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Mechanical Properties Of Concrete Modified With Nano-Titanium, Nano-Alumina, And Nano-Silica

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Abstract

An experimental program is conducted in this research to investigate the mechanical properties of concrete modified with nano-titanium, nano-alumina, and nano-silica. A total of 48 cylinders and 24 beams were prepared from three different concrete mixes modified with nanomaterials. Cement was replaced by 1.5 % nano-titanium, 1.5 % nano-alumina, and 1.5 % nano-silica (by cement weight). Half of the specimens were subjected to a temperature of 720 °C for 2 hours, while the others remained unheated. Compression, tension, and flexural strength tests were conducted according to the ASTM standards. Test results have shown that the addition of nanomaterials improved concrete compression and flexural strength, whereas the best improvement was measured in concrete modified with nano-titanium. The addition of nano-titanium duplicated the flexural strength of concrete and enhanced the compressive strength of concrete by 29%. It also showed good performance with heat, duplicating the flexural strength of heat-damaged concrete and improving its compressive strength by 25%.

Index Terms— Concrete, Mechanical Properties, Nano-Titanium, Nano-Alumina, Nano-Silica, Nanomaterials.

INTRODUCTION

Concrete is a brittle material; therefore, several experimental studies were conducted to enhance its mechanical properties. Natural-based and artificial materials have been recently used to improve the mechanical properties of concrete. Nanomaterials have also been lately applied to enhance the mechanical properties of concrete. The Nanomaterials have high surface-volume relation because they are incredibly tiny, with diameters varying between 0.1 to 100 nm [1].

Shekari and Razzaghi [2] experimentally studied the influence of nano-titanium and nano-alumina on concrete's compressive and tensile strength. They found that both nanomaterials improved concrete's compressive and tensile strength, whereas the best performance was measured with concrete modified with nano-alumina. Rahman and Dev [3] investigated the mechanical properties of concrete modified with various percentages of nano-alumina, and they found that the utilization of nano-alumina in any adopted percentage improved the mechanical properties of concrete. Orakzai [4] found that the flexural, compressive, splitting tensile strength of concrete modified with nano alumina and nano titanium dioxide was improved by 28%, 42%, and 34%, respectively, where the optimum enhancement was measured with 0.5% and 1% of nano alumina and nano titanium dioxide, respectively. Mustafa et al. [5] found that the optimum replacement percentage of cement by nano-silica is up to 2%, which can enhance concrete's flexural and compressive strength. They also found the replacement of cement weight by 3% nano-silica reduced the compressive strength of concrete. Jian et al. [6] found that adding nano alumina to cement pastes increased the compressive strength of concrete because of the reduction in macropores and the accelerating effect on cement hydration motivated by nano alumina. Elkady et al. [7] showed that the mechanical properties of concrete modified with nano-silica were significantly influenced by the dispersion of the nano-silica, where the addition of 1.5, 3, and 4.5% nano-silica improved the bond strength of concrete. They also found that exposing specimens to temperature quickly deteriorated the bond strength of concrete.

Previous studies [8–16] have shown that adding nanomaterials within an optimal range can enhance the mechanical properties of concrete. Limited studies were conducted to investigate the influence of nanomaterials on the mechanical properties of heat-damaged concrete. This research aims to investigate the mechanical properties of heat-damaged and unheated concrete modified with nano-titanium, nano-alumina, and nano-silica. A total of 48 cylinders and 24 beams were prepared from three different concrete mixes, where cement was replaced by 1.5 % nano-titanium, 1.5 % nano-alumina, and 1.5 % nano-silica (by cement weight). Half of the specimens were subjected to a temperature of 720 °C for 2 hours, while the others remained unheated. Compression, tension, and flexural strength tests were then carried out according to the ASTM standards.

CONCRETE MIX DESIGN

The concrete mix design of the plain concrete is shown in Table 1. The plain unheated concrete's compressive, tensile, and flexural strengths are 10.7 MPa, 1.8 MPa, and 3.38 MPa, respectively. The heat-damaged concrete's compressive, tensile, and flexural strengths are 7.56 MPa, 0.8 MPa, and 0.65 MPa, respectively. Subjecting control test specimens to a temperature of 720 ℃ for 2 hours decreased concrete's compressive, tensile, and flexural strengths by 29.5%, 55.5%, and 81%, respectively.

Table 1 Concrete mix proportions

Mix Design	
Materials	**Kg/m^3**
cement	220
Washed sand crushed	345
Sand	660
Aggregate 5-12 mm	680
Aggregate 12-20 mm	325
water	181
Superplasticizer	5.5

EXPERIMENTAL PROGRAM

An experimental program is carried out in this research to investigate the influence of nanomaterials on the mechanical properties of heat-damaged and unheated concrete. Cement in the specimens was replaced by 1.5 % nano-titanium, 1.5 % nano-alumina, and 1.5 % nano-silica (by cement weight). A total of 48 cylinders and 24 beams were prepared from three different concrete mixes modified with the three types of nanomaterials. Twelve cylinder specimens were prepared from each concrete mix, six cylinders were used for the compression strength test, and the other six were used for the splitting tensile strength test. Half of the specimens from each group were subjected to a temperature of 720 ℃ for 2 hours, while the other twelve specimens remained unheated. Twelve beams were prepared from three concrete mixes, modified nano-titanium, nano-alumina, and nano-silica, and were subjected to heat while another twelve specimens remained unheated. Three beams were prepared from each concrete mix. The dimensions of the concrete cylinders are 150mm x 300mm, and the dimensions of the beam are 50 cm x 10 cm x 10 cm. Compression, tension, and flexural strength tests were conducted according to the ASTM standards, as shown in

Figure **1**.

Figure 1 Test setup

(a) Compression test

(b) splitting tensile test

(c) flexural test

TEST RESULTS AND DISCUSSION

Test results are listed in Table 2, whereas the variation in the compressive, tensile, and flexural strengths of the unheated concrete specimens modified with nanomaterials are listed in Table 3 compared to the unheated control concrete specimens. Furthermore, the variation in the compressive, tensile, and flexural strengths of the heat-damaged concrete specimens modified with nanomaterials are listed in Table 4 compared to the heat-damaged control concrete specimens. It should be noted that the each compressive, tensile, and flexural strength value, listed in Table 2, is the average of three values taken from three different samples. The symbol (H) in Table 2 stands for heat-damaged, (Ti) stands for titanium, (Si) stands for silica, and (Al) stands for alumina.

Test results have shown that the addition of nanomaterials improved concrete compression and flexural strength, whereas the best improvement was measured in concrete modified with nano-titanium. The addition of nano-titanium duplicated the flexural strength of concrete and enhanced the compressive strength of concrete by 29%. It also showed good performance with heat, duplicating the flexural strength of heat-damaged concrete and improving its compressive strength by 25%, as shown in Table 3 and Table 4. The addition of nano-titanium, nano-alumina, or nano-silica had an adverse effect on the tensile strength of concrete.

The addition of nano-silica enhanced the flexural and compressive strengths of unheated concrete by 72% and 28%, respectively. It also showed good performance when subjected to heat, where the compressive and flexural strength of heat-damaged concrete modified with nano-silica increased by 4% and 69%, respectively, compared to the control heat-damaged concrete specimens.

The addition of nano-alumina enhanced the flexural strength of unheated and heat-damaged concrete by 56% and 49%, respectively, compared to the control unheated and heat-damaged concrete specimens. It also improved the compressive strength of unheated and heat-damaged concrete by 27% and 7%, respectively.

Table 2 Test results (Average Results)

Specimen	Compressive strength (MPa)	Tensile Strength (MPa)	Flexural Strength (MPa)
control	10.72	1.80	3.38
control-H	7.56	0.80	0.65
Ti	13.83	1.31	6.65
Ti-H	9.45	0.68	1.28
Al	13.62	1.29	5.28
Al-H	8.07	0.59	0.97
Si	13.72	0.87	5.81
Si-H	7.88	0.77	1.10

Table 3 The variation in the compressive, tensile, and flexural strengths of the unheated specimens modified with nanomaterials compared to the control unheated specimen

Specimen	Compression	Tension	Flexural
Ti	**29%**	**-27%**	**97%**
Al	**27%**	**-28%**	**56%**
Si	**28%**	**-52%**	**72%**

Table 4 The variation in the compressive, tensile, and flexural strengths of the heat-damaged specimens modified with nanomaterials compared to the control heat-damaged specimen

Specimen	Compression	Tension	Flexural
Ti-H	25%	-15%	98%
Al-H	7%	-26%	49%
Si-H	4%	-4%	69%

Conclusion

An experimental program is conducted to study the mechanical properties of concrete modified with 1.5 % nano-titanium, 1.5 % nano-alumina, and 1.5 % nano-silica (by cement weight). A total of 48 cylinders and 24 beams were prepared from three different concrete mixes modified with nanomaterials. Half of the specimens were heated, while the others remained unheated. Compression, tension, and flexural strength tests were carried out according to the ASTM standards. Test results have shown the following.

1. The addition of nanomaterials improved concrete compression and flexural strength, whereas the best improvement was measured in concrete modified with nano-titanium.
2. The addition of nano-titanium duplicated the flexural strength of concrete and enhanced the compressive strength of concrete by 29%. It also showed good performance with heat, duplicating the flexural strength of heat-damaged concrete and improving its compressive strength by 25%.
3. The addition of nano-titanium, nano-alumina, or nano-silica had an adverse effect on the tensile strength of concrete.
4. The addition of nano-silica enhanced the flexural and compressive strengths of unheated concrete by 72% and 28%, respectively. It also showed good performance when subjected to heat, where the compressive and flexural strength of heat-damaged concrete modified with nano-silica increased by 4% and 69%, respectively, compared to the control heat-damaged concrete specimens.
5. The addition of nano-alumina enhanced the flexural strength of unheated and heat-damaged concrete by 56% and 49%, respectively, compared to the control unheated and heat-damaged concrete specimens. It also improved the compressive strength of unheated and heat-damaged concrete by 27% and 7%, respectively.

The influence of nano-titanium, nano-alumina, or nano-silica was significantly evident in enhancing the flexural strength of concrete.

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