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The Evaluation Effect of Copper Fibre Diameter on Enhancing Compressive Strength of Pure Gypsum

Arshad Nadhom Shubber[1], Firas Saeed Abbas[2], Hayder Mohammed AL-Taweel[3], Sinan Khaleel Ibrahim[3], Ali Al-Balhawi[1], Yasir M. Al-Badran[1], Layth Sahib Dheyab[4] Ahmed S.D. Al-Ridha[1*]

[1] Civil Engineering Department, Engineering College, Mustansiriyah University, Baghdad, Iraq
[2] Enviromental Engineering Department, Engineering College, Mustansiriyah University, Baghdad, Iraq
[3] Highway and Transportation Engineering Department, Engineering College. Mustansiriyah University, Baghdad, Iraq
[4] Iraqi Engineers Union, Baghdad, Iraq
* Corresponding author's e-mail: dr.ahmed.al_ridha@uomustansiriyah.edu.iq

ABSTRACT

The sustainability and impact of copper fibres on pure gypsum is the primary purpose of this study to investigate a combination of two kinds of copper fibres obtained from environmental waste (damaged electrical wires). The copper fibres are dividings into a fixed length of 10 mm, but with two different diameters: the first is 0.83 mm and the second is 0.63 mm, where the ratio of width to height (L/D) is 12 and 15.9, respectively, with a volume ratio V_f = 0.4%, the ratios 0.5 and 0.6 represent the water to gypsum ratio (W/G) individually. Each W/G ratio has two types of mixtures which organize according to diameter. The first considers a reference mixture without copper fibres (CF), and the other is a copper fibres mixture. This work found that the compressive strength increased from adding the copper fibres to a mixture of pure gypsum. Furthermore, this increase is apparent in pure gypsum compressive strength when raising the aspect ratio because of reducing the copper fibres' diameters. In another way, increasing ratio of W/G in the case of existing copper fibres or none may reduce a compressive strength of mixtures. Therefore, when the ratio of W/G drops, the significance of copper fibres may become more apparent.

Keywords: sustainable materials, pure gypsum, environmental waste, compressive strength, CF volume fraction, copper fibre, aspect ratio.

INTRODUCTION

Some of the most important materials in the building industry is $CaSO_4 \cdot 2H_2O$, called gypsum (calcium sulfate hydrate), which is necessary for sound insulation at walls, in addition to many applications such as precast panels and parts, interior finishing works, and as a binder (Mucha et al., 2016; Yu and Brouwers, 2011). Moreover, all this could be due to the attraction of the design, the simplicity of manufacture and configuration, the favorable price in the market, so it is relatively stable, and the low density with the possibility of playing an important role in repelling and spreading fires and reducing its heat (Yıldızel and Çarbaş, 2018; Yu and Brouwers, 2011). Gypsum also plays an influential role in medicine, especially dentistry (Sanad et al., 1982). In order to achieve a delay period installation time at cement-ceramic casting, gypsum adding as an additive to the concrete (Papageorgiou et al., 2005). For study additives' ability in the mixture to improve or strengthen the properties of materials, physically and chemically.

Several practical studies work on materials such as gum tree powder, copper fibers, clay, fly

ash, carbon fibers, polyvinyl chloride, cork, metals, rice husks, silica fume, and Portland (Abbood, 2018; Abbood et al., 2020; Al-Chalabi et al., 2022; Ahmed S.D. Al-Ridha et al., 2020b; AL-Ridha et al., 2022a, 2022b, 2020; Bentur et al., 1994; Dêbska et al., 2019; Deng et al., 1998; Dhaheer et al., 2018; Hernández-Olivares et al., 1999; Joshi et al., 1992; Murat and Attari, 1991; Rutkowska et al., 2016; Strzałkowski and Garbalińska, 2019). The Addition of fibers to gypsum mixtures approved by many research works is a central topic of study, Especially after showing that the fibers increase gypsum strength and shape consistency in general (Al-Ridha et al., 2021; Elaiwi, EH; Al-Chalabi, 2020; Flores Medina and Barbero-Barrera, 2017; Li et al., 2003; Singh and Garg, 1992; Wu and Dare, 2006; Yıldızel and Çarbaş, 2018). Other researchers have also been interested in additives, such as chipped carbon fibers, steel fibers and agro waste as reinforcement materials for mixtures such as cement mortar, concrete mix, and asphalt concrete (Abbas et al., 2022; Ahmed S.D. Al-Ridha et al., 2020; Ahmed S.D. Al-Ridha et al., 2020a; Chairunnisa et al., 2022; Elaiwi, EH; Al-Chalabi, 2020; ZAl-Sarraf et al., 2011). This work investigates the effectiveness of random copper fibers in general and for two different diameters of copper fibers in particular, with two different ratios of water to gypsum. The copper fibers' high ductility may prevent gypsum smash or breaking by preventing pullout from the mixture (Kittl et al., 1985).

Research aims

- Examine the possibility of sustainability of copper fibers with pure gypsum as an additive from environmental waste.
- Investigate the ability of compressive strength to improve the pure gypsum using electrical waste as fiber (copper fibers, CF).
- Study the effect of copper fibre aspect ratio (L/D) by changing fiber diameter with variable water/gypsum ratios.

EXPERIMENTAL AND MATERIALS DETAILS

The characteristics of copper fiber

The process begins with collecting the waste of various electrical works, from which, in particular, damaged or cut electrical wires are produced. After the stranded single-core wires were stripped from the outer rubber (which covers seven wires combined) for two different wires: the first one has a diameter of 4 mm and the second one 3.5 mm. The density of electric wires used in this work is 9810 kg/m^3 with a yield strength equal to 70 MPa and an ultimate strength of 220 MPa. All electric wires follow "IEC 60227- 3 and BS EN 50525; 2- 31" (Beer et al., 2011). In order to choose entirely new fibres that were not previously adopted, and it is possible to work as fibres added to the mixtures, only one model of the seven wires (fixed length) is taken, with a diameter of 0.83 mm and 0.63 mm separately. Moreover, as shown in Figure 1, the approved models for working as additive fibres can be described as fixed fibres with a length of 10 mm for each model but with aspect ratios L/D of 12 and 15.9 for diameters; 0.83 mm and 0.63 mm respectively (L/D is the ratio of lengths of copper wire to diameter).

Water

The essential element in the material composition required in this work is clean water to ensure the best results, so it uses the main natural water available.

Pure gypsum

The materials used in the present work are pure calcium sulfate hydrate gypsum with the chemical composition $CaSO_4 \cdot 1/2H_2O$, often known as pure gypsum, and an environmental residue CF.

Mixtures of pure gypsum

According to the W/G ratio, six mixtures dividing into two separate parts, as in Figure 2. each part contains three mixes, one basic reference mixture with no copper fibers added with two more mixtures containing copper fibres ($V_f = 0.4$) with a diameter equal to 0.83 mm for the second mixture and 0.63 mm for the third mixture and an aspect ratio equal to 12 and 15.9, respectively. The length of the copper fibres is 10 mm each, as shown in Table 1.

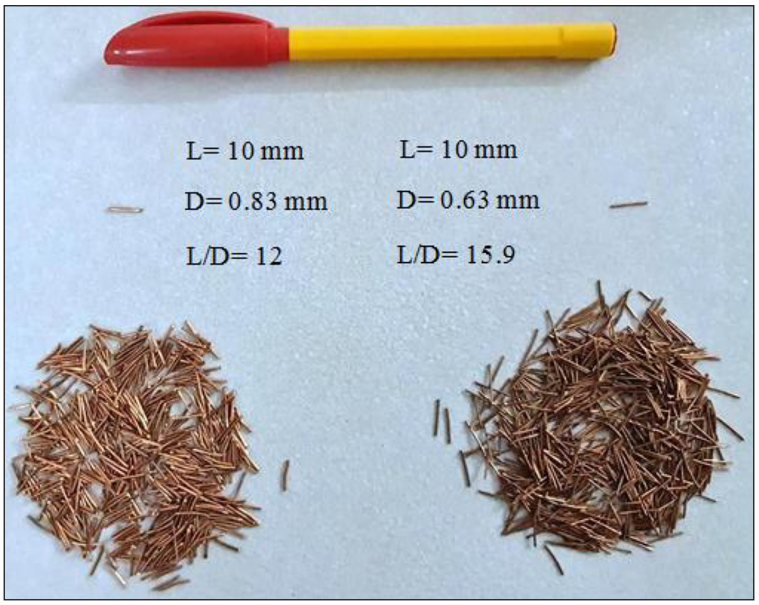

Figure 1. Copper fiber

Mixing method

For homogenizing copper fibres with pure gypsum, the copper fibres are weighed in a volume ratio equal to 0.4%, using the dry mixing method. Depending on the W/G ratio approved by the current work (0.5 and 0.6), water added to the mixture is homogeneous. After the mixing completing, the mixture pouring into standard and cubic forms (50 mm for side). When the required maturation period is complete, the resulting gypsum cube is drawn from standard models and applied to an external heat source (45 °C) for 30 hours–tests occurring in Mustansiriyah University "Structural Materials Laboratory" laboratories in the College of Engineering.

Compression strength for copper fibers mixtures

To explore the strength of copper fibres to develop the strength of pure gypsum, after 36 hours, a compressive strength test according to ASTM: C472–99 for cubes with dimensions (50×50×50) mm (ASTM C472–99, 2014).

RESULTS AND DISCUSSION

The aspect ratio (for two different diameters) and the water/gypsum ratio 0.5 and 0.6 at copper fibers pure gypsum mixtures strength are available by Figure 3 and Table 2. The mixes

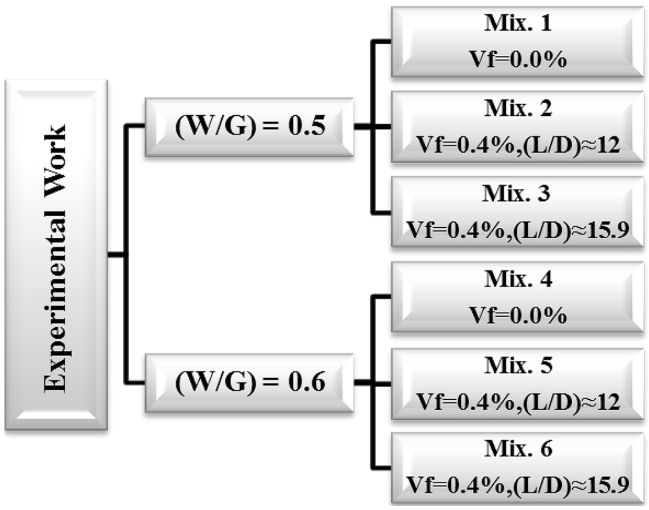

Figure 2. Work scheme

Table 1. Mixtures description

Mixture No.	Diameter of copper fibre	Ratio	Copper fibre volume fraction	Aspect ratio	Copper fibre lengths
	D, mm	*W/G*	V_f, %	≈ *L/D*	*L*, mm
Mix 1	None	0.5	0.0	None	None
Mix 2	0.83	0.5	0.4	12	10
Mix 3	0.63	0.5	0.4	15.9	10
Mix 4	None	0.6	0.0	None	None
Mix 5	0.83	0.6	0.4	12	10
Mix 6	0.63	0.6	0.4	15.9	10

compressive strength containing copper fibers increased noticeably. So copper fibers adding may delay crack creation and slow down the spreading of it at the mixture cube. By the water gypsum ratio 0.5 and 0.6, it was noticed that the increase in the aspect-ratio (by decrease a diameter of the copper fibers) might lead to the effectiveness of the copper fibers. The reason may belong to the increment in copper fiber quantity by diameter reduction, which could lead to an increase in its spread in the gypsum mixture. Accordingly, it turns out that the effectiveness of copper fibers increases significantly when the ratios of W/G decrease in pure gypsum and for all ratios and diameters. The most explanation may be that when the W/G ratios decrease. So, the adhesion from copper fiber to the gypsum mixture increases; this may reduce the CF withdrawal hypothesis from pure gypsum.

Effect of variable aspect ratios and W/G ratio on strength pure gypsum

Pure gypsum compressive strength PG by a change in the aspect ratio (with two different diameters) for copper fibre and by a change in the

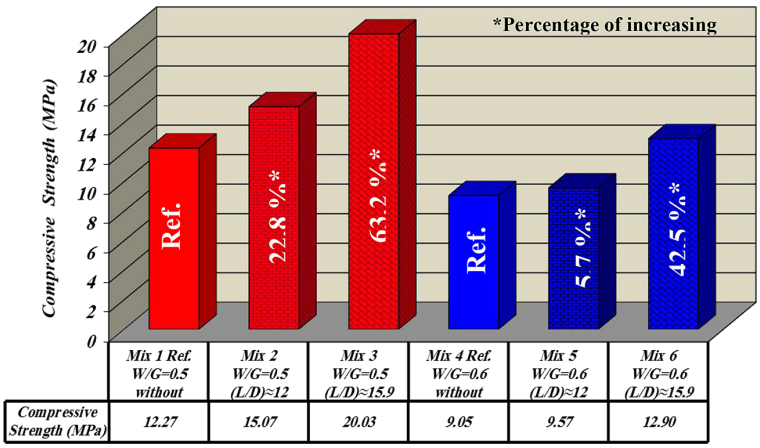

Figure 3. The influence of copper fibers to strengthen pure gypsum mixtures through the aspect ratio (for two different diameters) and the water/gypsum ratio

Table 2. Pure gypsum mixtures details

Mixture No.	Ratio	Diameter of copper fibre	Copper fibre lengths	Aspect-ratio	Copper fibre as volume fraction	Compressive strength	Increasing percentage
	W/G	*D*, mm	*L*, mm	*L/D* ≈	V_f, %	MPa	%
Mix 1	0.5	Non	Non	Non	0.0	12.27	–
Mix 2		0.83	10	12	0.4	15.07	22.8
Mix 3		0.63	10	15.9		20.03	63.2
Mix 4	0.6	Non	Non	Non	0.0	9.05	–
Mix 5		0.83	10	12	0.4	9.57	5.7
Mix 6		0.63	10	15.9		12.9	42.5

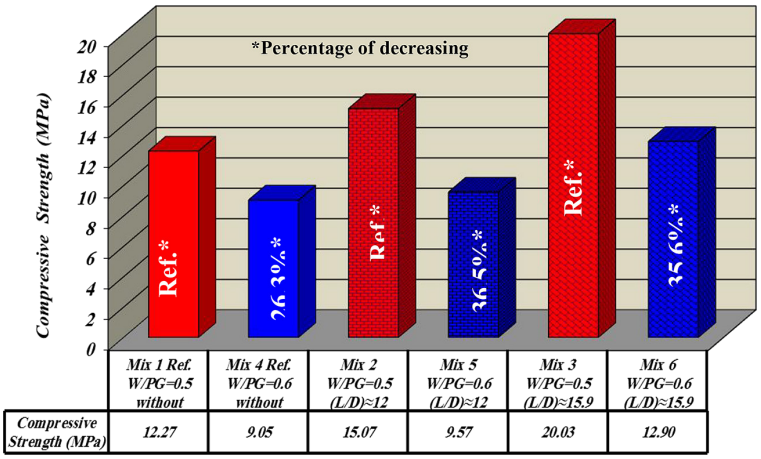

Figure 4. Effect of variable aspect ratios and W/G ratio at compressive strength of the mixture

Table 3. Variable aspect ratios and ratio of W/G details

Mix. No	Ratios	Diameter of copper fibre	Copper fibre lengths	Copper fibre volume fraction	Aspect ratio	Compressive strength	Decreasing percentage
	W/G	*L*, mm	*L*, mm	V_p %	*L/D* ≈	MPa	%
Mix 1	0.5	–	Non	0.0	Non	12.27	–
Mix 4	0.6	–		–		9.05	26.1
Mix 2	0.5	0.83	10	0.4	12	15.07	–
Mix 5	0.6	–		–		9.57	36.5
Mix 3	0.5	0.63	10	0.4	15.9	20.03	–
Mix 6	0.6	–		–		12.90	35.6

ratio W/G observed in Figure 4 and Table 3. As the W/G ratio increases, the compressive strength decreases. This decrease behaviour applies if copper fibers are present or not present in the mixture, as this decrease was higher in mixtures containing copper fibers than others (for all aspect ratios). Perhaps it behaves like this because of the effect of using copper fibers in increasing compressive strength of mixture, as it increases when in W/G ratio decrease. That behavior is also well described in Figure 3.

CONCLUSION

Pure gypsum compressive strength increases by adding copper fibres. When the diameter of the copper fibre decreases, the percentages of the increases generally increase with the increase in aspect ratio from 12 to 15.9. The effect of copper fibres in increasing Pure gypsum compressive strength improves for both aspect- ratios 12 and 15.9 by decreasing the ratio of W/G from 0.6 to 0.5. When the ratio of W/G increases, Pure gypsum compressive strength decreases and this behaviour is for all mixtures (with and without copper fibres). The decreases percentage for Pure gypsum compressive strength increased by raising the ratio of W/G at the mixture that contains copper fibres (for all aspect ratios) due to the high effect of copper fibres in improving the value of compressive strength for W/G ratio at 0.5, more than a ratio at 0.6.

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