressive strengths of concrete with limestone aggregate were found to be 80.15 and 84.30 MPa, and compressive strengths of concretes with corundum aggregates were found to be 90.30 and 93.58 MPa. According to the abrasion test results, 0.65% and 0.60% weight loss occurred in concrete with limestone aggregate, while 0.38% and 0.36% weight loss occurred in corundum aggregate concretes. Corundum aggregate concretes gave better results than limestone aggregate concretes in terms of abrasion test. The abrasion resistance is high due to the hardness of the corundum aggregate being 9 according to the Mohs scale.

When concretes produced with limestone and corundum aggregate are subjected to impact test at the same time, 4 and 2.9% volume loss occurred in concrete with limestone aggregate, while 7.5 and 6.3 volume loss occurred in corundum aggregate concretes. With the increase in the amount of Macro steel fiber (35 mm in length, 0.75mm in diameter), the impact strength of concrete increased. With the increase in the length and diameter of the macro steel fiber, the bond length formed in the concrete increased and the energy absorption capacity improved.

It was determined that prepared concrete with limestone aggregate and 80 kg/m^3 macro steel fiber had the highest energy absorption capacity with 6296 joules in this study and the weight loss was the least with 2.9% in the impact resistance test. Although the concrete produced with corundum aggregates increased the compressive strength and abrasion resistance, it was found that corundum aggregates did not affect the impact and energy absorption capacity much. In the load-deflection graphics, the first fractures and the first crack formation occurred in the cement paste. After the first crack formation, the load is placed on the fibers. In the creep test, it was revealed that the compressive strength of concrete samples was effective in the formation of the first cracks, while the fiber dosage was important in toughness and energy absorption capacity.

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