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STUDIES ON ACID RESISTANCE OF TERNARY BLENDED CONCRETE

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Abstract

This paper presents a detailed experimental investigation on the acid resistance of ternary blended concrete immersed up to 32 weeks in sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) solutions. The results are compared with those of the control and binary blended concrete. ASTM class F fly ash was considered to develop the binary blended concrete at the replacement level of cement as 20% by weight. Then silica fume was considered to develop the ternary blended concrete and the replacement of cement in the ternary system by silica fume was suggested as 8% of total powder content by weight. The variable factors considered in this study were concrete grades (M_{20}, M_{30} and M_{40}) and curing periods (28 days and 90 days) of the concrete specimens. The parameter investigated was the time in days taken to cause 10% mass loss and strength deterioration factor of fully immersed concrete specimen in a 5% H_2SO_4 and 5% HCl solutions. The investigation indicated that the ternary blended concrete prepared by 20% fly ash and 8% silica fume performed better acid resistance than the ordinary plain concrete and binary blended concrete.

Keywords: Binary blended concrete; ternary blended concrete; acid resistance; mass loss

1. Introduction

The usage of blended cements is growing rapidly in construction industry due to the considerations of cost saving and environmental protection [1]. The use of FA, a siliceous material derived from thermal plants, as a partial replacement of ordinary Portland cement has found very suitable in developing the durable concrete [2]. Durability of concrete is its resistance to deteriorating agencies to which the concrete may be exposed during its service life [3]. When one deals with the durability aspects of concrete, the chemical attack, which results in loss of weight, cracking of concrete and the consequent deterioration of concrete, becomes an important part of investigation [4]. Ordinary Portland cement concrete usually does not have good resistance to acid attack. The addition of FA improves the micro structural properties of concrete like porosity, permeability and sorptivity [5]. The reduction of porosity and permeability implies the improvement in chemical attack and corrosion

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resistance [6]. Apart from the merits, the greatest drawback of FA addition in concrete is the reduction of initial age strength development rate and increasing the setting time of concrete. These drawbacks can be eliminated by means of adding one more superfine mineral admixture in the binary blended system like SF called ternary blended concrete. The silica fume plays a vital role for improving the early age performance and the FA continuously improving the properties of the hardened concrete [7]. The numerous investigations have been conducted for the acid resistance behaviour of plain cement concrete and binary blended concrete.

However it is observed that only very limited datas have reported on the durability studies of the ternary blended concrete [8]. Thus the objectives of this experimental work were to compare the relative performance of ternary blended concrete to that of conventional plain cement concrete (control concrete) in sulfuric and hydrochloric acid solutions. The time taken to cause 10% mass loss of fully immersed concrete specimens was determined and strength deterioration factor (SDF) was also determined to understand the vulnerability. Tests were carried out at room temperature in laboratory environment for the period of 32 weeks in both the acidic solutions.

2. Experimental Investigation

2.1 Materials used

The ordinary Portland cement (43 Grade as per IS: 8114-1978) was used in this investigation and other cementitious materials used in this experimental programme were low calcium fly ash (ASTM type F) and silica fume. The specific gravity of the cement and fly ash was 3.15 and 2.92 respectively. The specific gravity of SF was calculated as 2.28. The fineness of cement was determined as 2950 cm^2/g. The fineness FA and SF was 2170 and 21750 cm^2/g respectively. The chemical compositions of cement and the mineral admixtures were mentioned in the Table 1. Local river (Cauvery) sand was used as fine aggregate with the fineness modulus of 2.67, which belongs to the grade zone–II. The specific gravity of the sand was 2.71. Blue granite metal of 20mm size (maximum) was used as coarse aggregate. The fineness modulus and the specific gravity of the coarse aggregate were 7.19 and 2.78 respectively. Both the aggregate complied with the requirements of IS: 383-1970.

2.2 Mix proportions

In this study, the normal strength concretes (M_{20}, M_{30} and M_{40} grades) were considered. BIS code procedure as per IS: 10262-1982 was followed for finding the mix proportions of all the concrete specimens. Water binder ratio was considered for M_{20}, M_{30} and M_{40} grades as 0.55, 0.50 and 0.45 respectively. Table 2 shows the summery of material required for control concrete mix used in this investigation. The various mix combinations of binary blended concrete (BFC-20) and ternary blended concrete (TFS-8) are shown in the Tables 3.

Table 1. Chemical compositions of cementitious materials

Chemical composition (%)	Cement	Fly ash	Silica fume
SiO_2	22.40	50.65	87.10
Al_2O_3	5.20	30.10	0.78
Fe_2O_3	3.80	5.20	2.10
MgO	1.70	1.80	1.40
CaO	61.60	0.62	0.9
LoI	1.40	2.50	1.09

Table 2. Mix proportion for control concrete

Concrete grade	Materials required per m^3 of concrete			
	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (litre)
M_{20}	329	720	1181	181
M_{30}	376	680	1207	188
M_{40}	411	662	1162	186

Table 3. Cementitious material combinations for binary and ternary blended concrete

Mix designation	Cement content				Mineral admixture content							
					Fly ash				Silica fume			
	%	kg/m^3			%	kg/m^3			%	kg/m^3		
		M_{20}	M_{30}	M_{40}		M_{20}	M_{30}	M_{40}		M_{20}	M_{30}	M_{40}
PCC	100	329.00	376.00	411.00	-	-	-	-	-	-	-	-
BFC-20	80	263.20	300.80	328.80	20	65.80	75.20	82.20	-	-	-	-
TFS-8	72	236.88	270.72	295.92	20	65.80	75.20	82.20	8	26.32	30.08	32.88

2.3 Testing methods

The assessment of ternary blended concrete in acidic environment was made based on the performance from visual assessment, mass loss and strength deterioration factor.

2.3.1 Visual assessment

Cylindrical specimens of 45 mm diameter and 90 mm long were cast for visual assessment and the prepared specimens were cured in water for 28 days and 90 days after which they were immersed in 5% H_2SO_4 and 5% HCl solutions. The cylindrical specimens were positioned so that all sides were in contact with the solutions. The pH_5 of the two solutions were regularly monitored and adjusted to keep constant by replacing the consumed solutions by fresh solutions. The visual observation of acid attack was made as per the performance scale mentioned in Table 4 followed by Al-Tamimi [8].

Table 4. Scale of visual deterioration level of concrete specimens immersed in acidic solutions [8]

Scale	**Deterioration level**
0	No attack
1	Very slight attack
2	Slight attack
3	Moderate attack
4	Severe attack
5	Very severe attack
6	Partial disintegration

2.3.2 Mass loss

The concrete cubes of 150 mm size were cast for finding the mass loss due to the acid attack [8-10]. The prepared cubes were cured in water for 28 days and 90 days after which they were immersed in 5% H_2SO_4 and 5%HCl solutions. The initial mass and the mass of concrete specimens after the immersion period of 2, 4, 8 and 16 weeks were measured for finding the mass loss due to the deterioration of concrete specimens. The average value of three specimens was considered for assessment.

2.3.3 Strength deterioration factor (SDF)

The deterioration of concrete cube specimens was investigated by measuring the strength deterioration factor expressed in percentage and it was calculated by using the equation [11-12].

$$SDF = \left[\frac{(f_{cw} - f_{ca})}{f_{cw}}\right] x\ 100$$

Where, f_{cw} is the average compressive strength of concrete cubes cured in water and f_{ca} is the average compressive strength of cubes immersed in acid solutions. The compressive strength test was carried out for each specimen in both the solutions after 2, 4, 8 and 16 weeks of immersion period. In each test period, the average value of five specimens were tested and reported.

3. Results and Discussion

3.1 Visual assessment

Table 5 shows the summery of the visual assessment of the cylindrical specimens after 32 weeks immersed in 5% H_2SO_4 and 5% HCl solutions. The edges and surfaces of all the specimens were maintained without any disintegration while immersed in water after the observation period of 32 weeks. From the table 5, it was observed that the PCC specimen suffered a greater degree of acid attack than those of BFC-20 and TFS-8 specimens in acid solutions. The deterioration of PCC specimens was ranging from severe attack to very severe attack in 5% H_2SO_4 solution. In 5%HCL solution, the degree of deterioration appeared slightly lesser than the 5% H_2SO_4 solution. Due to the expansive reactions, the specimens were disintegrate and turned into a white pulpy mass in addition to peeling [8, 13]. The acid diffuses into concrete structure destroys the cement gel binder and forming soft and soluble gypsum (calcium sulphate hydrate), which reacts with C_3A to form ettringite. The formation of secondary ettringite results in a substantial expansion of PCC specimens and leads to increase the degree of acid attack [10]. The reduction of $Ca(OH)_2$ in blended concrete reduces the formation of secondary ettringite and reduces the expansion of concrete specimens. The binary blended concrete specimens containing 20% FA (BFC-20) was suffered a moderate attack in 5% H_2SO_4 solution and slight attack in 5% HCl solution. The ternary blended concrete has shown slight attack in 28 days cured specimens and very slight attack in 90 days cured specimens. This is due to the development of dense concrete mass by reducing the micro pores and its sizes.

3.2 Mass loss

Figures 1 to 6 display the results of mass loss of control (PCC), binary (BFC-20) and ternary (TFS-8) blended concrete due to acid attack and the mass loss is consider as a function of time. The resistance of cement based materials to chemical attack is mainly due to permeability and alkalinity of concrete mass. The PCC mix suffered the most deterioration in terms of mass loss when immersed in 5% H_2SO_4 solutions. The mass loss of 28 and 90 days cured M_{20} grade PCC specimens was 19.6% and 16.1% respectively. The mass losses of the PCC specimens were reduced when the cement content increases (increasing the concrete grades) per m^3 of concrete. The time taken to cause 10% mass loss due to the acid attack was mentioned in Table 6. From the Table 6, it can be seen that the PCC specimens losses their weight more than 10% and the 28 days cured M_{20} grade concrete specimen reaches the 10% loss level within two weeks of immersion period in 5% H_2SO_4. When increasing the curing period, the time to reach 10% level of mass loss also increases and it shows that the hydration process of cementitious materials was not fully completed with in 28 days curing. In the case of PCC specimens immersed in 5% HCl shows lesser deterioration and indicates that after 6 weeks immersion period only the specimen losses their 10% mass. The other results for time to reach 10% mass loss of PCC specimens in 5% HCl solutions were shown in Table 6.

Table 5. Visual assessment of concrete deterioration level

Mix designation	Concrete grade	28 days cured specimens		90 days cured specimens	
		5% H_2SO_4	5%HCl	5% H_2SO_4	5%HCl
PCC	M_{20}	4-5	4	4	3-4
	M_{30}	4	3-4	3-4	3
	M_{40}	3-4	3-4	3	3
BFC - 20	M_{20}	3-4	3	3	2-3
	M_{30}	3-4	3	3	2-3
	M_{40}	3	2-3	2-3	2
TFS - 8	M_{20}	3	2-3	3	2
	M_{30}	2-3	2	2	1-2
	M_{40}	2	1-2	1-2	1

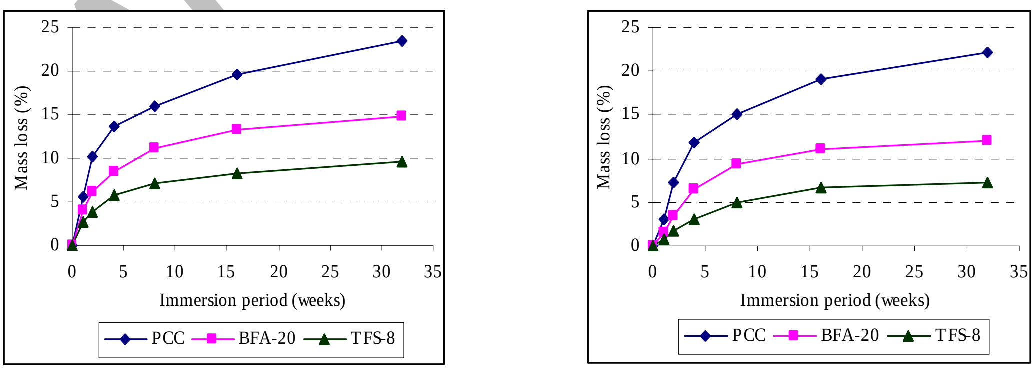
Table 6. Time taken to cause 10% mass loss due to immersion in acidic solutions

Mix designation	Concrete grade	Time to cause 10% mass loss (weeks)			
		28 days cured specimens		90 days cured specimens	
		5% H_2SO_4	5%HCl	5% H_2SO_4	5%HCl
PCC	M_{20}	2	6	3	7
	M_{30}	4	8	6	8
	M_{40}	6	14	14	32
BFC-20	M_{20}	6	32	11	-
	M_{30}	15	-	21	-
	M_{40}	-	-	-	-
TFS-8	M_{20}	-	17	-	32
	M_{30}	-	-	-	-
	M_{40}	-	-	-	-

The development of binary blended concrete with 20% FA replacement level reduces the mass losses considerably. The mass loss of BFC-20 specimens was approximately reduces 30%–40% mass loss of PCC when immersed in 5% H_2SO_4 solutions. The 10% mass loss was observed in M_{20} and M_{30} grade concrete only. The time for 10% mass loss of 28 days and 90 days cured M_{20} grade BFC-20 specimens was observed after 6 and 11 weeks immersion periods respectively and that of M_{30} grade concrete was 15 and 21 weeks respectively. The M_{40} grade BFC-20 specimens were shown only less than 10% mass loss within the observation period of 32 weeks. After the observation period, the mass loss of 28days and 90days cured M_{40} grade BFC-20 was measured as 8.49 and 7.2% respectively. The mass loss with time for BFC-20 specimens immersed in 5% HCl was much lower than that of the specimens immersed in 5% H_2SO_4 solutions. The results show that the resistance against the acid attack increased when cement replaced by FA and the main reason for the increased acid resistance of blended concrete investigated was the formation of dense hardened cement paste and aggregate interface with low porosities.

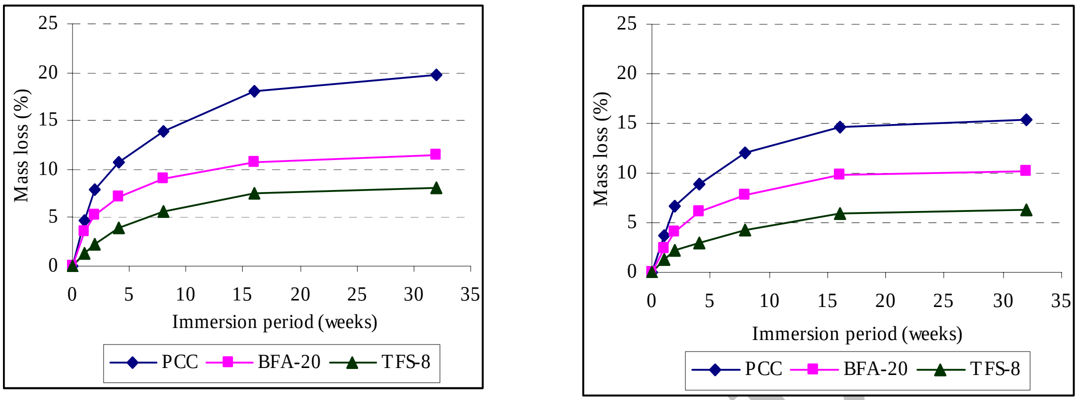
The ternary blended concrete (20% FA and 8% SF replacement levels) shows very good resistance to sulphuric acid. Only less than 9% mass loss was observed in TFS-8 specimens immersed in 5% H_2SO_4 solutions. The rate of mass loss due to acid attack (5% H_2SO_4 solutions) in PCC was observed as rapid up to 8 weeks. In controversy, the mass loss of TFS-8 specimens in HCl solution was slightly more than that of BFC-20. At 32 weeks the mass loss of M_{20}, M_{30} and M_{40} grade TFS-8 specimen was 11.01%, 7.97% and 7.07% respectively in 28 days cured specimens and that of in 90 days cured specimens were 9.91%, 7.31% and 6.13% respectively.

Figure 7 shows the comparison of mass loss between ternary blended (TFS–8) concrete specimens and 28 days cured PCC specimens. The mass loss of 28 days and 90 days cured TFS-8 specimens immersed in 5% H_2SO_4 solutions were reduced to 40% and 31% of the mass loss of 28 days cured PCC specimens respectively, whereas the specimens immersed in 5% HCl solutions were reduced to around 50% in 28 days cured specimens and around 45% in 90 days cured specimens. The formation of unstable ettringite causes the concrete matrix to be more porous and susceptible to the acid attack through the capillary pores [10]. The development of ternary blended concrete with the optimum replacement levels shows the reduction of secondary unstable ettringite and reduces the acid attack considerably.



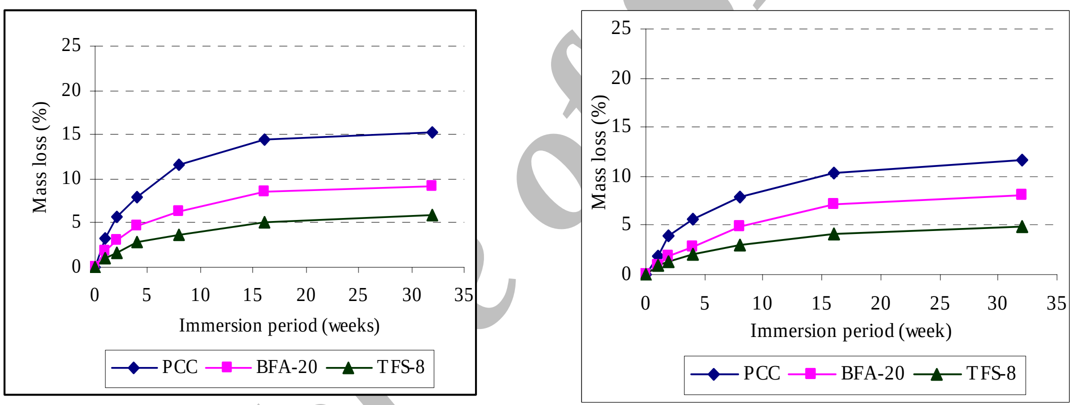
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 1. Mass loss of M_{20} grade concrete due to immersion in 5% H_2SO_4 solution



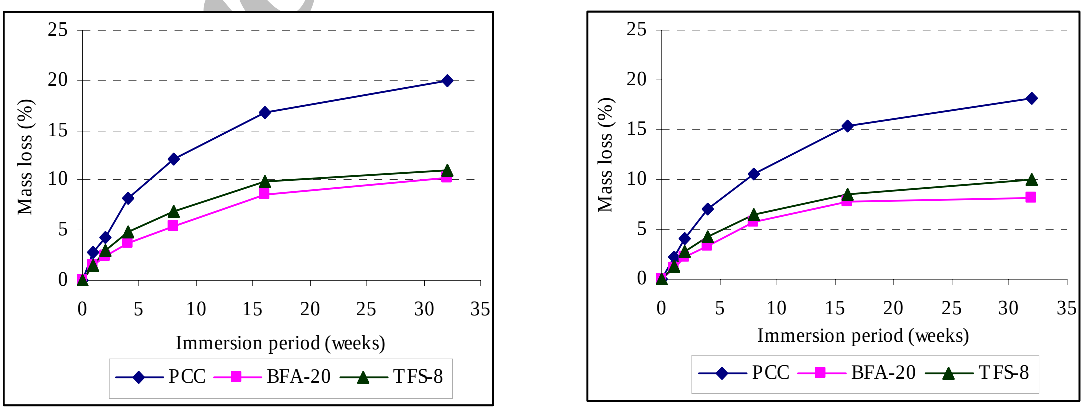
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 2. Mass loss of M_{30} grade concrete due to immersion in 5% H_2SO_4 solution



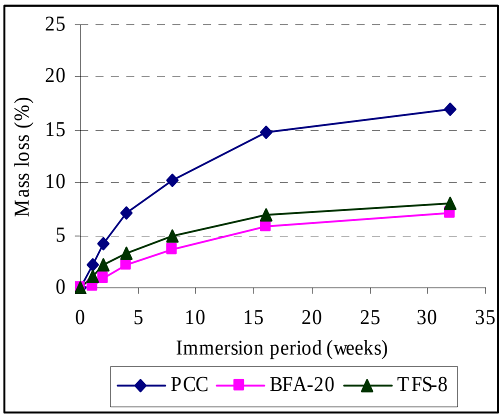
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 3. Mass loss of M_{40} grade concrete due to immersion in 5% H_2SO_4 solution

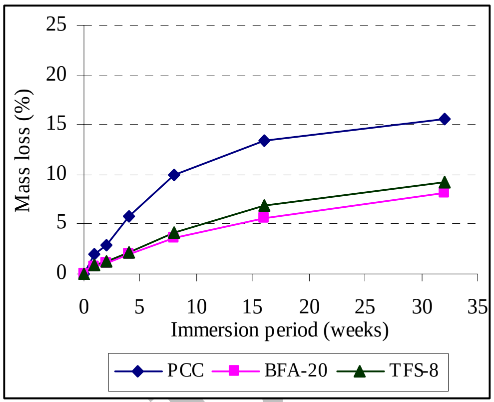


(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 4. Mass loss of M_{20} grade concrete due to immersion in 5% HCl solution

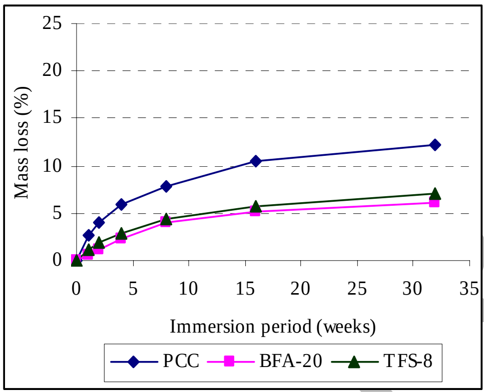


(i) 28 days cured specimens

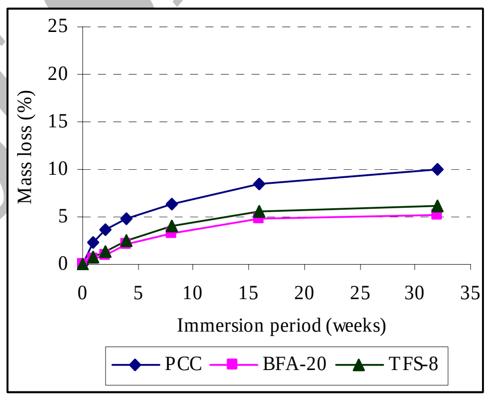


(ii) 90 days cured specimens

Figure 5. Mass loss of M_{30} grade concrete due to immersion in 5% HCl solution

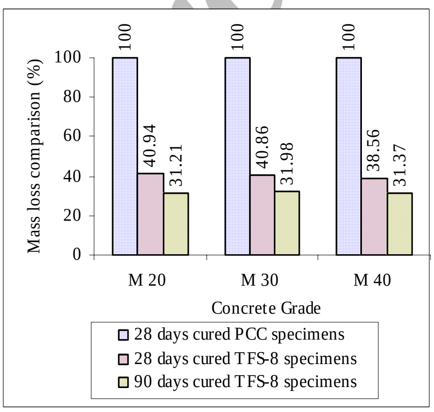


(i) 28 days cured specimens

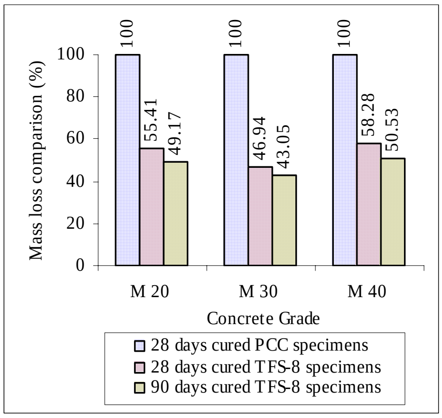


(ii) 90 days cured specimens

Figure 6. Mass loss of M_{40} grade concrete due to immersion in 5% HCl solution



(i) Immersed in 5% H_2SO_4 solutions



(ii) Immersed in 5% HCl solutions

Figure 7. Comparison of mass loss with 28 days cured PCC specimens

3.3 Strength deterioration factor (SDF)

The reduction of compressive strength due to acid attack was expressed in the form of strength deterioration factor (SDF). Figures 8 to 10 show the SDF of 28 days and 90 days cured specimens of M_{20}, M_{30} and M_{40} grade concrete immersed in 5% H_2SO_4. The PCC specimens are severely affected the acid attack and hence the SDF values of PCC specimens were more than 78%. The rate of change SDF for PCC specimen was observed as rapid change up to 8 weeks of immersion period. The SDF for 5%HCl were shown in figures 11 to 13. The SDF of PCC specimens were comparatively lesser than the effect of 5% H_2SO_4 solutions.

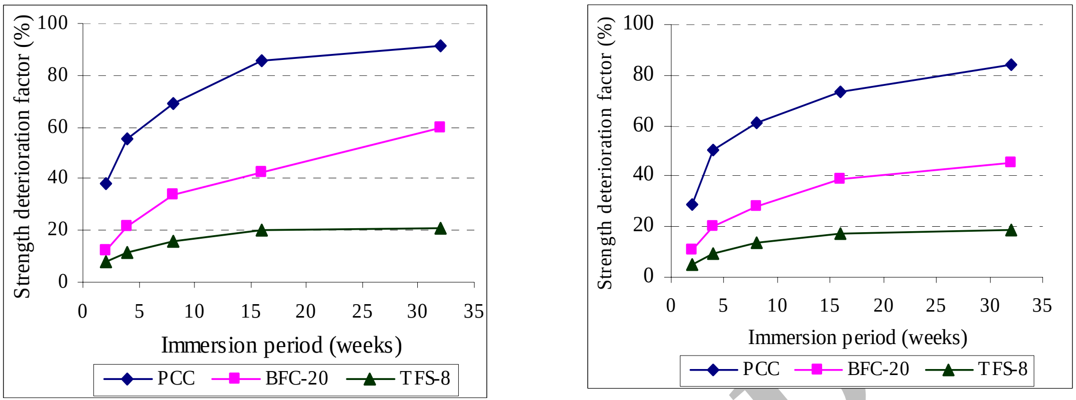
The maximum SDF value of 87% was observed in 28 days cured M_{20} grade BFC-20 specimens after the immersion period of 32 weeks. Meantime the minimum SDF value of 58% was observed in 90 days cured M_{40} grade concrete after the immersion period of the same 32 weeks. The addition of FA in BFC-20 concrete specimens consumes $Ca(OH)_2$ and develop the secondary hydration products (C-S-H gel) which reduces the micro pores of concrete and makes dense concrete mass. The dense impermeable concrete mass increases the resistance against chemical attack. After the immersion of 32 weeks in 5% H_2SO_4, the BFC-20 concrete specimens reduce the SDF up to 21% against PCC specimens. From figures 11 to 13, it was observed that the deterioration of BFC-20 concrete specimens were less in 5%HCl solution than 5% H_2SO_4 solutions, which shows the lesser SDF values in all the immersion periods.

The ternary blended concrete (TFS-8) specimens are less affected than that of the binary and control concrete mixes immersed in 5% H_2SO_4 solutions. The presence of SF offered the resistance against permeability during early ages and the FA contents prevents the entry of acidic solutions during the latter ages. The ternary blended combination increases the impermeability of concrete in the higher order and hence the observed SDF values were very less than that of the other mixes. The maximum value of SDF for TFS-8 specimen was only 20% at 28 days cured M_{20} grade specimen immersed up to 32 weeks, which is 77% lesser than the PCC and 50% lesser than the BFC-20 concrete specimens. In 5%HCl solution, the controversial results were observed. The TFS-8 concrete shows slightly high SDF values than that of BFC-20 specimens. Meantime the difference was only marginal when compared to the PCC specimens. Comparison the effect of HCl and H_2SO_4 on concrete, sulfuric acid attack is more damaging to concrete as it combines an acid attack and a sulfate attack [10]. Figure 14 shows the comparison of SDF between ternary blended (TFS–8) concrete specimens with 28 days cured PCC specimens. The SDF of 28 days and 90 days cured TFS-8 specimens immersed in 5% H_2SO_4 solutions were ranged between 21 to 24% and 14 to 20% of the SDF of 28 days cured PCC specimens respectively, whereas the specimens immersed in 5% HCl solutions were reduced to around 60% in 28 days cured specimens and around 45% in 90 days cured specimens.

4. Conclusions

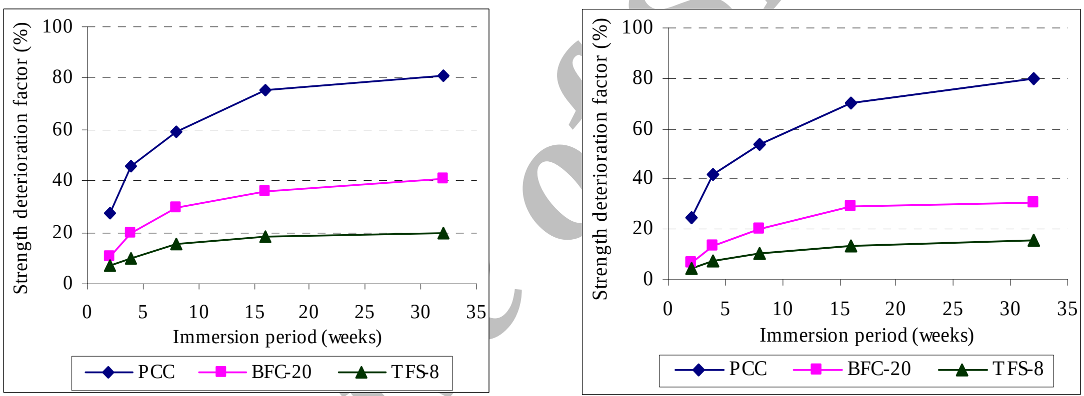
The following conclusions are drawn from the results of the investigations:

- The PCC specimens of all the M_{20}, M_{30} and M_{40} grade concrete were severely deteriorated after immersion of 5% H_2SO_4 solutions and 5%HCl solutions up to 32 weeks.



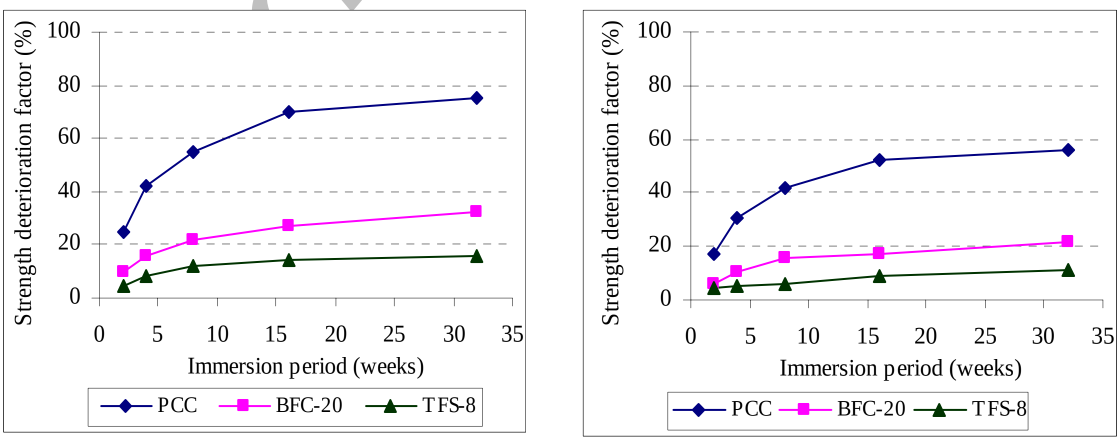
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 8. SDF for M_{20} grade concrete due to immersion in 5% H_2SO_4 solution



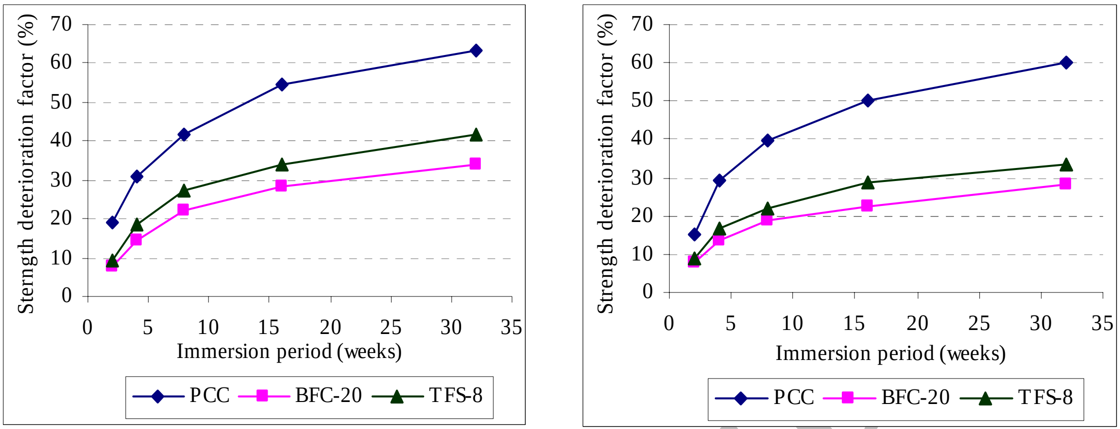
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 9. SDF for M_{30} grade concrete due to immersion in 5% H_2SO_4 solution



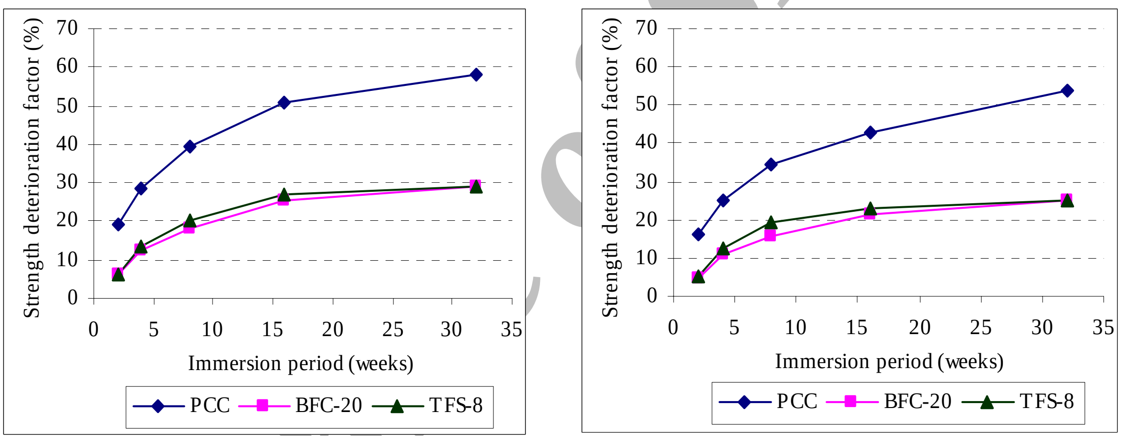
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 10. SDF for M_{40} grade concrete due to immersion in 5% H_2SO_4 solution



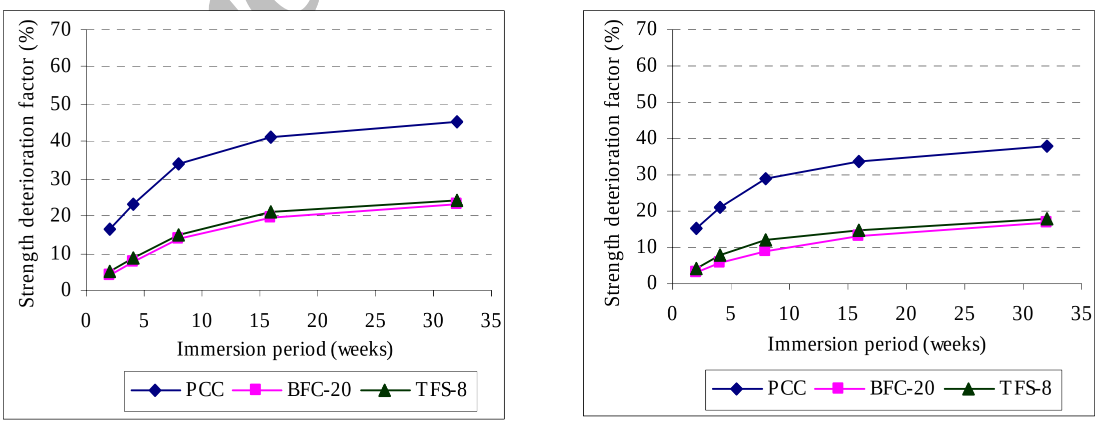
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 11. SDF for M_{20} grade concrete due to immersion in 5% HCl solution



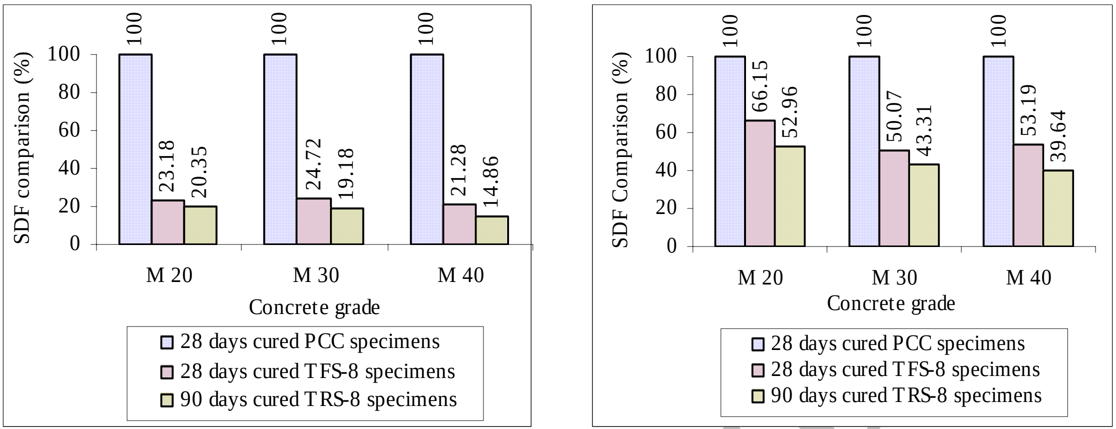
(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 12. SDF for M_{30} grade concrete due to immersion in 5% HCl solution



(i) 28 days cured specimens (ii) 90 days cured specimens

Figure 13. SDF for M_{40} grade concrete due to immersion in 5% HCl solution.



(i) Immersed in 5% H_2SO_4 solutions (ii) Immersed in 5% HCL solutions

Figure 14. Comparison of mass loss with 28 days cured PCC specimens

- The 28 days cured binary blended concrete (BFC-20) specimens were suffered moderate acid attack and the 90 days cured binary blended concrete were affected slightly by acid attack.
- The 28 days cured ternary blended concrete (TFS-8) specimens were suffered slight acid attack and the 90 days cured binary blended concrete were affected only very slight acid attack after the immersion of 32 weeks in acid solutions.
- The mass loss of 28 and 90 days cured M_{20} grade PCC specimens was 19.6% and 16.1% respectively.
- The mass loss of BFC-20 specimens was approximately reduces 30% - 40% mass loss of PCC when immersed in 5% H_2SO_4 solutions.
- The 10% mass loss was observed only in M_{20} and M_{30} grade concrete immersed in 5% H_2SO_4 solutions and 5%HCl solutions up to 32 weeks.
- The mass loss of 28 days and 90 days cured TFS-8 specimens immersed in 5% H_2SO_4 solutions were reduced to 40% and 31% of the mass loss of 28 days cured PCC specimens respectively, whereas the specimens immersed in 5% HCl solutions were reduced to around 50% in 28 days cured specimens and around 45% in 90 days cured specimens.
- The PCC specimens are severely affected the acid attack and hence the SDF values of PCC specimens were more than 78%.
- The SDF of PCC specimens immersed in 5% HCl were comparatively lesser than the effect of 5% H_2SO_4 solutions.
- In 5%HCl solution, the TFS-8 concrete shows slightly high SDF values than that of BFC-20 specimens.
- The SDF of 28 days and 90 days cured TFS-8 specimens immersed in 5% H_2SO_4 solutions were ranged between 21 to 24% and 14 to 20% of the SDF of 28 days cured PCC specimens respectively, whereas the specimens immersed in 5% HCl solutions were reduced to around 60% in 28 days cured specimens and around 45% in 90 days cured specimens.

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