

A PRELIMINARY STUDY - FIBER REINFORCED CEMENT MIXES WITH PARTIAL REPLACEMENT OF WASTE FLY ASH

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ABSTRACT

The recent technology is to produce an eco-friendly cementitious material using waste products, such as waste incineration fly ash. The fly ash used in the present research was retained on boilers generated by incinerators, in Lebanon. Cement based mixes were reinforced with polypropylene fibers, in addition to partially replacing cement or sand by fly ash. The experimental testing includes compression and flexural tests on 50 mm cubes and prisms. Several cement-based mixes were used in the research by varying the proportion of fly ash and the polypropylene fibers. The percentage of cement or sand was replaced by 0 to 30% fly ash. The dosage of fibers was 0 to 1.8 kg/m³. The water-cement ratio was fixed to 0.5. Compressive strength and flexural strength results, presented in this paper, reveal that mortar with partial cement or sand replacement, in addition to the fibers, show promising improvement in compressive strength and an increase of around 15% was noted.

Keywords: PP fibers, fly ash, cement mixes, compressive and flexural strengths.

INTRODUCTION

The recent trend is to reduce CO₂ emissions and to recycle waste such as waste to energy fly ash. Fly ash is composed of black particles retained on chimneys filters and generated by the combustion of paper, nylon, and plastics. The present research aims to produce a green shotcrete mix by partially replacing cement, mainly responsible for CO₂ emission in the construction industry, by fly ash and to find the optimum replacement percentage and satisfactory mechanical properties. Meanwhile, Lebanon is suffering from a garbage crisis. One of the proposed solutions is to build incinerators across the country and burning all of the produced garbage.

Lane and Best (1982) reported strength increase of 50% at 1 year for concrete containing fly ash, as compared with 30% for concrete without fly ash.

Siddique (2003) evaluated the mechanical properties of concrete mixture with fly ash replacing sand, 10%, 20%, 30%, 40%, and 50% of Class F fly ash at 7, 14, 28, 56, 91,

and 365 days. Significant improvement of the compressive and flexural strength on concrete containing fly ash replacing sand was observed.

Sadrmomtazi and Fasihi (2009) performed a flexural strength study on specimens of mortar containing 0.1%, 0.3%, 0.5% volume fraction of PP fibers, and reported a slight increase in the flexural strength of fiber reinforced mortar compared to plain mortar, the flexural strength increased to reach an optimum at 0.3% of fibers and dropped to some lower values at higher volumes of fibers.

Shrivastava and Bajaj (2012) studied the performance of fly ash and high-volume fly ash concrete in pavement design and found that flexural strength increased with increase of fly ash up to 35% replacement in concrete.

Narendra (2013) studied the compressive strength on mixes for cement replacement of 20%, 35%, and 50%, for different periods of curing and found that as curing period advanced the strength of fly ash concrete and normal concrete increased. While the addition of fly ash reduced the compressive strength in comparison to normal concrete at early ages, it increased the compressive strength of fly ash concrete between 28 days and 56 days and noted a slight increase up to 91 days.

Harison (2014) compared the compressive strength of fly ash replacing cement in the range of 0%, 10%, 20%, 30%, 40%, 50% and 60% at 7 days 28 and 56 days and found that the rate of strength gain decrease with the increase of the fly ash : at 7 days it is seen that the compressive strength decrease with the increase of fly ash content, at 28 days it is noted that 0%, 10%, and 20% have the same strength while above 30% the compressive strength continue to decrease, and at 56 days it is indicated that 0%, 10%, 20% and 30% have the same strength while above 40% the compressive strength continue to decrease.

Salahaldein and Muhsen (2016) performed a study aiming to find the optimum quantity of PP fibers to achieve maximum compressive strength in concrete, using 0%, 1.0%, 1.5%, 2.0% of fiber content with concrete mix, they found that the compressive strength increases proportionally with the increase of fiber volume and noted a 12% increase in the compressive strength from 25 MPa to 28 MPa.

In the present paper, we aim to study the mechanical behavior of the modified mortar with different dosage of waste fly ash and polypropylene fiber. Specimens were prepared to specify the effect of polypropylene fiber, waste fly ash and combined mix on compressive and flexural behavior of cement mortar.

MATERIALS AND METHODS

Cement and Aggregates

Ordinary Portland cement was used, grade P 42.5 type I cement, conforming with the Lebanese Standard Specifications NL 53:1999, EN 197 and ASTM C150. It is a general use cement with 6 to 15% limestone content. The fineness and specific gravity of the cement used were 3174 cm²/g and 3.15, respectively. The chemical composition of the cement used was as follows: 19.7% SiO₂, 4.98% Al₂O₃, 63.52% CaO, 0.88% MgO, 2.57% SO₃, and 2.75% loss-on-ignition (LOI). For fine aggregates natural local sand with a 4.75-mm maximum size was used after sieving as a fine aggregate. It was tested to determine fine content and gradation. Its properties and sieve analysis results show a sand equivalent of 80.57% and a complied gradation with ASTM C33 grading limits (Standard Specification for Concrete Aggregates).

Polypropylene Fibers

The length of fibers is 6mm and the thickness is 18 microns. Fibers are made of 100% virgin polypropylene fiber conformed to the ASTM C1436. The tensile strength is equal to 300 MPa and the Young's modulus is 4000 MPa.

Fly Ash

The fly ash was obtained from energy power plant in Lebanon. The fly ash derives from the combustion of plastics, paperboards and nylon, and it is captured by filters before reaching power plant's chimney. Based on the chemical results, fly ash may be a type CH class due to high content of CaO (21.3%) > 20%, that is higher than the allowed limits of ASTM C618.

Superplasticizer

A commercially available Poly-naphthalene-based superplasticizer was used in all mixes. Superplasticizer (1%) was added to the mixes containing 0%, 10%, 20% of fly ash content, while 1.5% superplasticizer were added to the mixes with 30% of fly ash content to overcome the decrease of workability with the increase of fly ash content in the mix.

Compressive Strength Test

The testing on 5 cm cubes (Fig. 1) was performed in accordance with the ASTM C109. The rate of compression is 2400 N/sec.



Fig. 1. Compressive Strength Test of Half Prism And Flexural Strength Test of Prism.

Flexural Strength Test

The testing on 4x4x16 cm beam specimens (Fig. 1) was performed in accordance with the ASTM C348. The rate of test at 2mm/min.

EXPERIMENTAL TEST PROCEDURES

Mix Proportions

This experimental program presents three variables and based on the fly ash (FA) content: FA-Cement replacement (FA-C), FA-Sand replacement (FA-S), and polypropylene fiber (PP) content. 28 mixture proportions were made as indicated below:

- Control mix (without fly ash and without PP fibers).
- 3 mixes with fly ash replacing cement without PP fibers.
- 3 mixes with fly ash replacing sand without PP fibers.
- 3 mixes with PP fibers without fly ash.
- 9 mixes with 10%, 20%, 30% by weight FA-cement replacement and 0.6, 1.2, 1.8 kg/m³ fiber content.
- 9 other mixes with 10%, 20%, 30% by weight FA-Sand replacement and 0.6, 1.2, 1.8 kg/m³ fiber content.

Several mixes were repeated to test the accuracy of the results. In total 38 mixes were realized, 28 mixes needed for the experimental results and the 10 other mixes to evaluate the results.

Mixing Method

The mix design of the control mix was carried out according to ASTM C109M-02. The control mix and all other mixes present following weight ratio: cement/sand is 1/2.75, water cement ratio equal to 0.5. For mixes containing fly ash replaced by cement, fly ash passing sieve no.200 was used and was mixed with the cement before the mixing process. It was treated as a cementitious product. While for mixes containing fly ash replaced by sand, fly ash retained on the sieve no. 200 was used and was mixed with the sand before introducing to the mixes. It was treated as a fine

aggregate product.

Casting

According to ASTM C109M-02, after mixing process, the mix was immediately poured into molds within a total elapsed time of no more than 2 min and 30s. Casting was carried out in two layers approximately for one half of the depth each time and each cube tamped 32 times in about 10 s in 4 rounds. The complete compaction was determined by appearance of a film of cement mortar on the top and the air void was no longer appearing. After compaction, the top surfaces of specimens were troweled level for obtaining smooth surface.

Curing

After casting, all specimens were kept in a closed room to assure a humid air around the specimens and to prevent fast evaporation of water from the specimens. After 24 hours they were demolded and cured in a water storage plastic tank until they were tested at 7 days and at 28 days.

While the 30% FA-cement replacement and 20% Fa-sand replacement were demolded after 48 hours and kept without curing till the 7th day due to long final set, expansion of mix and crack appearance when the mix was saturated with water at trials of 1,2 and 5 days of curing after mix.

RESULTS AND DISCUSSION

Density

Density of mortar containing fly ash (FA) has been determined and presented in Fig. 2 for different fly ash content. All fly ash mortar (FAM) presented higher density than the control mix with 0% FA, an optimum value of 2209.1 is observed for 10% FA content, while a decrease in density is present with the increase of the fly ash content. In contrary, of what was predicted, since fly ash has a higher specific gravity than cement, this density increase can be explained by the fact that fly ash fineness and round particle shape decrease the energy needed to compact the mortar mix.

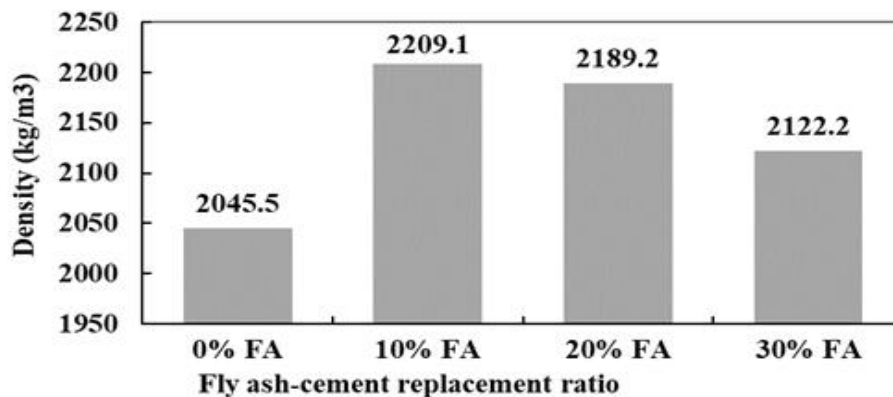


Fig. 2. Variation of Mortar's Density in Function of Fly Ash Content.

Effect of Cement Replacement with Fly Ash

Compressive strength of control mix and fly ash mortar at 7 and 28 days are given in Fig. 3. The compressive strength at 7 days increased to an optimum, at 10% FA replacement, then decreased with the increase of the fly ash. This behavior may be due to high level of calcium oxide CaO present in the waste to energy. Fly ash material can contribute to an early pozzolanic activity and can increase the strength gain at early ages.

This behavior is also present at 28 days, as can be seen an optimum value of 44.6MPa at 10% FA compared to 36.5 MPa for the control mix, showing an increase of 22%. While for 20% FA content, it is observed that the compressive strength value is 34.8 MPa less than the control mix, in contrary of what was observed for 7 days.

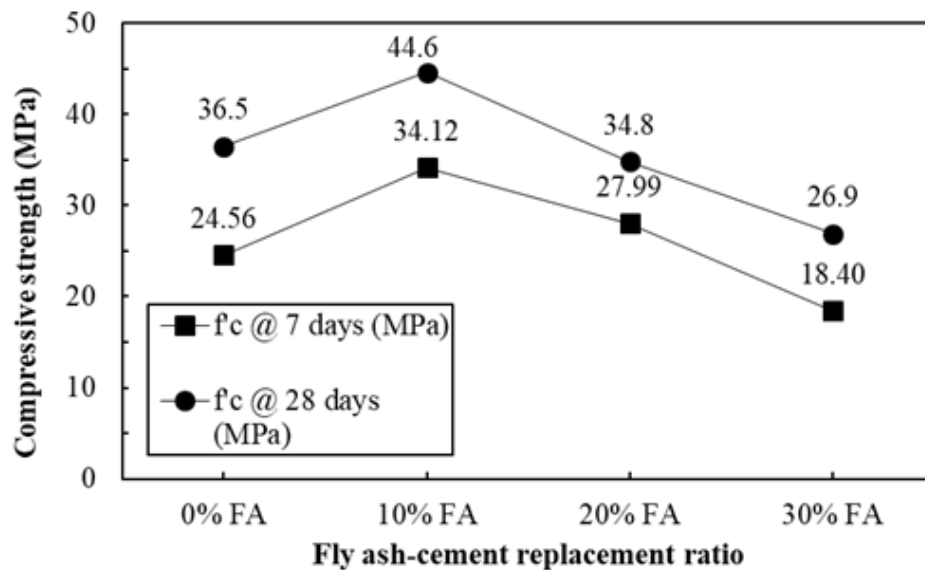


Fig. 3. Compressive Strength Results of Mortar with FA-Cement Replaced without Fiber at 7 and 28 days.

Effect of Sand Replacement with Fly Ash

The compressive strength of mortar made with and without fly ash were determined at 7 and 28 days. The test results in Fig. 4. show the variation of compressive strength with time and fly ash partially replacing the sand.

At 7 days, it is noted that the compressive strength results of the control mix and the 10% FA are nearly the same, 24.6 MPa and 24.7 MPa, while the compressive strength of 20% FA is higher with an optimum value of 29.8 MPa.

While at 28 days a compressive strength decrease occurred from 36.5 MPa for the control mix to 30.7 MPa for the 10% FA mix and a large increase to 48.4 MPa for the 20% FA mix, exceeding the 42.5 MPa grade of cement used. Similar to Siddique (2002) who evaluated the compressive strength of concrete mixture with FA replacing sand with 10%, 20%, 30%, 40%, and 50% and tests were determined at 7, 14, 28, 56, 91,

and 365 days. The results indicated a significant improvement in the compressive strength on concrete containing fly ash replacing sand for all ages, where all the mixes containing fly ash presented a higher compressive strength than the control mix and strength gain continued with the increase of age.

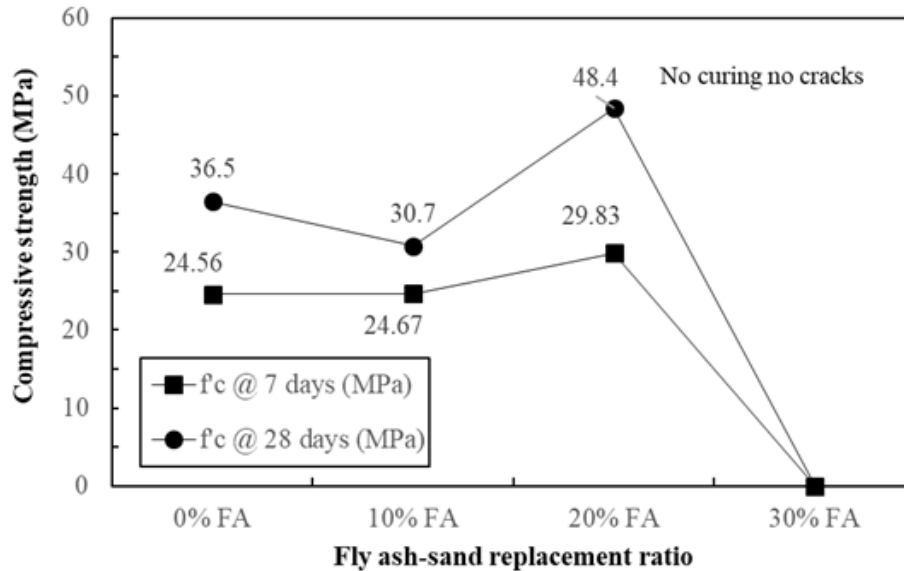


Fig. 4. Compressive strength results of mortar with FA-sand replaced without fiber at 7 and 28 days.

This compressive unexpected strength decreases at 28 days for 10% FA content due to the fact that the specimens presented micro cracks due to expansion that happened with the contact of curing water at 24 hours. It should be noted that the 20% FA mix was not cured until the 7th day, which resulted in fixing the cracking problem and leading to higher strength mortar, in contrary of what was expected as no curing should decrease the compressive strength due to lack of hydration. Also, the 30% FA mix replacing sand presented a very low workability contributing to a mixing failure and incapability to obtain any results.

Effect of Polypropylene Fibers

The compressive strength value of cube specimens at 7 and 28 days are shown in Fig. 5. It is observed that the compressive strength of mortar with 0.6, 1.2, and 1.8 kg/m³ fiber content is higher than the compressive strength of the control mix.

At 28 days, another trend was observed and the compressive strength of mortar containing fibers shows a convex behavior. A minimum value of 33.5 MPa is shown at 0.6 kg /m³ compared to the control mix of 36.5 MPa, while a maximum value of 40.1 MPa was observed at 1.8 kg /m³, an increase of 10% in comparison with the control mix.

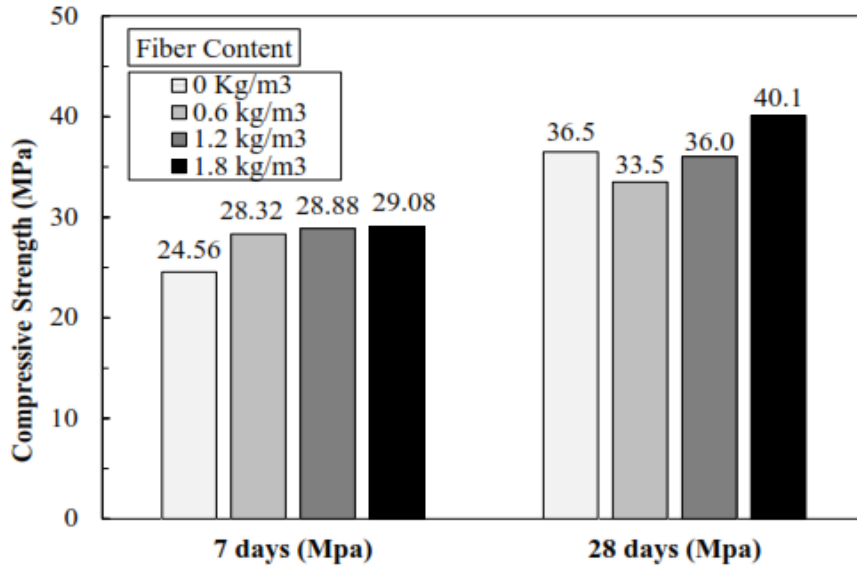


Fig. 5. Effect of Polypropylene Fibers on Compressive Strength without Fly Ash at 7 and 28 Days.

Combined Effect of PP Fibers and Cement Replacement with Fly Ash

The combined effect of PP fiber and FA-C content on the compressive strength of cube specimens at 7 and 28 days are shown in Fig. 6 and Fig. 7, respectively. It is clearly shown that the increase of PP fiber has a positive effect on the compressive strength of the control mix without fly ash and a negative effect on the compressive strength of all mixes containing fly ash.

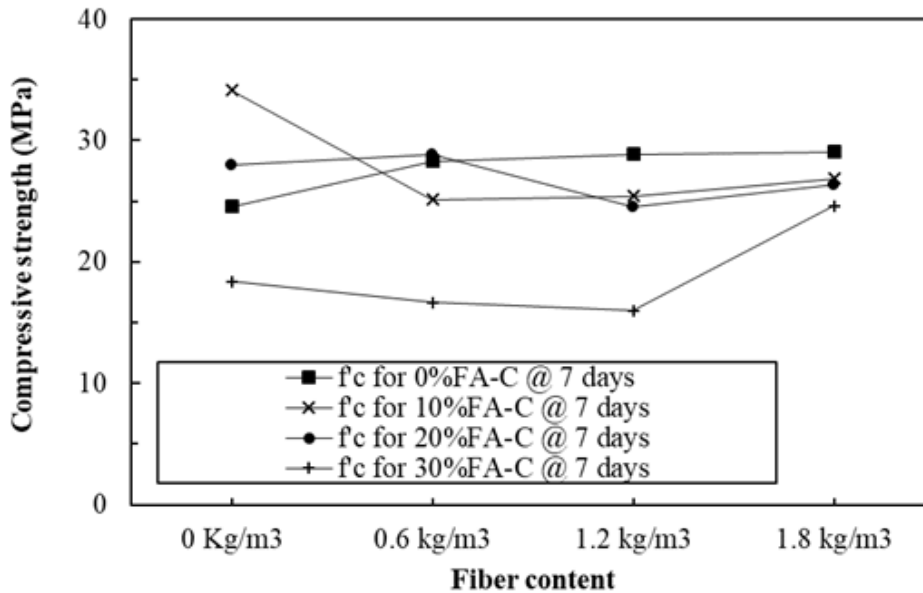


Fig. 6. Effect of PP Fiber on Compressive Strength of FAM-Cement at 7 Days.

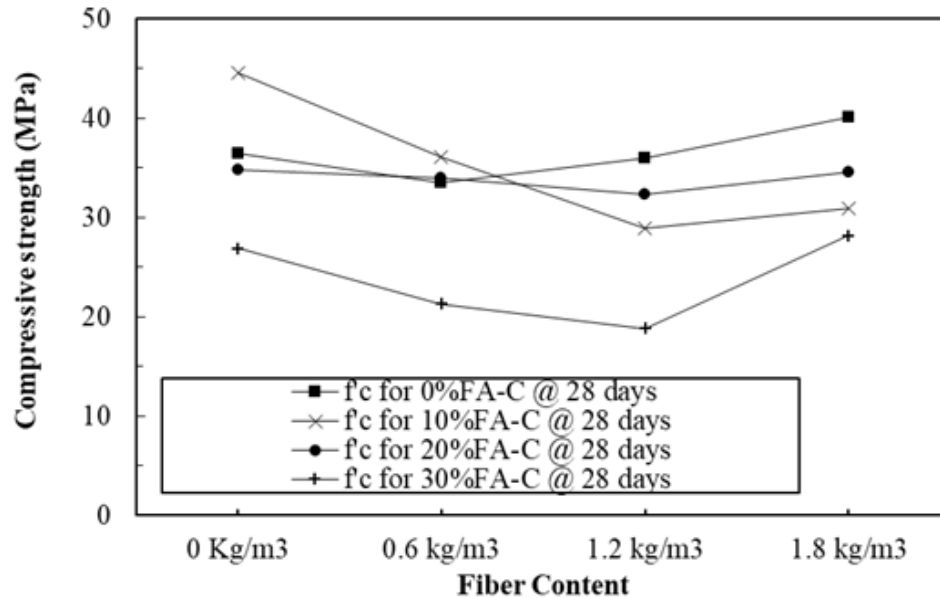


Fig. 7. Effect of PP Fiber on Compressive Strength of FAM-Cement at 28 Days.

In Fig. 8 and Fig. 9, the effect of FA-C on the compressive strength of fiber reinforced mortar is presented at 7 and 28 days. The compressive strength of 0%, 10%, 20%, and 30% FA content is tested for mortar with fiber content of 0, 0.6, 1.2, and 1.8 kg/m³. At 7 days, the optimum value shift from 10% to 20% FA with the increase of fiber content from 0 to 0.6 kg/m³. For higher fiber content (1.2 and 1.8 kg/m³), continuous decreasing of compressive strength with the increase of the fly ash content was observed with no presence of optimum peak.

At 28 days, it is observed that the 0 and 0.6 kg/m³ fiber reinforced mortar presented optimum compressive strength values at 10% FA content and a continuing decrease for higher fly ash content. For 1.2 and 1.8 kg/m³ of fiber ratio, the fiber reinforced mortar presented a minimum compressive strength value for the 10% FA. This result shows that the fiber content presented the most negative effect on the compressive strength.

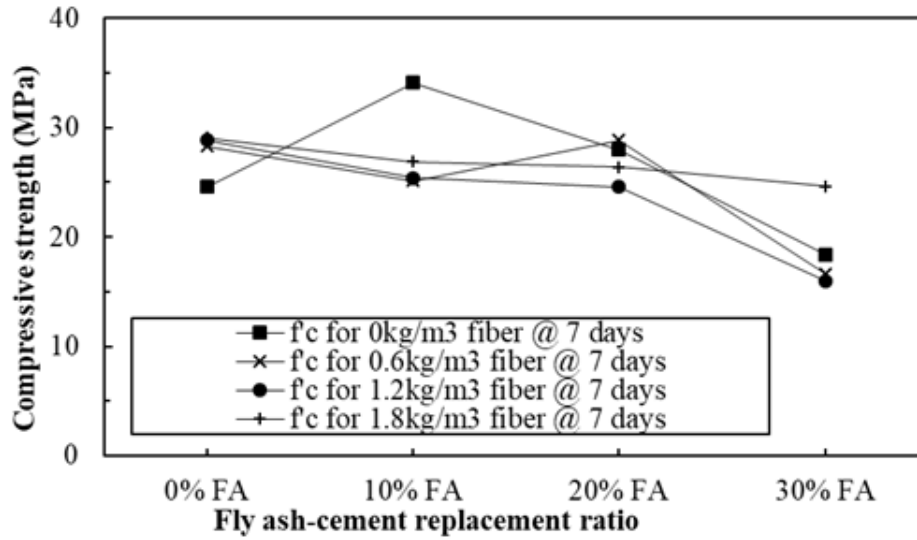


Fig. 8. Effect of FA-Cement Content on Compressive Strength of Fiber Reinforced Mortar at 7 Days.

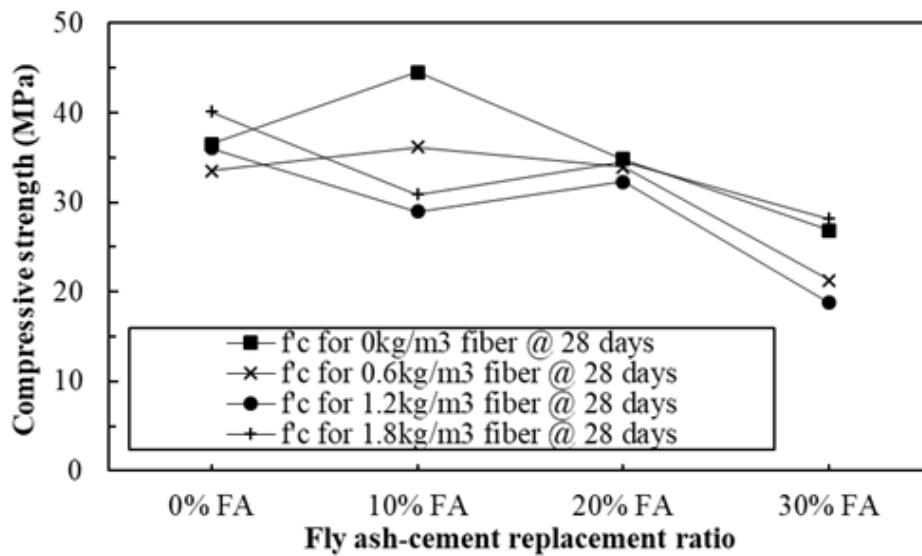


Fig. 8. Effect of FA-Cement Content on Compressive Strength of Fiber Reinforced Mortar at 28 Days.

Combined Effect of PP Fibers and Sand Replacement Fly Ash

The combined effect of PP fiber and FA-S content on the compressive Strength of cube specimens at 7 and 28 days are shown in Fig. 10 and Fig. 11.

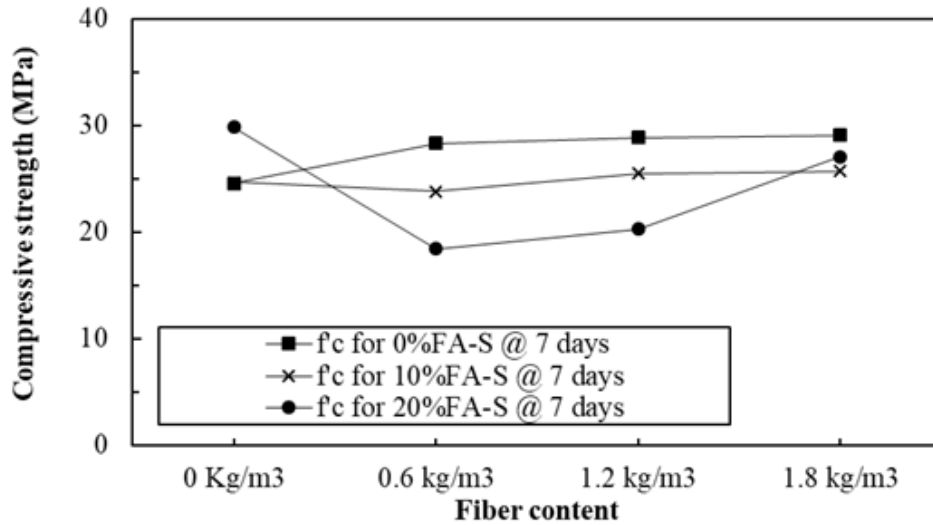


Fig. 10. Effect of PP fiber on compressive strength of FAM-sand at 7 days

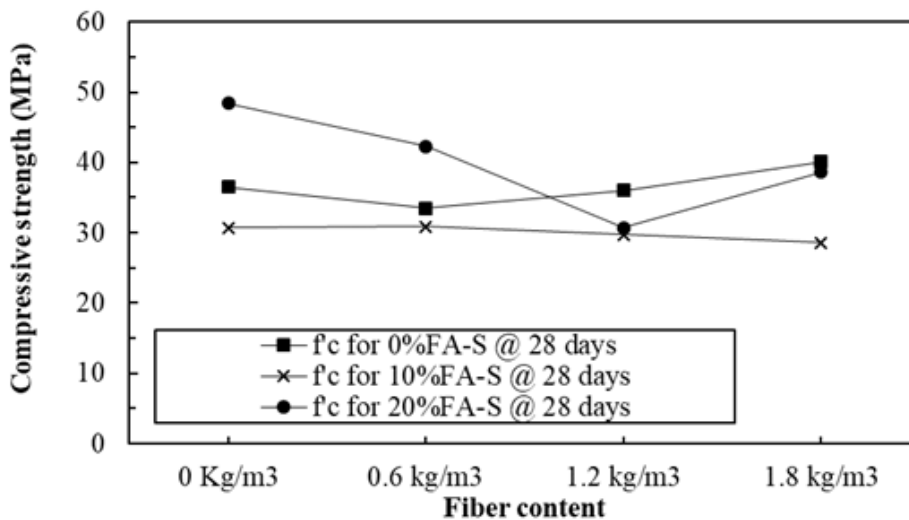


Fig. 11. Effect of PP fiber on Compressive Strength of FAM-sand at 28 days.

At 7 days, the compressive strength of mortar without fly ash presents an increasing trend with the increase of fiber content. While with the increase of FA content in the mortar, the trend of the curves changed from an increase trend to a more convex trend with the increase of fiber content.

Effect of PP Fibers on Flexural Strength

The flexural strength value of prism specimens at age 7 and 28 days are shown in the below Fig. 12. It is observed that the flexural strength of mortar with 0.6, 1.2, 1.8 kg/m³ (0.07, 0.14, 0.21% per volume) fiber content presents a convex trend at 7 days with 7.15 MPa, 7.30 MPa, 7.81 MPa, respectively compared with the control mix 7.39 MPa. It presents a slight variation of flexural strength with a minimum flexural strength at 0.6kg/m³ fiber content and a maximum flexural strength at 1.8 kg/m³ fiber content. While at 28 days, the same trend is observed but with no results above flexural strength of control mix (8.97 MPa), with a minimum value of 8.40 MPa at 0.6 kg/m³, a reduction of 6.35%, and a slight increase of flexural strength with the increase of fiber content.

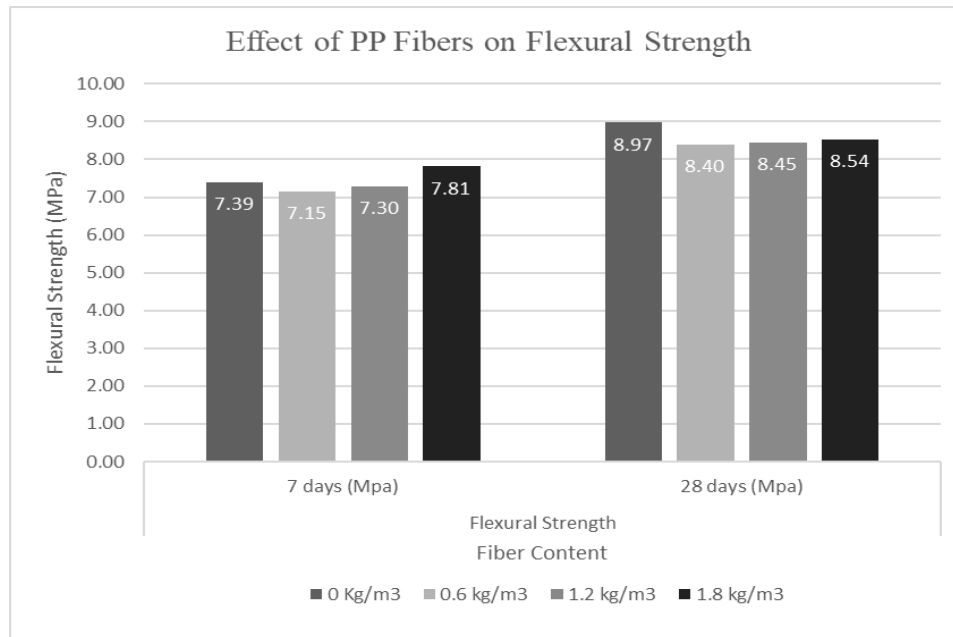


Fig. 12. Effect of PP on the flexural strength.

CONCLUSIONS

From this study, it can be concluded that energy to waste fly ash in a 10 to 20% range is an effective cement substituent. Fly ash slightly increases the density of the mortar slightly. Fly ash replacing sand and cement contributes to higher compressive strength.

The compressive and flexural strength of normal mortar slightly increases with the increase of the polypropylene fibers content, while the polypropylene fibers present a negative effect on the compressive strength of fly ash mortar replacing cement and sand.

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