Enhancement of Tensile Strength of High Strength Concrete using Polyvinyl Alcohol Fibre (PVA)

Ahmed Abdelrahman, Ahmed Elshahat, Ahmed Refaey, Osama Ali, Ismail Salah and Khalid Said

Construction and Building Department, Faculty of Engineering, October 6 University, Egypt.

201708873@o6u.edu.eg, 201710219@o6u.edu.eg, 201709462@o6u.edu.eg, 20179467@o6u.edu.eg, 201704930@o6u.edu.eg, 20168071@o6u.edu.eg.

Supervisor: Wael Montaser, Associate Professor, Head of Department

Construction and Building Department, Faculty of Engineering, October 6 University, Egypt, wmontaser.eng@o6u.edu.eg

Supervisor: Ahmed Afifi, Assistant Professor of Reinforced Concrete Structures

Construction and Building Department, Faculty of Engineering, October 6 University, Egypt. ahmedafifi.eng@o6u.edu.eg

Supervisor: Moataz Mahmoud, Teaching Assistant

Construction and Building Department, Faculty of Engineering, October 6 University, Egypt. Eng.moatazeltaher@gmail.com

Supervisor: Mina Nabil, Teaching Assistant

Construction and Building Department, Faculty of Engineering, October 6 University, Egypt. mina.nabil.eng@o6u.edu.eg

***Abstract*– In recent years, the use of high-strength concrete (HSC) has gained significant interest in the construction industry. However, the fundamental issue with HSC is its low tensile strength comparing to its high compressive strength, which limits the use of high strength concrete in the flexural structural elements. Therefore, this paper presents an experimental study to investigate the tensile behavior of concrete including Polyvinyl Alcohol (PVA) ranges from 0 to 1.5%. A total of 18 cubes and 18 cylinders were cast and tested till failure. It was found that the inclusion of PVA improves the compressive and tensile strength significantly. The results showed that the tensile strength results were two times the average tensile strength of HSC without PVA. Consequently, the use of PVA has solved the main problem with HSC and provide a creative solution for the construction industry.**

Keywords—High Strength Concrete. PVA. Tensile Strength. Steel Fibers.

I. INTRODUCTION

High-strength concrete is a modern material, which occupies its own niche on the construction material market. It is applicable in a large-scale high-rise construction. The construction industry has shown a significant use of high strength concrete (HSC), in applications such as dams, bridges and high-rise buildings. This is due to significant structural, economic and architectural advantages that HSC can provide compared to conventional, normal concrete strength. However, the HSC structural elements become more brittle due to its low tensile strength. This issue limits the use of HSC in reinforced concrete structures.

Polyvinyl Alcohol fibre (PVA) is an environment friendly fibre with excellent alkali resistance. PVA fibre is economic nomic, exhibits higher tensile strength and elastic modulus compared to polypropylene (PP) fibre [1]. Researchers [1–4] reported that the overall cost of mortar/concrete composites including PVA, such as Engineered Cementitious Composites (ECC), can be reduced by using an optimized dosage of micro-fibres and local materials including cement, fine aggregate, cement replacement materials such as fly ash and silica fume, and chemical admixtures. Zhu et al. [6] reported the benefit of adding silica fume and fly ash in improving durability and compressive strength of PVA-mortar composite elements. Kanda et al. [7], used PVA fibres to produce ECC and they reported that the PVA is the main contributor to achieve the high strain hardening and ductility for ECC. Furthermore, Kanda et al. [8] described the design concept and material characteristics of PVA composite mortar elements. They showed that composites containing PVA exhibited a remarkably ductile tensile property with more than 1% tensile strain capacity, which in turn, has enhanced structural performance in seismic conditions. In the above reviewed literature, the importance of PVA fibres in improving the ductility of composite mortar was reported. The positive effect of PVA with fly ash on the tensile behaviour of concrete was mentioned.

II. RESEARCH SIGNIFICANT

Based on the literature review, the current study aims to investigate the feasibility of producing HSC with high tensile strength through adding PVA to concrete with different percentages of PVA up to 1.5%. This will be achieved by testing a number of cubes and cylinders and evaluating the failure load in compression and tension.

III. EXPERIMENTAL PROGRAM

A. Constituent Materials

The mix ingredients used throughout this investigation were Portland cement, silica fume, polyvinyl alcohol (PVA) micro-fibers, natural siliceous sand, water, high range water reducer. The properties of these materials are given in the following sections.

B. Cement and Cement Replacement Materials

A grade 52.5 Portland cement was supplied by a local Egyptian factory, and is compatible with European standards [9]. The silica fume was supplied by Sika Egypt for Construction Chemicals and it was com- plied with ASTM C 1240 [10]. The physical and chemical properties of cement replacement material is shown in Tables 1 (provided by the supplier).

C. Polyvinyl Alcohol Fibre (PVA)

Different volume percentages of polyvinyl alcohol (PVA) fibers (1, and 1.5%) were used in the mortar. The properties of PVA fiber are listed in Table 2 (provided by the supplier). The same mechanical properties PVA fibers were presented by Cao and Said et al. [11]

D. Quartz Sand

The crushed quartz sand was used as an aggregate substitution. It was in form of yellowish-white with particle size between 0.125 µm and 200 µm. the sieve analysis is presented in Fig. 1. The Properties of Quartz sand are: Specific gravity = 2.45, Water absorption = 1.98%, and Fineness modulus = 4.2.

E. Water and High Range Water Reducer

Potable tap water is used for mixing and curing of the test specimens. Poly-carboxylic High Range Water Reducer (HRWR) from BASF Construction Chemicals (Master Glenium RMC 315) complying with BS EN 934-2 [22] was used. The objective of adding HRWR was to ensure that the PVA fibres were well-dispersed in the mixes and to achieve workability as indicated by a slump of 163 60 mm ± 10 mm.

F. Steel Fibres

The physicochemical parameter of steel fibre should meet the requirements of JGT 472-2015. The length of steel fibre should be 20 mm~60 mm and diameter or equivalent diameter should be 0.3 mm~1.2 mm; length to diameter ratio was 30~65.

Table 1 Properties of the used silica fume

SiO2	≥88.9%
Moisture	≤0.57%
Alkalis like Na2O	≤0.5%
Free CaO	≤0.1%
Free SI	0.14%
Free Cl%	0.02%
SO3	≤0.25%
L.O. I	≤4.5%
Specific surface	≤20 m2/g
Size	≤0.15 microns

Table 2 Properties of the used PVA

Length (mm)	12
Shape	Monofilament
Diameter (mm)	0.04
Tensile strength (MPa)	1620
Elastic modulus (GPa)	42.80
Density (ρ) (g/cm3)	1.3

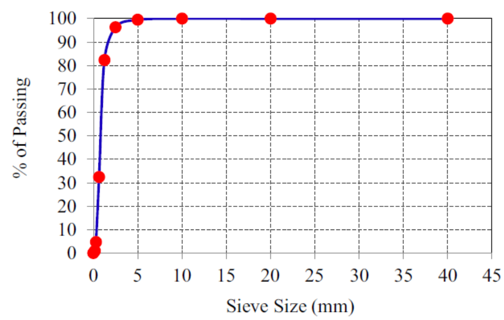

Fig. 1 Sieve analysis curve of the fine aggregate

G. Mixing Process, Specimen Preparation, and Curing

Trial mixes were carried out varying the percentage of water binder ratio (w/b) to obtain the required f_{cu} (≥80 MPa at 28 days). Finally, the following specific mix was considered. The mix ingredients were mixed and poured in cubes and cylinders in the material laboratory at faculty of engineering, October 6 University.

Table 3 The Mix ingredients

Components	Weight (kg/m3)
CEMENT	967
Quartz SAND	710
PVA	0 - 9.67-14.5
SILICA FUME	236
STEEL FIBERS	169
SUPERPLASTICIZER	42

PVA Silica Fume Steel Fibers

Fig.2 Different mix materials.

Fig. 3 Mixing and pouring of Concrete.

IV. Experimental Results

The cubes and cylinders were tested until failure under axial load after 7 and 28 days, and the weight and failure loads were recorded for each specimen. The tensile strength of the cylinders was calculated from the splitting test.

Fig.4 Failure modes of cubes.

Fig.5. Failure modes of cylinders.

A. Compressive Strength Results

Test results of the compressive strength are shown in Table 4. Gained results of the compressive strength measured by cubes. The results showed that adding the PVA with 1%, and 1.5% has a slight increase of concrete compressive strength by 3 %, and 2% respectively.

B. Tensile Strength Results

The results of tensile strength, by splitting of concrete cylinders demonstrated a great enhancement in the tensile behaviour of PVA concrete. The first mix with 1% PVA was able to gain a tensile strength increase of 61 % compared to the concrete without PVA. While, adding 1.5% PVA enhanced the tensile strength by 92 % compared to HSC without PVA as shown in table 5.

Table 4 Compressive strength results

	Mix	Average Weight (Kg)	Average Force (KN)	Average Compressive Stress (N/mm^2)
After 7 Days	0 PVA	8440	1070.1	47.56
	1% PVA	8320	1128.4	50.25
	1.5%PVA	8310	1124.55	50.1
After 28 Days	0 PVA	8460	1845	82.1
	1% PVA	8390	1912.5	85
	1.5%PVA	8370	1890	84.2

Table 5 Tensile strength results

	Mix	Average Weight (Kg)	Average Force (KN)	Average Tensile Stress (N/mm^2)
After 7 Days	0 PVA	13.65	202.35	2.86
	1% PVA	13.83	314.86	4.45
	1.5%PVA	13.77	393.4	5.56
After 28 Days	0 PVA	13.76	367.9	5.2
	1% PVA	13.84	594.34	8.4
	1.5%PVA	13.81	714.622	10.1

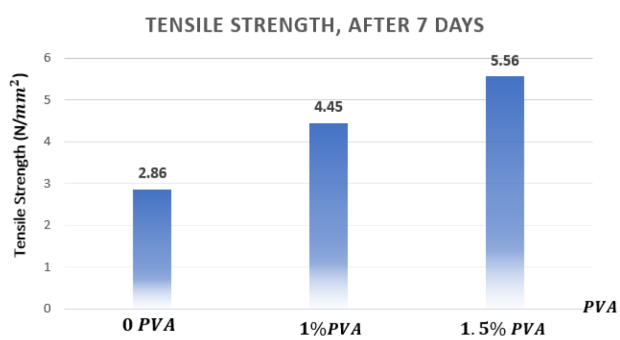

Fig. 6 Tensile strength after 7 days

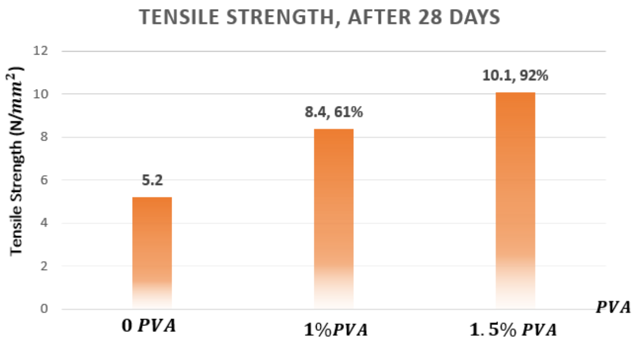

Fig.7 Tensile strength after 28 days

V. Conclusion

In this paper, the compressive strength, and splitting tensile strength of PVA high strength concrete made by different proportions of PVA were analyzed. The main conclusions are as follows:

- The tensile behaviour of HSC has improved significantly with the presence of higher percentage of PVA.
- The results indicate that the tensile strength of HSC with 1.5% PVA was two times the average tensile strength of HSC without PVA.
- Adding PVA to HSC has a slight effect on compressive strength. The compressive strength has increased by 3% and 2% with adding 1% and 1.5% PVA respectively.

In summary, Polyvinyl Alcohol fibres enhanced the mechanical properties of high strength concrete, however the overall study has shown further testing should be conducted to study the behaviour of the structure elements with PVA high strength concrete.

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