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Investigating Effect of Rheological Properties of Fiber Reinforced Self-Compacting Concrete on Stress-strain Curve

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ABSTRACT: In fiber reinforced self-compacting concrete, fibers and properties such as filling ability create a homogeneous mixture. In this research, 10 mix designs are examined and tested, one of which is related to the control sample and the other 9 designs include steel, macrosynthetic monofilament (MEX 100), and carbon fiber reinforced polymer (CFRP) fibers with volumetric percentages of 0.25, 0.5 and 0.75. The rheological behavior of fresh self-compacting concrete is investigated by rheometer test. Moreover, conventional tests that determine the self-compacting properties of fresh concrete, including slump flow, J-ring, L-box, U-box, and V-funnel tests, are examined. The behavior of hardened concrete is analyzed based on tests to determine mechanical properties (compressive strength and modulus of elasticity). The results indicate adding fibers to fresh concrete reduces the self-compacting and rheological properties of concrete. This effect becomes more visible by increasing the fiber volume ratio so that the greatest effect could be observed in designs containing CFRP fibers. The results of mechanical properties of hardened concrete show adding small amounts of fibers to self-compacting concrete improves some of these properties, while using large amounts of fibers increases ductility and, consequently, decreases compressive strength and modulus of elasticity in self-compacting concrete.

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1- Introduction

Nataraja et al. (1999) investigated stress-strain curves of concrete containing steel fibers. The results showed adding fibers to concrete affected some of the main parameters of the stress-strain curve. Moreover, adding these fibers to concrete increased the engineering properties of mortar and concrete, especially toughness (hardness), compressive strength, tensile strength, and fatigue resistance [1]. Ponkiewski (2006) investigated the effect of different types of steel fibers on the mechanical and rheological properties of self-compacting concrete. The rheological properties of concrete were examined by rheometer test. Moreover, parameters of flow limit and plastic viscosity were investigated and mechanical properties of concrete were measured by compressive strength test. The results demonstrated adding these fibers reduced fresh concrete performance and increased compressive strength of hardened self-compacting concrete [2]. Babu et al. (2008) investigated the mechanical properties and stress-strain behavior of self-compacting concrete containing glass fibers. In this research, the mixing ratio of self-compacting concrete strength was adjusted by Nan Su's method, and its precise ratios were determined by the Okamura method. The results revealed adding glass fibers to self-compacting concrete had no significant effect on the self-compacting properties of concrete. However, it increased the 28-day compressive strength, tensile strength, and flexural strength of concrete [3]. No study has ever examined and compared the effect of using MEX 100 and CFRP fibers on self-compacting concretes focusing on rheological properties (specifically rheometer device). This research aims to investigate the effect of new types of fibers on the behavior of hardened self-compacting concrete using tests that determine mechanical properties (compressive strength and modulus of elasticity) as well as rheological behavior of fresh self-compacting concrete by the novel rheometer test and conventional tests that determine self-compacting properties of fresh concrete, including slump flow, J-ring, L-box, U-box and V-funnel tests.

2- Experimental set up

The fine- and coarse-grained materials used in this research were double-washed river sand and broken pea gravel, respectively. The used filler was limestone powder prepared from one of the mines in Qazvin Province. Moreover, three types of steel, MEX 100 and CFRP fibers were employed. CFRP fibers were in the form of sheets, which were cut into 20 mm long sections and used in chopped form.

To investigate the behavior of the mentioned fibers on self-compacting concrete, 10 mix designs were tested, one of which was used for the control sample and the other 9 designs

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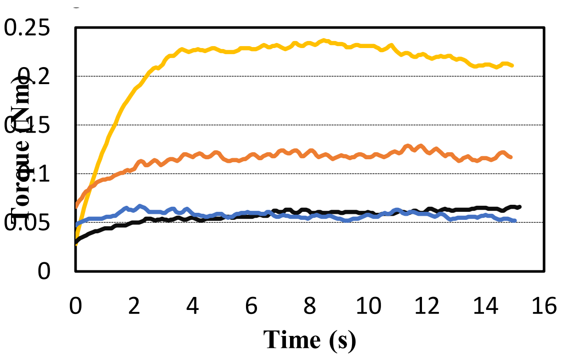

Fig. 1. Torque-time curves of optimal designs

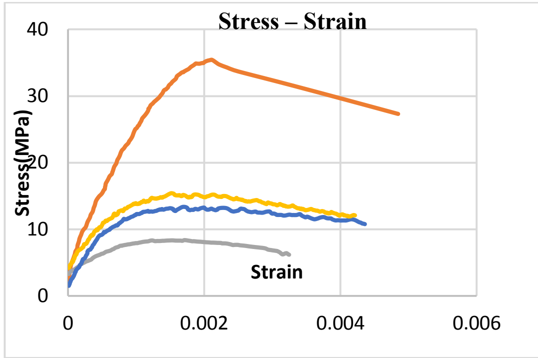

Fig. 3. Stress-strain curve of designs containing macro-synthetic fibers

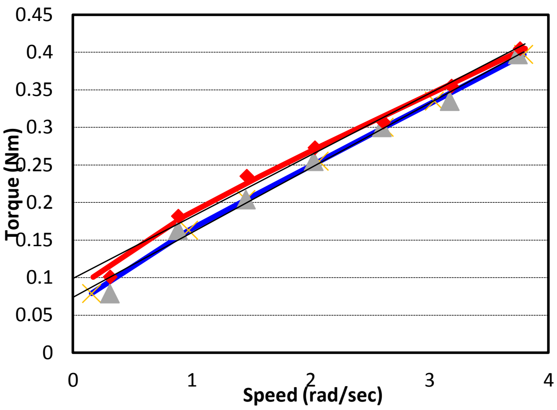

Fig. 2. Torque-velocity curve of control sample and steel fibers

included steel, MEX 100, and CFRP fibers with volumetric percentages of 0.25, 0.5 and 0.75. Several trials and errors were performed to achieve fiber self-compacting concrete with the proper efficiency recommended by EFNARC standard. Self-compacting concrete tests were carried out in two modes of fresh and hardened concrete. Fresh concrete tests included slump flow, J-ring, V-funnel, L-box, U-box and rheometer tests. Hardened concrete tests included concrete mechanical tests such as compressive strength, modulus of elasticity and stress-strain behavior.

3- Results and Discussion

Fig. 1 illustrates the maximum torque values of the tested designs. The design with CFRP fibers had the highest value, so that its peak torque values were about 3.4 times that of the control sample, the reason for which could be attributed to the increased viscosity of concrete in the design with these fibers.

Fig. 2 indicates torque-time curves in designs with optimal volume of fibers and compares these designs with the control sample. The results revealed the design with CFRP had the most change compared to the control sample, so that the torque increased with increasing the relative viscosity and flow resistance values. The linear curve obtained from this design had a higher slope compared to the control sample due to having greater torque and was in a higher position.

The elasticity modulus test results were first estimated by the equations provided in the section of testing process. Then, the real values were examined in chord and secant modes. The results showed increasing volume of fibers decreased stress in stress-strain curves as well as modulus of elasticity and increased ductility in self-compacting concrete.

Among the used fibers, the most changes in the curves compared to the control sample were related to designs containing CFRP, which was in a lower position than the control sample and its modulus of elasticity values decreased by about 43% in the design containing 0.75% fibers compared to the control sample, indicating high ductility and lower efficiency of self-compacting concrete containing this type of fibers. Macrosynthetic fibers had a smaller area under the stress-strain curve at high percentages compared to the control sample, and its elasticity modulus values in the design containing 0.75% fibers decreased by about 15% compared to the control sample. However, its stress-strain curves in designs containing 0.25 and 0.5 steel fibers were very close to the control sample, and its modulus of elasticity values increased by about 1.5% and 0.5% compared to the control sample, respectively, indicating tension tolerance was more in designs containing these fibers.

4- Conclusion

Based on the performed tests, the following results were obtained:

1. The tests conducted by the rheometer device were carried out in two parts of stress growth and flow curve. Results of stress growth tests indicated static flow stress values were directly associated with the maximum torque so that the static flow stress increased with increasing the maximum torque values. Results of flow curve tests, including dynamic flow stress, torque-velocity curve, plastic viscosity

and condensability, in torque-velocity curves showed the design containing CFRP fibers had the greatest change compared to the control sample. The torque increased with increasing relative viscosity and flow resistance. The linear curve obtained from this design had a higher slope compared to the control sample due to having greater torque and was in a higher position. Investigating dynamic flow stress, plastic viscosity and condensability showed adding the optimal volume of fibers to self-compacting concrete increased these values.

2. The test results of fresh self-compacting concrete containing fibers showed adding high volume of fibers could reduce concrete rheological properties and self-compacting concrete efficiency. Among the fibers used in this research, the behavior of steel fibers was close to self-compacting concrete, and macrosynthetic and CFRP fibers caused more changes in self-compacting concrete, respectively.

3. Results of compressive strength tests of hardened self-compacting concrete revealed the highest and lowest compressive strength values were related to designs containing steel and CFRP fibers, respectively. The values obtained from the tested designs showed the compressive strength had a downward trend with increasing the volume of fibers, the reason for which could be attributed to shrinkage, disruption of homogeneity, and improper distribution of concrete fibers. Using low volumes of steel and macrosynthetic fibers increased compressive strength, which could be attributed to the reduced length of cracks and microcracks in concrete.

4. Results of elasticity modulus and stress-strain tests indicated increasing the volume of fibers decreased stress in stress-strain curves as well as elasticity modulus and increased ductility in self-compacting concrete. Among the used fibers, most of the changes observed in the curves compared to the control sample were related to designs containing CFRP, which was in a lower position than the control sample, and its modulus of elasticity in the design containing 0.75% fibers decreased by about 43% compared to the control sample, indicating high ductility and low efficiency of self-compacting concrete containing this type of fiber.

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