THE INFLUENCE OF CHOPPED COPPER FIBRE (CF) ON THE IMPROVEMENT OF PURE GYPSUM BY COMPRESSIVE STRENGTH

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This study investigates the efficacy, performance, and effect of chopped Copper Fibre (CF) on a Pure Gypsum (PG) mixture. The Copper Fibre (CF) is extracted from the waste of electrical wires that are considered as environmental waste. Three models of Copper Fibre (CF) with a diameter of 0.83 (mm) and lengths of 10 (mm), 20 (mm), and 30 (mm) (Aspect-Ratio L/d = 12, 24 and 36 respectively), with Volume Fraction (V.f.) for Copper Fibre (CF) by two Water/Gypsum Ratios (W/G) worth (0.5 and 0.6) are created. The mixtures are divided into two groups of W/G ratios. Each group contains four samples, one reference without Copper Fibre (CF) and the other three with the addition of Copper Fibre (CF) individually with different lengths. The results show that adding Copper Fibre (CF) to the Pure Gypsum (PG) mixture increases the Compressive Strength. Further, the effect is to heighten the Compressive Strength of Pure Gypsum (PG) when the Aspect-Ratio is raised. In other words, when the (W/G) Ratio is reduced, the Compressive Strength increases in the presence or absence of Copper Fibre (CF). Moreover, the efficiency of the Copper Fibre (CF) develops further when the W/G ratio is decreased.

Key words: environmental waste, copper fibre (CF), pure gypsum (PG), (L/d) aspect-ratio, compressive strength, volume-fraction of CF (V.f.)

INTRODUCTION

Gypsum substance (calcium sulphated hydrate, CaSO₄·2H₂O) is necessary for most building applications. It is popularly available as a binder, in boards and precast parts, indoor finishing work and walls for Acoustic Isolation [1-2]. Gypsum has multiple excellent features such as a readily formed process, volumetric stability, affordable cost, fire and thermic protection, engaging design, reduced density and simply made [2-3]. Gypsum is used as a support material in medicine and dentistry [4]. Concrete admixtures use gypsum to delay timing for setting in cement and ceramic casting [5]. According to various experimental research studies [6-17], the addition of substances such as fly ash, gum tree powder, silica fume, clay, polyvinyl chloride, cork, Portland, and minerals to a mixture may support the developmental properties of the gypsum matrix. This is true in terms of the physical and chemical aspects appearing in the actual effects of its hardening and fresh characteristics. Regarding the use of strengthening substances, a good deal of research demonstrates the relevance of including various fibres in gypsum mixtures [3, 18-23]. This is because the fibres increase the gypsum tensile strength and shape stability to support the mixture to reduce degradation and breakdown. Many researchers have studied the effect of even more substances such as steel fibre or chipped carbon fibres to reinforce a concrete mix, cement mortar, and asphalt concrete admixtures [24-32]. The current work proposes to design Pure Gypsum (PG) of unique fibres that strengthen as a composite form by use of compact and ductile copper fibres haphazardly scattered in the gypsum. Copper fibres present high ductility [33] to improve problematic brittle material fractures to become ductile fractures and also block the tendency to pull-out from the gypsum. Therefore, this work adopts copper fibres as an additive to gypsum.

RESEARCH OBJECTIVES

The objectives of this research are to:
- Test and study the potential of adding for the first time copper fibres extracted from environmental waste to pure gypsum as an environmental sustainable form.
- Study the effect of copper fibre on a pure gypsum mixture and discover if it has the ability to improve Compressive Strength.

MATERIALS AND METHODS

Pure Gypsum (PG)

Essentially Pure-Gypsum (PG) is used in this investigation as pure calcium sulphate hemihydrate-gypsum (CaSO₄·1/2H₂O), which is available locally.
**Chopped Copper Fibre (CF)**

Waste electrical wiring is considered an environmental waste, which is the material used in this study. After electrical work is performed for buildings, the wires are gathered from the waste materials. The standard properties that apply to copper wire are "BS. EN. 50525-2-31" and "IEC. 60227-3", with 9810 Kg/m³ density, 70 MPa Yield Strength, 220 MPa Ultimate Strength [34]. The Single Core Stranded wires used in this work have a total diameter of 4 mm, and after stripping the rubber outer insulation, they produce seven wires with a combined diameter of 3.2 mm. To create a suitable model for the fibre-forming electrical conductors, the seven-wires were modelled as a single wire with a diameter of 0.83 mm. Then the copper wires are divided into three groups with different lengths, so that the length of each group is one of 10 mm, 20 mm, or 30 mm individually. The Aspect Ratio (L/D) will be (12, 24, and 36 consecutively) as shown in Figure 1. The Aspect Ratio may be defined as the ratio between the length and diameter of the copper wire.

![Figure 1: Copper Fibre (CF)](image)

**The mixing water**

The pure gypsum mixture utilises tap water to perform this work.

**Pure Gypsum Mixes**

| Mixture No | Volume Fraction, (Copper Fibre) (V.f.) % | Length of Copper Fibre (L) mm | Diameter of Copper Fibre (D) mm | Aspect Ratio (L/D) | (W/G) Ratio |
|------------|----------------------------------------|------------------------------|--------------------------------|-------------------|-------------|
| 1          | 0.0                                    | None                         | None                           | None              | 0.5         |
| 2          | 0.4                                    | 10                           | 0.83                           | 12                | 0.5         |
| 3          | 0.4                                    | 20                           | 0.83                           | 24                | 0.5         |
| 4          | 0.4                                    | 30                           | 0.83                           | 36                | 0.5         |
| 5          | 0.0                                    | None                         | None                           | None              | 0.6         |
| 6          | 0.4                                    | 10                           | 0.83                           | 12                | 0.6         |
| 7          | 0.4                                    | 20                           | 0.83                           | 24                | 0.6         |
| 8          | 0.4                                    | 30                           | 0.83                           | 36                | 0.6         |

**Mixing procedure**

The mixing process starts with the weight of Copper Fibre (CF) equivalent to the Volume Fraction (V.f.) of 0.4%, then mixed with the amount of Pure Gypsum (PG) required for mixing (dry mixing) until the Copper Fibre (CF) is homogeneous with the Pure Gypsum. After that, water is added according to the W/G ratio (0.5 or 0.6). The mixture is mixed and placed in cubic moulds of (50 × 50 × 50) mm. After completing the hardening phase, the Pure Gypsum (PG) mixture is removed from the moulds and exposed for 30 hours to a heat source with a temperature of 45 °C. The reference mixtures use the same previous steps but without Copper Fibre (CF).

**Testing programme**

All tests are performed at the College of Engineering using the tools and a series of test machines of the MUSTANSIRIYAH UNIVERSITY laboratories known as the "Structural Materials Laboratory".

**Compression strength**

The samples are tested with a cubic size of 50 mm conducted for 36 hours to investigate the compressive strength using the standard ASTM: C472-99 applied to the tests [35].
RESULTS AND DISCUSSION

The effect of the Aspect Ratio of differing lengths for Copper Fibre (CF) on Pure Gypsum (PG) through testing Compressive Strength with varying W/G ratio.

Figure 3 and Table 2 show the effect of the Aspect Ratio of differing lengths for Copper Fibre (CF) on Pure Gypsum (PG) through testing Compressive Strength with varying W/G ratios (0.5 and 0.6). The test result presents a cumulative increase in the value of Compressive Strength in pure gypsum (PG) mixtures containing copper fibres. This increase is perhaps because of the presence of CF (Copper Fibres). This increase means the Copper Fibres work to delay the appearance of cracks and to reduce the speed of their growth. In addition, the result shows the effectiveness of the Copper Fibre (CF) increases with an increase in the Aspect Ratio, which arises from the increase of the length of the Copper Fibre (CF) for both W/G ratios (0.5 and 0.6). Perhaps this behaviour is developed by increasing the length of the Copper Fibre length, so the possibility of the Copper Fibre (CF) pulling out is reduced.

![Figure 3. Effect of Aspect-Ratio (differing lengths) of Copper Fibre (CF) on the Compressive Strength for Pure Gypsum (PG) with varying (W/G) ratio](image)

| Mixture No. | W/G (ratios) | Volume Fraction of Copper Fibre (V.f.) % | Length of Copper Fibre (L) mm | Aspect-Ratio (L/D) | Compressive Strength (MPa) | Increasing Percentage (%) |
|-------------|--------------|----------------------------------------|-------------------------------|-------------------|---------------------------|--------------------------|
| 1           | 0.5          | 0.0                                    | Non                          | Non               | 12.03                     | ------                   |
| 2           | 0.5          | 0.4                                    | 10                            | 12                | 15.90                     | 32.2                     |
| 3           | 0.5          | 0.4                                    | 20                            | 24                | 18.22                     | 51.5                     |
| 4           | 0.5          | 0.4                                    | 30                            | 36                | 22.26                     | 85.1                     |
| 5           | 0.6          | 0.0                                    | Non                          | Non               | 8.97                      | ------                   |
| 6           | 0.6          | 0.4                                    | 10                            | 12                | 9.11                      | 1.6                      |
| 7           | 0.6          | 0.4                                    | 20                            | 14                | 10.01                     | 11.6                    |
| 8           | 0.6          | 0.4                                    | 30                            | 36                | 11.86                     | 32.3                     |

The effect of the Copper Fibre (CF) (for all Aspect Ratios or lengths) is active in improving the Compressive Strength of the Pure Gypsum (PG), which increases very significantly when the W/G decreases. The most likely explanation is that a decrease in the Water Gypsum ratio drives an improvement in cohesion and adhesion between the Pure Gypsum (PG) and the Copper Fibre (CF), which leads to a scaling down and reduction of the hypothesis of pulling the Copper Fibre (CF) from the Pure Gypsum (PG).

![Water Gypsum ratio effect on Compressive Strength of Pure Gypsum (PG) by varying Aspect Ratios](image)
Table 3: Effect of Water Gypsum ratio on Pure Gypsum (PG) Compressive Strength values with the variable Aspect Ratios (variable length) of the Copper Fibre (CF)

| Mixture No | W/G Ratio | (V.f.) % | Volume Fraction of Copper Fibre | Copper Fibre Length (L) mm | Aspect-Ratio (L/D) | Compressive Strength (MPa) | Increasing Percentage (%) |
|------------|-----------|----------|---------------------------------|---------------------------|-------------------|---------------------------|--------------------------|
| 5.0        | 0.6       | 0.0      | Non                             | Non                       | 8.97              | -----                     |                          |
| 1.0        | 0.5       | 0.0      | Non                             | Non                       | 12.03             | 34.1                      |
| 6.0        | 0.6       | 0.4      | 10                              | 12                        | 9.11              | -----                     |                          |
| 2.0        | 0.5       | 0.4      | 10                              | 12                        | 15.90             | 74.5                      |
| 7.0        | 0.6       | 0.4      | 20                              | 24                        | 10.01             | -----                     |                          |
| 3.0        | 0.5       | 0.4      | 20                              | 24                        | 18.22             | 82.0                      |
| 8.0        | 0.6       | 0.4      | 30                              | 36                        | 18.86             | -----                     |                          |
| 4.0        | 0.5       | 0.4      | 30                              | 36                        | 22.26             | 87.6                      |

CONCLUSION

1. The addition of Copper Fibre (CF) to Pure Gypsum (PG) increases the compressive strength, and it rises even more when the Aspect Ratio (increase the length of copper fibre) is increased.

2. Copper Fibre (CF) works to enhance the Compressive Strength of the Pure Gypsum (PG) by increasing the Compressive Strength when the W/G ratios are reduced for all Aspect Ratio values (12, 24, and 36).

3. By decreasing the Water Gypsum ratio, the Compressive Strength increases with or without Copper Fibre (CF) in the mixtures.

4. The effect of reducing the Water Gypsum ratio on the Compressive Strength of gypsum in mixtures containing Copper Fibre (CF) (V.f. = 0.4) is already increased (at item 3 above) but rises even more when the Aspect Ratio increases (the length increases).

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REFERENCES

1. Mucha M., Mróz P and Kocemba A. (2016) Polymer composites based on gypsum matrix. VIII International Conference on Times of Polymers and Composites, American Institute of Physics.

2. Yu Q and HJ Brouwers (2011) Microstructure and mechanical properties of b-hemihydrate produced gypsum; An insight from its hydration process. Construction and Building Materials 25,3149–3157.

3. Yildizel S and Çarbaş S. (2011) Mechanical performance comparison of glass and mono fibers added gypsum composites. Challenge Journal Of Structural Mechanics 4(1),9-12.

4. Sanad ME, Combe and Grant AA. (1982) The Use of Additives to Improve the mechanical properties of Gypsum Products. Journal of Dental Research. 61(6), 808-810.

5. Papageorgiou A and Tzouvalas G Tsimas S. (2005) Use of Inorganic Setting Retarders in Cement Industry. Cement and Concrete Research 25,183-189.

6. Murat M and Attari A. (1991) Modification of some physical properties of gypsum plaster by addition of clay minerals. Cement and Concrete Research 2,378-378.

7. Joshi RC, Thomas JO and Adam RB. (1992) Properties of gypsum wall boards containing fly ash. Journal of Materials in Civil Engineering 4(2),212–25.

8. Bentur A, Kovier K and Goldman A. (1995) Gypsum of improved performance using blends with portland cement and silica fume, advance in cement research 6(23),109-116.

9. Deng Y, Furuno T and Uehara T. (1998) Improvement on the properties of pure gypsum particleboard by adding cement. Journal of Wood Science 44, 98-102.

10. Hernandez F, Bollati MR, Rioc M and Parga B. (1999) Development of cork gypsum composites for building applications. Construction and Building Materials13, 179–86.

11. AL-Ridha, S. D., Ali A. Abbood, and Hussein H. Hussein. (2015) Improvement of gypsum properties using SF additive. International Journal of Science and Research 6(8) 504-509.

12. Abbood A. A. (2018) Improvement of Gypsum Characteristics using (T.G.P.) and (P.V.A.) Additives, International Journal of Science and Research (IJSR) 7(2).

13. AL-Ridha, Ahmed SD, Ali A. Abbood, Ali F. Atshan, Hussein H. Hussein, Layth Sahib Dheyab, Mohammed Sabah Mohialdeen, and Hamed Zaier Ali (2019) A Comparative Study Between the Individual, Dual and Triple Addition of (SF), (TGP) and (PVA) for Improving Local Gypsum (Juss) Properties. In International Congress and Exhibition Sustainable Civil Infrastructures, 65-79. Springer, Cham, https://doi.org/10.1007/978-3-030-34249-4_7

14. Dhaheer, MS Abo, and H. K. Ammash. (2018) Improvement of ordinary and pure gypsum properties by using polyvinyl alcohol (PVA). Int. J. Civ. Eng. Technol 9(9), 323-334.

15. AL-Ridha Ahmed SD, et al. (2021) A Comparative Study between the Individual, Dual and Triple Addition of (SF), (TGP) and (PVA) for Improving Local Plaster of Paris (LPOP) Properties IOP Conference Series: Materials Science and Engineering. IOP Publishing.
16. Abbood, Ali A., Ali F. Atshan, and Ahmed SD AL-Ridha. 2020 Improvement of Local Gypsum Plaster Setting Time by the Combined Usage of (TGP) and (PVA) Additives. In IOP Conference Series: Materials Science and Engineering 870(1), 012106. IOP Publishing. https://doi.org/10.1088/1757-899X/870/1/012106

17. AL-Ridha, Ahmed SD, Ali A. Abbood, Essam H. Elaiwi, Hussein H. Hussein, and Layth Sahib Dheyab. Increasing the Setting Time of Local Gypsum (Joss) by the Use of TGP additive. In IOP Conference Series: Materials Science and Engineering 888 (1), 012078. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/888/1/012078

18. Singh M and Mridul G. (1992) Glass fibre reinforced water resistant gypsum based composites. Cement Concrete Research 14(1), 23–32.

19. Li G, Yu Y, Zhao Z, Li J and Li C. (2003) Properties study of cotton stalk fiber/gypsum composites. Cement Concrete Research 33(1), 43–6.

20. Medina NF and Barbero-Barrera MM. (2017) Mechanical and physical enhancement of gypsum composites through a synergic work of polypropylene fiber and recycled isostatic graphite filler. Construction and Building Materials 131, 165-177.

21. Wu YF and Dare MP. (2006) Flexural and shear strength of composite lintels in glass fiber reinforced gypsum wall constructions. Journal of Materials in Civil Engineering 18(3), 415-423.

22. AL-Ridha, Ahmed SD, Ali A. Abbood, Laith S. M. Al-Asadi, Hussein H. Hussein and Layth Sahib Dheyab (2020) Effect of Adding Chopped Carbon Fiber (CCF) on the Improvement of Gypsum Plaster Characteristics. In IOP Conference Series: Materials Science and Engineering, IOP Publishing.

23. AL-Ridha, Ahmed SD, et al. 2021 Effect of Chopped Sisal Fiber (CSF) on the Compressive Strength of Local Plaster of Paris (LPOP) IOP Conference Series: Materials Science and Engineering. IOP Publishing.

24. AL-Ridha, Ahmed SD, Ali Kadhim Ibrahim, Hayder Mohammed AL-Taweel, and Layth Sahib Dheyab (2019) Effect of Steel Fiber on Ultrasonic Pulse Velocity and Mechanical Properties of Self-Compact Light Weight Concrete. In IOP Conference Series: Materials Science and Engineering, 518(2), 022017. IOP Publishing. https://doi.org/10.1088/1757-899X/518/2/022017

25. AL-Ridha A. S. D 2014 The Influence of Size of Lightweight Aggregate on The Mechanical Properties Of Self-Compacting Concrete With and Without Steel Fiber. International Journal of Structural & Civil Engineering Research 3(1)

26. AL-Ridha, Ahmed SD, Ali A. Abbood, Saeb F. Al-Chalabi, Abaa M. Aziz, and Layth Sahib Dheyab (2020) A Comparative Study between the Effect of Steel Fiber on Ultrasonic Pulse Velocity (UPV) in Light and Normal Weight Self-Compacting Concretes. In IOP Conference Series: Materials Science and Engineering 888 (1) 012081. IOP Publishing. https://doi.org/10.1088/1757-899X/888/1/012081

27. AL-Ridha, Ahmed SD, Ali A. Abbood, and Ali F. Atshan (2020) Assessment of the Effect of Replacing Normal Aggregate by Porcelinite on the Behaviour of Layered Steel Fibrous Self-Compacting Reinforced Concrete Slabs under Uniform Load. Journal of Engineering. 2020. https://doi.org/10.1155/2020/3650363

28. Al-Ridha, Ahmed SD, A. Hameed, and Sinan Khaleel Ibrahim (2014) Effect of steel Fiber on the Performance of Hot Mix Asphalt with Different Temperatures and Compaction. Australian Journal of Basic and Applied Sciences 8 (6), 123-132.

29. AL-Ridha, Ahmed SD, Sinan K. Ibrahim, and Layth Sahib Dheyab 2016 Steel Fiber Effect on the Behavior of Hot Mixture Asphalt with Variable Asphalt Content. International Journal of Advanced Technology in Engineering and Science 04(01).

30. Al-Sarraf, S.Z, Diab, A.S., Al-Shaarbaf, I.A. and Diab, A.S. (2011) Effect of Steel Fiber on the Behavior of Deep Beams with and without Web Opening. Engineering and Technology Journal, 29(1), 1-19.
31. Elaiwi EH, Al-Chalabi SF, Al-Asadi LS, Abbood AA, AL-Ridha AS. (2020) Evaluating the Performance of Fibrous Cement Mortar Containing Chopped Carbon Fiber (C.C.F.) In IOP Conference Series: Materials Science and Engineering 2020. IOP Publishing

32. AL-Ridha, A.S.D., Abuzaid, E.K.M. and Abbood, A.A.R., (2018) Effect of Addition of Chopped Carbon Fiber on The Behavior of Reinforced Concrete Beams With Variable (Shear Distance To Effective Depth) Ratios. Journal of Engineering and Sustainable Development 22(1), 137-148.

33. Kittl, P., E. Galleguillos, and G. Diaz. (1985) Properties of compacted copper fibre reinforced cement composite. International Journal of Cement Composites and Lightweight Concrete 7(3), 193-197.

34. Ferdinand P. Beer, E. Russell Johnston Jr., John T. DeWolf, David F. Mazurek, (2011), Statics and Mechanics of Materials, McGraw-Hill Companies, ISBN 978-0-07-338015-5

35. ASTM C472-99 (2014), Standard Test Methods for Physical Testing of Gypsum, Gypsum Plasters and Gypsum Concrete, ASTM International, West Conshohocken, PA.

Nomenclature

(W/G) Water/Gypsum Ratios
L/d Aspect-Ratio

Abbreviations

CF Copper Fibre
PG Pure Gypsum
V.f. Volume Fraction

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