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Research Article

The Mechanical Properties of the Concrete Using Metakaolin Additive and Polymer Admixture

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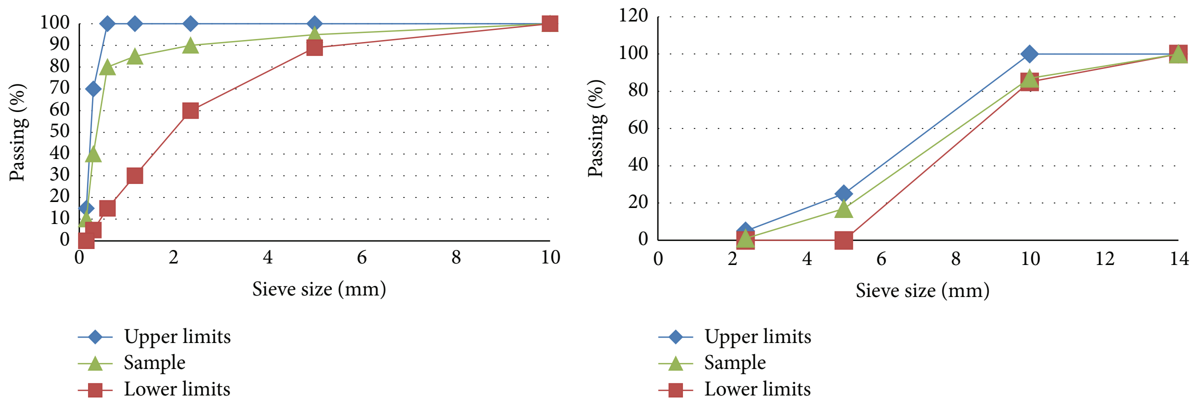
Environmentally friendly and high performance concrete is very import for the applications in sewage and water treatment industry. Using mineral additives such as fly ash and silica fume has been proven to be an effective approach to improve concrete properties. This paper reports a study of the effect of using both polymer and metakaolin additives together on the mechanical and durability properties of concrete. Different proportions of the combination using two different polymers, metakaolin, and recycled fiber reinforcement have been studied. The effects of water-to-cement ratio and the curing methods have also been compared. At last an optimized mixture and curing method has been suggested.

1. Introduction

Using mineral additives such as fly ash and silica fume has been proven to be an effective approach to improving concrete properties. With the increasing of the environmental concern, in recent years [1], the use of metakaolin (MK) as an optional additive has also raised more and more interests [2]. As a supplementary cementitious material MK has the expected pozzolanic nature activated by tricalcium silicate (C3S) and tricalcium aluminate (C3A) [3]. When used as a partial replacement for cement, MK reacts with portlandite ($Ca(OH)_2$) to generate additional CSH gel which results in the increase of strength. Previous work by Khatib et al. [4] showed that the 20% replacement of cement using MK had resulted in a substantial 50% increase of the compressive strength of mortar. However, with over 30% replacement of cement by MK, the compressive strength started to decrease. It has also been shown that the sample containing 10% MK replacement displayed the best performance in terms of ultrasonic test. Justice [5] compared the effects of the use of two different types of MK on concrete workability and setting time. It was found that MK caused a considerable reduction in workability and reduced the setting time of cement paste by 35–50%. The study also showed that the use of MK had increased the compressive strength, splitting tensile strength, flexural strength, and the elastic modulus of concrete samples. Guneyisi et al. [6] compared the effects of the use of silica fume and MK on the water sorptivity of concrete. It was observed that the water sorptivity decreases more when using MK additive than when using silica fume.

In concrete practice, polymers have been also commonly used as additives to improve concrete durability because of its effect on reducing water absorption. Styrene butadiene rubber (SBR) and poly vinyl acetate (PVA) are two polymers commonly used in concrete with the effect on reducing the pore spaces and connection [7]. Previous work [8] has found that while it increases the strength and decreases the water permeability, SBR can increase the workability of concrete as well. The work by Jamshidi et al. [9] also showed that a polymer admixture of the SBR, acrylic, and PVA generated a decrease in water permeability of the concretes. A work by W. J. Lewis and G. Lewis [10] showed that the workability of SBR modified concretes was much higher than that of normal concrete and increases with the increase of polymer content. However, the workable time was greatly reduced when compared with normal unmodified concrete.



(a) Fine sand aggregate

(b) Course limestone aggregate

Figure 1: Particle size distribution.

Wang et al. [11] studied the physical and mechanical properties of SBR modified cement mortars using different polymer/cement ratio (p/c) and a constant water/cement ratio of 0.4. They also compared two curing methods, that is, wet cure for 2, 6, or 27 days by being immersed in 20°C water and mixed cure for 6 days by being immersed in 20°C water followed by 21 days at 20°C and 70% relative humidity (RH). The results showed that the mixed cure produced an improvement on the mortar properties. Ganiron Jr. [12] ever investigated the influence of polymer fiber on the strength of concrete. They added two kinds of polymer fibers, that is, polyvinyl alcohol and polyvinyl acetate, into concrete mixes. It was found that the polymer modified concrete of 2% p/c showed the highest compressive strength and that of 6% p/c displayed a similar result to that of the conventional concrete.

2. Experimental Investigation

This research aims to investigate the combined effect of using both MK and polymer together on the improvement of the concrete mechanical and durability properties. At first, control sample was made using a mixture of Portland cement, sand, and gravels. Second, modified concrete specimens were made by adding two types of polymer additives, that is, SBR and PVA, and partially replacing the cement using MK. Different water cement ratios were used for all of these mixtures. In addition, plastic and glass fiber made of recycled materials were used to reinforce the concrete mixtures. Experimental tests of the concrete mixtures after different setting time have been carried for mechanical properties, including compressive strength, splitting tensile strength, flexural strength, and, the durability related property, water absorption. The effects of using different curing methods have also been compared.

2.1. Component Materials and Mixtures. Portland limestone cement, the CEM II/A-LL (BS EN 197-1:2011), was used in the experiment. The cement properties have been listed in Table 1. The fine aggregate used sand, while the coarse aggregate was crashed limestone gravel with maximum size of 10 mm. The specific gravity of the limestone aggregate is 2.49. Their particle size distribution followed BS 882:1992 and BS 812:1992. Figure 1 shows the sieve analysis results. A premium metakaolin produced by Whitchem Ltd. (http://whitchem.co.uk/) was used in this study. Its properties have been shown in Table 2. Both SBR and PVA were used as polymer additives. Tables 3 and 4 have listed their proprieties, respectively. Table 5 lists the SBR and PVA composition in the polymer mixture studied. Alkali resistant glass fiber (GF) and a recycled polypropylene plastic fiber (PF) were also used in the study.

Table 1: Properties of the cement used.

Particulars	Unit	Value	Standard
Setting time—initial	Minutes	150	80–200
Compressive strength			
2 days	N/mm^2	17	16–26
7 days	N/mm^2	29	27–37
28 days	N/mm^2	40	37–47

Table 2: Metakaolin properties.

Particulars	Value
Colour	White
ISO brightness	>82.5
$-2\,\mu$m (mass%)	>60
+325 mesh (mass%)	<0.03
Moisture (mass%)	<1.0
Aerated powder density (kg/m^3)	320
Tapped powder density (kg/m^3)	620
Surface area (m^2/g)	14
Pozzolanic reactivity (mg $Ca(OH)_2/g$)	>950

The control concrete mixture took the proportion of cement/sand/gravel as 1/1.5/3. The modified mixtures were made based on the control mix with the replacement of the cement using MK and a polymer mixture. The MK took 0, 10, 15, and 20% of the weight of cement, respectively, while the polymer mixture took 0, 2.5, 5, and 7.5%, respectively.

Table 3: Styrene butadiene rubber properties.

Particulars	Value
Brand	Cementone
Colour	White
Model name	SBR
Product type	Admixture
Resistance type	Water, chemical & abrasion resistance

Table 4: Polyvinyl acetate properties.

Particulars	Values
Typical performance data (approx.) application temperature	5°C–25°C.
Wet grab	10 minutes approx. at 15°C.
Tack development	10–90 minutes at 15°C.
Bonding	Maximum strength is attained in 24 hours.
Colour	White.
Form	Liquid.
Specific gravity	1.1 approx.
Composition	Polyvinyl acetate emulsion.

Table 5: The polymer mixture used in this study.

	Polymer composition		MK
	SBR %	PVA %	(% cement)
Study for optimizing the polymer mixture composition	0	0	15
	100	0	15
	80	20	15
	60	40	15
	50	50	15
	40	60	15
	20	80	15
	0	100	15
	5	15	15

Table 6: The mixtures proportion used in this study.

	Polymer (% cement)	MK (% cement)	Fiber (% cement)
Study for optimizing the polymer and MK combination	0/2.5/5/7.5	0	
	0/2.5/5/7.5	10	
	0/2.5/5/7.5	15	
	0/2.5/5/7.5	20	
Study for optimizing fiber content	0/5	0	0/5
	0/5	15	0/5

The added fiber took the 0, 2.5, and 5% of the cement weight of the control mixture. The mixtures are listed in Table 6. The effects of three water-to-cement ratios, 0.35, 0.4, and 0.45, were studied based on the control mix. The effects of three curing methods, the wet, dry, and moist, were also compared.

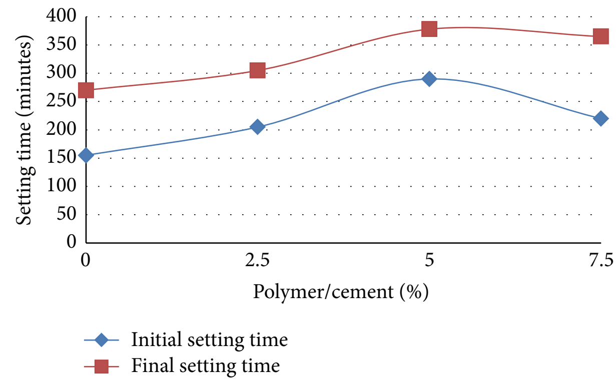


Figure 2: The setting time of polymer modified cement paste with 0% MK.

2.2. Experimental Tests

Setting Time. The initial and final setting time tests were conducted on cement pastes for a standard consistency. The consistence was measured using Vicat apparatus according to ASTM C187-86:1986. The sitting time was measured according to the penetration of a needle gauge according to ASTM C 191-82:1986

Slump Test. The workability of mixtures was tested following BS EN 12350-2:2009.

Compressive Strength. Compressive test was conducted using cubic samples with a dimension of 100 mm × 100 mm × 100 mm according to BS 1881 part 116:1983.

Splitting Tensile Strength. Splitting tensile test was conducted using cylindrical samples with a dimension of 150 mm (D) by 300 mm (L) according to BS 1881 part 117:1983.

Flexural Strength. Flexural test was conducted using prismatic samples with a dimension of 100 mm (D) by 100 mm (H) by 500 mm (L) by applying a concentrated load at the centre according to ASTM C293-02.

Water Absorption. Water adsorption test was conducted using cubic samples with the dimension the same as that used for compressive test according to BS 1881: part 122:2011.

3. Results and Discussions

Figures 2–4 have showed the results of the initial and final setting times. It can be seen that polymer has a significant effect on delaying setting time. The effect increases with the increase of polymer content. It also can be seen that the setting time accelerates with the increase of MK content. With the addition of both polymer and MK, it has been found that the mixture of 15% MK displayed a relatively stable setting time at varied polymer contents.

Figure 5 shows that the workability increases with the increase of polymer content but decreases with the increase of MK, and similar results were observed for all w/c ratios.

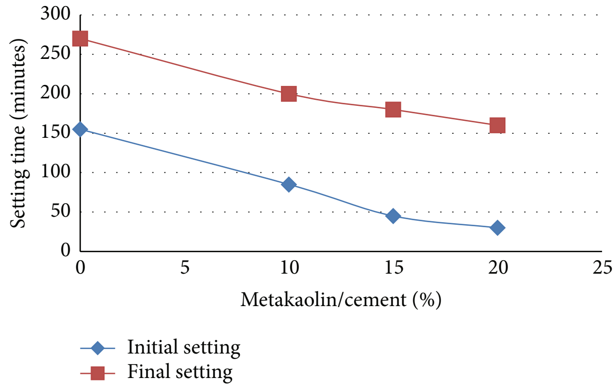


Figure 3: The setting time of MK modified cement paste with 0% polymer.

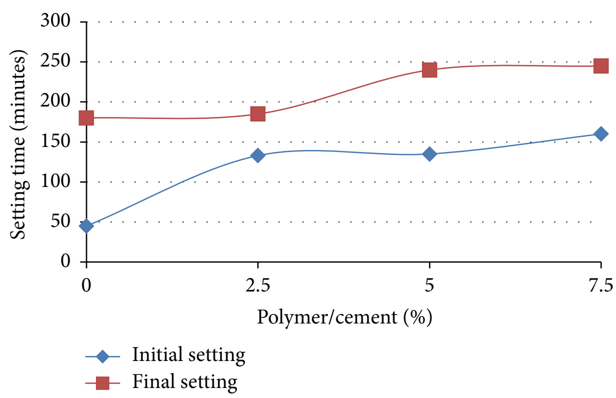


Figure 4: The setting time of polymer modified cement paste with 15% MK.

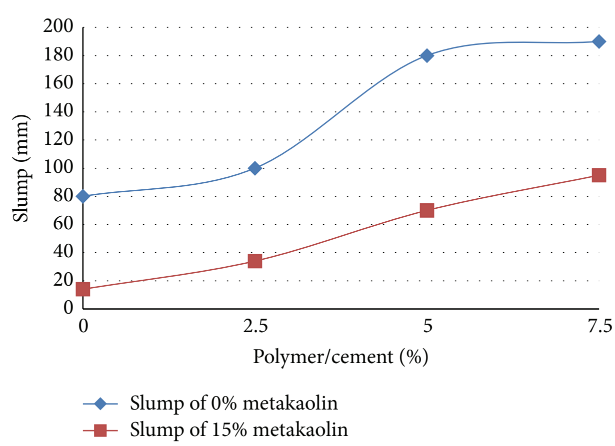


Figure 5: Effect of polymer and MK on workability for modified concrete with w/c 45%.

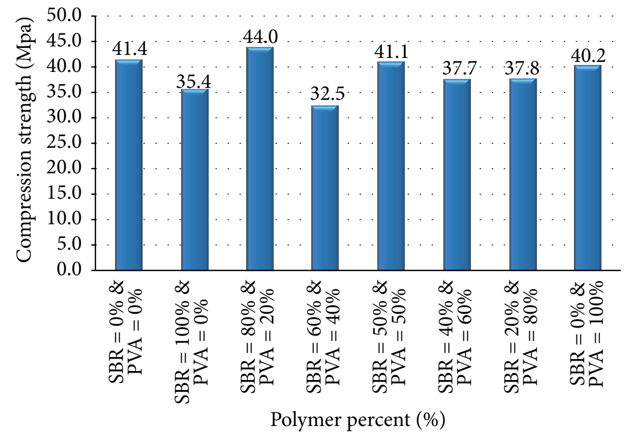


Figure 6: 28-day compressive strength of the concrete containing 5% polymer and 15% MK.

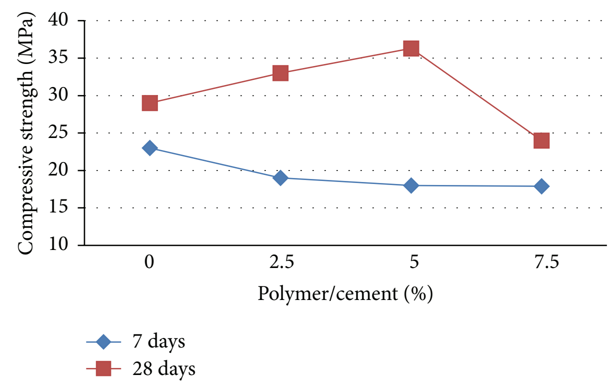


Figure 7: The compressive strength at different polymer contents with 0% m/c and w/c = 45%.

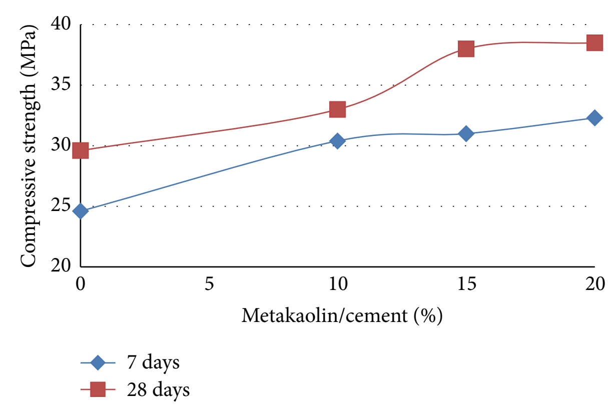


Figure 8: The compressive strength at different MK contents and 0% polymer.

The effect of the polymer of different composition of the SBR and PVA was studied. Figure 6 shows that the polymer consisting of 80% SBR and 20% PVA displays the highest compressive strength. Figures 7–9 show the effect of varied contents of the polymer, consisting of 80% SBR and 20% PVA, and MK on the compressive strength. It can be seen that the mixture of 5% polymer and 15% MK displayed the highest compressive strength. It also can be seen that while the 28-day compressive strength decreases when polymer content exceeds 5%, however, both 7-day and 28-day compressive strengths increase with the increase of MK. Figures 10 and 11 show the effect of different curing methods

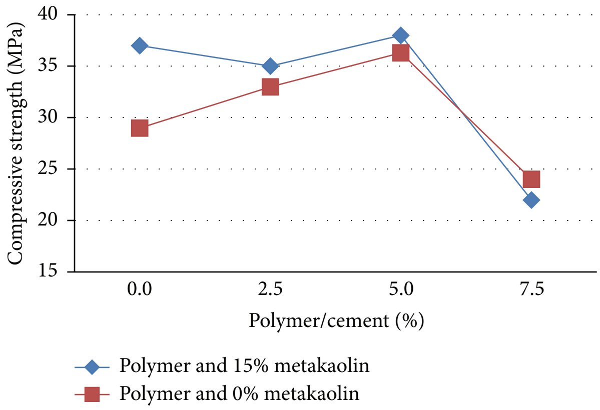


Figure 9: The compressive strength at different polymer contents at age of 28 days.

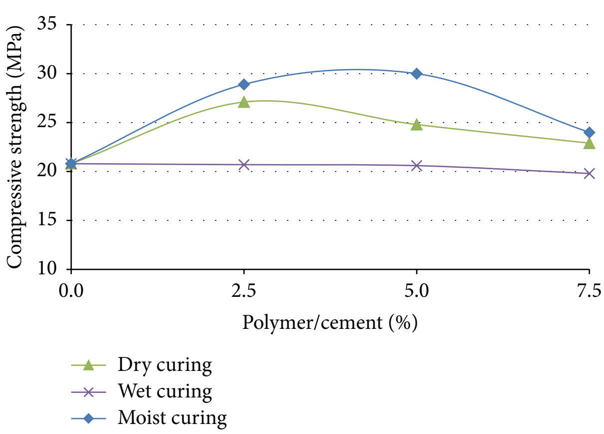


Figure 10: The effect of curing methods on the compressive strength at different polymer contents and 0% MK at age of 28 days.

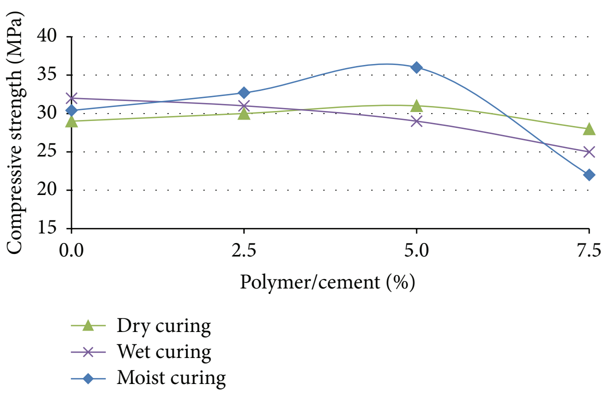


Figure 11: The effect of curing methods on the compressive strength at different polymer contents and 15% MK at age of 28 days.

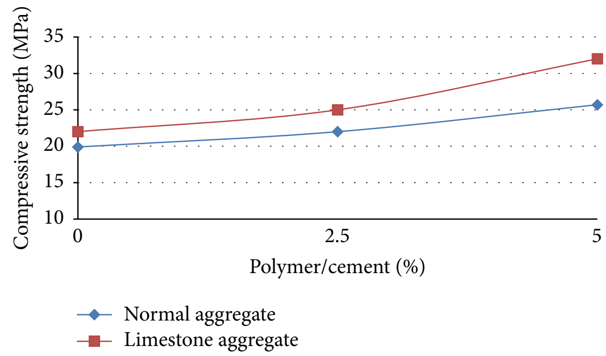


Figure 12: The effect of the aggregates type on the compressive strength at different polymer content and 0% MK at age of 28 days.

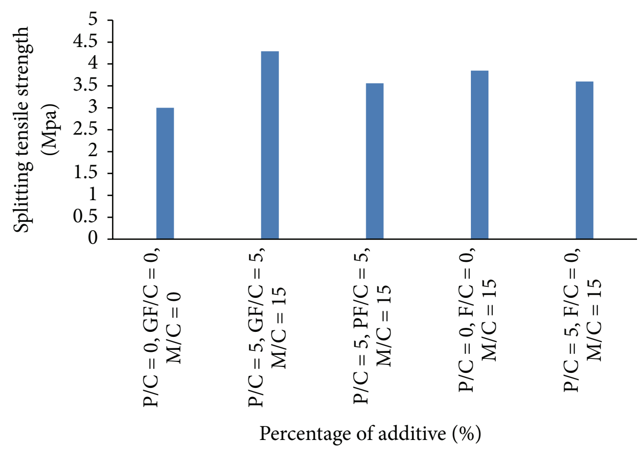


Figure 13: Splitting tensile strength at age of 28 days.

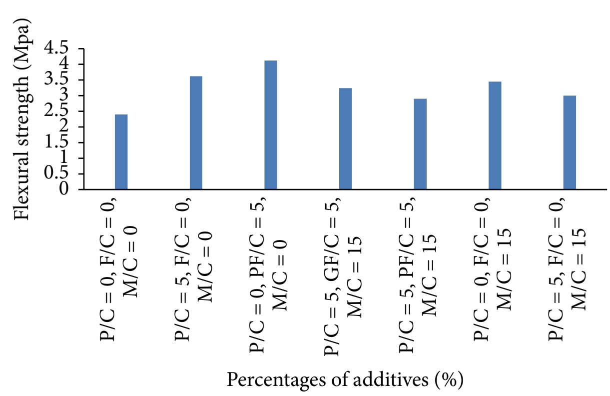


Figure 14: Flexural strength at age of 28 days.

on the compressive strength of the modified concretes. It can be seen that the moist curing generated the best results. Figure 12 shows the results using different types of coarse aggregates. It can be seen that limestone aggregate is better than normal aggregate.

Figure 13 shows the effect of plastic fiber (PF) and glass fiber (GF) on the splitting tensile strength. It can be seen that using glass fiber for reinforcement produced the highest splitting strength.

Figure 14 shows the effect of fiber reinforcement on flexural strength. It can be shown that the flexural strength has been improved with the fiber reinforcement. The use of glass fiber (GF) and polymer presents the best flexural strength. It also can be seen that using MK will enhance

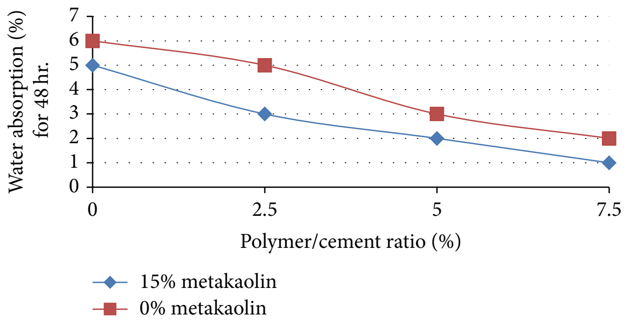


FIGURE 15: Water absorption at different polymer contents.

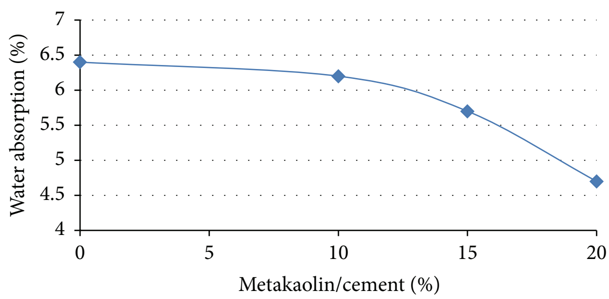


FIGURE 16: Water absorption at different MK contents and 0% polymer.

the flexural strength as well. However, using both MK and polymer together, the mixture shows a decrease in flexural strength. To explain this, further study is needed.

Figures 15 and 16 show the total adsorbed water percentage in terms of the weight of dry samples. It can be seen that, with the increase of polymer and MK content, the water absorption reduces remarkably. This might be due to a reduction in porosity as a result of the added polymer latex and the pozzolanic reaction of metakaolin.

4. Conclusions

The following conclusions can be drawn from the reported experimental study:

(i) Metakaolin will accelerate the setting time of cement pastes but reduce the workability of concrete. However, polymer has an inverse influence on the two properties.

(ii) The polymer composition of 80% SBR and 20% PVA shows an optimized result when it works together with MK.

(iii) The appropriate water/cement ratio is 0.45 for the concrete using polymer and metakaolin additives.

(iv) The addition of 5% optimized polymer and 15% cement replacement using metakaolin generates an optimized concrete mixture for both strength and durability.

(v) For the optimized polymer and MK mixture, the 5%, in terms of the cement weight, addition of the plastic and glass fibers can effectively improve the tensile strength.

Competing Interests

The authors declare that they have no competing interests.

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References

[1] K. Srinivasu, M. L. N. K. Sai, and N. V. S. Kumar, "A review on use of metakaolin in cement mortar and concrete," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 3, no. 7, pp. 14697–14701, 2014.

[2] S. Aiswarya, A. G. Prince, and C. Dilip, "A review on use of metakaolin in concrete," *Engineering Science and Technology*, vol. 3, no. 3, pp. 592–597, 2013.

[3] J. Ambroise, S. Maximilien, and J. Pera, "Properties of metakaolin blended cements," *Advanced Cement Based Materials*, vol. 1, no. 4, pp. 161–168, 1994.

[4] J. M. Khatib, E. M. Negim, and E. Gjonbalaj, "High volume metakaolin as cement replacement in Mortar," *World Journal of Chemistry*, vol. 7, no. 1, pp. 7–10, 2012.

[5] J. M. Justice, *Evaluation of Metakaolin for use as supplementary cementitious materials [M.S. thesis]*, The Academic Faculty, Georgia Institute of Technology, 2005.

[6] E. Guneyisi, M. Gesoglu, S. Karaoglu, and K. Mermerdas, "Strength, permeability and shrinkage cracking of silica fume and metakaolin concretes," *Construction and Building Materials*, vol. 34, pp. 120–130, 2012.

[7] D. W. Fowler, Ed., *Polymer Modified Concrete*, American Concrete Institute, Detroit, Mich, USA, 1987.

[8] V. Bhikshma, K. J. Rao, and B. Balaji, "An experimental study on behavior of polymer cement concrete," *Asian Journal of Civil Engineering*, vol. 11, no. 5, pp. 563–573, 2010.

[9] M. Jamshidi, H. R. Pakravan, and A. R. Pourkhorshidi, "Application of polymer admixtures to modify concrete properties: effects of polymer type and content," *Asian Journal of Civil Engineering*, vol. 15, no. 5, pp. 779–787, 2014.

[10] W. J. Lewis and G. Lewis, "The influence of polymer latex modifiers on the properties of concrete," *Composites*, vol. 21, no. 6, pp. 487–494, 1990.

[11] R. Wang, P.-M. Wang, and X.-G. Li, "Physical and mechanical properties of styrene-butadiene rubber emulsion modified cement mortars," *Cement and Concrete Research*, vol. 35, no. 5, pp. 900–906, 2005.

[12] T. U. Ganiron Jr., "Influence of polymer fiber on strength of concrete," *International Journal of Advanced Science and Technology*, vol. 55, pp. 53–66, 2013.