Effect of Adding Chopped Carbon Fiber (CCF) on the Improvement of Gypsum Plaster Characteristics

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Abstract. The current work studies the effect of adding chopped carbon fiber (CCF) on gypsum plaster properties (precisely the compressive strength and the modulus of rupture). The research plan consists of using six mixes of gypsum plaster; these mixes are divided into two groups according to the (Water/Gypsum) ratios (0.5 & 0.6). Each group was divided into three subgroups according to CCF volume fraction (Vf): 0.0%, 0.2% and 0.4%. Three cubic (50×50×50) mm and three prismatic (40×40×160) mm samples were performed for each mix. It was found that, the addition of CCF to the gypsum plaster mixes increases both the compressive strength and the modulus of rupture for both (W/G) ratios, and the percentage of this increase is enlarged with increasing (W/G) ratio. On the other hand, when (W/G) ratio is enlarged, the compressive strength and the modulus of rupture is deteriorated for all (Vf) of CCF, and this percentage of deterioration is decreased in the presence of CCF.

Keywords : Chopped Carbon Fiber (CCF), Compressive Strength, Modulus of Rupture, Volume-fraction (Vf) of Chopped Carbon Fiber.

1. Introductions
In the latest years, gypsum composites have been excessively used as in-door finishing. Houses, especially in the US and Europe, are either built from or line with gypsum-based products chosen by designers because of their fabulous features, such as obtainable availability of in-expensive raw materials, volumetric stability, acoustic and thermal insulation, fire resistance, quite-low toxicity and the relatively low energy and temperatures needed in its production [1]. Gypsum is also used in many aspects beyond the building field: e.g. in manufacturing moulds for ceramic products [2], in medical [3], and dental accessories or implants [4], moreover, it’s the basic constitutive material in Portland cement for the purpose of delaying its setting time [5]. The huge number of implementations of gypsum plaster are mostly based on its specific features [6], [7].

Some investigators have tried to improve gypsum characteristics and widen its domain of implementations by adding other additives [8-15]. Carbon fibers, which are a new generation of high-strength materials, are basically utilized in reinforcing composite materials [16], it is also used for applications of high technology aspects, which includes aero-space and nuclear engineering [17]. Carbon fiber offer the highest specified modulus (and strength) of all types of fiber reinforcement. The carbon fibers don’t suffer from stress corrosion or stress rupture failure at room temperature, as glass and organic polymer fibers do. Especially at high temperature, the strength and modulus
are distinguished in comparison with other materials [16]. Carbon fiber compounds are suitable for implementations where strength, stiffness, lower-weight, and fabulous fatigue features are critical needs. They have also found that implementations where high-temperature, chemical inertness, and high-damping are necessary. Carbon fibers also have good electrical as well as thermal conductivity, and low linear coefficient of thermal expansion [18]. Carbon fiber properties depend on the structure of the carbon used. Carbon fiber is lighter and stiffer than any other fiber [19]. It is worth noting that there are many researches have studied the effect of other types of fibers, such as steel fibers, on the behavior of concrete, cement mortar and asphalt [20-25].

2. Research Objective

This work aims to improve two basic properties of “Gypsum Plaster” namely; the compressive strength and the modulus of rupture by the addition of three volume fractions of “Chopped Carbon Fiber (CCF)” (0.0%, 0.2% & 0.4%) and for two (Water / Gypsum) ratios (0.5 & 0.6).

3. Experimental Works

3.1. Constituent Materials

3.1.1. Gypsum Plaster

Local Gypsum Plaster utilized as a major Material in current work was calcium sulphate hemihydrate gypsum (CaSO₄·1/2H₂O), which was brought from the local markets in Iraq.

3.1.2. Chopped Carbon Fiber

In the current research, a carbon Fibers chopped from the manufacture source in (8 mm) length as shown in figure (1), and the properties of a typical carbon fiber are listed in Table (1) [26].

Table 1. Properties of Chopped Carbon Fibers

| Properties        | Results                  |
|-------------------|--------------------------|
| Fiber Type        | Carbon                   |
| Elongation        | 1.5 %                    |
| Unit-weight       | 1.79 g/cm³               |
| Fabric Diameter   | 166 μm                   |
| Tensile strength  | (3450 – 3900) MPa        |
| Tensile modulus of elasticity | 230 GPa               |

Figure 1. Chopped carbon fibers

3.1.3. Mixing water
Ordinary potable water is the mixing water that was used for all gypsum mixtures in the present study.

3.2. Gypsum Mixes

Six gypsum mixes were made-up in the current work, they were divided into two groups according to their (W/G) ratios (0.5 & 0.6), each group was subdivided into three subgroups according to their volume fraction of CCF (0.0 %, 0.2 % and 0.4 %) as demonstrated in figure (2) and figure (3) respectively.

3.3. Mixing procedure
In the beginning, CCF was weighted and added to the weighted quantity of gypsum plaster and dry-mixed carefully until the CCF is uniformly spread and distributed all over the dry mix, then the required amount of water was added to the mixture, then mixed again manually for about (30 seconds). After that, the mixture is poured into the mold and then vibrated for nearly one minute. After around one hour, the cubic (50×50×50)mm and the prismatic (40×40×160)mm samples were taken off from the mould. Finally, all samples were exposed to the direct sunlight for approximately one week at around 30°C heat to ensure a complete dryness of the samples is attained.

3.4. Testing program

The testing program of this work includes executing the required tests that demonstrate the effect of adding CCF on the compressive and the flexural strengths of the gypsum mix using the instruments and the testing machines of one of a series of laboratories affiliated with Mustansiriya University called “The structural materials laboratory”, located at the College of Engineering at which numerous researchers have carried out the tests of their research such as [27-31].

3.4.1. Compression strength.

The 50 mm cubic specimens were tested in the current study at age of around one week to find their compressive strengths. Figure (4-a) illustrates the testing machine utilized in the current work, test is performed according to ASTM : C472-99 [32].

3.4.2. Modulus of Rupture.

Since the modulus of rupture is a quite reasonable index to the flexural strength of each material, the (40 × 40 × 160)mm prismatic specimens were tested in this research (at age of about one week) to find their modulus of rupture by using the testing machines shown at figure (4-b), test is performed according to ASTM C348 standard (three-point bending test) [33], in line with the Iraqi Standard Specification [34]. The final results are calculated using the following Eq. (1) -

\[
\text{MOR} = \frac{P \times c}{L} = \frac{PL}{bh^3} \times \frac{h}{L^2} = \frac{3PL}{2bh^2} \quad …… (1)
\]

Where :-

MOR = Modulus of Rupture (MPa)
P = Failure load (N)
L = (c/c) Span length= 100 mm
b = Width of specimen’s cross-section = 40 mm
h = Height of specimen’s cross-section = 40 mm
4. Outcomes and Discussion

4.1. Influence of Chopped Carbon Fiber (CCF) on Gypsum Compressive Strength with Variable (W/G) Ratios.

Table (2) and figure (5) display the outcomes of the influence of adding CCF with two contents (0.2% & 0.4%) on the compressive strength of gypsum plaster for the two (W/G) ratios (0.5 & 0.6). It can be seen that the compressive strength is enlarged with the increase in CCF content in comparison with the reference mix (Mix1 and Mix4), and this behaviour is similar for both (W/G) ratios. This behavior may be attributed to the high tensile strength of CCF which enable them to act to prevent the initiation of potential cracks (unc reated yet) and hindering the growth of the cracks that are created (existed) as a result of load progression, and the visual proof of this interpretation is that the failed specimens containing CCF didn’t suffer from fragmentation unlike other specimens that are free of CCF (i.e. reference ones) as can be obviously seen from figure (6).

One could also notice from the above mentioned table (2) and figure (5), that the percentages of increase in the compressive strength when CCF is added with two contents (0.2% and 0.4%) are magnified with the increasing in W/G ratio (from 0.5 → 0.6) in comparison with the reference mixtures (Mix1 & Mix4). In fact, when CCF is added with (0.2% and 0.4%), the amount of increase in the compressive strength for both ratios of W/G (0.5 and 0.6) is very close, the reason behind this might be imputed to the failure mode (crushing) of the cubic specimens which makes the effect of CCF in increasing the compressive strength is very close for the two W/G ratios (0.5 and 0.6). And the reason behind the increase in the percentage of increase in the compressive strength with increasing (W/G) ratio, is that the compressive strength of the reference mix having (W/G = 0.6: i.e. Mix4) is less than that for the reference mix having (W/G = 0.5: i.e. Mix1).

Table 2. Effect of CCF volume fraction (Vf) on compressive strength with various (W/G) ratios.

| Mix No. | (W/G) ratio | Volume Fraction of Chopped Carbon Fiber (Vf) % | Compressive Strength (MPa) | Percentage of Increase (%) |
|---------|-------------|---------------------------------------------|----------------------------|---------------------------|
| Mix 1   | 0.0         | 11.32                                       |                            | -----                     |
| Mix 2   | 0.5         | 0.2                                         | 14.12                      | 24.7                      |
| Mix 3   | 0.4         | 15.17                                       |                            | 34.0                      |
| Mix 4   | 0.0         | 9.07                                        |                            | -----                     |
| Mix 5   | 0.6         | 0.2                                         | 11.95                      | 31.8                      |
| Mix 6   | 0.4         | 12.86                                       |                            | 41.8                      |
4.2 Effect of Chopped Carbon Fiber (CCF) on Gypsum Modulus of Rupture with Variable (W/G) Ratios.

Table (3) and figure (7) illustrate the influence of adding CCF with two contents (0.2% and 0.4%) on the modulus of rupture of gypsum plaster for the two (W/G) ratios (0.5 and 0.6). They show that the modulus of rupture is increased with the increasing CCF content in comparison with the reference mixtures (Mix1 & Mix4), and this behavior is similar for both (W/G) ratios. The reason for this behavior may be attributed to the high tensile strength of CCF which enable them to act to prevent the initiation of potential cracks (uncreated yet) in the tension zone and hindering the growth of the cracks (in the same zone) that are created (existed) as a result of load progression. Moreover, CCF may participate in reducing the bad effect of voids existence in the gypsum mass on resisting the tensile stresses in the tension zone, and the visual proof of this interpretation is that the failed specimens containing CCF didn’t suffer from separation unlike other specimens that are free of CCF (i.e. reference ones) as can be obviously seen from figure (6).

One could also notice from the above mentioned table (3) and figure (7), that the percentages of increase in the modulus of rupture when CCF is added with two contents (0.2% and 0.4%) are also...
increased with the increase of (W/G) ratios in comparison with the reference mixtures (Mix1 & Mix4). The reason of this behavior is that the role of CCF in reducing the bad effect of voids existence on resisting the tensile stresses in the tension zone is bigger in the mixes of larger voids ratio (larger porosity) in comparison with the reference mixtures that are free of CCF, and since the increasing in (W/G) ratio leads to increase the porosity (and the voids ratio) [11, 35], then this explains why the role of CCF is larger as the (W/G) ratio is increased in comparison with the reference mixtures that are free of CCF.

Table 3. Effect of CCF volume fraction (Vf) on modulus of rupture with various (W/G) ratios

| Mix No. | (W/G) ratio | Volume Fraction of Chopped Carbon Fiber (Vf) % | Modulus of Rupture (MPa) | Percentages of Increasing (%) |
|---------|-------------|---------------------------------------------|--------------------------|------------------------------|
| Mix 1   | 0.0         | 14.14                                       | -----                    | -----                        |
| Mix 2   | 0.2         | 15.23                                       | 7.7                      | 7.7%*                        |
| Mix 3   | 0.4         | 16.72                                       | 18.2                     | 18.2%*                       |
| Mix 4   | 0.0         | 10.08                                       | -----                    | -----                        |
| Mix 5   | 0.2         | 11.25                                       | 11.6                     | 11.6%*                       |
| Mix 6   | 0.4         | 13.95                                       | 38.4                     | 38.4%*                       |

Figure 7. Effect of CCF volume fraction (Vf) on modulus of rupture with various (W/G) ratios

4.3. Influence of (W/G) Ratios on Gypsum Compressive Strength with Variable Chopped Carbon Fiber (CCF) Volume Fractions (Vf).

Table (4) and figure (8) display a study of the effect of increasing (W/G) ratios from (0.5) → (0.6) on the compressive strength of gypsum plaster for three contents of CCF (0.0%, 0.2% & 0.4%). They demonstrate that the compressive strength is deteriorated when (W/G) ratio is enlarged in comparison with the reference mixtures (Mix1, Mix2 & Mix3), and this behavior is similar for the three CCF contents. The interpretation behind this behavior is that when the water increases, the
amount of water (excessive to the reaction-water) will produce voids after its evaporation leading to an increase in the porosity of the hardened mixture and hence the gypsum internal structure is weakened and as a result, the mixture strength will be deteriorated [11, 36].

Table (4) and figure (8) also show that the percentages of the deterioration in the compressive strength are reduced in the presence of CCF. In fact, the amount of deterioration in the compressive strength induced by the increase in (W/G) ratio is very close for all CCF contents (0.0%, 0.2% and 0.4%). The reason behind this outcome might be attributed to the failure mode (crushing) of the cubic specimens which makes the effect of CCF on increasing the compressive strength is very close for the two ratios of (W/G). As for the reason behind the reduction in the deterioration in the compressive strength with the presence of CCF, it may be because the compressive strength of the reference mixes having CCF (Mix2 & Mix3) is higher than that of the reference mixtures free of CCF (Mix1).  

Table 4. Influence of (W/G) ratios on compressive strength with various CCF volume fractions

| Mix No. | Volume Fraction of Chopped Carbon Fiber (Vf) % | (W/G) ratio | Compressive Strengths (MPa) | Percentages of decreasing (%) |
|---------|---------------------------------------------|-------------|----------------------------|-------------------------------|
| Mix 1   | 0.0                                         | 0.5         | 11.32                      | ------                        |
| Mix 4   |                                             | 0.6         | 9.07                       | 19.9                          |
| Mix 2   | 0.2                                         | 0.5         | 14.12                      | ------                        |
| Mix 5   |                                             | 0.6         | 11.95                      | 15.4                          |
| Mix 3   | 0.4                                         | 0.5         | 15.17                      | ------                        |
| Mix 6   |                                             | 0.6         | 12.86                      | 15.2                          |

Figure 8. Effect of (W/G) ratios on compressive strength with various CCF volume fractions

**4.4. Influence of (W/G) Ratios on Modulus of Rupture with Variable Chopped Carbon Fiber (CCF) Volume Fractions (Vf).**

Table (5) and figure (9) investigate the effect of increasing (W/G) ratios from (0.5) → (0.6) on the modulus of rupture of gypsum plaster for three CCF contents (0.0%, 0.2% and 0.4%). From these
table and figure, it can be realized that the modulus of rupture is deteriorated when (W/G) ratio is enlarged in comparison with the reference mixtures (Mix1, Mix2 & Mix3), and this behavior is similar for the three CCF contents. The same reason mentioned in the first paragraph of section (4.3) demonstrates this behavior.

Table (5) and figure (9) also show that the percentage of the deterioration in the modulus of rupture is reduced in the presence of CCF. This behavior may be attributed to the fact that the role of CCF on increasing the modulus of rupture is enlarged with the increasing in (W/G) ratio for the same reason mentioned in the second paragraph of section (4.2), and this explains the reason behind the reduction in the percentage of deterioration of the modulus of rupture in the presence of CCF.

**Table 5. Influence of (W/G) ratios on modulus of rupture with different CCF volume fractions**

| Mix No. | Volume Fraction of Chopped Carbon Fiber (Vf) % | (W/G) ratio | Modulus of Rupture (MPa) | Percentages of Increasing (%) |
|---------|---------------------------------------------|-------------|--------------------------|-------------------------------|
| Mix 1  | 0.0                                         | 0.5         | 14.14                    | ......                        |
| Mix 4  | 0.6                                         | 0.5         | 10.08                    | 28.7                         |
| Mix 2  | 0.2                                         | 0.5         | 15.23                    | ......                        |
| Mix 5  | 0.6                                         | 0.5         | 11.25                    | 26.2                         |
| Mix 3  | 0.4                                         | 0.5         | 16.72                    | ......                        |
| Mix 6  | 0.6                                         | 0.6         | 13.95                    | 16.6                         |

*Percentage of decreasing

**Figure 9. Influence of (W/G) ratios on modulus of rupture with different CCF volume fractions**

5. Conclusions

- The compressive strength is increased with the increasing of CCF content in comparison with the reference mixtures (i.e. free of CCF : Mix1 and Mix4), and this behavior is similar for both (W/G) ratios.
- When (W/G = 0.5), the percentage of increase in the compressive strength is enlarged by (24.7% and 34.0%) when (Vf) of CCF is increased from (0.2% to 0.4%) respectively, as compared with reference mixes (Mix1 and Mix4).
When \((W/G = 0.6)\), the percentage of increase in the compressive strength is enlarged by (31.8% and 41.8%) when \((Vf)\) of CCF is increased from \((0.2\% \rightarrow 0.4\%)\) respectively in comparison with the reference mixtures (Mix1 and Mix4).

The percentage of increase in the compressive strength when CCF is added with two contents \((0.2\% \text{ and } 0.4\%)\) is enlarged when increasing \((W/G)\) ratio \((from \ 0.5 \rightarrow 0.6)\) as compared with the reference mixtures (i.e. mixes of \(W/G = 0.5\): Mix1, Mix2 & Mix3), and this behavior is similar for the three \((Vf)\)s of CCF.

When \(W/G\) is increased from \((0.5 \rightarrow 0.6)\), the compressive strength is deteriorated by \((19.9\% \text{, } 15.4\% \text{ and } 15.2\%)\) at each \((Vf)\) of CCF \((0.0\%, 0.2\% \text{ and } 0.4\%)\) respectively in comparison with the reference mixtures (Mix1, Mix2 & Mix3).

When \(W/G\) ratio is enlarged from \((0.5 \rightarrow 0.6)\), the percentages of the deterioration in the compressive strength are reduced in the presence of CCF.

The modulus of rupture is increased with increasing CCF content in comparison with the reference mixtures (i.e. free of CCF : Mix1 and Mix4), and this behaviour is similar for both \((W/G)\) ratios.

When \((W/G = 0.5)\), the percentage of increase in the modulus of rupture is enlarged by \((7.7\% \text{ and } 18.2\%)\) when \((Vf)\) of CCF is increased from \((0.2\% \text{ and } 0.4\%)\) respectively, as compared with reference mixes (Mix1 and Mix4).

When \((W/G = 0.6)\), the percentage of increase in the compressive strength is enlarged by \((11.6\% \text{ and } 38.4\%)\) when \((Vf)\) of CCF is increased from \((0.2\% \text{ and } 0.4\%)\) respectively as compared with reference mixes (Mix1 and Mix4).

The percentage of increase in the compressive strength when CCF is added with two contents \((0.2\% \text{ and } 0.4\%)\) is enlarged when increasing \((W/G)\) ratio \((from \ 0.5 \rightarrow 0.6)\) in comparison with the reference mix (Mix1 and Mix4).

The modulus of rupture is deteriorated when \((W/G)\) ratio is enlarged from \((0.5 \rightarrow 0.6)\) in comparison with the reference mixtures (i.e. mixes of \(W/G = 0.5\): Mix1, Mix2 & Mix3), and this behavior is similar for the three \((Vf)\)s of CCF.

When \(W/G\) is increased from \((0.5 \rightarrow 0.6)\), the modulus of rupture is deteriorated by \((28.7\% \text{, } 26.2\% \text{ and } 16.6\%)\) at each \((Vf)\) of CCF \((0.0\%, 0.2\% \text{ and } 0.4\%)\) respectively in comparison with the reference mixtures (Mix1, Mix2 & Mix3).

When \((W/G)\) ratio is enlarged from \((0.5 \rightarrow 0.6)\), the percentages of the deterioration in the modulus of rupture are reduced in the presence of CCF.

6. References

[1] Khalil, A.A.; Gad, G.M. “Mineral and chemical constitutions of the UAR gypsum raw materials”. Indian Ceramics, 16 (1972) 173 - 177. Cited by reference [9].

[2] Combe, E. C.; Smith, D. C. “Some Properties of Gypsum Plaster” . J. Brit. Dent., 17 (1964) 237-245. Cited by reference [9].

[3] Peters, C. sff.; Hines, J. L.; Bachus, K. N.; Craig M. A.; Bloebaum, R. D. “Biological Effect of Calcium Sulfate as Bone Graft Substitute in Ovine Metaphyseal Defects” J. Biomed. Mater. Res. A., 76, No3 (2005) 456-462. Cited by reference [9].

[4] Craig, R. G. “Restorative Dental Materials” 7th Edition, St. Louis, Toronto, and Princeton. The C.V. Mospy comp., (1989) 303-330. Cited by reference [9].

[5] Papageorgiou, A.; Tzouvalas, G.; Tsimas, S. “Use of Inorganic Setting Retarders in Cement Industry” Cem. Concr. Res., 27 (2005) 183-189. Cited by reference [9].

[6] El-Maghraby, H.F.; Gedeon, O.; Khalil, A.A. “Formation and Characterization of Poly(vinyl alcohol – co – vinyl Acetate – co-itaconic Acid/Plaster Composites: part II: Composite Formation and Characteristics” Ceramic Silikaty 51, n° 3 (2007) 168-172. Cited by reference [9].

[7] Bas_pinar, S. M.; Kahraman, E. “Modifications in the properties of gypsum construction element via addition of expanded macroporous silica granules”. Construction
Building Materials 25 (2011) 3327–3333. Cited by reference [9].
http://dx.doi.org/10.1016/j.conbuildmat.2011.03.022
[8] Khalil, A.A.; Abdel kader, A. H. “Preparation and physicomechanical Properties of Gypsum Plaster-Agro Fiber Wastes Composites” Interceram Int. J. Refractories Manual (Special Technologies) 21(2010), 62-67. Cited by reference [9].
[9] A. Khalil, A. Tawfik, A. A. Hegazy, M. F. El-Shahat "Effect of different forms of silica on the physical and mechanical properties of gypsum plaster composites" Materiales de Construccion Vol. 63, 312, 529-537, octubre-diciembre 2013.
[10] AL-Ridha, Ahmed SD, Ali A. Abbood, Ali F. Atshans, Hussein H. Hussein, Layth Sahib Dheyab, Mohammed Sabah Mohialdeen, and Hameed Zaier Ali. "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, pp. 65-79. Springer, Cham, 2019.
[11] AL-Ridha, S. D., Ali A. Abbood, and Hussein H. Hussein. "Improvement of gypsum properties using SF additive." International Journal of Science and Research 6.8 (2015): 504-509.
[12] Abbood, Ali A., Ali F. Atshan, and Ahmed SD AL-Ridha. "Improvement of Local Gypsum Plaster Setting Time by the Combined Usage of (TGP) and (PVA) Additives." In IOP Conference Series: Materials Science and Engineering, vol. 870, no. 1, p. 012106. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/870/1/012106
[13] Abbood A. A. "Improvement of Gypsum Characteristics using (T.G.P.) and (P.V.A.) Additives", International Journal of Science and Research (IJSR), Volume 7, Issue 2, February 2018.
[14] Zeki A. Aljubouri Auday M. Al-Rawas "Physical Properties and Compressive Strength of the Technical Plaster and Local Juss" Iraqi Journal of Earth Sciences, Vol. 9, No. 2, pp 49-58, 2009.
[15] 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, vol. 888, no. 1, p. 012078. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/888/1/012078
[16] W. S. SMITH, “Engineered Materials Handbook-Vol. 1” (ASM International, Ohio, 1987) p. 49. Cited by reference [17].
[17] Chand, S. "Review carbon fibers for composites." Journal of materials science 35.6 (2000): 1303-1313.
[18] J. B. DONNET and R. C. BANSAL, “Carbon Fibers” (Marcel Dekker, Inc., New York, 1990). Cited by reference [17].
[19] S. Bharathidasan, T. K. Krushnadesikan " Carbon Fibre Reinforced Gypsum Buildings" International Journal of Innovative Science Engineering and Technology , Vol. 2 Issue 2, February 2015.
[20] AL-Ridha, Ahmed SD, Ali Kadhim Ibrahim, Hayder Mohammed AL-Taweel, and Layth Sahib Dheyab. "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, vol. 518, no. 2, p. 022017. IOP Publishing, 2019. https://doi.org/10.1088/1757-899X/518/2/022017
[21] AL-Ridha A. S. D “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, Vol. 3, No. 1, February 2014.
[22] AL-Ridha, Ahmed SD, Ali A. Abbood, Saeb F. Al-Chalabi, Abaa M. Aziz, and Layth Sahib Dheyab. "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, vol. 888, no. 1, p. 012081. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/888/1/012081
[23] Elaiwi EH, Al-Chalabi SF, Al-Asadi LS, Abbood AA, AL-Ridha AS. "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
[24] AL-Ridha, Ahmed SD, A. HAmeed, and Sinan Khaleel Ibrahim. "Effect of steel Fiber on the Performance of Hot Mix Asphalt with Different Temperatures and Compaction" Australian Journal of Basic and Applied Sciences 8, no. 6 (2014): 123-132.

[25] AL-Ridha, Ahmed SD, Asst Lec Sinan K. Ibrahim, and Eng Layth Sahib Dheyab. "Steel Fiber Effect on the Behavior of Hot Mixture Asphalt with Variable Asphalt Content" International Journal of Advanced Technology in Engineering and Science, Volume No 04, Special Issue No. 01, February 2016.

[26] 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), pp.137-148.

[27] AL-Ridha, Ahmed SD, Ali F. Atshan, Hussein H. Hussein, Ali A. Abbood, Layth Sahib Dheyab, and Ayoob Murtadha Alshaikh Faqri. "Evaluation of Tensile Strength and Durability of Microbial Cement Mortar." In International Congress and Exhibition “Sustainable Civil Infrastructures”, pp. 80-89. Springer, Cham, 2019. https://doi.org/10.1007/978-3-030-34249-4_8

[28] AL-Ridha, A. S., Atshan, A. F., Mahmoud, K. S., & Hameed, Q. K. (2019). Effect of Strengthening of Steel Beams with Variable Length by Using Carbon Fiber. Journal of Engineering, 2019. https://doi.org/10.1155/2019/1631692

[29] AL-Ridha, A. S., Hameed, Q. K., Atshan, A. F., Abbood, A. A., & Dheyab, L. S. (2020). Evaluation of strengthening steel beams using the technique of carbon fiber confinement by a steel plate (CFCSP). Advances in Civil Engineering Materials, 9(1), 53-66. https://doi.org/10.1520/ACEM20190164

[30] Ahmed, SD AL-Ridha, Ali A. Abbood, and Ali F. Atshan. "Evaluating the Efficiency of Strengthening Hot-Rolled I-Sectioned Steel Beams by using Additional Plates and Inclined Stiffeners with Various Widths." In IOP Conference Series: Materials Science and Engineering, vol. 870, no. 1, p. 012102. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/870/1/012102

[31] AL-Ridha, Ahmed SD, Ali A. Abbood, and Ali F. Atshan. "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 (2020). https://doi.org/10.1155/2020/3650363

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

[33] ASTM C348-14, Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars, ASTM International, West Conshohocken, PA, 2014

[34] “Iraqi standard specification for physical tests of gypsum for building purposes” NO.27. 1988. (In Arabic), Ministry of Planning.

[35] J. Lewry and J. Williamson, “The setting of gypsum plaster: part II The development of microstructure and strength,” Journal of Materials Science, vol. 29, pp.5 524-5528, 1994. Cited by reference Sayonara M. M. Pinheiro and Gladis Camarini "Characteristics of Gypsum Recycling in Different Cycles" IACSIT International Journal of Engineering and Technology, Vol. 7, No. 3, June 2015.

[36] Q. L. Yu and H. J. H. Brouwers, “Microstructure and mechanical properties of b-hemihydrate produced gypsum: An insight from its hydration process," Construction and Building Materials, vol. 25, pp.3149-3157, 2011. Cited by reference Sayonara M. M. Pinheiro and Gladis Camarini "Characteristics of Gypsum Recycling in Different Cycles" IACSIT International Journal of Engineering and Technology, Vol. 7, No. 3, June 2015.

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