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Improving Durability of Concrete to Phosphoric Acid Attack

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ABSTRACT

This paper investigates the effect of microsilica, water proofer and super plasticizer on the durability of concrete to phosphoric acid attack, in addition to their sole and combined effects on workability, air content, modulus of elasticity, durability to freezing thawing, compressive strength and modulus of rupture after 28 days. Different microsilica, water proofer and super plasticizer contents were considered: 10%, 15% and 20% by weight of cement for microsilica, 0.4, 0.6 and 0.8 L for water proofer and 0.15, 0.2 and 0.25 L for super plasticizer. The water to cement ratio was considered to be constant in this study. The degree of acid attack was evaluated by measuring the percentage changes in weight of concrete cubes. The results showed that the combined effect of microsilica and water proofer was the best to enhance the durability of concrete to phosphoric acid attack without major effect on the response of concrete to other factors. The optimum concrete mixes were 10% microsilica with medium portions of water proofer.

KEYWORDS: Durability of concrete, Phosphoric acid attack, Microsilica, Water proofer, Super plasticizer, Workability.

INTRODUCTION

Every concrete structure should perform its intended functions through the expected life time of the structure, irrespective of external exposure conditions. The ability of concrete to withstand any environmental condition that may result in premature failure or severe damages is a major concern to the engineering professional. Acidic attack is one of the phenomena that may disintegrate concrete structures depending on the type and concentration of the acid. Certain acids, such as oxalic acid, are considered harmless, while weak solutions of some acids have insignificant effects. Although acids generally attack and leach away the calcium compounds of the paste, they may not readily attack certain aggregates, such as siliceous aggregates. Calcareous aggregates often react readily with acids. However, the sacrificial effect of calcareous aggregates is often a benefit over siliceous aggregate in mild acid exposures or in areas where water is not flowing (Chang et al., 2005). With calcareous aggregate, the acid attacks the entire exposed concrete surface uniformity, reducing the rate of attack on the paste and preventing loss of aggregate particles at the surface. Also, calcareous aggregates tend to neutralize the acid, especially in stagnant locations.

Sulphate attack is one of the world's wide problem that may cause gradual but severe damages to concrete structures and its mitigation techniques, and related testing methods are still being studied (Neville, 2004). Many researchers in the past decades covered the issue of sulphate attacks from different aspects (Zivica and Bajza, 2002; Zivica, 2004; Rozière et al., 2009).

To improve the resistance of concrete to different

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acid and salt attacks, many researchers used industrial byproducts as mineral additives in cement and concrete, such as fly ash and silica fume. The use of these artificial pozzolans can achieve not only economical and ecological benefits, but technical benefits as well. Nevertheless, it is also well known that mineral additives may reduce the early strength of concrete.

Hossain and Lachemi (2006) used volcanic ash and finely ground volcanic pumice based ASTM (Type I) and (Type V) blended cement concrete mixtures to investigate the deterioration of concrete due to mixed sulfate attack. Adesanya and Raheem (2010) used Corn Cob Ash (CCA) blended cement to investigate the durability of concrete to chemical attack involving H_2SO_4 and HCl. The results indicated that the use of CCA blended cement reduces the water absorption of concrete, and the resistance to chemical attack was improved as a result of the addition of CCA up to 15% replacement level, but this caused a decrease in permeability and a reduction in weight loss due to the reaction of the specimens with HCl and H_2SO_4 acid water.

Also, the role of permeability in sulphate attack was evaluated by Khatri et al. (1997). Resistance to sulphate attack was measured by determining the expansion caused in concrete specimens with exposure to 5% Na_2SO_4 solution. Concrete specimens were prepared from five binders; namely: Ordinary Portland Cement (OPC), High Slag Cement (HSC), Sulphate-Resistant Cement (SRC), OPC with 7% Silica Fume (SF) and HSC with 7% SF. It was found that the relative performance of concretes cannot be explained by either their permeability only or by only the chemical resistance of the binder. However, by combining the information on permeability and the chemical resistance of the binder, the relative performance of concretes can be estimated. Thus, both permeability and the type of the binder play an important role in sulphate attack.

Al-Akhras (2006) investigated the effect of metakaolin (MK) replacement of cement on the durability of concrete to sulfate attack. Three MK replacement levels were considered in the study: 5%, 10% and 15% by weight of cement. The degree of sulfate attack was evaluated by measuring expansion of concrete prisms, compressive strength reduction of concrete cubes and visual inspection of concrete specimens to cracks. The study showed that MK replacement of cement increased the sulfate resistance of concrete. The sulfate resistance of MK concrete increased with increasing the MK replacement level.

In this paper, improving the durability of concrete to phosphoric acid attack is investigated. Many countries in the world produce phosphoric acid from rock phosphate for use in agriculture and industry. The largest phosphorite mines are primarily found in the United States of America, Africa and the Middle East, especially in Morocco, Tunisia, Togo, Saudi Arabia and Jordan. Phosphoric acid is usually stored in concrete tanks. Significant deterioration of these tanks due to leakage of the acid could cause environmental and economical problems. Very high costs are involved in repairing such deteriorated structures in the world. Although the durability of concrete to resist phosphoric acid attack is an important subject, it is unfortunately not covered in literature. Katkhuda et al. (2010) investigated some effects of microsilica and water proofer on the resistance of concrete to phosphoric acid attack. In this paper, microsilica, water proofer and super plasticizer were used to study their sole and combined effects on the resistance of concrete to phosphoric acid attack in addition to their effects on workability, air content, modulus of elasticity, durability to freezing thawing, compressive strength and modulus of rupture after 28 days. Different microsilica, water proofer and super plasticizer contents were considered: 10%, 15% and 20% by weight of cement for microsilica, 0.4, 0.6 and 0.8 L for water proofer and 0.15, 0.2 and 0.25 L for super plasticizer. The degree of acid attack was evaluated by measuring the percentage changes in weight of concrete cubes.

Table 1. Properties of concrete mixes used

Mix	W/C	Cement (kg/m^3)	Micro Silica (MS) (%)	Water Proofer (WP)(L)	Super Plasticizer (SP) (L)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
M1: CM	0.64	411	---	---	---	555	1090
M2: CM- MS10	0.64	400	10	---	---	540	1060
M3: CM- MS15	0.64	394	15	---	---	532	1144
M4: CM- MS20	0.64	389	20	---	---	525	1035
M5: CM- WP 0.4	0.63	410	---	0.4	---	554	1087
M6: CM- WP 0.6	0.63	409	---	0.6	---	552	1084
M7: CM- WP 0.8	0.62	408	---	0.8	---	551	1080
M8: CM- SP 0.15	0.64	408	---	---	0.15	550	1080
M9:CM- SP 0.20	0.64	407	---	---	0.2	550	1080
M10:CM- SP 0.25	0.64	407	---	---	0.25	550	1079
M11: CM- MS 10-WP 0.4	0.63	399	10	0.4	---	539	1058
M12: CM- MS 10-WP 0.6	0.62	401	10	0.6	---	541	1062
M13: CM- MS 10-WP 0.8	0.62	400	10	0.8	---	540	1060
M14: CM- MS 15-WP 0.4	0.63	395	15	0.4	---	533	1046
M15: CM- MS 15-WP 0.6	0.63	395	15	0.6	---	533	1047
M16: CM- MS 15-WP 0.8	0.62	396	15	0.8	---	534	1049
M17: CM- MS 20-WP 0.4	0.63	390	20	0.4	---	527	1034
M18: CM- MS 20-WP 0.6	0.62	389	20	0.6	---	525	1031
M19: CM- MS 20-WP 0.8	0.62	388	20	0.8	---	524	1030
M20: CM- MS 10-SP 0.15	0.64	399	10	---	0.15	539	1057
M21: CM- MS 10-SP 0.2	0.64	399	10	---	0.2	539	1057
M22: CM- MS 10- SP0.25	0.64	399	10	---	0.25	539	1059
M23: CM- MS 15- SP0.15	0.64	394	15	---	0.15	540	1044
M24: CM- MS 15- SP 0.2	0.64	394	15	---	0.2	532	1045
M25: CM- MS 15- SP0.25	0.64	395	15	---	0.25	533	1047
M26: CM- MS 20- SP0.15	0.64	392	20	---	0.15	531	1040
M27: CM- MS 20- SP 0.2	0.64	392	20	---	0.2	531	1041
M28: CM- MS 20- SP0.25	0.64	393	20	---	0.25	531	1043

CM = Control Mix
MS = Micro Silica
WP = Water Proofer
SP = Super Plasticizer

Experimental Program

Materials

A local sulphate resisting cement (ASTM Type V) and microsilica were used in this study. The average SiO_2 content was 94%. The coarse aggregate used was gravel with 4.75 to 19.5 mm particle distribution. The specific gravity was 2.60 and water absorption was 3.95%. The fine aggregates used had a specific gravity of 2.49 and water absorption of 6.6%.

Water proofer was used to give maximum reduction in permeability. It is amber coloured liquid with specific gravity of 1.01 at 20 ^oC, viscosity of 26cP at 20 ^oC and pH of 9.5. Finally, a super plasticizer in a liquid form was used to improve the workability of concrete mixes and to allow an effective reduction in the free water content. It is based on a high grade, modified lignosulphonic acid derivative. It is a dark brown liquid with specific gravity of 1.16 at 20^o C and viscosity of 11.6cP at 20^o C. This super plasticizer can be used with all types of Portland cement including sulphate resisting cements.

Concrete Proportions and Specimens Preparation

Twenty eight concrete mixes were designed and used in this paper with different microsilica, water proofer and super plasticizer contents for investigation of their resistance in phosphoric acid solution. The mixes proportions are shown in Table 1. The water/cement (w/c) ratio was constant for all mixes at about 0.64 and the cement used was sulphate resisting cement (Type V) as stated earlier.

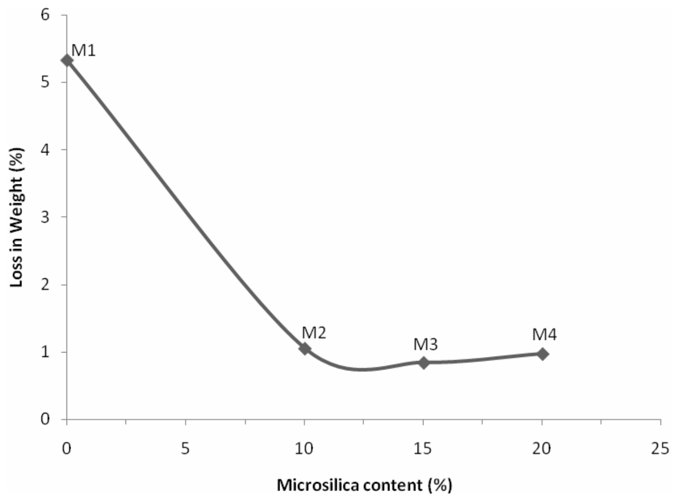

Figure 1: Effect of microsilica content on loss in weight after 15 cycles of wetting and drying in phosphoric acid

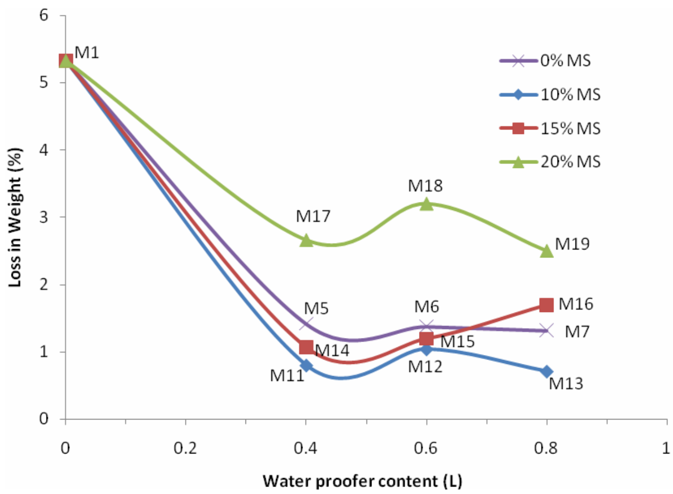

Figure 2: Effect of the combination of water proofer and microsilica contents on loss in weight after 15 cycles of wetting and drying in phosphoric acid

Mix (M1) was the control mix which contains 411 kg/m^3 of cement, 555 and 1090 kg/m^3 of fine and coarse aggregates, respectively. This mix does not contain any microsilica, water proofer or super plasticizer contents. The details of the concrete mixes are as follows:

1. Three concrete mixes (M2, M3 and M4) contain microsilica replacement levels at 10%, 15% and 20% by weight of cement.

2. Three concrete mixes (M5, M6 and M7) contain 0.4, 0.6 and 0.8 L of water proofer and without any replacement levels of microsilica.
3. Three concrete mixes (M8, M9 and M10) contain 0.15, 0.2 and 0.25 L of super plasticizer and without any replacement levels of microsilica or water proofer.
4. Nine concrete mixes (M11 to M19) contain 0.4, 0.6 and 0.8 L of water proofer with microsilica replacement levels at 10%, 15% and 20% by weight of cement.
5. Nine concrete mixes (M20 to M28) contain 0.15, 0.2 and 0.25 L of super plasticizer with microsilica replacement levels at 10%, 15% and 20% by weight of cement.

Conventional concrete specimens were utilized in this paper; i.e., cubes (150 x 150 x 150 mm) and beams (100 x 100 x 500 mm). Casting of concrete specimens was conducted in two layers. Each layer was compacted on a vibrating table to ensure good compaction. Fresh concrete was poured into steel molds and covered with wet burlaps for 24 h. Concrete specimens were then demolded, labeled as to the date of casting and mix type and stored in a water solution tank for curing. Three concrete specimens were cast and tested for each test condition to obtain average values.

Experimental Procedures

Although the aim of this study is to improve the durability of concrete to phosphoric acid attack by using microsilica, water proofer and super plasticizer, it is essential to investigate the effect of workability, air content, modulus of elasticity, durability to freezing thawing, compressive strength and modulus of rupture after 28 days on the performance of concrete mixes used. Accordingly, this study was conducted on 756 specimens and the following tests were performed:

1. Slump test (ASTM C143) to measure the workability of all concrete mixes.
2. Pressure method (ASTM C231) to measure the air content for non-air entrained concrete.
3. Unit weight of all fresh concrete mixes.
4. Compressive strength test after 28 days, where (150 x 150 x 150 mm) cubes were tested.
5. Flexure test to measure the modulus of rupture after 28 days, where (100 x100 x500 mm) beams and a symmetrical two-point loading setup, with a beam span of 400 mm, were used.
6. Modulus of elasticity test for all concrete mixes.
7. Durability of concrete to freezing and thawing by applying 400 cycles of freezing and thawing for all concrete mixes to measure the loss in weight.
8. Pulse velocity to all concrete mixes after applying 400 cycles of freezing and thawing.
9. Durability of concrete to phosphoric acid attack by applying 15 cycles of wetting and drying in phosphoric acid solution to measure the loss in weight. The test was conducted by immersing the concrete specimens in a water tank containing moderate to high concentration of phosphoric acid solution for about 16 hours. After that, the specimens were un-immersed and dried for about 8 hours. This procedure was repeated for 15 cycles.

RESULTS AND DISCUSSION

Durability to Phosphoric Acid Attack

The durability of concrete to phosphoric acid attack was measured by the loss in weight after 15 cycles of wetting and drying in phosphoric acid solution. The effects of microsilica, combination of microsilica and water proofer and combination of microsilica and super plasticizer contents were investigated.

Effect of Microsilica Content

The microsilica replacement levels by cement weight enhanced the durability of concrete to phosphoric acid attack. Fig. 1 shows the relationship between the percentage changes in weight of the concrete cubes and different microsilica contents. As expected, the control mix (M1) showed the least resistance to phosphoric acid attack, where the loss in weight was measured and found to be 5.32%. On the other hand, mix (M3) that contains 15% microsilica replacement showed minimum loss in weight with a value of 0.84%. A close observation of Fig.1 exhibits that very high percentages of microsilica beyond 15% increase the durability of concrete to phosphoric acid attack but less than that of below 15%.

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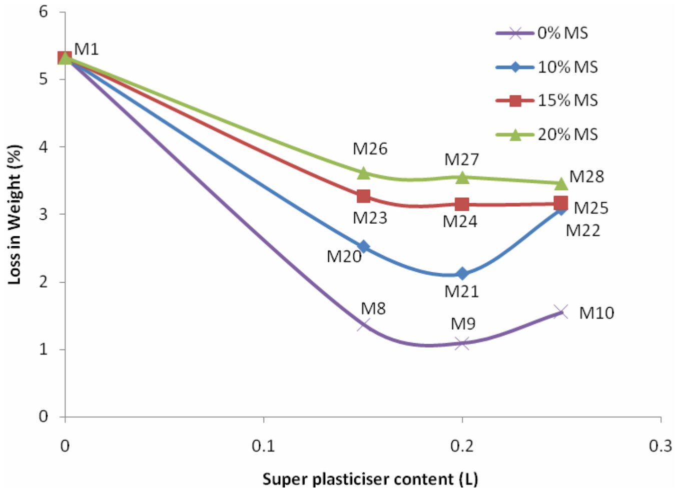


Figure 3: Effect of the combination of super plasticizer and microsilica contents on loss in weight after 15 cycles of wetting and drying in phosphoric acid

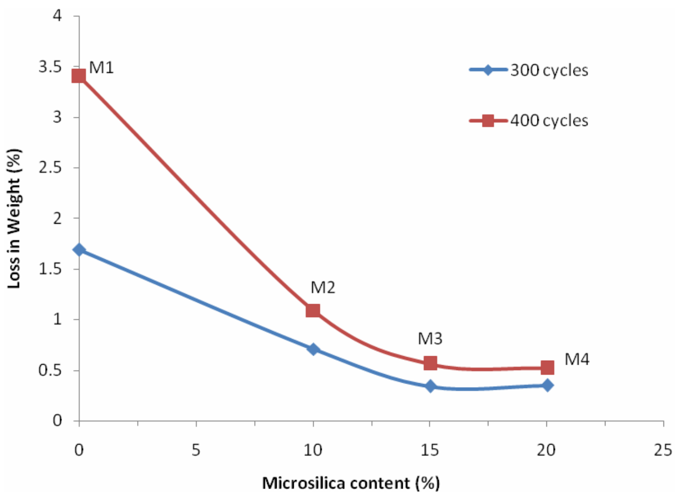


Figure 4: Effect of microsilica content on loss in weight after 300 and 400 cycles of freezing and thawing

Effect of Water Proofer and Microsilica Contents

Fig. 2 shows the combined effect of microsilica and water proofer contents on the durability of concrete to phosphoric acid attack. It is clear from the figure that the durability of concrete increases with the increase in the concentration of water proofer in the mix, and the combined effect enhanced the durability by different percentages. The optimum resistance for phosphoric acid attack for this group of concrete mixes was for mix (M13) that has 10% microsilica and 0.8 L of water proofer, where the loss in weight was 0.71%. Mixing water proofer with more than 15% microsilica results in higher loss in weight compared to that of below 15%, where the loss in weight for 20% microsilica with 0.4, 0.6 and 0.8 L water proofer was 2.66%, 3.2% and 2.5%, respectively.

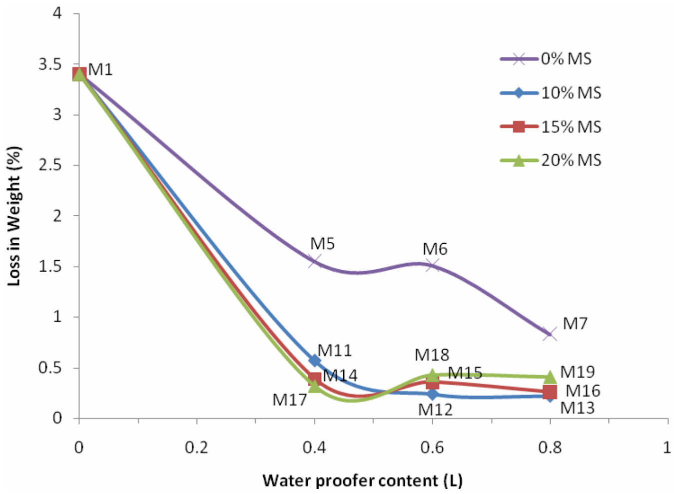


Figure 5: Effect of the combination of water proofer and microsilica contents on loss in weight after 400 cycles of freezing and thawing

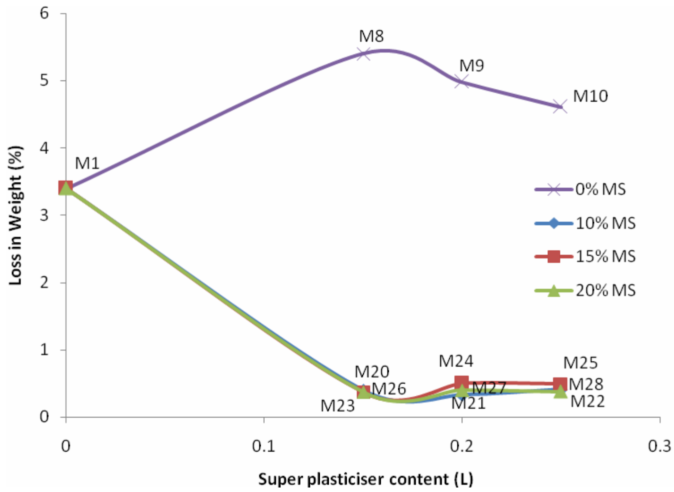


Figure 6: Effect of the combination of super plasticizer and microsilica contents on loss in weight after 400 cycles of freezing and thawing

Effect of Super Plasticizer and Microsilica Contents

The combined effect of super plasticizer and microsilica contents on the loss in weight of the test cubes is shown in Fig.3. Although it is apparent that the durability of concrete mixes with super plasticizer and microsilica is better than that of control mix (M1), the utilization of higher ratios of super plasticizer resulted in higher loss in weight of the test specimens, thus reducing the durability of the concrete. These results confirm the fact that when the super plasticizer concentration is increased, there is always a corresponding decrease in the water content. Also, it can be observed from Fig. 3 that 0% microsilica shows the optimum resistance to phosphoric acid compared to combined microsilica replacement levels with super plasticizer. The maximum loss in weight for this group of mixes was 3.62%, 3.55% and 3.46% for mixes (M26), (M27) and (M28), respectively, that contain 20% microsilica replacement; i.e., (0.15, 0.2 and 0.25 L of super plasticizer, respectively).

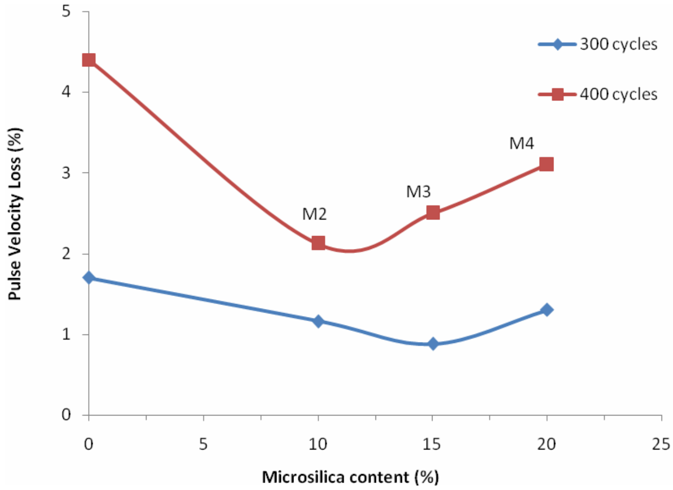


Figure 7: Effect of microsilica content on pulse velocity after 300 and 400 cycles of freezing and thawing

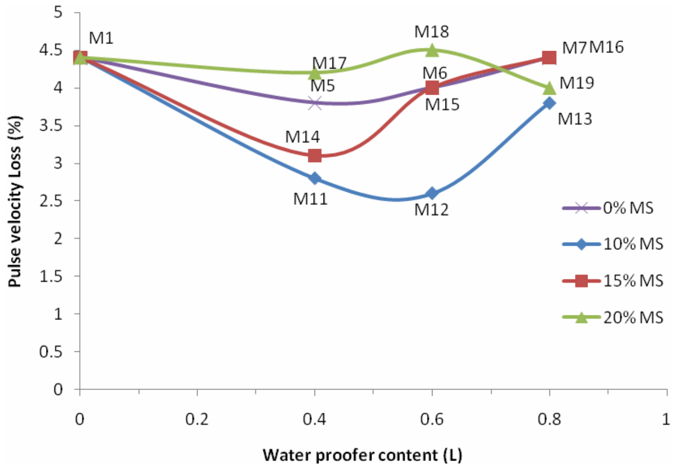


Figure 8: Effect of the combination of water proofer and microsilica contents on pulse velocity after 400 cycles of freezing and thawing

Durability to Freezing and Thawing

The durability of the twenty eight concrete mixes to 400 cycles of freezing and thawing was determined from loss in weight and loss in pulse velocity of the test specimens. Figs. 4, 5 and 6 show the relationship between loss in weight and microsilica, microsilica and water proofer and microsilica and super plasticizer contents, respectively, after 400 cycles of freezing and thawing. Figs. 7, 8 and 9 show the relationship between loss in pulse velocity and microsilica, microsilica and water proofer and microsilica and super plasticizer contents, respectively, after 400 cycles of freezing and thawing.

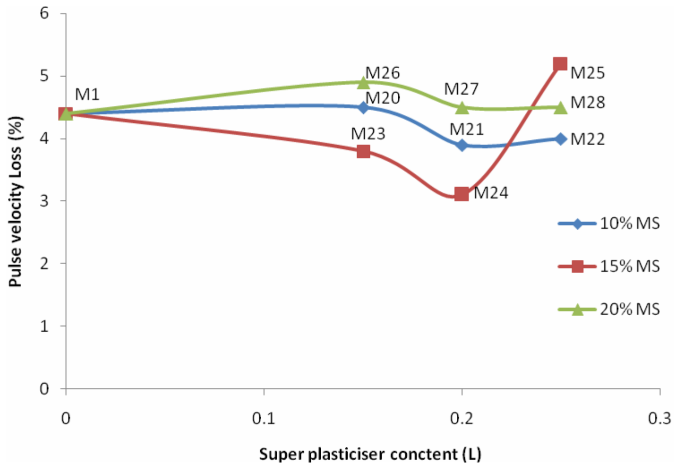


Figure 9: Effect of the combination of super plasticizer and microsilica contents on pulse velocity after 400 cycles of freezing and thawing

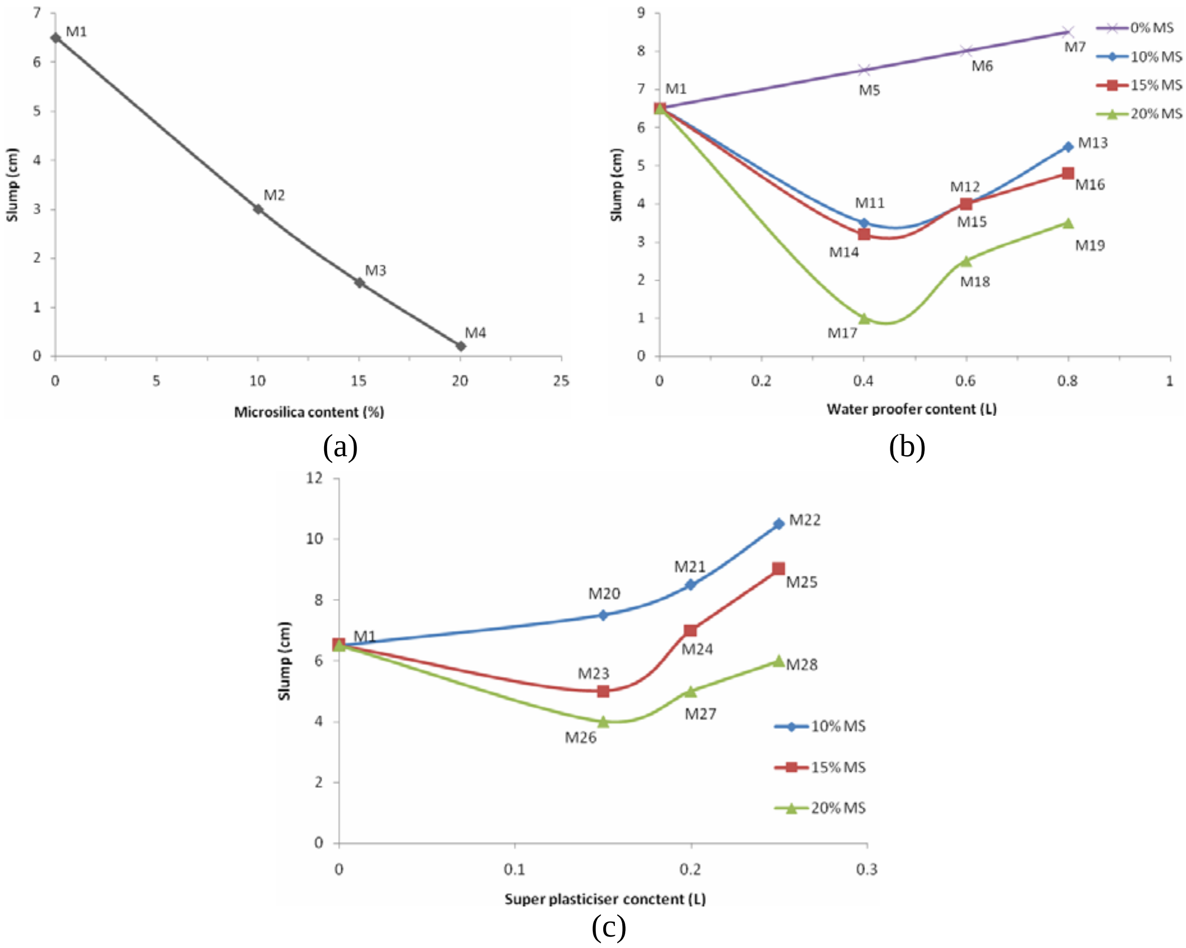
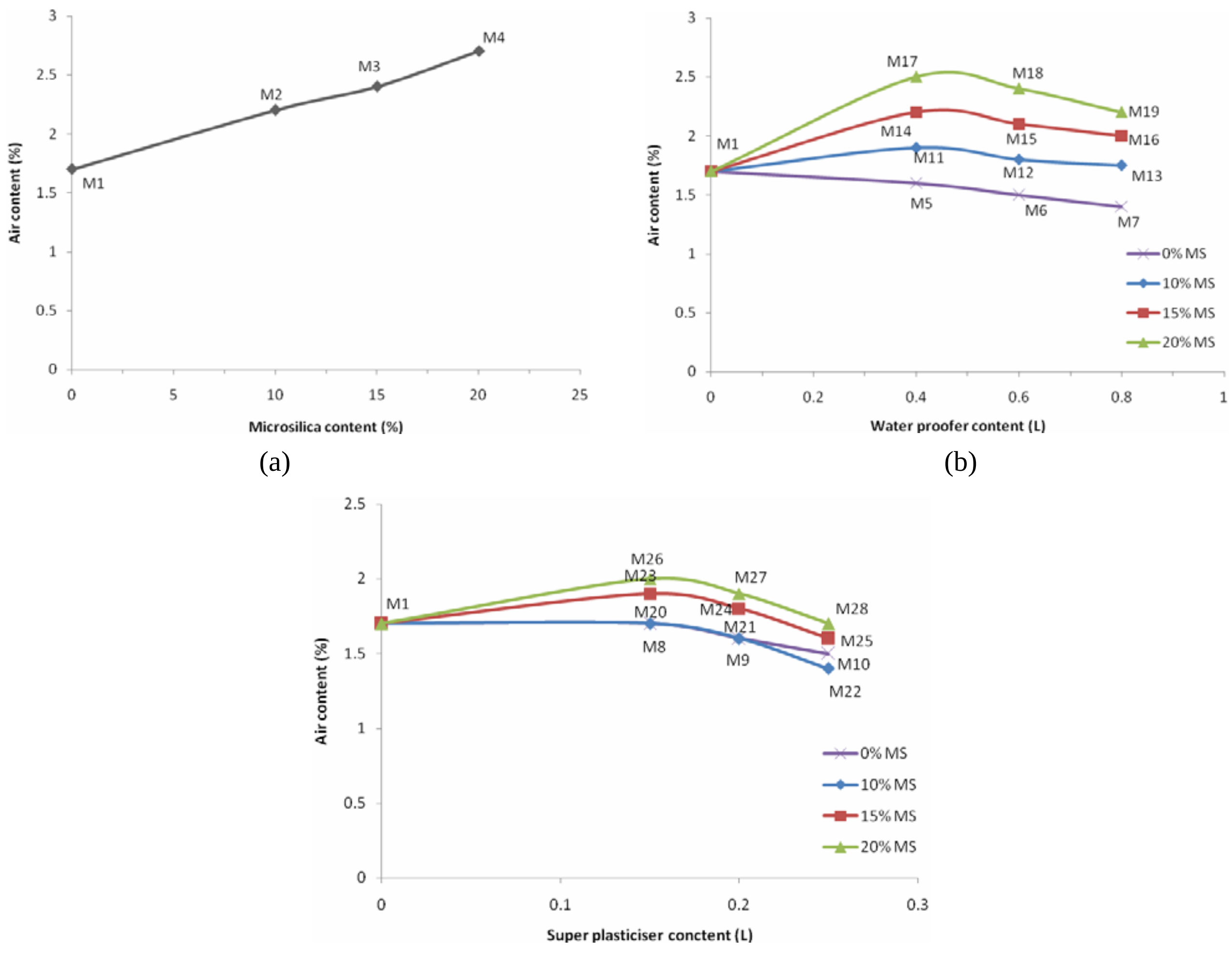


Figure 10: Effect on the workability of concrete due to (a) microsilica content, (b) water proofer and microsilica contents, (c) super plasticizer and microsilica contents



(c)

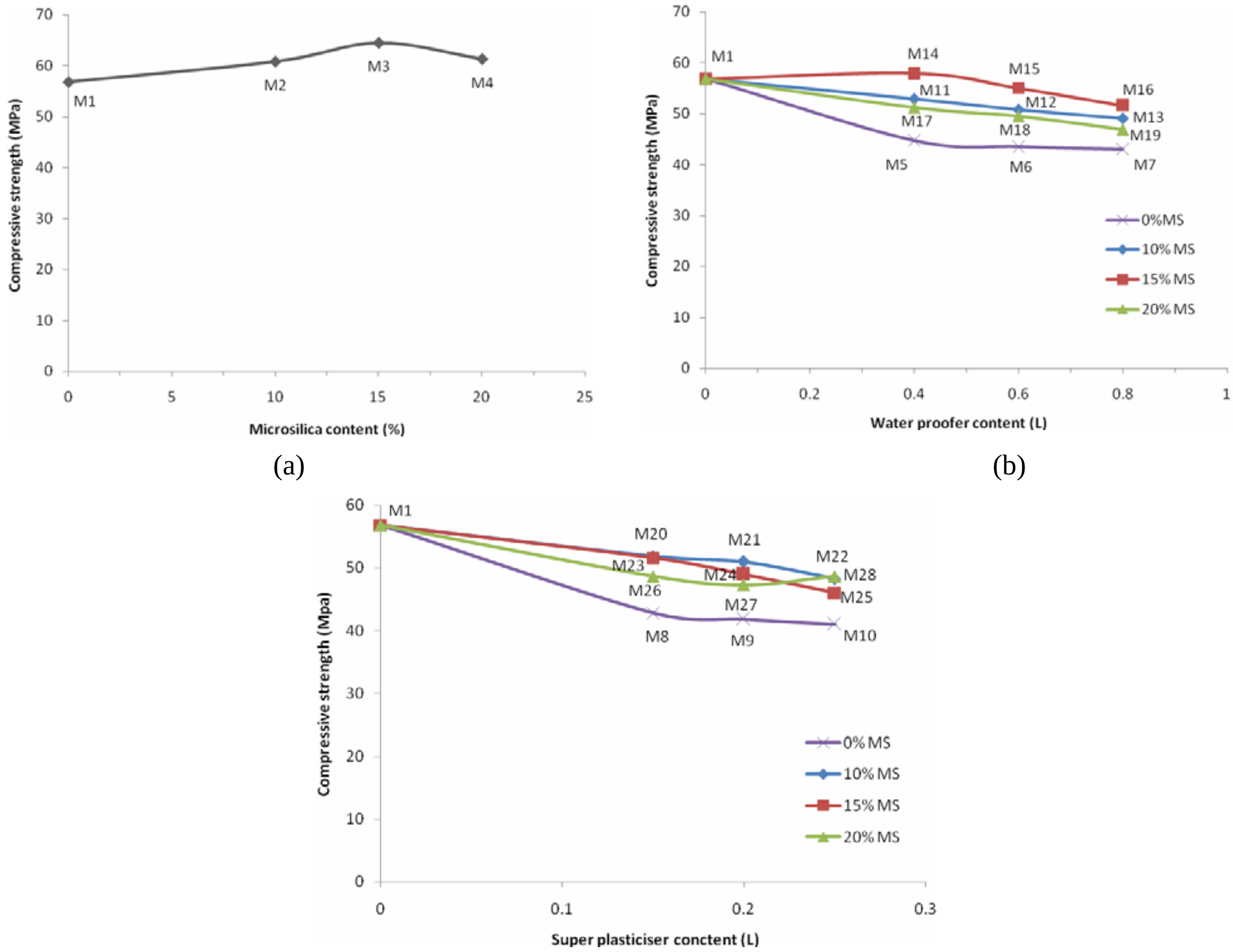
Figure 11: Effect on air content due to (a) microsilica content, (b) water proofer and microsilica contents, (c) super plasticizer and microsilica contents

Effect of Microsilica Content

Although increasing the microsilica replacement levels enhanced the durability of concrete to freezing and thawing as shown in Figs.4 and 7, the optimum resistance was for the mixes that have 15% microsilica. The loss in weight and pulse velocity showed that the control mix (M1) had the least resistance to freezing and thawing, where the loss in its weight was 1.69% and 3.4% and the loss in its pulse velocity was 1.7% and 4.4% after 300 and 400 cycles, respectively.

Effect of Water Proofer and Microsilica Contents

In general, the combined effect of microsilica and water proofer enhanced the durability of concrete as shown in Figs. 5 and 8. The loss in weight for 0% microsilica; i.e., mixes (M5), (M6) and (M7) was the highest compared with other microsilica replacement levels. It is clear from the figures that increasing microsilica contents beyond 15% with water proofer decreases the durability, where the highest loss in pulse velocity was for the mixes that contain 20% microsilica and water proofer contents less than or equal to 0.6 L.



(c)

Figure 12: Effect on compressive strength after 28 days due to (a) microsilica content, (b) water proofer and microsilica contents, (c) super plasticizer and microsilica contents

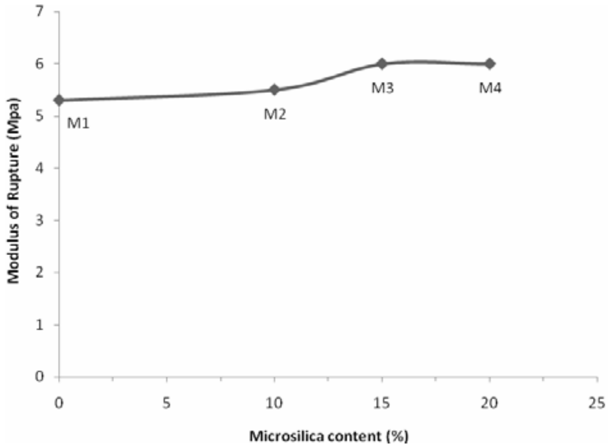
Effect of Super Plasticizer and Microsilica Contents

The effect of super plasticizer only had increased the loss in weight beyond the control mix (M1) as shown in Fig. 6, while the combined effect of microsilica and super plasticizer enhanced the durability significantly as shown in Figs. 6 and 9. This enhancement is less compared with the combined effect of water proofer and microsilica contents. The optimum combination of microsilica and super plasticizer for the durability of concrete in terms of weight loss is Mix (M23); i.e., 15% Microsilica and 0.15 L super plasticizer.

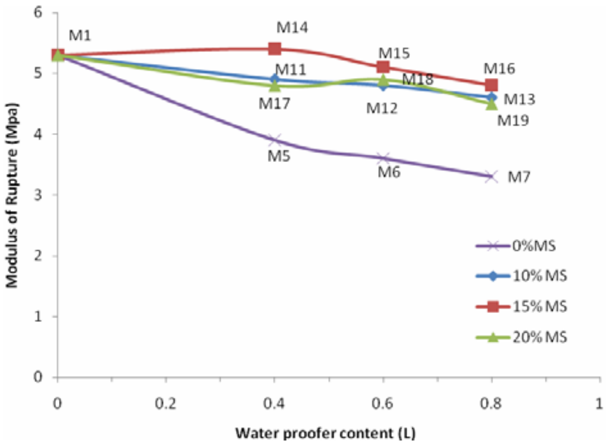
Workability and Air Content

The workability and air content of the 28 concrete mixes were measured using the slump test (ASTM C143) and the pressure method (ASTM C231) to investigate the effects of microsilica, water proofer and super plasticizer contents on those factors. Figs. 10 and 11 show the relationship between slump in (cm) and air content in (%) with different microsilica, water proofer and super plasticizer contents, respectively.

Fig. 10 shows that the control mix (M1) slump was measured to be 6.5 cm; i.e., medium workable concrete. The increase in the replacement of microsilica decreases the workability of concrete significantly as expected as shown in Fig.10 (a). The reduction in workability is attributed to the fact that microsilica is a very fine material and more absorbing. On the other hand, the combined effect of microsilica and water proofer contents increases the workability. Fig.10 (b) shows the increase of workability for mixes M11 to M19. The combined effect of microsilica and super plasticizer contents is shown in Fig. 10 (c).



(a)



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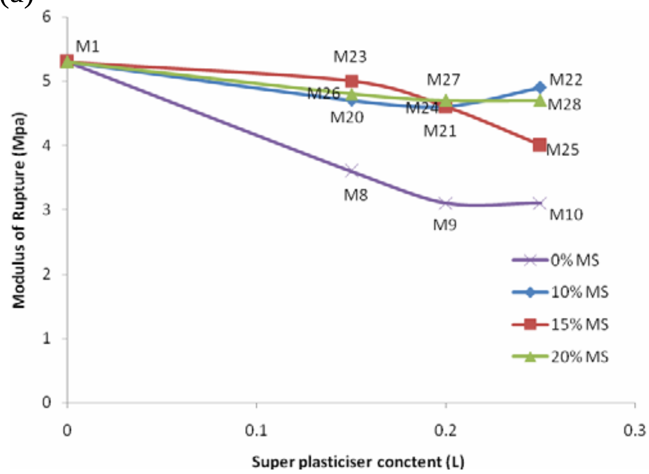
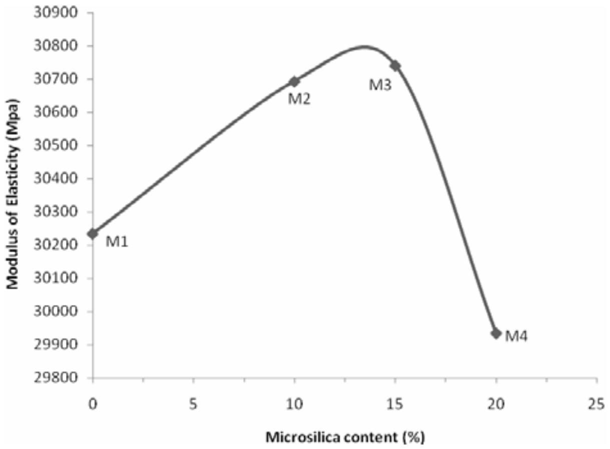


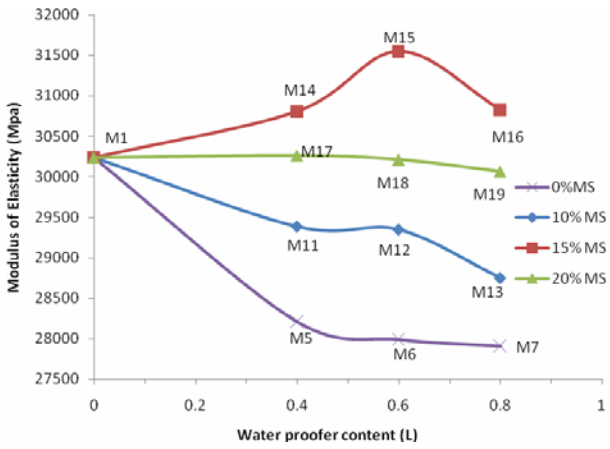
(c)

Figure 13: Effect on modulus of rupture after 28 days due to (a) microsilica content, (b) water proofer and microsilica contents, (c) super plasticizer and microsilica contents

The air content for non-air entrained concrete of the control mix (M1) was 1.7% as shown in Fig. 11. Increasing the microsilica content only increased the air content as shown in Fig. 11 (a); i.e., mixes (M2), (M3) and (M4). The combined effect of microsilica and water proofer contents increases the air content as shown in Fig. 11 (b). The highest increase in air content percentages was for mix (M17) that contains 20% microsilica and 0.4 L water proofer. On the other hand, Fig. 11 (c) shows the effect of microsilica and super plasticizer contents on the air content, which is an increase in air content.



(a)



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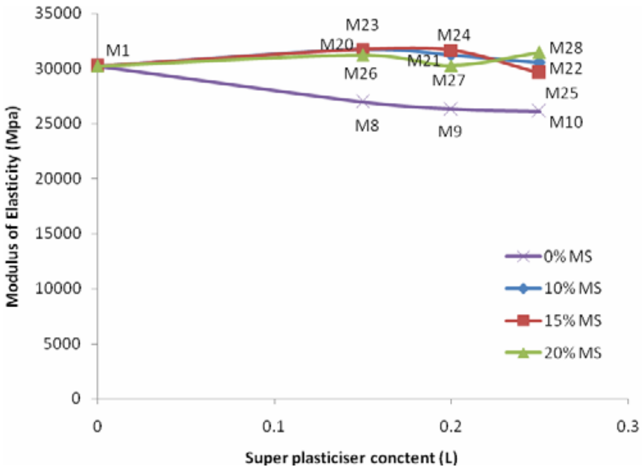

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Figure 14: Effect on modulus of elasticity due to (a) microsilica content, (b) water proofer and microsilica contents, (c) super plasticizer and microsilica contents

Compressive Strength

The compressive strength after 28 days was reported for all the concrete mixes. The compressive strength for control mix (M1) was 56.8 MPa as shown in Fig. 12.

Figs. 12 (a), (b) and (c) show the relationship between the compressive strength and microsilica only, combined microsilica and water proofer and combined microsilica and super plasticizer contents, respectively. The following observations can be obtained:

1. The low levels of microsilica only increased the compressive strength better than the high levels; i.e., the maximum increase was 13.5% for mix (M3) that contains 15% microsilica, while for mix (M4) that contains 20% microsilica the increase in the compressive strength was 8% only.
2. The effect of water proofer alone reduced the compressive strength. The maximum decrease was in mix (M7) with 24%.
3. The combined effect of microsilica and water proofer contents decreases the compressive strength but less than water proofer alone. Mix (M14) that contains 15% microsilica and 0.4 L water proofer

showed an increase in the compressive strength of 2%.

4. The effect of super plasticizer alone significantly reduced the compressive strength. The maximum decrease was 28% in mix (M10).
5. The combined effect of microsilica and super plasticizer contents decreases the compressive strength more compared to microsilica and water proofer contents.

Modulus of Rupture

The modulus of rupture was measured from the flexure test. Control concrete mix (M1) has a modulus of rupture after 28 days of 5.3 MPa as shown in Fig 13.

Figs. 13 (a), (b) and (c) show the relationship between modulus of rupture and microsilica only, combined microsilica and water proofer and combined microsilica and super plasticizer contents, respectively. The following observations can be obtained:

1. The microsilica content only increased the modulus of rupture after 28 days. The maximum increase was in mix (M4); i.e., 20%MS, where the modulus of rupture was measured to be 6.0 MPa.
2. The effect of water proofer alone significantly reduced the modulus of rupture. The maximum decrease was in mix (M7); i.e., 0.8L WP, where the decrease was 37%.
3. The combined effect of microsilica and water proofer contents decreases the modulus of rupture but much less than water proofer alone. Mixes (M14), (M15) and (M16) that contain 15% microsilica and 0.4, 0.6 and 0.8 L water proofer showed the least reduction in the modulus of rupture.
4. The effect of super plasticizer alone reduced the modulus of rupture. The maximum decrease was 42% in mix (M10); i.e., 0.25 L SP.
5. The combined effect of microsilica and super plasticizer contents decreases the modulus of rupture more compared to microsilica and water proofer contents.
6. The optimum values of the modulus of rupture among all mixes were for (M14), (M15) and (M16).

Modulus of Elasticity

The modulus of elasticity was measured for all concrete mixes. For the control mix (M1), Ec was 30234 MPa as shown in Fig. 14.

Figs. 14 (a), (b) and (c) show the relationship between the modulus of elasticity and microsilica only, combined microsilica and water proofer and combined microsilica and super plasticizer contents, respectively. The following observations were obtained:

1. The low levels of microsilica content only increased the modulus of elasticity. The maximum increase was in mix (M3) that contains 15% microsilica.
2. The high levels of microsilica only decrease the modulus of elasticity.
3. The effect of water proofer alone reduced the modulus of elasticity. The maximum decrease was 8% in mix (M7).
4. The 15% microsilica and water proofer contents increased the modulus of elasticity.
5. The 10% and 20% microsilica and water proofer contents decrease the modulus of elasticity but less than water proofer alone.
6. The effect of super plasticizer alone reduced the modulus of elasticity. The maximum decrease was 14% in mix (M10).
7. The combined effect of microsilica and super plasticizer contents generally decreased the modulus of elasticity.

CONCLUSIONS

This paper investigated the effect of microsilica, water proofer and super plasticizer contents on the resistance of concrete to phosphoric acid attack in addition to their effect on workability, air content, modulus of elasticity, durability to freezing and thawing, compressive strength and modulus of rupture after 28 days. Based on the results obtained from this research, the following conclusions can be drawn:

1. In general, the use of microsilica, water proofer and

super plasticizer enhances the durability of concrete to phosphoric acid attack. The optimum resistance was for the combined effect of microsilica and water proofer contents.

2. A high level of microsilica has a negative effect on the performance of concrete, especially on durability of concrete, workability and strength.
3. The combined effect of microsilica and super plasticizer enhanced the durability of concrete to phosphoric acid attack and to freezing and thawing. Also, it enhanced the workability, strength and modulus of elasticity. This enhancement can be considered much less than that of the combined effect of microsilica and water proofer.
4. The use of microsilica only has a negative impact on the workability of concrete, while the use of water proofer only and super plasticizer only increases the workability of concrete. This problem can be solved by the combined effect of microsilica and water proofer and microsilica and super plasticizer which provides a medium workability for concrete.
5. The use of water proofer only and super plasticizer only reduces compressive strength, modulus of rupture and modulus of elasticity.
6. The optimum mix to resist phosphoric acid attack, yet having no major effect on the performance of concrete to other factors, is that containing 10% microsilica with medium portions of water proofer.

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