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EFFECT OF SYNTHETIC FIBERS ON ENERGY ABSORPTION CAPACITY OF NORMAL AND HIGH PERFORMANCE CONCRETE

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A b s t r a c t

With the increasing aim of incorporating concrete in different applications and infrastructure elements, the use of macro synthetic fiber incorporated concretes has become real popular thanks to their high energy absorption capacity, toughness and impact resistance. The aim of this study is to investigate the effects of synthetic fibers on toughness and energy absorption of normal and high performance concretes. For this experimental study, eight concrete groups were designed using synthetic fibers of various amounts (0, 3, 6 and 9 kg/m3) for both normal and high performance concretes. To determine the energy absorption capacity of concrete mixtures performance tests were conducted over square plates specimens with dimensions of 600×600×100 mm3, loaded on the center according to the EN 14488 standard. Besides the energy absorption capacity, other mechanical properties such as Poisson ratio, elasticity modulus and compressive strength were also determined. The test results show that the energy absorption capacity of concrete has been enhanced significantly with increasing the amount of the synthetic fibers.

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Introduction

The incorporation of fibers into concrete has helped to overcome a big disadvantage of this material. Thanks to this improvement, concrete elements are not just used in compression loading cases, but also in places where toughness and impact resistance are needed. Not to mention that many disadvantages of concrete, such as plastic shrinkage, are able to be compensated by the use of fibers. All of these enhancements and much more can be satisfied when the proper type, shape and size of fibers are used. These enhancements and their effects on the properties of concrete were examined by many researchers[1]–[4]. Because of their local nature, the cracks induced by humidity or temperature variations are best controlled by short fibers, while the long ones are more effective when it comes to the applications where good ductility is needed or higher deformations are expected [5]. In addition to the length (L) the diameter (D) of the fibers has also a big influence on the bonding between the fibers and the concrete, that can be seen better through the ratio of L/D [6]. Moreover, fibers made from different materials like steel, glass and synthetic fibers also have different effects on concrete's behavior[1]–[3], [7].

Synthetic fibers which are made of polymers that come from raw materials such as petroleum based chemicals or petrochemicals have been widely used in concrete applications mostly for economic reasons. The mechanical properties of synthetic fiber concrete vary widely in relation to the strength, modulus of elasticity, type, length, and dosage of the fiber [3]. Therefore, these variations are also reflected on the geometry of test specimens especially on the direction perpendicular to the applied stress.

For concrete test specimens, it is generally known that the dimensions of the specimen affect the test results depending on the size of the concrete's ingredients. Even though, the test standards allow the use of different geometries for the same test, like cubic or cylindrical specimens for compressive strength test. For fiber reinforced concrete, bending tests applied on beams are the most commonly used mechanical test. According to the Brite-Euram Project BRPR-CT98-0813 "Test and Design methods for Steel Fiber Reinforcement Concrete", the reduction of the depth of the tested beam enhances the scatter of the results particularly with low dosages due to small number of fibers crossing the crack in contrast well orientation of fibers known as wall effect enhances the general performance of fiber reinforced concrete [8], [9].

The main objective of this study was to quantify differences in flexural toughness of concrete made with different dosages (3, 6 and 9 kg/m3) using the same macro synthetic fiber type for a normal concrete with a mean compressive strength 48.6 MPa and a high performance concrete with a mean compressive strength of 56.4 MPa. In addition to that, the effect of specimen size on the test result was also investigated.

Experimental Study

1. Materials and mix proportions

In all the concrete mixes CEM I 42.5 R Type Portland cement, class F fly ash and crushed limestone aggregates were used. Furthermore, to enhance the workability of the concrete silica fume and polycarboxylic ether based, high range superplasticizer are used for high performance concrete (HPC) while a normal range water reducer was used for normal performance concrete (NPC). Three different sizes of crushed limestone aggregate were used in this work, a 0-4 mm fine aggregate with a ra/7tio of 50% and two coarse aggregates, a 4-12 mm and a 12-25 mm, with a ratio of 25% each. The fiber used in this study was a polypropylene macro synthetic fiber which has a 54 mm length, a 0.91 specific gravity and nearly 600 MPa tensile strength, shown in Fig. 1.

Fig. 1. Synthetic fibers used in this study (Forta- Ferro).

In the two concrete groups there were 250 and 400 kg/m3 of Portland cement, 0.5 and 0.32 of water cementitious ratio respectively for NPC and HPC.

The mix Proportions for each concrete specimen group are shown in Table 1. Eight concrete groups were designed with respect to the amount of synthetic fibers for each normal and high performance concrete.

Table 1. Mix Proportions (kg/m^3) for each concrete group.

Mix ID	w/c	C	W	S.F	F.A	C.A	Synthetic Fibers	Fine Agg.	Coarse Agg. 1	Coarse Agg. 2	Total
HPC-0	0.32	400	170	30	100	5.30	-	819	423	423	2370
HPC-3							3	817	423	423	2370
HPC-6							6	811	420	420	2362
HPC-9							9	808	418	418	2358
NPC-0	0.50	250	156	-	62.5	3.75	-	890	461	461	2305
NPC-3							3	936	484	484	2380
NPC-6							6	932	482	482	2375
NPC-9							9	928	480	480	2369

NOTE: w/c= water to cementitious ratio, C = Cement, W = water, S.F = Silica Fume, F.A = Fly Ash, C.A = Chemical Admixture

Three plate specımens were prepared which dimensions of 600 x 600 x 100 mm^3 .In addition to that, three cylindrical specimens with a diameter of 100 mm and a height of 200 mm were also used to determine the compressive strength and the modulus of elasticity of each concrete group. Fresh concrete properties are shown for each mix design as shown Table 2.

Table 2. Fresh concrete properties for each concrete groups.

Mix ID	Unit weight (kg/m^3)	Slump (cm)
HPC-0	2508	70 (flow)
HPC-3	2381	60 (flow)
HPC-6	2483	20
HPC-9	2457	5
NPC-0	2393	23
NPC-3	2457	Zero slump
NPC-6	2495	Zero slump
NPC-9	2406	Zero slump

2. Testing method

All the tests were applied after 28 days of curing. The elastic modulus and the compressive strength of each mixture were determined by using the cylindrical specimens according to ASTM C 469 and ASTM C 39.

Energy absorption capacity tests were performed on 600 x 600 x 100 mm slabs according to the EN 14488-5 which is performed to assess the flexural performance and the residual resistance characteristics of fiber reinforced concrete (FRC) and shotcrete slabs. Three slabs were tested for each group. During the test, the slab was supported on its four edges and a central point load was applied through a contact surface of 100 × 100 mm², at a constant speed of 1 mm/min by using a displacement controlled loading scheme through an MTS Landmark 250 kN loading frame as shown Fig 2.

Fig. 2. Energy Absorption Capacity test are performed by using MTS Landmark 250.

Test Results

1. Compressive strength and modulus of elasticity

The mean compressive strength at 28 days for both control mixtures of HPC and NPC were 56.4 MPa and 48.6 MPa respectively. The test results are shown in Table 3. After a slight decrease in the strength comparing to the control mix, the incorporation of the synthetic fibers enhanced the compressive strength by about 3 to 4 MPa with increasing the amount of synthetic fibers for HPC. On the other side, the fiber addition decreased the compressive strength by about 8 MPa in average for NPC. The modulus of elasticity decreased slightly when compared to control specimens because of the lower modulus of the fibers. This fluctuation in the results of these two tests might be because of the fact that each mixture has a different compactibility, and hence it has a different pore distribution and different density. Therefore, it is difficult to correlate the synthetic fibers addition amount to the compressive strength and the modulus of elasticity.

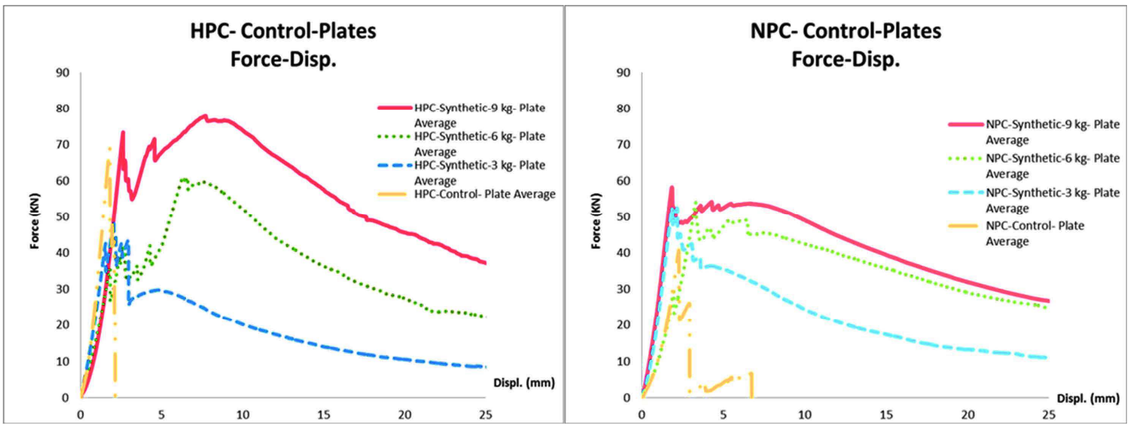
Table 3. Results of mean mechanical properties of test specimens.

Mix ID	Compressive Strength (MPa)	Modulus of Elasticity (GPa)
HPC-0	56.4	42.2
HPC-3	53.6	35.3
HPC-6	56.2	35.3
HPC-9	62.7	36.7
NPC-0	48.6	31.3
NPC-3	40.5	32.9
NPC-6	43.2	34.4
NPC-9	34.1	

2. Load deformation relationship

The average load deformation curves obtained for each concrete group are shown in Fig. 3. The dosage value affected the scatter of results in the post crack region. The scatter was relatively small for the plain concrete and for the dosage value of 3 kg/m3 synthetic fibres.

Fig. 3. Load deflection relationship for normal and high performance concretes.



As it is clear from those figures, the addition of the fibers significatly altered the load-deformation behaviour. For NPC mixtures the load at the first crack was about 50 kN whereas for HPC mixtures this increased to about 70 kN.

Moreover, at the end of each test, the bottom surface of the panels was photographed. Typical pictures are shown the following figures (Fig 4-5). As it can be seen from these pictures, the patterns of the cracks are similar for NPC and HPC.

Fig. 4. Crack patterns for High Performance Concrete (HPC)

Fig. 5. Crack pattern for Normal Performence Concrete (HPC)

As it can be seen from the photos above, as the amount of fibers increased more cracks were observed which is consisted with the continued recovery of the load reductions, which is especially more visible for HPC mixtures.

3. Energy Absorption Capacity (Flexural Toughness)

The Energy Absorption Capacity is determined by calculating the area under the load deflection curve of the concrete specimens under flexural loading as explained by the related standard (the maximum deflection is taken as 25 mm).

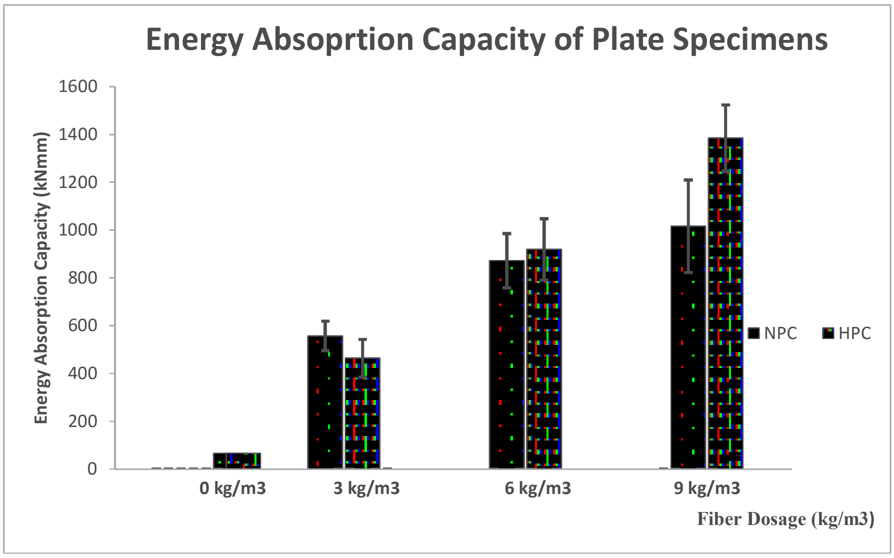
The results are shown in Table 4.

Table 4. Mean energy absorption and coefficient of variability of each group

	Load Deflection Curve (25 mm)					
Synthetic	**NPC**			**HPC**		
Energy	**Mean (kN.mm)**	**CoV**	**Percent Increase %**	**Mean (kN.mm)**	**CoV**	**Percent Increase %**
0	66	50	-	66	19	-
3 kg	557	11	744	464	17	603
6 kg	872	13	1221	919	14	1292
9 kg	1016	19	1439	1385	10	1998

Fig. 6 shows a graphical presentation of the findings. As shown in this figure there is a tremendous increase in the energy absorption capacity with increased fiber addition. In addition, high performance concrete specimens exhibited more energy absorption than normal concrete for the same dosage.

Fig. 6. Energy absorption capacity of specimens with different fibers



Conclusions

In this study, flexural performance and energy absorption capacity of normal concrete (NPC) and high performance concrete (HPC) are evaluated with respect to the use of macro synthetic fibers.

The following conclusions are drawn as the results of the experimental study.

• Energy absorption capacity of concrete plates (600 x 600 x 100 mm3) enhanced significantly with increasing amount of synthetic fibers. The increment was 15 and 21 times greater than control groups of normal concrete and high performance concrete respectively for 9 kg/m3 synthetic fiber in concrete.

• Normal concrete plates showed better energy absorption than high performance concrete plates up to 6 kg/m3 synthetic fiber usage.

• It is difficult to correlate the synthetic fibers amount and the mechanical properties of concrete such as compressive strength, elastic modulus, Poisson ratio. However, the modulus of elasticity decreased slightly when compared to the control specimens because of the lower modulus of fibers.

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