The effects of silica fume and nano-silica on the workability and mechanical properties of self-compacting concrete containing polypropylene fibers

Amirhosein Abna[1] and Moosa Mazloom[2*]

[1]PhD Candidate in Structural Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran
[2]Faculty of Civil Engineering Department, Shahid Rajaee Teacher Training University, Tehran, Iran

Abstract

Due to the widespread usage of self-compacting concrete and the need to reduce the level of cement and increase the strength of concrete, this study investigates the effects of silica fume, nano-silica and polypropylene fibers on self-compacting concrete. For this purpose, 23 mixes were made. In order to study the self-compacting properties of concrete, J-ring, V-funnel, slump flow and T50 tests were casted. Compressive, tensile and flexural strength tests also were performed on hardened concrete at the age of 28 days. The experimental results showed that silica fume and nano-silica, in addition to reducing the workability of self-compacting concrete, increased its compressive, tensile and flexural strengths. Polypropylene fibers increased mechanical properties, especially tensile and flexural strengths. In addition, with the simultaneous addition of microsilica, nanosilica and fibers, the mechanical properties of self-compacting concrete were further improved. The best mix, with the highest compression characteristics, had 5% silica fume, 0.75% nano-silica and 1.5% fibers. The compressive strength of this mix design increased by 40% compared to the control mix. The best mix in tensile and flexural strength had 5% silica fume, 0.75% nano-silica and 1% fibers. Tensile and flexural strengths of this mix design increased by 26% and 28% compared to the control mix, respectively.

KEYWORDS

Silica fume, polypropylene fibers, nano-silica, Compressive strength, Self-compacting concrete

* Corresponding Author: Email: mazloom@sru.ac.ir

1. Introduction

Concrete is the most widely used and important building material in construction [1]. Due to the advancement of construction science and technology, new structural systems as well as the expansion of construction, the need for new and more efficient building materials is very noticeable [2]. One of the advances in the field of concrete construction in the last two decades is self-compacting concrete [3, 4]. Self-compacting concrete is defined in such a way that it does not require any internal or external vibration, and it can be compacted by its own weight. When this concrete flows into the formwork, it is completely aerated and fills the formwork using only gravity, covering the existing reinforcements and at the same time maintaining its uniformity [5]. For various reasons, a significant portion of concrete always cracks. The cause of cracking can be structural or non-structural. However, most cracks are due to the inherent weakness of this material in tension. For example, shrinkage in bonded concrete causes cracks [6]. Most of the weight of concrete is made up of coarse and fine aggregates, and usually accounts for about 60% of the volume of SCC [7]. The large volume of cement used in self-compacting concrete is not suitable for the environment [8]. In addition, the high grade of cement raises the hydration temperature too much, and the concrete cracks [9]. In order to reduce the environmental effects and reduce the grade of cement, pozzolanic materials are used as a substitute for a part of cement. The use of pozzolans improves the compressive and tensile strength of concrete [10]. In the study of Mazloom et al. [11], The effect of micro-silica on self-compacting lightweight concrete has been investigated. Finally, they stated that micro-silica has increased the durability and mechanical properties of this concrete [12]. In order to create isotropic conditions and reduce the fragility and brittleness of concrete, the use of thin and relatively long fibers has become common [13]. The aim of this study is to investigate the effect of silica fume, nano-silica and polypropylene fibers on the properties of fresh and hardened self-compacting concrete.

2. Methodology

In this research, type 1-425 Portland cement of Tehran cement factory with density of 3.07 g/cm^3 and the specific surface area of 3290 cm^2/g has been used. Consumed silica fume from Shahriar ferrosilicon plant has been used. Utilized stone powder with the density of 2.68 g/cm^3 was the production of Qom factory. Coarse aggregate had the maximum size of 12.5 mm and the specific gravity of 2.66 g/cm^3. River sand with the density of 2.66 g/cm^3 was used. Nano-silica was provided by Fadak New Technologies Company of Isfahan. The fibers used were polypropylene with a length of 12 mm. In order to investigate the effect of polypropylene, nano-silica and silica fume on the strength properties and fracture parameters of self-compacting concrete, 23 different concrete mix designs were fabricated. To perform compressive, tensile and flexural strengths, and modulus of elasticity tests, 3 samples were prepared for each design. In order to accurately evaluate the mentioned parameters under constant conditions, all tests were performed at the age of 28 days. In fact, a total of 322 concrete specimens were made. Mix design No. 1 was the control sample without micro-silica, silica fume and fibers. Mix designs 2 to 5 had no fibers and silica fume, but they had 1, 2, 3 and 4% nano-silica, respectively. Mixes 6 to 10 did not have nano-silica and fibers, but they had 4, 8, 10, 12 and 16% silica fume, respectively. Designs 11 to 15 did not have fibers, but they contained 5% silica fume with 0.5, 0.75, 1, 1.5 and 2% nano-silica. The optimum nano-silica content in single mix designs was 2%. For this reason, designs 16 to 18 had 2% nano-silica along with 0.5, 1 and 1.5% by volume of polypropylene fibers. Similarly, in designs containing silicafume, the sample had an optimum silica fume content of 10%. Also designs 19 to 21 had 10% silica fume with 0.5, 1 and 1.5% polypropylene fibers. In order to investigate the effect of the combination of silica fume, nano-silica and polypropylene fibers, the samples containing 5% silica fume and 0.75% nano-silica along with 0.5, 1 and 1.5% polypropylene fibers can be seen in designs 22 to 24.

3. Results and discussion

The results of hardened concrete tests include the compressive, tensile and flexural strength tests are described below.

3.1. compressive strength

By increasing the amount of nano-silica in single samples without fibers, the compressive strength first increased and then decreased. Among the samples with silica fume, the sample containing 10% silica fume had the maximum compressive strength. Also, in the samples with nano-silica and different amounts of polypropylene fibers, the sample containing 2% nanosilica and 1.5% fibers had the maximum compressive strength. In the composite samples, the sample containing 5% silica fume, 0.75% nano-silica and 1.5% polypropylene fibers had the maximum compressive strength. The above sample, with the compressive strength of 61.8 MPa, was about 40% stronger than the control one.

3.2. Tensile strength

In single samples containing nano-silica, the sample with 3% nano-silica had the maximum tensile strength. Among the samples containing silica fume, the sample containing 10% of it had the maximum tensile strength. Also, among the samples without fibers and with the combination of silica fume and nano-silica, the sample containing 5% silica fume and 1% nano-silica had the maximum tensile strength. In composite samples, the sample containing 5% silica fume, 0.75% nano-silica and 1% polypropylene fibers had the maximum tensile strength. This sample, with the tensile strength of 4.49 MPa, had about 26% better tensile strength than the control mix.

3.3. flexural strength

In single samples containing nano-silica, the sample with 3% nano-silica had the maximum rupture modulus. Among the samples with silica fume, the sample containing 10% of it had the maximum flexural strength. Also, among the samples without fibers and with the combination of silica fume and nano-silica, the sample containing 5% silica fume and 1% nano-silica had the maximum modulus of rupture. In the samples containing nano-silica and different amounts of polypropylene fibers, the sample containing 2% nano-silica and 1.5% fibers had the maximum modulus of rupture. The sample having 1% polypropylene fibers had the maximum flexural strength of 6.42 MPa. This specimen had 28% improvement in flexural strength compared to the control specimen.

4. Conclusions

In the initial mix designs, compressive, tensile and flexural strengths of self-compacting concrete increased by adding silica fume or nano-silica. In hybrid mixes including silica fume and nano-silica, the above strengths were better than the initial ones. The combined mix design containing 5% silica fume and 1% nano-silica was the best mix design. Compressive, tensile and flexural strengths of this sample increased by 30, 10 and 18% compared to the control one, respectively. The best composite sample in compressive strength had 5% silica fume, 0.75% nano-silica and 1.5% polypropylene fibers. The best composite specimen in tensile and flexural strengths had 5% silica fume, 0.75% nano-silica and 1% polypropylene fibers. The tensile and flexural strengths of this sample were 4.49 and 6.42 MPa, respectively, which were 26% and 28% better than the control one.

5. References

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