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Polymer Modification of Fine Grained Concretes Used in Textile Reinforced Cementitious Composites

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***Abstract*—**Textile reinforced cementitious composite (TRCC) is a development of a composite material where textile and fine-grained concrete (matrix) materials are used in combination. These matrices offer high performance properties in many aspects. To achieve high performance, polymer modified fine-grained concretes were used as matrix material which have high flexural strength. In this study, ten latex polymers and ten powder polymers were added to fine-grained concrete mixtures. These latex and powder polymers were added to the mixtures at different rates related to binder weight. Mechanical properties such as compressive and flexural strength were studied. Results showed that latex polymer and redispersible polymer modified fine-grained concretes showed different mechanical performance. A wide range of both latex and redispersible powder polymers were studied. As the addition rate increased compressive strength decreased for all mixtures. Flexural strength increased as the addition rate increased but significant enhancement was not observed through all mixtures.

***Keywords*—**Textile reinforced composite, cement, fine grained concrete, latex, redispersible powder.

I. Introduction

In civil engineering, the most commonly used composite material is steel reinforced concrete in structural applications. A development of a composite material is TRCC where biaxial or multiaxial fabrics are used in combination with fine grained concrete. The use of technical textiles, generally made of alkali resistant AR-glass, PVA (polyvinyl alcohol), and polyethylene (PE); sometimes other materials like polypropylene (PP), carbon, PBO (poly-p-phenylene benzobisoxazole) are used in the production of TRCC.

Standard processing techniques such as conventional mixing have been traditionally used for the development of cement-based composites. An efficient production method for fabric-cement composites is the pultrusion process. Assuring uniform production, pultrusion has been demonstrated to produce cement composites with continuous filaments (filament winding technique), exhibiting significantly improved performance. Cement composites containing 5% alkali-resistant (AR) unidirectional glass fibers produced by pultrusion achieved tensile strength of 50MPa [1], [2]. This high strength can be achieved from high strength matrix. For this reason, the material properties of the matrix (fine grained concrete) as a main component of the composite should be known as they will be applied in different models supporting analytical and numerical simulations of the TRCC elements. The matrices used for producing TRCC generally meet specific requirements regarding production processes, mechanical properties of the composite and durability of the reinforcement material. In most cases a small maximum grain size (<2 mm) is used so these matrix systems are called fine grained concrete.

Polymer modification of the fine grained concretes with polymer latexes and powders, which are film forming additives, enhances the flexural strength of these materials [3]. The special properties of fine grained concrete matrices like highly flowable consistencies are achieved by using a small maximum grain size, high binder content and using different pozzolanic additives and plasticizers [4].

Researchers investigated usage of latex and redispersible powder polymers in fine grained concretes used in TRCC. Ten latex and ten RDP were used in the mixtures at different rates of addition. Latex polymers added to the mixtures at 10%, 15% and 20% level and RDP added to the mixtures at 1%, 3%; 5% level by weight of binder content. Compressive and flexural strength tests were performed on the samples in the hardened state. In the fresh state, bulk density, air content and flow table diameter tests were performed. Effect of polymer addition rate and chemical composition of polymer to the mechanical properties were investigated.

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II. Materials & Methods

A. Materials

The binder was consisting of cement, fly ash and silica fume. Portland cement was CEM I 42.5R specified by European Standard EN 197-1. Silica fume is densified dry silica fume powder. Aggregate was silica sand from Istanbul region. Chemical composition of cement, silica fume and aggregate is shown in Table I. Physical and chemical properties of cement and silica fume are shown in Table II. Particle size distribution of aggregate is shown in Fig. 1.

Redispersible and latex polymer powders had different origin and different suppliers. Ten latex and ten redispersible polymer powders were used in the study. Chemical properties of latex polymers are shown in Table III and physical properties are shown in Table IV. Properties of RDP polymers are shown in Table V.

TABLE I
CHEMICAL COMPOSITION OF CEMENT, SILICA FUME AND AGGREGATE

Oxide (wt%)	Cement	Silica Fume	Aggregate
SiO_2	15.82	87.56	84.03
Al_2O_3	3.77	0.33	7.94
Fe_2O_3	3.33	3.51	0.60
MgO	1.04	0.31	0.24
CaO	66.11	1.00	0.75
Na_2O	0.23	0.48	1.58
K_2O	0.97	1.32	3.63
TiO_2	0.28	0.01	0.13
P_2O_5	0.10	0.40	0.04
MnO	0.11	0.22	0.02
Cr_2O_3	0.08	0.24	ni**
Cl	0.04	0.07	ni
SO_3	4.52	1.17	ni
LOI*	3.47	3.21	ni

* Loss on ignition
** Not identified

TABLE II
PHYSICAL AND CHEMICAL PROPERTIES OF CEMENT AND SILICA FUME

Physical Properties	Cement	Silica Fume
Specific Gravity (gr/cm^3)	3.14	2.20
Specific Surface (cm^2/g)	Blaine Method 3950	BET Method 200000
Chemical Properties	**Cement**	**Silica Fume**
Setting Time		
İnitial (min)	129	-
Final (min)	191	-
Soundness (mm)	1.0	-

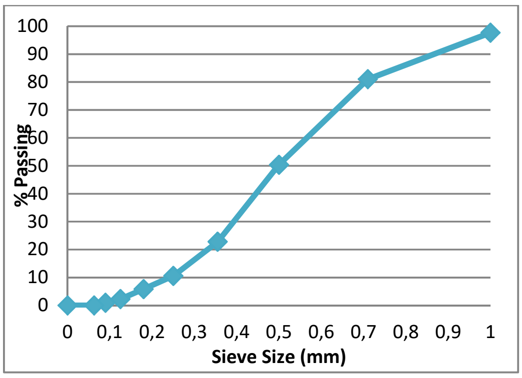

Fig. 1 Particle size distribution of aggregate

TABLE III
CHEMICAL PROPERTIES OF LATEX POLYMERS

Chemical Properties	L1	L2	L3	L4	L5
MFFT* (°C)	-	-	-	0	0
Tg** (°C)	15	-10	-22	-8	-8
Chemical Composition	Pure Acrylic	Styrene Acrylic	Butylacrylate and styrene		Acrylic Acid ester & Styrene
Chemical Properties	**L6**	**L7**	**L8**	**L9**	**L10**
MFFT* (°C)	0	-	0	0	1
Tg** (°C)	-10	14	-23	-10	-7
Chemical Composition	Styrene Acrylic	Styrene and butadiene	Styrene Acrylic		Styrene and butadiene

* MFFT: Minumum Film Forming Temperature
** Tg: Glass Transition Temperature

TABLE IV
PHYSICAL PROPERTIES OF LATEX POLYMERS

Physical Properties	L1	L2	L3	L4	L5
Consistency	Liquid	Liquid	Liquid	Liquid	Liquid
Density (g/cm^3)	1.03	1.04	1.03	1.04	1.08
Solid Content (%)	47	57	49	56	57
Chemical Properties	**L6**	**L7**	**L8**	**L9**	**L10**
Consistency	Liquid	Liquid	Liquid	Liquid	Liquid
Density (g/cm^3)	1.0	1.01	1.05	1.08	1.03
Solid Content (%)	59	52	53	57	50

TABLE V
PROPERTIES OF REDISPERSIBLE POWDER POLYMERS

Chemical Properties	L1	L2	L3	L4	L5
MFFT* (°C)	-	-	0	6	0
Tg** (°C)	15	-10	-	-	-
Chemical Composition	Pure Acrylic	Styrene Acrylic	vinyl acetate and ethylene	VAM/ VeoVa	VAE/VeoVa
Chemical Properties	**L6**	**L7**	**L8**	**L9**	**L10**
MFFT* (°C)	4	1	5	8	9
Tg** (°C)	14	-15	-	-	-
Chemical Composition	Va / VeoVa	Acrylic acid ester and styrene	VA/VeoVa/ Acrylic	VA/VeoVV/Acrylic	VA/ VV

* MFFT: Minumum Film Forming Temperature
** Tg: Glass Transition Temperature

Defoamer material and superplasticizer were used in the study. Properties of defoamer and superplasticizer are shown in Table VI.

TABLE VI
PROPERTIES OF DEFOAMER AND SUPERPLASTICIZER

Chemical Properties	Chemical Composition	Density (gr/l)	Powder Liquid	Ash Content (%)	Water Solubility
Defoamer	Polyglicol	320.0	Powder	33	Insoluble
Chemical Properties	**Chemical Composition**	**Density (gr/cm^3)**	**Powder Liquid**	**PH**	**Water Solubility**
Superplasticizer	Melamine Sulfonat	1.80	Powder	10	Soluble

B. Methods

Fine grained concretes were casted into 4x4x16 cm sized molds, removed after 24 hours and cured in lime saturated water at 20 °C for three days. After curing period, they were dry cured in laboratory conditions until test days. Mixture design of polymer modified concretes is shown in Table VII.

TABLE VII
QUANTITY OF THE MATERIALS IN THE MIXTURE

Materials	Weight (%)
Cement	38.0
Silica Fume	4.0
Total Binder Content	**42.0**
Silica Sand	56.8
Superplasticizer	0.8
Defoamer	0.4
TOTAL	**100**
Water/Binder	0.35
Binder/Aggregate	1:1.35

Redispersible powders were added to the mixture at a dosage of 3% respect to binder weight (cement + silica fume). Latex polymers were added to the mixture at a dosage of 10% respect to binder weight. Mixtures have different consistency parameters because polymers act differently in the mixture and influence flow parameters. Consistency 1: Self leveling (SL), Consistency 2: Plastic consistency (flow table diameter at 25 tapping) (PC). Tests were conducted using related standard ASTM C1437.

Water/cement ratio was kept constant as 0.35 for all mixtures modified with either latex polymer or redispersible powders for comparable test results. The water come from latex was considered and mixing water was reduced according to their water content. The unit weight of fine grained concretes was measured and air content was determined in fresh state according to related standard ASTM C231.

III. Results & Discussion

Bulk density, air content and flow diameter tests were performed on fine grained concretes in fresh state according to related ASTM C185, ASTM C231 and ASTM C230 standards. Results are shown in Tables VIII and IX. Compressive and flexural strength tests were performed in hardened state according to ASTM C348 and ASTM C349.

TABLE VIII
FRESH STATE TEST RESULTS OF LATEX MODIFIED MIXTURES

Materials	Addition (%)	Bulk Density (gr/cm^3)	Air content (%)	Flow Diameter (cm)	SL or PC
Latex 1	10	1.64	12.0	20.0	SL
Latex 2	10	1.74	9.0	29.0	SL
Latex 3	10	1.75	4.5	18.0	PC
Latex 4	10	1.40	11.3	17.3	PC
Latex 5	10	1.98	6.5	18.5	SL
Latex 6	10	1.96	4.8	17.3	SL
Latex 7	10	2.05	4.8	15.8	SL
Latex 8	10	1.94	10.8	18.5	SL
Latex 9	10	2.00	6.7	20.8	SL
Latex 10	10	2.01	4.5	16.5	SL

TABLE IX
FRESH STATE TEST RESULTS OF RDP MODIFIED MIXTURES

Materials	Addition (%)	Bulk Density (gr/cm^3)	Air content (%)	Flow Diameter (cm)	SL or PC
RDP 1	3	1.91	6.0	24.0	PC
RDP 2	3	1.98	7.0	27.0	SL
RDP 3	3	2.07	5.5	22.4	SL
RDP 4	3	1.92	5.0	22.0	SL
RDP 5	3	2.10	5.8	21.3	SL
RDP 6	3	2.13	3.4	17.7	SL
RDP 7	3	2.07	5.2	19.0	SL
RDP 8	3	2.09	3.2	24.0	SL
RDP 9	3	2.12	4.8	16.0	SL
RDP 10	3	2.12	4.7	12.7	SL

Based on the test results, polymer modification increased the amount of air content in fine grained concretes compared to conventional mortars. This is because of an action of surfactants contained as emulsifiers and stabilizers in polymer additives [5]. The amount of air entrainment in the fine grained concretes modified with latex polymers was generally higher than modified with redispersible polymers. Fine grained concretes modified with Latex I with 10% polymer content had the highest air content value which is 12%. This is because surfactants found in chemical composition of latex polymer. As the amount of surfactant in the latex polymer increases, air entraining effect of the polymer increases too [6]. As a result, the usage of polymers of different origin (latex or redispersible powder) causes different air entraining effect.

Increase in air content results in decrease in strength and durability. Fine grained concretes cast with Latex I had the highest air entrainment and air void content value. Although defoamer was used at the highest rate specified in its technical data sheet, the amount of air in Latex I mixtures did not lower to the level of conventional mortars. As a consequence, air content of Latex I mixtures was too high that defoamer material was not capable of blocking air bubbles enough.

Consistency of the mixtures was obtained by using flow table tests. RDP polymer modified mixtures had bigger flow table length than latex polymer modified mixtures. This systematic test results is caused by ball bearing action of polymer particles, entrained air and dispersing effect of surfactants in polymer additives [5].

Flexural strength of these samples is summarized in Figs. 2, 3. Related tests were performed at 7th and 28th days after moist curing of 3 days and dry cure until test days.

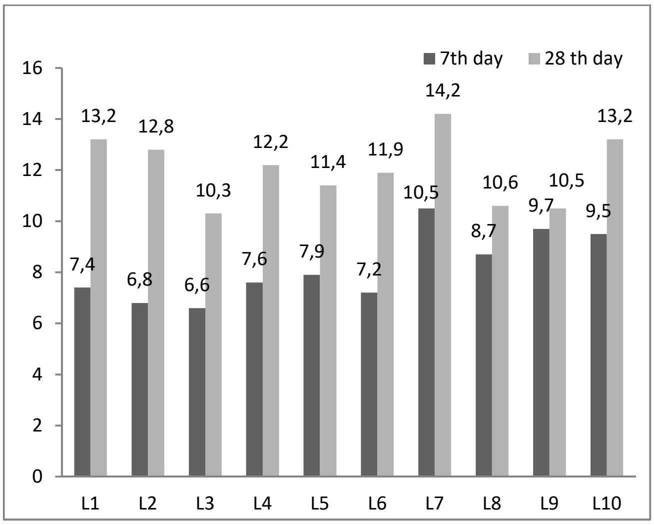

Fig. 2 Flexural Strength of Latex Series

Researchers showed in the further studies that polymer modification reduces compressive strength in mortars and concretes [7]. Latex polymers reduced the compressive strength more than redispersible powders in this study. This is because when latex polymers contain water in their composition, they need long period of time to get dry and make film formation in the internal structure [8]. Also, increase in flexural and tensile strength with decreasing compressive strength is because improvement in cement-aggregate bond by addition of the polymer [5]. Mortars modified with more rigid polymers have higher strength than modified with flexible ones. Series prepared with RDP I at 3% content with defoamer had the highest flexural strength, 14.4 MPa. Polymer modified fine grained concretes had lower compressive but higher flexural strength. They differ from normal concretes from this aspect.

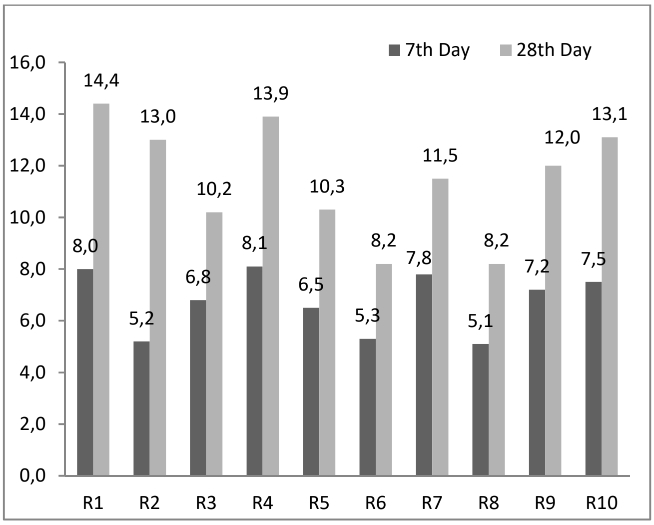

Fig. 3 Flexural Strength of RDP Series

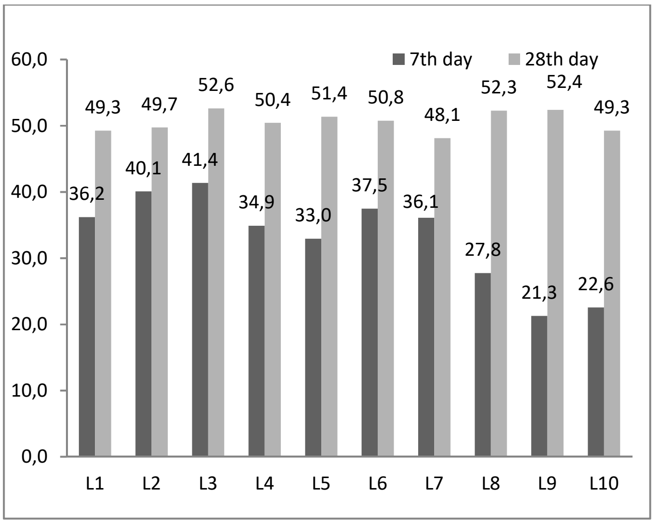

Fig. 4 Compressive Strength of Latex Series

IV. Conclusion

In this study, results showed that polymer modification increased the amount of air content in fine grained concretes. Usage of polymers with different chemical compositions causes different air entraining effect in the mixtures. Also consistency of the mixtures changed by adding polymers with different chemical compositions. Polymer modified fine grained concretes had lower compressive but higher flexural strength. Fine grained concretes modified with latex redispersible polymers had higher compressive strength than modified with latex polymers. Latex modified mixtures had a little less flexural strength than redispersible powder modified mixtures but both of the polymer modified mixtures had superior properties compared to conventional mortars. Polymer modified fine grained concretes used in TRCC were researched and comparable test results were obtained.

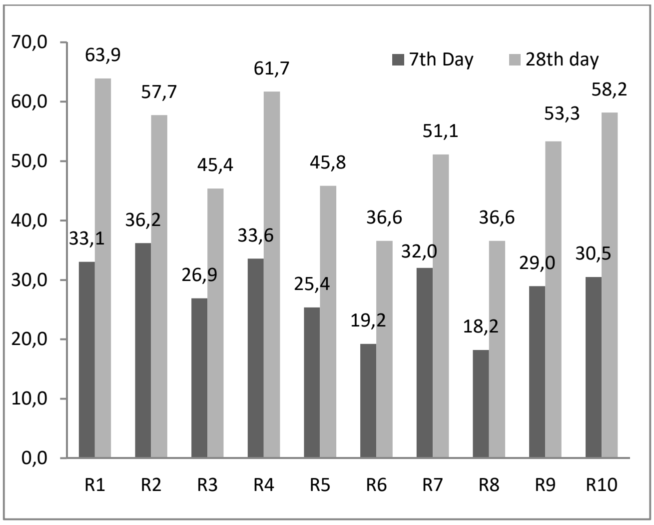

Fig. 5 Compressive Strength of RDP Series

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