Studying physico-mechanical properties of Portland cement mortar in presence of admixture based on copolymer latexes

[1,2*]Negim E.S.M., [3]Mun G.A., [3]Rakhmetullayeva R., [4]Yeligbayeva G.Zh, [3]Mamutova A.A., [4]Bakytbekovna D., [1]Iskakov R.

[1] School of Chemical Engineering, Kazakh-British Technical University, 106 Walikhanov Street, Almaty, 050010, Kazakhstan
[2]National Research Centre, Polymer & Pigment Department, 33 El Bohouth St., Dokki, Giza, 12622, Egypt
[3]Al-Faraby Kazakh National University, 050038 Almaty, Kazakhstan
[4]K.I. Satpaev Kazakh National Technical University, 22 Satpaev avenue, Almaty, 050013, Kazakhstan

*Corresponding author: E-Mail: elashmawi5@yahoo.com

Abstract: The paper deals with the influence of copolymer latexes on the physico-mechanical properties of Portland cement mortar including, W/C ratio, setting time, workability, density, porosity and compressive strength. Copolymer latexes were used based on 2-hydroxy ethyl acrylate (2-HEA) and butyl acrylate (BuA) with different composition ratios (99/01, 95/05 and 90/10) respectively. The result showed that, the physico-mechanical properties of the mortar are dependent on the composition ratios of 2-HEA and BuA in the latexes. However, as the ratios of 2-HEA in copolymer increased, the W/C-ratio, total porosity, setting time, flow and density decrease while the compressive strength increases.

Keywords: Copolymer latexes; Mortar; Setting time; Workability; Compressive strength, Density

INTRODUCTION

The addition of polymer in cement-based materials such as mortar mixes can lead to reduction of amount of water required to achieve adequate workability. Some researchers were conducted to evaluate critical factors that explain this behaviors, by considering different kind of polycarboxylate type superplasticizer and modifying polymer chemical structure [1-8]. The research demonstrated that chemical composition and structure of polymers are strictly connected to improving the mortar behaviors. For example, polyvinylacetate-g-polyoxyethylene monomethylether [9], and polyacrylic latexes [10, 11] decrease the water/cement ratios, and increase compressive strength and combined water, while co-surfactants (dodecyl benzene sodium sulfonate/ polyvinyl alcohol) increase the water/cement ratio and decrease the compressive strength of mortar.

Authors [12, 13] found that the types of the surfactant, which were used in preparing of emulsion latexes as chemical admixtures, played an important role in the specific characteristics of the cement pastes. The compressive strength and chemically combined water of cement pastes premixed with styrene/methacrylate latexes in the presence of polyvinyl alcohol (PVA) as a surfactant seem to be higher than that of latexes in presence of polyoxyethylene glycol monomethylether (POE) as a surfactant [10]. However, the compressive strength and chemically combined water for mortars with styrene/methacrylate latexes containing PVA are lower than mortar containing styrene/methacrylate in presence of POE.

On the other hand, the longer side chains of the polymer latexes gave more fluidity, a shorter setting time, lower water absorption, a higher strength and hydration of Portland cement mortar. Similar results are reported by Yamada et al [14], who found an increase in the final setting of cement pastes containing polycarboxylate-based polymer with decreasing side chain. Negim et al [10] indicated an increase in the compressive strength of mortar containing copolymer latex based on styrene/glycidyl methacrylate with increasing side chain.

Negim et al [11] prepared copolymer latexes based on 2-hydroxy ethyl acrylate (2-HEA) and butylacrylate (BuA) with different composition ratios (99/01, 95/05 and 90/10) respectively as a chemical admixture. Theses latexes were found to be effective in improving the workability of the resulting cementitious materials. Moreover, an increasing BuA content in the composition ratio of copolymer improves the rheological, physical and mechanical properties of Portland cement pastes. The work was further extended to investigate the application of the obtained copolymer latexes to modify physico-mechanical properties of Portland cement mortar. The effects of copolymer latexes on the workability, W/C ratio, density and compressive strength of mortar materials were examined and discussed.

MATERIALS AND METHODS

Materials

The raw materials used in the present study are Portland cement clinker (PCC) and raw gypsum (G). Each of those raw materials was separately ground in a steel ball mill until the surface area of respectively 3650 and 2800 cm^2/g was achieved. The chemical composition of the raw materials is shown in Table 1. The mineralogical composition of the PCC sample is C_3S, 58.79 %; β- C_2S, 17.68 %; C_3A, 8.08 %; C_4AF, 9.72 %. The Portland Cement (PC) was prepared by mixing 96 % PCC and 4 % G (by weight), as CEM1 according to BS EN 197-1 [15], in a porcelain ball mill for one hour using 3 balls to ensure complete homogeneity of the cement. The Blaine surface area of the cement sample was 3350 cm^2/g [16]. The fine aggregate used was sand with particle size ranging from 0.21mm to 0.53 mm and is free from organic or clay-like materials.

Table 1. The chemical composition of the raw materials, mass %.

Oxides / Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I
PCC	21.48	6.03	4.22	64.29	0.68	0.39	0.21	0.11	1.32
G	0.58	0.14	0.11	30.08	0.13	45.36	0.07	0.09	22.16

Synthesis and characterization of copolymer latexes

Copolymer latexes based on 2-hydroxy ethyl acrylate (2-HEA) with butylacrylate (BuA) P[2-HEA-co-BuA] with various ratios of hydrophilic chains [(M1= 99: 01), (M2= 97: 03), (M3= 95: 05)] respectively were synthesized by solution polymerization using azo-bis-isobutyro-nitrile as initiator and ethanol as solvent at 60 ºC. The preparation of copolymers and the methods of analysis (^{1}H NMR, rheological and morphological techniques) have been previously described in a previous investigation [11].

Mixing and testing

Four mortar mixes were employed to conduct this study. Specimens in the form of cubes of 70mm in size were used. The control mix (M0) consists of Portland cement (PC), sand and water. The proportion of cement to sand was 1:3 (by weight) and the water/cement ratio (w/c) was 0.45. In mixes M1, M2 and M3, copolymer latexes were added respectively. The addition rate was 2% latex by weight of cement. The cement to sand ratio was kept constant. However the water to cement ratio was changed from 0.4 to 0.48 in order to obtain the same consistency was achieved.

The cement and sand were intermixed until homogeneity was achieved. Then the prepared latexes were added to the mixing water. This was then added gradually to cement/sand mixture in order to determine the water of consistency and setting time using Vicat apparatus [17, 18]. Workability was measured by the flow of the fresh latex mortar on flow table for mortar according to ASTM C1437-07 [19].

The resulting mortar was directly placed into 70 mm cube stainless steel moulds. The moulds were manually agitated for 2 minutes and then on a vibrator for another 2 minutes. The moulds were kept in a humidity chamber at 100 % R.H. and a temperature of 25±1 ºC for 24 hours. After that the specimens were demoulded and cured in water at 25±1 ºC till the time of testing. Testing included compressive strength; porosity and density were conducted at 3, 7 and 28 days. The determination of compressive strength was according to ASTM C170-90, American standard test method [20], the values reported in the results are the average of three specimens and the variation of the results was +5%. The porosity and density were described in equations 1 and 2.

The density of the mortar was calculated from equation 1:

Density (g/cm^3) = $W_1/(W_1-W_2)\times 100$ (Eq. 1)

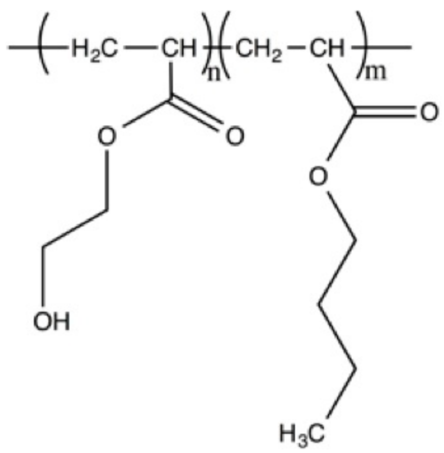
Whereas the apparent porosity was detected by equation 2:

Apparent porosity, % = $(W_1-W_3)/(W_1-W_2) \times 100$ (Eq. 2)

Where W_1, W_2 and W_3 are the saturated, suspended and dry weight, respectively. Further details about the compressive strength, density and porosity are given elsewhere [21, 22]

RESULTS AND DISCUSSION

The structure of the copolymer latexes P[2-HEA-co-BuA] is shown in Scheme 1 and further details about the synthesis and characterization have been previously reported by the authors [11].



Scheme 1. The chemical structure of copolymer latexes [11].

Water of consistency and setting time

Figures 1 and 2 show the effect of the copolymer latexes with different composition ratios of 2-HEA and BuA on water/cement ratio of mortar mixes required to maintain the same consistency and the setting time, respectively. Figure 1 shows that the required quantity of water decreases with the addition of copolymer latexes in M1 and M2 compared to M0. However, the water demand increases for mix M3. It has been reported that polymer exhibits a good dispersing effect in mortar, and can reduce water demand by up to 20% [23]. However, the water/cement ratio of mortar premixed with latexes decreases with increasing the ratio of 2-HEA in the latexes, which agrees with other studies on the similar system by authors [9-11]. Water/cement ratio of mortars with the addition of chemical admixture depends on various parameters including chemical composition and the molecular structure of the admixture [7, 10, 11]. From result of Figure 1, it is found that water/cement ratio of mortar is depending on the composition ratios of 2-HEA and BuA in latexes.

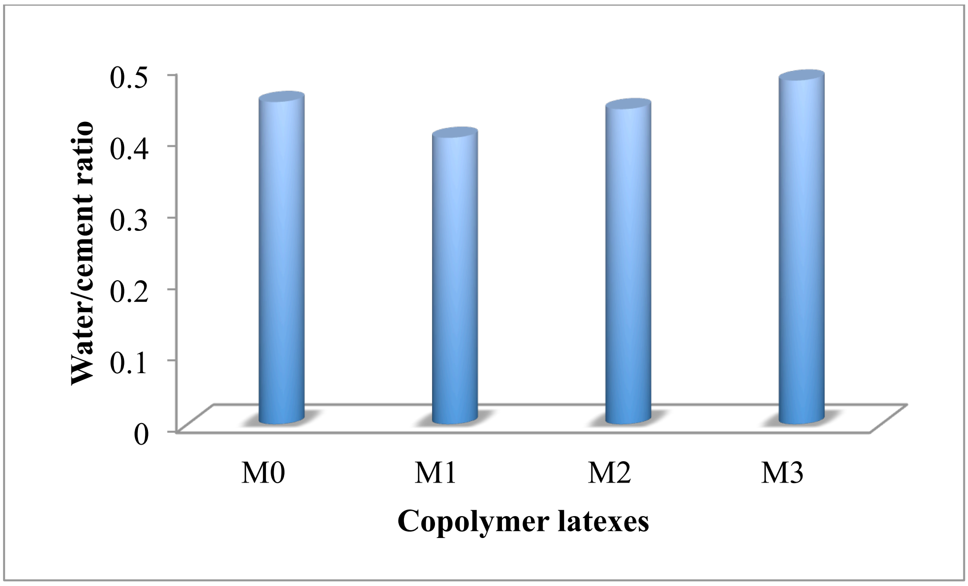


Figure 1. The effect of copolymer latexes on the water/cement ratio of mortar.

The initial and final setting times of mortar mixes with latexes (M1-M3) were longer than reference mortar (M0) without latexes as shown in Figure 2. However, as the ratio of the 2-HEA in latexes decreases, setting times lengthen. The delay of setting is thought to relate to the hydroxyl groups in the aqueous phase. In contrast with what is generally reported in the literature [9-11, 24], as the ratio of acrylic acid in the latexes decreased, the setting times shorten due to the carboxyl group in the aqueous phase. On the other hand, the initial and final setting times of mortar containing latexes increased with increasing W/C ratio as shown in the Figure 2. With increasing water content, the cement concentration in mortar decreases, causing a decrease in the volume of the hydration product, and a longer setting time. This is likely to be due to the polymer interaction with cement particles and hydration products as long as the change in microstructure of crystals cause by polymer [24-26].

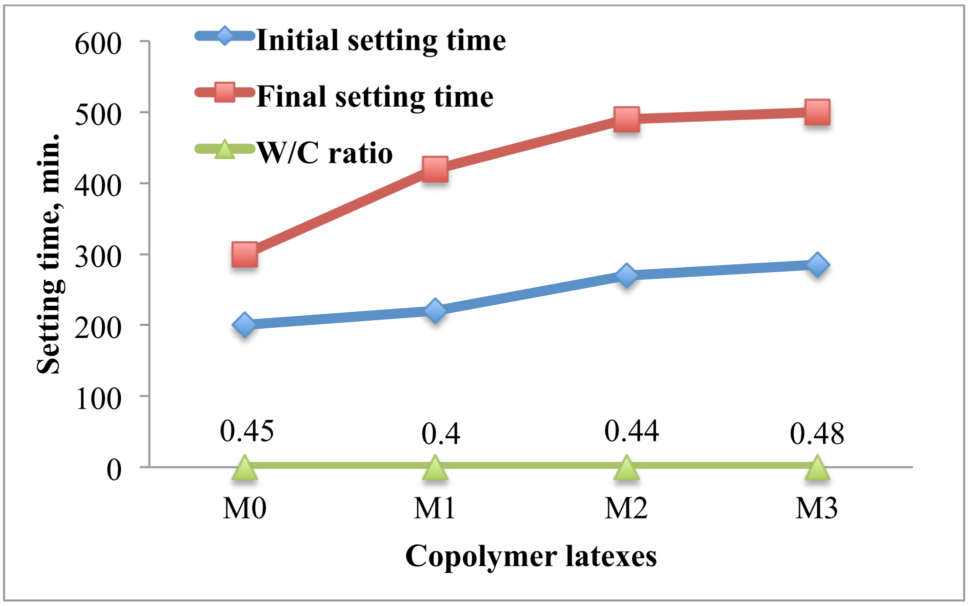


Figure 2. The effect of copolymer latexes on the setting time of mortar.

Flow table

It is well known that the chemical admixtures have effective dispersing properties on the cement particles and improve the flow of mortar. Figure 3 shows the influence of composition ratios of monomers in latexes on the fluidity of the mortar mixes. The results clearly showed that an increase in flow of mortar with the addition of copolymer latexes to the mortar mixes. Because of ball bearing action and dispersing effect of polymer particles among cement particles, there is afluidity increase in the mortar mixture [27, 28]. It has been reported that, the dispersing effect of polymer is generally dependent on the composition, type, and functional groups of monomers in latexes [29, 30]. The results showed that by increasing 2-HEA ratio to 99%, the flow of mortar increases up to 165 mm, and then the flow of mortar decreases to 151 mm with decreasing 2-HEA ratio to 95% in latexes but still higher than the control mixture (M0) without latexes. Moreover it is reported that the factors that affect the workability of mortar include quantity and characteristics of cement, gradation, shape of aggregates, admixture, W/C ratio and other additives [31, 10]. As shown in Figure 3, the workability of mortar mixes increases with decreasing W/C ratio in the mortar premixed with copolymer latexes. However, the increase is relatively more in case of M1 with lower W/C ratio (0.4). At lower w/c ratio, a slight fluctuation of water content in concrete can cause large variations of the fluidity.

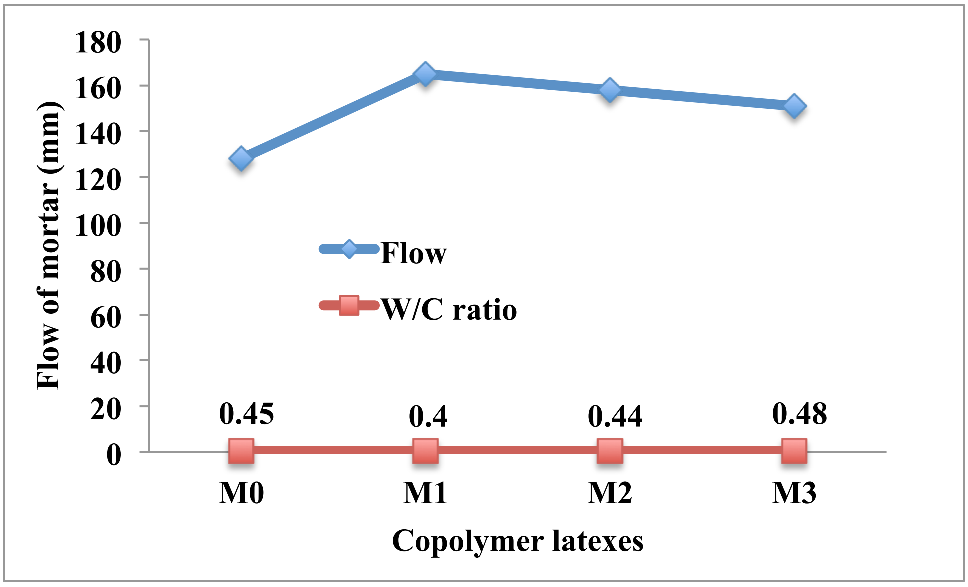


Figure 3. The effect of copolymer latexes on the flow of mortar.

Density

Figure 4 shows the moist density of mortar premixed with copolymer latexes in comparison with density of mortar reference (M0). The density gradually increased with curing time. That was attributed to the continual deposition of the formed hydration products that fill the pore of the hardened cement pastes [29, 32]. Moreover, the density of mortar decreased with the addition of copolymer latexes. Generally the density of mortar decreases when polymer latex is added to the mortar, which maybe due to the lower density of latex with regard to mortar density. However, the density decreased with increasing the ratio of 2-HEA in the copolymer latexes. The same behavior was reported by Negim *et al*. [11] when they studied properties of cement pastes with additions of poly(acrylate) latexes.

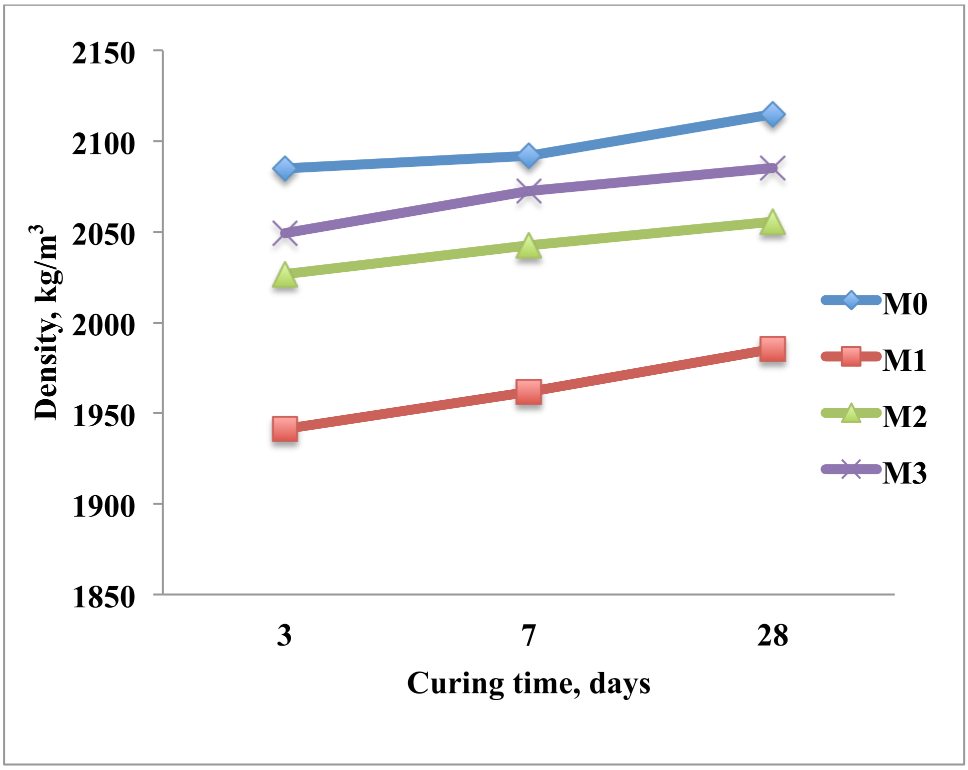


Figure 4. The effect of copolymer latexes on density of mortar

Total porosity and compressive strength

The total porosity and compressive strength of the mortar (M_0) and those premixed with copolymer latexes (M_1-M_3) are graphically represented as a function of curing time up to 28 days in Figures 5 and 6 respectively. Generally, the total porosity of the various mortars decreased with curing time up to 28 days (Figure 5), while the compressive strength increased (Figure 6). This is mainly due to the continual formation of hydration products, which tend to deposit into the pore structure of the mortar. This leads to about 39% decrease in total porosity [33]. As shown in Figure 5, the incorporation of copolymer latexes decreases the porosity properties of mortar. However, porosity of mortar decreases with increasing the ratio of 2-HEA in the copolymer latexes. The decrease in porosity of mortar can be attributed to the formation of polymer films which intertwined to form a space network structure and filling up the pores of the mortar.

Figure 6 shows the effect of copolymer latexes on the compressive strength of mortar. The addition of the latexes to the mortar mixes increased the compressive strength due to the plasticizing effect of latexes; however as the ratio of 2-HEA increased, the obtained compressive strength increased.

As shown from Figs. 5 and 6, mortars with highest strength (M1) are the one with lowest porosity (M1), in contrast with another authors [32]. Consequently, the total porosity decreased and accordingly the compressive strength increased [26].

The relationship between compressive strength of mortar mixes and glass transition temperature (T_g) of the copolymer latexes at 28 days of curing is shown in Figure 7. It is seen that, the compressive strength increased with increasing T_g of the latexes. For example, adding the latexes to mortar mixes resulted in an increase of the compressive strength from 37 MPa for M3 (T_g, -19.59 ºC) to 45 MPa for M1 (T_g, -13.01 ºC). In general, the higher the T_g, the harder the polymer and the higher the compressive strength of the mortar [34, 35].

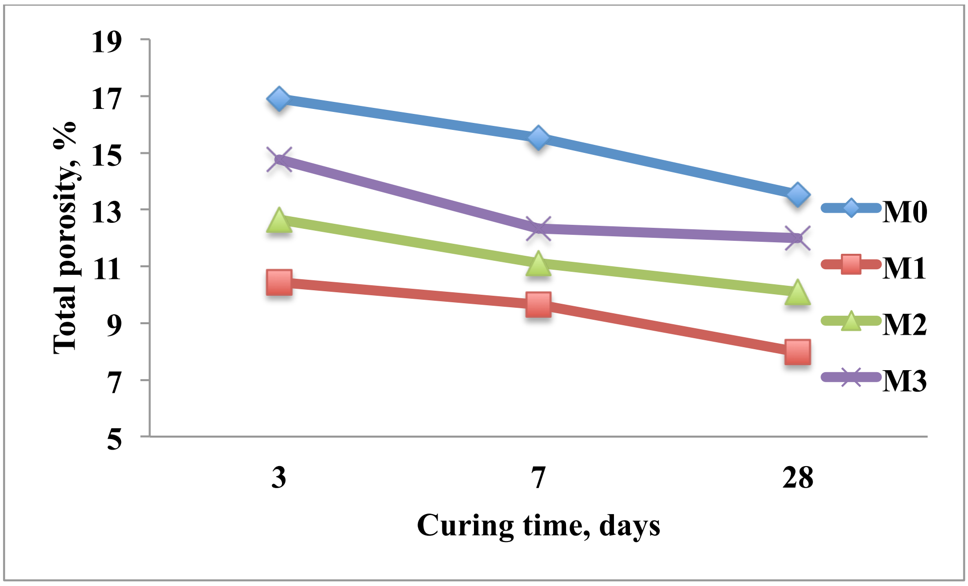


Figure 5. The effect of copolymer latexes on the porosity of mortar.

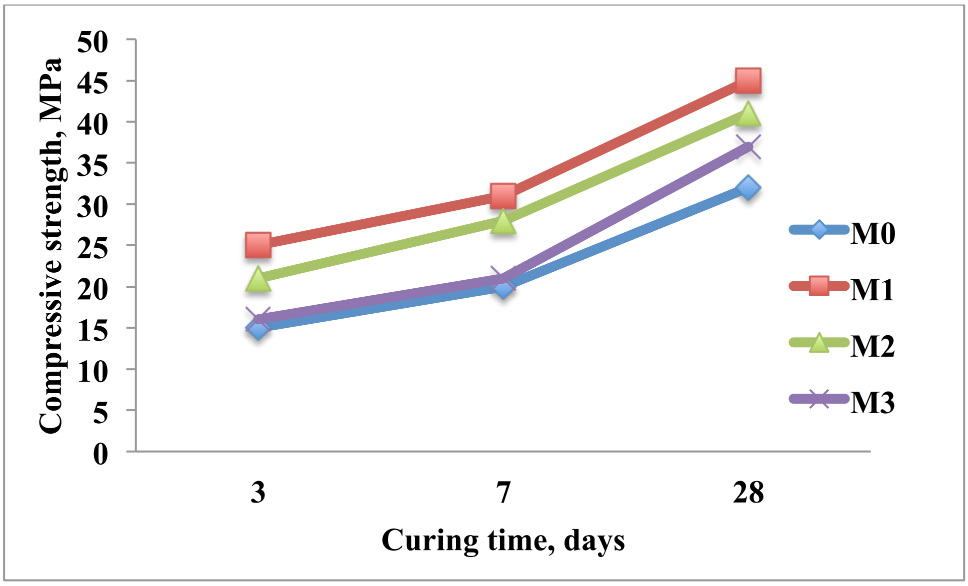


Figure 6. The effect of copolymer latexes on compressive strength of mortar

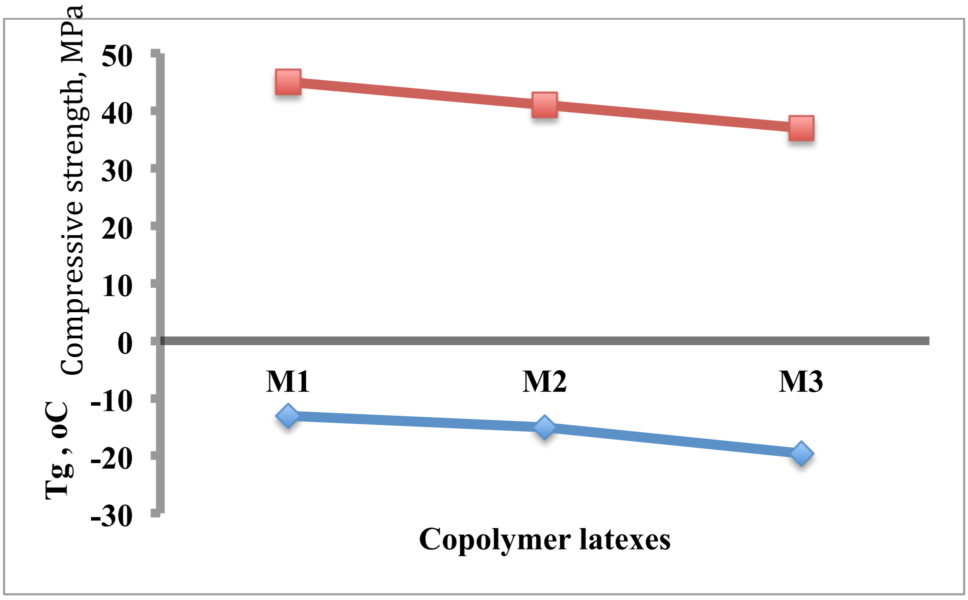


Figure 7. Relationship between compressive strength of mortar and *Tg* of copolymer latexes.

CONCLUSIONS

1. Mixing of mortar with water that is premixed with copolymer latexes based on 2-HEA and BuA evidently improves most of the physico-mechanical properties of mortar mixes.
2. The W/C ratio decreases, i.e. the copolymer latex act as a water reducing agent when mixed with mortar. This is associated with longer initial and final setting times, lower porosity as well as higher strength.
3. Flow of mortar mixed with copolymer latexes is higher than that of reference mortar (M0), due to the ball bearing action and dispersing effect of polymer particles among cement particle.
4. T_g of the copolymer latexes played an important role in the specific characteristics of the mortar.

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