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Effect of polymer addition on air void content of fine grained concretes used in TRCC

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

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

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Abstract. Textile Reinforced Cementitious Composite (TRCC) became the most common construction material lately and have excellent properties. TRCC can be employed in the manufacture of thin-walled facade elements, load-bearing integrated formwork, tunnel linings or in the strengthening of existing structures. These composite materials are a combination of matrix and textile materials. There isn't much research done about the usage of polymer modified matrices in textile reinforced cementitious composites. In this study, matrix materials named as fine grained concretes ($d_{max} \leq 1.0$ mm) were investigated. Air entraining effect of polymer modifiers were analyzed and air void content of fine grained concretes were identified with different methods. Aim of this research is to study the effect of polymer modification on the air content of fine grained concretes and the role of defoamer in controlling it. Polymer modifiers caused excessive air entrainment in all mixtures and defoamer material successfully lowered down the air content in all mixtures. Latex polymer modified mixtures had higher air content than redispersible powder modified ones. Air void analysis test was performed on selected mixtures. Air void parameters were compared with the values taken from air content meter. Close results were obtained with tests and air void analysis test found to be useful and applicable to fine grained concretes. Air void content in polymer modified matrix material used in TRCC found significant because of affecting mechanical and permeability parameters directly.

Keywords: fine grained concrete; polymer modification; air void; textile reinforced cementitious composite; defoamer

1. Introduction

Textile reinforced cementitious composites are a new kind of construction material with superior tensile strength and ductility properties (Soranakom and Mobasher 2009). Most commonly used technique of these composite is to strengthen steel reinforced concrete structures by application of externally bonded patches in the form of TRCC (Angelis *et al*. 2016). These composites are a new development where biaxial or multiaxial textiles are used in combination with matrices. These matrices were named as fine grained concretes by researchers (Daskiran *et al*. 2016, Brameshuber 2006). In previous studies, ready-mix mortars were used as a matrix material in the production of textile reinforced cementitious composites (Larbia 2013). Furthermore, new matrices were designed in laboratory and tests were carried out on these samples (Bramashuber 2002). Some of these matrices were polymer modified fine grained concretes (Bramesuber 2006). However, data about the mix design of polymer modified matrices and their physical or mechanical properties is limited. Also comparative experiments are insufficient in polymer modified fine grained concrete which are used as matrices in textile reinforced cementitious composites. Polymer modification causes air entraining in the cementitious mixtures. Thus, the aim of this study is to control the air content of polymer modified fine grained concretes and improve the mechanical and durability performance.

Polymer modified mortar and concrete show noticeable increase in the tensile and flexural strength but no improvement in the compressive strength compared to ordinary cement mortar and concrete. Polymer modifications of the fine grained concretes were investigated within the research ‘‘Textile Reinforced Concrete (TRC) – Technical Basis for the development of a New Technology’’ (SFB532) at Aachen University. According to the research, polymer modification enhances the flexural strength of fine grained concretes by film forming characteristics (Bramashuber 2002). Because of the small diameter of the dispersed particles, the polymeric dispersions can penetrate into the spaces between the textile filaments before the setting of concrete. Bonding of fine grained concrete and textile reinforcement is influenced by the polymers positively. These matrices also offer high chemical resistance (Walk 2003). Also, polymer modified fine grained concretes provide a good workability over conventional mortar and concrete (Ohama 1995). In contrast to ordinary cement mortar and concrete, the resistance of polymer modified fine grained concretes to bleeding and segregation is excellent in spite of their larger workability characteristics. Polymer modified fine grained concretes have a structure in which the capillary pores can be filled with polymers or sealed with continuous polymer

*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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films (Ohama 1995).

In most polymer modified fine grained concretes, a large quantity of air is entrained compared to conventional cement mortar and concrete. Air entrainment occurs in polymer modified fine grained concretes due to addition of polymer additives into the mixtures. An excessive amount of entrained air causes a reduction in strength and must be controlled by using proper defoaming agents. By using proper defoaming agents at suitable addition rates, air entrainment can be controlled and decreased considerably. Excess air entrainment also cause discontinuities of the formed polymer network structure and reduces the strength of the mortar and concretes. The air content of most latex modified mortars is in the range of 5 to 20%. Redispersible powder modified mortars have less air content than latex modified mortars. Latex modification causes much air entrainment because of the surfactants they have in their structure. Commonly used agents are insoluble oils, polydimethylsiloxanes and other silicones, certain alcohols, stearates and glycols. Powder defoamers are in principle oil based defoamers on a particulate carrier like silica. An essential feature of a defoamer product is to spread rapidly on foamy surface and destabilize the foam. This causes rupture of the air bubbles and breakdown surface foam (Hubbe 2012). In this study, defoamer material was added to the mixtures cast with both latex and powder polymers. Performance of defoamer material in combination with different polymers was investigated, since there is no literature describing systematically the influence of defoamer addition in reducing air content of mixtures cast with different polymers at varied addition rate (Hofer 2000).

Air void analyzer was used to analyze the amount of entrained air in polymer modified fine grained concretes. Total air content, the spacing factor and the specific surface of the air bubbles are traditionally determined according to ASTM C457 wherein a manual method is described using either a point count or a linear-traverse method (Rosiwal method). These measurements are made on finely ground sections of the hardened concrete mounted under a microscope. The air void system (ASTM C457-90, EN480-11) is most often characterized and assessed in terms of the total air content, the specific surface and the spacing factor of the air bubbles. The total air content is the proportion of volume of air voids to the total volume of concrete, expressed as a percentage by volume. The specific surface is a calculated parameter representing the total surface of all voids divided by the total volume of voids (mm^{-1}). The spacing factor is defined by Powers as a parameter related to the maximum distance of any point in the cement paste from the periphery of an air void (Powers 1950).

Researchers investigated air entraining effect of polymers and effectiveness of defoamer materials in polymer modified fine grained concretes. In this research, the effect of different type of polymers on air content was investigated. Effect of air entraining on the mechanical performance of fine grained concretes were also investigated.

2. Materials and experimental methods

2.1 Materials

The cement used in this study was Portland cement CEM I 42.5 R, specified by European standard EN 197-1, 2000. The chemical composition, physical and mechanical properties of the cement and microsilica are shown in Tables 1 and 2 respectively.

Silica sand was obtained from a quarry in Istanbul, Turkey. Aggregate was silica sand with a specific gravity of 2.63 gr/cm^3, $d_{max} \leq 1.0$ mm. Particle size distribution was obtained according to related ASTM C136 standard and shown in Fig. 1.

Supplementary material used in the mixtures was silica fume. Two different latex polymers (emulsion) were used in the study. Also two different redispersible powders were used in the fine grained concrete mixtures. Typical properties of redispersible polymers are shown in Table 3 and latex polymers in Table 4.

Table 1 Chemical composition 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

Table 2 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	BET Method
		3950	200.000
Chemical Properties		**Cement**	**Silica Fume**
Setting Time (ASTM C191)	**Initial (min)**	129	-
	Final (min)	191	
Soundness (mm) (BS EN 196-3)		1,0	-

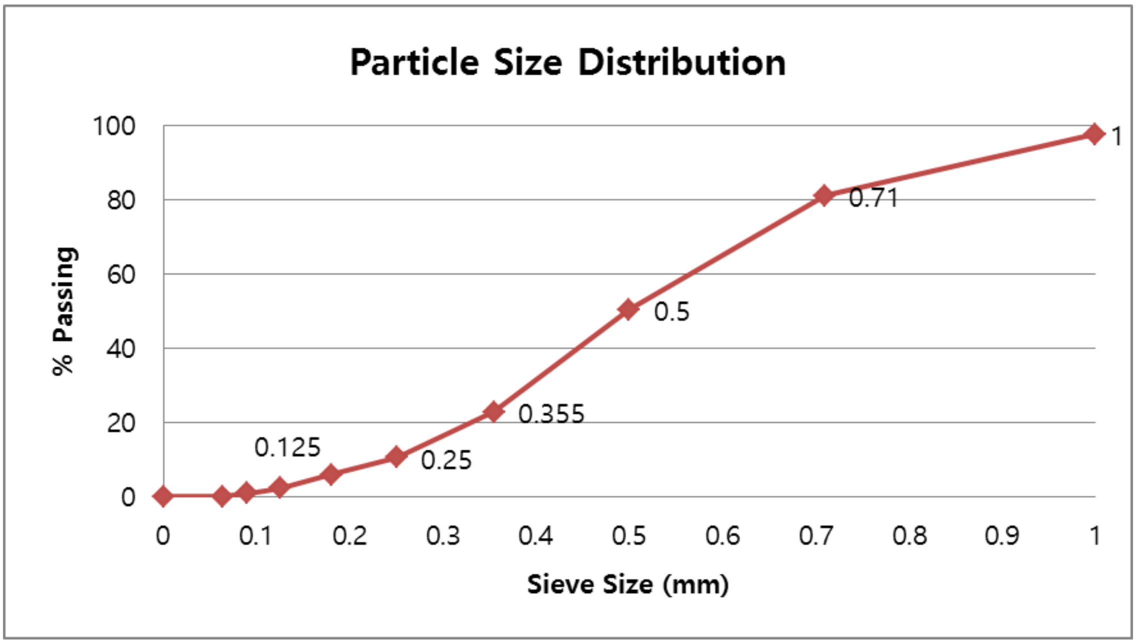


Fig. 1 Particle size distribution of aggregate

Table 3 Properties of redispersible polymer additives

Chemical Properties	RDP I	RDP II	Physical Properties	RDP I	RDP II
MFFT [*] (°C)	8	0	**Consistency**	Powder	Powder
Stabilizer	PVOH	PVOH	**Color**	White	White
Resistance to Alkali	High	High	**Density(g/l)**	320,0±75	540±70
pH	6.0-7.0	6.0-7.0			
Chemical Composition	VA/VeoVa Acrylic[**]	VA/VeoVa Copolymer [***]	**Ash Content (%)**	12,0±2	12,0±2

[*] MFFT: Minumum Film Forming Temperature
[**] VA/VeoVa Acrylic: Vinyl Acetate-Vinyl Versatate Acrylic
[***] VA/VeoVa Copolymer: Vinyl Acetate-Vinyl Versatate Copolymer

Table 4 Properties of latex polymer additives

Chemical Properties	Latex I	Latex II	Physical Properties	Latex I	Latex II
Tg [*] (°C)	15	-10	**Consistency**	Liquid	Liquid
			Color	White	White
pH	9.0-10.0	7.0-9.0	**Density(g/cm^3)**	1,03	1,04
Chemical Composition	Pure Acrylic	Styrene Acrylic	**Solid Content (%)**	47	57
			Viscosity (RVT 3/60)	300	200-700

[*]Tg: Glass Transition Temperature

Table 5 Properties of other chemical additives

	Chemical Composition	Density (gr/l)	Powder/Liquid	Ash Content (%)	Color	Water Solubility
Defoamer	Polyglicol	320,0	Powder	33	White powder	Insoluble
	Chemical Composition	**Density (gr/cm^3)**	**Powder/Liquid**	**pH**	**Color**	**Water Solubility**
Superplasticizer	Melamine Sulfonate	1,80	Powder	10,0	White Powder	Soluble

In order to see air entraining effect of polymers in fresh state, mixtures were prepared with defoamer and without defoamer. Defoamer was also used at the same rate to achieve comparable test results. Defoamer material was added to the mixtures at 0.4% rate in respect to total powder material.

A defoamer with a blend of polyglicols was used in this study to avoid air entraining effect of polymer additives. To achieve desired consistency and workability, a melamin sulfonate powder superplasticizer was used. Properties of defoamer and superplasticizer material are shown in Table 5.

2.2 Experimental methods

Fine grained concretes were casted into 4x4x16 cm sized molds, removed after 24 hours and cured in water at 20℃ 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 6.

Typical addition rate for redispersible powders and latex polymers are shown in Table 7. Redispersible powders were added to the mixture at a dosage of 1%, 3% and 5% respect to binder weight (cement + silica fume). Latex polymers were added to the mixture at a dosage of 10%, 15% and 20% respect to binder weight.

Table 6 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

Table 7 Quantity of the polymer admixtures in the mixture

Latex Polymer Series		Redispersible Polymer Series	
Latex I	**Latex II**	**RDP I**	**RDP II**
%10	%10	%1	%1
%15	%15	%3	%3
%20	%20	%5	%5

Mixtures have their own consistency parameters because polymers act differently in the mixture and influence flow parameters. Consistency 1: Self leveling (flow time to 20 cm diameter ,T_{20}). Consistency 2: Plastic consistency (flow table at 25 tapping). Tests were conducted using related standard ASTM C1437.

Mesh diameter of textile is very important while designing textile reinforced cementitious composites. Fine grained concrete mixtures should have appropriate workability properties. Water at the mixtures kept constant to compare test results. Water/cement ratio kept constant as 0.35 for all mixtures modified with either latex polymer or redispersible powders. 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. Air content of the selected mixtures were determined in hardened state using automated air void analysis method in accordance with ASTM C457-12. Results taken from air void meter and automated air void analysis were compared. Since automated air void analysis is used for concretes, researchers wanted to apply this method to fine grained concretes also. Similar test results were received from these two different methods.

3. Test results and discussion

Bulk density, air content and flow diameter tests were performed on fine grained concretes in fresh state. Compressive, flexural and air void analysis tests were performed on fine grained concretes in hardened state.

Table 8 Physical test results of latex polymer modified fine grained mortars

Polymer Admixture		Addition (%)	Bulk Density (gr/cm^3)	Air Content	Flow Diameter (cm)	T_{20} (sec)	Self-Leveling or Plastic Consistency
Latex I	Without Defoamer (%0)	10	1,64	12,0	20,0	8,0	SL
		15	1,38	14,0	17,5	-	PC
		20	1,47	13,0	20,0	-	PC
Latex II		10	1,74	9,0	29,0	1,1	SL
		15	1,85	6,5	29,5	1,3	SL
		20	1,88	6,0	29,0	1,0	SL
Latex I	With Defoamer (%0.4)	10	1,98	4,6	29,0	6,5	SL
		15	1,92	5,0	28,0	9,0	SL
		20	1,90	5,5	27,0	13,6	SL
Latex II		10	2,06	3,0	30,0	3,0	SL
		15	2,03	2,2	31,0	1,5	SL
		20	2,02	2,7	32,0	1,1	SL

*PC: Plastic Consistency
*SL: Self Leveling

Table 9 Physical test results of redispersible polymer modified fine grained mortars

Polymer Admixture		Addition (%)	Bulk Density (gr/cm^3)	Air Content	Flow Diameter (cm)	T_{20} (sec)	Self-Leveling or Plastic Consistency
RDP I	Without Defoamer (%0)	1	2,10	4.0	20.0	-	PC
		3	1,91	6.0	24.0	-	PC
		5	1,99	5.5	22.0	-	PC
RDP II		1	2,24	3.5	17.0	3.5	SL
		3	1,98	7.0	27.0	4.0	SL
		5	1,84	10.0	22.0	7.0	SL
RDP I	With Defoamer (%0.4)	1	2.19	1.8	24.5	4,0	SL
		3	2.14	2.4	23,0	5,0	SL
		5	2.14	2.1	22,0	6,0	SL
RDP II		1	2.34	1.7	19,0	4,5	SL
		3	2.12	2.4	23,0	9,0	SL
		5	2.13	2.1	21,0	12,0	SL

*PC: Plastic Consistency
*SL: Self Leveling

Moreover, observations made on the AVA (Air void analyser) micrographs and discussed in the following paragraphs.

3.1 Bulk density, air void content and flow table test results

Bulk density, air void content, flow diameter and T_{20} flow time (flow time until 20 cm diameter) tests were performed on mixtures cast with and without defoamer according to related ASTM C185, ASTM C231 and ASTM C230 standards. Results are shown in Tables 8 and 9.

Based on these 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 (Ohama 1995). The amount of air entrainment in the fine grained concretes modified with latex polymers was higher than modified with redispersible polymers. Fine grained concretes modified with Latex I with 15% polymer content without defoamer has the highest air content value which is 14%. This is because surfactants found in chemical composition of latex polymer. As the amount of surfactant in the latex polymer increase, air entraining effect of the polymer increase too (Negim 2014).

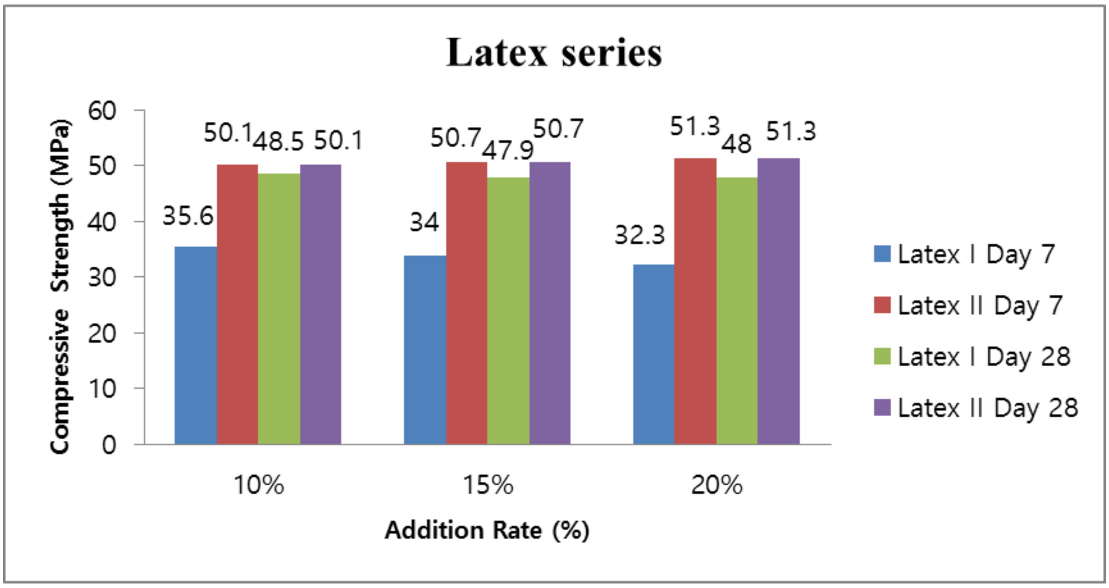


Fig. 2 Compressive strength of latex series

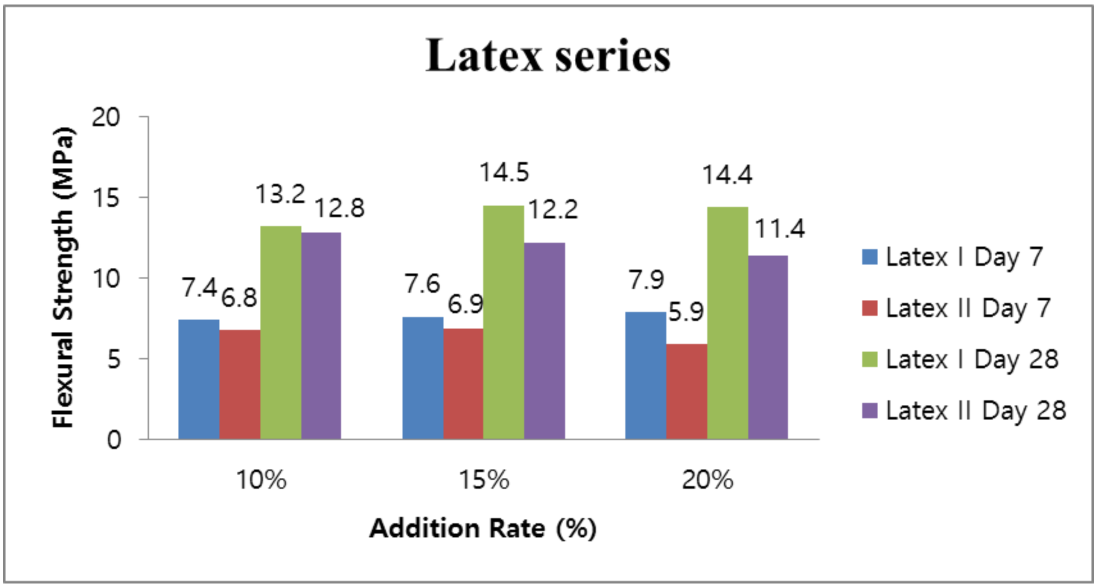


Fig. 3 Flexural strength of latex series

As a result, the usage of polymers of different origin (latex or redispersible powder) causes different air entraining effect.

Excessive air entrainment cause discontinuities of the formed monolithic network structure whose strength is reduced although some chemical reactions proceed effectively. Increase in air content results in decrease in strength and durability. To solve this problem, defoamer material was added to the mixtures. The amount of defoamer added to the mixtures were kept constant. With addition of defoamer to the mixtures, the amount of air was reduced in all series successfully. Air content was reduced to the level of conventional mortars. 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 were obtained by using flow table tests. Both latex polymer modified and redispersible polymer modified fine grained concretes had higher flowability when defoamer was used in the mixtures. When comparing latex modified series; mixtures with defoamer were more flowable than the ones without defoamer. Same results were valid in redispersible powder modified series. Mixtures cast with RDP I and with defoamer had higher flowability than mixtures cast without defoamer. Also consistency of the mixtures cast with RDP I

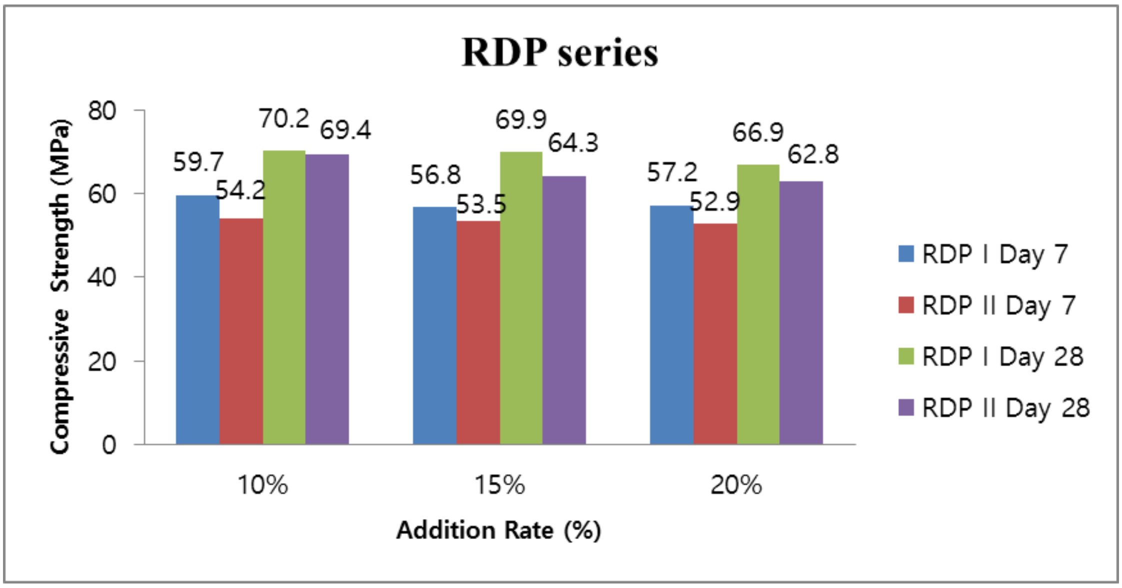


Fig. 4 Compressive strength of RDP series

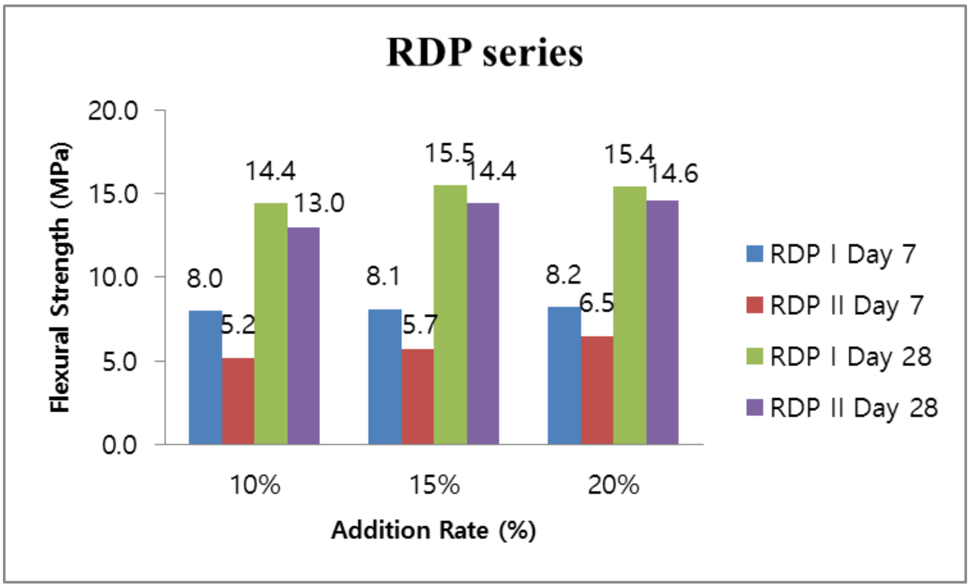


Fig. 5 Flexural strength of RDP series

changed plastic consistency to self levelling behavior in the usage of defoamer. These test results is caused by plasticizing effect of defoamer material in both latex modified and redispersible powder modified fine grained concretes. In conclusion, latex polymer modified mixtures had bigger flow table length than redispersible powder mixtures. This systematic test results is caused by ball bearing action of polymer particles, entrained air and dispersing effect of surfactants in polymer additives (Ohama 1995).

3.2 Compressive and flexural strength test results

Mechanical tests were performed according to ASTM C348 and ASTM C349 standards on fine grained concretes prepared with defoamer. Compressive and flexural strength of these samples are summarized in Figs. 2-5. Related tests were performed at 7th and 28th days after moist curing of 3 days and dry cure until test days.

3.2.1 Mechanical properties of latex series

Researchers showed in the further studies that polymer modification reduces compressive strength in mortars and concretes (Ali 2012). Latex polymers reduced the compressive strength more than redispersible powders in this study. This is because when latex polymers contains water in their composition, they need long period of time to get dry and make film formation in the internal structure (Afridi 2003). Also, increase in flexural and tensile strength

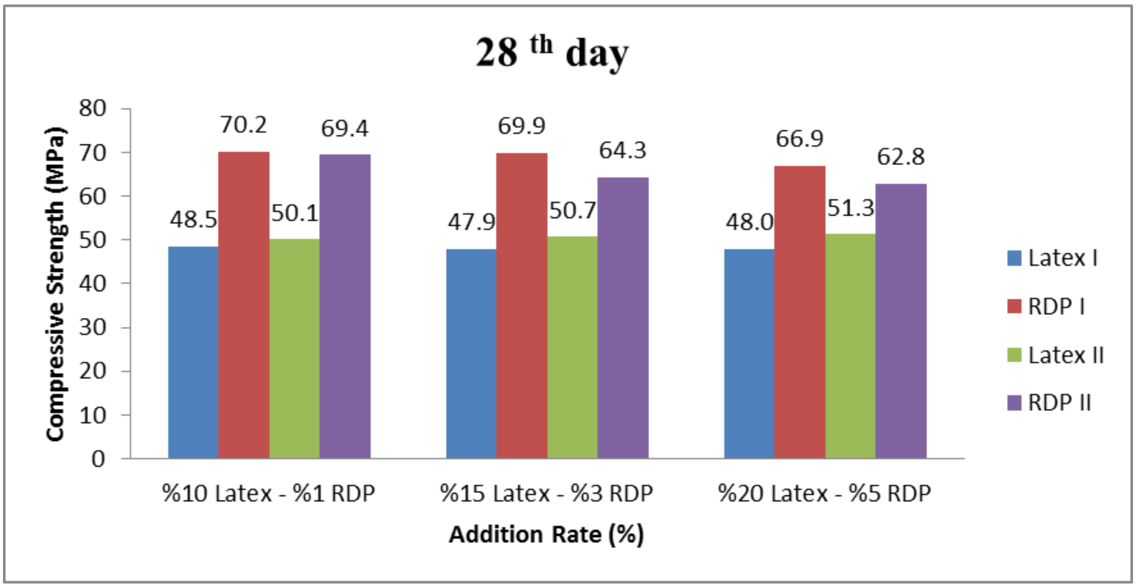


Fig. 6 Comparison of compressive strength

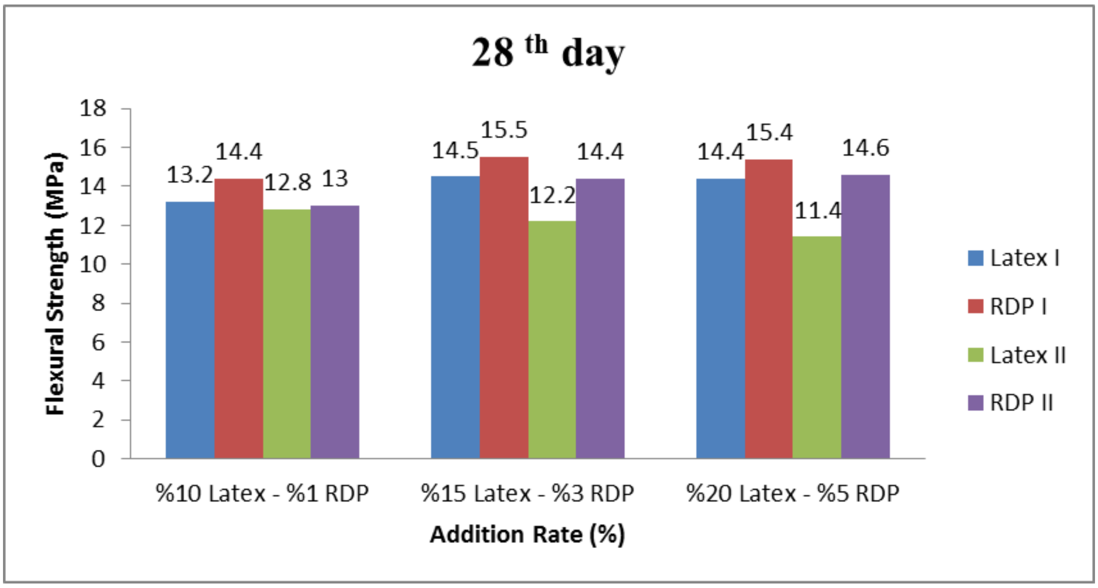


Fig. 7 Comparison of flexural strength

with decreasing compressive strength is interpreted in terms itself and overall improvement in cement-aggregate bond of the contribution of high tensile strength by the polymer (Ohama 1995). Mortars modified with more rigid polymers have higher strength than modified with flexible ones.

Latex I has 15℃ Tg and MFFT values. Latex 2 is a more flexible material because Tg and MFFT values are -10 and 0 ℃. Flexural and compressive strengths of the polymer modified fine grained concretes appear to reach a maximum value with rising glass transition temperature of polymer additives (Ohama 1995).

3.2.2 Mechanical properties of RDP series

Similar to latex systems, the properties of redispersible powder polymers modified systems are improved in comparision with ordinary cement mortar and these depends on the nature of polymer and polymer/cement ratio (Walters 1992). VA/VeoVa powder improves the flexibility of cement mortar significantly (Wang 2012). As the polymer content increased in fine grained concretes modified with redispersible polymers, compressive strength values decreased. Series prepared with RDP I at %3 content with defoamer had the highest flexural strength,15.5 MPa. Nearly the same flexural strength value for the same polymer at %5 content with defoamer was 15.4 MPa. Polymer modified fine grained concretes had lower compressive but higher flexural strength. They differ from normal concretes from this aspect. VA/VeoVa powder has air entrainment effect, making the air content of fresh mortar increase and the bulk density decrease (Wang 2011). Usage of defoamer resulted in controlling air void amount in the mixtures and having high mechanical performance.

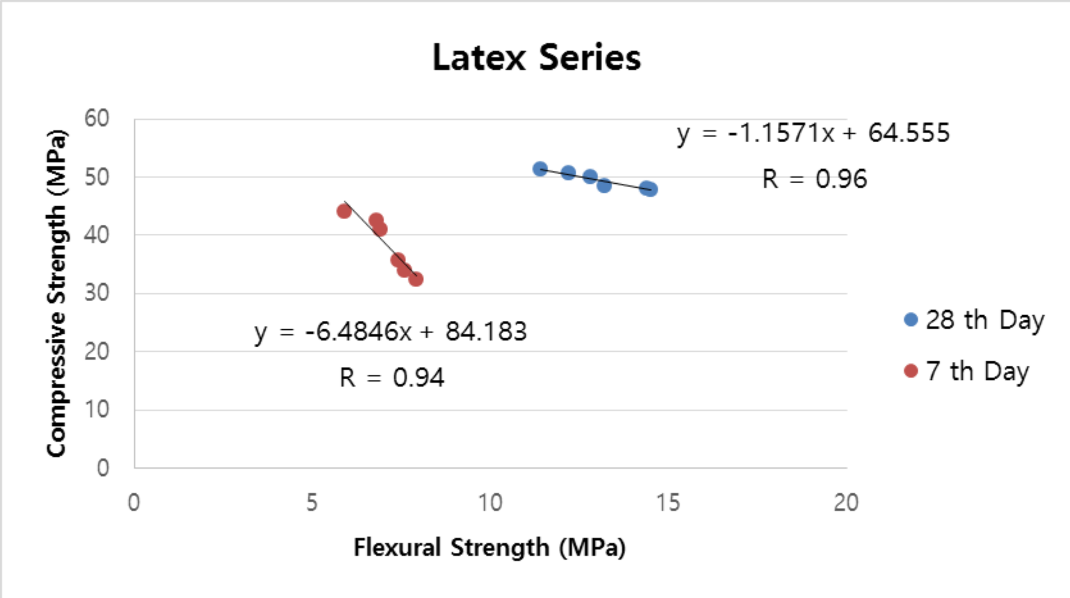


Fig. 8 Compressive strength of RDP series

Table 10 Results of automated air void analysis

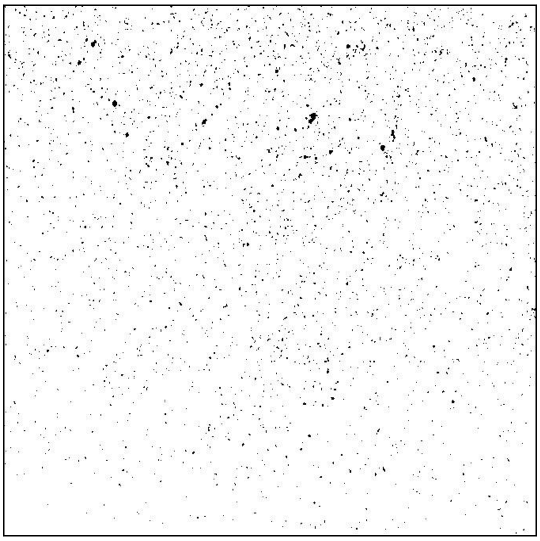
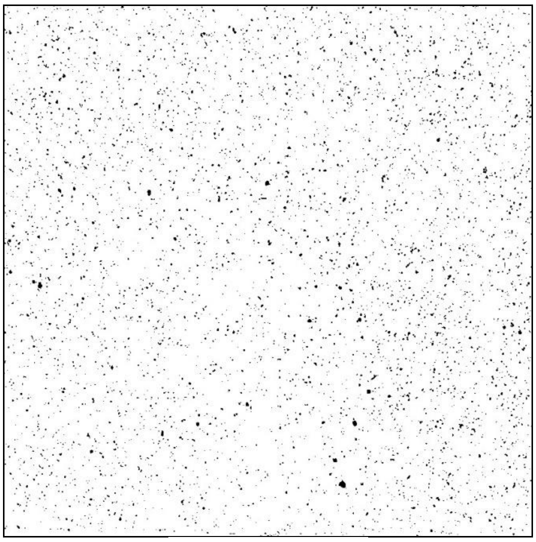
No	Polymer Modification	Addition (%)	Defoamer	Air content (%)	Specific Surface (mm^{-1})	Spacing Factor (mm)
1	RDP II	%5	√	4.6	28.08	0.2438
2	RDP II	%5	×	6.6	23.18	0.2517
3	Latex I	%15	√	5.0	42.01	0.1576
4	Latex I	%15	×	12.5	40.64	0.1075
5	RDP II	%1	√	2.5	30.43	0.2929

*√: With defoamer
×: Without defoamer

3.2.3 Comparison between latex and RDP series

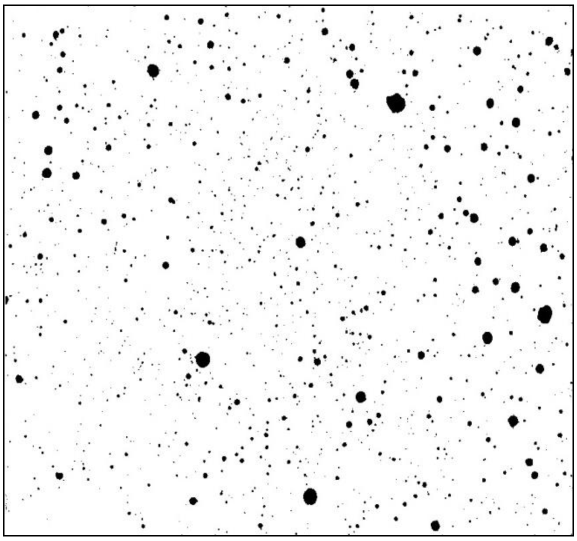
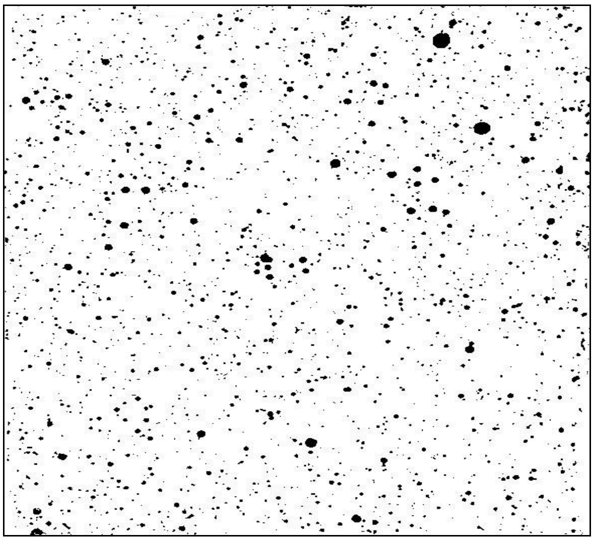
Mixtures prepared with RDP I at %1 content with defoamer had the highest compressive strength, 70.2 MPa.
Fine grained concretes modified with redispersible polymers had higher compressive strength than the others modified with latex polymers. RDP I fine concrete series had a little higher flexural strength values than RDP II series. Series prepared with Latex I had higher flexural strength than Latex II at all levels of polymer contents.

Latex modified mixtures had a bit less flexural strength than redispersible powder modified mixtures but both of the polymer modified mixtures had superior properties compared to conventional mortars. Compressive strength of mixtures cast with latex polymers was much lesser than the mixtures cast with redispersible polymers. Compressive and flexural strength at 28 days were compared and are shown in Figs. 6 and 7.
Relation between compressive and flexural strength at 7 & 28 days are shown in Fig 8. Results show that there is a good correlation for latex modified fine grained concretes. This correlation becomes higher at 28 days with a regression number of R=0.96. Difference in compressive strength behavior at 7 days is higher than that observed at 28 days depending on the type of Latex used. Polymer modified fine grained concretes have lower compressive but higher flexural strength. By film formation of polymers, flexural strength increases and compressive strength decreases. They differ from normal concretes from this aspect. Because Compressive/Flexural Strength (C/F) ratio is generally 8-11 in normal concretes and mortars, this ratio becomes 5 – 4 in polymer modified mortars.. At 7th day polymer film formation hasn't completed yet so this ratio was higher. At the end of 28 days flexural strength increased but compressive strength didn't increase likewise. Thus, these values became closer and the C/F ratio reduced. When the C/F of mortar is higher , brittleness of cement mortar is bigger (Wang 2012).
As the C/F ratio decreases, flexibility of cement mortar increases. From this aspect, polymer modified mortars are more flexible materials than conventional mortars.

With defoamer Without Defoamer

Fig. 9 Latex I at %15 Level

With defoamer Without Defoamer

Fig. 10 RDP II at %5 Level

3.3 Automated Air Void Analysis (AVA) test results

Automated air void analysis applied on selected and comparable mixtures. Results are shown in Table 10. Air content, specific surface and spacing factor parameters were obtained from the analysis. Fine grained concretes cast with Latex I polymer at 15% rate had the highest air content among these selected mixtures. Specific surface of latex polymer modified mixtures were higher than RDP modified mixtures. Spacing factor of RDP modified fine grained concretes were higher than latex modified fine grained concretes.

Mixtures cast with latex polymers had higher specific surface than mixtures cast with RDP polymers. When specific surface goes higher, air voids become thinner. It can easily be seen that mixtures cast with latex polymers had thinner air bubbles as shown in Fig. 7. As the spacing factor decreases, space between air voids becomes closer to each other. Since spacing factor values are higher in latex modified fine grained concretes, air voids are closer and air content was much higher than RDP modified concretes. It can easily be seen that mixtures cast with RDP polymers had larger air bubbles as shown in Fig. 8.

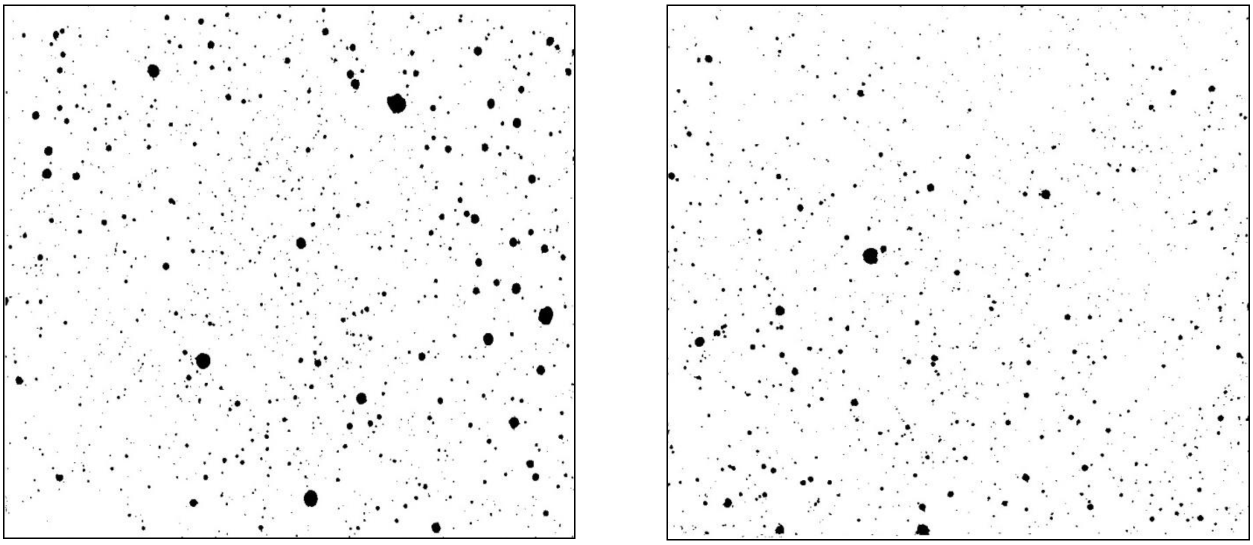


Fig. 11 RDP II with defoamer

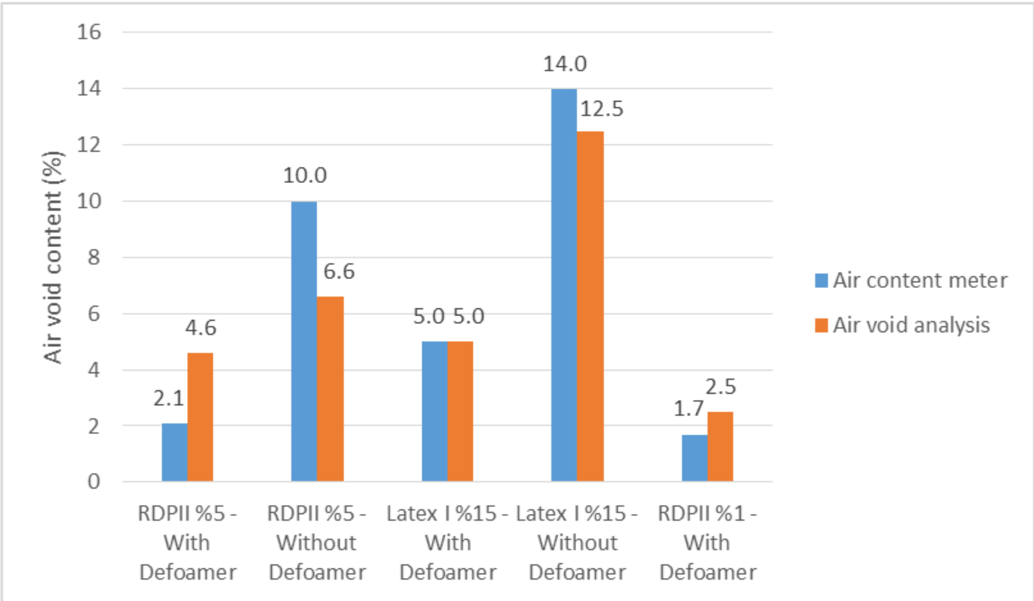


Fig. 12 Comparison of air void content parameters

This is probably because; latex polymers have monomers which have smaller particles than monomers in redispersible polymers. Monomers with smaller size disperse easily into internal structure and results in thin, close and well dispersed air voids. Also, dispersing effect of surfactants in latex polymers contributes to this effect.

Mixtures cast with RDP II with defoamer but at different rate was compared in Fig 8 and 9 below. Fine grained concretes cast with 1% RDP II polymer had lower air content than fine grained concretes cast with 5% RDP II. When spacing factors of these two mixtures were compared, 1% RDP II series had higher value and it had lower air void content.

Results taken from air content meter and automated air void analysis are compared and can be seen in Fig. 12. It can be seen that nearly close test results were achieved within both methods. Automated air void analysis can be used in hardened mortars for comparable test results.

5. Conclusions

In the study, air void parameters of polymer modified fine grained concretes designed for the use in TRCC as the matrix were investigated. An extensive research has been proposed in this study.

- Defoamer material successfully reduced the amount of air entrained in all polymer modified fine grained concretes.

- Defoamer had plasticizing effect on fine grained concrete mixtures and consistency of some mixtures were changed plastic consistency to self-leveling behavior.
- Polymers with different origin and chemical composition showed dissimilar air entraining effect in fine grained concretes.
- Flexural strength increased in fine grained concrete mixtures by adding latex and redispersible polymers.
- Compressive strength decreased in mixtures by adding latex and powder polymers.
- As the polymer modification rate in mixtures increased, compressive strength decreased.
- Latex polymer modified fine grained concretes had lower compressive strength than redispersible polymer modified ones.
- Automated air void analysis method and air content meter showed similar test results.
- Thin section analysis taken from microscope showed air bubbles in mixtures prepared with redispersible polymers were separate and round, air bubbles in mixtures prepared with latexes were close and thin.

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