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Effect of Micro Bubbles on Mechanical Properties of Fiber-Reinforced Concrete

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Abstract- The present study aims at investigating the effect of the amount of metal fiber in concrete Type with C35 strength class on the concrete behavior's indicators in terms of the various aspects of the strength thereof. The sample mixing design was set to achieve a strength degree of 350MPa, and the effect of this mixing plan was examined in two kinds of ordinary water and water containing microbubbles (MBs). The samples were also constructed at certain strength rates with an amount of fiber, 25kg/m^3. The results indicated that the use of metal fiber considerably increases the impact resistance, duration of the first crack's development and the final strength of the concrete. Moreover, the addition of such a type of fiber was found to have little effect on the concrete's compressive strength. Also, the effect of an amount of steel fiber on the mechanical specifications in the seven and 28-day ages of the concrete was examined. Based on the findings, using a mixing design and changing the type of water increased the concrete's slump when applying ordinary water compared to MBs-containing water. Considering the slump and the type of water used, the compressive strength increased in the 7- and 28-day ages for MBs-containing water mixing plan compared to the ordinary water application. The results indicated that the use of steel fiber also influences the rheological properties and brings about reductions in the concrete's efficiency. Furthermore, the use of steel fiber for 1% of the concrete's volume causes an increase in the compressive strength and concrete's durability.

Keywords- steel fiber, microbubbles-containing water, compressive strength, elasticity module.

Introduction

Concrete is one of the most widely used constructional materials. This material contains sand and gravel and cement and water. In 1992, 63 million tons of Portland cement were transformed into 500 million tons of concrete only in the US, which is per se five times the use of weighted steel for a similar period. In most countries around the globe, the ratio of concrete to steel has exceeded 10 to one. The total amount of concrete used in 1991 worldwide was over 3 billion tons which means one ton per every individual globally.

The ordinary concrete made of Portland cement and natural gravel features has a number of weaknesses such as its high weight. Efforts to reduce the concrete's weight led to innovations and the construction of modern concrete types containing various additives and fibers. Meanwhile, reducing the specific weight of concrete and mixing these materials with essential masonry of high-strength concrete causes an increase in resistance and decrease in the weight of concerts. despit the numerous advantages that concrete possesses.

In a research performed by Ghods and Sohrabi (2006) on fiber-reinforced light concrete containing Lika and Taftan pozzolans, it was observed that the tensile strength is increased tangibly with the increase in the use of steel fiber. As for the flexural strength, it was also observed that the highest strength of the concrete is attained when using steel fiber for 0.5%. Bernard (2008) investigated the load resistance of low age shotcrete reinforced with fiber and showed that the presence of fiber increases the punching shear strength of the shotcrete, though, as stated in this research, the type of the fiber does not exert much of an effect on this increase. Khaliq and Kodur (2011) dealt with the mechanical and thermal properties of the fiber-reinforced concrete such as thermal conduction, thermal expansion, and compressive-tensile strength as elasticity module for a temperature range between 20°C and 800°C. The results of the experiments indicated that the existence of steel fiber causes an increase in the concrete's tensile strength and elasticity module. Fushu et al. (2002) explored the adhesion of steel fiber to shotcrete. Their three-point bending tests indicated that the increase in the volumes of steel fiber, cement and silica causes a considerable increase in the shotcrete's adhesion. Sheng et al. (2008) dealt in research with the effect of the steel fiber on the concrete and its application in the tunnel construction industry. Based on the experiments, the concrete's failure force increased between 20% and 70% for a range from 0.05% to 1%. Jalal and Fathi (2011) dealt with the use of steel and propylene fiber separate and together, and they also investigated their roles in the flexural strength's increase or decrease. It was observed that the simultaneous use of this fiber causes an increase in the adhesion between the steel fiber and concrete as well as the maximal use of the steel fibers to ensile capacity. Ding et al. (Ding and Kusterle 2000) dealt in research with the effect of steel fiber on the compressive strength, duration of reaching maximum strength and energy absorption capability under uniaxial pressure in low ages of concrete and shotcrete. According to this research's results, adding fiber in a 2D format to the shotcrete and in a 3D format to concrete causes the strengthening and improvement of shotcrete and concrete against the disintegrations stemming from the orthogonal disintegrations and shear forces. Cengiz and Turanli (2004) dealt with investigating and comparing steel and propylene fiber types and steel meshing regarding adhesion, flexural softness, and energy absorption capability for the shotcrete. The results indicated that the use of propylene fiber causes an increase in the adhesion, flexural softness and energy absorption of the shotcrete and a reduction in the refluxing of the shotcrete masonry.

In the recent years and with the investigation of the durability of the reinforced concrete structures, especially in corrosive concrete regions, the attention of most the concrete experts and specialists has been directed to the idea that the strength cannot alone respond to all of the properties related to the concrete, especially its durability, and it is necessary for designing concrete for various regions to take into account the strength and load-bearing capacity during the productivity period, in addition, the reliability and resistance thereof. One of these methods includes nanotechnology, which enables the designing of the structures with atomic-molecular accuracy and delicacy. This means precise engineering of a structure within billionth or the very nanometer limit. Structures prepared with such precision exhibit specific and unique properties. Nowadays, the research domains related to nanotechnology have undergone a lot of expansion. One of these domains includes the investigation of the nanofluids' properties. The concept "nanofluid" points to a new form of the multiphase environments produced by getting the particles in nano sizes floated in the base fluid. Microbubbles and nanobubbles are very small bubbles. Usually, bubbles within a range from 10 micrometers to 1000 micrometers are called microbubbles; those within the ranges below 10 micrometers are called nanobubbles, and those larger than 1000 micrometers are called microbubbles (Prevenslik 2014).

The production of the microbubbles based on this method is hard for the difficulty in preventing the intermixing of the bubbles (Vlyssides et al. 2004). Due to the same reason, microbubbles are produced in various methods, and they can be divided based on their mechanism into three sets of compression, cavitation, and circulation flows. In the cavitation flow type, when the peripheral pressure in a fluid point reaches below the vapor pressure, the fluid undergoes a phase change in ambient temperature. This leads to the production of empty spaces termed cavitation bubbles. Cavitaion occurs in pumps, propellers and engines, and, usually, in most of these cases, it is an unfavorable and harmful process. However, the researchers take advantage of this phenomenon; the venturi tube is an example of this same case (Wiraputra et al. 2016). The Venturi tube is conical in shape. Suppose a pump transfers the fluid into the venturi tube. In that case, a velocity increase occurs in the compressed section of the venturi tube and the pressure is simultaneously reduced, which ends in the suction of gas from the same venturi tube.

When the pressure increases down the stream again, the bubbles that have entered the fluid are decomposed, resulting in the generation of smaller bubbles. The gas-forming bubble also affects the occurrence of cavitation. It has been proved that some materials cause the creation of a larger number of smaller spaces, and this is due to the stabilization of these empty spaces and the prevention of their disintegration and intermixing. The generator of the circulating flow features a conical shape. The production of the microbubbles is commenced using water pumping from a tangent route to inside the generator; the fluid flows in a circulating motion along the interior wall that leads to the creation of eddy flow at the center of which the pressure is low; due to the same reason, gas enters it. When the fluid expels the air from inside the generator at a very high circulation speed, the air is transformed into microbubbles (Zimmerman et al. 2008). In recent years, venturi tubes have been extensively applied for measuring the flow, transmission of natural gas, engines' internal combustion systems, industrial wastewaters' treatment, and aerosols' elimination. For example, in transferring natural gas, using a venturi tube's jet causes intermixing between the gas produced at low pressure and the natural gas produced at high pressure (Zhou et al. 2015). In cleaning the industrial wastewaters, a venturi scrubber is applied to discharge water using a high-speed gas in the chokepoint section to eliminate aerosols. Quiroz-P´erez et al. (2014) theoretically studied the gases produced by venturi tubes in gas wells. In better terms, the use of a venturi tube is very useful for combining and improving the chemical reaction and, in this way, causes an increase in efficiency. Therefore, the perception of the fluid flow and pressure changes in venturi tubes is important for saving industrial energy costs. In general, regarding the use of microbubbles in constructing concrete, no special research has been so far carried out; thus, the present study tries to investigate the effect of air microbubbles-containing water on the mechanical properties of the tested concrete. A mixing plan with a 0.4 water to cement ratio was used to make the concrete.

Materials and Methods

Specimens' Specifications

In total, 18 cubic specimens were utilized for the compressive test (in 7 and 28-day ages) as well as for determining their specific weights; for each of the compressive-tensile tests, the 18 specimens were made using water containing microbubbles, and the results were compared with the specimens made using ordinary water as stated in the article by Rakhshani and Bakhshi (2015). The production of the microbubbles-containing water was carried out using a venturi tube, as explained in the article by Ghannadi et al. (2019). displays an image of the venturi tube.

The mixtures were constructed using a cement scale of 400kg/m^3. Meanwhile, for every test plan, nine cubic specimens, 15cm×15cm×15cm, were made, and their specific weight and compressive strength were determined following seven days of curing. The compressive and tensile strength rates were measured for the specimens at 28 days. At 7-day age, nine cubic15cm×15cm×15cm specimens and, at 28-day age, nine cubic 15cm×15cm×15cm specimens were utilized for determining the indirect compressive and tensile strength rates.

The cement used in this research was Portland type that procured from the Sufian Company. In this research, two kinds of microbubbles-containing water made in Mr. Engineer Motallebi's laboratory and drinking water from Sarab city were utilized to construct the concrete samples. The sand used in this research passed through a 12.5-millimeter sieve, but it was retained in a 9.5-millimeter sieve. Use was made herein of the alluvial sand prepared from a sand-washing mine in Sarab city Jaldeh Bakhan, with its density being 2560kg/$m^{3,}$ as evidenced in the tests. In this research, users will also be made of round sand procured from a sand-washing factory in Jaldeh Bakhan, Sarab County. According to the experiments, the sand value (SE) is about -85%, so it is appropriate for making concrete. According to the tests, the gravels' water absorption was 2.86%, with their density being 2600kg/m3. The granularity of this kind of sand has been proved to match the ASTM standard, and the sand was seminally allowed to pass through a sieve no.4 so that its softness module of it can be determined.

The fiber used in the construction of the specimens is of the steel type with crimped end manufactured based on Wire 820 ASTM Standards by Zanjan's Wire Manufacturing Industries Company.

Designing the Concrete Mixing Plans

In this study, use has been made of the mixing plan presented in the article written by Rakhshani and Bakhshi (2015). They made concrete specimens using ordinary water, which is changed to microbubbles-containing water. To obtain the amount of water intended for the concrete, a ratio of water to cement materials should be preliminarily estimated. For instance, in case of efforts are made in the laboratory for making concrete, the water to cement ratio can be set to values below 0.25, considering the availability of more facilities for better compressing of the concrete and also considering the use of a proper amount of superplasticizer; however, in case it is intended to produce more efficient concrete, the ratio above can be set between 0.32 and 0.4. But, based on the laboratory and workshop experiences, a minimum amount should be considered for this ratio. At the time of the concrete part's mixing, water can be added thereto if it lacks the required efficiency.

To determine the amount of stone masonry, use was made of the mixing plan introduced in Rakhshani and Bakhshi (2015) article. They presented three mixing plans with and without additives. Considering that the present study uses the additives-free plan, C35 is the mixing plan of choice without any additives. Five hundred seventy kilograms of pea gravel was used in this article for every cubic meter, and almond gravel was applied for 380kg per every cubic meter; additionally, 825kg of sand was used per every cubic meter; a mixture of the materials above was used for an amount of 25kg along with braced or fixed-end metal fiber for constructing the specimens.

The weighted rate of the masonry for various mixing plans was calculated according to the type of concrete for a given amount of concrete in such a way that the required volume of concrete is met for the performing of the experiments. Next, the masonry was weighed. All of the applied gravels have been utilized with the dry matured surface so that there would be no need for the addition of free water. The mixing process was carried out in two stages inside a concrete mixer in such a way that, in the first stage, the mortar that included cement, sand and metal fiber was mixed with two-thirds of water and poured inside a concrete mixer and stirring was continued for four minutes so that the granules' separation possibility is reduced through initial water absorption. Then, in the second stage, the coarse grains were added along with the residue of ordinary water into a concrete mixer devise and stirring was continued for two more minutes. Concrete produced in this method features a very good homogeneity and proper performance. It is worth mentioning that the device was kept working at first for 3 to 5 minutes to mix the dry masonry so that the construction materials could be completely mixed. It was concluded through numerous preliminary tests that correct mixing in terms of both mixture and duration exerts a considerable effect on the concrete's strength. Thus, the mixing duration has been set with consideration of this significant matter and efforts were made through the proper number of mixer's circulation and stirring to mix all of the materials very well. After the termination of the mixing and making of the concrete, an amount of concrete was applied to determine the slump. The produced concrete was poured into well-lubricated and clean 15cm×15cm×15cm cubic moulds in three layers in each of which 25 strokes are blown using a metal bar onto the concrete surface and, then, using the vibration desk; it is allowed to be vibrated for 20 seconds. After the vibration, the specimens were smoothed on their surfaces and covered for 16 to 24 hours with a moist canvas fabric and, finally, extracted from inside the molds by exercising a lot of care and without striking the mould to prevent any possible damage and they were eventually kept till the experiment in a water pond with a temperature of 20±2°C.

All of the constructed specimens were selected by considering the two essential parameters of efficiency and strength of concrete (concrete's compressive strength) from both groups, namely ordinary water and microbubbles-containing water.

Hardened Concrete Tests

Before the experiment, the specimens were withdrawn from the pond and allowed to be dried on their surfaces. Then, the cubic test specimens were placed between the two plates of the device so that their surfaces were in contact with the cubic mould. Then, an orthogonal force was exerted with a fixed speed onto the cubic specimen; this force exertion was continued until the cube was broken due to the compression force. The device's hand on the force display screen returned to its zero position. The amount of force was written down from the monitor that shows a value on the jack screen following the breaking of the specimen; dividing this force by the cubic surface area gives the specimen's compressive strength.

In this research, the compressive strength was tested for the 15cm×15cm×15cm cubic specimens. Based on ASTM Standards (ASTM C 39/C 39M-0.13 2004), the compressive strength of concrete is equal to the mean of the force imposed by the jack onto the concrete surface divided by the concrete's surface area (relation 1):

$$\int \text{c}\, of\ the\ final\ strength = \frac{mean\ of\ the\ exerted\ force}{specimen's\ cross{-}section\ are}$$

(1)

Based on ASTM C39 Standards (ASTM C 39/C 39M-013 2004), the standard compressive strength test should be conducted on cylindrical specimens, 6inch in diameter and 12 inches in height (15cm in diameter and 30cm in height), with at least two specimens of the same age. However, based on the English standards, this test should be conducted on at least two cubic 15cm×15cm×15cm specimens at any age. In case the test is performed on specimens with other sizes, the obtained strength rates can be converted to one another using the correction coefficient.

Results

The cubic specimens' compressive strength results have been given in Table 1 respectively for microbubbles-containing water and ordinary water.

exhibits the ascending trend of the compressive strength in the constructed specimens; as seen, the compressive strength is increased in the specimen with the increase in the specific weight thereof. This finding holds for the concrete specimens made using ordinary and microbubbles-containing water.

Considering the results in Table 2, it is observed that the compressive strength of the concrete made using microbubbles is 1.35 times higher than that of the concrete made using ordinary water.

The observations figured out that the compressive strength is increased in the mixing plan with the increase in the specific weight .

The elasticity module test's results and the investigation of show that the increase in the specific weight of the concrete causes an increase in the elasticity module.

Considering the results of Table 4, an increase of 4.64% in the specific weight causes the compressive strength of the concrete made using microbubbles-containing water to be increased by 1.35% higher than the concrete made using ordinary water.

Considering the results in Table 4, the increase of 0.57% in the compressive strength of the microbubbles-containing concrete specimens compared to the concrete specimens made using ordinary water causes the elasticity module of the former to be increase 0.58% higher than the latter.

In an investigation of, as expected, the increase in the water to cement ratio brings about a reduction in the compressive strength.

According to Table 5, the increase of 26.15% in the slump of the concrete made using ordinary water as compared to that of concrete made using microbubbles-containing water with identical water to cement ratios causes the compressive strength of the concrete made using ordinary water to be decreased for 1.35% lower than that of the concrete made using microbubbles-containing water.

Conclusion

The results obtained from the tests performed in the current research have been summarized below:

1) The increase of 26.15% in the slump of the concrete made using ordinary water as compared to that of the concrete made using microbubbles-containing water with identical cement to water ratios causes the compressive strength of the concrete made using ordinary water to be decreased by 1.35% lower than that of the concrete made using microbubbles-containing water. In the tests of concrete specimens made using ordinary water and microbubbles-containing water with identical water to cement ratios, it was concluded that the slump of the concrete made using ordinary water is larger than that of the concrete made using microbubbles-containing water with identical water to cement ratios and this is the result of the existence of 2- to 4-micron-large particles that constitute the microbubbles and prevent the large slip between the constructional materials.
2) The compressive strength of the concrete made using microbubbles-containing water is 1.35% larger than that of the concrete made using ordinary water. Considering the use of microbubbles-containing water with particles to the micron size, this factor causes an increase in the porosity between the concrete particles as well as an increase in the integration of the concrete, which per se causes the compressive strength of the concrete made using microbubbles-containing water to become larger than that of the concrete made using ordinary water.
3) The increase by 4.64% in the specific weight causes the compressive strength of the concrete made using microbubbles-containing water to be increased by 1.35% larger than that of the concrete made using ordinary water. Masonry used in this research is of the deposited type, and since the water used in all of the specimens has been procured from one source. Only manipulations have been made inside the particles of these two kinds of water; the specific weight of the concrete obtained with both types of water (ordinary water and microbubbles-containing water) is identical and negligible in both kinds of concrete.
4) The concrete growth in terms of the 7-day and 28-day strength rates is identical for both concrete types made using ordinary water and microbubbles-containing water.
5) An increase of 0.57% in the compressive strength of the concrete specimens made using microbubbles-containing water compared to that of the concrete specimens made using ordinary water causes the elasticity module of the former to be increased by 0.58% larger than that of the latter. Considering the direct relationship between the strength and specific weight in the formula offered for the elasticity module, the elasticity module is increased with an increase in the specific weight hence the compressive strength.
6) There is no significant direct relationship between the compressive strength and the amount of fiber used in the concrete; thus, the compressive strength of the concrete cannot be so much changed with the increase in the amount of fiber or by adding more microbubbles to the water.
7) Considering that the amount of fiber does not affect the compressive strength, the increase in the elasticity module cannot be concluded from the increase in the amount of fiber.

According to the abovementioned results, it is suggested that the shrink and creep properties of the structural concrete made using microbubbles-containing water, as well as the flexural and shear behaviors of the beams made of structural concrete using microbubbles-containing water, should be investigated in the short and long run.

Data Availability Statement: Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Disclaimer: The authors declare that they have no conflict of interest.

References

[1] Bernard, E. S. 2008. "Early-age load resistance of fibre reinforced shotcrete linings." *Tunn. Undergr. Space Technol.*, 23 (4), 451-460.

[2] Cengiz, O., and L. U. T. F. U. L. L. A. H. Turanli. 2004. "Comparative evaluation of steel mesh, steel fibre and high-performance polypropylene fibre reinforced shotcrete in panel test." *Cem. Concr. Res.*, 34 (8), 1357-1364.

[3] Ding, Y., and W. Kusterle. 2000. "Compressive stress–strain relationship of steel fibre-reinforced concrete at early age." *Cem. Concr. Res.*, 30 (10), 1573-1579.

[4] Fushu, J., L. M. Lang, and Y. Sh. Che. 2002. "Performance of Toughness Indices for Steel Fiber Reinforced Shotcrete." *Tunn. Undergr. Space Technol.*, 17, 69-82.

[5] Ghannadi, M., S. F. Sagharavani, and H. Niazmand. 2019 "Laboratory analysis of the formation of micro-nano bubbles (MNBs) in venturi tube by the assistance of high-speed photography and image processing." *Mech. Eng.*, 19 (12), 3039-3049.

[6] Ghods, A., and M. R. Sohrabi. 2006. "Investigating the mechanical properties of the fiber-reinforced light concrete containing Lika and Taftan pumice." In *The seventh international congress on civil engineering*, Teacher Training University.

[7] Jalal, M., and M. Fathi. 2011. "Laboratory investigation of the role of polymeric propylene fiber along with metal fiber in the increases in the flexural strength of the light concrete." In *The first national concrete on light concrete*, Tehran University.

[8] Khaliq, W., and V. Kodur. 2011. "Thermal and mechanical properties of fiber reinforced high performance self-consolidating concrete at elevated temperatures." *Cem. Concr. Res.*, 41 (11), 1112-1122.

[9] Prevenslik, T. 2014. "Stability of nanobubbles by quantum mechanics." In *Proceeding of topical problems of fluid mechnics*, 113-116. Institute of Thermomechanics, Czech Academy of Sciences, Prague.

[10] Quiroz-P´erez, E., R. V´azquez-Rom´an, R. Lesso-Arroyo, and V. M. Barrag´an-Hern´andez. 2014. "An approach to evaluate Venturi-device effects on gas wells production." *Pet. Sci. Eng.*, 116, 8-18.

[11] Rakhshani Mehr, M., and H. Bakhshi. 2015. "Investigating the effect of the fiber amount and strength category on the mechanical properties of the concrete made using steel fiber." *Concr. Res.*, 8 (1), 101-112.

[12] Sheng, W., B. Qi, G. Zh. Yan, S. H. A. O. Peng, and J. R. Rui. 2008. "Experiment on Mechanical Properties of Steel Fiber Reinforced Concrete and Application in Deep Underground Engineering." *J. China Univ. Min. Technol.*, 18, 64-81.

[13] Tutsumi, K. 2004. "Water treatment technology and facility in future." *Kagaku Soti.*, 1, 71-80. (In Japanese)

[14] Vlyssides, A. G., S. T. Mai, and E. M. P. Barampouti. 2004. "Bubbles size distribution formed by depressurizing air-saturated water." *Ind. Eng. Chem. Res.*, 43, 2775-2780.

[15] Wiraputra, I. G. P. A. E., D. Edikresnha, and M. M. Munir. 2016. "Generation of submicron bubbles using venturi tube method." *J. Phys. Conf. Ser.*, 739, 012058.

[16] Zhou, Y., Z. Shun, H. Gu, and Z. Miao. 2015. "Injection performance and influencing factors in self-priming Venturi scrubber." *CIESC J.*, 66 (1), 99-103.

[17] Zimmerman, W. B., V. Tesar, S. Butler, and H. C. H. Bandulasena. 2008. "Microbubble generation." *Recent Pat. Eng.*, 2 (1), 1-8.