Investigating the effect of polypropylene fibre on mortar mechanical properties with the aid of microwave curing

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Abstract In recent times, there has been increased interest in using various types of fibres in the cement-based materials industry. This work thus aims to investigate the possibility of improving the mechanical properties of mortar samples by using available and cheap polypropylene fibre with the aid of a microwave curing technique. For this purpose, 5×5×5 cm cubes of mortar containing different percentages and lengths of polypropylene fibres were cast and then subjected to various ranges of curing time under microwaves. Compressive strength, direct tensile strength, and density tests were conducted on reference mortar (specimens without fibres) and mortar reinforced with polypropylene fibre specimens at various ages (3, 7, and 28 days) of curing. The results showed a marginal decrease in the compressive strength against an increase in the direct tensile strength as fibre content increased. All mixes showed acceptable values for density against the reference mixes.

Keywords: Mortar; Polypropylene Fibre; Mechanical Properties; Microwave Curing Technique.

1. Introduction

Currently, cement mortar is one of the most widely spread construction materials in the structural industry due to its low cost and high compressive strength. However, cement mortar is more brittle than other construction materials and has inherently low impact and tensile strengths. Besides, cement mortar can crack easily because of its ability to shrink, and the concentration of stress it must withstand [1–5]. Related research has revealed that employing cement mortar in repairing various old concrete structures is a straightforward and widely recognised cost-effective way to lengthen service life [6, 7], and all repair materials with adequate durability characteristics and excellent mechanical properties are in high demand.

Throughout the last thirteen years, cement-based materials reinforced with fibre have thus become the most commonly utilised materials for repairing deteriorated cement-based constructions [8, 9]. Several studies have been undertaken on the properties of fibre reinforced mortar and fibre reinforced concrete; these studies have revealed that fibre additions can often increase the mechanical properties of mortar and concrete, particularly in terms of the flexural and tensile strengths [10–12]. Besides, utilising various types of fibres in mortar and concrete has
been proved to considerably enrich the bond strength between the repairing material and the old substrate, a crucial step in producing an active repair [1, 8, and 13]. Similarly, adding fibres can substantially improve toughness and flexural post-cracking behaviour when used in a mortar or concrete mixes [7, 14–16], and fibre presence can also lessen the width and number of cracks in cement-based materials by forming a bridging action [17]. More significantly, the incorporation of fibres in mortar or concrete can improve their durability properties [18, 19] such as resistance to aggressive solutions and abrasion.

Examining prior research, it can be concluded that the influence of fibres on the properties of cement-based materials, especially mortar, has been well-established [20–22]. More specifically, polypropylene (PP) fibres have been widely utilised in reinforcing various cementitious materials to enhance energy absorption and toughness capability [23, 24]. They are particularly useful in deferring the occurrence of the first crack, in controlling the development of cracks, and in decreasing free plastic shrinkage [25-26]. However, although many studies have verified the effectiveness of adding PP fibres in terms of increasing impact resistance, managing shrinkage cracks, and improving cement matrices' ductility, its effect on flexural and compressive strengths is not as clear [27]. Several researchers have suggested that there might be no or only slight chemical adhesion within the PP fibre and cement mortar matrix because of the chemical inertness of the former [28] and the smooth surface of the fibres, which seems to intensify this effect. Furthermore, it has been proposed that the existence of PP fibres in cement-based materials can form a water film at the matrix and PP fibre interface, known as the wall effect. Owing to the calcium ions' superior mobility in a wet atmosphere, macro crystals of calcium hydroxide (portlandite) can then develop, producing a highly porous transition zone [29] that can cause undesirable effects on the bonds between the mortar-PP fibre matrix. In this regard, it is apparent that it is essential to improve PP fibres' interfacial bonds when they are used in this manner.

The effects of microwaves could be useful in reducing the wall mentioned above effect among PP fibre and cement mortar matrices, as stated by several authors [30-32]. Accordingly, the present work aims to focus on the influence of PP fibres of various length and ratios on the mechanical characteristics of cement mortar samples cured additionally by the application of microwaves for four periods. The findings from this illustrate the densification effect of the PP fibre-mortar matrix interface in terms of the effectiveness of reinforcement with such fibres. In this study, various mortars reinforced with PP fibre of various lengths and volume fractions were thus prepared. The density and compressive and direct tensile strengths of all mortars produced were then assessed in order to offer a more comprehensive overview of the influence of PP fibre on such properties.

2. Experimental Set-up

2.1. Materials

2.1.1. Cement

A conventional Portland cement (OPC) was utilised that corresponds to ASTM C 150, bought from a local cement plant. The physical properties and chemical compositions of the OPC were confirmed as meeting Iraqi specification.
2.1.2. Fine Aggregates

Fine aggregate refers to all fractions from 4.75 mm to 150 μm. Natural river sand conforming to ASTM-C778 was used as a fine aggregate for mortar preparation in this case. The physical properties and distribution of particle size were within the standard requirements.

2.1.3. Fibre

A polypropylene (PP) fibre with two different lengths, 0.5 and 1.5 cm, was used as a micro-reinforcement with the properties presented in Table 1.

| Technical Property      | Description       |
|-------------------------|-------------------|
| Composition             | 100% polypropylene|
| Specific gravity        | 0.90 kg/l         |
| Tensile strength        | 137-689 MPa       |
| Young's modulus         | 3.4-4.8 GPa       |
| Toughness               | 8.82 GPa          |
| Elongation              | 25-40%            |
| Melting point           | 160° C            |
| Softening point         | 150° C            |
| Ignition point          | 580° C            |
| Chloride content        | Nil               |
| Sulphate content        | Nil               |
| Alkali content          | Nil               |

2.1.4. Water

Water is a vital component in mortar production; it reacts chemically with cement and helps form the strength-giving cement gel. Ordinary tap water was used in all mortar specimen preparation processes.

2.2. Preparation and Curing

The mortar ingredients were batched by weight and the fine aggregate and cement mixed in their dry conditions using a mixer for 60 seconds. After that, the PP fibres were added to the dry mixture and re-mixed dry for an additional 60 seconds. Finally, the mixes were cast into moulds that were placed on a vibrating table for 120 to 180 seconds to achieve proper compaction. The mortar samples were immediately covered with polythene sheets to avoid water evaporation from the surface and placed in the laboratory at 23°C for 24 hours. After one day, the mortar samples were de-moulded and relocated to a room with adequate humidity at a temperature of 20±2°C and a humidity percentage of 90 ± 5 until they reached testing age, when they were then treated in a domestic microwave. Thus, two different techniques were followed: The first technique involved samples tested immediately after water pool curing, while in the second technique, the samples were treated using a domestic microwave (900 W at 2.45 MHz) for different periods of 1, 2, or 3
minutes following curing by water. The fresh mortar was cast into 5cm cubes for the
compressive and density tests, following ASTM C109 and ASTM C270, respectively, while dog
bone-shaped steel moulds with a dimension of 76 mm long by 25 mm thick were used for testing
the direct tensile test.

2.3. Mix Proportions

In this study, seventeen mortar mixes were prepared, including one reference mortar. The sixteen
test mortar mixes were prepared using PP fibres of various length and volume fractions, with
lengths being 0.5 cm or 1.5 cm and the volume fractions being 1.5% and 3%. The mix proportion
of the mortar was 1:3. All specimens were fabricated with a water/cement ratio of 0.5, and the
density and compressive and direct tensile strengths results were determined at 3, 7, and 28 days
of curing. The reference mortar and the reinforced mix sample not subject to microwave curing
were tested at 28 days, while at 3 and 7 days, three reinforced mixes were subjected to microwave
curing for various times (1, 2, and 3 min), and the fourth tested without being subject to
microwave curing. Each test result was the average of three test specimens.

3. Experimental Investigation and Results

3.1. Compressive Strength

Three specimens per batch were tested, with strength values being represented by their average.
The loading rate on each cube was 35 MPa per min. Fig. 1 show the results of the compressive
strength tests for various mortar mixes at 3, 7, and 28 days with different curing times by
microwave, along with the control mortar mix (no microwave curing and no fibres). It is clear
that the mortars' compressive strengths decreased as the amount of PP fibre increased. It can also
be concluded that using higher PP content (3% instead of 1%) did not significantly improve
compressive strength. According to [16], the homogeneous microstructure that is crucial for
cement matrix strength cannot be produced where fibres cannot be well distributed. The marginal
change in 28-days strength of PP mortar can be attributed to a decrease in the Ca(OH)2 content
that does not have cemented properties and cannot produce hydrated calcium silicate (CSH),
which plays an essential role in developing the mechanical properties of cement paste [17-18].
However, PP fibres can also generate nucleation sites for the hydration products of cement,
producing a more homogenous microstructure and marginally improving permeability and
strength [19].

According to the results, cement mortar with the addition of 1% PP fibre was selected as an
optimal mix. The strength development at 1 and 3% PP fibre additions varied based on the
mixtures' natures. The mortar containing 1% of 0.5 cm length PP fibre showed lower average
enhancement compared to the 1.5 cm fibre cement mortars with the same ratios. At 3% fibre
addition, the control mortar' compressive strength decreased more than that of the mortar
containing 1% PP fibre. It is observable that the increase in the lengths of PP beyond 15mm can
decrease the strength of compression. This is reasonable, as the uniform dispersal of considerable
lengths of PP fibres is quite challenging to achieve. Moreover, fibres tend to clusters and to
generate more micro-defects in the mortar matrix, which inevitably affect compressive strength.
Nevertheless, mortar specimens cured with microwaves have lower compressive strength
compared with those not cured with microwaves, the strength decreases as the period of curing
with microwave increases.
Figs. 1 Mortar mix versus average compressive strength (N/mm²)
3.2. Direct Tensile Strength

The direct strength test of tensile was carried out on specimens at 3, 7, and 28 days of curing under the same conditions as the compressive strength test. The procedure followed is as given below. The property of tensile strength is an essential property of mortar, as mortar structures are incredibly vulnerable to tensile cracking due to multiple influences. However, the tensile strength of mortar is deficient in comparison to its compressive strength. Indirect tensile strength tests use the same machine as in the compressive strength tests. The load is, however, applied without shock and increased gradually until the specimen is crushed. The direct tensile strength testing machine is shown in Fig. 2.

![Fig. 2 Direct tensile strength test](image)

The results for various mortar mixes at 3, 7, and 28 days with different curing times by microwave are illustrated within Fig. 3 alongside the control mortar mix (no microwave no fibres). The direct tensile strength of cement mortar increases as the PP fibre content increases and a large amount of PP seems to improve tensile strength. The potential reason for this behaviour may be the fact that PP fibres can arrest cracks, depending on the mode of failure, as shown in Fig. 4. The uniform distribution of PP fibres can act as a reinforcement to the mortar against disintegration by disallowing microcrack proliferation and growth and resisting the further opening of initial cracks. The specimens cured with microwaves recorded lower direct tensile strength compared with those not cured with microwaves; the strength decreased as the period of curing with microwaves increased.
Figs. 3 Mortar mix verse average direct tensile strength (N/mm²)
3.3. Density test

Fig 5 show the results of density testing for mortar mixes at 3, 7, and 28 days. It is quite apparent that there were not many differences in the densities of the various types of mortars; the PP ratios were not active in increasing or decreasing density due to the fibres’ own very low density.

4. Conclusion

This work highlights the contribution of PP fibres to cement mortar exposed to microwave curing for various times. The following points can be concluded:

1. For all PP fibre mortars, the compressive strength improved marginally at 3, 7, and 28 days.
2. For PP fibre mortars, the direct tensile strength increased more at 7 days than at 28 days.
3. The addition of 1% PP fibres by cement weight offers a better compressive strength in comparison to the reference mortar, especially at the early stages.
4. The direct tensile strength of mortar reinforced with PP fibre at higher quantities shows higher values compared to the reference mortar, which helps prevent cracks.
5. Microwave curing has a deleterious effect on the properties of mortars reinforced with PP fibres.
6. Increasing the period of curing with microwaves results in further deterioration in the properties of mortars reinforced with PP fibres.
Fig. 5 Mortar mix versus average density (kg/m³)
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