Feasibility of Cement Mortar System with Industrial Metal Fibre Waste

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***Abstract*— The traditional cement mortar has limited characteristics. Because of the lack of expected results, the engineering scope has focused on alternative materials instead of using the traditional constituents. As a result of that different types of fibres have been used in the past. In addition, the electrical distribution cables no longer operate for power transmission purposes when the length is not adequate and after it reaches its' end of life and the disposal methods are not eco-friendly. Therefore, the purpose of the study was to evaluate the feasibility of cement mortar with the metal fibre waste which was extracted from electrical distribution cables. 1.35 mm diameter aluminium fibres were used by changing their volume ratio at four levels 0.5%, 1.0%, 1.5%, and 2.0%. Wet and dry density and compressive tests were mainly carried out to determine the behaviour of the developed mortar systems. The wet, dry densities and modulus of elasticity were increased with the fibre addition. The maximum compressive strength of the MFRM was increased respect to reference mortar by 19.7% (3rd day), 19.8% (7th day), 11.7% (28th day dry) and 25% (28th day wet). The overall results of the study emphasized the mortar mix with 1.5% of fibres performed well in all mechanical tests and also it showed.**

Keywords—Metal waste fibre, Fibre reinforced mortar, Waste management, Sustainability.

I. Introduction

Cement mortar is a homogeneous mixture of fixed proportions of cement, sand, and water. Based on the usage of the mortar system the expected characteristics are differentiated according to the circumstances. Because of the lack of the expected results such as load-bearing conditions the engineering scope has focused on alternative materials instead of using the traditional constituents [1]. Various types of fibres (metallic and non-metallic) have been used as reinforced elements in cementitious matrices and there were several investigations conducted more specifically using short steel fibres, polymeric fibres, hybrid combinations of both synthetic and natural fibre such as sisal fibres, bagasse and hemp fibres [2,3]. The intention of using different types of fibres was to minimize the limitations of cement mortar systems and enhance mechanical properties, durability and also workability hence, under different circumstances the usage of cement mortar systems has differed and improved mortar systems are now highly demanded [4,5].

Inclusion of fibre would refrain from the growth of internal cracks, transfer the load effectively due to the enhanced mechanical properties and improve the durability as well [3]. Further different characteristics of fibre; the type, surface characteristics (shape, roughness) of fibre, volume fraction and aspect ratio of fibre considerably affect the improvements of the mortar system and the final output [2,6,7]. Moreover, the recent investigations have elaborated that the specimens which are having steel fibre had higher ductility and significant enhancement in energy absorption or toughness, and compared to the other fibres the direct usage without initial treatments was also highlighted [3]. Most of the existing experiments have been done using commercially available fibre and more attention has been paid to hooked-end steel fibre. Furthermore, a significant amount of steel fibre waste is produced annually in electrical industries and exposed to the environment by creating negative impacts on nature. Metal fibre waste which is produced from electrical distribution cables is one of the valuable by-products that are kept as leftovers of their products and it seems this waste is increasing and now it hints that it will be a major issue in the future as well. Traditional cement mortar has a limited mechanical capacity which contains average strength to weight ratio. Therefore, those mortar systems have limitations, which may not be suitable for structures such as high-rise buildings where the weight of the structure plays a critical role. By adding metal waste fibre into the traditional mortar system, enhancement of its properties such as high strength to weight ratio can be achieved [8]. The aforementioned steel fibre waste can be used to enhance the properties of conventional mortar systems and it may lead the construction scope towards sustainable consumption and production [9,10]. Hence incorporation of waste material in construction and building materials is a novel way of ensuring sustainable consumption that is a key goal pointed out by the United Nations Development Programme due to the enormous consumption of the natural environment and resources that causes destructive effects on the planet [11,12]. The present study investigates the feasibility of the development of Metal Fibre Reinforced Mortar (MFRM) systems by incorporating metal fibre from electrical distribution wire waste.

II. Materals and Methods

A. *Materials*

Waste electrical cables (Cable- Aluminium insulated -H.S. Duplex (7/1.35) 10sqmm) were used which were supplied by the Ceylon Electricity Board, Jaffna region, Sri Lanka. As shown in Fig. 1, the length of fibre was used as 10 mm and the average density of the aluminium metal was 2746.21 kgm^{-3}. According to the available literature, the density of aluminium alloy ranges between 2640 kgm^{-3} - 2810 kgm^{-3} and the experimental value was well within the range. The ultimate tensile strength of the metal was found as 114.5 MPa and it is well within the range of tensile strength of aluminium alloys.

Commercially available ordinary Portland cement with a strength class of 42.5 N/mm^2, was used in this study. Determination of the density of cement was carried out according to ASTM C188, and the average bulk density of the cement was 1417 kgm^{-3}. River sand was used as fine aggregates and the particle size distribution of fine aggregate was carried out per ASTM C136 / C136M. The particle size distribution of 4.75 mm downgraded fine aggregate is within the acceptable range according to ASTM C 33. Relative density of fine aggregate and water absorptions were conducted according to the standard of ASTM C128. The bulk density of aggregate was determined according to ASTM C29 / C29M. The relative density of the fine aggregate was 2.59, and bulk density was measured as 1645.3 kgm^{-3}. Water Absorption and moisture content of the surface saturated dry fine aggregates were 1.65% and 0.40% respectively.

Fig. 1. Aluminium metal fibres.

B. *Preparation of Metal Fibre Reinforced Mortar Specimens*

The cement to sand volume ratio was used as 1:5 (M4) and the water to cement ratio was kept at 0.5 throughout the study. Control mortar specimens were prepared without any fibre inclusion, and four types of MFRM systems were obtained by introducing aluminium fibre (1.35 mm diameter and 10 mm length) with 0.5%, 1.0%, 1.5%, and 2.0% volume ratios. According to the literature the fibre length was used from 10mm to 45mm [2,13] and for this particular study the mentioned length was used. Motor cubes with the dimension of 50 mm × 50 mm × 50 mm were prepared. Investigation of the Characteristic of Metal Fibre Reinforced Mortar

Six specimens were used to determine each characteristic. Hardened test specimens cured for 28 days were used to determine the densities, and the determination of dry bulk density was carried out according to BSI - BS EN 1015-10. Compressive strength was tested at 3, 7 and 28 days after casting and the test was carried out following ASTM C109 / C109M.

III. Results and Discusiion

This section covers the test results of MFRM, particularly dry and wet densities of mortar and compressive strength values at different ages..

A. *Dry bulk density*

Fig.2 represents the dry and wet bulk density variations of hardened mortar specimens. Dry

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density was measured after 28 days of casting, and readings were taken after 24 hours fully submerged in water and placed in an oven respectively. The dry density of the reference mortar was 1691.9 kgm^{-3}. Fig.2 clearly shows that the dry density of mortar increased as the percentage of fibre increased. When the percentage of metal fibre increased it replaces some extent of sand and it leads to an increase in the dry density because the density of fibre is higher than sand.

B. Wet Bulk Density

Wet bulk density was measured after 24 hours fully submerged in water. The wet density of reference mortar was 1905.6 kgm^{-3}. As shown in Fig. 2, the wet density of mortar was increased with fibre percentage which is a similar finding observed in the dry density. The density of mortar specimen is higher in wet condition than in dry condition in each fibre percentage, due to the pore water within the mortar in wet state. When the fibre percentage is increasing the fine aggregate that can be contained in the matrix will be reduced. Hence the water accessibility will be reduced and the gap between the dry and wet densities will be reduced, hence the ratio between dry and wet density will be increased.

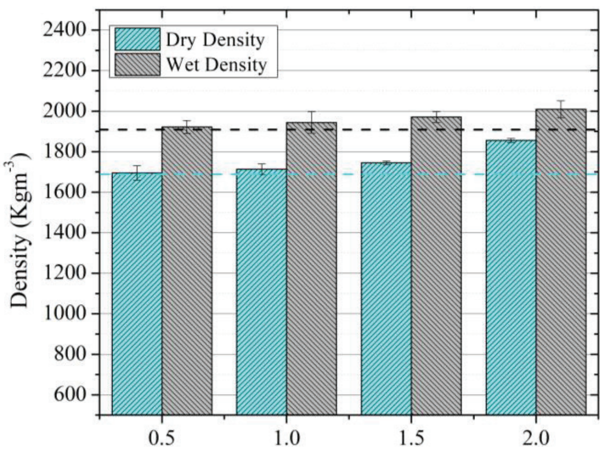

Fig. 2. Dry and wet bulk densities of hardened mortar.

C. Compressive Strength

1) 3^{rd}-day strength: The ultimate compressive strength after three days of casting is shown in Fig. 3. Compared with the reference mortar mix the compressive strength of the MFRM system at 0.5% of fibres are showing a similar strength. An increment of the ultimate compressive strength can be observed with the addition of fibre up to 1% and then the strength tends to be reduced. Compared with reference mortar, the 3^{rd}-day compressive strength of the MFRM system at 1% of fibres inclusion was increased by 19.7%. When the fibre percentage is increasing the presence of those pores is reduced significantly and the available cement paste to fibre adherence surface is increasing hence the strength tends to increase. The Aluminium fibres arrest the development of microcracks, and it is leading to higher compressive strength in mortar. Furthermore, Fig. 3 shows that for fibres percentage ratios of more than 1.0%, a reduction in compressive strength was observed. This behaviour was also observed by many researchers, and it was related to the increment in air voids due to the non-uniform packing of fibres in high volumes of fibres [13].

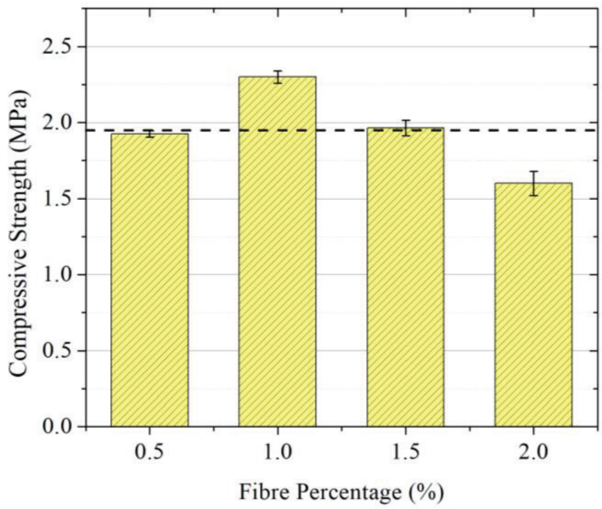

Fig. 3. 3^{rd}-day compresive strength.

2) 7^{th}-day strength: The ultimate compressive strength on 7^{th} day and the influence of different fibres are shown in Fig. 4. Compared with the reference mortar mix, the MFRM systems showed an increment in compressive strength. Fig 4 implies when the fibre percentage is increasing the compressive strength also increases up to 1.5% of fibre. A similar observation was reported by Neves and Almeida, (2005) [14]. Compared to reference mortar, the 7^{th}-day compressive strength of MFRM was increased by 19.8%, with the 1.5% of fibre inclusion. The causes for the variations of the strength values can be discussed as per the aforementioned phenomenon which was mentioned under the 3^{rd}-day strength.

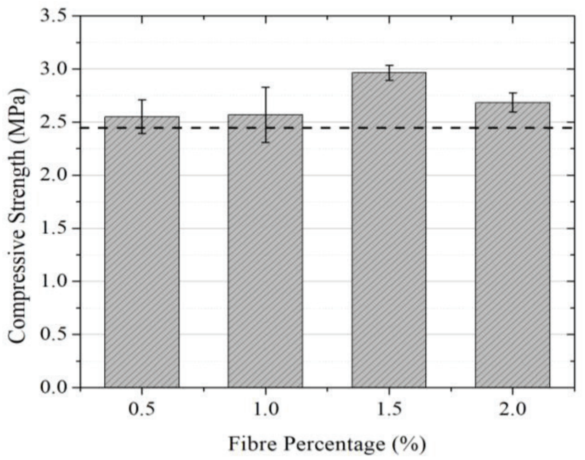

Fig. 4. 7th-day compresive strength.

3) *28th-day strength:* Fig. 5 shows the behaviour of the MFRM with fibre after 28 days under the dry state. It is clear from the results that there is an obvious improvement in the compressive strength value due to the addition of fibres with percentage ratios of fibres. A significant increment can be observed in 1.5% of fibre added specimens. Compared to the reference mortar, the ultimate compressive strength of MFRM was increased by 11.7%, with 1.5% of fibre inclusion. This can be explained by the fact that the Aluminium fibres arrest the development of micro-cracks, and it is leading to higher compressive strength. Furthermore, the figure shows that for fibres percentage ratio of more than 1.5%, a reduction in compressive strength is observed.

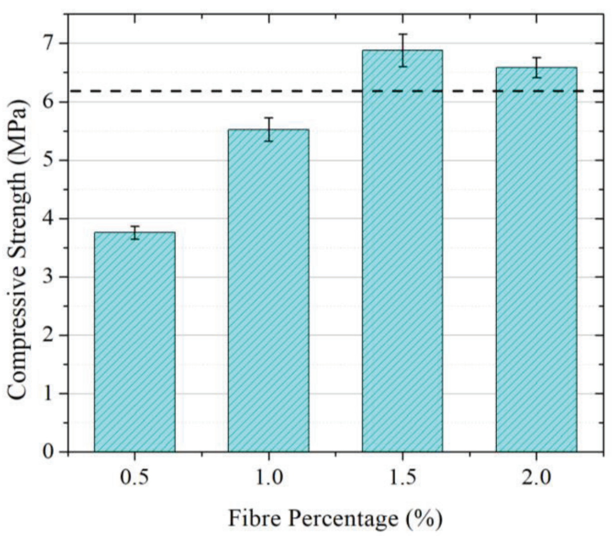

Fig. 5. 28th-dry compresive strength.

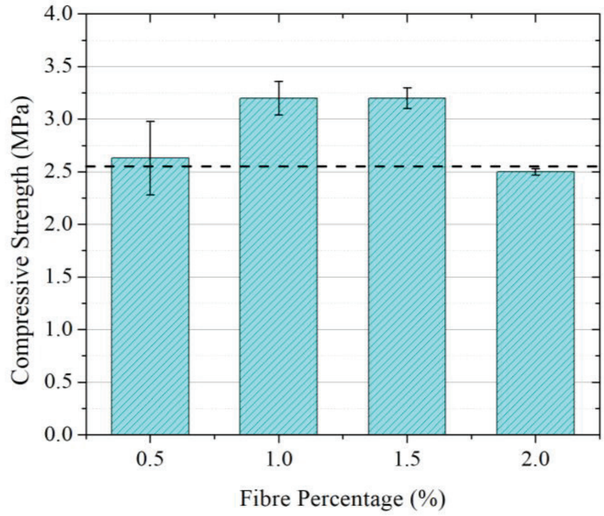

Fig. 6. 28th-wet compresive strength.

It mostly shows a similar pattern in 3rd day and 7th-day strength and the variation can be explained in the same manner. Fig. 6 shows the wet compressive strength after 28 days of curing. A clear reduction in the wet strength was observed compared to the dry condition for each type. It is because of the voids are filled with water and it causes to reduce the friction between particles and it tends to break easily. A similar pattern was observed under dry conditions, and the highest wet compressive strength was observed with 1.5% of fibre inclusion.

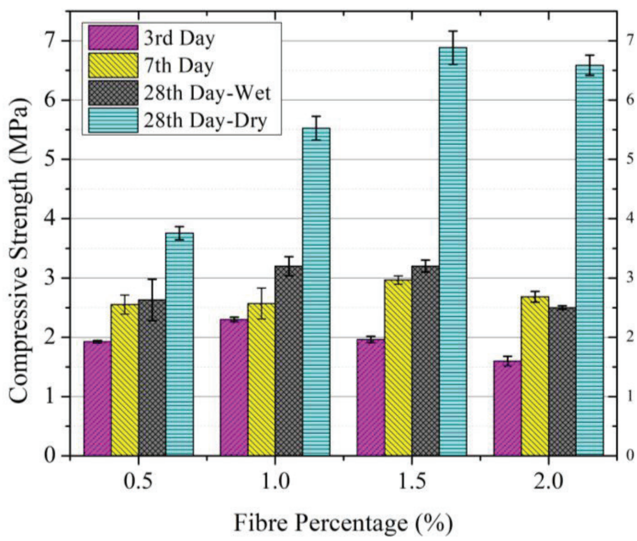

Fig. 7. Compressive strength variation with time

Fig. 7 shows the compressive strength variation with the time. As per the ASTM C109 / C109M the compressive strength was found in 3rd days, 7th days and 28th days. The strength is increasing with

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the aging days as shown in figure. Hence, the hydration of cement is happening with the time and it will increase the strength.

D. Modulus of Elasticity

1) 3rd-day: The modulus of elasticity is a very important parameter reflecting the ability to deform elastically. In addition, to make full use of the compressive strength potential, it requires a higher elastic modulus to maintain its stiffness [15]. The results are shown in Fig. 8 and it can be observed that the modulus of elasticity is increased with the fibre percentages. The highest 3rd-day modulus of elasticity was observed with the addition of 1.5% of fibre and it is slightly higher compared to the reference mortar.

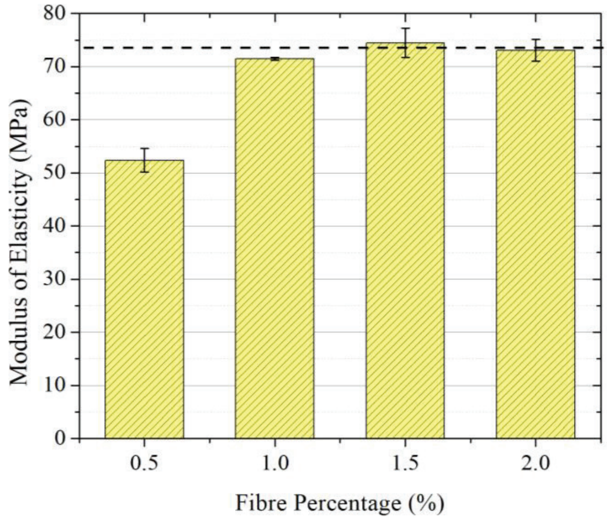

Fig. 8. 3rd-day modulus of elasticity.

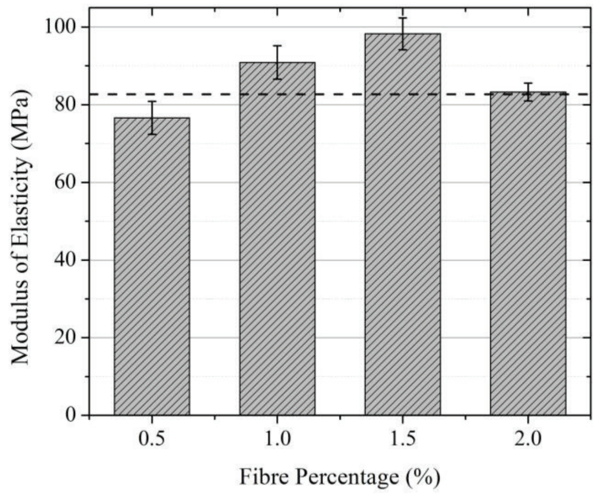

Fig. 9. 7th-day modulus of elasticity.

2) 7th-day: Fig. 9 shows the modulus of elasticity which was taken from the 7th day compressive test. As observed in the above sections there is a similar pattern in which is an increment of the elastic modulus was observed up to 1.5% then it was reduced when the fibre content reaches 2%. This is caused due to the high elastic modulus of the metal fibres, which enhances the elastic deformation capacity of the mortar mix with the inclusion of metal fibres [6]. The nonlinear packing of fibre is causing the reduction of the elastic modulus in high volume percentages of fibres.

3) 28th-day: Fig. 10 shows the variation of the modulus of elasticity of the specimens after 28 days of curing under dry conditions. As discussed at the peak stress, a similar pattern was observed which is increasing up to 1.5% then it reducing close to 2% which has been encountered by recent studies [15]. This is because of the high elastic modulus of the metal fibres, which enhances the elastic deformation capacity of the mortar mix with the metal fibre addition [6]. The nonlinear packing of fibre is causing the reduction of the elastic modulus in high volume percentages of fibres. Gul et al. (2014) also observed an enhancement of the modulus of elasticity with the aspect ratio [15]. Fig. 11 shows the modulus of elasticity of the specimens under wet conditions after 28 days of curing. An increment of the modulus of elasticity can be observed in the wet condition with 1% of fibre inclusion, which is dissimilar behaviour observed under dry conditions.

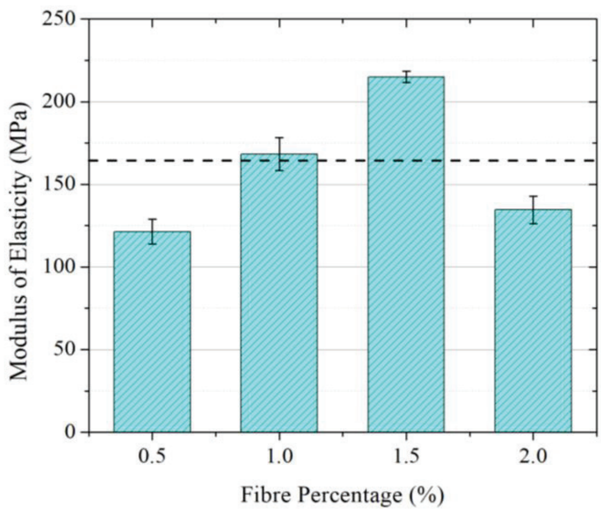

Fig. 10. 28th-day modulus of elasticity (Dry state)

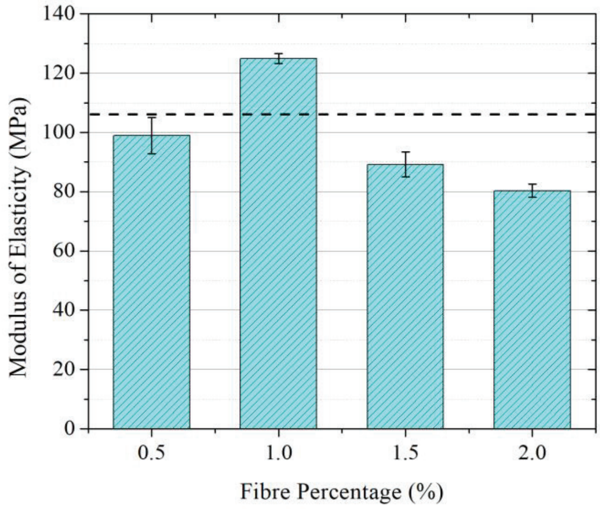

Fig. 11. 28th- day molulus of elasticity (Wet state)

IV. Conclusions

The maximum compressive strength of the MFRM was increased respect to reference mortar by 19.7% (3rd day), 19.8% (7th day), 11.7% (28th day dry) and 25% (28th day wet). The modulus of elasticity also increased up to 1.5% of fibre addition in all conditions. Based on the overall findings, 1.5% fibre addition (volume-based) was observed as the optimal fibre percentage to develop MFRM. This will provide a novel and feasible way to reuse electrical cable waste and developed MFRM will be a novel and noble material which can be used in special structures such as high-rise buildings where strength to weight ratio is vital as repair mortar, blocks, partition wall panels and cement rendering of floors. Moreover, the materials used here, especially metal fibre will be the waste cable parts of CEB which are available in Sri Lanka and it will add better waste management for a sustainable future in Sri Lanka.

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