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The Influence of Microwave Incinerated Rice Husk Ash on Foamed Concrete Workability and Compressive Strength Using Taguchi Method

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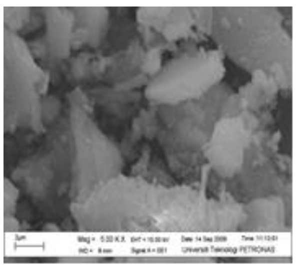
Graphical abstract



Abstract

Foamed concrete is lightweight concrete with a green material concept. One of cement-based materials is Microwave Incinerated Rice Husk Ash (MIRHA) foamed concrete (FC) as a pozzolanic material, that is interesting to be studies since the information about the ingredient can be used to understand the product behaviors. This study is more focused on the investigation towards the effect of composer of MIRHA FC on the workability and compressive strength. The mix proportion of the MIRHA FC here was designed by means of Taguchi method with L_{16} orthogonal array through five parameters (MIRHA contents, water cementitious ratio (w/c), sand cement ratio (s/c), superplasticizer (SP) content, and foam content). The mixtures were tested both in fresh and hardened states to fulfill the technical requirement of FC. It was also supported by the analysis on the characteristics of concretes including its workability and compressive strength. Based on the analysis, it is shown MIRHA is capable of enhancing FC workability and strength.

Keywords: Foamed concrete, Microwave Incinerated Rice Husk Ash (MIRHA), compressive strength, workability

1.0 INTRODUCTION

Foamed concrete is lightweight concrete initially considered as a void filing and insulation material [1]. It has a great contribution for its lighter weight and potential for large-scale utilization of wastes [2]. In Malaysia, the potential of rice husk is large in which it could reach approximately 2.231 million tons in a year [3]. Through a burning process, it is possible to convert about 20% of the rice husk to be rice husk ash (RHA) [4]. In other words, one hundred thousand tons of RHA potential can annually be used in Malaysia.

Several studies [5-7] explained the rice husk burning at properly controlled temperature would produce an ash mostly containing pure silica in the amorphous form. It is also identified that the RHA characteristic with high silica oxide (SiO2) and sponge structure can lead to high pozzolanic activity comparable with silica fume. [8]

Several kinds of cement replacement materials (CRMs) such as fly-ash[1, 9, 10], ground granulated blast-furnace slag (GGBFS)[11], bottom ash[12], sewage sludge ash[13], mud[14] and condensed silica fume[15] have proven effective in use since RHA has shown some better effects on normal concrete and may add value in FC. There are some concerns regarding the use of RHA, which may complicate its applications, however. These problems might include the very high water demand due to the refined porous structure of RHA in which the particle size could range between 10 and 75 μm. When added to a FC mixture, water might be absorbed into the pores as occurred in a sponge. For this, the use of a considerable proper amount of mixing water is necessary to obtain a workable FC mixture. Compared to the normal concrete, FC is more sensitive to water demand. When the water is added so little to the mixture, it will not be sufficient for initial reaction of the cementitious material that in turn will withdraw water from foam, thus causing the rapid foam degeneration. Otherwise, the exceeding poured water can bring an effect on segregation. This then may cause various densities. (ii) Another problem is related to the infrequent application of superplasticizer to create workable FC [1] but previous study explained that using superplasticizer in FC might bring a negative effect on stability in the foam [16]. In normal concrete concept, an improved strength can be obtained by reducing the water content in a mix proportion. In this study, superplasticizer has been used to optimize RHA for the requirements of the FC workability. So far known, there is no any investigation on the effects of compatibility of RHA and superplasticizer on FC workability and compressive strength in detail.

This paper is designed as the continuance of a previous study [17-20] on how to investigate and to understand the ingredient effect of MIRHA FC on workability and compressive strength. Here, Taguchi method was arranged to build the design of experimental work.

2.0 EXPERIMENTAL

The process of MIRHA burning procedure production was based on one-stage burning technique at a constant temperature of 500°C within 2 hours. The incinerated ash ground in a ball mill here was used to achieve the required fineness. The capability of MIRHA to convert calcium hydrate to the gels of calcium silicate hydrate was determined by the amorphous state of MIRHA, the amount of SiO2 content, the pozzolanity and the particles size distribution and specific surface area of MIRHA. X-Ray Diffraction Test and X-Ray Fluorescence Test in this case were used in analyzing MIRHA.

Table 1 presents the chemical properties of MIRHA and OPC used. The particle size distribution of MIRHA as seen in Figure 1 was not similar to the other binders namely OPC, silica fume and fly ash.

Table 1 Binder properties [a]

Oxide composition	Weight	
	MIRHA	OPC
Na_2O	0.02	0.02
MgO	0.63	1.43
Al_2O_3	0.75	2.84
SiO_2	90.75	20.44
P_2O_5	2.50	0.10
K_2O	3.77	0.26
CaO	0.87	67.73
TiO_2	0.02	0.17
Fe_2O_3	0.28	4.64
SO_3	0.33	2.20
MnO	0.08	0.16
LOI	0.12	

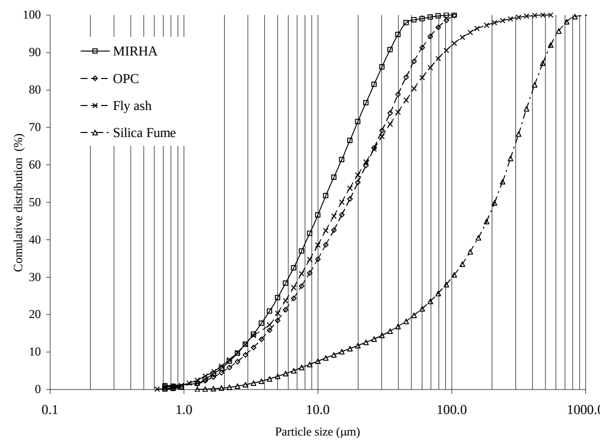


Figure 1 Comparison of MIRHA gradation to cement, fly ash and silica fume

X-Ray Diffraction (XRD) technique was used to analyze the crystalline phases of a material. A representative XRD pattern of the MIRHA samples was shown in Figure 2.

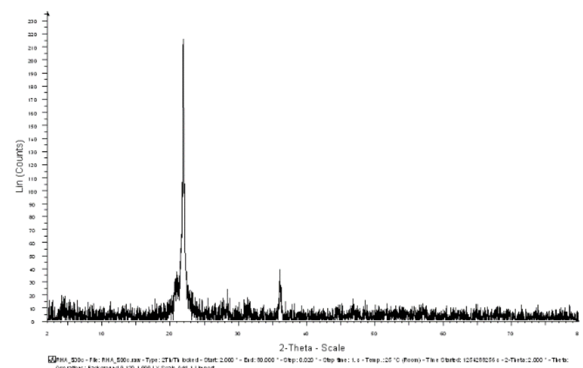


Figure 2 XRD Graph of MIRHA

Figure 3 shows the microstructure of raw rice husk before burning and Figure 4 presents the microstructure for MIRHA at 500°C for 2 hours after burning. Having compared the microstructure of raw rice husk and rice husk ash after burning and grinding, the structure of MIRHA was found finer than the raw rice husk.

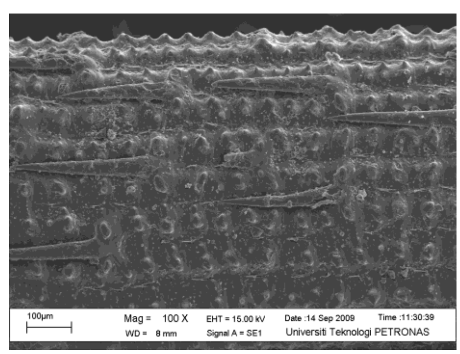


Figure 3 Microstructure for raw rice husk

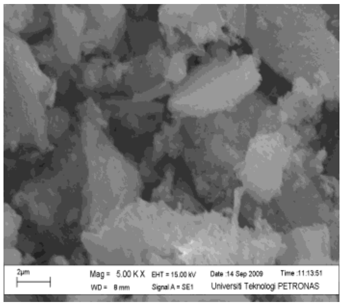


Figure 4 Microstructure for MIRHA at 500°C for 2 hours

The constituent materials used in the laboratory to produce FC comprised (i) Portland cement (Ordinary Portland Cement (OPC) BSEN 197-1) (ii) natural sand with 100% passing 425 µm sieve, (iii) MIRHA with high reactive silica content under the controlled combustion of rice husk (iv) free water and (v) superplasticizer. The foam agent used for the production of the preformed foam was by aerating the palm oil based LCM at the ratio of 1:30 (by volume), aerated to the density of 110 kg/m3.

In experiment design, the selection of the control factors is the most important stage. A maximum number of variables should be included in the investigation for identifying the non-significant variables at the earliest chance. Taguchi developed a method as a process optimization technique during the 1950s [21]. Taguchi's approach could provide a design engineer with a systematic and efficient method in determining the near optimum design parameters in the achievement of performance target and cost. However, no standard method has been found so far to conduct the mix design of FC. To understand the relationships between FC raw material mixtures and the resultant mechanical properties and the influence of MIRHA on hydration of FC, it is necessary to study and prepare many mixtures proportions. In this investigation, the following selected parameters were considered in the mix compositions, including: Microwave incinerated Rice Husk Ash contents (MIRHA), water cementitious ratio (w/c), sand cementitious ratio (s/c), superplasticizer content (SP), and foam content (FC). A methodical approach was used in applying Taguchi's parameter design methodology [22]. The significant difference between the Taguchi's approach and classical methodology is in term of an orthogonal array matrix employed in some parameters and at some levels. Table 2 shows the details of the variables used in the experiment. It is noted that the parameters were at four levels. It was only 16 experiments required to study the whole experimental parameters using the standard L16 (45) orthogonal arrays (Table 3)

Table 2 Parameters and their variation levels

Variable	unit	Level 1	Level 2	Level 3	Level 4
MIRHA	% by weight of cementitious	0	5	10	15
w/c	Ratio, by weight of cementitious	0.35	0.4	0.45	0.5
s/c	Ratio, by weight of cementitious	0.25	0.5	0.75	1
SP	%by weight of cementitious	1	1.5	2	2.5
FC	% by volume of mortar	20	25	30	35

When designing a foamed concrete mix, two variables-the cement content and the foam content-should be established; therefore, two equations must be solved. To prepare 1 m^3 of foamed concrete, the sum of the material weights should be equal to the required casting density and the sum of the volume of the all the constituent materials should be one cubic meter (1000 liter). In addition, MIRHA was used to replace Ordinary Portland Cement (OPC) at the rate of 5%, 10%, and 15% by weight of cementitious as binder. Table 4 presents the schema of mix proportion with parameters and each level adopted from Table 2 and Table 3.

Table 3 Standard L_{16} orthogonal array

Exp. no	Independent variables					Perform parameter value
	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5	
1	1	1	1	1	1	FC-1
2	1	2	2	2	2	FC-2
3	1	3	3	3	3	FC-3
4	1	4	4	4	4	FC-4
5	2	1	2	3	4	FC-5
6	2	2	1	4	3	FC-6
7	2	3	4	1	2	FC-7
8	2	4	3	2	1	FC-8
9	3	1	3	4	2	FC-9
10	3	2	4	3	1	FC-10
11	3	3	1	2	4	FC-11
12	3	4	2	1	3	FC-12
13	4	1	4	2	3	FC-13
14	4	2	3	1	4	FC-14
15	4	3	2	4	1	FC-15
16	4	4	1	3	2	FC-16

Table 5 presents the mix proportions of binders. The mixes were prepared at about 5.5 min with a rotating planetary mixer. The fine aggregate was first mixed with 1/2 of water followed by the addition of PC and MIRHA. It was followed by pre-mixing the rest of water and chemical admixtures to be added to the mix. Finally, the appropriate volume of the foam was generated, immediately added to the base mix and mixed for duration until there was no any physical sign of the foam on the surface. All the foam subsequently was uniformly distributed and incorporated into the mix.

Table 4 Mix proportion with parameter and each level

Code	RHA (%)	w/c (ratio)	s/c (ratio)	SP (%)	FC (%)
FC- 1	0	0.35	0.25	0	20
FC-2	0	0.4	0.5	0.5	25
FC-3	0	0.45	0.75	1	30
FC-4	0	0.5	1	1.5	35
FC-5	5	0.4	0.25	1	35
FC-6	5	0.35	0.5	1.5	30
FC-7	5	0.5	0.75	0	25
FC-8	5	0.45	1	0.5	20
FC-9	10	0.45	0.25	1.5	25
FC-10	10	0.5	0.5	1	20
FC-11	10	0.35	0.75	0.5	35
FC-12	10	0.4	1	0	30
FC-13	15	0.5	0.25	0.5	30
FC-14	15	0.45	0.5	0	35
FC-15	15	0.4	0.75	1.5	20
FC-16	15	0.35	1	1	25

Table 5 Mixture proportion of concrete

Exp No	Cement (kg/m³)	Sand (kg/m³)	Water (kg/m³)	MIRHA (kg/m³)	Foam (liter/m³)	SP (kg/m³)
FC-1	1050	263	368	0	200	0
FC-2	828	414	331	0	250	4
FC-3	666	500	300	0	300	7
FC-4	544	544	272	0	350	8
FC-5	779	195	312	39	350	8
FC-6	797	398	279	40	300	12
FC-7	668	501	334	33	250	0
FC-8	685	685	308	34	200	3
FC-9	827	207	372	83	250	12
FC-10	761	381	381	76	200	8
FC-11	653	490	229	65	350	3
FC-12	614	614	246	61	300	0
FC-13	715	179	357	107	300	4
FC-14	635	318	286	95	350	0
FC-15	749	562	300	112	200	11
FC-16	674	674	236	101	250	7

Once completing the mixing procedure, six 50 mm cube samples from each concrete mix were cast within 3, 7, 28, 90, and 180 days. The specimens were demoulded for 24 hours after the casting and placed in a water tank at 23±2°C. A compressive test was conducted at the given ages using ELE International Compression Testing Machine.

3.0 RESULTS AND DISCUSSION

3.1 Workability

Table 6 shows the spread test results of various mixes with the mean spread measurement diameter in the range of 13.7 cm and 31.8 cm. The main effect plotted by each factor for the spread test of FC is shown in Figure 5. The degree of contribution of each factor was clearly calculated by means of ANOVA (analysis of variance), purposely to understand the influence of the factors to the spread test of FC (Table 7).

Table 6 Test results of spread test for MIRHA-FC

Mixes	Spread test (cm)
FC- 1	26.3
FC-2	25.0
FC-3	24.4
FC-4	24.3
FC-5	26.9
FC-6	24.4
FC-7	25.8
FC-8	19.5
FC-9	31.3
FC-10	29.2
FC-11	17.1
FC-12	17.2
FC-13	31.8
FC-14	23.6
FC-15	18.0
FC-16	13.7

Figure 5 shows the lower (220 mm) and upper (250 mm) values of the spread workability test values. All the critical values attached to MIRHA, w/c, s/c, SP and foam were within some stipulated ranges.

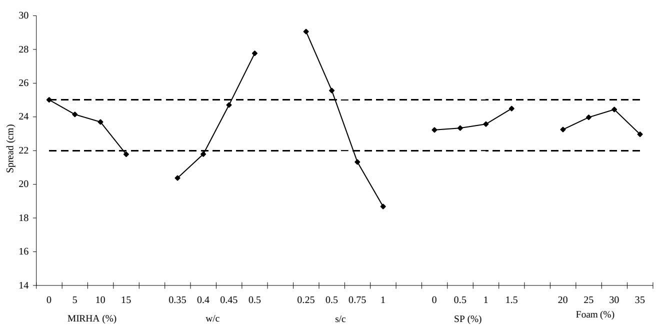


Figure 5 Main effect plot for Spread test

a. Effect of MIRHA Content

In Figure 5 FC incorporating MIRHA shows a lower spread result compared to the normal FC. The spread measurement decreased with the increase of MIRHA percentage due to the high specific surface area of MIRHA, thus increasing the water demand. This was mainly because of the adsorptive character of MIRHA cellular particles; therefore, FC containing MIRHA required more water for a given consistency. However, for FC with high water cement ratio, the addition of MIRHA could improve the concrete stability since it absorbed water and was able to reduce the tendency towards bleeding and segregation. The addition of MIRHA truly absorbed a large amount of water in the mixture, and needed superplasticizer (SP) with a specific amount to increase the workability and reached the similar slump as control concrete. The increment in percentage of MIRHA added was followed with the increment in percentage of SP used. The contribution of MIRHA parameter to achieve the required consistency of FC was at 12.06%. A stabled and consistent FC could be achieved with 5 to 15% of MIRHA in view of the percentage inclusions in the spread rest range proposed.

Table 7 Analysis of variance results of workability of foamed concrete

Parameter	statistical parameters	Workability
MIRHA	Degree of freedom (DoF)	3
	Sequential sum of square (SSS)	175.47
	Adjusted sum of square (ASS)	175.47
	Mean square /variance (MS)	58.49
	F-statistic; F0.5 (3,13)	325.86
	Contribution (%)	12.06%
w/c	DoF	3.00
	SSS	847.41
	ASS	847.41
	MS	282.47
	F-statistic; F0.5 (3,13)	1573.70
	Contribution	58.03%
s/c	DoF	3.00
	SSS	353.79
	ASS	353.79
	MS	117.93
	F-statistic; F0.5 (3,13)	657.01
	Contribution (%)	24.07%
SP	DoF	3.00
	SSS	51.97
	ASS	51.97
	MS	17.32
	F-statistic; F0.5 (3,13)	96.51
	Contribution (%)	3.96%
foam	DoF	3.00
	SSS	27.40
	ASS	27.40
	MS	9.13
	F-statistic; F0.5 (3,13)	50.88
	Contribution (%)	1.88%

b. Effect of Water Cement Ratio

The workability of FC was significantly determined by water cement ratio as shown by F-test value at 1573.30 higher than F-test criteria at 3.13. Moreover, as shown in Table 7 w/c parameter's contribution to create the consistency of FC was the highest one reaching at 58.03% compared to the other parameters.

Increasing water cement ratio would affect the enhancement of mixture consistency. According to the criteria of good stability and consistency, the range of water cement ratio for FC was between 0.4 and 0.45 with 220 to 250 mm spread range (see Figure 5). This range was classified as a medium level in a spread percent range based on the classification of FC study by Nambiar [23]. In contrast, another comparison shows that this range was higher than the required value for flowing properties, which is 200-mm in spread range [24].

c. Effect of Sand Cement Ratio

According to literature [25], the workability of FC was affected by the sand cement ratio (s/c). This was supported by sand cement ratio contribution on FC workability reaching at 24.07%. Figure 5 depicts that the increase of sand cement ratio would decrease the workability. This was due to the increase of the amount of solid volume at the same water cement ratio. Consequently, it led to the reduction of the water solid ratio and the decrease of consistency. In line with the results from FC workability tests, the result also shows that the effects of higher sand cement ratio could be either eliminated or reduce the paste volume of mortars.

d. Effect of Superplasticizer

As shown in Figure 5, the addition of SP increased the workability of FC. Due to the mechanism of action of SP [24], the surface potential of all cement phases became negative as they started to repel to each other. In common, there are four main clinker phases of cement namely C2S, C3S, C3A, and C4AF. The chemical compounds of these SP's are grafted on them. C2S and C3S have a negative zeta-potential while C3A and C4AF have a positive one at the fresh stage. This then leads to the faster coagulation of the cement grains. In principle, SP directly adsorbs on the surface and changes its characteristics. The value range of SP to have a stable and consistent FC was from 0.5 to 1.5 (220-250 mm spread). The contribution of SP value to improve workability of FC was at 3.96%.

e. Effect of Foam Content

All foam content percentages, as shown in Figure 5, fulfilled the workability requirement. The level of 30% above indicated the decrease of the workability for the mechanism of the adhesion between the bubbles and solid particles in the mixture. If the amount of foam would be increase, it might reduce the spread-ability. However, at the level below 30% the workability increased in the increase of the percentage foam content where the foam was assumed as "aggregate" in mortar. The large amount of foam would also reduce the friction between particles in FC. As shown in ANOVA analysis, foam has a minimum contribution to create the FC workability.

Table 7 presents the overall view of the effects of constituent of MIRHA-FC on workability. Here, it is found that MIRHA-FC workability was strongly influenced by the w/c because of two reasons: (i) the key factor to overcome the friction between solid particles and bubbles and (ii) to maintain the adsorptive characteristics of MIRHA.

3.2 Compressive Strength

The average of compressive strength was determined in the period of 3, 7, 28, 90 and 180 days. Table 8 presents the average of compressive strength results in N/mm2 of the 16 trial mixture proportions. The results show that in 3, 7, 28, 90 and 180 days the strength could be obtained in the range of 1.2-6.9, 2.3-12.6, 5.5-28.1, 13.9-47.3 and 12-57.9 N/mm2 respectively. Meanwhile, the highest and the lowest compressive strength were obtained from FC-4 and FC-10 respectively. Figure 6 presents the summary of main effect plot for 3 to 180 days compressive strength of FC.

Table 8 Test results of average of compressive strength for MIRHA FC

Code	Compressive strength (N/mm2)				
	3d	7d	28d	90d	180d
FC-1	3.2	8.3	17.1	27.7	34.7
FC-2	6.4	12.2	26.8	43.6	52.2
FC-3	3.1	5.9	13.4	31.1	27.5
FC-4	1.2	2.3	5.5	13.9	12.0
FC-5	4.2	7.5	17.4	27.8	36.7
FC-6	4.6	11.0	20.3	33.8	42.4
FC-7	4.1	7.2	17.3	26.3	34.4
FC-8	5.8	12.2	24.8	39.0	51.1
FC-9	6.0	11.2	25.5	44.2	55.8
FC-10	6.9	12.6	28.1	47.3	57.9
FC-11	3.1	7.4	14.5	25.6	33.0
FC-12	4.5	8.3	19.1	37.9	42.6
FC-13	3.0	5.8	13.2	21.3	26.5
FC-14	4.0	7.6	16.8	26.6	31.9
FC-15	5.1	9.7	21.4	34.7	41.8
FC-16	3.6	9.2	17.3	32.5	35.5

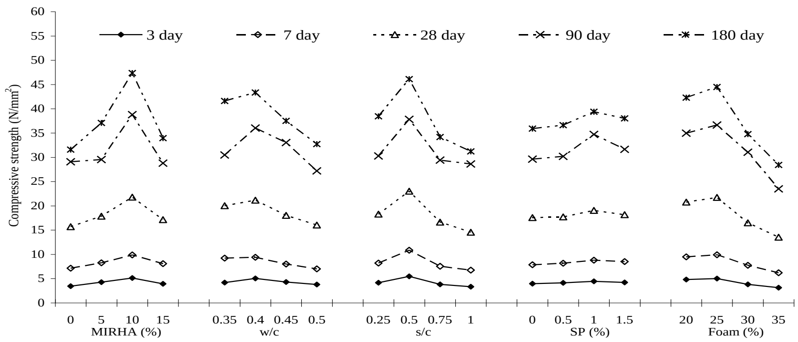


Figure 6 Summary of main effect plot for compressive strength

Table 9 Analysis of variance results of compressive strength for FC

Parameter	statistical parameters	Compressive strength at different ages (days)				
		3	7	28	90	180
MIRHA	DoF	3.0	3.0	3.0	3.0	3
	SSS	35.6	91.7	490.9	1682.9	3479
	ASS	35.6	91.7	490.9	1682.9	3479
	MS	11.9	30.6	163.6	561.0	1160
	F-statistic; F0.5 (3,411)	3.48	17.6	11.8	9.0	19
	Contribution	20%	15%	17%	25%	28%
w/c	DoF	3.0	3.0	3.0	3.0	3
	SSS	60.4	227.6	931.0	1294.3	3006
	ASS	60.4	227.6	931.0	1294.3	3006
	MS	20.1	75.9	310.3	431.4	1002
	F-statistic; F0.5 (3,411)	5.9	43.7	22.4	6.9	17
	Contribution	34%	36%	32%	19%	24%
s/c	DF	3.0	3.0	3.0	3.0	3
	SSS	21.4	91.8	413.0	1014.1	1770
	ASS	21.4	91.8	413.0	1014.1	1770
	MS	7.1	30.6	137.7	338.0	590
	F-statistic; F0.5 (3,411)	2.1	17.6	9.9	5.4	10
	Contribution (%)	12%	15%	14%	15%	14%
SP	DF	3.0	3.0	3.0	3.0	3
	SSS	2.9	12.0	32.2	371.8	171
	ASS	2.9	12.0	32.2	371.8	171
	MS	1.0	4.0	10.7	123.9	57
	F-statistic; F0.5 (3,411)	0.3	2.3	0.8	2.0	1
	Contribution (%)	2%	2%	1%	5%	1%
Foam	DF	3.0	3.0	3.0	3.0	3
	SSS	56.9	208.1	1049.2	2470.4	3870
	ASS	56.9	208.1	1049.2	2470.4	3870
	MS	19.0	69.4	349.7	823.5	1290
	F-statistic; F0.5 (3,411)	5.6	40.0	25.2	13.2	22
	Contribution (%)	32%	33%	36%	36%	31%

a. Effects of MIRHA Content

In common, a normal FC has a lower compressive strength in comparison to the MIRHA-FC. At the early ages (3 days), the control MIRHA-FC samples had a superior compressive strength compared to the normal FC. It was because the pozzolanicity of MIRHA started almost immediately when being mixed with the concrete. Additionally, the increasing percentage of MIRHA in the concrete directly led to the declining percentage of Portland cement used in the proportion. This then reduced both the production of Ca(OH)2 and the acceleration of the reaction with SiO2 as presented in MIRHA. On the other hand, the pozzolanic material supported in achieving the more consistent distribution of air voids by providing a uniform outside layer on each bubble and thereby prevented the merging of bubbles. In addition, the replacement level at 5%-10% of MIRHA was found optimum to contribute a void distribution and to facilitate the strength. However, the trend of 5-10% level was different from the level of 15% that showed the decrease in the strength due to the excessive water absorption. The character of its pore structure in MIRHA led to excessive water absorption and yielded a disordered foam distribution. This, as a result, decreased the concrete strength.

At the age of 28 days, the average normal strength of FC without MIRHA was found at 92.3% of the required strength for structural lightweight concrete, which is 17 N/mm2. On the other hand, the FC concrete mixes containing 5% and 15% MIRHA achieved 113.8% and 109.3% of the strength of normal FC. The 10% of MIRHA, however, enhanced the strength above the normal FC by 138.9%. Even at the age of 90 days, the compressive strength of 10% of MIRHA mixes was about 33.3% higher than that of the normal FC. Further, above 90 days, the compressive strength of 10% MIRHA increased reaching at 49.9% at the age of 180 days.

The contribution of the MIRHA to improve the FC strength was obtained in the range of 15% to 28%. In addition, the contribution of MIRHA on the early compressive strength of FC reached 20% still lower than the contribution of foam content and w/c (see Table 6). MIRHA content contribution did not give any effect on the early age compressive strength. Figure 7 below presents the compressive strength versus age of MIRHA FC with the effect of MIRHA.

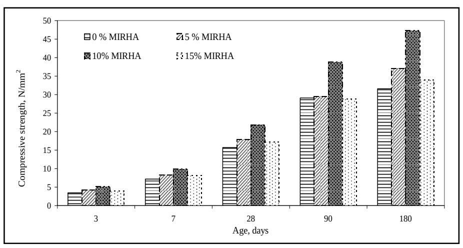


Figure 7 Compressive strength versus age of FC with effect of MIRHA

b. Effects of Water Cement Ratio

The adequate amount of water and high pozzolanic reactivity were the main factors of the acceleration of MIRHA reaction in the hydration process of concrete. When studying the effect of w/c on compressive strength, a similar finding was observed until 28 days. At w/c of 0.35 and 0.4, maximum compressive strength was found. It was due to the optimum of amount water required to facilitate the hydration process using pozzolanic material with the Ca(OH)2 produced by OPC. However, when w/c exceeded 0.4, it retained the utilized water for the hydration reaction and contributed to the formation of capillary pores in foamed concrete leading to a decrease in strength. Hakan's [26] suggested that decreasing w/c and increasing curing time would reduce the pore width of the specimen, which later automatically enhances the strength. The contribution value of w/c factor to facilitate the strength of FC was in the range of 19% to 36%. The compressive strength versus age of MIRHA FC with respect to w/c is shown in Figure 8.

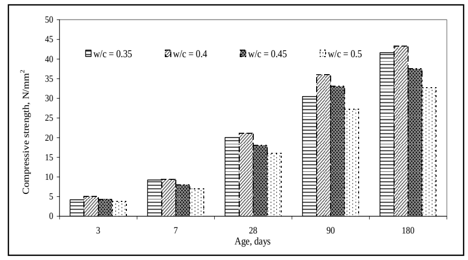


Figure 8 Compressive strength versus age of FC with various w/c

c. Effects of sand cement ratio

According to previous work [25], the compressive strength of FC was determined by the sand cement ratio (s/c). The high FC strength achieved the mixes containing 0.25 s/c at the age of 7 days and 0.5 s/c at the age of 28 days above. Figure 9 presents the compressive strength against the age of MIRHA FC with various s/c values. The aggregate cement ratio indicated that the amount of filler in the binder and the strength of the FC would decline if the amount of filler was raised.

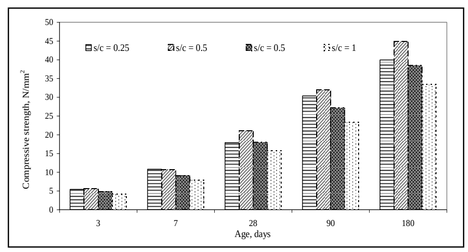


Figure 9 Compressive strength versus age of FC with various level of s/c

d. Effects of Superplasticizers

As shown in Fig.10, the strength of FC with SP was higher than that of FC without SP. The highest strength was obtained when SP dosage was at 1%. The dosage at 1.5% experienced the reduced strength due to a disordered void distribution and the unsteadiness in the foam. Superplasticizer contributed the value of SP to improve compressive strength in the range of 1% to 5%.

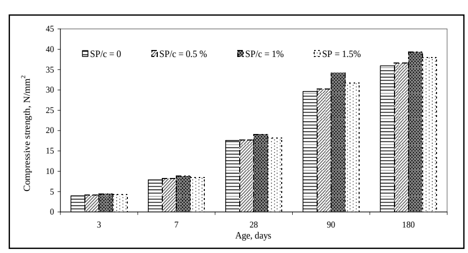


Figure 10 Compressive strength versus age of FC with various level of SP

e. Effects of Foam Content

The presence of bubbles in the FC significantly contributed to the FC performance. The strength of FC was significantly influenced by the existing voids volume. In addition, the volume of foam affected the interconnectivity of bubbles, thus making the void distribution and sizes affected, and hence the spacing factor in the FC. The effects varied with different air contents but affected the mechanical properties. As shown in Fig.11 the strength of FC with 20% foam, however, did not demonstrate better compressive strength for the least amount of foam and the imperfect and uneven distribution. For this, the bubble merger occurred in certain places [27]. This resulted in a large space. This weakness reduced the compressive strength when being tested. It is found that the optimum FC was at 25% and higher compressive strength were obtained at all ages.

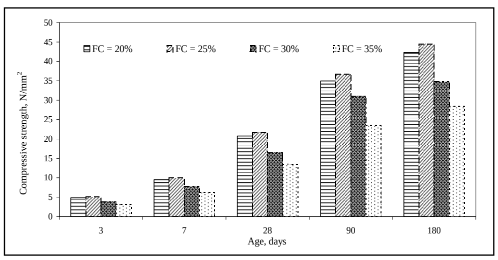


Figure 11 Compressive strength versus age of FC with various foam content

4.0 CONCLUSION

The desired level for the optimum of compressive strength MIRHA FC are 10%, 0.4%, 0.5%, 1%, and 25% for MIRHA content, w/c, s/c, SP and foam respectively. MIRHA content contributed 10%-28% to the compressive strength. MIRHA content was characterized with FC that has significantly increased the strength of normal FC lower than MIRHA FC. It might be indicated in the pozzolanicity of MIRHA to accelerate the hydration process faster.

The compressive strength of MIRHA FC was dominated by MIRHA content, w/c and foam content. The significant contributions of these parameters were related to: (i) the facilitation of MIRHA in the dissemination stage bubbles in fresh FC, (ii) w/c as a key parameter for the workability FC and hydration process of cement and (iii) determination of foam content towards the amount of voids in the concrete and a strong influence of the void space on the FC compressive strength.

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