CHAPTER 4

WORKABILITY AND MECHANICAL PROPERTIES OF MULTIPLE BLENDED BINDERS CONCRETE USING MIRHA, SF AND PFA

4.1 Introduction

The influence of mineral admixtures containing pozzolanic properties in concrete mixes have been reported to give different effects on the engineering properties of concrete in fresh or structure concrete. The different effects depend on type of minerals used and the minerals properties (Malhotra et al, 2004). As an example, minerals admixture with high surface area may increase the water requirement of binders, but at the same time may offer a bigger surface area for better chemical reactions to take place (Gallias et al, 2000).

The concrete containing high pozzolanic properties as mineral replacement materials may have low compressive strength compared to control mixes especially at early age and at later age, the strength performance of the concrete may improve even better than control mixes (Malhotra et al, 1999).

4.2 Physical Properties of the Constituents Material

All cementitious binders that have been used in concrete industries have to be confirmed of their properties. The chemical and physical properties have to satisfy the minimum requirements specified by the selected standard specifications.

The cementitious properties discussed in this chapter are based on three parameters that were stated in the British standard specification. The parameters are fineness, chemical composition and compressive strength. Investigation on the cementitious properties was to identify either the binders used satisfied the cement standard specifications requirements before it was used as cementitiuos binders in the studies. The influence of pozzolanic materials to the properties of cement paste and concrete in ternary cementitous system compared to binary and OPC cementitous system was studied and presented.

X-Ray Defraction (XRD) test and analysis was carried out to identify the pozzolanicity of harden cement paste containing multiple blended binders at specific curing time under water curing. The pozzolanicity of multiple blended binders was then compared with the pozzolanicity of multiple blended binders and OPC. Table 4.1 presents the chemical index for MIRHA.

Table 4.1 Chemical Index for MIRHA using X-Ray Defraction (XRD)

Oxide composition	**Weight (%)**
	MIRHA
Na_2O	0.02
MgO	0.63
Al_2O_3	0.75
SiO_2	90.75
P_2O_5	2.5
K_2O	3.77
CaO	0.87
TiO_2	0.02
Fe_2O_3	0.28
SO_3	0.33
MnO	0.08

Noted : The sample were examined by X-ray diffraction (XRD) model Bruker AXS D8 ADVANCE. Tested done at SIRIM

4.3 High Strength Concrete Mixes Proportions

The mixes proportions employed in these investigations derived from a number of trial mixes that was carried out and designed to achieve a compressive strength of 70 N/mm^2 at 28 days curing using OPC. The materials used in the mixes proportions are as stated and discussed in
chapter 3.

Sixteen (16) types of concrete mixes using 825kg of binders for each mix with 0.35 binder cement ratio were prepared. The details of the mixes proportions for control mix as well as the concrete mixes containing mineral replacement materials used in these investigations are given in Table 4.2. For the mixes containing pozzolanic materials, part of cement was replaced by direct replacement method, on mass-for-mass basis with the pozzolanic materials at specified replacement level determined before.

Table 4.2: Concrete Mix Design

Grade	Cement (kg)	Coarse Agg. (kg)	Sand (kg)	W/C ratio	Slump (mm)	Super Plasticizer (kg)
70	825	1170	610	0.35	50-100	1% per cement weight

4.4 Influence of Prepared Binders to the Workability of Concrete

Table 4.3 presents the slump values of concrete containing OPC, blended binders concrete and multiple blended binders concrete systems. From the Table 4.3 also shows that the use of multiple blended binders concrete has reduced the slump diameter of OPC concrete.

Although the slump of multiple blended binders concrete was lower than OPC concrete, the magnitude slump of multiple blended binders concrete was still considered as very high. The difference of slump magnitude between types of binders was considered as not significant since concrete using all typs of binders in the investigations gave almost the same slump values. The use of superplasticizer is contributing to the effect of high slump magnitude present in the experiment.

From the slump test analysis, it was found that all the mixes are having very good slump high. The slump high given more than 70 mm has been carried out. The test carried out to study the effect of using multiple blended binders concrete systems on the slump test of concrete.

Table 4.3: Workability of Concrete

Types of binders					Slump Test (mm)	
Item	**OPC** (%)	**MIRHA** (%)	**SF** (%)	**PFA** (%)	Without SP	With SP (1% from cement weight)
1	100				80	-
2	95	5			48	83
3	92.5	7.5			46	81
4	90	10			45	82
5	92		8		43	80
6	87	5	8		42	76
7	84.5	7.5	8		40	73
8	82	10	8		42	71
9	90			10	41	73
10	85	5		10	39	72
11	82.5	7.5		10	36	72
12	80	10		10	40	70
13	82		8	10	34	73
14	77	5	8	10	32	78
15	74.4	7.5	8	10	30	71
16	72	10	8	10	27	75

Referring to the result of slump test presented in Table 4.3, it is found that the multiple blended binders concrete may contribute to a reduction of slump test. The multiple blended binders concrete shows that was 50% less slump high compared to OPC. These conditions happened for multiple blended binders because the waste product used in this research absorbed more water during concrete mix process. To make sure the multiple blended binders mixes used were achieved the target for high slump similar in design for normal concrete; superplasticizer was added in mixes of 1% based on cement weight.

Figure 4.1 shows the slump value of 80mm for OPC control mix. The slump value of concrete containing multiple blended binders (5%,7.5%,10%MIRHA:8%SF:10%PFA) are 32, 30 and 27mm. Multiple blended binders (5%,7.5%,10%MIRHA:8%SF:10%PFA) concrete containing 1% of cement weight used superplasticizer showed slump value of 78, 71 and 75mm while give 2.4, 2.3 and 2.7 times the multiple blended binders slump respectively. The result is shown in Table 4.3 above.

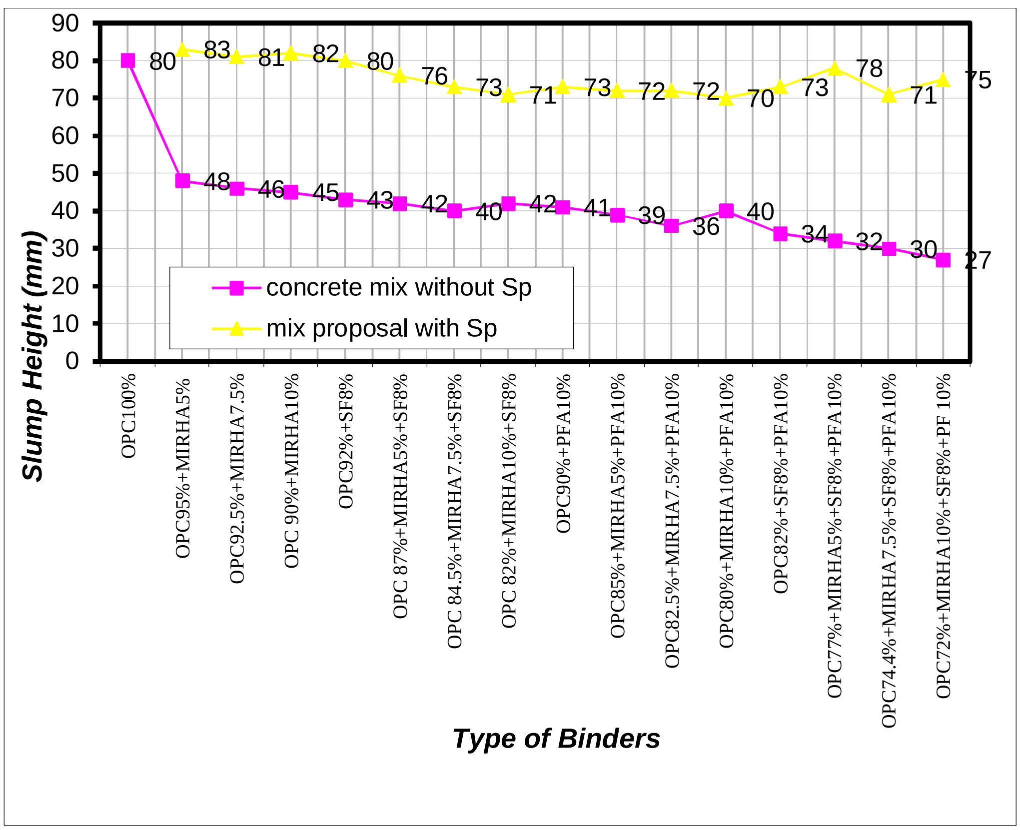


Figure 4.1: Slump height versus type of binders

From the result obtained, slump value of multiple blended binders concrete increase significantly when superplasticizer was added. The slump value of multiple blended binders concrete containing superpiasticizer was almost the same as OPC control mix. This was due to the large surface area of multiple blended binders itself that can produce dry or unworkable mixtures unless superplasticizer is used in 1% of cement weight.

Superplasticizer acts as water reducer in increasing workability. It performs their function by deflocculating the agglomerations of lumps of cement grains. In the normal stage the surface of cement grains contain a combination of positive and negative chargers. As they are agitated and bumped into each other, incorporating of superplasticizer repelled each other. When the water trapped within the original flows is released, it can contribute to the workability of the concrete. The mechanism for interaction of superplasticizer deflocculated the cement grains.

The spherical shape, smooth glassy texture and finer particle size distribution of multiple blended binders (MIRHA,PFA,SF) may provide a greater plasticizing effect when compared to OPC mixed particularly at higher replacement level.

The effect of multiple blended binders to increase the workability of concrete also became a reason on the improvement of concrete spread diameter in multiple blended binders cement concrete. The inclusion of SF and PFA at 5%MIRHA replacement level to OPC in multiple blended binders cement was found has increased the slump value of blended binders cement concrete containing SF and PFA at 7.5% &10%MIRHA. The characteristic directly influences the increment on water demand of MIRHA blended binders cement binders to reduce the workability of concrete.

The inclusion of PFA in multiple blended binders cement systems has compensated the reduction in workability due to the inclusion of MK and RHA and this finding is supported by other findings on the same matter by Sabir B.B. Wild S, Bai J.(2001). Bai et a1 (1999) studies on the workability of concrete incorporating PFA at 30% found to have workability at 30-60 mm at a water binder ratio of 0.4 and 0.5 respectively.

The reduction of slump in multiple blended binders cement systems containing 10%MIRHA, 8%SF and 10%PFA may be due to the density increment of multiple blended binders cement binders that improve the cohesiveness of concrete. Concrete with high cohesiveness level

normally will have low slump value and may reduce the effectiveness of superplasticizer effect. SF has reported as a material that can increase the cohesiveness of concrete due to the increment of gel strength generated by SF was presented by Hedda Vikan and Harald Justnes (2007).

4.5 Compressive Strength

Concreting works carried out in determining the ultimate binders mix proportion of Multiple Blended Binders Concrete use waste product. The optimum mix proportion of pozzolans studied was determined by the compressive strength result of concrete cubes that were tested at 3, 7, 28, 56 and 90 days. The optimum mix proportion of MIRHA, SF and PFA to OPC was determined referring to the minimum percentage of replacement level used of the pozzolanic materials that gave the maximum compressive strength value at 28 day

The selected mix proportions of Multiple Blended Binders Concrete and Blended Binders Concrete studied in this investigation were determined by the compressive strength result of optimum mix proportions stated above.

The strength of pozzolanic cement depends very much on the formation of 'cementing agents', and any condition that hastens the formation of dicalcium silicate (C_2S) will give pozzolanic cement of reasonably good strength. Generally, the results from Table 5.1 reveal that the compressive strength of OPC and Multiple Blended Binders Concrete increase with age.

The MIRHA concrete attained higher values of compressive strength than the control OPC concrete at early age of 7 days. The percentage increase in strength depends on the amount of cement replacement with MIRHA. This is an indication that, the primary product of hydration formed by the reaction between cement and water account for a greater proportion of the compressive strength than do the secondary products of hydration resulting from the pozzolanic reaction between $Ca(OH)_2$ and the silica and alumina contained in RHA which occurs at a slower rate than the primary reaction.

Table 4.4: Average Characteristic Compressive Strength of High Strength Concrete using Multiple Blended Binders of Waste Product

Item	OPC	MIRHA	SF	PFA	Stress (N/mm^2)				
	(%)	(%)	(%)	(%)	3d	7d	28d	56d	90d
1	100.0	-	-	-	33.10	50.64	69.51	79.67	79.32
2	95.0	5	-	-	37.30	56.71	77.19	81.74	86.48
3	92.5	7.5	-	-	36.20	55.21	75.25	78.44	83.61
4	90.0	10	-	-	34.20	53.70	73.20	77.52	81.43
5	92.0	-	8	-	58.24	63.02	77.21	80.68	86.52
6	87.0	5	8	-	56.31	60.00	75.23	79.19	84.31
7	84.5	7.5	8	-	54.36	59.10	74.24	79.74	82.25
8	82.0	10	8	-	49.78	56.58	73.71	75.02	81.33
9	90.0	-	-	10	56.41	61.33	78.25	81.83	85.57
10	85.0	5	-	10	59.43	67.38	81.17	84.65	89.16
11	82.5	7.5	-	10	58.30	66.48	80.27	82.55	87.36
12	80.0	10	-	10	52.75	57.25	71.04	75.31	77.58
13	82.0	-	8	10	51.34	67.16	81.27	82.06	87.13
14	77.0	5	8	10	60.26	70.71	86.53	91.85	95.41
15	74.4	7.5	8	10	57.61	67.60	84.22	89.41	92.67
16	72.0	10	8	10	55.36	59.13	84.13	86.35	91.34

4.5.1 Effect of MIRHA/SF and MIRHA/PFA on the Compressive Strength

From Table 4.4, it shows that the compressive strength increase from 33.10 N/mm^2 to 50.64 N/mm^2 to 69.51 N/mm^2 to 79.67 N/mm^2 to 79.32 N/mm^2 for the control concrete without blinded with SF, PFA and MIRHA.

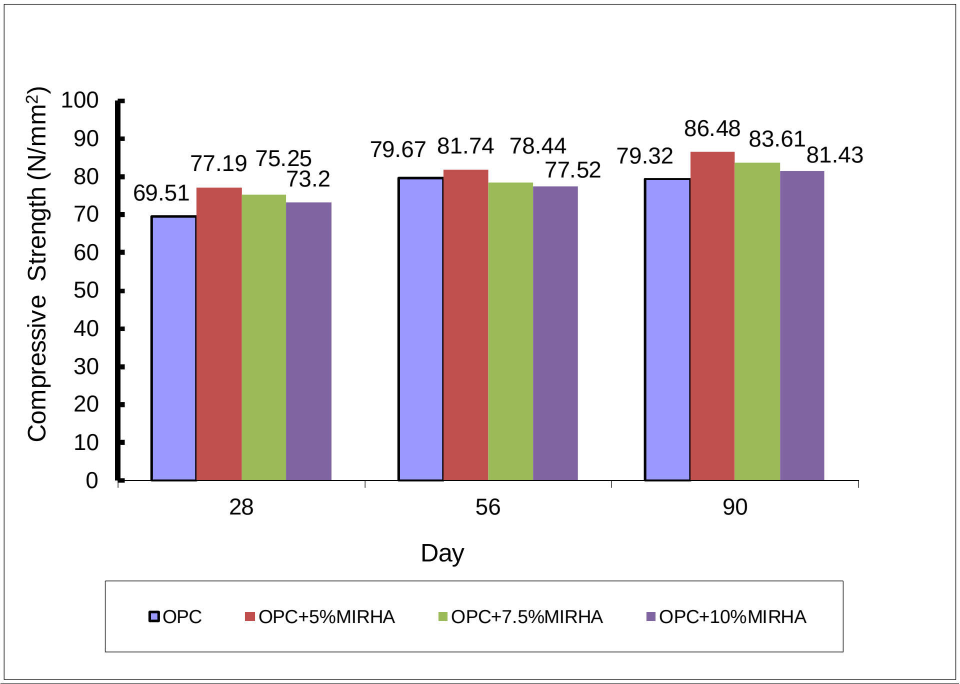


Figure 4.2: Effect of MIRHA on the Compressive Strength

From Figure 4.2 shows the cube test results at 28 days and 56 days, the result showed that all concrete specimens with MIRHA achieved above 69.51 N/mm^2 of strength and the highest value is up to 81.74 N/mm^2. The result showed that the strength of concrete increased after the percentage of MIRHA used in concrete mix 5%. The result also showed that increment of compressive strength due to the age of concrete specimen.

At 90 days, the result showed that all concrete specimens with MIRHA achieved above 79.32 N/mm^2 of strength and the highest value was 86.48 N/mm^2. The result showed that the strength of concrete decreased after the percentage of MIRHA used in concrete mix increased more than 5%. The result also showed that increment of compressive strength due to the age of concrete specimen.

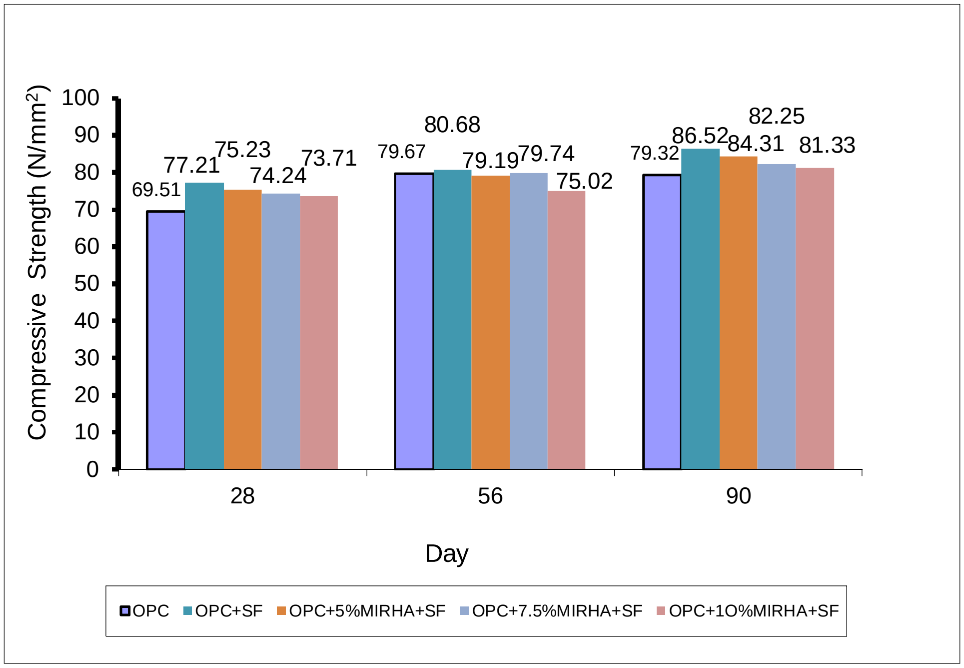


Figure 4.3: Effect of MIRHA and SF on the Compressive Strength

Based on the result shown in Figure 4.3, normal concrete achieved 69.51 N/mm^2 of strength and increase to 86.52 N/mm^2 for concrete specimen containing with 0% MIRHA and 8% SF. The result also showed that the strength of concrete increased to 84.31 N/mm^2 to 82.25 N/mm^2 for 5% MIRHA and 8% SF used to 7.5% MIRHA and 8% SF used in concrete mix.

The strength of concrete continued decrease to 81.33 N/mm^2 after 10% MIRHA and 8% SF was added as a cement replacement in concrete mix.

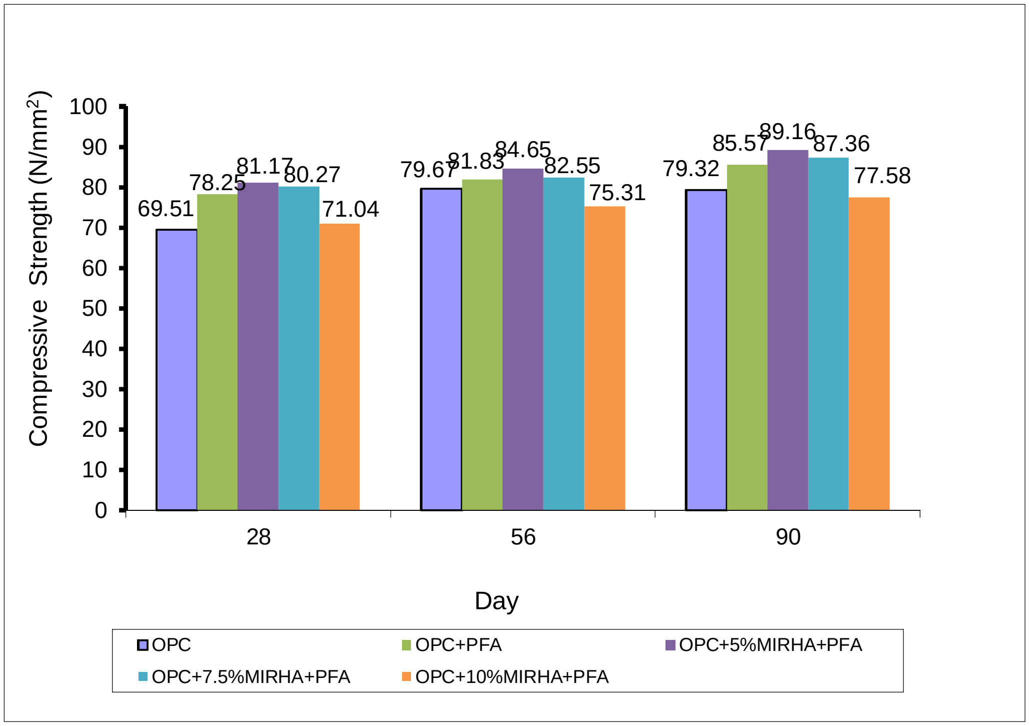


Figure 4.4: Effect of MIRHA and PFA on the Compressive Strength

The result shown in Figure 4.4, effect of MIRHA and PFA on the compressive strength test result similar pattern with the effect of MIRHA and SF. The result also showed that, the strength of concrete increased when used MIRHA 5% and the strength of concrete decreased after the percentage of MIRHA used in concrete mix increased more than 5%. The result also showed that increment of compressive strength due to the age of concrete specimen.

It also showed that as the MIRHA content in the mix increased, the compressive strength of MIRHA concrete also increased. This might be due to the fact that replacing OPC with MIRHA resulted in increasing of C_3S in the blend, which is the most important compound responsible for initial setting and early strength.

4.5.2 Effect of MIRHA, SF and PFA on the Compressive Strength

It is noted that the compressive strength increased with an increase in MIRHA content with 8% SF and 10% PFA content, for 7 days age tested. On the other hand, increasing the

MIRHA content for a particular 8% SF and 10% PFA content above 5% replacement level, results in an increase rapidly in compressive strength. Figure 4.5 shows a compressive strength of concrete using multiple blended binders concrete with 8%SF and 10%PFA replacement to OPC.

It is evident that 5% MIRHA incorporation in multiple blended systems has beneficial effect in increasing compressive strength which 69.51 N/mm^2 and 86.53 N/mm^2 respectively. However, it increases 6.1% from 86.53 N/mm^2 to 91.85 N/mm^2. Compressive strength rapidly decreased 1.4% from 92.67 N/mm^2 to 91.34 N/mm^2 for the multiple blended when increasing percentage of MIRHA more than 5%. In other word, 5% percentage used of MIRHA, PFA and SF increase the strength 20.2% from 79.32 N/mm^2 to 95.41 N/mm^2 for the multiple blended binders concrete.

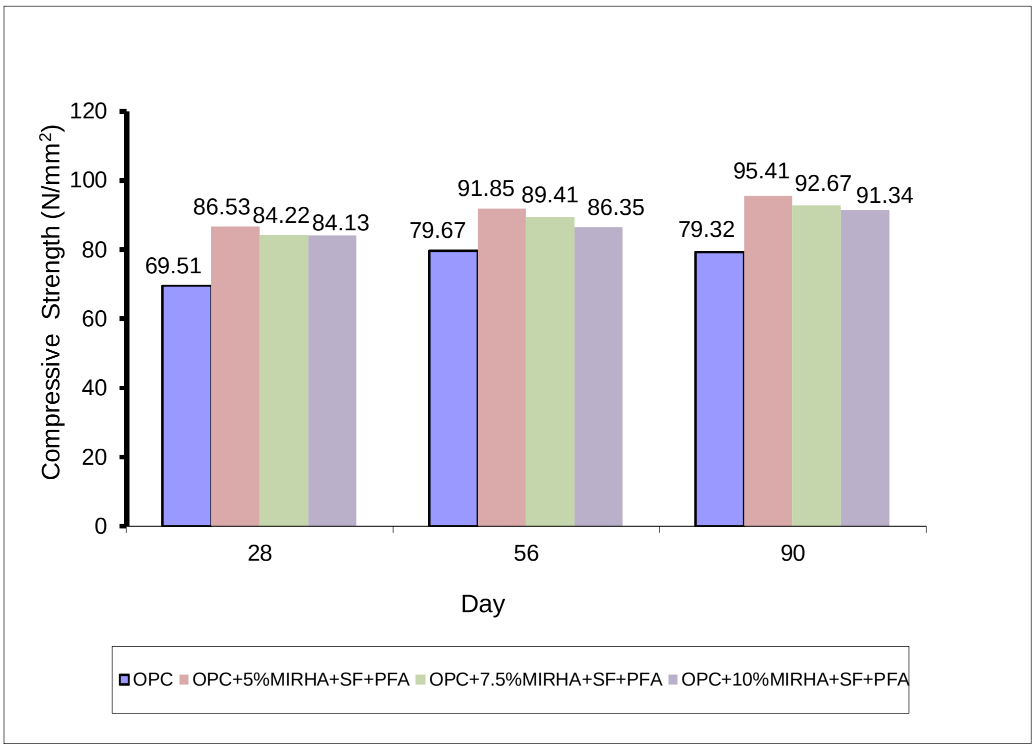


Figure 4.5: Effect of MIRHA, SF and PFA on the Compressive Strength

The Figure 4.5 shows that the inclusions of 5%MIRHA as cement replacement materials have increased the compressive strength of concrete at 28, 56 and 90 days. 5% replacement of MIRHA in blended binders concrete system have given the highest compressive strength compare to others replacement level. This make concrete mix using MIRHA, SF and PFA which contain 5%, 7.5% and 10% of MIRHA have been chosen as the optimum replacement level to be used in preparing a multiple blended binders concrete system.

Increment in the rate of hydration of C_3S, C_3A and C_2S due to the presence of MIRHA, SF and PFA may contribute a increment in the early strength. The quantitative analysis of $Ca(OH)_2$ content on the OPC concrete and concretes with MIRHA-OPC-SF-PFA blended was conducted in this present work, that if the amount of cement content in the MIRHA-OPC-SF-PFA blended is higher than the OPC control concrete, the $Ca(OH)_2$ content in the MIRHA-OPC-SF-PFA blend is also higher, thus, affecting the pozzolanic reaction in the MIRHA-OPC-SF-PFA concrete.

4.5.3 Relationship between the 3, 7, 28, 56 and 90 days Strength of Multiple Blended Binders using MIRHA, SF and PFA Concretes

Compressive strength of concrete using blended binders concrete system with PFA for 10% replacement level of PFA to OPC is present in Figure 5.5. The figure shows that the inclusions of PFA as cement replacement materials have increased the compressive strength of concrete at 3, 7, 28, 56 and 90 days reversely proportionate with replacement level. The optimum replacement level of PFA to be used in multiple blended binders concrete system was chosen based on the maximum replacement level of PFA to OPC in blended binders concrete that can achieve target mean strength.

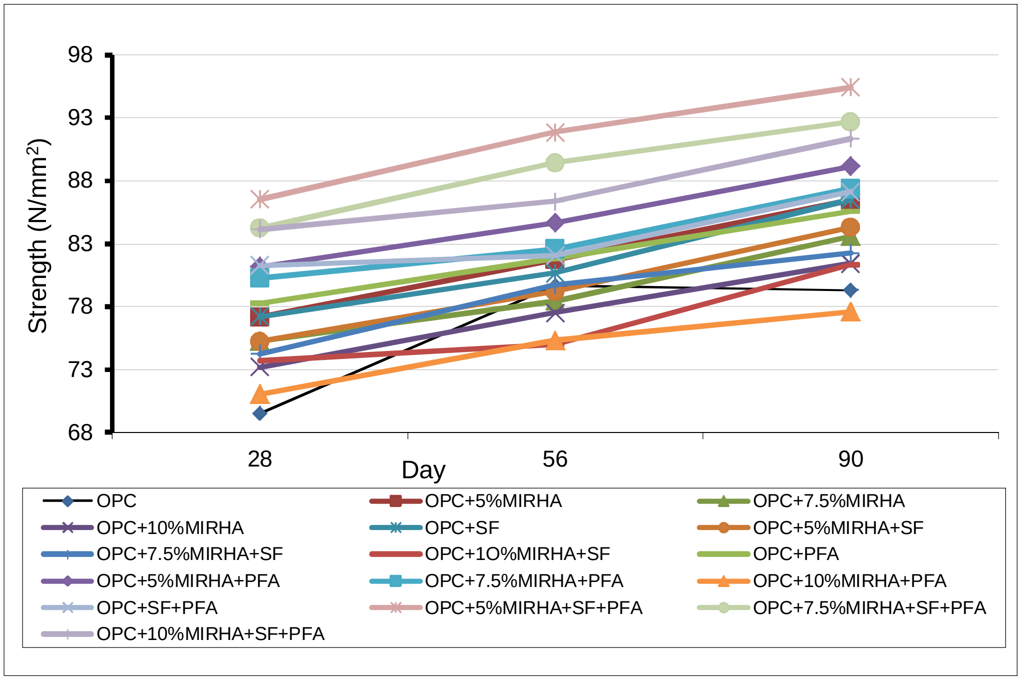


Figure 4.6: Strength on Compressive test

Figure 4.6 shows that mix with multiple blended binders concrete containing maximum replacement level of 5% replacement of MIRHA in blended binders concrete system have given the highest compressive strength compare to others replacement level. This makes concrete mix 77%OPC, MIRHA, 8%SF and 10%PFA which contain 10% of MIRHA have been chosen as the optimum replacement level to be used in preparing a multiple blended binders concrete system. Adding the correct amount of RHA is important for achieving high strength. A study conducted by Hwang and Wu (1989) showed that large amount of RHA have an adverse effect and reduce strength.

4.5.4 Effect of Multiple Blended Binders Concrete on the Compressive Strength

Figure 4.7 presents the graph for Compressive Strength versus Day and the data based on result from Table 4.4. The graph shows the value of compressive strength of concrete specimens increases as age of specimen increases. It also shows the different value of compressive strength based on different percentage of cement replacement used in concrete mix.

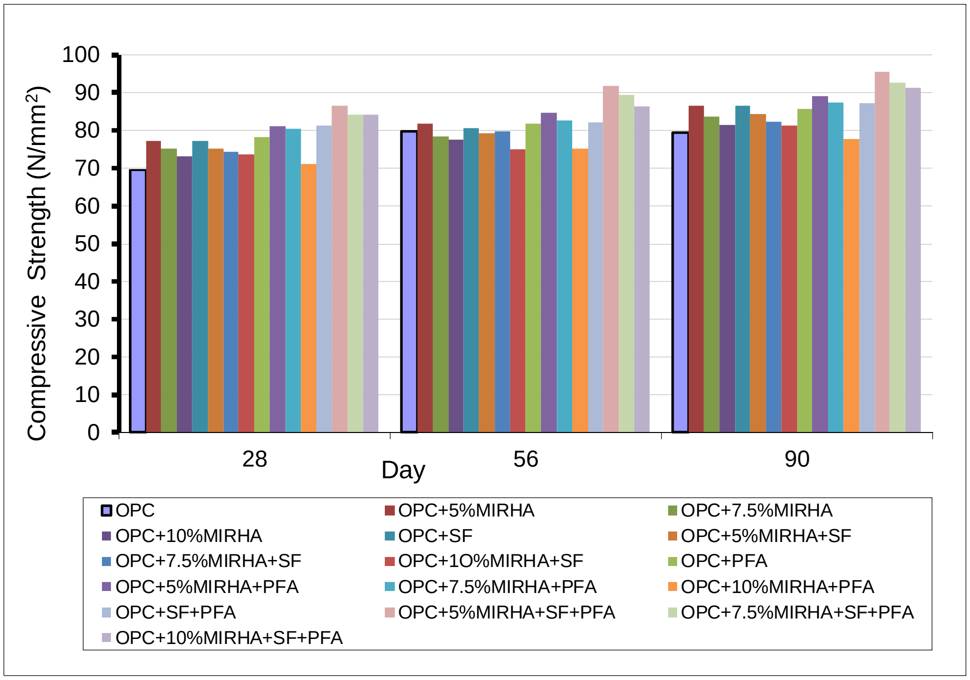


Figure 4.7: Strength versus Day – Compressive test

A maximum increment in compressive strength for multiple blended binders concrete from 3 to 7 days was observed as 52.9% while the maximum increment from 7 to 28 days was obtained as 37.3%. It may be due to the fact that the finer particle size enabled SF, MIRHA and PFA to act as filler that managed to fill the tiny spaces between cement particles and as well as spaces between cement particles and aggregate. A greater surface area providing space for nucleation of C-S-H and calcium hydroxide $Ca(OH)_2$ accelerated the reactions and formed smaller calcium hydroxide crystals.

The improvement of compressive strength was due to the pozzolanic reaction between Portland cement, silica fume and PFA. More than 30% of Portland cement is composed of the primary mineral tricalcium silicate, which upon hydration forms calcium silicate hydrate (C-S-H) and calcium hydroxide, $Ca(OH)_2$. In these mixes, silica fume acts as pozzolanic because of a very high non-crystalline silica ($Si0_2$) glass content which is the principal reactive constituent of pozzolana. This silica combines with the calcium hydroxide released on the hydration of Portland Cement. Calcium hydroxide in hydrated Portland Cement does not contribute to the development of strength, but by adding pozzolana such as silica fume and PFA will utilize reactive silica. Slowly, and gradually it forms additional C-S-H which is a binder and fills up the space, and gives impermeability and ever-increasing strength.

4.5.5 Summary

From Table 4.4 and Figure 4.7, it shows that the strength of concrete is related to the density of the specimens. The higher density of concrete shows the higher compressive strength will be achieved. From the result it can be observed that addition of multiple blended binders will result in increase of compressive strength.

Other possible causes are:
a) Interference of cement hydration by multiple mix; Silica Fume, MIRHA and PFA.
b) Chemical reaction between water and cement might be affected by the stabilizers added to the MIRHA and SF.

From the results and analysis, MIRHA, SF and PFA as cement replacement in concrete mix affected the compressive strength on hardened concrete. It also depends on the percentage of amount that has been added. The different results between normal concrete and other samples are shown and comparison can be defined.

From the result obtained all specimens containing MIRHA, SF and PFA are achieved above 70 N/mm^2 at the age of 28 days and it shows the combination of MIRHA, SF and PFA is acceptable for use as a cement replacement in producing a HSC. This is due to the lower water cement ratio, optimum admixture and cement content. The combination of MIRHA, SF and PFA can gave higher early strength compared to normal concrete. However, use of only 10% PFA also achieved high compressive strength compared to normal concrete. This improvement in compressive strength is caused by the finer particles of MIRHA, SF and PFA size that enables to act as filler that seeped into the tiny spaces between cement particles and as well as spaces between cement particles and aggregate. It also causes the concrete to become more dense and improve its compressive strength.

The production and investigation of pozzolanic materials used has been briefly described in this thesis. The investigation on the optimum mixes proportions of blended binders concrete in designing multiple blended binders concrete was performed. The potential of using multiple blended binders concrete in obtaining HSC mixes was also determined.

4.6 Flexural Strength of Concrete under Multiple Blended Binders with MIRHA, SF and PFA

4.6.1 Samples preparations and testing

The flexure strength of concrete containing Multiple Blended Binders Concrete (MBBC) compared to Blended Binders Concrete (BBC) and OPC mixes was carried out by the prism flexure test. Three concrete prism specimens of 100x100x500mm for each type of binder were prepared and tested at 28, 56 and 90 days. Mean reading of maximum stress applied to the concrete prism by 3-point load test using flexure testing machine was recorded and used to calculate the flexure strength of the concrete prism containing prepared blended cements.

4.6.2 Influence of Multiple Blended Binders (MBB)

Figures 4.8 and Table 4.5 present the effect of Multiple Blended Binders to the flexure strength of concrete prism compared to OPC concrete. It shows that concrete containing Multiple Blended Binders with 5% MIRHA+8%SF+10%PFA that illustrates the highest flexure strength that is 12.66Mpa at 90 days age, that is 28.7% higher than OPC concrete.

The strength increment of MIRHA concrete is due to the high amorphous silica and fineness of MIRHA used. The effective burning method of UTP microwave incinerator adopted to produce amorphous silica in the rice husk ashes is instrumental in creating good quality MIRHA concrete. The addition of MIRHA caused an increment in the compressive strength that was due to the capacity of pozzolan consuming the calcium hydroxide generated during reactions of hydrated cement paste. The end product of the pozzolanic reaction was the formation of C-S-H gel that enhanced the flexural strength.

Table 4.5: Characteristic Flexural Strength using Multiple Blended Binders

Item	OPC	MIRHA	SF	PFA	(N/mm^2)		
	(%)	(%)	(%)	(%)	28d	56d	90d
1	100	-	-	-	9.28	10.01	9.83
2	95	5	-	-	10.41	10.62	11.07
3	92.5	7.5	-	-	10.17	10.43	10.90
4	90	10	-	-	9.53	10.68	10.83
5	92	-	8	-	10.43	10.78	11.42
6	87	5	8	-	10.71	10.92	11.19
7	84.5	7.5	8	-	10.07	10.34	10.82
8	82	10	8	-	9.96	10.13	10.13
9	90	-	-	10	10.61	10.75	11.25
10	85	5	-	10	10.97	11.19	11.80
11	82.5	7.5	-	10	10.85	11.34	11.86
12	80	10	-	10	9.52	10.21	10.26
13	82	-	8	10	10.98	11.10	11.53
14	77	5	8	10	11.68	11.68	12.66
15	74.4	7.5	8	10	11.38	11.65	12.36
16	72	10	8	10	11.28	11.67	12.23

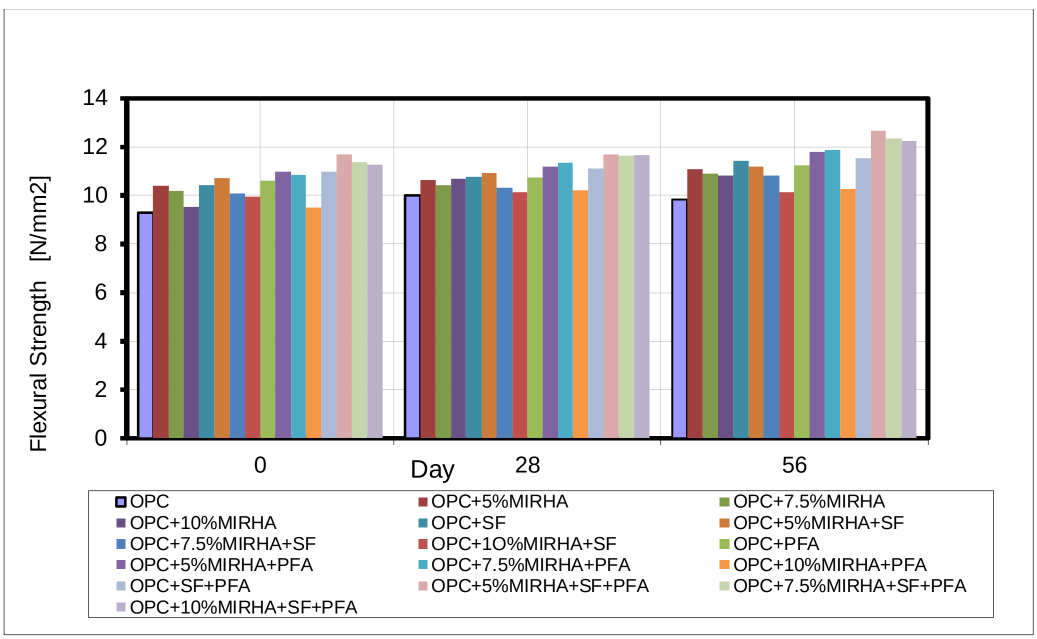


Figure 4.8: Load versus Day – Flexural Test.

The Multiple Blended Binders Concrete with 10% MIRHA+8%SF+10%PFA showed the lowest flexure strength compared to other types of Multiple Blended Binders Concrete, but was 28.8% higher compared to control mixes. The higher flexure strength of all Multiple Blended Binders Concrete compared to OPC was influenced by the inclusion of MIRHA that presented the higher flexure strength among all Blended Binders Concrete systems. The higher flexure strength of Multiple Blended Binders Concrete compared to Blended Binders Concrete with MIRHA concrete shows how the inclusion of SF and PFA had improved the flexure properties of Blended Binders Concrete with MIRHA concrete.

The increment of loading (KN) results for Multiple Blended Binders Concrete samples was influenced by the quantity of MIRHA, SF and PFA that were used. The flexure strength of concrete containing Multiple Blended Binders Concrete is shown in Figures 4.9 revealed that Multiple Blended Binders Concrete with 7.5%MIRHA+8%SF+10%PFA is only having 12.36MPa of flexure strength that is 25.7% higher than OPC. The higher flexure strength of concrete containing Multiple Blended Binders with MIRHA may be due to the high replacement level of MIRHA to OPC.

The reduction of OPC content in concrete resulted give the higher replacement MIRHA amount of C-S-H produced in Blended Binders Concrete that is responsible for additional strength properties. The other type of Multiple Blended Binders Concrete systems seems to have a comparable flexure strength even all of them are better compared to OPC concrete. When multiple blended binders cement is used as part of the cementitious material in a concrete mix, it reacts with water and $Ca(OH)_2$ to form more CSH. The additional CSH densities the concrete matrix, enhancing strength.

Concrete made with multiple blended binders cement will have higher strength growth over the lifetime of the concrete element compared with straight portland cement concrete mixtures.

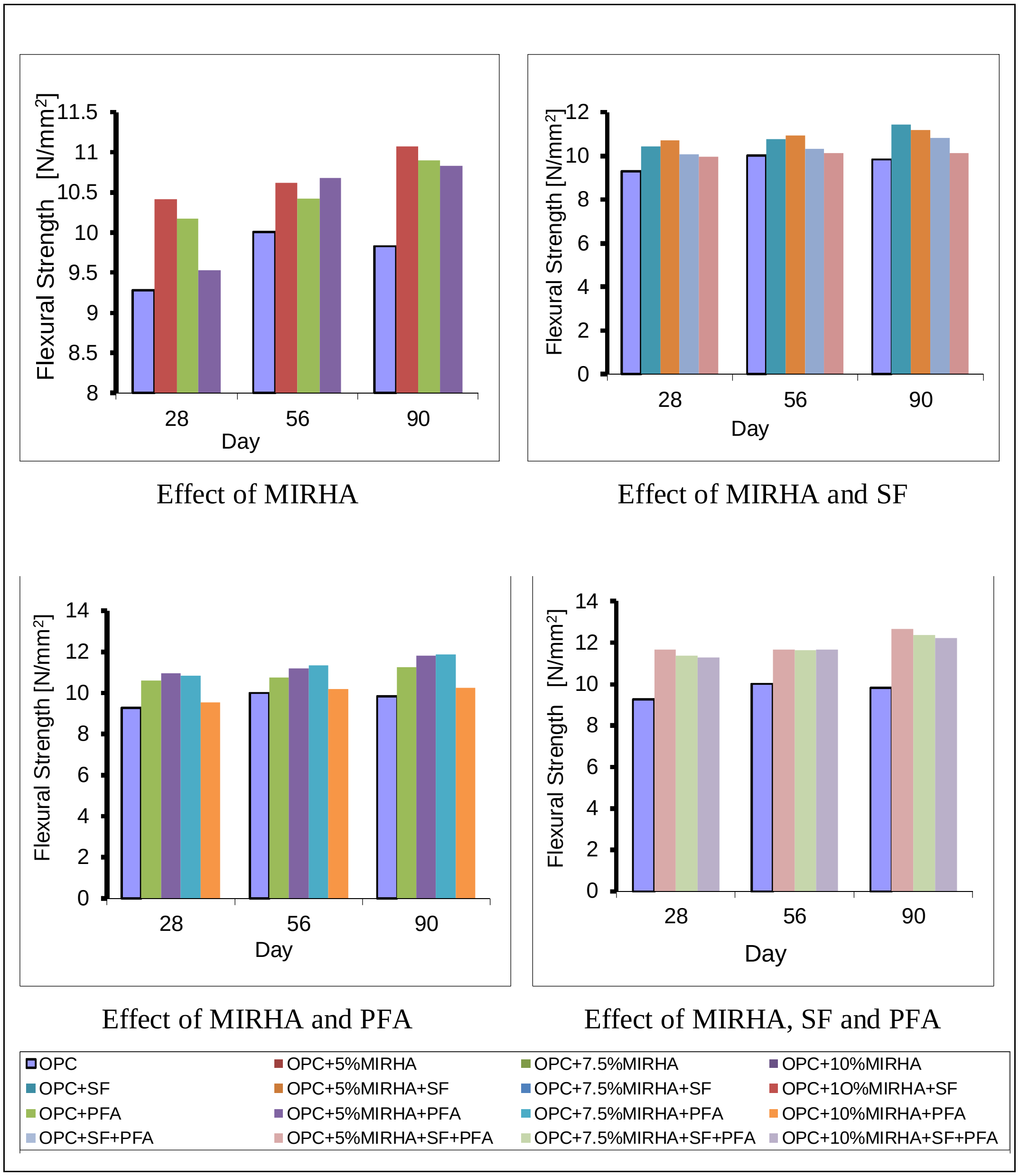


Figure 4.9: Effect of MIRHA, SF and PFA on the Flexural Strength

4.6.3 Comparison with Published Data

From results and analysis, used of MIRHA, SF and PFA as a cement replacement in concrete mix are affect the flexural strength on strength of concrete and it is depend on the percentage of amount that has been added.

Malhotra (2004) indicated that there is no significant difference in terms of flexure strength for a concrete containing SF and FA compared to OPC at low replacement level. Cengiz (2003) studies on the use of high volume FA in concrete, found that the used of FA at high replacement level affected the flexure strength of concrete and other type of properties as well. The inclusion of MIRHA was also reported to increase the flexure strength of concrete but the performance of MIRHA is largely depended on the quantity of MIRHA provided.

4.7 Tensile Splitting Strength

The tensile strength of the 16 type selected concrete mixes under water curing condition are tabulated in Table 4.6.

Table 4.6 : Average of Characteristic Tensile Splitting Strength

Item	OPC	MIRHA	SF	PFA	STRENGTH (N/mm^2)		
	(%)	(%)	(%)	(%)	28d	56d	90d
1	100				4.85	5.25	5.21
2	95	5			5.47	5.42	5.67
3	92.5	7.5			5.28	5.51	5.73
4	90	10			5.19	5.34	5.61
5	92		8		5.48	5.82	5.93
6	87	5	8		5.37	5.56	5.87
7	84.5	7.5	8		5.16	5.53	5.63
8	82	10	8		5.23	5.12	5.56
9	90			10	5.46	5.64	5.82
10	85	5		10	5.78	5.96	6.19
11	82.5	7.5		10	5.63	5.76	6.14
12	80	10		10	5.04	5.21	5.36
13	82		8	10	5.65	5.94	6.11
14	77	5	8	10	6.03	6.29	6.67
15	74.4	7.5	8	10	5.97	6.11	6.55
16	72	10	8	10	5.78	6.23	6.43

4.7.1 Effect of Multiple Blended Binders on the Tensile Splitting strength

Table 4.6 and Figure 4.10 showed that the Multiple Blended Binders (MBB) with MIRHA, SF and PFA concrete cured in water was marginally higher tensile splitting strength compared to OPC concrete, and increasing the MIRHA content in Multiple Blended Binders resulting in reduction in tensile values. Compared to the OPC concrete with multiple blended binders, the difference in the strength of 5% MIRHA with MBB concrete at 28, 56 and 90 days were 24.3%, 19.8% and 28%, for 7.5%MIRHA with MBB concrete the difference were 23%, 16.4% and 25.7%, while for 10%MIRHA with MBB concrete the difference were 19.2%, 18.7% and 23.4% respectively.

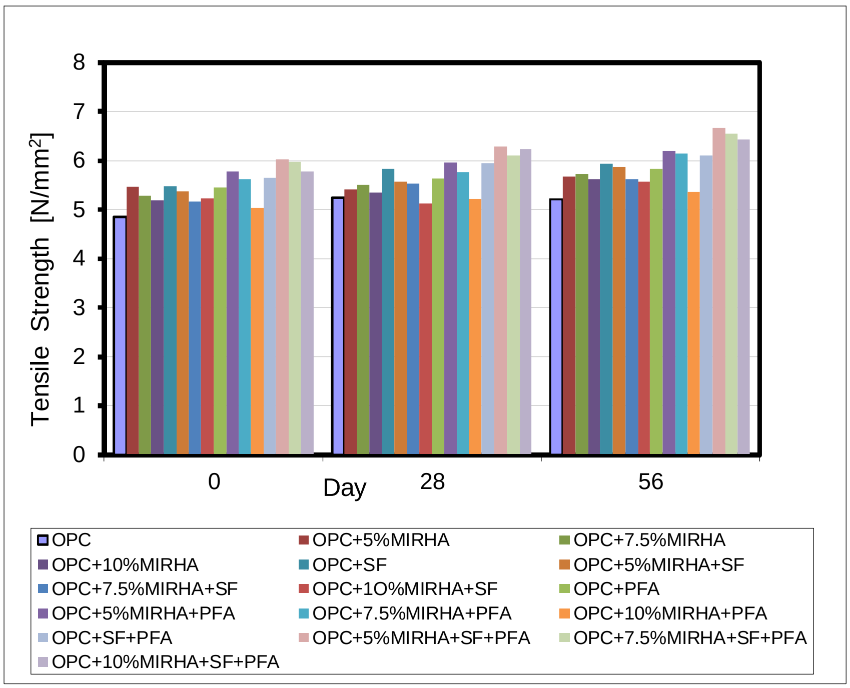


Figure 4.10: Tensile Strength versus Day – Tensile Splitting Test.

In this study, we can say that, the MIRHA being a pozzolanic material required the presence of water to develop its strength as the pozzolanic reaction in hydration of C_3A, C_3S and OPC appears to be retarded in the early stages. However, at later ages the strength will increase more rapidly than OPC concrete because the amount of $Ca(OH)_2$ is reduced as it has been replaced by MIRHA. Therefore, there will more C-S-H and less portlandite in the OPC-MIRHA mix. These contributed to the increase in strength of MIRHA concrete.

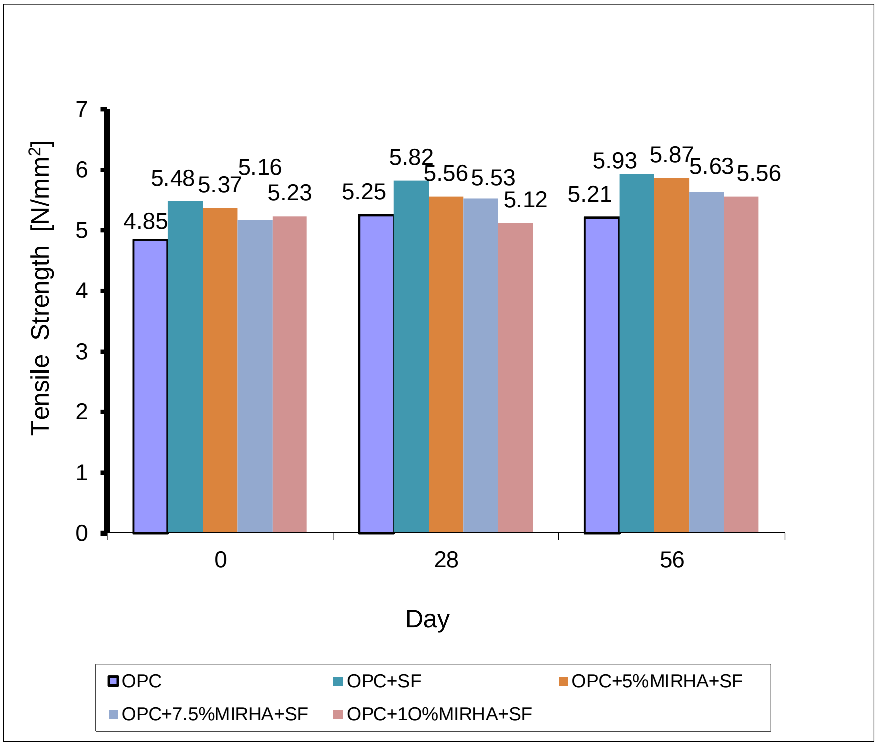


Figure 4.11: Effect of MIRHA and SF on the Tensile Strength

Table 4.6 and Figure 4.11 showed that the Multiple Blended Binders with MIRHA and SF concrete cured in water is marginally higher tensile splitting strength compared to OPC concrete, and increasing the MIRHA content resulting in reduction in tensile values.

Compared to the OPC concrete, the higher difference in the strength of 5% MIRHA and SF concrete at 28, 56 and 90 days were 10.7%, 5.9% and 12.6%, for 7.5%MIRHA and SF concrete the difference were 6.4%, 5.3% and 8.1% while for 10%MIRHA concrete, the difference were 7.8%, -2.5% and 6.7% respectively.

That result would occur because the silica came from Multiple Blended Binders that combines with the calcium hydroxide released on the hydration of Portland cement. Calcium hydroxide in hydrated Portland cement does not contribute to the development of the strength, but by adding pozzolana such as SF, PFA and MIRHA will utilize with reactive silica. Slowly, and gradually it forms additional C-S-H which is a binder and fills up the space and increasing the strength.

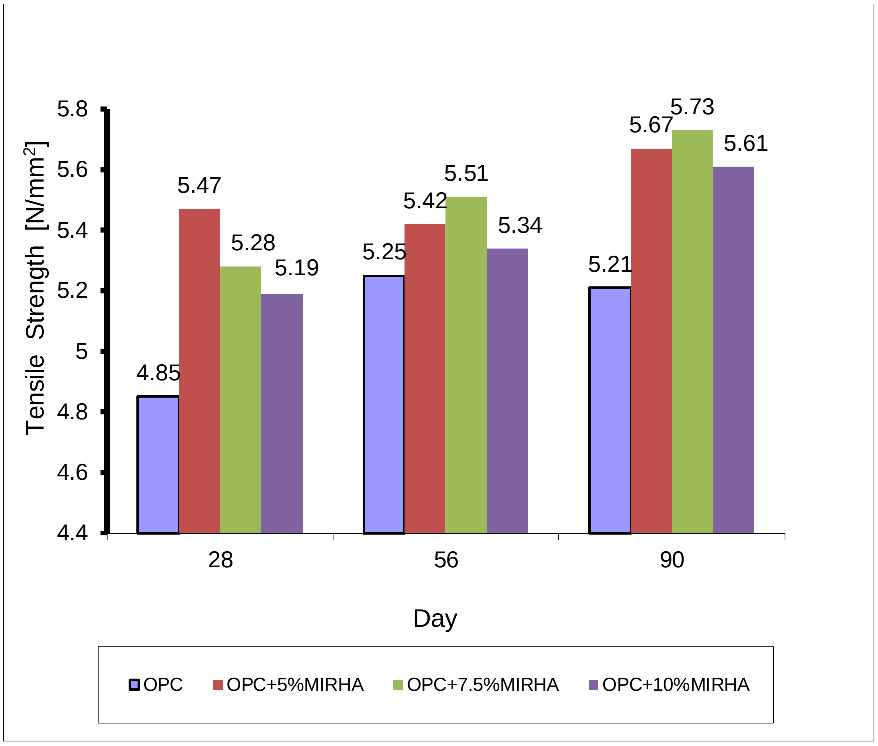
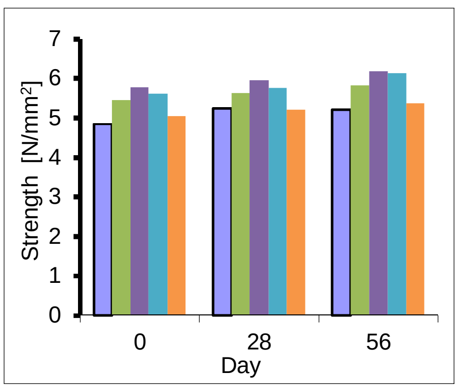


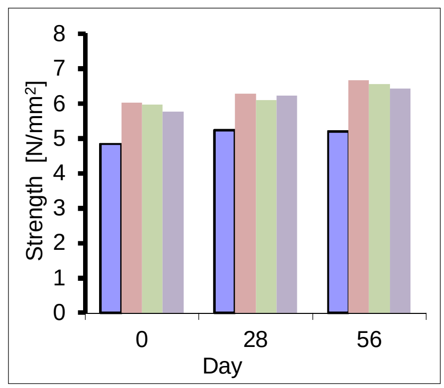
Figure 4.12: Effect of MIRHA on the Tensile Strength

Table 4.6 and Figure 4.12 also show that Multiple Blended Binders concrete cured in water marginally had higher tensile splitting strength compared to OPC concrete, and increasing the MIRHA content resulting in reduction in tensile values. Compared to the OPC concrete, difference in the strength of 5% MIRHA concrete at 28, 56 and 90 days were 12.7%, 3.2% and 8.8%, for 7.5%MIRHA concrete the difference were 8.7%, 5% and 10%, while for 10%MIRHA concrete the difference were 7%, 1.7% and 7.7% respectively.

These data indicate that the variation in indirect tensile strength with age is similar to that observed with compressive strength. These investigations revealed that as the Multiple Blended Binders with MIRHA, SF and PFA replacement level increases, the tensile splitting strength decreases. It is proven that the inferior performance of RHA concrete in the present study is mainly due to the lower amount of cement employed for normal grade concrete. The results of the present study are also with agreement with results obtained from Karasudhi and Nimityongskul (1979), that addition of RHA with decreasing amount of cement in the mix decreases the concrete splitting tensile strength.



MIRHA and PFA on the Tensile Strength



MIRHA,SF and PFA on Tensile Strength

Figure 4.13: Effect of MIRHA, SF and PFA on the Tensile Strength

From the Figure 4.13, it can be seen that for specimens, the percentage increase of strength based on the 28, 56 and 90 days strength for Multiple Blended Binders with MIRHA, SF and PFA concrete is higher compared to OPC concrete irrespective of with Sp. This indicates that the Multiple Blended Binders with MIRHA, SF and PFA concrete exhibit slower rate of pozzolanic cementing reaction, in which it continues to show an increase in the strength more at 56 days onwards compared to OPC concrete.

It also shows that 7.5% exhibits higher tensile strength compared to 5%MIRHA, SF and PFA and 10%MIRHA, SF and PFA concrete, and this may be due to the reduction in the cement content in the concrete. Therefore, these is higher amount of reduction of C_3S in the mix. For 7.5%MIRHA, SF and PFA concrete, even though there is strength increase with age, the increase is modest from age 56 days onwards.

4.7.2 Comparison with Published Data

Published data on the tensile strength of MIRHA, SF and PFA concrete specimens are limited because concrete is not normally designed to resist direct tension. However, the knowledge of tensile strength is of value in estimating the load under which cracking will develop.

The tensile splitting of Multiple Blended Binders concrete with 5%, 7.5% and 10% replacement with MIRHA is higher than the control, mainly due to the factor that the amount of cement in multiple blended binders mixture was lower. Results by Cook et al., (1976) also show that at 10% replacement with RHA, the tensile splitting is higher than the control, but when the replacement is increased, the tensile splitting is lower than the control. Results by Rodriguez (2006) on RHA concrete specimens without Sp shows that as the percentage of replacement increases, the tensile strength reduces.

Nevertheless, the tensile strength increases as multiple blended binders replacement level increase on concrete with addition of Sp. The total amount of cementitious used is high, about 400 kg/m^3 for normal concrete. These data indicate that the variation in indirect tensile strength with age and curing condition is similar to that observed with compressive strength. While findings by Shimizu and Jorillo (1990) on two series of investigations revealed that as the RHA replacement level increases, the tensile splitting strength decreases. It is noted that the total cementitious content adapted is similar or lower to that used in the present investigation. It is proven that the inferior performance of multiple blended binders concrete in the present study is mainly due to the lower amount of cement employed for normal grade concrete.

4.8 Non-Destructive Tests

4.8.1 Ultrasonic Pulse Velocity (UPV)

The variation of UPV with age for the selected OPC and MIRHA, SF and PFA concretes conducted on 150 mm cube specimens at 28, 56 and 90 days, which either under air and water curing conditions prior to the test are tabulated in Table 4.7.

Table 4.7: Average of Characteristic Ultrasonic Test Result using Multiple Blended Binders – Direct Transmitter

Item	OPC (%)	MIRHA (%)	SF (%)	PFA (%)	Velocity (km/sec.) 28d	56d	90d
1	100	-	-	-	4.6	4.8	4.9
2	95	5	-	-	4.5	4.6	4.7
3	92.5	7.5	-	-	4.8	4.9	4.9
4	90	10	-	-	4.9	5.0	5.1
5	92	-	8	-	5.1	5.2	5.3
6	87	5	8	-	5.3	5.4	5.4
7	84.5	7.5	8	-	5.4	5.5	5.5
8	82	10	8	-	5.4	5.5	5.6
9	90	-	-	10	5.2	5.4	5.5
10	85	5	-	10	5.3	5.4	5.5
11	82.5	7.5	-	10	5.4	5.5	5.7
12	80	10		10	5.5	5.6	5.6
13	82	-	8	10	5.5	5.6	5.7
14	77	5	8	10	4.4	4.5	4.8
15	74.4	7.5	8	10	4.7	4.9	5.0
16	72	10	8	10	4.9	5.0	5.2

4.8.1.1 Effect of Multiple Blended Binders on UPV

It can be seen clearly from Figure 5.16 that all the concrete mixes produce UPV range between 4.4-5.5 km/sec at 28 days for specimen placed under water curing respectively BS EN 12504-4:2004. Neville (1997) specifies that concrete with pulse velocity more than

4.5 km/sec can be classified as excellent concrete, while concrete with pulse velocity ranged between 3.5-4.5 km/sec can be categorized as good or even excellent concrete.

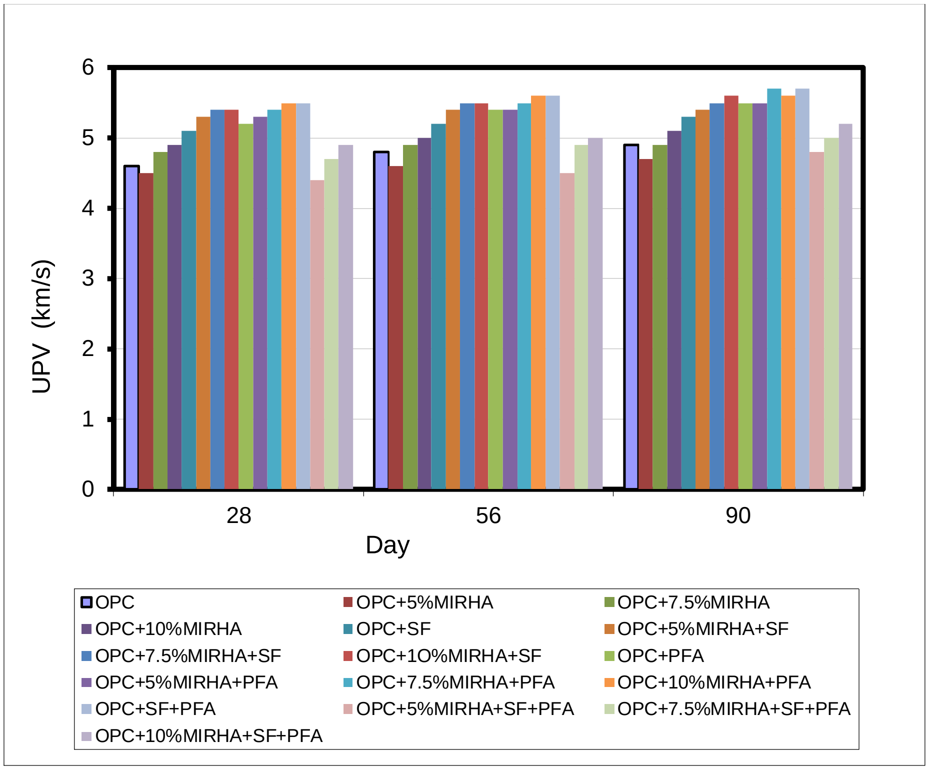


Figure 4.14: Velocity versus Day – Ultrasonic test under direct transmitted

Measurement of pulse velocities at points on a regular grid on the surface of a concrete structure provides a reliable method of assessing the homogeneity of the concrete. Figure 4.14 shows that, it can be classified as excellent concrete because the result more than 4.0 km/s. So, concrete produced very excellent concrete quality.

To improve its physical structure and that account for increase in strength of such concrete, therefore the resulted increased in the pulse velocity value. The speed of pulse propagation is much less through voids and in fact the pulse cannot travel directly through the void but deflected around it, so that the pulse can be transmitted through the solid concrete. This increases the time of travel of the pulse and hence, decreases the calculated velocity.

The velocity of the propagation through concrete increases with age. Increasing the multiple blended binders with MIRHA, SF and PFA content in mixes reduces the UPV values.

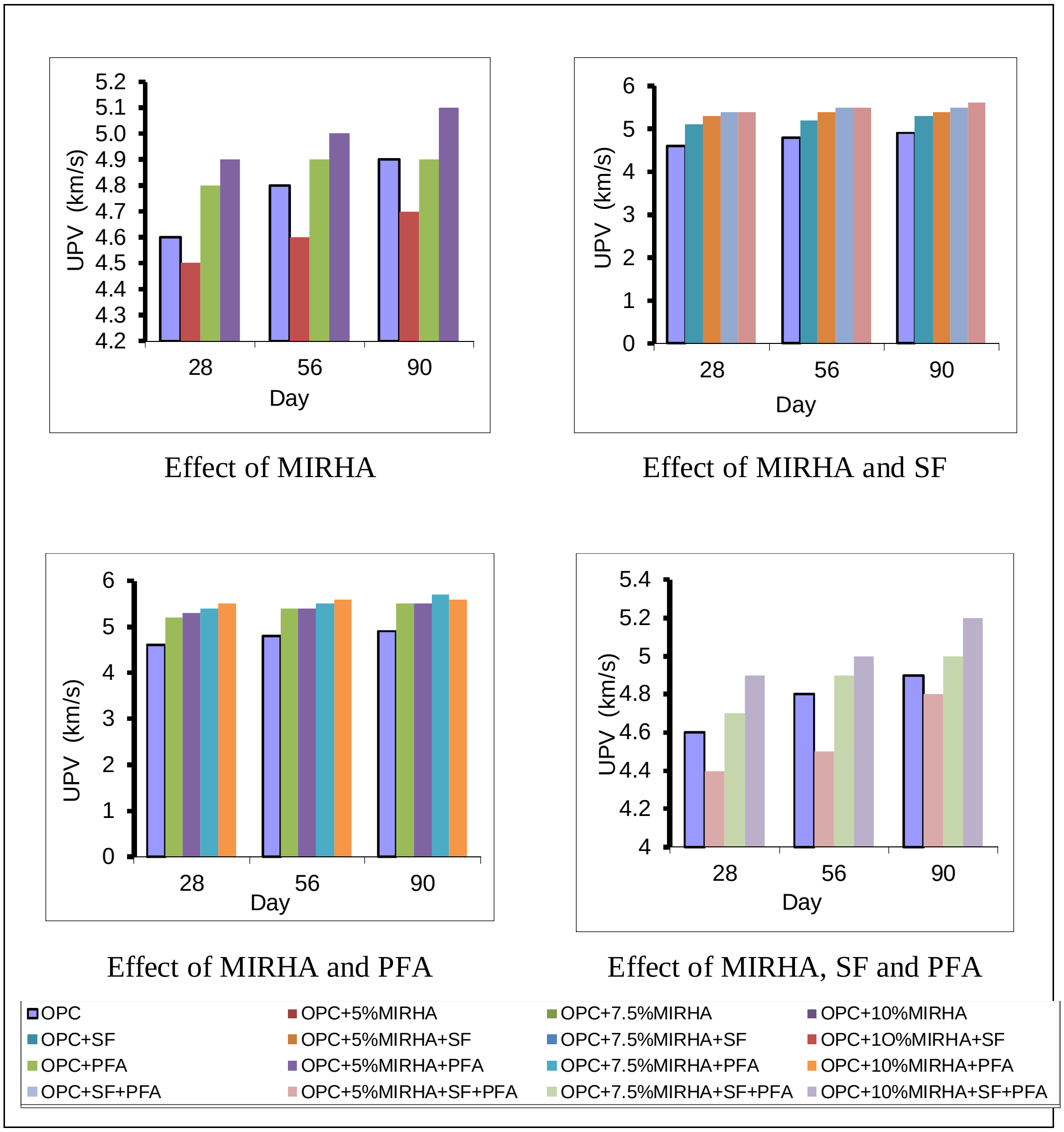


Figure 4.15: Effect of MIRHA, SF and PFA on the UPV

From Figures 4.15, it can also be concluded that Multiple Blended Binders with MIRHA, SF and PFA concrete is marginally higher in the pulse velocity value than the OPC concretes. The primary products of hydration formed by the reaction between cement and water account for a greater proportion of compressive strength and UPV than the secondary products of hydration resulting from the reaction between $Ca(OH)_2$ and the silica and alumina contained in MIRHA. This means that a unit volume of cement contributes more to the strength and UPV than does an equivalent volume of MIRHA. Therefore, increase in the MIRHA content for the mixes are bound to attain higher strength and UPV values. This result suggested that moisture content in the mixes influence the quality of the concrete.

The uniformity of concrete is determined through the UPV readings taken from concrete cubes containing OPC, blended binders concrete and multiple blended binders concrete. From the analyses, it is found that the use of multiple blended binders concrete in HSC does not affect the uniformity of concrete. The UPV readings of concrete containing multiple blended binders concrete is grouped as excellent and found to be better than control mix and concrete mix containing PFA especially at later ages. Among the three types of multiple blended binders concrete produced and tested in the investigations, multiple blended binders concrete containing OPC+MIRHA+PFA is reported to have the highest readings of UPV.

4.8.1.2 Comparison with Published Data

The velocity of the propagation through concrete increased with age. Increasing the MIRHA content in multiple blended binders concrete, the mixes increase the UPV values. This trend is in line with the result by Ikpong (1993), based on 30 N/mm^2 design strength with RHA contents of 30%, 40% and 50%.

Specimen cured in water produced higher UPV values. Malhotra and Sivasundaram (1991) in their study reported that the pulse velocity of saturated concrete is higher up to 2% than that in dry concrete of the same composition and quality. Besides Ikpong (1993), no other studies reported on the relationship between compressive strength and UPV for multiple blended binders concrete together with MIRHA designed for Grade 70. Specimen multiple blended binders concrete produced higher UPV values as compared to normal concrete.

4.8.2 Rebound Hammer

The rebound hammer test conducted on the specimen measures the properties of only the surface zone of the tested specimen, which in accordance to BS EN 2504-2:2001, is about 30 mm. It is useful in the assessment of uniformity of concrete within the structure.

4.8.2.1 Effect of Multiple Blended Binders on Surface Hardness

The strength of rebound hammer for the OPC and Multiple Blended Binders with MIRHA, SF and PFA concretes is tabulated in Table 4.8. It shows that as the percentage of replacement of OPC with multiple blended binders concrete increases, the strength of rebound hammer also increases due to increase with age of concrete. When Sp is added, OPC and MIRHA concretes produced higher rebound hammer strength at all ages when compared to OPC. This is because the w/b ratio of these mixes was kept constant at 0.35, only the dosage of Sp similar with 1% cement weight to maintain the required workability. Therefore, they were more workable and compactable, thus resulting in increase in strength and rebound number.

Table 4.8 : Average of Characteristic Surface Hardness of HSC using Multiple Blended Binders

Item	OPC (%)	MIRHA (%)	SF (%)	PFA (%)	Stress (N/mm^2) 28d	56d	90d
1	100	-	-		32.71	32.15	34.11
2	95	5	-		35.63	36.12	37.74
3	92.5	7.5	-		34.37	34.58	37.53
4	90	10	-		33.89	33.75	36.60
5	92	-	8		35.64	37.25	39.13
6	87	5	8		34.73	34.38	38.24
7	84.5	7.5	8		34.17	35.41	37.82
8	82	10	8		34.12	34.17	36.30
9	90	-	-	10	36.33	36.22	38.71
10	85	5	-	10	37.58	37.85	40.41
11	82.5	7.5	-	10	37.26	37.61	39.68
12	80	10	-	10	32.86	32.97	34.98
13	82	-	8	10	37.63	37.99	39.75
14	77	5	8	10	40.03	40.04	43.36
15	74.4	7.5	8	10	38.72	39.90	42.35
16	72	10	8	10	38.95	38.92	41.97

Table 4.8 also shows the relative difference is higher for MIRHA5%, MIRHA7.5% and MIRHA10% concretes at age 7 days to 90 days under Multiple Blended Binders condition.

This suggested that the higher the MIRHA content, the higher will be the rebound hammer strength, the rebound hammer strength significantly increases as demonstrated in Figure 4.16.

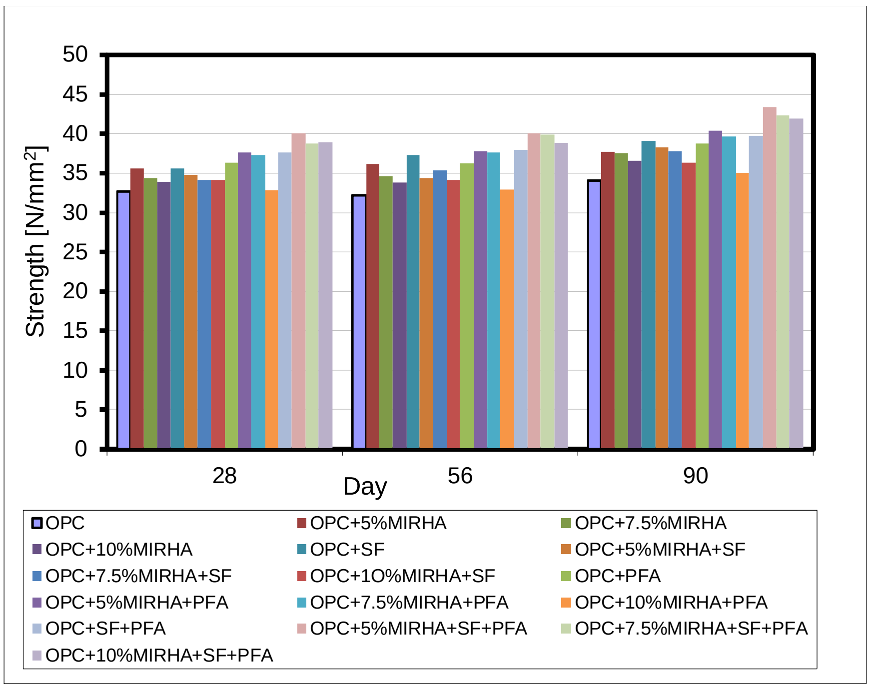


Figure 4.16: Surface Hardness of HSC using Multiple Blended Binders

4.8.2.2 Effect of MIRHA, SF and PFA on the Rebound Hammer Test

Multiple Blended Binders conditions is one of the factors that affect the surface hardness of concrete. The effect of MIRHA, SF and PFA on OPC concretes is demonstrated in Figure 4.17. Referring to Table 4.8, it is clearly seen that the rebound hammer strength for the effect of MIRHA, SF and PFA on the specimens are higher than the OPC concrete specimens, suggesting that the surface and the internal moisture condition influenced the rebound number. This is because when concrete is submerged in water, the surface will be saturated therefore resulting in surface softening, thus giving a smaller rebound number. It is to be noted that when conducting rebound hammer test on the multiple blended binders specimens, surface blemishes upon impact on the concrete cube surface were more severe compared to OPC concrete specimen.

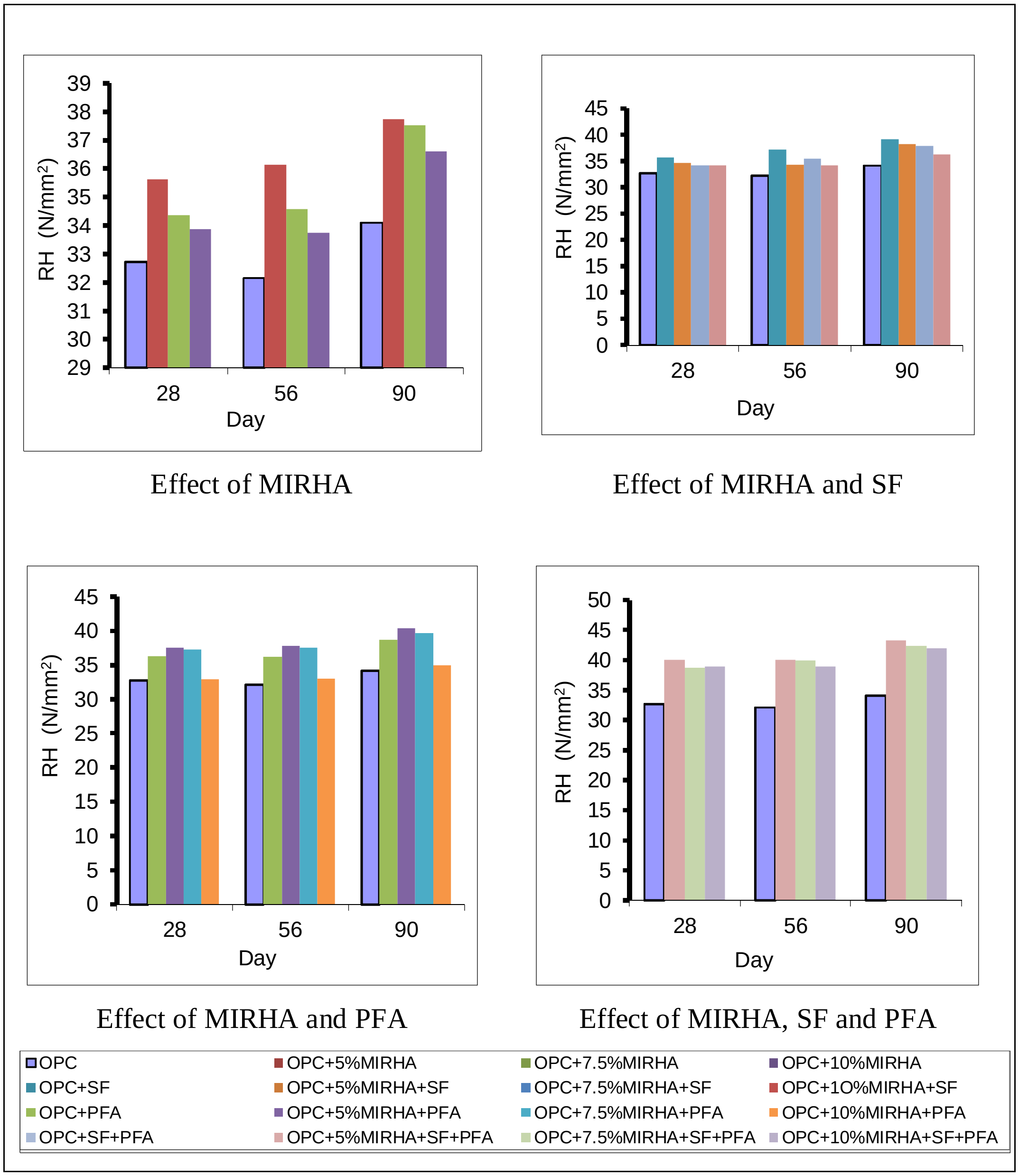


Figure 4.17: Effect of MIRHA, SF and PFA on the RH

The Figure 4.16 shows that the inclusions of 5%MIRHA as cement replacement materials have increased the surface hardness strength of concrete at 28, 56 and 90 days. 5% replacement of MIRHA in blended binders concrete system have given the highest surface hardness strength compare to others replacement level. This make concrete mix using MIRHA, SF and PFA which contain 5%, 7.5% and 10% of MIRHA have been chosen as the optimum replacement level to be used in preparing a multiple blended binders concrete system

Table 4.9: Effect of MIRHA, SF and PFA on the Rebound Hammer Test

	Mix		Relative difference with respect to OPC control to binders concrete					
			28d		*56d*		*90d*	
			Strength (N/mm^2)	*Ratio %*	*Strength (N/mm^2)*	*Ratio %*	*Strength (N/mm^2)*	*Ratio %*
1.	MIRHA5		35.63	8.93	36.12	12.35	37.74	10.64
	MIRHA7.5		34.37	5.07	34.58	7.56	37.53	10.03
	MIRHA10		33.89	3.61	33.75	4.98	36.60	7.30
2.	MIRHA5		34.73	6.18	34.38	6.94	38.24	12.11
	MIRHA7.5	SF8	34.17	4.46	35.41	10.14	37.82	10.88
	MIRHA10		34.12	4.31	34.17	6.28	36.30	6.42
3.	MIRHA5	PFA10	37.58	14.89	37.85	17.73	40.41	18.47
	MIRHA7.5		37.26	13.91	37.61	16.98	39.68	16.33
	MIRHA10		32.86	0.12	32.97	2.55	34.98	2.55
4.	MIRHA5	SF8	40.03	22.38	40.04	24.54	43.36	27.12
	MIRHA7.5	PFA10	38.72	18.37	39.90	24.11	42.35	24.16
	MIRHA10		38.95	19.08	38.92	21.06	41.97	23.04

- All the binders show that the strength increase from the normal control concrete

The result from Table 4.9 is analyzed for all samples of concrete mix at age of 28, 56 and 90days. The rebound hammer of surface hardness strength between each sample of concrete that contain cementitious materials and normal concrete are analyzed in percentage.

The use of multiple blended binders concrete in High Strength Concrete (HSC) concrete mixes also found to improve the surface hardness of concrete test. The multiple blended binders concrete found to have a comparable surface hardness to OPC concrete at 28 days and become better at the ages of 90 days. The multiple blended binders concrete also found to have a better surface hardness compared to blended binders concrete containing PFA. The use of high reactive pozzolanic materials named as MIRHA and SF has compensated the slow reactivity of PFA in multiple blended binders concrete systems.

Since multiple blended binders concrete shows that it is good to improve surface hardness of the concrete, this multiple blended binders concrete can act similar to FOSROC hardener cement in industry. The multiple blended binders concrete can be used in industry of floor hardeners and also can be used as structure repair.

4.8.2.3 Comparison with Published Data

From the present study, in general it can be seen that the values of the rebound hammer strength is influenced by the surface, in which when the specimens tested are in saturated surface dry condition. No available data can be obtained for MIRHA+SF+PFA concretes to compare with the present study. The present study shows that replacement of OPC with multiple blended binders concretes resulted in lower rebound hammer strength readings. However, with the incorporation of Sp, the rebound hammer strength for the MIRHA+SF+PFA concretes improves, suggesting that there is a densification of the pore structures in the mixes due to better compaction and workability.

4.9 Gas Permeability of Concrete

In identifying the effect of Multiple Blended Binders and Blended Binders on the permeability of concrete compared to control mix the German DIN 1048-1991 standard was utilized..

4.9.1 Influence of Multiple Blended Binders Permeability.

From Table 4.10, it can be seen that after 28 days of water curing the MIRHA+SF+PFA concrete were less permeable than the control OPC concretes. The coefficient of permeability of OPC and MIRHA+SF+PFA was 5.9 x 10^{-18} m/sec and 5.4 x 10^{-18} m/sec respectively. The results show that plain OPC concrete was about 8.4% more permeable than 72MIRHA+10SF+8PFA concretes. The reason can be explained by the fact that the pozzolanic material will occupy the empty space in the pore structure and substantially reduces the permeability of the concrete.

Table 4.10: Permeability Characteristic of Multiple Blended Binders Concrete

Item	**OPC** (%)	**MIRHA** (%)	**SF** (%)	**PFA** (%)	**Permeability x10^{-18} m/s** *28d*	*56d*	*90d*
1	100	-	-	-	5.9	5.2	4.4
2	95	5	-	-	5.7	4.9	4.2
3	92.5	7.5	-	-	5.6	4.8	4.2
4	90	10	-	-	5.4	4.7	4.0
5	92	-	8	-	5.1	4.4	3.8
6	87	5	8	-	5.3	4.6	3.9
7	84.5	7.5	8	-	5.4	4.5	4.0
8	82	10	8	-	5.4	4.7	4.0
9	90	-	-	10	5.4	4.6	4.0
10	85	5	-	10	5.3	4.6	3.8
11	82.5	7.5	-	10	5.2	4.5	3.9
12	80	10	-	10	5.5	4.7	4.1
13	82	-	8	10	5.5	4.7	4.3
14	77	5	8	10	5.8	5.0	4.3
15	74.4	7.5	8	10	5.7	4.9	4.2
16	72	10	8	10	5.4	4.6	4.0

Mehta and Monteiro (1993) stated that for normal weight aggregate concrete, the transition zone between aggregate and the cement paste in normal concrete is usually the weakest part (less dense) compared to the bulk paste and contains a large amount of plate-like crystal of calcium hydroxide which is suspected to induce micro-cracks at the transition zone due to tensile stresses caused by thermal and humidity change. This zone controls the strength and to a large extent the permeability of the concrete.

However, with the addition of pozzolanic material, that is. MIRHA, SF and PFA, it blocks the large voids pace in the pore structure and transformed large pores to micropores and substantially reduces permeability in the cementitious systems. This resulted in reduction in the porosity of the concrete and subsequently the pores are refined as illustrated by the results shown in Figure 6.1.

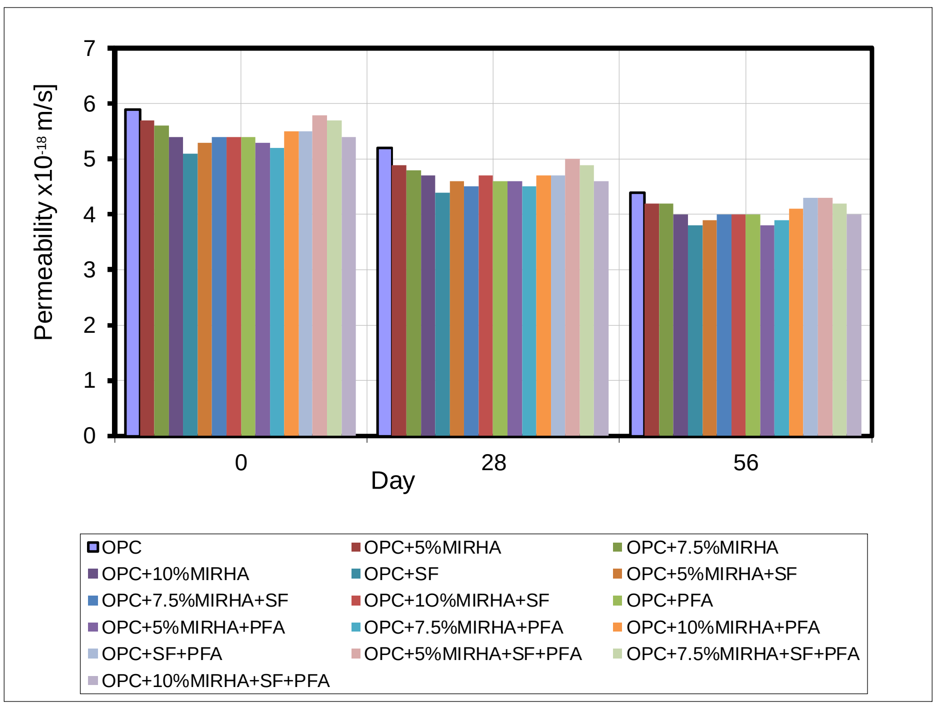


Figure 4.18: Gas Permeability versus Day – Gas Permeability Test

The ratio of permeability is defined as the permeability of concrete containing pozzolanic materials divided by the permeability of OPC concrete at the same age of testing. Figure

4.18 presents the permeability of concrete containing multiple blended binders using waste product at all curing ages. The permeability of multiple blended binders concrete found to be reduced by time concurrently with the permeability of control mix.

The permeability of multiple blended binders concrete was also found to be lower than control mix at all ages. In comparison to the blended binders concrete containing MIRHA+SF and concrete containing MIRHA+PFA, the multiple blended binders concrete containing MIRHA+SF+PFA has improved the permeability of HSC containing blended binders concrete with MIRHA+PFA system by about 10%, but the permeability value of HSC containing blended binders concrete with MIRHA+SF has increased at about 20%.

The inclusion of MIRHA, SF and PFA into the concrete had improved the permeability of HSC and the inclusion of MIRHA was responsible for late permeability performance of multiple blended binders concrete in the concrete produced. This shows that the utilization of multiple blended binders concrete will improved the permeability of concrete The finenes particles of the pozzolanic materials used in the investigations acting as filler effect in the multiple blended binders concrete has contributed for the low permeability value. The permeability of concrete is directly associated with the quantity of hydrated cementitious material at any given time.

Figure 4.18 also exhibits the permeability of concrete containing blended binders concrete. From the figure, it shows that the permeability of concrete containing blended binders concrete is lower than control mix. Among all blended binders concrete systems, concrete containing blended binders concrete with SF shows the lowest permeability value followed by PFA and MIRHA. The low permeability of the concrete compared to control mix even at early ages was influence by the filler effect and immediate acceleration of OPC due to the inclusion of pozzolanic materials. The pozzolanic reaction that has taken place at late ages

gives an extra reaction that gives better concrete permeability properties. The great effect of blended binders concrete in improving the permeability of concrete also influences the permeability performance of concrete containing multiple blended binders concrete except for blended binders concrete with MIRHA.

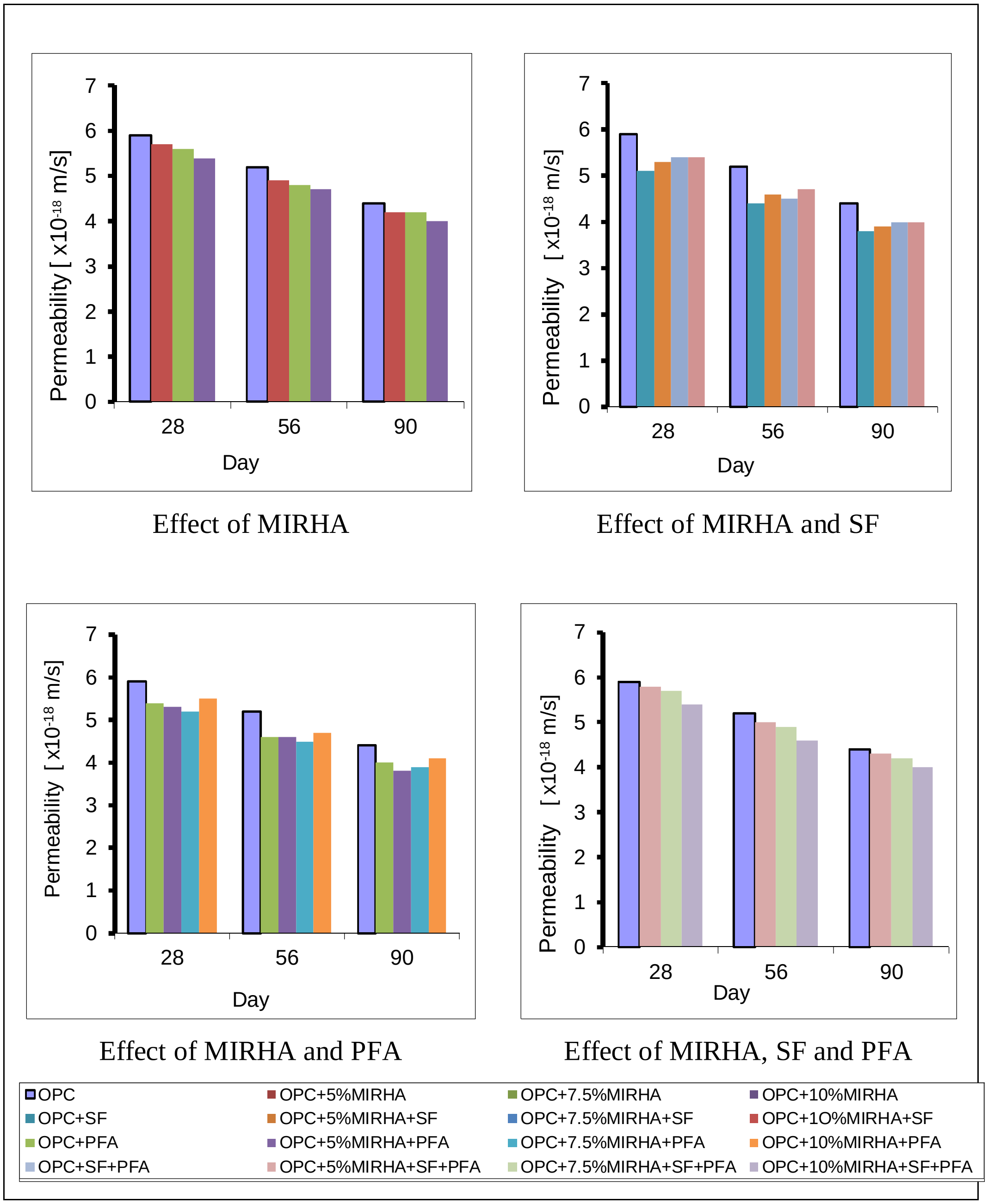


Figure 4.19: Effect of MIRHA, SF and PFA on the Gas Permeability Test

From Figure 4.19, it was found that blended binders concrete with MIRHA is having a permeability value higher than other mixes at early age and only lower than control mix at late age. The results explained that the fineness of MIRHA does not improve the permeability properties, and the high dosage of PFA used in the blended binders concrete systems has slow down the hydration of OPC which is responsible on the stability of concrete matrixes.

The effect of using active pozzolanic materials MIRHA, SF and PFA in improving the normal concrete properties was agreed by other researchers' findings. The combination of SF and PFA in multiple blended binders concrete systems improved the performance of cement through the effect of SF that compensates for low early strength of concrete with PFA. The produced C-S-H gel to reduction in porosity ratio of cement paste and consequently fills the gaps between the aggregates more effectively. The concrete produced with these mineral additives have low permeability characteristics (Temiz et al., 2007).

From Figures 4.19, it is interesting to note that by adding Sp to the MIRHA+SF+PFA the permeability of MIRHA+SF+PFA mix significantly improved (0.4×10^{-18} m/sec), that is. the lowest coefficient of permeability exhibited among the four mixes. Addition of Sp improves the workability and compactibility and subsequently, the concrete becomes denser. This result shows that the combined effect of MIRHA+SF+PFA inclusion and addition of Sp has resulted in the greatest reduction of permeability. Neville (1997) stated that at a w/c ratio of 0.75, the coefficient of permeability for normal concrete is typically 10^{-18} m/sec and represents the concrete with a high permeability, whereas at w/c ratio of 0.35 in this study, the coefficient of permeability is typically 5.9×10^{-18} m/sec or 4.4×10^{-18} m/sec.

The result shows that the more amount of MIRHA is added to the mix, the less will be the coefficient of water permeability. The reasons that attributed to such condition were that the practical w/c ratio of concrete is decreased due to the addition of MIRHA; more C-S-H gel and less portlandite are formed in concrete; and the average pore size of the concrete is reduced.

The porosity of multiple blended binders concrete clearly proved that the used of multiple blended binders reduced the total porosity of concrete compared to control mixes even at early age. It was found that among all the multiple blended binders concrete, the porosity of multiple blended binders concrete containing OPC+5MIRHA+SF+PFA is having the lowest porosity values followed by multiple blended binders concrete containing OPC+7.5MIRHA+SF+PFA and OPC+10MIRHA+SF+PFA.

4.9.2 Comparison with Published Data

The addition of pozzolans in a concrete mix can improve the properties of concrete by modifying the micro and macro structures of the concrete. However, there is limited information on the permeability of MIRHA+SF+PFA concrete.

Speare et al. (1999) shows that the presence of RHA resulted in lower coefficient of permeability. This study commented that the coefficient of permeability of MIRHA blended concrete is smaller than those without MIRHA. The reasons for these phenomena are that firstly, the practical w/b ratio of concrete is decreased due to the addition of MIRHA; secondly, more C-S-H gel and less portlandite are formed in concrete and thirdly, the average pore size of the concrete is reduced. The addition of pozzolanic material, that is. MIRHA can affect both the strength and permeability by strengthening the aggregate-cement paste interface and by blocking the large voids in the hydrated cement paste through pozzolanic reaction, that was similar with Hwang and Chandra (1997) who also suggested that would occur for the addition of pozzolanic material used in RHA.

Mehta (1992) in his research on cement paste with 10% - 30% RHA replacement revealed that the permeability is significantly reduced after 28 days curing. The result of this research also showed that the presence of MIRHA resulted in lower coefficient of permeability. Manmohan and Mehta (1981) in their finding concluded that adding RHA to OPC causes pore refinement or transformation of large permeable pores to small impermeable pores.

The established results obtained from the various researchers are in agreement with the present research that shows that the presence of MIRHA, SF and PFA in a concrete mix with addition of Sp will improved significantly the impermeability of the concrete, thus suggesting that there is a potential usefulness of MIRHA as a concrete additive for applications where corrosion of reinforcing steel is a major concern.