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Development of fine grained concretes for textile reinforced cementitious composites

Esma Gizem Daskiran[*], Mehmet M. Daskiran[a] and Mustafa Gencoglu[b]

Department of Civil Engineering, Istanbul Technical University, Istanbul, TURKEY

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Abstract. A new innovative composite material is textile reinforced cementitious composite (TRCC). To achieve high flexural performance researchers suggest polymer modification of TRCC matrices. In this study, nine ready mix repair mortars commonly used in construction industry and the production of TRCC elements were examined. Mechanical properties such as compressive and flexural strength, drying shrinkage were studied. Being a significant durability concern, alkali silica reaction tests were performed according to related standards. Results showed that, some ready repair mortar mixes are potentially reactive due to the alkali silica reaction. Two of the ready mortar mixes labelled as non-shrinkage in their technical data sheets showed the highest shrinkage. In this experiment, researchers designed new matrices. These matrices were fine grained concretes modified with polymer additives; latexes and redispersible powders. Two latexes and six redispersible powder polymers were used in the study. Mechanical properties of fine grained concretes such as compressive and flexural strengths were determined. Results showed that some of the fine grained concretes cast with redispersible powders had higher flexural strength than ready mix repair mortars at 28 days. Matrix composition has to be designed for a suitable consistency for planned production processes of TRCC and mechanical properties for load-carrying capacity.

Keywords: textile reinforced composite; durability; fine grained concrete; shrinkage; alkali silica reaction

1. Introduction

In civil engineering, the most commonly used composite material is steel reinforced concrete in structural applications. A new development of a composite material is textile reinforced cementitious composite (TRCC) where biaxial or multiaxial fabrics are used in combination with fine grained concrete. This leads to design of very thin structural elements which have high strength in compression as well as in tension. 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. However, Carbon and PBO textiles are very expensive.

Textile reinforced cement-based composites are new class of sustainable construction materials

[*]Corresponding author, Ph.D. Student, E-mail: aydines@itu.edu.tr
[a]Ph.D. Student, E-mail: mdaskiran@itu.edu.tr
[b]Associate Professor, E-mail: gencoglumu@itu.edu.tr

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with superior tensile strength and ductility (Soranakom and Mobasher 2009). These materials have the potential for becoming load-bearing structural members; therefore, wide arrays of structural and nonstructural applications are possible. Recent advances in textile manufacturing for construction systems have introduced new opportunities. Woven fabric reinforced composites have been recognized as more competitive than unidirectional composites. This is due to their stability and deformation characteristics that result from coupling of reinforcement in transverse and longitudinal directions, in the load direction.

Standard processing techniques such as conventional mixing have been traditionally used for the development of cement-based composites. This results in composites with a relatively low-volume fraction of short discrete fibers distributed in a random two or three dimensional orientation. Several novel techniques have been recently developed for manufacturing composite laminates. Innovative manufacturing provides the computational and control power needed to develop economic and versatile materials. For example, cement-based composites laminates prepared with continuous fibers allow the full potential of fibers in reinforcing the matrix to be used because the manufacturing technique is fully controlled and the composite laminates can be designed for the specific service loads they may encounter. Some of these processes include high-energy mixing, extrusion, pultrusion, filament winding, compression molding, cross-ply and sandwich lamination techniques and hybrid reinforcement (Mobasher 2011). These materials collectively offer a significant degree of strength, ductility, and versatility and can be easily be used as structural load bearing members.

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 50 MPa (Mobasher *et al*. 1997, Peled and Mobasher 2004). 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. These newly developed matrices should be appropriate to the production process and provide chemical stability of the textile reinforcement. These special matrices show a finer and homogenous system due to ordinary concrete and ensure an improved performance with high compressive and flexural strength with enhanced durability characteristics. For dimensioning and design of TRCC structures, the basic fracture characteristics and the mechanical properties of the fine grained concrete should be determined for the stress and strain state in compression, tension and shear.

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. Regarding matrix composition, the essential necessity is to get full penetration into technical textiles in order to get great bonding. The consistency of the matrix has to be adequate for the properties of the textile type and mesh size, geometry of the specimen and the production processes. Production techniques like lamination and pultrusion requires plastic consistencies. The matrix design will always be a best adjustment between all requirements regarding fresh, mechanical and durability aspects as well as economic aspects for industrial production of TRCC elements. These bonding between matrix material and technical textile leads to excellent loading behavior.

Polymer modification of the fine grained systems have been integrated in the investigations as polymer latexes and powders which are film forming additives and enhances the flexural strength of the concrete (Bramashuber *et al.* 2002). Polymer-modified or polymer cement mortar (PCM) and concrete (PCC) are a category of concrete-polymer composites which are made by partially replacing the cement hydrate binders of conventional cement mortar or concrete with polymers, i.e., polymeric admixtures or cement modifiers, thereby strengthening the binders with the polymers. Because of the small diameter of the dispersed particles in polymeric dispersions (about 50 nm to 200 nm), they can penetrate into the spaces between textile filaments before the onset of concrete. Also, the bonding of matrix and textile reinforcement is influenced by the polymers. These matrices also offer a high chemical resistance as described in (Felekoğlu 2009) Researchers designed different matrix systems which are differentiated in mineral based, polymer modified and alternative systems. 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 (Walk-Lauffer *et al*. 2003). Pozzolanic materials such as fly ash, silica fume and blast furnace slag can be used in the mixtures. Due to workability concerns, the amount of silica fume addition is limited to moderate quantities; lower than 10% by mass of total binder content. It is not possible to achieve a flowable consistency of this mixture when larger quantities of silica fume are added. So, in the current study silica fume was used while preparing the mixtures to improve durability performance of the mixture and the AR- Glass textile in the composite.

Researchers sometimes preferred to use ready mix repair mortars in TRCC instead of designing a new fine grained concrete mix (Carozzi *et al.* 2014 and Larbia *et al.* 2013). Commercially available repair mortars contain cement and sand; some of them contain silica fume, polymer powders and fibers called whisker. The capacity of repair materials (dimensional, chemical, electrochemical and permeability) used in TRCC is the most crucial property for these composite systems. Dimensional incompatibility of the materials is because shrinkage of cementitious materials. Repair materials are commonly cement based materials and achieve high shrinkage rates. Unfortunately, information on how compatibility is affected by material properties, how the various properties are connected, and durability problems that should be taken into consideration are limited. Among these durability problems, ASR is a really severe concrete deterioration and also is a serious concern about concrete structures. This specific reaction typically creates significant concrete expansion and causes damages which end up with failure of construction. Due to high amount of sand content (between 40% -70% of total weight) of repair mortars used in construction industry, repair mortars must be tested according to alkali silica reaction. If the ready mix is highly reactive, ASR causes expansions in TRCC and leads significant deterioration which cannot be easily controlled.

In the first part of the study, 9 ready mix repair mortars were obtained from their manufacturers. Preliminary tests were conducted on test specimens. Compressive and flexural tests were performed on 9 repair mortars. Shrinkage tests were performed to understand if these repair mortars are dimensionally compatible repair materials. Alkali silica reaction tests were concentrated on identifying the durability properties of repair mortars, appropriate test method and predicting field performance.

In the second part, researchers designed and offered new fine grained concrete mixes which can be used easily as repair mortar and also in casting TRCC. All of the mixtures were designed as polymer modified fine grained concretes. Two polymer latexes and six redispersible powders were used in the mixtures. Totally 8 different mixes were prepared. Fresh and mechanical properties of

Table 1 Mixture contents of ready mix repair mortars

Repair Mortar	Cement	Sand	Silica Fume	Polymer Modifier	Fiber	Non-Shrinkage
1	✓	✓	x	✓	x	✓
2	✓	✓	x	✓	✓	x
3	✓	✓	x	✓	✓	✓
4	✓	✓	x	✓	✓	✓
5	✓	✓	✓	✓	x	x
6	✓	✓	✓	✓	x	x
7	✓	✓	*	✓	✓	x
8	✓	✓	x	✓	x	x
9	✓	✓	*	✓	x	x

*Not mentioned

these mixtures were investigated. Air content of polymer modified fine grained concretes were obtained using air content meter. Polymer modification causes air entraining in the mixture and researchers also tried to find out if antifoamer were effective to prevent the air bubbles trapped in the mix. Antifoamer successfully lowered down the air content to normal levels in redispersible powder mixtures. They had very low air content similar to conventional mortars. Latex modified fine grained concretes had moderate air contents as expected. Some of the designed fine grained concrete mixtures had higher compressive and flexural strength than some of the ready mixtures.

Accordingly, a broad, multi-phase research program was developed to perform mechanical and durability performance of fine grained concretes and repair materials. Results of this investigation form a basis for engineers and researchers to pay attention on mechanical and durability performance of repair mortars used in construction industry and for designing TRCC.

2. Experimental materials and methods

2.1 Repair mortars

Nine commercially available polymer modified cementitious repair mortars were obtained from its manufacturers. They all contain cement and sand; some of them contain silica fume, polymer powders and fibers called whisker. Their material content was collected from technical data sheets and is shown in Table 1.

The mortar specimens were prepared regarding to the material weights in the technical data sheets. The ready packaged dry mix was added to the pan mixer first. Then the required water in the technical form was added. The quantity of the dry mix and water are shown in Table 2.

Each mortar was prepared regarding to its mixing procedure. Polymer modified mortars usually contains different admixtures such as defoamers, superplasticizers and shrinkage reducing admixtures. To ensure maximum benefit of these admixtures we must follow a suitable mixing

Table 2 Material amounts and ratios in ready mixed mortar mixtures

Repair Mortar	Mixture (kg)	Water (kg)	Total (kg)	Water/Dry Powder Ratio
1	5.000	1.000	6.000	0.20
2	5.245	0.755	6.000	0.14
3	5.172	0.828	6.000	0.16
4	5.145	0.960	6.105	0.19
5	5.150	1.000	6.150	0.19
6	5.310	0.800	6.110	0.15
7	5.000	1.250	6.250	0.25
8	5.000	1.250	6.250	0.25
9	6.000	0.720	6.720	0.12

Fig. 1 Air content meter with 1 liter capacity

procedure. Generally ready mix mortar is premixed. After mixing it is allowed to rest in the mixer for a while. Meanwhile essential and required reactions occur in the mixture and then it is mixed a little again. At the end of this mixing, the unit weight of repair mortars was measured and air content according to related standards, ASTM C185 (2008) and BS EN 1015-7 (1999). Air content meter is shown in Fig. 1.

The flow diameter test was performed according to related standard BS EN 1015-3 (1999). The flow cone was positioned at the center of the plate. After pouring the fresh mortar into the cone, the upper part of the cone was tamped 25 times in 5 seconds. Then the cone was gently lifted. The spread diameter of the given mixture represents the average of two perpendicular diameters recorded at the end of the tapping.

After mixing, 40×40×160 mm prisms were cast for flexure and compression tests. Six mortar specimens were prepared; three for each 7th and 28th day tests. The specimens were remolded after

Table 3 Chemical compositions of cement and silica fume

Oxide (wt%)	**Cement**	**Silica Fume**
SiO_2	17,70	91,0
Al_2O_3	3,95	0,58
Fe_2O_3	3,76	0,24
CaO	62,45	0,71
MgO	1,05	0,33
SO_3	4,12	1,06
LOI	4,82	1,84
$(Na_2O)_{eq}$	1,03	2,74

being cured at 20°C in air for 24 hours. Then they were stored in water cure at 20°C for three days. After that specimens were removed from the water cure and kept in air until testing day. Flexural tests were performed on the prisms. After flexure we have two broken parts and compression test was performed on these two broken specimens according to BS EN 196-1 (2005).

25×25×285 mm specimens were prepared to perform shrinkage and alkali silica reaction tests. The specimens were remolded after being cured at 20°C in air for 24 hours. Shrinkage prisms were kept in laboratory conditions until 28 days at 20°C/80±5 %Rh. Subsequent length readings were measured using comparator on 4, 7, 14, 28^{th} days according to BS EN 12617- 4 (2002).

The ASR expansion of the repair mortars was investigated by using the accelerated test method of ASTM C1260 (2014). Based on the test method, mortar bars were prepared by using repair mortar mix and required water in the technical data sheets. Two mortar bars (25×25×285 mm) were cast for each mortar mixture. After 24 hours, mortar bars were removed from the molds and stored in a water bath with tap water at 80°C for a period of 24 hours. After this preconditioning, the length of mortar bars were measured (initial reading). Then they are placed into storage containers filled with 1 Normality (1N) of NaOH solution at 80°C for the duration of the test. Subsequent length readings were made using comparator on 1, 3, 7, 14^{th} days. Expansions were measured as changes in mortar bar length. The same procedure was followed for the entire test.

2.2 Fine grained concrete mixtures

Table 4 Physical properties of cement and silica fume

Physical Properties		**Cement**	**Silica Fume**
Specific Gravity (gr/cm^3)		3,14	2,20
Setting Time	**Initial (min)**	129	-
	Final (min)	191	-
Soundness (mm)		1,0	-
Specific Surface (*cm^2/g*)		3950	200.000

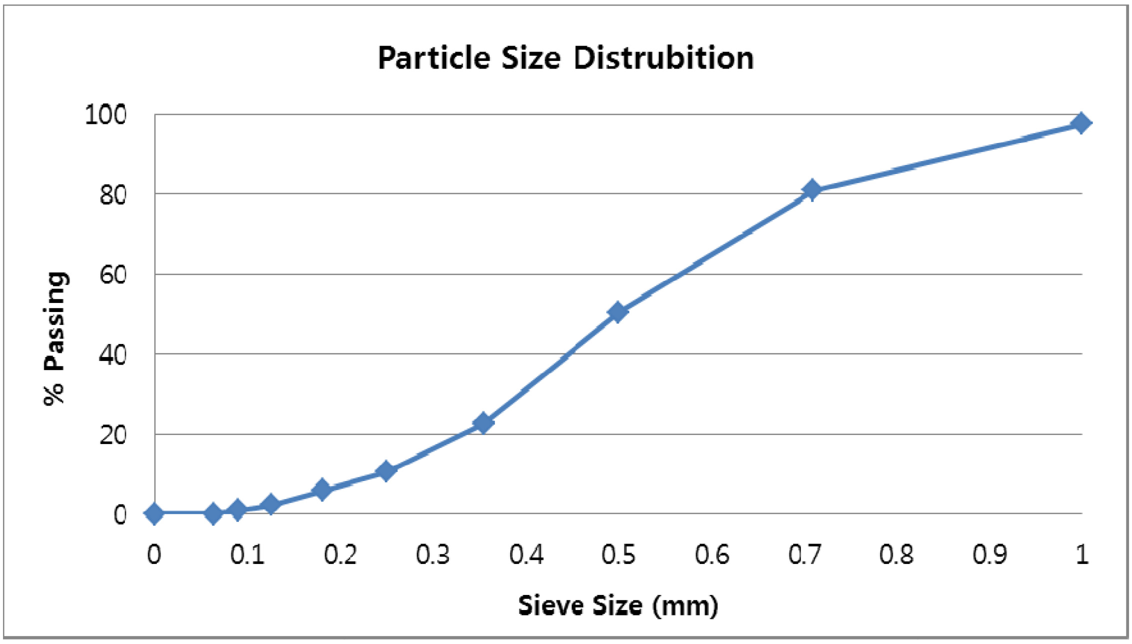

Fig. 2 Particle size distribution of aggregate

Table 5 Properties of polymer additives

Latex	Chemical Composition	Solid Content (%)	Viscosity (Brookfield,mPa.s)	Density (gr/cm^3)	MFFT[1] (°C)	Tg[2] (°C)
1	Styrene Acrylic	50	3000-7000	1.03	18	18
2	Styrene Acrylic	59-61	500-1500	1.00	0	-10

RDP	Chemical Composition	Appearance	pH	Density (gr/l)	MFFT (°C)	Tg (°C)
1	Vinyl Acetate/ VeoVa	White Powder	6.0-7.0	510±70	9	nm[3]
2	Vinyl Acetate/ VeoVa	White Powder	6.0-7.0	525±75	8	nm
3	Vinyl Acetate/ VeoVa	White Powder	nm	≤500	6	15
4	Vinyl Acetate/ VeoVa/ Acrylic	White Powder	nm	400-600	0	nm
5	Vinyl Acetate/ VeoVa/ Acrylic	White Powder	6.0-7.0	nm	8	nm
6	Vinyl Acetate and Etylene	White to light beige powder	6.0-7.0	400-550	0	nm

[1]MFFT :Minumum Film Forming Temperature

[2]Tg : Glass Transition Temperature

[3]nm: not mentioned

Table 6 Typical properties of polymer modified fine grained concrete

No	Mixture	Type of Mortar	Description
1	L1	SAE Modified Cement Based mortar	✓ Latex Emulsion ✓ Pre-mixed cement based powder (Cement+SilicaFume+Graded Aggregates+Additives) ✓ Water
2	L2		
3	RDP 1	EVA/VeoVa Modified Cement Based Mortar	✓ Redispersible Powder ✓ Pre-mixed cement based powder (Cement+SilicaFume+Graded Aggregates+Additives) ✓ Water
4	RDP 2		
5	RDP 3		
6	RDP 4	EVA/ VeoVa/ Acrylic Modified Cement Based Mortar	
7	RDP 5		
8	RDP 6	EVA	

The cement used in this study was Portland cement CEM I 42.5 R, specified by European standard EN 197-1, 2000. Table 3 shows its chemical composition, alkali equivalent (Na_2O equivalent) contents, and Table 4 shows its physical properties.

In this study, aggregate was obtained from a quarry in Istanbul region. Aggregate was a natural sand, its specific gravity was 2.54 gr/cm^3, dmax $\leq$ 1.0 mm and its particle size distribution is seen in Fig. 2. Supplementary material used in the mixtures is silica fume. Chemical composition and physical properties of silica fume is shown in Table 3 and 4, respectively. Two different polymer emulsions (latex) were used in this study. Also six different redispersible powders were used while preparing fine grained concretes. Typical properties of polymer additives are shown in Table 5.

A defoamer with a blend of polyglycols was used in this study to avoid air entraining effect of polymer additives. To achieve desired consistency and workability a melamin sulfonat powder super plasticizer was used.

The following fine grained concretes were cast into 4×4×16 cm molds and removed after 24 hours. Then they were cured in water at 20°C for 3 days. After curing period, they were dry cured in laboratory conditions until test days. Standard curing wasn't applied to specimens because

Table 7 Quantitiy of the materials in the mixture

Material	% of Total Weight
Cement (CEM I 42,5)	38
Silica Fume	4
Total Binder Content	**42**
Aggregate (dmax≤1.0 mm)	56.8
Superplasticizer	0.8
Defoamer	0.4
TOTAL	**100**
Binder/Aggregate Ratio	1:1.35

Table 8 Fresh properties of repair mortars

Repair Mortar	Flow Diameter (cm)	Unit Weight (kg/lt)	Air Content (%)
1	17.5	1.37	12.0
2	18.4	1.85	7.1
3	18.1	1.97	2.1
4	18.6	2.17	3.3
5	18.5	1.74	2.2
6	21.0	2.10	16.5
7	13.1	1.75	3.8
8	23.0	1.65	15.0
9	20.2	1.67	8.9

polymer modified cementitious materials need dry curing thus polymer film is formed internally while water evaporates from the system. Fine grained concretes casted in the laboratory are shown in Table 6. Mixture design of polymer modified concretes are shown in Table 7.

The typical dosage parameter for redispersible powders was 5% of binder weight (Cement + Silica Fume). Latex dosage was 10% (total powder in the emulsion/binder) in the mixture. Every mixture has its own consistency because polymer additives act differently in the mix and influence flow parameters. Researchers determined two flow parameters. Parameter 1: Self leveling (flow table diameter 17±1 cm), Parameter 2: Plastic consistency (flow table 14 to 22 at 25 tapping). 3 of the mixes were self-leveling and 5 of them had plastic consistency. Tests were conducted using related standard ASTM C1437.

Mesh diameter is very important here while deciding the appropriate mix and workability. In further studies, researchers are planning to use PVA and Ar-Glass textiles. Since PVA has smaller mesh sizes, flowable mixture will be appropriate for the production process. However, Ar-Glass textiles have bigger mesh sizes, plastic consistency will be better. Therefore water quantity of the mixes is different from each other but water/cement ratio are nearly the same. Water/cement ratio kept constant as 0.35 in order to compare mechanical results for redispersible powder modificated mortars. The water from latex was considered and mixing water was reduced according to their water content. L1 and L2 mixtures had water/cement ratios of 0.47 and 0.36. The unit weight of mortars was measured and air content according to related standards in fresh state, ASTM C1439 and ASTM C231. Air content meter is shown in Fig. 1.

3. Results

3.1 Repair mortars

The flow diameters, unit weight and air content of the mortars were measured and showed in the Table 8.

While flow diameter of 7 was very low, the flow of mixture 8 was very high. Compressive and flexural strength of the selected ready mixes are summarized in Table 9.

Table 9 Compressive and flexural strength of repair mortars

Test Date	**7th Day**		**28th day**	
Repair Mortar	**Compressive Strength (MPa)**	**Flexural Strength (MPa)**	**Compressive Strength (MPa)**	**Flexural Strength (MPa)**
1	33.3	3.9	41.7	8.9
2	36.2	4.0	40.9	8.4
3	50.0	5.1	61.4	12.0
4	62.4	5.3	71.3	11.9
5	51.8	6.8	66.3	13.6
6	21.7	4.3	31.0	8.0
7	13.4	4.7	38.3	7.9
8	11.8	2.9	14.7	2.6
9	22.1	5.0	35.4	7.0

Related tests were performed at 7th and 28th days after moist curing of 3 days and dry cure until test days. The highest compressive strength measured in the specimens prepared with 4th mix. The compressive strength of 3, 4, and 5 repair mortars was more than 60 MPa. Flexural strength results range from 2.6 to 13.6 MPa. The maximum value of flexural strength was measured in the specimens prepared with 5, and the lowest value is recorded in the specimens prepared with 8.

Durability performance of mortars due to alkali silica reaction was investigated. Expansions of mortar bars are shown in Fig. 3.

Mortars showed expansion between 0.10 and 0.20% at the end of 14 days were defined potentially reactive by researchers (Touma *et al*. 2000). Considering the average of 14 days expansions, ready mix 4, 5 and 6 are defined as potentially reactive mix and may cause cracking in the field. Mortars showed expansions higher than 0.20% is defined as reactive by researchers and

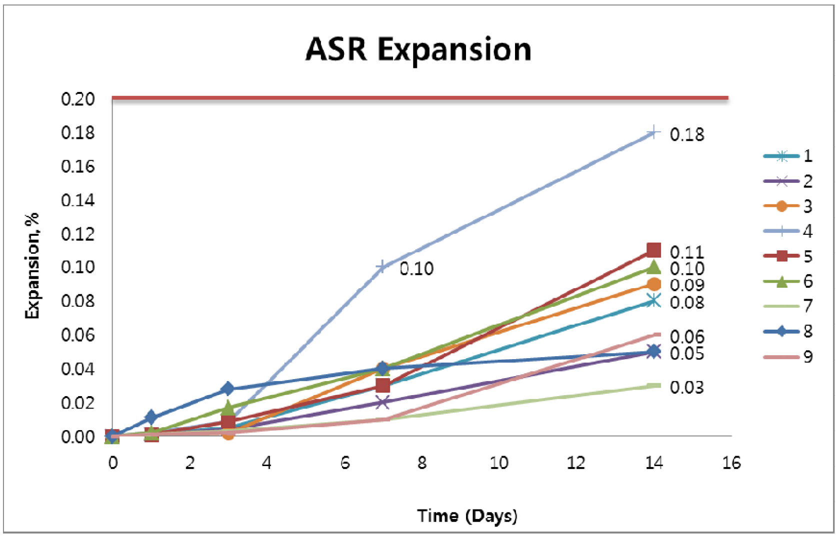

Fig. 3 ASR expansions of ready mix repair mortars

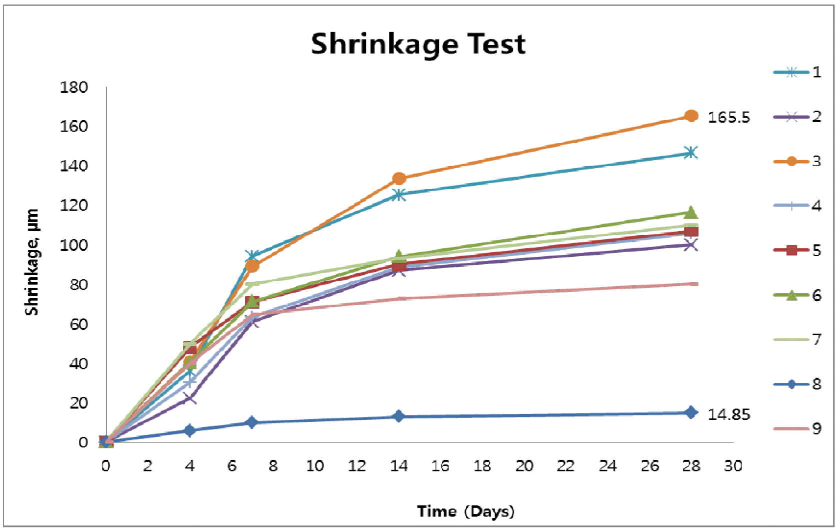

Fig. 4 Drying shrinkage of ready mix repair mortars

related standard (Touma *et al*. 2000). Mortar 4 showed the highest expansion 0.18% and was very close to the upper limit.

Shrinkage test was performed to verify if the ready mix mortars are non-shrinkage as they were indicated in their technical data sheets. Comparator length readings were done on 1, 4, 7, 14, 28th days. The drying shrinkages of the cement based repair mortars are shown in Fig. 4.

The drying shrinkage strain increased with time in all repair mortars, increasing more rapidly at the early stages and slowly later. Further, the ultimate drying shrinkage strain in these ready mix mortars was belongs to particularly 3 and 1. Ready mix 3 is specified as shrinkage compensated mortar and 1 is specified as nonshrinkage mortar in the technical data sheets. In spite of being

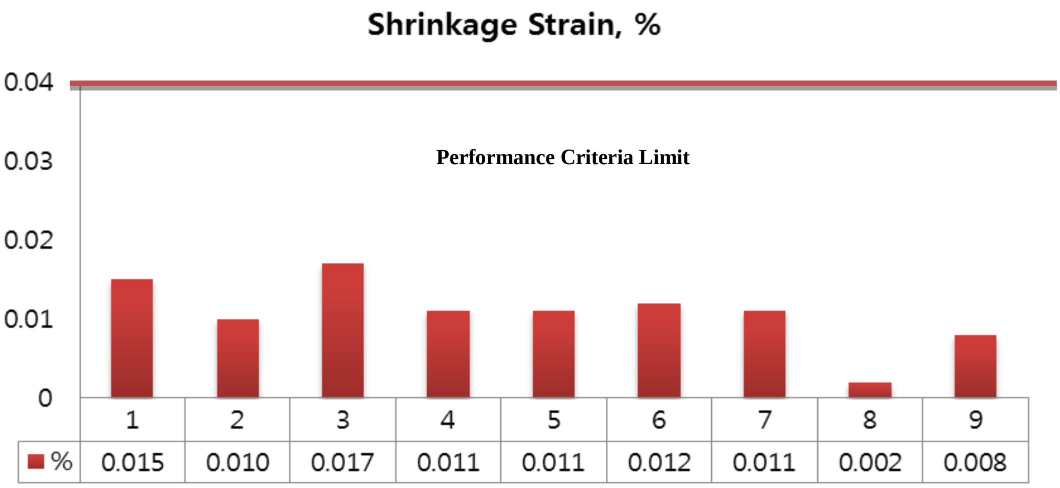

Fig. 5 Shrinkage Strain of ready mix repair mortars

Table 10 Fresh state properties of fine grained concretes

Mixture	Bulk Density (gr/cm^3)	Flow Diameter (cm)	Air Content (%)
L1	1.90	14	2.0
L2	1.97	19	4.0
RDP 1	2.11	22	1.6
RDP 2	2.14	21	1.7
RDP 3	2.10	16*	1.9
RDP 4	2.13	21	1.8
RDP 5	2.10	18*	1.9
RDP 6	2.11	17*	1.6

*Self Leveling

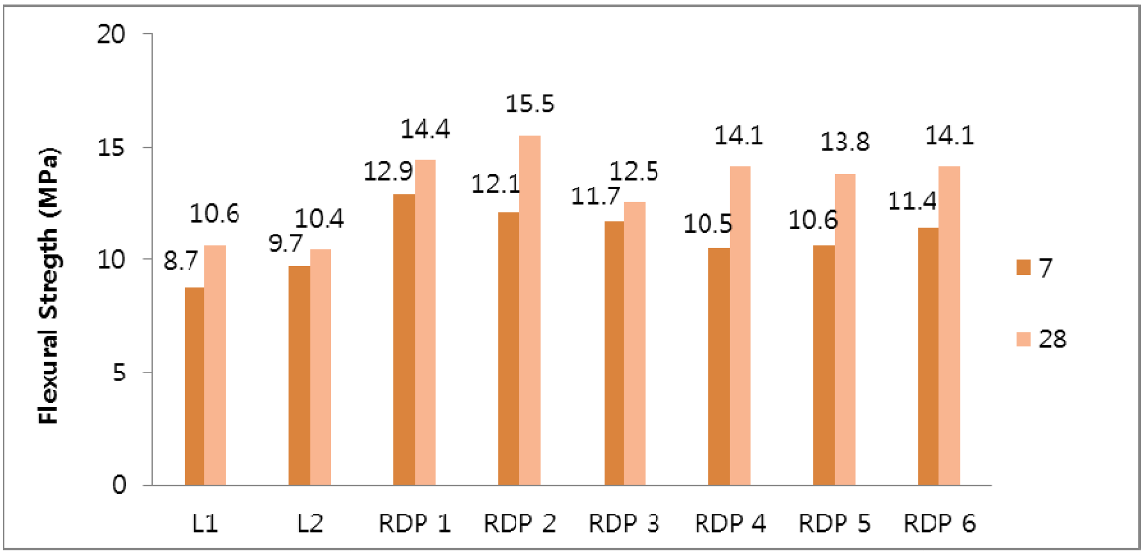

Fig. 6 Flexural strength of mortars at 7th and 28th days

labeled as non-shrinkage, mortar 3 showed the highest shrinkage at the end of 28 days. Shrinkage strains of ready mix repair mortars are shown in Fig. 5.

3.2 Fine grained concretes

Polymer modified fine grained concretes were prepared and cast into the molds after fresh state tests. Bulk density, flow diameter and air content values were measured in fresh state. Water/Cement ratio kept constant and flow diameter was measured. Several polymer latexes and redispersible powders had distinct flow diameters. Although the percentage of latex is the same; the consistency of the mixes are different from each other. This shows polymers affect differently the mixture flowability. Air content of the mixtures were measured especially using air content meter because predicting air content using bulk density method was not certain.

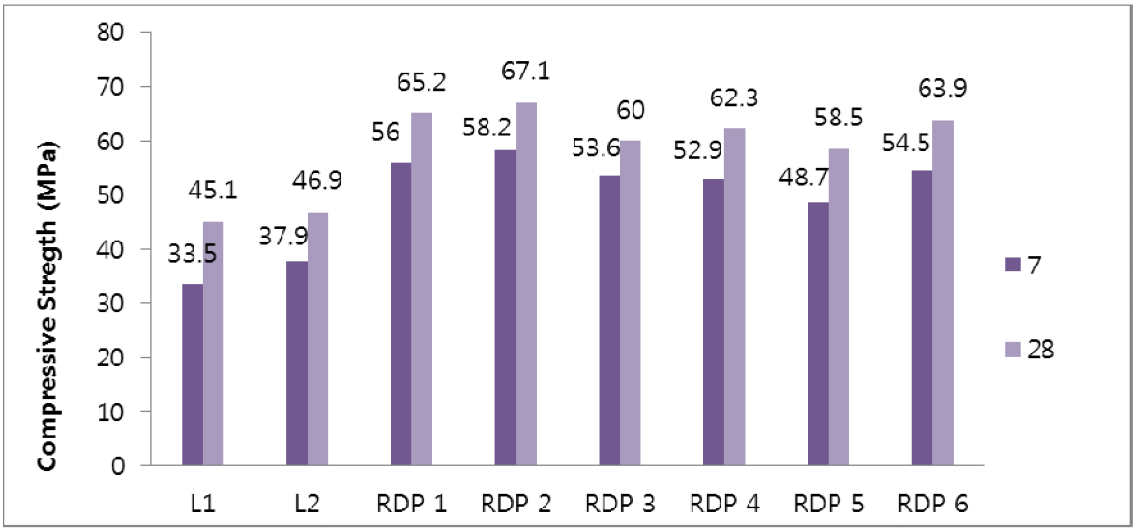

Fig. 7 Compressive Strength of Mortars at 7th and 28th days

Bulk density and air content of fine grained concretes prepared with redispersible powders had similar test results. But flow diameters and consistency of mortars are dissimilar. Some of the concretes showed plastic consistency and others showed self-leveling behavior. Test Results are shown in Table 10. Flexural and compression test results of polymer modified fine grained concrete mixes at 28 days are presented at Figs. 6 and 7.

Mixture RDP 2 prepared with redispersible powder 2 had the highest flexural strength. Mixture L1 and L2 prepared with latex emulsion showed lower flexural strength than mixtures prepared with redispersible powders for constant W/C. Mechanical properties of matrix material directly affect the properties of textile reinforced cementitious composite. Despite the superior properties of textile materials we have, we can't obtain the best performance from TRCC materials if matrix material doesn't show high strength. At the production process which will be performed with new machine. Mixture RDP 2 can be used because its high mechanical properties and appropriate consistency. Mixture RDP 2 had the highest bulk density in the fresh state and showed higher mechanical properties.

L1 had higher flexural strength than L2 although having higher water/cement ratio. This is because the higher the Tg and MFFT temperature, the more rigid the polymer (Ohama 1995). Mortars modified with more rigid polymers have higher strength than modified with flexible ones. Latex 1 has 18 °C Tg and MFFT values. Latex 2 is a more flexible material because Tg and MFFT values are -10 and 0 °C.

4. Discussion

4.1 Repair mortars

Researchers suggested performance criteria for durable repair in Manual of Structural Maintenance (Hong Kong Housing Department 1987). They agreed that, for non-structural or protective repair, there isn't any requirement for compressive strength due to potential cracking of cement. Performance criteria indicate that there is a significant correlation between tensile strength and field performance. According to this, manufacturers offer applying flexural tests (indirect tensile test) to their customers on the 4×4×16 cm mortar bar specimens since it can be easily performed than a direct tensile test.

Technical specifications for repair mortars were proposed in the same performance criteria and repair mortars are classified into three groups due to their seven characteristics. Compressive strength at 28 days and minimum tensile strength at 7 days were among them. Researchers wanted to compare strength values derived in this with performance criteria limits. Results showed a wide variation in the mechanical properties of the selected cement based repair mortars. It should be noted that the mechanical properties of selected repair materials were generally within acceptable range due to performance criteria except mixture 8. This mixture had very low mechanical properties.

In this study, the shrinkage test results indicated that non-shrinkage ready mixes made higher shrinkage. Considering dimensional stability and cracking risk of repair, usage of non-shrinkage repair mortars is highly effective. High shrinkage rates decreases the capacity and lowers the success of repair. In order to get a better performance and stability in repair projects, repair mortars should make little or no shrinkage as mentioned in technical data sheets. After applying the repair material to old concrete, properties of structural element must be similar to pre-damage status and should not have lost by time. Due to the performance criteria suggested by Poston, Kesner and Emmons (1998), maximum free drying shrinkage strain shouldn't exceed 0.04% at the end of 28 days. Researchers suggested this value to achieve a high durable crack free repair. All of the mortar mixes used in this study had shrinkage strain lower than 0.04% and conforms to related performance criteria as seen in Fig 5.

The results of alkali silica reaction tests show that some commercial repair mortars have potential reactivity due to ASR and may show deleterious expansions in the field. This significant mortar expansions lead to serious damages and ends up with failure of repair and construction .The presence of silica fume lowers the expansions under acceptable limits at the end of 14 days (Aydin and Yildirim 2012). Although ready mix 5 and 6 had contains silica fume, they showed significant expansions upper limits due to alkali silica reaction. The reason for this is reactiveness of sand due to ASR. Permeability of repair material should be considered before selection because an impermeable mortar has better durability performance. Aggressive environments cause durability problems in cementitious structures and this ends up with damage and collapse before predicted service life. The alkali silica reaction is the most destructive one. There are several alternatives to control or even stop this destructive ASR expansion. These alternatives are: avoiding usage of reactive aggregate, usage of low cement content, usage of chemical additive, and partially replacing of alkali cement by supplementary materials. The best option for repair mortars is usage of non-reactive sand or making the ready mixture non-reactive by using supplementary materials like silica fume, fly ash or blast furnace slag.

4.2 Fine grained concretes

Matrix composition of TRCC should have suitable consistency for planned production processes and mechanical properties for load-carrying capacity of composite elements. It should not be too plastic or too flowable to achieve best product. Over the years, several types of polymer modified cement based repair mortars have been developed and used in both repair/rehabilitation

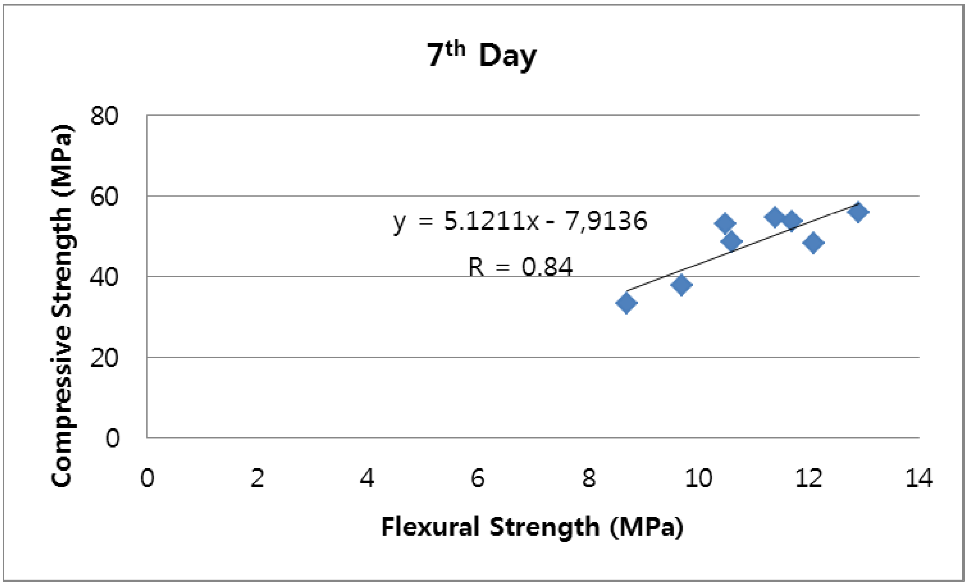

Fig. 8 Relation between compressive and flexural strength on 7th day

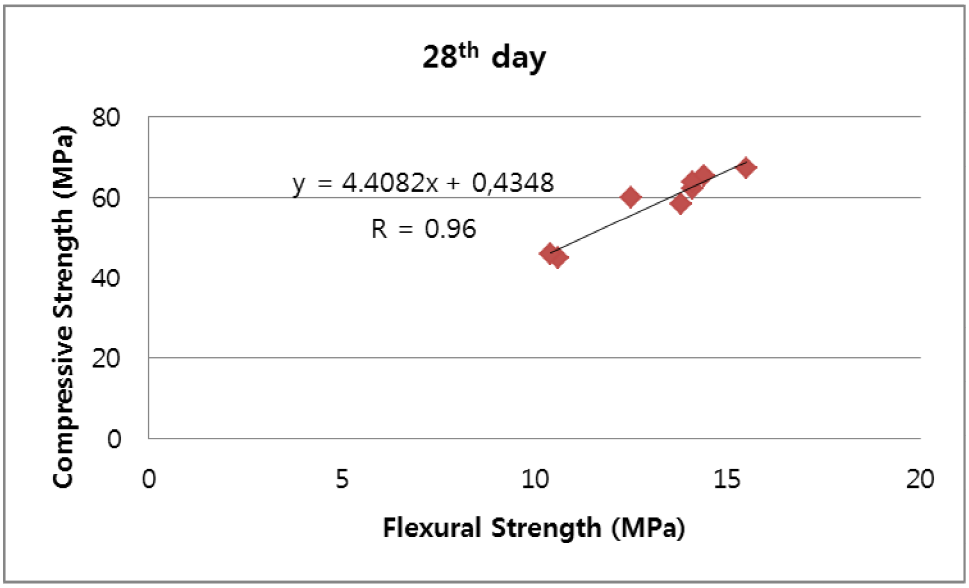

Fig. 9 Relation between compressive and flexural strength on 28th day

of concrete structures and TRCC composites. Although these materials have enough and sometimes high strength, they may develop unexpected deterioration problems when used in severe environments. This leads to unconformity in properties, such as drying shrinkage strain between repair material and the concrete substrate.

In the present work, different polymer modified mixtures were designed. Latex polymers and redispersible powders were used to compare their performance. Polymer modified fine grained concretes prepared with 8 different polymers showed distinct properties. All of them achieved high flexural strength. Especially mixtures prepared with redispersible powder polymers showed high strength properties. These mixtures can be alternative for repair mortars used in casting TRCC materials.

Relation between compressive and flexural strength at 7 & 28 days are shown in Figs. 8 and 9. Results show that there is a good correlation for all the 8 fine grained concretes. This correlation becomes higher at 28 days with a regression number of 0.96. Polymer modified fine grained concretes have lower compressive but higher flexural strength. They differ from normal concretes from this aspect. Because Compressive/Flexural Strength (C/F) ratio is generally 8-11 in normal concretes and mortars but this ratio becomes 5–4 in polymer modified mortars. Flexural strength increases while compressive strength decreases as internal structure changes and polymers make film formation. At 7th day polymer film formation hasn't completed yet so this ratio was bigger. At the end of 28 days flexural strength increased but compressive strength didn't increase as much. So these values became closer and the C/F ratio reduced.

Researchers offer to prepare mortars used in TRCC on their own because ready mix repair mortars doesn't show superior performance in the field as mentioned before. Designed mortars can be easily controlled by adding different materials to the mixtures. Researchers should be aware of designing the right mixes for the specific production technique and repair of structures.

5. Conclusion

In this study, the results showed that some of the ready mixed repair mortars used for producing TRCC have potential reactivity due to ASR and some of them didn't show sufficient flexural performance. Upon to this findings, testing of ready mixed mortars due to mechanical and durability properties before using is very crucial. In addition, the importance of environmental impact while using these mixtures should be well understood. Using laboratory designed matrices for TRCC will be better and useful to achieve desired properties. TRCC matrix should meet specific requirements due to production technique, mechanical properties and durability of textile material.

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