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IMPROVED STRENGTH, ELASTIC AND ADHESION PROPERTIES OF MORTARS MODIFIED WITH DIFFERENT POLYMER-CEMENT RATIOS & EFFECTS OF REDUCTION IN $Ca(OH)_2$ ON THE PROPERTIES

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ABSTRACT

Polymer-modified mortars (PMMs) are prepared by using dispersible polymer powders or powdered emulsion (powered cement modifiers) and aqueous polymer dispersion (aqueous cement modifiers) with various polymer-cement (P/C) ratios. Specimens are made with the help of moulds and cured. Different tests like compressive strength, flexural strength, tensile strength, maximum deflection, maximum extreme tensile fibre strain, maximum tensile strain and adhesion in tension or bond strength are performed for the cured specimens. Afterward, powder samples are made from the broken specimens, which are then subjected to X-ray diffraction, differential thermal analysis (DTA) and thermal gravimetric analysis (TGA). From the test results, it is concluded that the formation of calcium hydroxide ($Ca(OH)_2$) is reduced in (PMMs). Whereas, on the other hand, their compressive strength, flexural strength, tensile strength, maximum deflection, maximum extreme tensile fibre strain, maximum tensile strain and adhesion in tension or bond strength have been improved. However, variation in the above-mentioned properties depend upon the P/C ratio and cement modifier used or both. It has been concluded that the reduction of $Ca(OH)_2$ content in PMMs does not cause any detrimental or adverse effect on their strength, elastic and adhesion properties, they are improved.

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1. INTRODUCTION

Calcium hydroxide, $Ca(OH)_2$ or Portlandite is one of the phases of hydrated Portland cement systems were representing a significant volume of the hydration products formed from cement — water reaction (Mindess and Young, 1981., Beaudoin, 2001). $Ca(OH)_2$ occupies about 20 to 25 % of the paste volume in the ordinary Portland cement concrete (Mindess and Young, 1981; Mindess, 2001; Sornchomkaew et al. 2018). Despite the fact that $Ca(OH)_2$ is a phase of hydrated Portland

cement systems, lesser attention has been paid in understanding the role of this constituent (Skalny et al., 2001). Most of the engineering properties of concrete are closely associated with the presence of $\text{Ca}(\text{OH})_2$ in hydrated concrete (Sklany et al., 2001). The speculative advantage for the presence of $\text{Ca}(\text{OH})_2$ is its capability to protect calcium-silicate-hydrate (C-S-H) gel (Gebaur, 2001). Studies tell that only lime-rich cement render sufficiently high early strength of concrete—the most demanded property of present-day concrete. The excessive presence or absence of $\text{Ca}(\text{OH})_2$ in the system may change the path of the involved reactions. $\text{Ca}(\text{OH})_2$ was also considered to affect the physico-mechanical properties of hydrated cementitious systems to a considerable extent being one of the major phases (Ramachandran, 1979). In the system $\text{CaO-SiO}_2\text{-H}_2\text{O}$, the calcium to silicon (C/S) ratio of the C—S—H varies between 0.83-2.0 (Brown and Clark, 2001). The C—S—H gel in the composition range Ca/Si 1.5 to 2.0 is labile and can liberate $\text{Ca}(\text{OH})_2$ in a range of situations. Thus C—S—H gel in the high lime range becomes increasingly unstable and readily contributes $\text{Ca}(\text{OH})_2$ to other more acidic reactants or will spontaneously evolve $\text{Ca}(\text{OH})_2$ upon prolonged gentle heating (40°C or more) within a few months. Thus the potential of cement could be viewed as consisting of two sources: one is measured by actual free $\text{Ca}(\text{OH})_2$ content occurring as physically discrete crystallites while another source is $\text{Ca}(\text{OH})_2$ furnished by labile, high-ratio C-S-H gel (Glasser, 2001). $\text{Ca}(\text{OH})_2$ grew epitaxially on mineral aggregates in cementitious systems (Struble et al. 1980) and C—axis of $\text{Ca}(\text{OH})_2$ was found preferentially to the interface (Barnes et al. 1979). The zone of orientation may extend to as much as 50µm into the paste (Grandet and Olliver, 1980). While this might enable the cleavage to act as strength reducing factor, also the poor crystallite packing in the process zone will itself be a strength reducing flaw. Exceptionally large $\text{Ca}(\text{OH})_2$ crystals in mortar specimens ranging in age from 7 days to 85 years were associated with the regions of low paste density (Scrivener and Pratt, 1986). In concretes, $\text{Ca}(\text{OH})_2$ and C—S—H are not distributed homogeneously throughout the paste. $\text{Ca}(\text{OH})_2$ forms preferentially in association with aggregates. Implications of this distribution are (i) $\text{Ca}(\text{OH})_2$ does not play a significant role in influencing the hydration kinetics by acting as a physical barrier, (ii) $\text{Ca}(\text{OH})_2$ is important in affecting the properties which rely on the transfer of stress from paste to aggregates. Because of its relatively large amounts and dissemination in the paste, it was proposed that $\text{Ca}(\text{OH})_2$ may be considered even in a first approximation model for the material (Diamond, 1976).

The above background sufficiently indicates that there is a lack of understanding in establishing the role of $\text{Ca}(\text{OH})_2$ in hydrated Portland cementitious systems. Hence, there is a further need to clarify the role of $\text{Ca}(\text{OH})_2$ in hydrated Portland cement-based systems. Further, there is a lacking in understanding the role of $\text{Ca}(\text{OH})_2$ in hydrated Portland cement-based systems modified by or containing chemical admixtures or additives. The usage of polymer-modified cement systems (PMCS) has now tremendously increased for various architectural and civil engineering applications. However, the role of $\text{Ca}(\text{OH})_2$ in affecting the mechanical and durability properties of PMCS is still not clear. Some of the contributions made in this regard are those of (Afridi et al, 1989, 1990, 1992, 1993, 2001; Diamond, 2001; Su et al, 1991; Beeldens et al, 2004; Ohama, 1995; Heins, 1972; Gebauer, and Coughlin, 1971; Cook et al 1976 and Mikhail et al, 1983; Ben-dor et al; 1985 Barker, 1984). In this research the effect of $\text{Ca}(\text{OH})_2$ (produced in various PMMs) on their compressive strength, flexural strength, tensile strength, maximum deflection, maximum extreme tensile fibre strain, maximum tensile strain, adhesion in tension or bond strength.

2. MATERIALS AND METHOD

2.1 MATERIALS

2.1.1 CEMENT AND FINE AGGREGATES

Ordinary Portland cement and Toyoura standards sand as specified in JIS (Japanese Industrial Standard) were used in all mixes. The chemical compositions and physical properties of the cement are listed in Table 1.

2.1.2 POWDERED AND AQUEOUS CEMENT MODIFIERS

Commercially available, two powdered and two aqueous cement modifiers were used. The powdered cement modifiers used included one brand of poly (vinyl acetate-vinyl carboxylate) (VA/VeoVa) type and one brand of poly (ethylene-vinyl acetate), (EVA) type. The aqueous cement modifiers used were one brand of EVA emulsion and one brand of styrene-butadiene rubber (SBR) latex type. Their typical properties are given in Table 2. Before mixing, a silicone emulsion type anti-foamer containing 30% silicone solids was added to the cement modifiers in a ratio of 0.7% of the silicone solids in the anti-foamer to the total solids in the powdered and aqueous cement modifiers.

2.2 PREPARATION OF MORTARS

The PMMs were mixed according to JIS A 1171 (Method of Making Test Sample of Polymer-Modified Mortar in Laboratory) as follows: cement: standard sand = 1:3 (by weight), polymer-cement ratios, P/C (calculated on the basis of total solids in powdered and aqueous cement modifiers) of 0, 5, 10, and 20% and their flows were adjusted to be constant at 170 ± 5 . The mix proportions of polymer-modified mortars are given in Table 3.

3. TESTING PROCEDURE

3.1 FLEXURAL AND COMPRESSIVE STRENGTH TESTS

Beam type cured mortar specimens measuring 40x40x160 mm were tested for flexural and compressive strengths according to **JIS A 1172** (Method of Test for Strength of Polymer-Modified Mortar). Details can be seen elsewhere (Afridi 1992, Afridi et al. 1994).

3.2 TENSILE STRENGTH TESTS

Cured briquet type mortar specimens were tested for tensile strength according to ASTM C 190 (Standard Test Method for Tensile Strength of Hydraulic Cement Mortar). Details can be seen elsewhere, (Afridi 1992, Afridi et al. 1994).

3.3 DEFLECTION AND EXTREME TENSILE FIBER STRAIN MEASUREMENTS

Deflection and Extreme Tensile Fiber Strain Measurements were made during the above mentioned flexural strength test. The details are mentioned elsewhere, (Afridi 1992, Afridi et al. 1994).

3.4 TENSILE STRAIN

During the tensile strength test as mentioned above, a tensile strain was also measured. The details are elsewhere (Afridi 1992, Afridi et al. 1994). Samples for powder X-ray diffraction and thermal analysis. The broken pieces of specimens, after the compressive strength test, were crushed

and samples were taken from them. The samples were firstly dried in a vacuum for sufficient time to remove evaporable water. Fine powders were made by using a mortar and pestle before subjecting them to powder X-ray diffraction and thermal analyses.

3.5 POWDER X-RAY DIFFRACTION

X-ray diffraction patterns were recorded on the RIGAKU X-ray diffraction meter for the qualitative determination of $\text{Ca}(\text{OH})_2$. The details are mentioned in Afridi et al. (1989) and Afridi (1992).

3.6 THERMAL ANALYSIS

Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were carried out for the quantitative determination of $\text{Ca}(\text{OH})_2$ using the RIGAKU thermal analyzer containing TGA accessory. The details are mentioned in Afridi et al. (1989) and Afridi (1992).

Table 1A : Cement Chemical Composition (%)

Ig.loss	Insol.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Total
1.0	0.1	22.0	5.2	3.2	65.0	1.4	1.8	99.7

Table 1B: Cement Physical Properties

Specific gravity (20°C)	Fineness		Setting Time (h- min)		Flexural Strength of Mortar (kgf/cm ²)			Compressive Strength of Mortar (kgf/cm ²)		
	Residue on the sieve of 88µm (%)	Blaine Specific surface area (cm ² /g)	Initial set	Final set	3 days	7 days	28 days	3 days	7 days	28 days
3.16	1.4	3250	2-31	3-32	334	50	73	150	251	417

Table 2: Typical Properties of Cement Modifiers (Stabilizer Type: Anionic)

Type of Cement Modifier	Appearance	Gravity (20°C)	pH (20°)	Viscosity (20°C, c P)	Total Solids
Powdered VA /Veova emulsion	Milky-white powder without coarse particles	1.100	-	-	-
Powdered EVA — 1 emulsion		1.180	-	-	-
EVA emulsion	Milky-white aqueous dispersion	1.056	5.2	1600	44.4
SBR latex		1.019	8.5	155	45.8

Table 3: Mix Proportions of Polymer Modified Mortars (cement-sand ratio (by weight) = 1:3)

Type of Mortar	Polymer-Cement Ratio (%)	Water-Cement Ratio (%)	Flow
Unmodified	0	77.5	165
	5	72.2	172
	10	75.5	172
Powdered	20	75.0	168
	5	73.8	170
	10	75.2	173
VA / Veova-	20	73.8	172
	5	72.5	170
	10	66.8	167
Modified	20	59.8	168
	5	74.2	172
	10	70.6	168
Powdered	20	57.7	168

4. TEST RESULTS AND DISCUSSION

Figures 1-7 show relationships between weight loss or quantity formed of $\text{Ca}(\text{OH})_2$ in various

PMMs (using both powdered and aqueous cement modifiers) and their compressive strength, flexural strength, tensile strength, maximum deflection, maximum extreme tensile fibre strain, maximum tensile strain and adhesion in tension or bond strength. It is clearly seen from the test results that the addition of cement modifiers (both powdered and aqueous) reduces the formation of Ca(OH)_2 in PMMs possibly due to absorption of Ca(OH)_2 on polymer films (Afridi et al. 1989) or due to a reduction in unit cement content or both. However, the extent of reduction of Ca(OH)_2 in all PMMs depends upon the type of cement modifier used, P/C ratio or both (Afridi et al. 1989, Ohama, 1995). Whereas, on the other hand, this reduction in Ca(OH)_2 content does not produce any detrimental or adverse effect on all of the above-mentioned strength, elastic and adhesion properties of PMMs. Generally, all of the above-mentioned strength, elastic and adhesion properties markedly improve with the addition of polymers or cement modifiers. However, the extent to which these properties improve depends upon the type of polymer or cement modifier used or both. Such properties of PMMs are improved because of their modified structure. Such a monolithic structure of PMMs has reduced porosity, improved bond/adhesion between aggregates and matrix and an additional binder in the form of reinforcing polymeric network or polymer films that supports and improves the performance of C-S-H gel matrix of the system involved (Afridi et al. 1994).

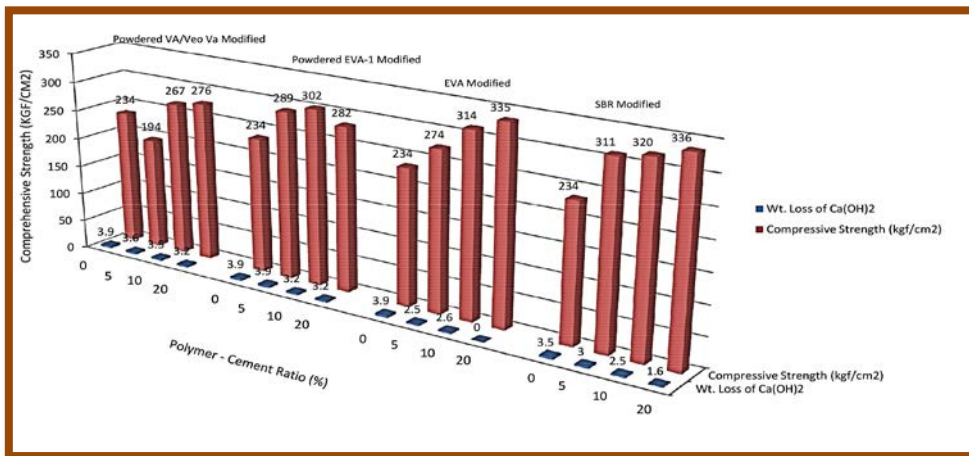


Figure 1: A Relationship Between Weight (Wt.) Loss or Quantity Formed of Ca(OH)_2 and Compressive Strength of Various Polymer-Modified Mortars.

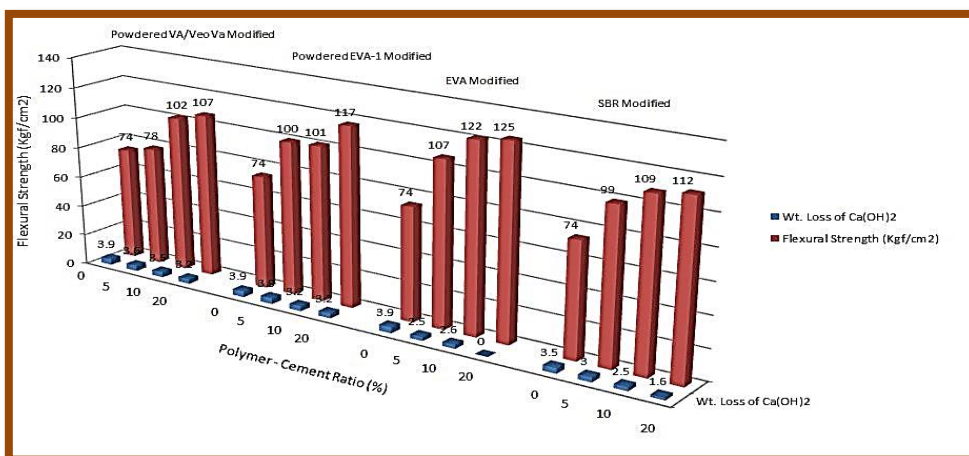


Figure 2: A Relationship between Weight (Wt.) Loss or Quantity Formed of Ca(OH)_2 and Flexural Strength of Various Polymer-Modified Mortars.

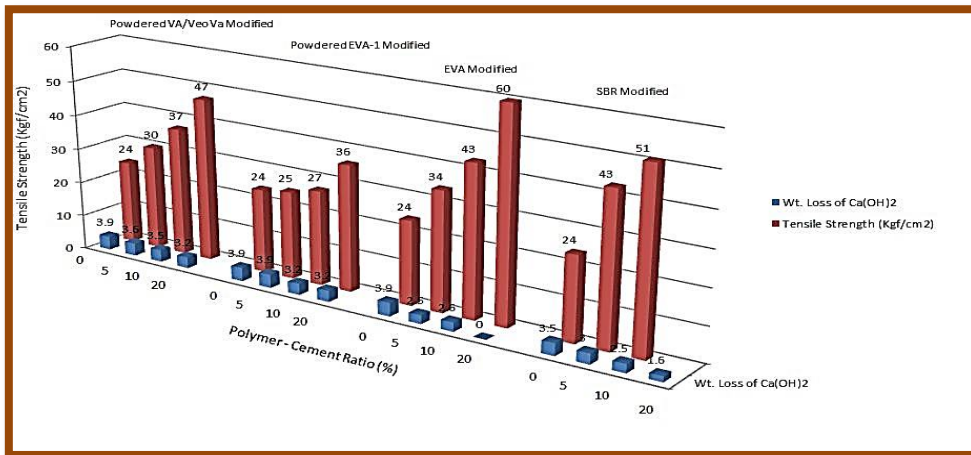


Figure 3: A Relationship Between Weight (Wt.) Loss or Quantity Formed of Ca(OH)₂ and Tensile Strength of Various Polymer-Modified Mortars.

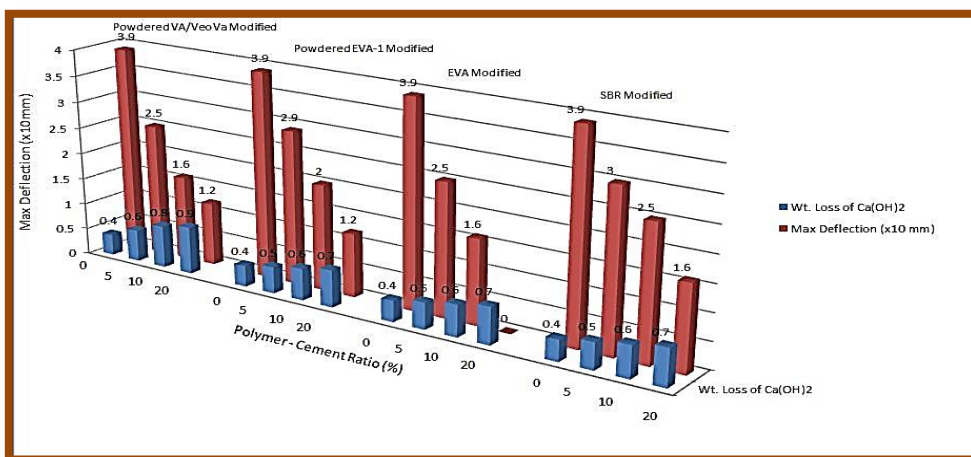


Figure 4: A Relationship between Weight (Wt.) Loss or Quantity Formed of Ca(OH)₂ and Maximum Deflection of Various Polymer-Modified Mortars.

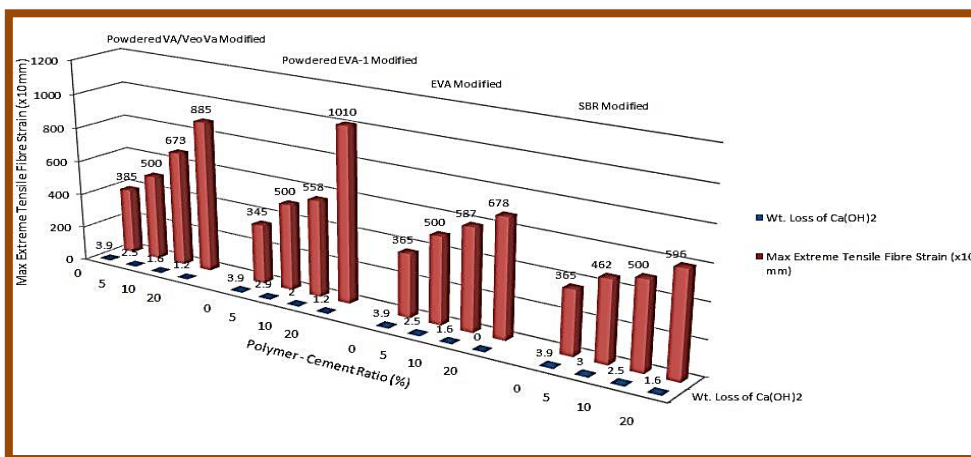


Figure 5: A Relationship between Weight loss (Wt.) or Quantity Formed of Ca(OH)₂ and Maximum Tensile Fibre Strain of Various Polymer-Modified Mortars

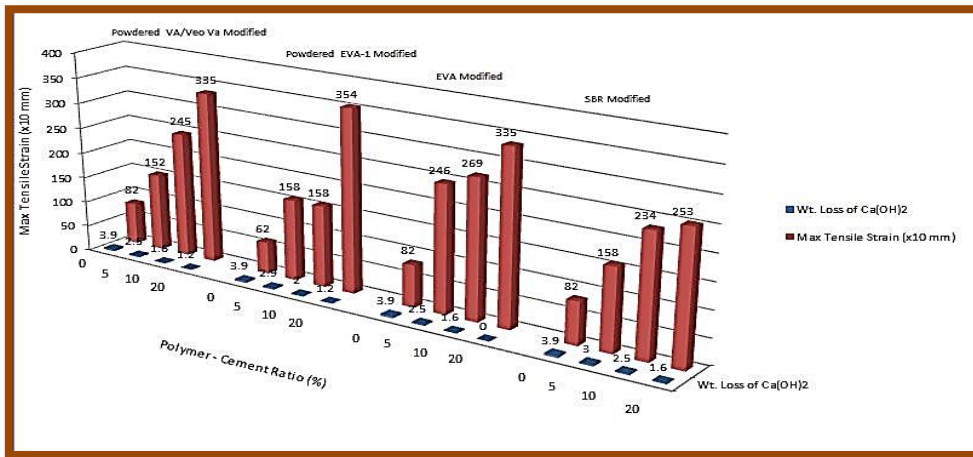


Figure 6: A Relationship between Weight Loss (Wt.) or Quantity Formed of Ca(OH)_2 and Maximum Tensile Strain of Various Polymer-Modified Mortars.

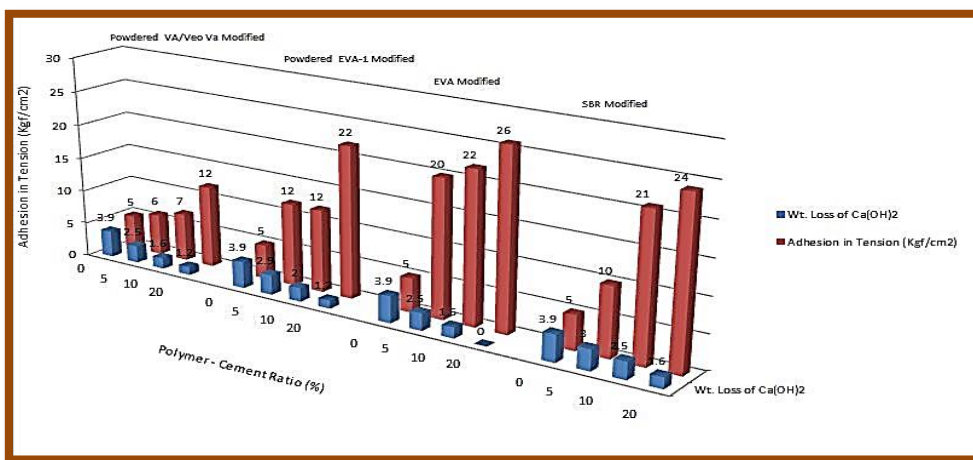


Figure 7: A Relationship between Weight (Wt.) or Quantity Formed of Loss and Ca(OH)_2 and Adhesion in Tension of Various Polymer-Modified Mortars.

5. CONCLUSION

The addition of polymers or cement modifiers to mortars (both powdered and aqueous) reduces the formation of Ca(OH)_2 in polymer-modified mortars. However, the extent to which reduction of Ca(OH)_2 takes place, depends upon the P/C ratio, the type of polymer or cement modifier used or both.

The addition of polymers or cement modifiers to mortars improves their mechanical properties like compressive strength, flexural strength, tensile strength, maximum deflection, maximum tensile fibre strain, maximum tensile and adhesion in tension or bond strength. However, the extent to which these properties improve depends upon the P/C ratio, type of polymer or cement modifier used or both.

The reduction in Ca(OH)_2 content does not produce any detrimental or adverse effect on strength, elastic and adhesion properties of PMMs; rather they are improved.

6. AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding authors

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