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CHARACTERIZATION OF CEMENT-BASED MORTAR REINFORCED WITH CHOPPED STEEL WOOL AND POLYPROPYLENE FIBERS

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ABSTRACT

Appropriate cement based mortar design plays an important role in building construction. The cement based mortar designed with suitable reinforcement materials shall significantly help to improve the properties of resulted mix. A cement based mortars incorporating chopped steel wool and polypropylene fibers addition of up to 2.5% of the cement mass was used. Various test methods in terms of flow ability, wet density, air content, flexural and compressive strength were used to evaluate its performance and possible applications in civil engineering. The results indicated that the addition of chopped steel wool and polypropylene fibers had affected the fresh and hardened properties. Increased fiber content in the cement mortar was found to reduce the flow whereas there was increase in the air content irrespective of the type of fiber used. The wet density results showed that the two fibers showed contrasting impacts. Incorporating chopped steel wool fiber increased the wet density whereas polypropylene fiber was found to decrease the wet density. Furthermore, it was observed that flexural and compressive strength proportionally increased with the chopped steel wool and polypropylene fibers addition. The improved performance of the chopped steel wool and polypropylene fibers reinforced mortar not only signifies its potential use for the application, but also is helpful to standardize the process of reinforced mortar design.

KEYWORDS: Mortar, Polypropylene Fiber, Chopped steel wool fiber, Compressive and flexural Strength.

INTRODUCTION

Cement based mortar is one of the most widely used structural materials. It is a composite material containing hydraulic cement as a binder, water, and fine aggregates as inert granular material. Cement mortar is an affordable, reliable, and mouldable and can provide good performance for masonry construction, plastering and with the addition of coarse aggregates for concrete. However, it is brittle, poor deformability, weak crack resistance in practical application and lower tensile and flexural strength when compared to their compressive strength [1-3].

Incorporation of reinforcement materials at optimum fractions in cement based materials have been suggested as one of the most effective methods in improving the performance behavior of the resulting mix [4]. However, this improvement mainly depends on the type and shape of the used reinforcements [5].

Several types of reinforcement materials and their impacts on the performance of cementitious materials have been studied by several researchers. Filho et al. [6] indicated that the addition of steel and polypropylene fibers can reduce the plastic shrinkage cracking of cement based materials by increasing the tensile strength and by bridging. Furthermore, the addition of fibers to cement mortar can increase its ability to resist crack development [7, 8]. In addition, it was observed that steel fibers can significantly reduce cracking behavior of concretes [9]. Crack behavior investigation also done by Vandewalle [10]. In this investigation, concrete beams reinforced with different fractions of steel fibers showed that the addition of steel fibers decreases the cracking spacing and crack width. Moreover, Grdic et al. [11] reported that the addition of fibers contributes to reduction of both size and rate of the cracks in concrete during early stage. The reason is the randomly oriented fibers hold the micro-cracking and limit the crack progression, thus improving the strength and ductility[12].

Al-Ghaban [1] has been cited that the toughness of cementitious matrices can be raised with the addition of fibers in the cement-based materials. The outcome from a study by Rai [7] showed that the addition of steel fiber, glass fiber, natural fiber and polymer fiber was an effective way to increase the toughness and shock resistance of the concrete. Investigation shows that the toughness of concrete reinforced by different fiber which includes hooked end, crimped circular, crimped crescent and twin cone end steel fibers brought significant improvement compared to plain concrete [13].

Contradictory outcomes have been reported by different researchers regarding the effects of fiber on the compressive strength of cement based materials. Whereas Hughes and Fattuhi [14] stated that the compressive strength decreases with increase of polypropylene fiber (PF)**,** contrary, Alhozaimy et al. [15] observed that PF has no significant effect on compressive strength. On the other hand, the improvements in compressive strength and flexural strength has been observed with the addition of PF in ordinary Portland cement concrete [16]. Habib et al. [17] showed that the addition of PF into the mortar increases the compressive strength of mortar composites. Moreover, the addition of glass fibers into the concrete mixture marginally improves the flexural and compressive strength when compared with plain concrete [18]. In addition, the outcome of using recycled steel particles as *partial replacement* of *fine aggregate* in concrete showed that the flexural strength was 38% higher than that of a conventional concrete [19]. Also, an improvement in the tensile and flexural properties were obtained when cement matrix composite containing short carbon fiber [20]. These disagreements may have been caused because of the variations in types, fractions of fiber and in the composition of the mixes [21].

Luo et al. [22] performed a test on the mechanical properties and resistance against impact on steel fiber reinforced high-performance concrete. Armor penetration projectiles were used and launched at a high velocity between 365m/s and 378m/s. The results indicated that the specimens without fibers were smashed up, whereas steel fiber reinforced high-performance concrete kept intact with some minor cracks. Gupta et al. [23] showed that fiber reinforcement in wet-mix shotcrete improves the fracture energy absorption and toughness under impact loading.

It has been found that steel fibers added in specific percentage to concrete improves the durability and serviceability of the structure [24]. Wang et al. [25] applied different recycled fibers which included tire cords/wires, carpet fibers, feather fibers, steel shavings, wood fibers, and high-density polyethylene as reinforcement in concrete. The result showed that recycled fibers effective, improving the durability, toughness, and shrinkage characteristics of concrete.

The most important drawback of incorporating a fiber in cement based materials is the loss of **workability** thus, increasing the difficulty of casting [26]. Several researchers reported inclusion of fibers can cause decrease in workability of the resulting mixes [27-29]. Chen and Liu [30] reported that at %1 volume content, polypropylene fiber reduced slump values of concrete by about 21%. Shekarchi et al. [31] cited that in constant water to cement ratio, the use of polypropylene fiber decreased workability. They also found that doubling the length of fibers in the same fiber content ratio did not affect workability and that mixes with low fiber content (0.1%) did not make considerable changes in workability.

Kang et al. [32] reported that non-homogeneous distribution of fibers reduced the strengthening effect of fiber whereas, the improved fiber distribution has an important role in enhancing the hardened properties of the cementitious composite [33]. Fiber distribution is *significantly* influenced by fiber size, fiber ratio and workability of the matrix [32].

Fiber reinforced cement based materials was successfully used in a variety of engineering applications due to its acceptance and prominent performance in the industry and construction field [34]. Research and practice have shown that steel fiber reinforcement is effective and economical for industrial floors. Chen [35] demonstrated that the load bearing capacity is effectively increased when the slabs are reinforced with steel fibers. Fiber reinforced cement- based mortar is mainly desirable because it narrows the width of cracks caused by unpredictable strain from shrinkage and temperature change which ensure homogeneity and stability of a structure under failure [36]. Fibers reinforced cement based mortar uses in the construction industry are varied from the renovation of minor damaged parts to the normal or the spraying plastering of the structure. It can also be used for the construction of load-bearing and partition walls in brick or cement blocks and to create stairs and floors laying marble slabs. Furthermore, the presence of **fibers** in the composition of cement based mortar allows this product to be used for masonry **buildings in earthquake zones [37]**. In addition, the fiber reinforced cement based mortars can be used for cladding, which usually applied in thin sheet components [38].

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The existing literature has identified some effects of the reinforcement materials on the properties of cement based materials. However, there are still many open research questions have not been thoroughly investigated and need to be addressed in order to cover the gap in the area and understand the associated phenomena. For example, the optimum contents and types of reinforcement materials to produce cement-based composites with acceptable properties are not yet clear. Furthermore, the interaction between the cementitious matrices and reinforcement materials is another area of concern and need more investigation. This knowledge can then be used to create guidance on using reinforcement materials to produce mortars of specified strength. This type of information is expected to help create opportunities for the use of reinforced cement-based mortar within a higher structural application.

The objective of this research work is principally to focus on understanding the impact of incorporation different reinforcement materials on the performance of fresh and hardened properties of the resultant cementitious mixes. Specifically, the research utilized Portland cement based mortar incorporated different mass fractions of chopped steel wool and Polypropylene fibers.

EXPERIMENTAL METHODOLOGY AND DESIGN

Materials

Cement

ASTM type 1 cement (El-Borge, Zliten (BZ) which meets GPC requirements ASTM C150 [39] was used to produce the mortars. General purpose cement is preferred because the observation of mortar properties can be done during the normal hydration process, hence the effects of reinforcement materials in the mortar can be observed. The chemical properties of the El-Borge cement are given in Table 1.

Table 1: Percent chemical composition of El-Borge cement analysed by XRF method

Parameter	Content (%)	
	El-Borge cement	ASTM C150-16
CaO	62.36	61 - 67
SiO_2	22.06	19 - 23
Al_2O_3	4.8	2.5 – 6.0
Fe_2O_3	3.68	6 Max
MgO	2.01	5 Max
K_2O	0.63	<1.0
SO_3	2.47	3 Max
Na_2O	0.08	<1.0

Sand

The fine aggregate used was locally available silica sand collected from Awjilah town and called Awjilah sand with an absorption capacity of 0.20%, specific gravity of 2.60. Prior to use, the fine aggregate was dried in ambient conditions to eliminate any free water. The particle size distribution by sieving method specified in ASTM C 136 [40] is illustrated in Figure 1.

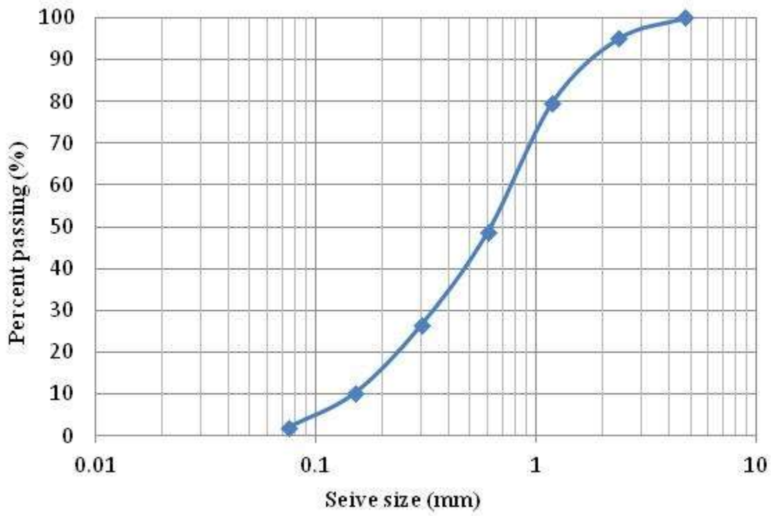

Figure 1: Particle size distributions (sieving method) of Awjilah sand

Water

Drinking grade tap water (TW) (pH 7.4; 2.29 µS/cm) was used and conditioned at 22±2 °C prior to use.

Reinforcement materials (RM)

Chopped Steel wool Fibre (CSWF)

Very fine steel wool (Grade 00 #) with low carbon steel was obtained from a local market (kitchen cleaning steel wool) then chopped manually by scissor to achieve the required length range. Properties of used steel wool material are shown in Table 2.

Table 2: Physical properties of chopped steel wool used

Physical properties	Values
Length (mm)	2-3
Diameter (µm)	40
Density (kg/m^3)	7160
Thermal conductivity (W/mk)	50

Polypropylene Fiber (PPF)

Polypropylene fiber from Sikca Company for Construction Chemicals, Libya was used. Polypropylene fiber followed the requirements of ASTM C1116 [41]. It was put away under cover far from warm sources. Table 3 presents the physical and technical properties of polypropylene fiber [42].

Table3: Physical properties of Polypropylene used

Physical properties	Values
Length (mm)	2-3
Thickness (µm)	18 - 30
Density (kg/m^3)	910
Young's modulus (Mpa)	5500 - 7000
Thermal conductivity (W/mk)	Low

Mortar composition and mixing procedure

The composition of control mortar was in accordance with ASTM C270 [43] with the mix proportions being 1 part of cement and 3 parts of sand (by mass) at a fixed water/cement ratio (w/c) of 0.50. Each mortar batch comprised cement (450 g), fine aggregate (1350 g), water (225 g). The fractions of the reinforcement materials were calculated by weight of the cement in the composite (0.5%, 1%, 1.5%, 2% and 2.5%. The mixing process was following the procedure outlined in ASTM C305 [44]**.** In the case of adding the reinforcement materials to the mixes, the adopted ASTM C305 [44] test method was modified with additional steps. Immediately, after the finishing of mixing mortar, the required masses of reinforcement materials were added manually in the mixing bowl for 3 to 5 minutes by using a spatula to ensure thorough mixing. The Hobart mixer was then turned up to a high speed and left to mix for 60s. At this time, the Hobart mixer was turned off and the mixing bowl removed. The mortar was then subjected to several performance tests as detailed later.

Casting and Curing
The cement mortar specimens were cast using cubes of (50 mm), prisms of (40*40*160) mm from steel molds. The moulds were sealed using zip lock plastic bags to prevent water from evaporating and stored in a moist atmosphere for 24 h using a large plastic box. Demoulding take place after that and thereafter placed in a curing tank filled with water saturated with lime (ASTM C511[45]) for up to 28 days at a temperature of 22.0 ± 0.5. Water not saturated with calcium hydroxide (high-calcium hydrated lime) may affect test results due to leaching of lime from the test specimens.

Test methods
The fresh mortars were tested for flow (ASTM C1437 [46]), wet density (ASTM C138 [47]) and air content (TESTING Bluhm & Feuerherdt GmbH, ASTM C231 [48]). Mortar specimens (50 x 50 x 50 mm) were tested at the age of 7 and 28 days for compressive strength whereas flexural strength at 28 days. An ADR –Auto V2.0 250/25 compression testing machine was used for both tests. The compressive strength was followed the listed procedures of the test method ASTM C109/C109M [49]. Vertical load at a rate of 0.99 $kN.s^{-1}$ was exerted on the specimens and the maximum load indicated by the testing machine (load at failure) has been recorded.

Flexural strength of the prism mortar specimens (160 x 40 x 40 mm) was performed using three-point bending method according to the ASTM C 348 [50]. The load applied through displacement control was at a rate of 0.05 $kN.s^{-}$1.The automatic horizontal jolting table was used instead of tamper at a rate of 60 jolts per minute to compact the fresh cement mortar in the three gang moulds instead of tamper. Each value of the results presented in this report is the average of three test samples.

RESULTS AND DISCUSSION

Influence of CSWF and PPF on flow and wet density
The addition of CSWF and PPF was found to decrease flow gradually with increasing CSWF and PPF contents (Figure 3). A reduction in flowability was between 5.8-35% and 9.4-41.2% for CSWF and PPF respectively compared to the control mortar. This reduction and variation in the flowability of mortar mixes can be attributed to the diameter, geometry and specific surface area of CSWF and PPF. Studies show that increase in fiber content decreases the workability due to a high specific surface area of the fibres [51-53]. This decreases in flow for mixes containing reinforcement materials is a similar to other studies reported in literature [54-56].

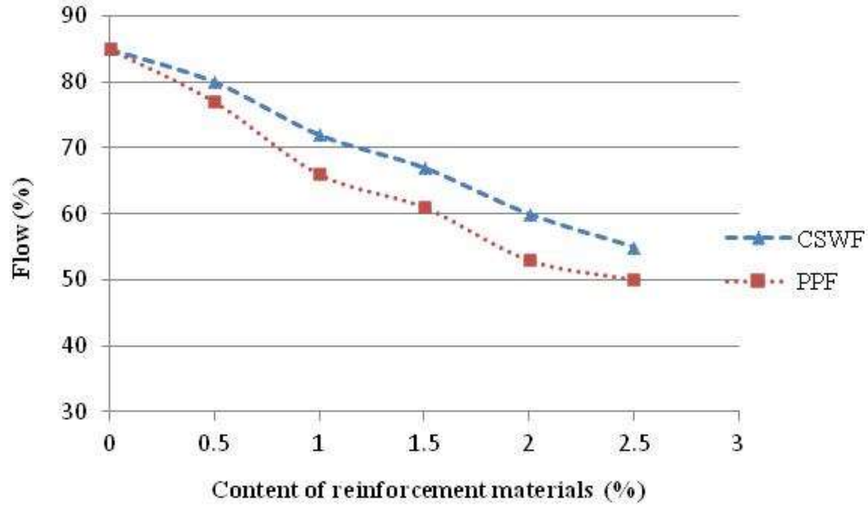

Figure 3: Effect of reinforcement materials on flow of mortar mixes

Measurement of the wet density showed that adding CSWF to the mixes at 2.5% increased the wet density by about 7% compared to the mixes without CSWF. Conversely, it can be observed that when the same amount of PPF added, the wet density of the mixes slightly decreased by about 1% compared to the control mix (Figure

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4). This difference can be attributed to the control mortar (2237 kg/m^3) being replaced by higher density CSWF (7610 kg/m^3) and lower density PPF (910 kg/m^3) when it is placed in a mould of a fixed volume.

The increase and decrease in wet density of cementitious-based materials due to the incorporation of fibers has previously been reported. Elzaroug et al. [57] showed that the increase in content of steel fiber has led to an increase in the wet density of concrete. Additionally, test results showed that the addition of polypropylene fiber in higher amounts decreased the wet density of cement mortar [58].

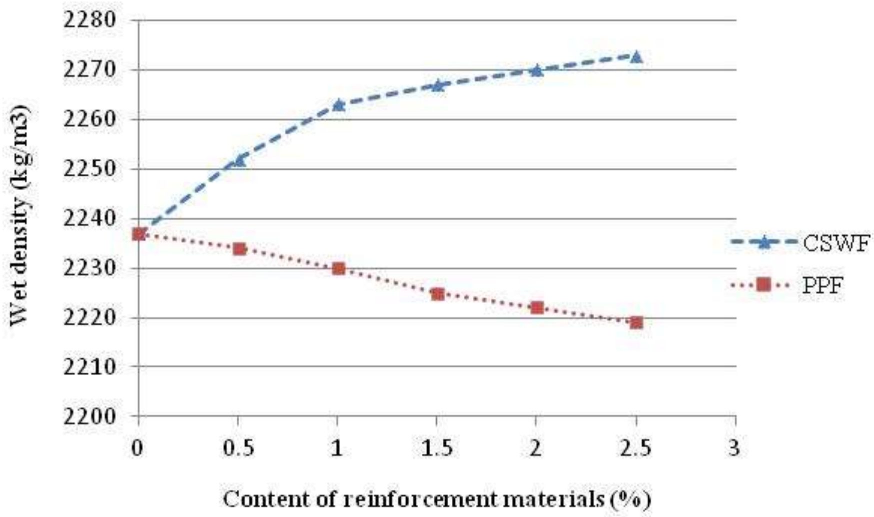

Figure 4: Effect of reinforcement materials on wet density of mortar mixes

Influence of CSWF and PPF on air content

CSWF and PPF alters the air content of fresh mortar as plotted in Figure 5. As a general trend, the percentage of air content slightly increase with increased CSWF or PPF content. However, mixes containing PPF more adversely affected air content than those containing CSWF. It is possible that the air content increases with the increasing CSWF or PPF content because of mixing related phenomena. However, this is still speculative and requires further work.

For the control mortar, the air content obtained was 6.5 %. This value is higher than in the literature. Other studies have shown that the typical air content obtainable for non-air entrained mortar is lower than 3% [59-61]. This difference in the air content values can be attributed to the methods used for measuring air content in mortar as proved by Almabrok [62]. An air meter gives a higher value for air content than a calculated one [63].

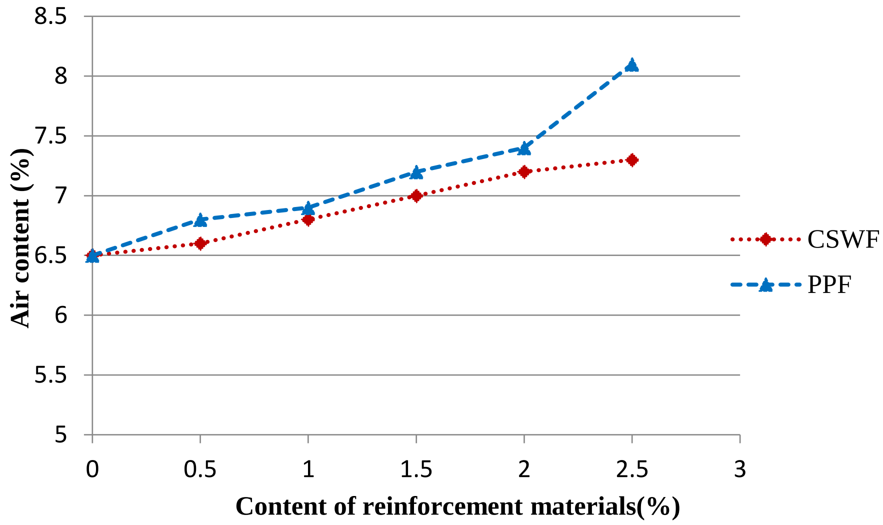

Figure 5: Effect of reinforcement materials on air content of mortar mixes

Influence of CSWF and PPF on compressive strength

The behavior at 28 days compressive strength of samples incorporating CSWF or PPF shows that most of the mixes follow a similar trend whereby a higher content of CSWF or PPF in mortars resulted in increased compressive strength (Figures 6). The increases were nearly linear rather than a step change at specific CSWF or PPF content, except a mixes contains 2.5% of PPF where about 6% reduction has been observed compared with control mortar. *This may be due* to *possible* balling, or uneven distribution within the samples [64].

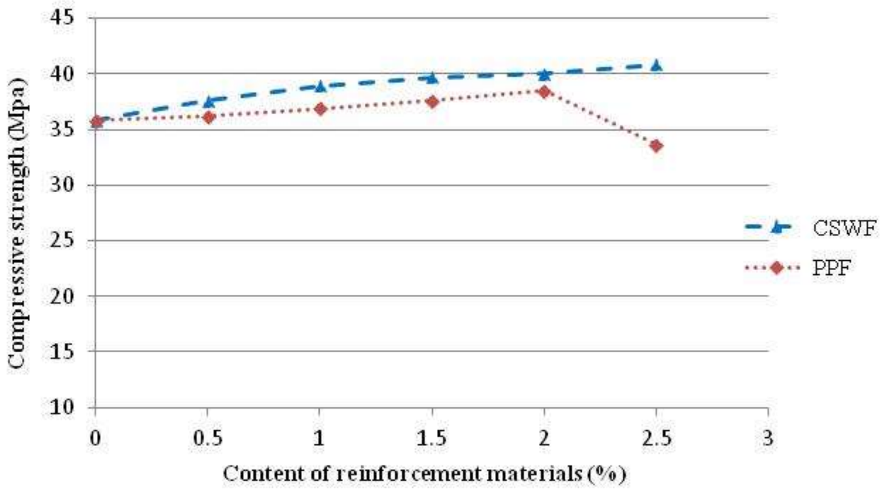

Figure 6: Variation in compressive strength at 28 days for mortar mixes containing reinforcement materials

It is noticeable from Figure 6 that the mixes exhibited different results in compressive strength based on the RM type and dosage used [5]. Furthermore, it can be seen that the mixes incorporating 0.5% to 2.5% of CSWF produced a higher compressive strength than PPF mixes by 4% to 21% with same contents. This difference in the obtained results could be attributed to the morphology, elemental composition and distribution of the RM added to the mortar [65]. Moreover, the position and orientation of the RM inside the specimens could be_also having contribution [66].

The improvement of compressive strength of cement based materials due to incorporating RM can be attributed to the greater resistance to sliding of pre-existing micro-cracks by reducing the driving energy for the crack growth. Furthermore, if the RM is aligned in the direction of crack growth they improve the ability of cement composites materials to resist fracture via crack bridging [67, 68].

The results show an almost systematic increase in compressive strength development at 7 and 28 days with the increase in CSWF content (Figure 7). The other noticed trend is that increasing CSWF contents relatively have a consistent impact on strength development. Furthermore the compressive strength of the PPF containing mortars was developed at all curing times even when the fraction of PPF was increased (Figure 8). However, the percentage increments of mixes containing PPF from 7 to 28 days were relatively lower than those of the mixes containing CSWF (Figure 9).

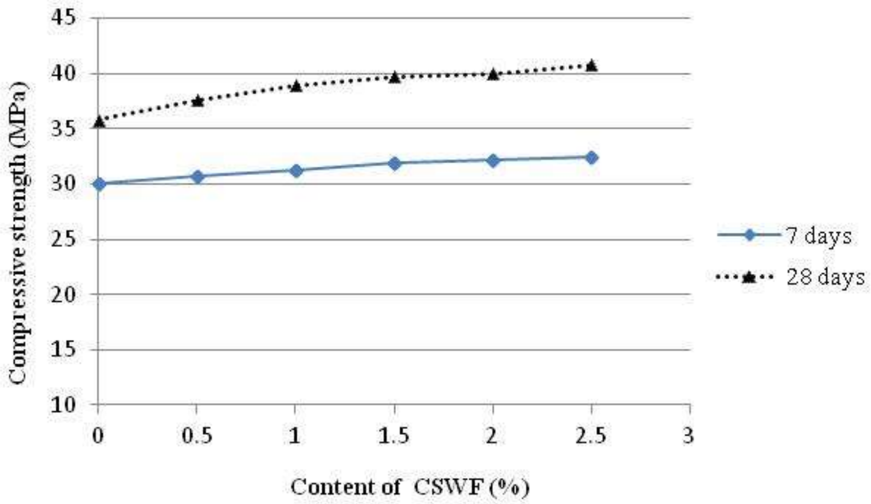

Figure 7: Compressive strength values of mortar mixes containing CSWF

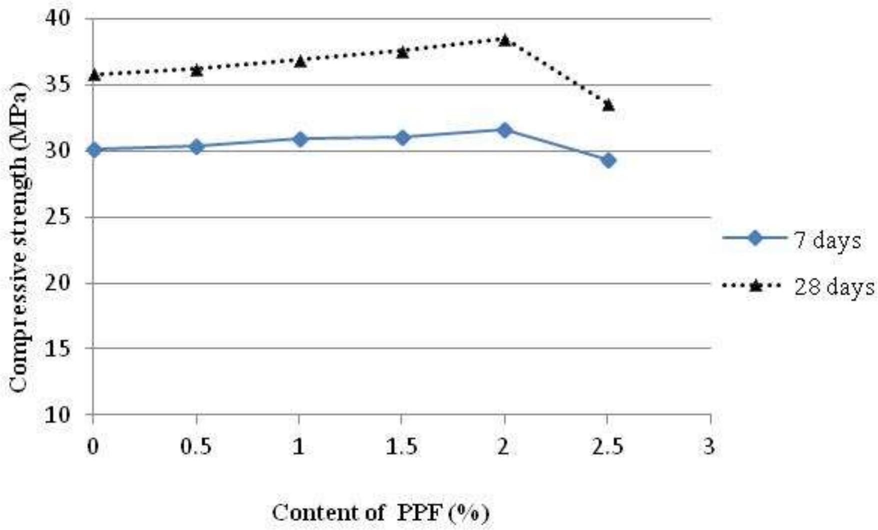

Figure 8: Compressive strength values of mortar mixes containing PPF

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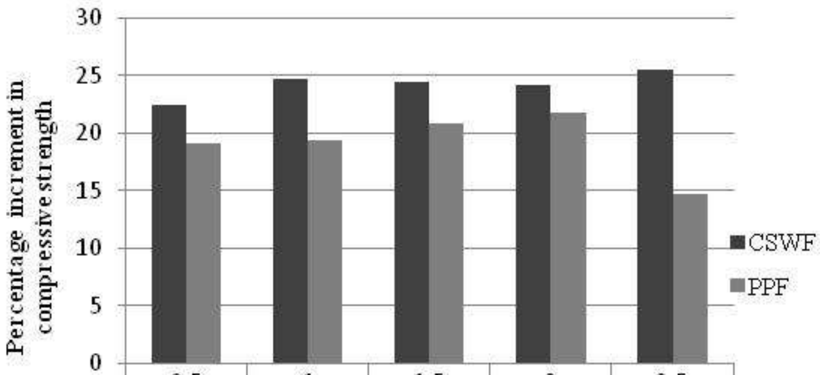

	0.5	1	1.5	2	2.5
CSWF	22.47	24.67	24.45	24.22	25.53
PPF	19.07	19.41	20.9	21.83	14.67

Content of reinforcement materials (%)

Figure 9: Percentage increment in compressive strength from 7 to 28 days of mortar mixes containing reinforcement materials

Influence of CSWF and PPF on flexural strength

A notable increase in the flexural strength was observed with increasing dosage of CSWF or PPF showing quite similar trends to those of compressive strength (Figure 10). The reasoning applied to describe the increase in compressive strength can be used to explain this improvement of flexural strength.

Additionally, the mixes containing CSWF exhibits the better flexural strength when compared to the PPF mixes. It can be seen that the mortar mixes incorporating 2.5% of CSWF and PPF causes the flexural strength to increase up to 36% and 25.5% respectively with regard to the control mortar. The observed variation in the results was attributed to the morphology and elemental composition of the RM added to the mortar mixes that showed different performance of flexural strength depending on their position and distribution inside the specimens [65].

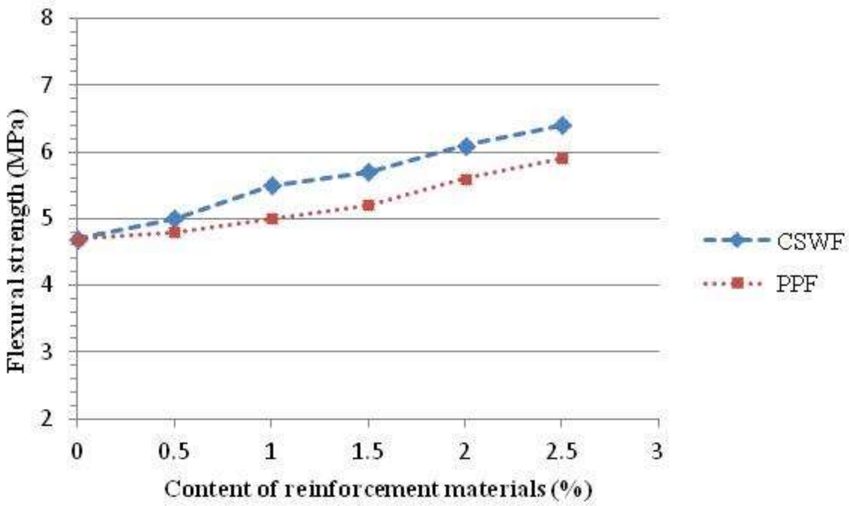

Figure 10: Variation in flexural strength at 28 days for mortar mixes containing reinforcement materials

CONCLUSION

Incorporation of reinforcement materials in cement based materials has been suggested by several researchers as effective methods in improving the performance behavior of the resulting mix. However, in regard to reinforced cement based mortar different properties have not been thoroughly investigated and understood yet. In this work, the influence of different mass fractions of chopped steel wool and polypropylene fibers on the fresh and hardened properties of cement based mortar have been presented.

It could be concluded that increased reinforcement materials content in the cement based mortar was found to reduce the flow, whereas there was an increase in the air content irrespective of the type of reinforcement materials used. The wet density results showed that incorporating CSWF increased the wet density, whereas PPF were found to decrease the wet density. Regarding the mechanical performance of mortar specimens, it was concluded that the addition of CSWF or PPF produced slight variations on their flexural and compressive strength. Compressive and flexural strength of mortar specimens proportionally increased with the increase of the CSWF or PPF content. Additionally, it was found that specimens with CSWF presented, on average, higher values of their mechanical properties than did specimens with PPF. This was attributed to the differences in their morphology and elemental composition.

The flexural and compressive strength of CSWF and/or PPF reinforced cement based mortar were suitable enough for construction of light weight structural elements as well as in repairing of minor damaged parts of the structure.

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