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Mechanical Properties of High Strength High Performance 100 Mpa Concrete Incorporating Rice Husk Ash

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Applying high strength concrete to high rise buildings can reduce the dead weight of structural elements, increase the span of beams and reduce the size of the elements. The most suitable method to get high strength concrete are packing density of mixtures utilizing modified Andreasen model, low w/b, utilizing RHA as partial replacement of cement and superplasticizer to provide required workability. This paper presents fresh and hardened properties of high strength high performance 100 MPa concrete incorporating RHA. The results revealed that the compressive strength, flexure strength, tensile strength and modulus elasticity of concrete incorporating 10 % RHA are better than that of 10% silica fume or plain concrete. RHA is proven as the alternative to silica fume in producing high strength high performance concrete through achievable target strength and strength efficiency of cement.

Keywords: High strength high performance concrete, rice husk ash, workability and mechanical properties.

1. Introduction

High performance concrete (HPC) has received much attention in recent years due to its mechanical properties, workability and durability. HPC is defined as concrete, which meets special performance and uniformity, and those requirements cannot always be achieved by using conventional material and normal mixing, placing and curing practice [1]. HPC offers important economic benefits in the long term due to increasing span and reducing the size of the beam, creating more space of the building. Also, it offers environment friendly as utilizing supplementary cementious material (SCM) as partial replacement of cement content without affecting strength. Nowadays, concrete strength of up to 100 MPa and more have been used in the lower columns of high rise building. To produce concrete of compressive strength of 100 MPa, the SCM mostly used is silica fume [2] and pulverized fly ash composite [3] both are industrial products. Those materials have a high content of SiO_2 and tiny and spherical shape of particle size. SiO_2 of SCM and CaOH of cement hydration product with available moisture reacted to form additional CSH, which improved mechanical properties of concrete due to more dense and less porosity [4; 5]. Even silica fume is important to improve mechanical properties of concrete; the price is very high compared than cement. As an alternative, SiO_2 can be produced from a product of agriculture harvest, such as rice husk. The paddy production of Malaysia annually is 2.6 million tons/year [6] and 20% of paddy will produce rice husk as waste. Some of them are used as parboiling paddy and generate electricity and the rest is dumped in the landfill area. It creates an environment problem due to air pollution as rice husk is burned in open area. However, rice husk burning while controlling the combustion at 500-700 ^{o}C produces RHA with rich amorphous silica and high content of SiO_2, which is very reactive [7]. RHA is produced about 20 % of rice husk weight. These chemical properties are similar with silica fume and potentially can be used as an alternative. Mahmud [7] reported that the mechanical properties of concrete of 60-80 MPa incorporating RHA could be achieved by utilizing low w/b ratio and superplasticizer.

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As mentioned earlier, high strength HPC is not similar to normal concrete especially in mixture proportions. In normal concrete, the concrete is assumed in three phases: the mortar, interface zone and aggregate. However, in HPC the interface zone is reduced due to low w/b ratio and utilized SCM. Concrete with similar cement content and a proper SCM content of the mix proportion can be pushed to higher strength and more durability by considering packing density of the concrete mixture, which causes concrete to be much dense and less porosity [8]. The main factors to be considered in finding the optimum packing density are the nominal minimum and maximum particle size and particle size distribution of aggregate beside shape and rough surface as each of these can influence the total void of concrete mixtures. In low w/b, the packing density is crucial due to limited mixing water available for hydration process. The specific surface area of particle size of aggregate affects the need of paste to cover the aggregate and the particle size distribution affect the void left in concrete mixtures. Mostly the characteristic of aggregate is described as fineness modulus, but it does not have a direct correlation with the specific surface area [9]. Furthermore as mentioned in USBR, when the FM of fine aggregate increases or decreases by 0.2, the sand ratio increases or reduces by 2% accordingly to get similar workability [9]. Considering surface area and void left in mixture can be an untidy process in mix design of HPC. However, the modified Andreasen model can be utilized in mix design of HPC and this model has been applied successfully in self compacting concrete [10], high performance concrete [8] and UHPC [11].

The packing density is affected by particle size distribution of concrete constituent: cement, cementious material and aggregates. There is limited information on how cementious material and fineness modulus (FM) of fine aggregate affect the packing density of a concrete mixture with constant coarse aggregate. By utilizing the modified Andreasen model which is sensitive to the minimum and the maximum particle size of constituent, this paper will present the effect of FM of fine aggregates, SCM and w/b to the curve provided by the modified Andreasen model as the ideal packing density of the concrete mixture. The FM of fine aggregate are 2.61, 2.84 and 3.12, cementious materials are OPC, 10% RHA and 10% CSF and w/b are 0.22 and 0.25. To asses those optimum of the curves, the integral absolute error (IAE) method is applied by comparing the minimum of those values. The selected w/b and FM of fine aggregate will be applied to find out the effect on the optimum proportion on mechanical properties of concrete.

2. Material and Methodology

2.1 Material

The materials used in this study were cement, rice husk ash (RHA), condensed silica fume (CSF), aggregates, water and superplasticizer. Ordinary Portland cement (OPC) Type I class 32.5 from local manufacturer was used and its specific gravity and specific surface area are 3.15 and 3280 m^2/kg, respectively. RHA was produced by uncontrolled burning in ferro cement furnace, but the temperature of burning did not exceeded 700 ^0C so that RHA is in amorphous form. RHA was grinded in LA machine for 16000 cycles to get average particle size of 13 µm. Its specific gravity and surface area was 2.06 and 23455 m^2/kg. Major chemical composition of RHA and CSF consist of SiO_2, above 90 %. The particle size of cement is greater than that of RHA and CSF, 1.5 and 40 times respectively. However, the surface area of RHA and CSF is much greater than that of cement, almost 100 times. It related to the nature porosity of RHA particles and the tiny spherical of CSF particles. The specific gravities of mining sand and crushed granite aggregate are 2.6 and 2.7, respectively. Figure 1 shows the particle size distribution of all mixture constituent. Aggregates were washed to minimize the clay in mining sand and dust in crushed granite aggregate. The mixtures were made using tap water.

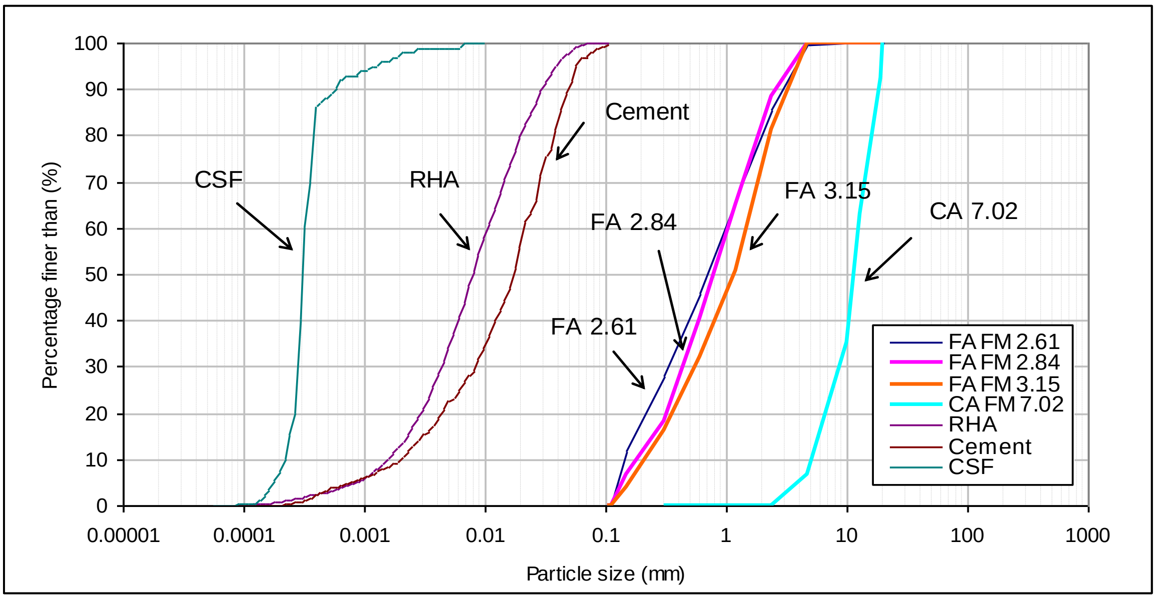

Figure 1: Particle distribution of fine aggregate and coarse aggregate

2.2. Mixture proportioning, mixing and test

2.2.1. Mixture proportioning

HPC mixes were proportioned by absolute method. To optimize the range of cement content and the w/b ratio for targeted compressive strength of 100 MPa, trial mixes were made by varying the cement content between 500 up to 600 kg/m^2 and water cement ratio between 0.22 up to 0.28. Based on the preliminary results, 550 kg/m^2 binder content and w/b of 0.22 and 0.25 were selected. The mix proportion is shown in Table 1.

Table 1: Mix proportion

Mix ID	W/b	Ingredient (kg/m^3)						
		Sp	Water	Cement	RHA	CSF	Aggregate	
							Fine	Coarse
OPC-22	0.22	2.41	121	550	0	0	719	1050
RHA10-22	0.22	3.93	121	495	55	0	708	1050
CSF10-22	0.22	3.49	121	495	0	55	710	1050
OPC-25	0.25	2.38	137.5	550	0	0	702	1050
RHA10-25	0.25	3.49	137.5	495	55	0	690	1050
CSF10-25	0.25	3.13	137.5	495	0	55	692	1050

2.2.2. Packing theory and approaching the optimum

In the mix proportioning process, the question of how the fine aggregate is changing the packing density and how it affects to results arises. Three FM of fine aggregates, 2.62, 2.84 and 3.15, are proposed to be chosen in this study. These FM represents the fine, medium and coarse of mining sand those are available in Malaysia. To check the change of packing density of mixture, the curve grouping of each mixture will be compared to the ideal curve from the modified Andreasen model according to the following formula:

$$P(D)= \frac{D_i^q - D_{\min}^q}{D_{\max}^q - D_{\min}^q} \quad (1)$$

Where *D* is the particle size (µm), *P* (*D*) is a fraction of the total solids being smaller than size *D*, D_{max} is the maximum particle size (µm), and *q* is the distribution modulus. By applying different value of distribution modulus q, this model can be used to design different types of concrete. The q value reveals the proportion between fine and coarse aggregate in the mixture if q>0.5 lead to coarse mixture and if q<0.25 lead to rich in finer mixture. Brouwers [10] reported that theoretically a *q* value in the range of 0–0.28 would result in an optimal packing. Hence, in this study, by considering the amount of fine particles to be around 50% of total aggregate, the model is utilized to produce high strength high performance concrete and the value of *q* is fixed at 0.28. To utilize the model in this study, EMMA software is used to find the curve of the mixture and this software has also been used by Brouwers [10] to find the composition of mixture in optimum packing density.

To assess the optimum packing density of mixtures, in this study, the reliability of the relationships curves of every mix and ideal curve of the modified Andreasen curve was assessed on the basis of IAE (%) as used by Nihal [12] and Oluokun [13] to evaluate the goodness of fit of proposed relationships, and is computed from Eq. (2)

$$\text{IAE (\%)} = \sum \frac{|(O_i - P_i)|}{\sum O_i} \times 100 \qquad (2)$$

Where O_i is the observed value, and P_i is the predicted value from the ideal curve of the modified Andreasen model. The IAE measures the relative deviations of data from ideal curve. When the IAE is zero, the predicted values from the regression equation are equal to the observed values; this situation rarely occurs. When comparing different equations, the regression equation having the smallest value of IAE can be judged as the most reliable. A range of IAE from 0 to 10% may be assumed as the limits for accepting higher packing density.

2.2.3. Test

The mechanical properties of concrete included in this study are compressive strength, tensile strength, flexural strength and modulus of elasticity. For compressive strength, cubes of 100x100x100 mm were used and the test follows BS EN 12390-3:2009. The tensile strength used was cylinders of 100 mm diameter x200 mm and the test follows BS EN 12390-6:2009. The Flexural strength test used was prisms of 100x100x500 mm and the test follows BS EN 12390-5:2009. Modulus of elasticity used was cylinders of 150 mm diameter x300 and the test follows BS EN 13412:2006. Fresh concrete was put in two layers for all samples except 3 layers for cylinder of 150 mm diameter x300 mm and all samples are vibrated. The samples were covered with plastic sheet and demolded after 24 hours. All samples are cured in water tank and taken it out before test on specific days.

3. Results and Discussions

3.1. Selection of FM of fine aggregates to be used in further study

In this study, each FM of 2.62, 2.84 and 3.12 of mining sand, cement, coarse aggregate, either RHA or CSF were mixed to find the optimum ideal gradation. For cementious material as cement replacement, 10 % RHA and 10% CSF were used. For OPC and RHA mixture, the minimum particle size and q adopted in the modified Andreasen model was 0.5 and 0.28, respectively. For CSF mixture, the minimum particle size and q adopted in the modified Andreasen model was 0.05 and 0.28. As seen in Figure 2, the fine material, 10-100 µm, of all mixtures is over that of on the ideal curve. But for coarser aggregate, 1 mm to 10 mm, the mixture is less than the optimum one. However, from the figures, it can be seen that the mix of 10% RHA and FM of 2.84 is close to ideal curve.

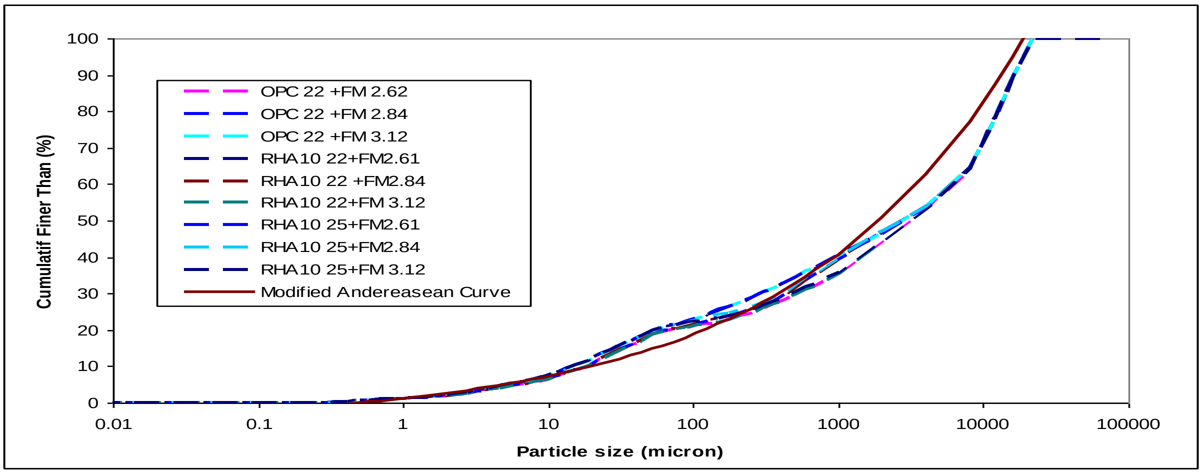

Figure 2: Particle size distribution of concrete mixtures series containing OPC and RHA combined with aggregates and modified Andreasen model curve for q =0. 28

In Figure 3, the curves show a little bit different compared to Figure 2 due to the minimum particle of CSF influence the shape of the ideal curve. For finer particles, it looks like the curve is almost close to the ideal one, but for coarser particles, it shows similar to RHA curve. It could be for the coarse particles, the effect of different FM does not significantly affect to the curve of mixture.

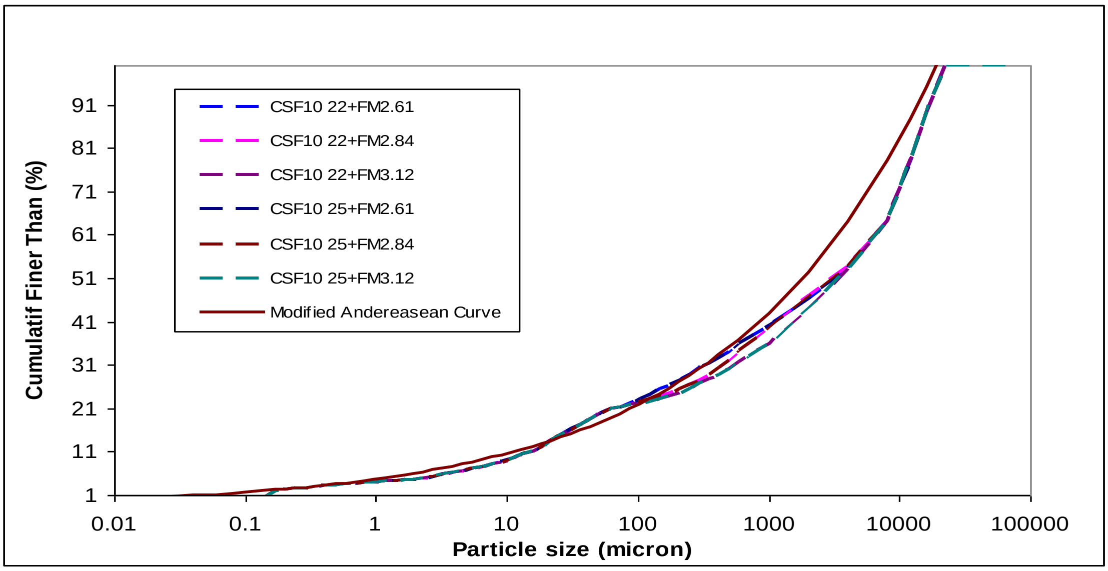

Figure 3: Particle size distribution of concrete mixtures series containing CSF combined with aggregates and modified Andreasen model curve for q =0. 28

Figure 4 shows that w/b and the FM of 2.62, 2.84 and 3.12 affect the packing density of mixture incorporating RHA, CSF and OPC. The change of w/b in low FM of fine aggregate is sensitive to the packing density compared to high FM. Reducing w/b with while keeping a similar amount of binder also reduce the volume of the mixture left by water and to keep the unity of mixture the fine aggregate is increased. For plain and RHA mixtures, mix with FM of 2.84 reveals the lowest IAE of 9.8%. However, for the CSF mixture, the packing density is lowest when it mixes with FM of 2.61 and the IAE value of 8.1 %. This is due to CSF having the minimum particle of 0.05 µm and it affects the ideal curve being closer to the mixture curve. Based on the lower value of IAE, the FM of the fine aggregate chosen is 2.84 and the w/b of 0.25 is chosen due to the effect of w/b less sensitive to the packing density if applying FM of 2.84.

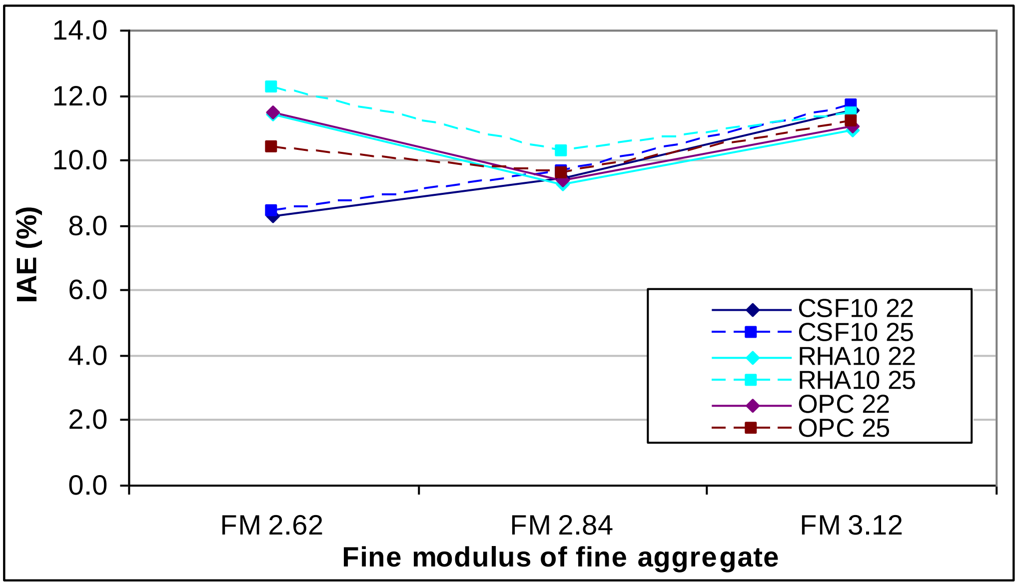

Figure 4: The IAE (%) of mixture

3.2. Concrete mixes evaluation

3.2.1. Fresh concrete

All mixtures were kept at similar workability by maintaining the slump in the range of 205-215 mm. Table 2 reveals that fresh properties of concrete are influenced by inclusion on RHA and CSF. As can be seen, the Sp dosage increases almost 50% compared to plain concrete regardless of w/b ratio. The increased dosage of Sp in RHA and CSF mixture could be related to the increase in specific surface area of fine particles and also absorption on Sp, which reduce the actual dosage of Sp available. Similar observation had been reported by Malhotra [14]. The fresh density decreased when incorporating RHA and CSF due to their specific gravity being lower than that of cement [15].

Table 2: Fresh properties of concrete

Mix ID	**W/b**	**RHA or CSF (% of binder)**	**Sp content (% of binder)**	**Slump**	**Fresh Density (Kg/m^3)**	**Air content (%)**
OPC-25	0.25	0	0.43	210	2478	1.8
RHA10-25	0.25	10	0.71	210	2458	1.7
CSF10-25	0.25	10	0.63	211	2452	1.7

3.2.2. Compressive strength

The aim of this study is to find out whether incorporating 10% RHA and 10% CSF in mixture with binder of 550 kg/m^3 and nominal maximum size of aggregate 19 mm can achieve 100 MPA. Figure 5 shows that all mixes can achieve 100 MPa at 28 days, especially when the method of curing was water cured. At early age of 1 day, the RHA and CSF have lower strength than plain concrete and it could be a lower hydration process in those concrete due to less cement content compared to plain concrete. Also at low w/b ratios, the reactivity of the silica fume is hampered and the hydration of the cementitious system is significantly retarded [16]. At 7 days, the compressive strength of RHA and CSF concrete are higher, 4 %, than that of plain concrete regardless of w/b and less having cement content than plain concrete. At 28 days, the compressive strength of RHA still increases 8 % compared to that of plain concrete. It shows also that the RHA and CSF can act as microfiller and contribute also pozzolanic activity [17]. It is important to note that all mixes achieve higher than 100 MPa at 180 days. It shows that the compressive strength of concrete in water curing regime achieves the optimum compared to that in air drying condition [18]. Similar finding also reported by Mahmud [19] that at low w/b, there was insignificant difference either water curing or drying curing on concrete strength. Based on these facts, it is possible to alternate silica fume with RHA in similar replacement and achieve the target strength.

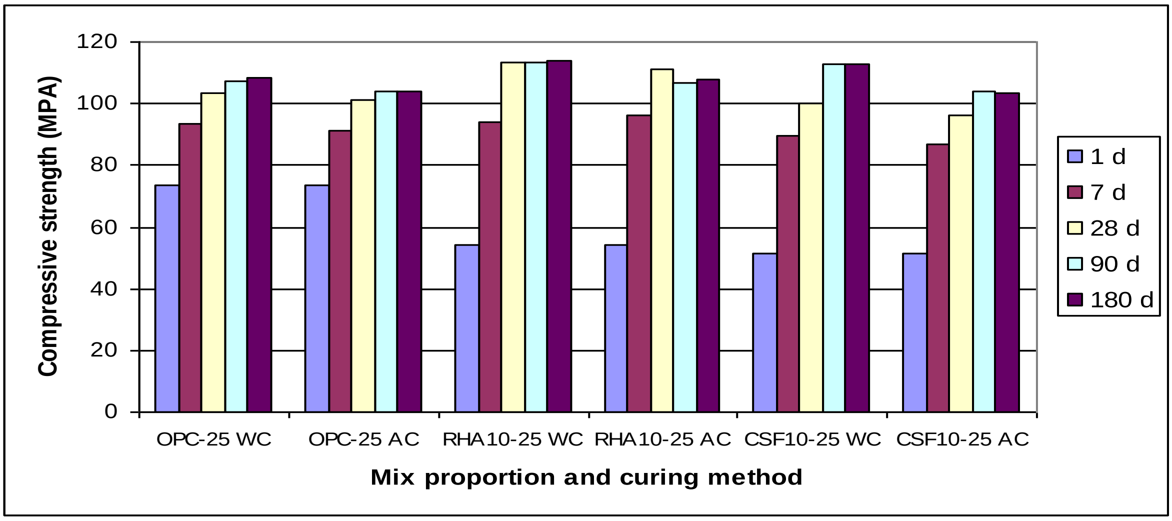

Figure 5: Compressive strength of high strength concrete

3.2.3. Splitting tensile strength

The splitting tensile strength of all the mixes is shown in Figure 6. All mixes containing RHA and CSF showed lower strength at early age, but their splitting tensile is higher than that of plain concrete at 28 days and afterward by about 4%. The difference in the splitting tensile strength of RHA and CSF concrete is negligible, only about 1-2%. It could be the strength of CSH from pozzolanic reaction is not similar to that from cement hydration. As known, the RHA and CSF mixture have lower cement content compared to plain concrete. However, those mixtures still can achieve similar strength of plain concrete due to the pozzolan reaction of RHA or CSF. The tensile strength development at 90 days is not much different for all mixes, only up to 4% increase compared to that at 28 days. Water curing or air drying is not sensitive to splitting tensile strength. The ratio of splitting tensile strength to compressive strength of all concrete mixes ranged from 6% to 7% at 28 days. Previous research showed that this value is in the range of 9% to 10% at 28 days for medium strength concrete [20]. For high strength concrete containing natural pozzolan and silica fume and of compressive strength of 80 MPa, the ratio of 6.6% and 6.8% were achieved [21].

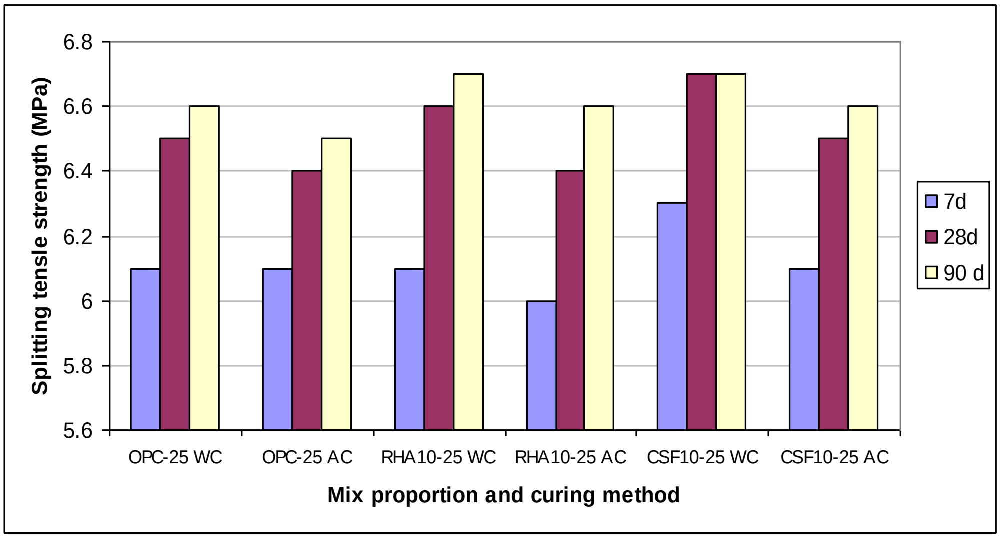

Figure 6: Splitting tensile strength of high strength concrete

3.2.4. Flexural strength

Figure 7 shows that flexural strength of RHA and CSF concrete achieve higher than that of plain concrete regardless of w/b and type of curing. At 7 days, the flexural strength of RHA and CSF mixes are lower than plain concrete, but at 28 and 90 days, the flexural strength of those mixes was higher by 5% compared to that of plain concrete, which is insignificant. The flexural strengths of all mixes at 28 and 90 days are in the range of 9.3 to 10.3 MPa. The ratio of flexural strength and compressive strength is between 9 - to 10%, which is a little bit higher than that of tensile strength to compressive strength ratio. The ratio of air drying and water curing strength varies between 0.92 and 0.95 at all ages.

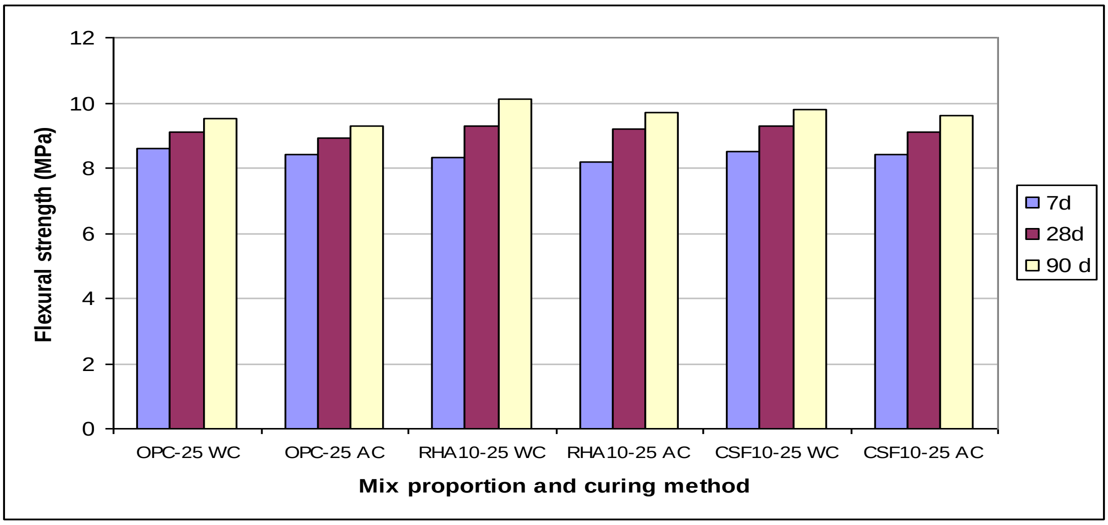

Figure 7: Flexural strength of high strength concrete

3.2.5. Modulus of elasticity

The modulus of elasticity of all concretes in this study was determined using the 150 mm diameter x 300 mm concrete cylinders and the results are shown in Figure 8. The modulus of elasticity presented is the selected mixtures due to the aim of this study is to find out compressive strength of 100 MPa concrete, which can be achieved at w/b 0.25. At 7 days and later, the modulus of elasticity of RHA and CSF concrete achieved higher than that of plain concrete regardless of type of curing. Similar results were found by Yin [3] in concrete containing fly ash when they produced C-100 high performance concrete. In high performance concrete, the packing density is of more concern than in normal concrete. This result shows that the modulus of elasticity of RHA and CSF increased slightly, by about 5%, compared to that of plain concrete, which indicates RHA and CSF improves the stiffness and volume stability of concrete.

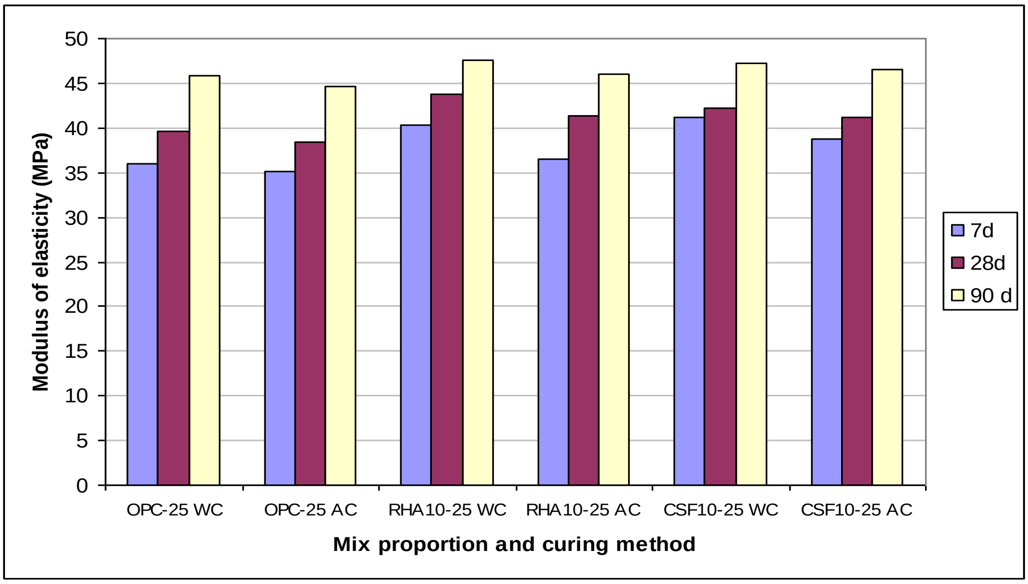

Figure 8: Static modulus of elasticity

3.2.6. Strength efficiency of cement

Figure 9 shows the strength efficiency of cement used on selected w/b mixtures, 0.25, and subjected to water curing. The strength efficiency of cement is denoted as MPa/kg cement. It shows that the strength efficiency value of RHA and CSF concrete is higher than that of OPC concrete after 3 days. At 180 days, all mixes regardless of w/b ratio and percentage of cement replacement achieved above 0.2 except for OPC mixes, which only achieved 0.2. For w/b of 0.25, compressive strength efficiency of cement rises to up to 0.25 for 10% replacement of cement with RHA. The values of 0.2 and 0.25 of efficiency coefficients are similar with 5 and 4 kg of cement/m^3 to produce 1 MPa of concrete strength. It is clear that using RHA and CSF in high performance concrete will reduce 20% of cement consumption to get similar compressive strength of concrete without RHA and CSF. Similar results are also reported by Hwang [22], who concluded that inclusion of RHA in concrete mixture increase the strength efficiency of cement. The energy consumption and the detrimental CO_2 emission to the environment during the production of cement can significantly be reduced to by the incorporate of RHA or CSF in concrete.

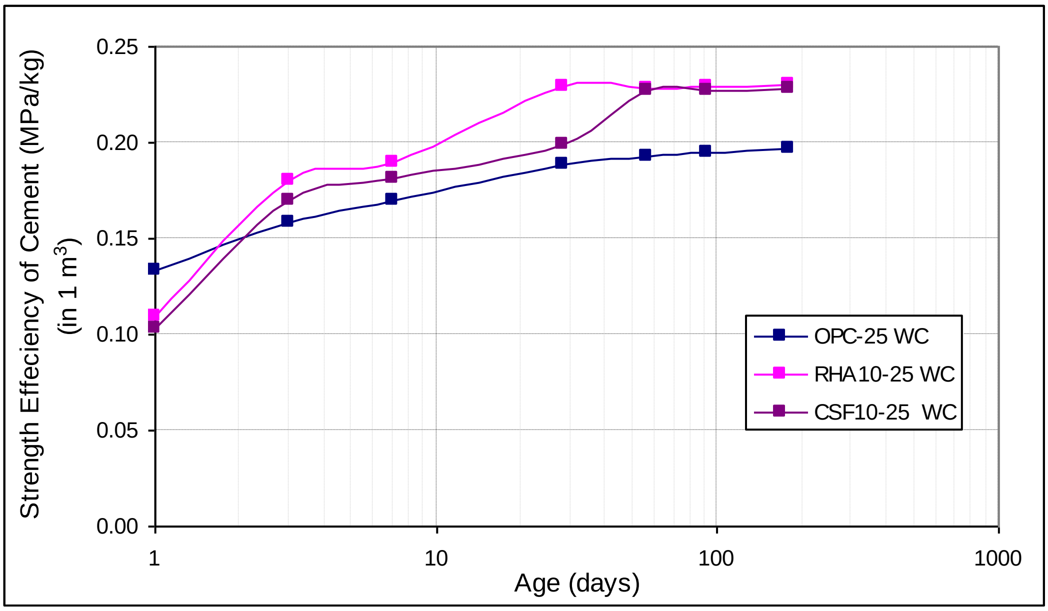

Figure 9: Strength efficiency of cement

4. Conclusion

1. The choice of FM of fine aggregate and the type of SCM affects the optimum packing density of mixture. From three types of FM of 2.62, 2.84 and 3.12, the mixture of the FM of 2.84 as well as RHA and CSF produce the optimum mixture, but for CSF the optimum is obtained with FM in 2.62, as shown by the IAE value of that mix less was 10%.
2. The compressive strength of concrete incorporating 10% RHA can achieve 100 MPa at 28 days and it could be related to the optimum packing density of the mixture, the filler effect and the pozzolanic activity of RHA.
3. The mechanical properties of RHA and CSF concrete are better than plain concrete from 7 days a on ward.
4. The strength efficiency of cement for concrete incorporating RHA and CSF is higher than that of plain concrete, which means that the usage of SCM does not reduce the strength but increase strength in term of strength per 1 kg cement.

5. Acknowledgement

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