The Effects of Cure Conditions on Mechanical Properties of Polymer Modified Cement Mortars

A. Çavdar, S. Sevin, Y. Kaya and Ş. Bingöl

***Abstract*-The uses of polymers for various structural applications are gaining popularity throughout the World. In this study, three different types of polymers are added to cement mortars, and then these mortars are cured under three different cure conditions. Thus, it is aimed to investigate their mechanical contributions to mortars and to determine the most suitable cure condition for polymer modified concrete, comparatively. SBR, PSBR, MAD polymers are chosen as polymers. These polymers are added into the mortars in five different ratios (0.0%, 5%, 10%, 15%, 20%) by volume and the mortars are cured under three different conditions that watering twice a day (FCC), 16 hours in the water - 8 hours out (SCC), one day in the water - one day out (TCC). The mortars modified with MAD polymer show the best performance for chosen polymer addition ratios and also FCC is the most suitable cure condition.**

Index Terms—**SBR, PMC, compressive strength, flexural strength, deflection.**

I. INTRODUCTION

CONCRETE is a material that is strong against compressive loads, however, weak under flexural and tensile loads. Because of these weak properties, cracks seen at concrete elements are usual. One another phenomenon causing cracking for concrete is shrinkage.[1,2] A polymer is a large molecule composed of many repeated subunits, known as monomers. Polymers without chemical activity have compressive and tensile strengths higher than normal concrete. However, the elasticity modulus is lower and creep deformation is higher. Therefore, tensile streght of concrete is weak and that can improve with use polymeric material. For this objective, polymer concrete is identified in three groups [3- 6].

- Polymer Concrete: Only polymer is used as a binder.
- Polymer Modified Concrete: A polymer emulsion is used instead of a part of the mix water.
- Polymer Impregnated Concrete: A polymer is impregnated to cavities of hardened concrete.

While polymer concrete and polymer modified concrete was known in the 1950s, polymer impregnated concrete has been used in the 1970s. Therefore, use of polymers in concrete has gained widespread. [7,8]. While very high compressive strengths concrete (140 MPa) is gained only in a few hours in polymer concrete, polymer modified concretes are known with provide excellent adhesion properties to the old. Polymer impregnated concrete generates high-strength concrete with superior impermeability[3]. Polymer impregnated concrete and polymer concrete is used less due to high material costs and technological challenges, but polymer-modified concrete is used commonly. Compared to normal concrete, polymer modified concrete is 2-3 times more costly, polymer impregnated concrete is 3-6 times more costly and polymer concrete is 8-20 times more costly [9].

Polymer-modified cementitious mixtures (PMC) have been called by various names, such as polymer portland cement concrete (PPCC) and latex-modified concrete (LMC). PMC is defined as hydraulic cement combined at the time of mixing with organic polymers that are dispersed or redispersed in water, with or without aggregates.

The majority of PMC placed today uses a polymer in latex form. Latex has been defined as a dispersion of organic polymer particles in water [10]. The average particle size varies from 100 to 2000 nanometers. Most latexes are made by a process known as emulsion polymerization, where the polymer is formed directly in water.[11]

A wide variety of polymer types have been investigated for use in PMC [12], but the major types in use today are as follows:

- Styrene-butadiene copolymers (S-B).
- Acrylic ester homopolymers (PAE) and copolymers,
- Particularly with styrene (S-A).
- Vinyl acetate copolymers (VAC).
- Vinyl acetate homopolymers (PVAC).

Selection of the type of polymer depends on the service life requirements and cost. It should be noted that PVACs should not be used where the PMC will be exposed to moist conditions.[13]

The main objective of this study is investigation of the effects of different types of polymers on mechanical properties of cement mortars. For this purpose thirteen different types of cement mortars are produced with three types of polymers and five types of addition ratios. Stiren Butadien Rubber (SBR), Polycarboxylate modified Stiren

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Butadien Rubber (PSBR), Modified Acrylic Dispersion (MAD) polymers are chosen as polymers and these are added to mortars five different ratio (0%, 5%, 10%, 15% and 20%) by volume and the polymer modified mortars are cured under three different conditions watering twice a day(First Cure Condition (FCC)),16 hours in the water - 8 hours out(Second Cure Condition (SCC)) and one day in the water - one day out(Third Cure Condition (TCC)) The physical properties and flexural strengths, deflections and compressive strengths of the cement mortars are investigated.

It is worked with cement mortar instead of concrete. Since cement mortars more homogeneous than concrete, determining differences of polymers from each other will become easier. In other words, polymers effects on mortar are brought up clearly.

The essential cases separating this study from the others are;

- Uncommon polymers like PSBR and MAD are also used in this study.
- The tests are realized under three conditions FCC, SCC and TCC. Thus, the performance of polymers in wet and dry conditions will be introduced separately.

II. MATERIALS AND METHODS

A. Material

Three different types of polymer are used in the experimental process. These are SBR, MAD and PSBR polymers. Some properties of these fibers presented in (Table 1).

TABLE I
THE PROPERTIES OF THE POLYMER USED IN THE EXPERIMENTS

Material	SBR	MAD	PSBR
Specific Mass (kg/l)	1,005-1,025	1,08	1,01-1,04
pH Value	8-12	7-10	6
Colour	White	White	Light Bluish
Alkali Resistance	High	High	High

It is seen from Table 1, specific mass of the polymers are changed between 1.01-1,08 g/cm^3,pH values are changed between 6-12. The strongest properties of SBR are high alkali resistance.

In the experiments, CEM I 42.5 R type cement is used. The compositions, physical and mechanical properties of the cement are given in (Table 2). The experiments are conducted according to EN 196, so CEN-standard sand is used as aggregate in mortars.

B. Methods

In accordance with the objective of the study, thirteen different polymer modified cement mortars are prepared with three different polymer types and five different proportions (Table 2).

The flexural and compression tests were conducted according to the suggested principles in EN 196. The “test mortar” consists of 450 g of the cement mixture, 1350 g of graded standard sand, and 225 g of water, and consequently the water/cement ratio is 0.50.

TABLE II
MIX DESIGN OF THIRTEEN DIFFERENT FIBER REINFORCED MORTARS

Fiber ratio by volume	Cement (g)	Sand (g)	SBR, PSBR and MAD (g)	Water (g)	W/C
0%	450	1350	0	225	0,5
5%	450	1350	22,5	213,75	0,475
10%	450	1350	45	202,5	0,45
15%	450	1350	67,5	191,25	0,425
20%	450	1350	90	180	0,4

While polymer modified mortar is being produced, water is reduced by half the amount of polymer. After the mixing water is added to the cement-sand mixture, the selected polymer is added to fresh mortar and the mortar is mixed as long as obtained homogeneous mixture. After the molding process, the molds (with the mortars in them) were placed in the moist room at 23±1°C for 24 h and removed at the end of this period, and the mortar prismatic specimens were cured under three different conditions until 28 days. These conditions are watering twice a day (First Cure Condition (FCC)), 16 hours in the water - 8 hours out (Second Cure Condition (SCC)), one day in the water - one day out (Third Cure Condition (TCC)),. The tests are realized on the specimens for every condition. Thus, it is investigated the best performance of polymers, ratios and cure conditions.

When the curing time is completed, flexural and compressive tests are realized. Six specimens were tested for each type of mixture at each testing age according to the Rilem-Cembureau method in EN 196. While the flexural strength are determining, deflections are measured. The deflection used in comparisons is maximum deformation of midpoint of beams at breaking instant.

III. RESULTS AND DISCUSSIONS

The mortars containing different type and different proportions of polymers are investigated according to mass properties, flexural strengths, deflections and compressive strength.

A. The Effects of Polymer Type and Content on Unit Mass of Mortars

When SBR polymer which specific mass (1.05 g/cm^3) is lower than mortar (2.1 g/cm^3) is added to mortar, it is expected that the mortar’s unit mass is decreases. It is seen from (Figure 1) and (Table 3) that PP fiber addition decreases unit mass of mortar. It is seen that MAD and PSBR presents similar results to SBR with 5% ration. The unit mass of mortar decreases down to roughly 1.80 g/cm^3 with the addition of 5% by volume of SBR, PSBR and MAD. All ratios of SBR and MAD similar behavior is observed. But, for PSBR with 5%, 10%, 15%, 20% constant decrease is observed. The biggest decline is observed with 29% for PSBR with 20% ration.

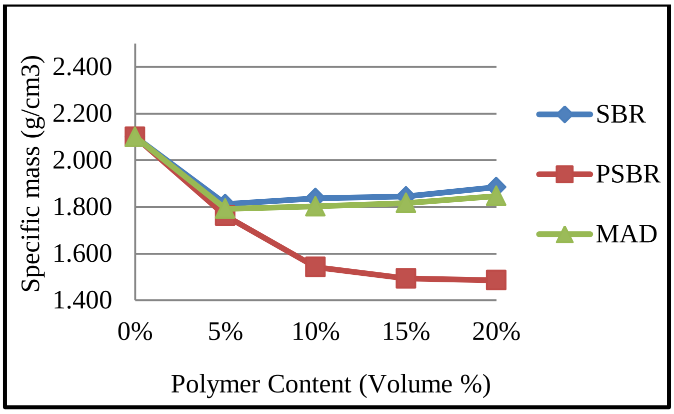

Fig. 1. *Relationship between polymer content and specific mass*

TABLE III
SPECIFIC MASS OF POLYMER MODIFIED MORTARS

	Dry Specific mass (g/cm3)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	2,100	2,100	2,100
5%	1,812	1,762	1,792
10%	1,837	1,542	1,802
15%	1,845	1,493	1,817
20%	1,885	1,486	1,847

B. The Effects of Polymer Type and Content on Flexural Strength of Mortars

Polymers are added into the mortars in five different ratios (0%, 5%, 10%, 15%, 20%) by volume and the polymer modified mortars are cured under three different conditions, watering twice a day (First Cure Condition (FCC)), , 16 hours in the water - 8 hours out(Second Cure Condition (SCC)) one day in the water - one day out(Third Cure Condition (TCC)). Flexural strengths of the cement mortars are investigated.

Flexural strengths of 0%ration specimens are investigated that average 6,42 N/mm^2 for FCC (Table 4). The results of experiments with %5, %10, 15% SBR addition, flexural strengths of mortars increase according to 0% addition. But, flexural strengths of mortars with SBR 20% decrease according to 0% addition. All ratios of PSBR and MAD similar behavior is observed. Both PSBR and MAD while the flexural strengths of mortars with 5% ratio decrease, with 10%, 15%, 20% ratios increase (Figure 2). MAD shows the highest strength with 20% ratio.

TABLE IV
FLEXURAL STRENGTH OF POLYMER REINFORCED MORTARS

	Flexural Strength (N/mm2)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	6,42	6,42	6,42
5%	7,48	4,57	5,09
10%	6,96	6,09	7,03
15%	7,97	5,88	7,01
20%	5,86	8,51	9,05

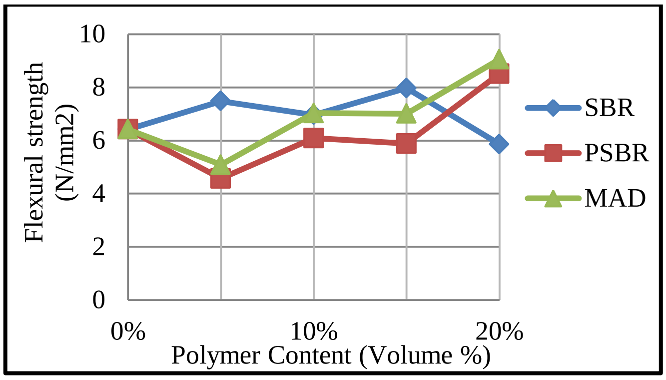

Fig. 2. *Relationship between polymer content and flexural strength in FCC*

Flexural strengths of 0%ration specimens are investigated that average 6,24 N/mm^2 for SCC. While the flexural strengths of mortars for SBR with 5% ratio increase, both MAD and PSBR decrease (Table 5). The flexural strengths of mortars for SBR with 10%, 15%, 20% ratios reduce, but for MAD with same ratios increase as well as PSBR cannot show fixed change (Figure 3). Flexural strengths of 0%ration specimens are investigated that average 6,24 N/mm^2 in TCC. The flexural strengths of mortars show similar behavior in SCC and TCC (Table 6 and Figure 4).

TABLE V
TABLE 5. FLEXURAL STRENGTH OF POLYMER MODIFIED MORTARS

	Flexural Strength (N/mm2)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	6,24	6,24	6,24
5%	7,03	3,84	3,18
10%	5,95	5,71	3,65
15%	5,84	5,03	4,19
20%	5,74	5,66	6,15

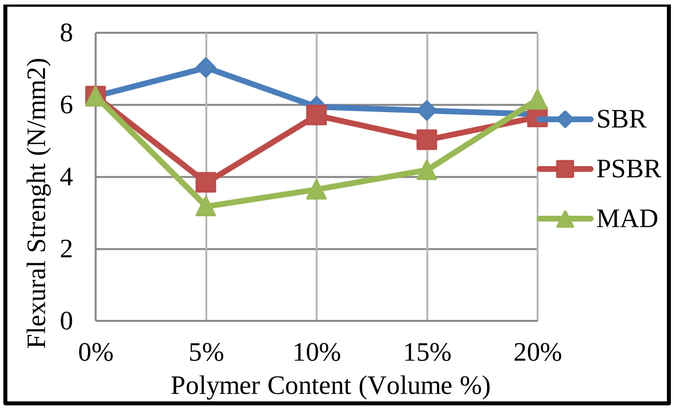

Fig. 3. Relationship between polymer content and flexural strength in SCC

TABLE VI
FLEXURAL STRENGTH OF POLYMER MODIFIED MORTARS

	Flexural Strength (N/mm2)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	6,75	6,75	6,75
5%	6,73	5,15	4,57
10%	6,77	7,49	5,78
15%	5,77	3,79	5,87
20%	4,99	5,19	7,18

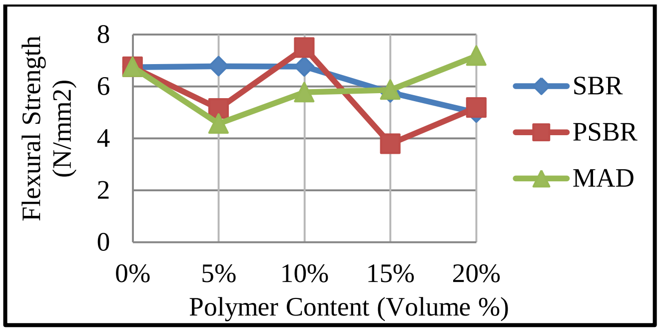

Fig. 4. *Relationship between polymer content and flexural strength in TCC*

FCC is the most suitable cure condition for flexural strength. PSBR and MAD provide increase (8,51 N/mm^2 – 9,05 N/mm^2) 24% and 29%, respectively. The biggest decline is observed with 49% for MAD in SCC.

C. The Effects of Polymer Type and Content on Deflections of Mortars

While flexural strengths are being tested, deflections of the beam samples are determined. One important reason of polymer addition to mortar is increasing ability of ductile behavior of mortars and so not to crack under small tensile stress. Thus, high level of deflection ability is desired.

TABLE VII
TABLE 7. DEFLECTION OF POLYMER MODIFIED MORTARS

	Deflection (mm)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	1,313	1,313	1,313
5%	1,207	0,780	1,291
10%	1,355	1,200	1,380
15%	1,531	1,232	1,536
20%	1,441	1,387	1,797

Both FCC and SCC especially the mortars contain SBR, PSBR and MAD present high level of deflection with 20% addition (Table 7, Figure 5). For the mortar has MAD, deflection increases as much as 36% in FCC. For PSBR mortar the deflections a bit less than the samples with reference specimen (0% ration) in SCC. The samples have SBR polymer is not influenced from increasing of polymer addition ratio, especially in SCC (Table 8, Figure 6). All polymer modified mortar present a diminish for all ratios in TCC. (Table 9, Figure 7). PSBR has the highest decrease 28% with 20% ration in TCC (from 1.782mm to 1.274mm). Direct relationship cannot setup between the deflections and flexural strength of mortars.

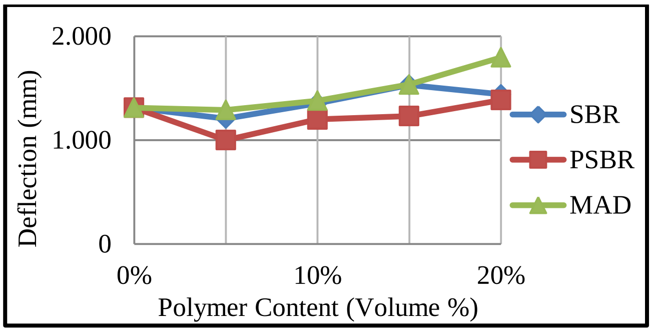

Fig. 5. Relationship between polymer content and deflection in FCC

TABLE VIII
DEFLECTION OF POLYMER MODIFIED MORTARS

	Deflection (mm)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	1,300	1,300	1,300
5%	1,336	1,197	0,857
10%	1,339	1,470	1,202
15%	1,302	1,280	1,306
20%	1,181	1,590	1,414

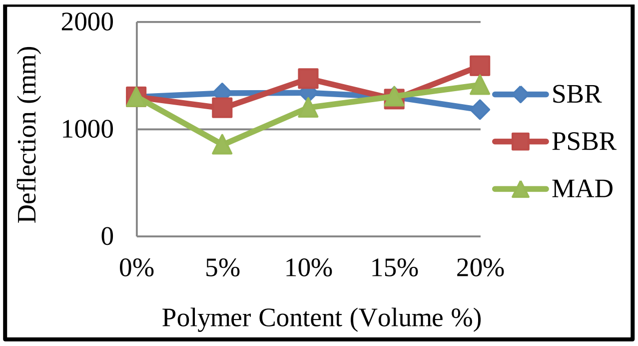

Fig. 6. Relationship between polymer content and deflection in SCC

As mentioned before, all mortars with 5% polymer addition present the worst character. MAD has the highest flexural strength, interestingly, does not show good performance in compressive strength in FCC, too.

TABLE IX
DEFLECTION OF POLYMER MODIFIED MORTARS

	Deflection (mm)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	1,782	1,782	1,782
5%	1,360	1,689	1,163
10%	1,419	1,722	1,215
15%	1,400	1,674	1,251
20%	1,296	1,274	1,495

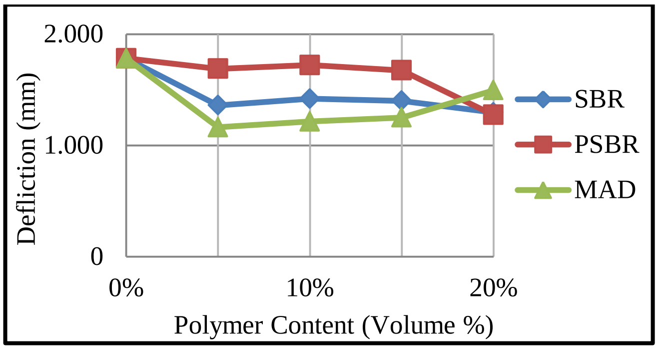

Fig.7. *Relationship between polymer content and deflection in TCC*

D. The Effects of Polymer Type and Content on Compressive Strength of Mortars

If the mortars have different polymer types are investigated, the compressive strength decreases with addition of all of the polymers types for both FCC and SCC. However, there is a bit increase in TCC for SBR with 10%, 15% and 20% rations.

TABLE X

Compressive Strength of polymer modified mortars

	Compressive Strength (N/mm2)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	50,73	50,73	50,73
5%	38,91	29,79	19,85
10%	27,73	42,6	30,91
15%	32,31	42,68	24,89
20%	37,82	42,57	27,36

When SBR, PSBR and MAD are added with 5% ration, compressive strength of mortars dramatically decrease in FCC (Table 10, Figure 8). MAD has the highest diminish from 50.7 N/mm^2 to 27.36 N/mm^2 (60%) with 5% ration in FCC, according to 0% ration. If PSBR is added with 10%, 15%, and 20% ratios, compressive strength of mortars is not show a change almost in FCC.

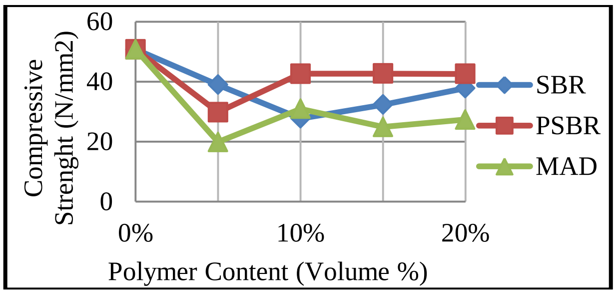

Fig. 8. Relationship between polymer content and compressive strength in FCC

For SCC with 5% polymer additions, a diminish is observed. These ratios changes as 33% for SBR, 23% for PSBR and 57% for MAD. Both PSBR and MAD show similar behavior for all ratios in SCC (Table 11, Figure 9).

TABLE XI

COMPRESSIVE STRENGTH OF POLYMER MODIFIED MORTARS

	Compressive Strength (N/mm2)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	48,45	48,45	48,45
5%	38,61	26,01	27,1
10%	32,05	41,49	31,5
15%	29,51	40,78	29,1
20%	32,38	37,01	20,6

MAD has the highest diminish from 48.45 N/mm^2 to 20.6 N/mm^2 (57%) with 20% ration in SCC, according to 0% ration.

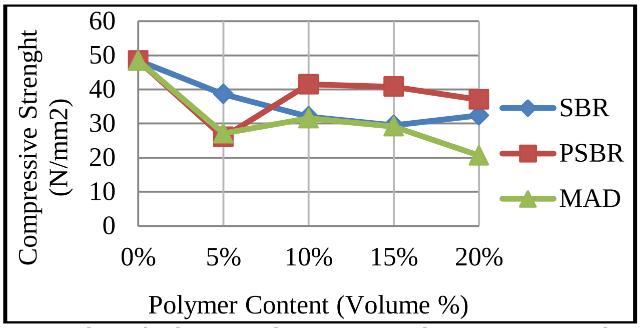

Fig. 9. Relationship between polymer content and compressive strength in SCC

When SBR, PSBR and MAD are added with 5% ration, compressive strength of mortars dramatically decreases in TCC (Table 12, Figure 10). MAD has the highest diminish from 51.21 N/mm^2 to 19.53 N/mm^2 (62%) with 20% ration in TCC, according to 0% ration. If PSBR is added with 10%, 15%, and 20% ratios, compressive strength of mortars show a bit increase, according to 0% ratio.

TABLE XII

COMPRESSIVE STRENGTH OF POLYMER MODIFIED MORTARS

	Compressive Strength (N/mm2)		
Fiber ratio by volume	SBR	PSBR	MAD
0%	51,21	51,21	51,21
5%	37,1	27,46	26,66
10%	50,76	36,82	35,09
15%	50,84	38,27	22,64
20%	51,88	36,87	19,53

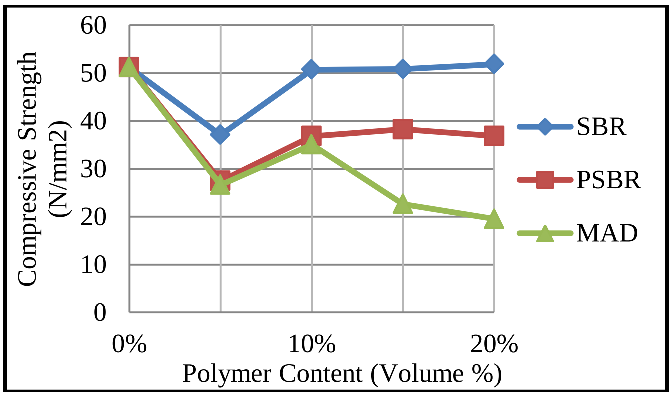

Fig.10. Relationship between polymer content and compressive strength in TCC

Although the polymers contribute flexural strength of mortar, they influence negatively on the compressive strength, when designing mix of concrete, strength class must selected one level high. For examples, if it will be produced C25/30 polymer concrete, at least C30/37 class concrete should be designed according to EN 206 concrete classes.

E. Determining Optimum Polymer Content from Relation between Flexural and Compressive Strength

As investigated above, with fiber addition, while flexural strength improves, compressive strengths influenced negatively. In this subsection, it is trying to be determined the optimum cure condition and the optimum polymer ratio that present better compressive strength and flexural strength for each polymer types separately. Since under SCC and TCC polymer modified mortars present unstable behavior, these comparisons are set up only for the samples under FCC.

It is understood from discussion above that each polymer show the best performance different addition ratio and different cure condition when flexural and compressive strength taken into consideration at the same time. It is seen that for after 5% addition ratio, flexural strength of PBSR and MAD increases and compressive strength remain reasonable level under FCC. However, big increase at 20% in flexural strength is taken into consideration; it can be said that these addition ratios are the best for MAD in FCC. For the samples have SBR show best results at 15% in FCC. The samples contain PSBR polymer give optimal results at 20% in FCC.

IV. CONCLUSIONS

It is investigated in this study that the effects of polymer types and content on mechanical and physical properties of cement mortars. The conclusions drawn from this study are;

i. Different types of polymers and cure conditions contribute to flexural strength at different contents. PSBR and MAD show best increments in flexural strength at 20% polymer content as 24% and 29%, respectively in FCC. For SBR, 24% increment in flexural strength is obtained at 15% polymer content by volume in FCC. Flexural strength of PSBR and MAD decrease at 5% ration for all cure condition.

ii. For all polymers types, addition of polymers decreases compressive strength. With 5% polymer addition for FCC, compressive strengths of mortars decrease 23% for SBR, 42% for PSBR, 60% for MAD. Only for SBR, in compressive strength of mortars is not observed a decrease at 10%, 15% and 20% ratios in TCC.

iii. Both FCC and SCC especially the mortars contain PSBR and MAD present high level of deflection in 20% ratio. The samples have SBR polymer are not influenced from increasing of polymer addition ratio in SCC. For all polymers show a decrease in TCC.

iv. The best of cure condition is investigated as FCC. Flexural strength and deflection show an increase in this condition. However, compressive strength shows a decrease for all ratios in FCC.

v. When polymer which specific masses are rather lower than mortar are added to mortar, the mortar's unit mass is decreases. SBR and PSBR show similar behavior in all ratios. It is seen that 20% SBR and MAD polymers addition decreases unit mass 10-15%, however PSBR decreases dramatically (29%).

vi. Since fiber addition influence negatively on the compressive strength, when designing mix of concrete, strength class should be selected one level high.

vii. All polymer increase consistency and workability of mortars especially at high dosages.

viii. Each fiber shows the best performance different addition ratio and cure condition when flexural and compressive strength taken into consideration at the same time. The optimum polymer addition ratios of the samples contain SBR are 20% for FCC. For the samples have PSBR show best results at 20% in FCC. The samples contain MAD polymers gives optimal results at 20% in FCC.

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REFERENCES

[1] Jackson N and R. Dhir, Civil Enginnering Materials, Palgrave Publishers Ltd, London, 1996.
[2] A. Çavdar, The Effects of Types and Content of Fibers on Mechanical Properties of Cementitious Composites, 2012
[3] Baradan, B., Yazıcı, H. ve Aydın, S., Beton, Dokuz Eylül Üniversitesi Mühendislik Fakültesi Yayınları, İzmir, 2012.
[4] Mehta, P.K. and Monterio, P.J.M., Concrete, Microstructure, Properties and Materials, McGraw Hill, 3rd Edition, 2006.
[5] Neville, A.M. and Brooks, J.J., Concrete Technology, 2nd Edition, Prentice Hall, 2010.
[6] T. Özturan, Özel Betonlar, Boğaziçi Üniversitesi, İstanbul, 2012
[7] Fowler, D.W., "Polymers in Concrete: A Vision for the 21st Century", Cement and Concrete Composites, V.21, pp. 449-452, 1999.
[8] Ohama, Y., "Recent Progress in Concrete – Polymer Composites", Advanced Cement Based Materials, V.5, pp. 31-40, 1997.
[9] Mindness, S. And Young, J.F., Concrete, Prentice Hall, New Jersey, 1981.
[10] Walters, D. G., "What are Latexes?" Concrete International, V. 9, No. 12, December, 1987, pp. 44-47.
[11] ACI 548. 3R-03, Polymer-Modified Concrete
[12] Ohama, Y., "Polymer-Modified Mortars & Concretes," Concrete Admixtures Handbook, Edited by Ramachandran, V. S., Noyes Publications, 1984, pp. 337-429.
[13] ACI 548. 1R-97, Guide for the Use of Polymers in Concrete.

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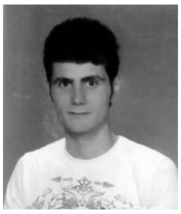

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