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Hydro-Mechanical Properties of Cement Mortar Using Bentonite as Partial Cement Replacement

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ABSTRACT

With the present emphasis on sustainability, it is critical to produce ecofriendly building materials aiming to reduce carbon dioxide emissions from cement manufacturing process. Bentonite is one of the most essential materials utilized in the construction of cementation structures because it acts as a binding ingredient which has a favorable impact on the characteristics of mortar. This is because bentonite has strong colloidal properties, and when in contact with water, its volume increases tremendously, producing a gelatinous and viscous fluid. The primary goal of this study is to determine the influence of partial cement replacement with dry bentonite (DBN) and colloidal bentonite (CBN) on specific hydro-mechanical mortar parameters. The cement replacement by weight percentages with bentonite were 0, 10, 15, and 20%. Different tests were performed at different curing ages including 7, 14, 28, 60, 91, and 120 days to assess the impact of bentonite on hydro mechanical properties of cement mortars. According to the findings of this study, when cement is partially replaced by bentonite with 15% bentonite substitution ratio, which is regarded the optimum ratio at 120 curing day age, both compressive and bending strengths are improved. Particularly, the compressive strength of colloidal and dry bentonite rose by around 21 and 16 %, respectively. While, the flexural strengths of colloidal and dry bentonite mixtures were 18 and 12 % greater, respectively, than the control mix.

Keywords: Bentonite, Mechanical properties, Colloidal state, Water absorption

1. INTRODUCTION

In the last decades, the building industry has taken significant steps forward. With the current emphasize on sustainable development, it is essential to develop an environmentally friendly construction materials that limit carbon dioxide emissions accompanied with low cost without reducing material properties [1].

The most significant part of the building industry is cement. Approximately, 7% of the overall global production of carbon dioxide comes from cement production. In other words, the production of cement produces plenty of technical and environmental issues due to a rise in hydration heat and the contribution of additional carbon dioxide emissions. For such considerations, a proposed option is to replace cement with pozzolanic additives. They can provide a low-cost, low-permeability, ecologically friendly choice as well as high-strength concrete [2, 3]. Moreover, the usage of natural

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pozzolans can have advantageous properties in concrete, for instance, low hydration heat, high strength and sulfate resistance [4].

One of the available natural pozzolans is bentonite. Bentonite is one of the natural pozzolans that can be found. It is a colloidal clay and natural pozzolan that is mostly montmorillonite, with a few other minerals and organic matter [5, 6]. Many studies have investigated the influence of incorporating bentonite on the characteristics of mortars and concrete in order to determine the capability of bentonite as a partial cement replacement.

Memon, *et al.* studied the capacity of using betonies to replace 3-21% weight of cement to develop economically, eco-friendly concrete. They found that all the mixes satisfied ASTM C618 strength requirements. However, lower strength was recorded after 3 days. The strength gradually increased as the curing time expanded to 56 days, eventually exceeding the control's strength. Moreover, the addition of bentonite provided better performance against acidic environment [7].

In Mesboua, *et al*., bentonite was introduced as a cement substitute in concrete. The replacement rate ranged from 8% to 18%. The strength of all of the samples met the ASTM C618 strength criteria, according to their findings. Accordingly, up to 18% of cement can be replaced to produce low cost grout with acceptable properties [8].

Laidani, *et al*. incorporated calcined bentonite in self-compacting concrete as partial replacement of cement ranging from 5-30% by weight of cement. Several experiments were conducted to determine the samples properties. Their results revealed that the incorporation of calcined bentonite lowered the fresh properties. However, adding 10-15% calcined bentonite to the mix has improved strength and other attributes after 90 days. They found that calcined bentonite is a good candidate to replace cement especially it is also considered as eco- friendly low-cost material [3].

The objective of this paper is assessing the viability of partial cement replacement with dry and colloidal bentonite using different replacement percentages as well as evaluate its impact on various mortar properties, particularly, water absorption, compressive and flexural strength. This study is attempted to develop cost effective, durable, eco-friendly cement mortar.

2. MATERIALS AND METHODS

2.1 Materials

Ordinary Portland cement which meets the ASTM C150-04 requirements was used in this study [9]. It was purchased from the Tasloga factory, in Sulymania, Iraq. It contains the chemical compounds as stated in Table 1.

Table 1 Chemical components of the used cement

component	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	Free CaO	Insoluble Residue	LOI	Lime Saturation Factor
%	61.39	20.26	5.5	2.29	2.19	2.5	1.12	0.71	3.4	0.92

Sand that passes the 2.36 mm sieve was used as fine aggregate which complied with ASTM C33-03 [10]. To achieve the appropriate workability of the combinations, Glenium 54, Type F, superplasticizer additive was utilized according to ASTM C494-05 [11]. The composition of bentonite used in this research was tested by the central laboratories of the Iraqi geological survey with fine modules of 2200 m^2/kg and specific gravity of 2.46, according to ASTM C618 requirements, stated in Table 2 [12].

Table 2 Content percentage of bentonite

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SiO_3	Loss on ignition	
%	64	16.5	3.2	2.64	6.3	0.26	0.13	-	6.13	Σ=99.16

2.2 Mix proportions

Nine mixtures were prepared in this study. The reference samples (RM) were prepared with ½ cement to sand ratio and 1.6% of Glenium 54, Type F to obtain 100±5 % flow. The samples designated as DBM were prepared with a partial cement replacement of 5, 10, 15, and 20% by dry bentonite. While CBM samples were prepared with the same cement replacement percentages by colloidal bentonite, as in Table 3. The water to binder ratio (W/B) was 0.34 for all the mixes. All the mixes were cured for 7, 14, 28, 60, 90, and 120 days.

Table 3 The composition of various mixes

Sample designation	*Cement weight (kg/m³)*	*Sand weight (kg/m³)*	*bentonite weight (kg/m³)*	*W/B*	superplasticizer *% weight of Cement*
RM	700	1400	-	0.34	1.6
CBM5	630	1400	63.5	0.34	2.8
CBM10	693	1400	127	0.34	3.0
CBM15	679	1400	190.5	0.34	3.2
CBM20	665	1400	254	0.34	3.3
DBM5	630	1400	63.5	0.34	2.8
DBM10	693	1400	127	0.34	3.0
DBM15	679	1400	190.5	0.34	3.2
DBM20	665	1400	254	0.34	3.3

2.3 Water absorption

The water absorption test was performed in accordance with ASTM C642 [13]. 100 mm cubes of various curing ages were utilized in this experiment. Water absorption is calculated, as follows: -

$$\text{Percentage of water absorption} = \frac{W_s - W_{od}}{W_{od}} \times 100 \qquad (1)$$

Where W_s = saturated weight,
W_{od} = weight of the samples dried by oven

2.4 Strength tests

Cubic samples of 50×50×50 mm were prepared for the compressive strength test. The samples were moulded and left for one day to cure at room temperature then the samples were demolded and cured in tap water for 7, 14, 28, 60, 91, and 120 days. ASTM C 109/C 109M-05 was used to conduct the compressive strength test [14] .

Flexural strength was measured for 40×40×160 mm mortar prisms of each mix at 7, 14, 28, 60, 91, and 120 age according to ASTM C 293-02 [15]. Using a flexural/tensile testing machine with a capacity of 10 KN, the samples were exposed to a simple supported load.

3. RESULTS AND DISCUSSION

3.1 Water absorption results

At 7, 14, 28, 60, 91, and 120 days of age, the water absorption of all mortar mixes was studied. The test findings are provided in Figures 1 to 9. When 5 and 10% of the cement is replaced by colloidal and dry bentonite, the water absorption values decrease as shown in Figures 1 to 5 as compared to the control mix.

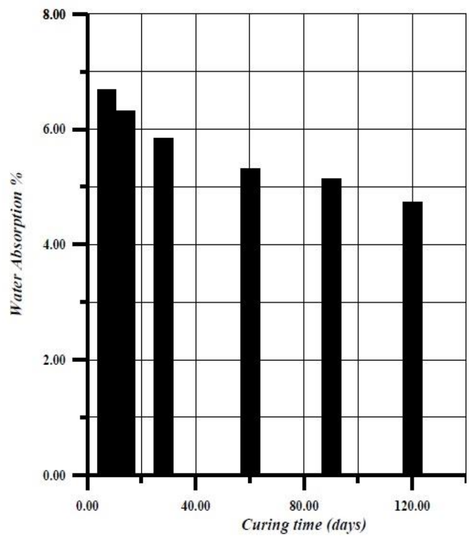


Figure 1. Water absorption for reference samples

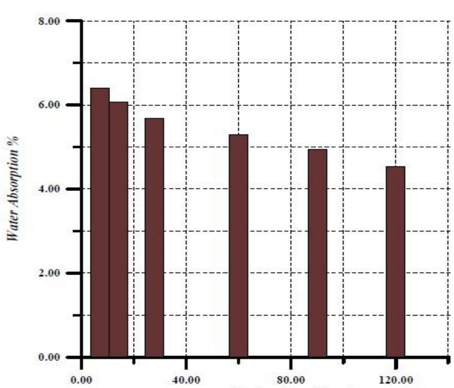


Figure 2. Water absorption for (5% DBM)

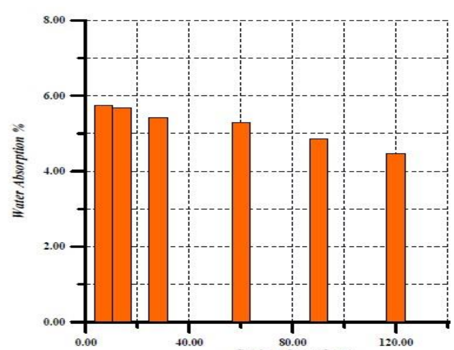


Figure 3. Water absorption for (5% CBM)

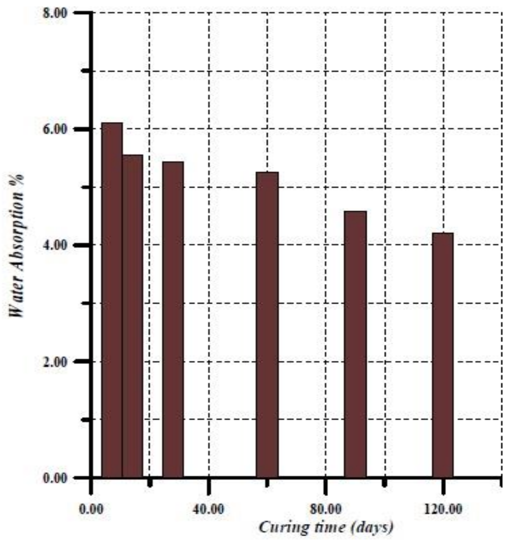


Figure 4. Water absorption for (10% DBM)

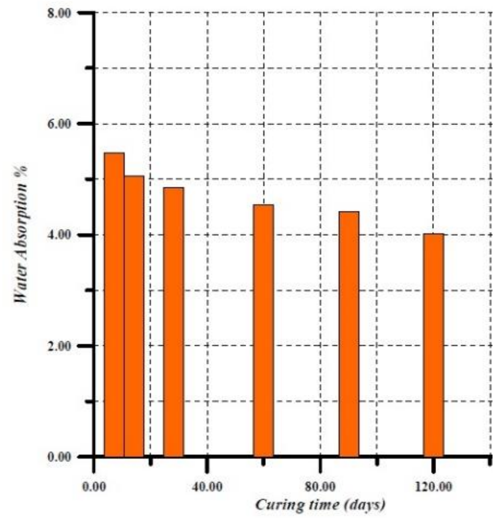


Figure 5. Water absorption for (10% CBM)

For instance, when compared to the reference mix RM, the water absorption values of the mix with 15% bentonite substitution decreased to roughly 27% for colloidal bentonite and 12.4% for dry bentonite (DBM) replacements correspondingly RM, as illustrated in Figures 6 and 7.

This decrease could be attributed to cement mortar's compact microstructure. As the colloidal betonies content is increased by up to 15%, the specific pore volumes can be lowered; in addition, the most likely pore diameters of mortar decreased and became within the less harmful pores, implying that colloidal bentonite replacement improves the structure of cement mortar.

The findings demonstrated that for 5-20% colloidal replacement mixes, there is a reduction in water absorption when opposed to the RM after 120 days of curing. Colloidal bentonite particles large surface area with strong electrostatic forces, which cause faster hydration as a result more hydration products that enclose the voids and decrease the absorption of water. These findings are consistent with the results of [16-18] . Also, replacement particle dispersion (colloidal bentonite) provides a good role as filler and the pozzolanic material occupies space that would otherwise be filled by water as a consequence. This behaviour results in a decrease in the overall porosity of the mortar mix.

Dry bentonite particles, on the other hand, caused particle agglomeration to commence. Figure 8 shows that when DBM is substituted for 20%, water absorption begins to approach the control sample values. Because of the dispersion of bentonite particles, it is possible to produce flaws that cause weak areas.

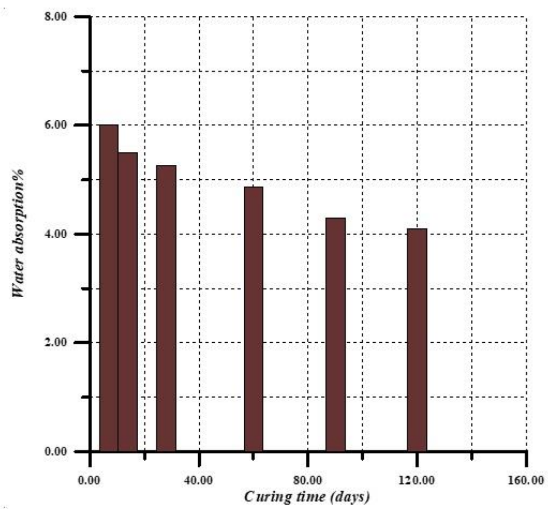


Figure 6. Water absorption for (15% DBM)

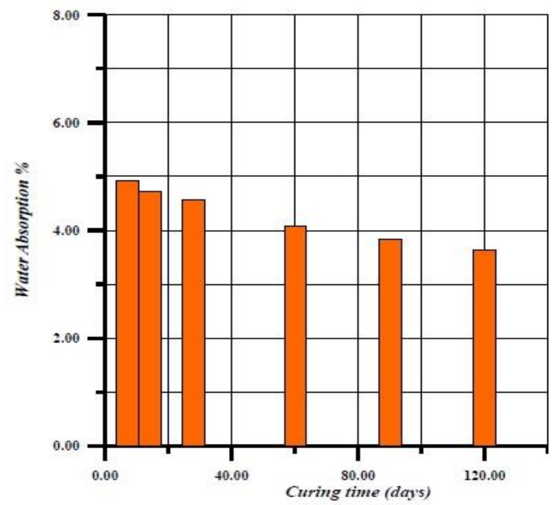


Figure 7. Water absorption for (15% CBM)

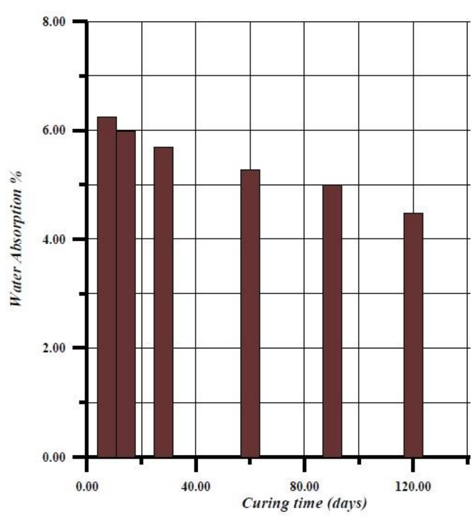


Figure 8. Water absorption for (20% DBM)

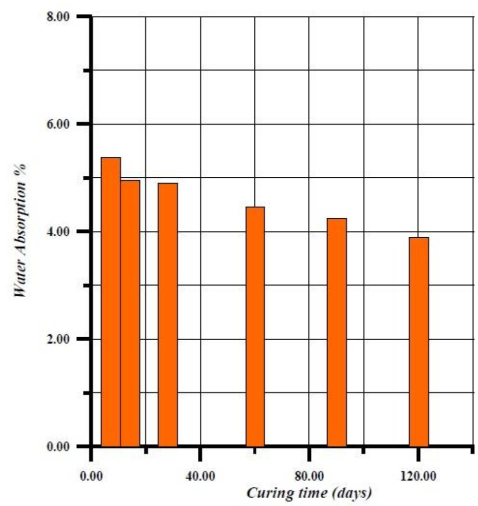


Figure 9. Water absorption for (20% CBM)

3.2 Strength results

Figures 10 to 18 present the results of specimen compressive strength testing at 7, 14, 28, 90, 60, and 120 days of curing age. The compressive strength values of the control mix are shown in Figure 10. Figures 11 and 12 demonstrate that at 120 days, the compressive strength of the mix with 5% of cement replaced by bentonite increased as compared to the reference mix (RM). This is because bentonite fills the fine pores and produce compact mortar which increase the compressive strength, as well as it is owing to the pozzolanic activity of the bentonite (CBM.)

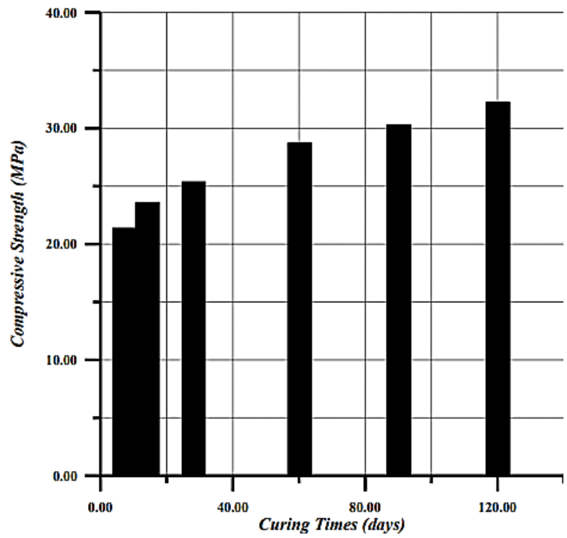


Figure 10. The compressive strength of reference specimens (RM)

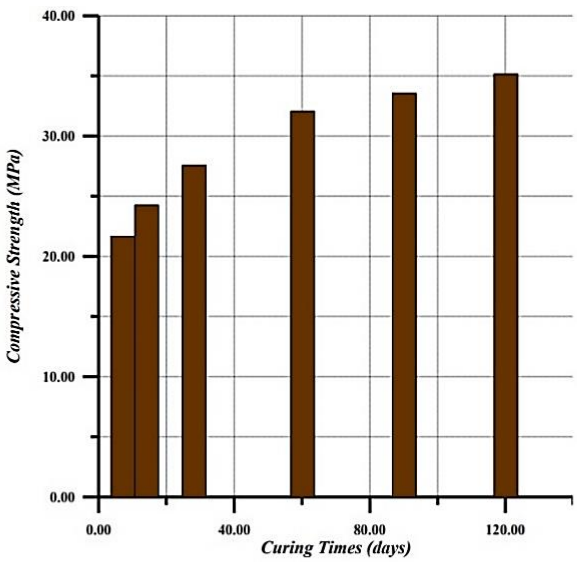


Figure 11. The compressive strength of 5% (DBM)

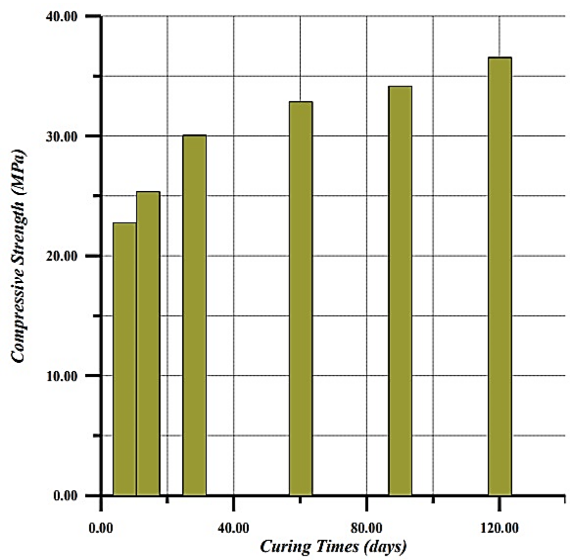
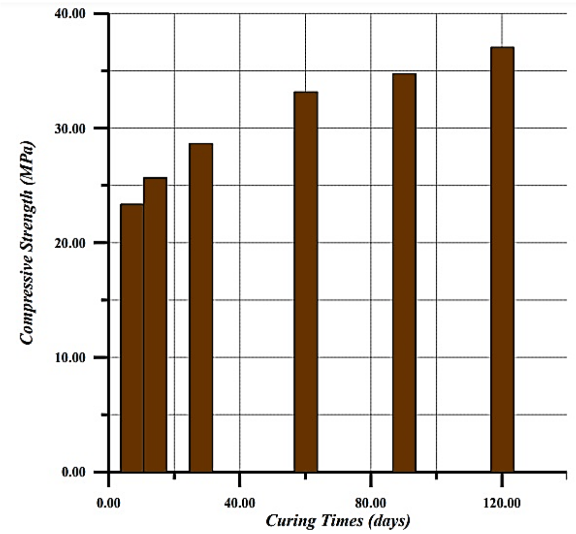


Figure 12. The compressive strength of 5% (CBM)

The compressive strength rises as the curing time increases with constant W / C when 10% of cement is substituted by bentonite. Figures 13 and 14 show similar behaviour for both colloidal and dry reactive particles.



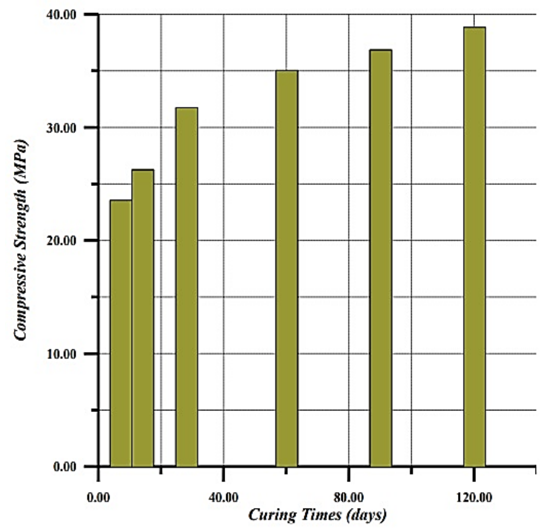
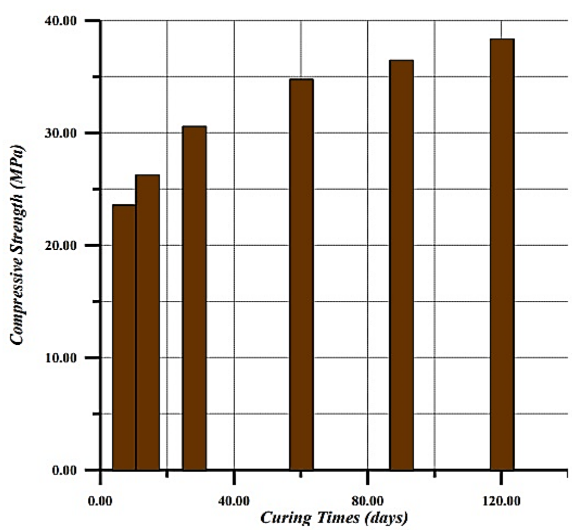


Figure 13. The compressive strength of 10% (DBM)

Figure 14. The compressive strength of 10% (CBM)

The results in Figures 15 and 16 clearly illustrate that a 15% substitution of cement by bentonite in mortar is optimal. In particular, the compressive strength increased by about 21 and 16 % at age of 120 for colloidal and dry bentonite respectively. This finding reveals that cement replacement by bentonite has a beneficial influence on enhancing mixes' compressive strengths which it could be owing to the fillers' large surface area. These findings are in agreement with [19, 20]. They found that the strength enhancement at age 3-7 days caused by the filling effect of the bentonite while at age 14 days the enhancement was due to the pozzolanic reaction starting at that age.



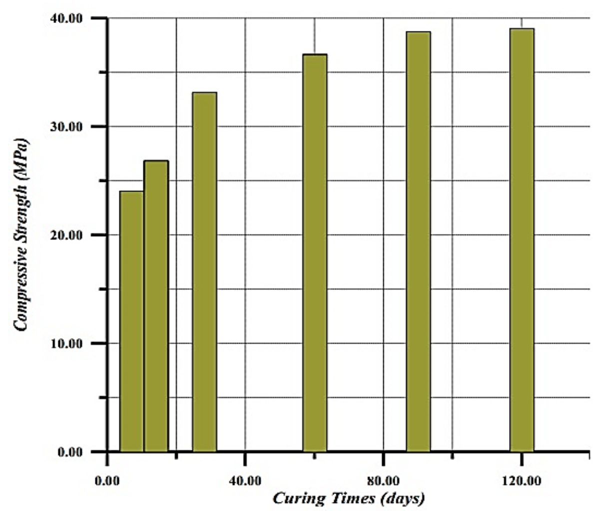


Figure 15. The compressive strength of 15% (DBM)

Figure 16. The compressive strength of 15% (CBM)

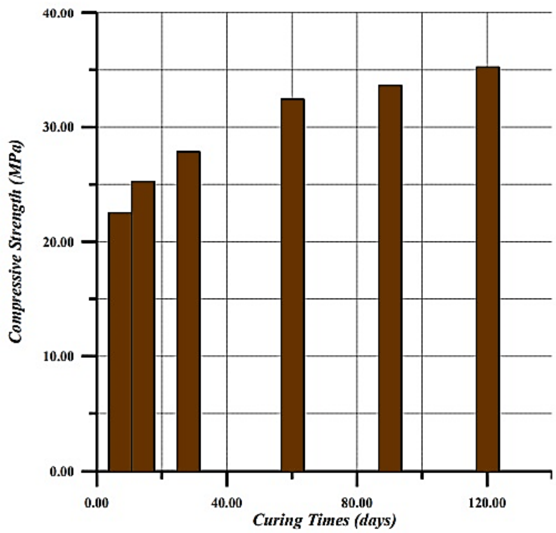


Figure 17. The compressive strength of 20% (DBM)

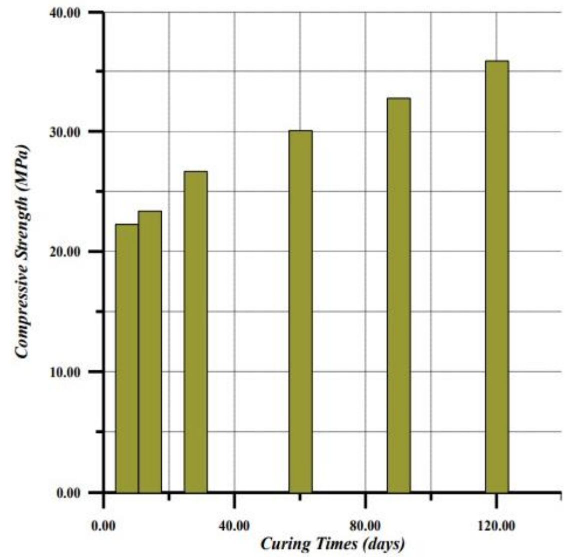


Figure 18. The compressive strength of 20% (CBM)

The flexural strength of a reference cement mortar prepared without any modifications is shown in Figure 19. The results of flexural tests for all bentonite blends are included in Figures 20 to 27. The use of 5, 10% bentonite as a cement substitute increased the flexural strength of the RM mix at all the ages, as can be seen in Figures 20 to 23 for both DBM and CBM particles. Similar behaviour was observed for 15% cement replacement by both dry and colloidal particles. Figures 24 and 25 show that the strength of mixes (CBM and DBM), for 120 days, was higher by about 18 and 12 % respectively as compared with RM mix.

In the case of using bentonite as a cement substitute, an improvement in concrete flexural strength has also been reported by Sithara [20]. The flexural strength enhancement is because bentonite acts as a filler within the cement mortar microstructure which improve its strength and produce mortar with higher density. Furthermore, the pozzolanic reaction that leads to strengthen the bond and the increments of solid volume [21, 22].

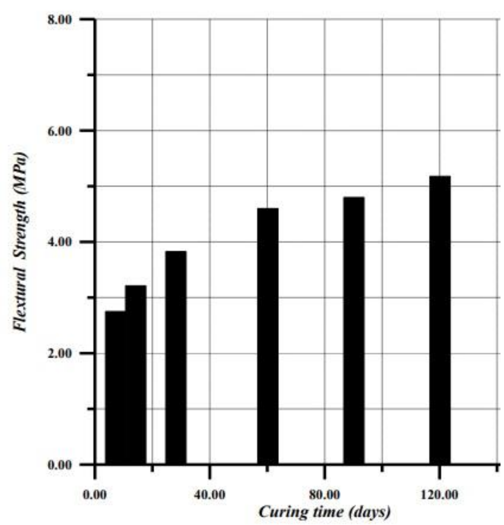


Figure 19. Flexural strength for reference specimens

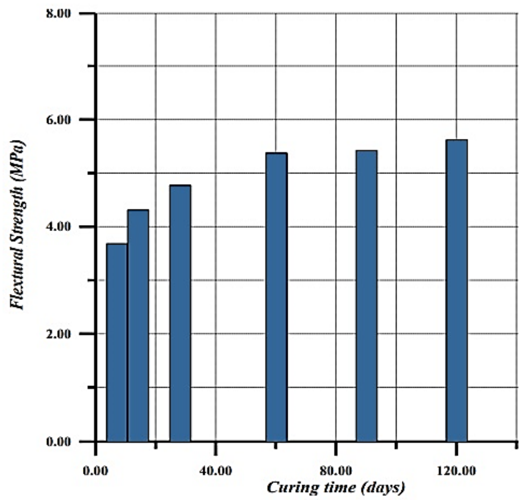


Figure 20. Flexural strength for 5% (DBM)

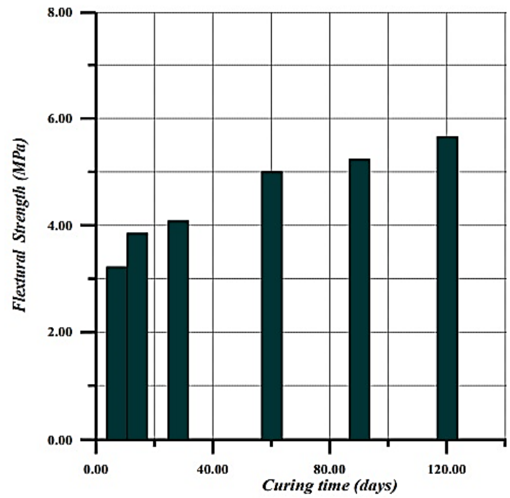


Figure 21. Flexural strength for 5% (CBM)

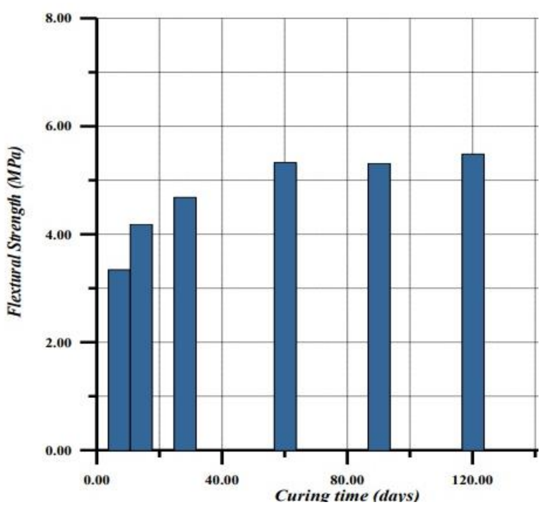


Figure 22. Flexural strength for 10% (DBM)

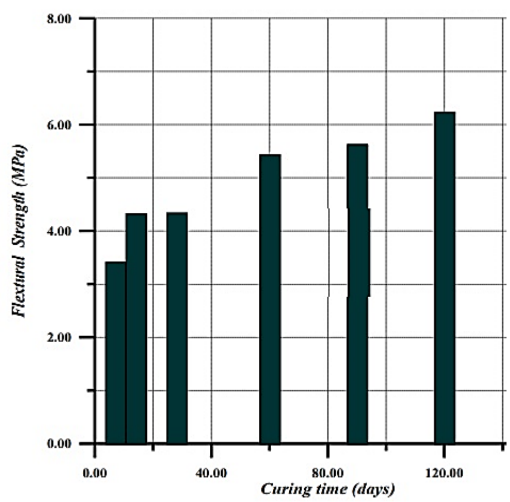


Figure 23. Flexural strength for 10% (CBM)

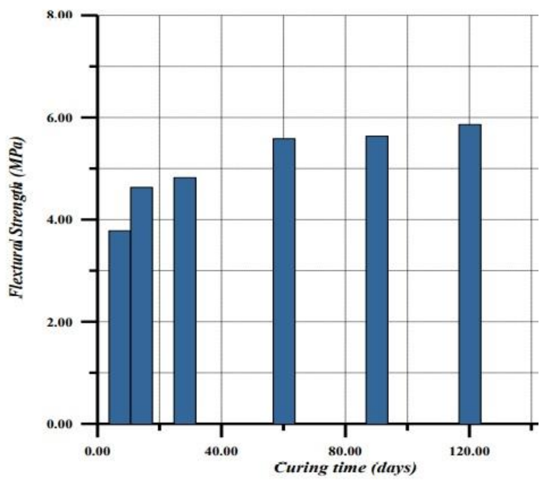


Figure 24. Flexural strength for 15% (DBM)

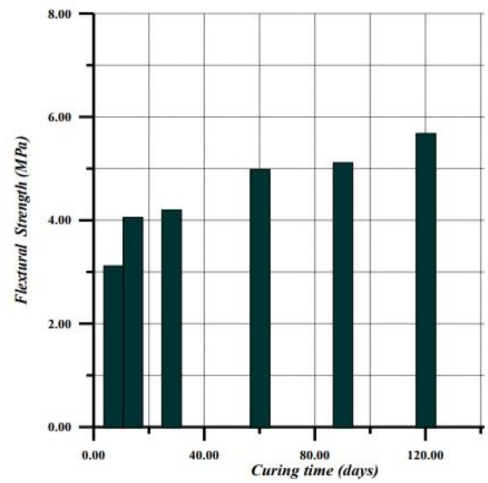


Figure 25. Flexural strength for 15% (CBM)

As cement was replaced by 20% bentonite colloidal and dry, the flexural strength was decreased, as shown in Figures 26 and 27. It may be attributed to the fact that the bentonite introduced in the mixtures was more than needed to combine with free lime resulting in a decrease in flexural strength as it substituting a portion of cementing material and did not involve in its strength.

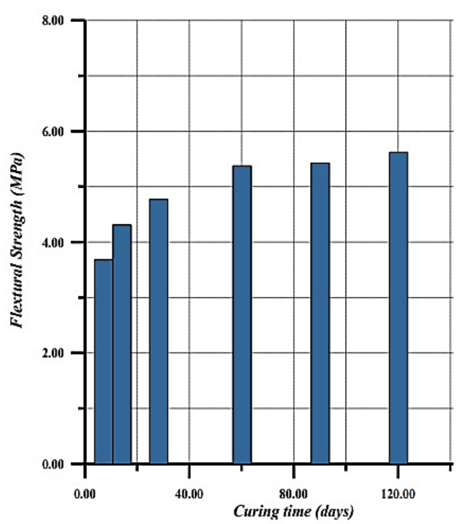


Figure 26. Flexural strength for 20% (DBM)

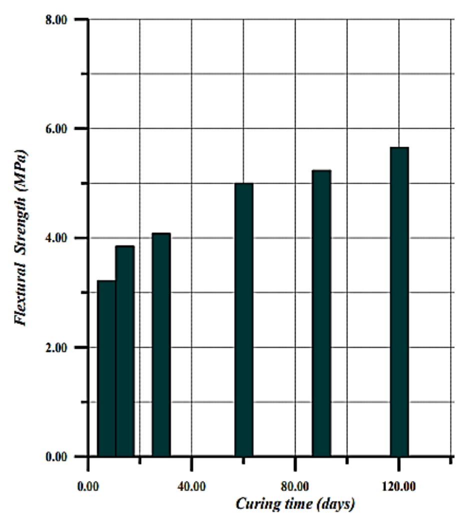


Figure27. Flexural strength for 20% (CBM)

4- CONCLUSIONS

The following inferences may be drawn according to the outcomes of this research:

1. Reactive powder in colloidal form has better dispersion than dry powder, which contributes to a well-homogenized particle distribution and minimizes agglomeration.
2. Bentonite served as fillers to fill the pores and increase density. Moreover, as a result of its chemical reaction with calcium hydroxide, it forms more calcium silicate hydrate.

3. When bentonite replacement was used up to 15%, there was a reduction in water absorption. It reduced by about 27% and 12% for 15 % of cement replacement by colloidal (CBM) and dry (DBM) respectively as compared with the reference mix (RM).
4. The addition of bentonite enhances both compressive and bending strengths. As well as high early strengths. Maximum compressive strength improvement was observed at 120 days.
5. Samples including colloidal bentonite have better compressive strength at all curing ages than that containing same amount of dry bentonite.
6. At 120 days in colloidal form, increases in compressive strength were seen in mixes having 5, 10, 15, and 20% bentonite replacement, with the percentage rising of 12.5, 15.6, 21, and 13.6% accordingly compared to the control.
7. The flexural strength of mixes CBM and DBM for 120 days, was higher by about 18 and 12% respectively compared with the reference mix (RM).

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