Journal of Engineering Science and Technology
Vol. 10, No.12 (2015) 1628 - 1640

PERFORMANCE OF MICROWAVE INCINARATED RICE HUSK ASH AND USED ENGINE OIL AS A GREEN CONCRETE ADMIXTURES

B. SALMIA*, M. F. NURUDDIN, N. SHAFIQ, M. K. NUR LIYANA, S. H. A. TALIB

Department of Civil Engineering, Universiti Tenaga Nasional,
43000 Kajang, Selangor, Malaysia
*Corresponding Author: Salmia@uniten.edu.my

Abstract

The utilization of waste materials in the construction industry is a novel approach let alone if these materials can further enhance the durability of the structures. Amongst the waste materials identified to be incorporated in this study is Rice Husk Ash (RHA) and Used Engine Oil (UEO). Productions of these waste materials are colossal with annual volume of 1.35 billion gallon and 40 million tons of used engine oil and rice husk respectively. The main aim of this research is to establish the effects of these two waste materials (as ingredients) in concrete. The rice husk was burn using microwave incinerator to produce better quality of Microwave Incinerated Rice Husk Ash (MIRHA). The pozzolanic reactivity of MIRHA helped to enhance concrete durability. The used engine oil acted as an admixture that improved the fresh state of the concrete. Workability, entrained air and compressive strength tests were conducted and the result showed that the concrete illustrated better performance compared to control sample in terms of workability, air contain and compressive strength.

Keywords: Microwave Incinerated Rice Husk Ash, used engine oil.

1. Introduction

Rice milling generates a byproduct known as husk that surrounds the paddy grain. During milling of paddy about 78 % of weight is received as rice, broken rice and bran. The other 22 % of the weight of paddy is received as husk. This husk is used as fuel in the rice mills to generate steam for the boiling process. This husk contains about 75% organic volatile matter and the balance about 25% is converted into ash during the firing process and is known as rice husk ash (RHA). It is a natural waste product and there is strong interest in using this material in concrete. Rice husk have a very high silica content, and slow firing at

Abbreviations

MIRHA	Microwave Incinerated Rice Husk Ash
OPC	Ordinary Portland Cement
SP	Superplasticizer
UEO	Used Engine Oil

temperature between 500 and 700 ˚C results in the formation of an amorphous material with a porous structure [1]. RHA if properly prepared shall be in an active form which behaves very much like cement [2]. Nuruddin [4] started the study on MIRHA using Universiti Teknologi PETRONAS microwave incinerator (UTPMI). To date it has been found that MIRHA contributed positively to the performance of concrete [9]. The superlative quality of MIRHA that is amorphous and contain 89% SiO2 increase the compressive strength by 56% when 5% of MIRHA is incorporated in the mix [10].

In addition, Utah Department of Environment Quality [3] reported that the increase number of vehicles globally has cause an increased in the production of used engine oil. Approximately 1.35 billion gallons of used engine oil is generated yearly. The study [4] shows that more than 45% of used engine oil is being collected worldwide while the remaining 55% is thrown by the end user to the environment.

Mindess and Young (1981) [7] reported that the leakage of oil into the cement in older grinding units resulted in concrete with greater resistance to freezing and thawing. This implies that adding used engine oil to the fresh concrete mix could be similar to adding an air-entraining chemical admixture, thus enhancing durability properties of concrete while serving as another technique of disposing the oil waste.

The study of the effect of used engine oil on the properties of concrete has been carried out by Bilal (2003) [6]. Focusing on 0.075, 0.15 and 0.30% UEO by weight of cement. The result showed that used engine oil acted as a chemical plasticizer improving the fluidity and almost doubling the slump of the concrete mix. Furthermore UEO also increased the entrained air of the fresh concrete mix (almost double), whereas the commercial chemical air-entraining admixture almost quadrupled the air content. They also found that UEO maintained the concrete compressive strength whereas the chemical air-entraining admixture caused a loss of approximately 50% compressive strength at all ages.

From the previous study [6], it has been found that UEO has the potential to become an admixture in concrete that can be used as an air entraining agent. In the absence of detailed research to support the hypothesis that the used engine oil can be used as an admixture for concrete, this research is needed in order to explore every potential of used engine oil as concrete admixture. Furthermore, there is not yet study published for the compatibility of used engine oil with microwave incinerated rice husk ash (MIRHA). Therefore, the inclusions of UEO in concrete need can be investigated compared to the commercially available superplasticizer. The successful of this research will bring some impact of new finding of new admixtures that are cost effective may have many economic and technical imparts on the Malaysian construction industry as well as worldwide concrete usage.

The main objective of this research is to identify the effects of UEO in MIRHA concrete with respect to workability, entrained air and compressive strength.

2. Experimental Program

Twenty two mixes were cast with fixed value of coarse aggregate, fine aggregate and water binder ratio (w/b) of 1138 kg/m3, 757 kg/m3 and 0.55 respectively.

Ordinary Portland Cement (OPC) Type 1 was used in this research, in accordance to BS EN 197-1 2000. OPC Type 1 was preferred because the observation on concrete properties can be done in normal hydration process hence the advantages of MIRHA usage in concrete can be optimized. In MIRHA concrete, MIRHA concrete replace 20% of cement content by weight. Chemical composition of OPC and MIRHA are illustrated in Table 1.

Superplasticizer and used engine oil used as chemical admixture. Superplasticizer was used in preparing concrete sample in order to decrease water content and to achieve early high strength. The superplasticizer incorporated in this research is in a form of dry liquid known as Sulfonated Naphthalene Formaldehyde (SNF) condensate supplied by SIKA Malaysia Sdn. Bhd. Used engine oil was collected from workshop around Tronoh and Seri Iskandar, Perak. It was collected randomly at the service stations that have no proper dispose. Various percentages of chemical admixtures added into the mix to study the optimum dosage that possible to use in this mixes as Tabulated in Table 3. Chemical composition of chemical admixtures is shown in Table 2. The mixture proportions of OPC and MIRHA concrete are shown in Table 3.

The specimens were cast in accordance to BS1880. Slump test was conducted to determine the workability of concrete. The test was carried out conforming to BS 1881: Part 102: 1983. Air content of fresh concrete was determined in accordance with ASTM C231. Concrete cubes of 100x100x100 mm were then water cured and the compressive strength monitored at ages 3, 7, and 28, 90 and 180 days. Three samples were prepared for each age.

Table 1. Chemical composition and physical properties of OPC and MIRHA.

Chemical Composition	Ordinary Portland Cement (%)	MIRHA (%)
SiO_2	21.98	86.1
Al_2O_3	4.65	0.17
Fe_2O_3	2.27	2.87
CaO	61.55	1.03
MgO	4.27	0.84
SO_3	2.19	0.41
K_2O	1.04	4.65
Na_2O	0.11	-

Table 2. Chemical composition of superplasticizer and used engine oil.

Chemical Composition	Superplasticizer (%)	Used engine oil (%)
SiO_2	-	86.1
Fe_2O_3	-	2.87
CaO	-	1.03
SO_3	99.9	0.84
P_2O_5	-	0.41
ZnO	-	4.65
Cl^-	-	-

Table 3. Mixture proportions of concrete.

Mix	OPC (kg/m^3)	MIRHA (kg/m^3)	UEO (%)	SP (%)
OPC	325	-	-	-
OPC-UEO-0.15	325	-	0.15	-
OPC-SP-0.15	325	-	-	0.15
OPC-UEO-0.3	325	-	0.3	-
OPC-SP-0.3	325	-	-	0.3
OPC-UEO-0.5	325	-	0.5	-
OPC-SP-0.5	325	-	-	0.5
OPC-UEO-0.8	325	-	0.8	-
OPC-SP-0.8	325	-	-	0.8
OPC-UEO-1	325	-	1	-
OPC-SP-1	325	-	-	1
MIRHA	260	65	-	-
MIRHA-UEO-0.15	260	65	0.15	-
MIRHA-SP-0.15	260	65	-	0.15
MIRHA-UEO-0.3	260	65	0.3	-
MIRHA-SP-0.3	260	65	-	0.3
MIRHA-UEO-0.5	260	65	0.5	-
MIRHA-SP-0.5	260	65	-	0.5
MIRHA-UEO-0.8	260	65	0.8	-
MIRHA-SP-0.8	260	65	-	0.8
MIRHA-UEO-1	260	65	1	-
MIRHA-SP-1	260	65	-	1

3. Results and Discussion

3.1. Slump value

Figure 1 shows the slump value of OPC and MIRHA concrete containing various percentages of both used engine oil and superplasticizer. From the result obtained, there are big differences in slump value between those OPC and MIRHA concretes. Comparing control mixes of OPC and MIRHA concrete, it can be concluded that MIRHA concrete reduced the workability of concrete by 67%. The slump results as a factor of OPC control (18 mm) are tabulated in Table 2.

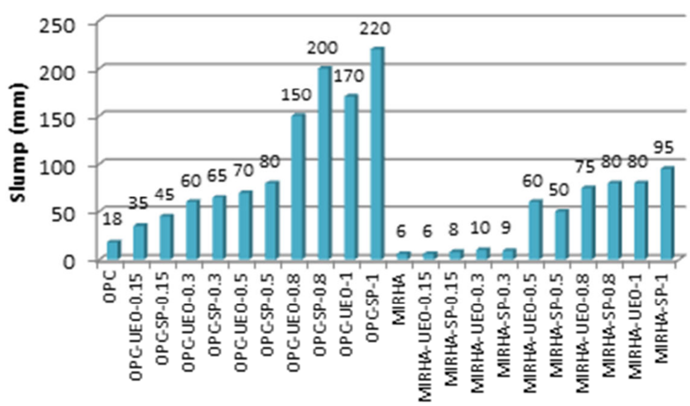

Fig. 1. Slump value for OPC and MIRHA concrete.

The increasing percentage of both UEO and superplasticizer indicated increase in slump value compared to control mix. The influence of used engine oil in enhancing the concrete workability was comparable to superplasticizer. The used engine oil acted as a chemical plasticizer by improving the fluidity and almost double the slump of the fresh concrete mix.

It can be stated that used engine oil acted as lubricant that could reduce the friction between fine and coarse aggregates with cement paste to make concrete workable. During mixing process, used engine oil generated a pressurized film between aggregate surfaces and cement paste that provided a slippery surface that could easily drove the aggregate and cement particle into the empty spaces. The mechanism of the lubrication is illustrated in Fig. 2.

The effect of superplasticizer viz-a-viz UEO on the workability was greater except for MIRHA samples at 0.3 and 0.5% inclusion level. MIRHA-UEO-0.5 had 16% higher workability compared to MIRHA-SP-0.5 whilst at 0.3% inclusion the slumps for MIRHA concrete with SP and UEO had little difference. The slump of MIRHA-UEO-0.5 was only 15% lower that of OPC-UEO-0.5. This was attributed to the large surface area of MIRHA itself that can produce dry or unworkable mixtures unless superplasticizer or used engine oil is used in higher percentage (0.5% and above).

Superplasticizer and UEO acted as water reducer that deflocculates 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 were agitated and bumped into each other, the presence of superplasticizer and used engine oil repelled each other and flocs did not form. When the water trapped within the original flocs was released, it contributed to the workability of the concrete.

It can be seen from Table 4 that slump values of OPC concrete is higher than that of its MIRHA counterparts. This may be attributed to the absorptive characteristic of cellular particles of MIRHA that required more water for a given consistency. The absorptive character of very fine MIRHA particles and their irregular shape with cellular structure that had a large surface area needed to be wetted and in turn reduced the fluidity.

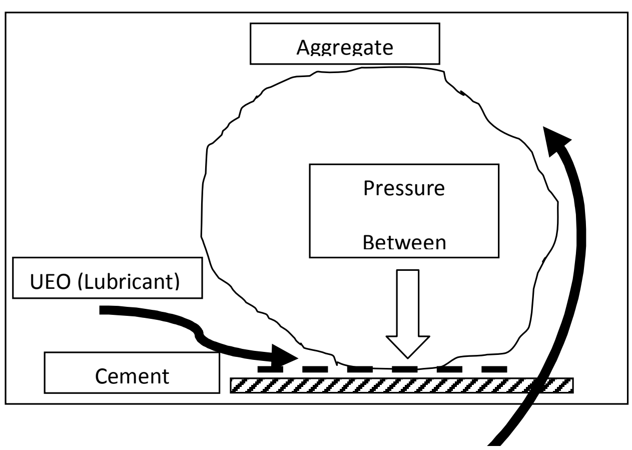

Fig. 2. Lubrication of aggregate and cement paste.

3.2. Entrained air

Figure 3 shows the entrained air of OPC and MIRHA concretes with various percentages of used engine oil and superplasticizer. It can be seen that the entrained air of OPC concrete containing used engine oil is higher than that containing superplasticizer. Entrained air of concrete containing used engine oil was more than double than the entrained air determined for the OPC control mix. This is in agreement with the results obtained by Bilal et al. [8] which stated that used engine oil increased the air content of the fresh concrete mix (almost double).

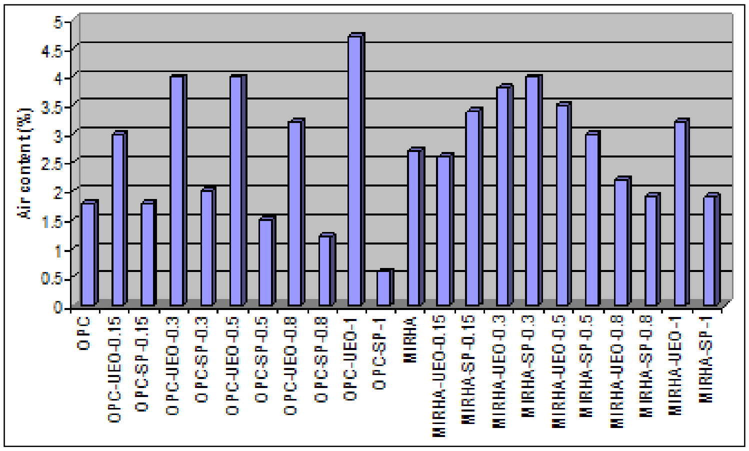

Fig. 3. Entrained air of OPC and MIRHA concretes.

Engine oil additive is a detergent that usually works together with dispersant to help dissolve contaminants and sludge so that deposits are not formed. Detergent is surfactant that reduces the surface tension of water by adsorbing at the liquid-gas interface. They also reduce the interfacial tension between oil and water by adsorbing at the liquid-liquid interface [10]. This lowering of surface tension is the main cause of both air entrainment and bubble stability [11]. This result revealed the statement that UEO performs not only superplasticizing effects but also as air entraining agent. Air content in concrete is important for durability purposes. Entrained air should be in the range of 4-8% for good frost protection [12]. Mix containing UEO 0.3-1% achieves the range hence has potential towards a high durability concrete.

Superplasticizer in normal OPC concrete demonstrated similar entrained air as control mix at the inclusion of 0.15%. Entrained air increased at dosage 0.3% of superplasticizer. Most organic chemical admixtures will increase air entrainment partly because they may reduce adsorbed air entraining agent molecules on solid surface through competition, such as superplasticizers. In addition, macromolecular materials may help stabilize the dispersed air bubbles [11].

Inclusion of superplasticizer above 0.3% caused entrained air to decrease. One of the possible reasons was due to the water content. At constant water content, addition of high dosage of superplasticizer caused severe bleeding [13] that caused gravity pulling the coarse aggregate down and therefore bleeding took place and bleed water ended up being reworked into the surface concrete (mortar). The paste at the surface then became thinner, and buoyancy allowed more air bubbles to escape thus decreasing the air content in concrete. Another reason was due to the difference in viscosity between UEO and superplasticizer. Viscosity of used engine oil is high because of a long chain hydrocarbon (15-20 carbon atoms). This high viscosity was necessary for the foam stability between processing and hardening. At constant w/c, viscosity and total stress at particular shear rate decreased by the addition of superpasticizer as stated by Ramachandran [14]. Inclusions of very high dosage of superplasticizer caused too much free water in concrete hence disturbed the stability of concrete mix. Because of higher viscosity of UEO compared to superplasticizer, it maintained fluidity without disturbing the air content. High viscosity of fresh concrete reduced bleeding thus stabilized it.

Superplasticizer in normal OPC concrete demonstrated almost similar entrained air as OPC control mix at the certain percentage of usage. According to Lianxiang Du et al. [11] some high range water reducers themselves may have the air entraining potential. However, the addition of straight calcium chloride may tend to reduce the amount of entrained air due to the precipitation of surfactants in the solution by formation of insoluble salts.

The results of MIRHA concrete are shown in Fig. 3. It can be seen that entrained air of MIRHA control mix is 2.7%. OPC concrete containing 0.15, 0.3, 0.5, 0.8 and 1% of used engine oil showed entrained air of 2.6, 3.8, 3.5, 2.2 and 3.2% which are 1.4, 2.1, 1.9, 1.2, and 1.8 times the entrained air of normal OPC respectively. Concrete mix containing same values of superplasticizer showed that the entrained air of 3.4, 4, 3, 1.9 and 1.9% gave 1.9, 2.2, 1.7, 1.1 and 1.1 times than the normal OPC entrained air respectively.

Because of high specific surface area of MIRHA, the required air entraining admixture dosage for concrete was relatively high. Furthermore, the air entraining admixture dosage increased with an increase in the percentage of MIRHA used as cement replacement material. MIRHA known to be highly pozzolanic material because of its microporous nature with high surface area. Based on the previous findings [15], at the replacement level of more than 10% RHA, the RHA concrete required more superplasticizer and more air entraining admixture to achieve constant entrained air. This may be attributed to the high specific surface area and high carbon content [17] of MIRHA. Therefore, the MIRHA content of 20% replacement from cement content required water reducing admixture to maintain the water-binder ratio hence increase the performance of the MIRHA concrete.

The lower entrained air in all mixes was due to the carbon content in MIRHA that acted as activated carbon that possessed the potential to adsorb surfactants used in air entraining agents therefore lowering the air content of concrete.

3.3. Compressive strength

Compressive strength for each mix measured at the age of 3, 7, 28, 90 and 180 days and the strength development of OPC concrete mixes containing used engine oil and superplasticizer are shown in Figs. 4 and 5 respectively.

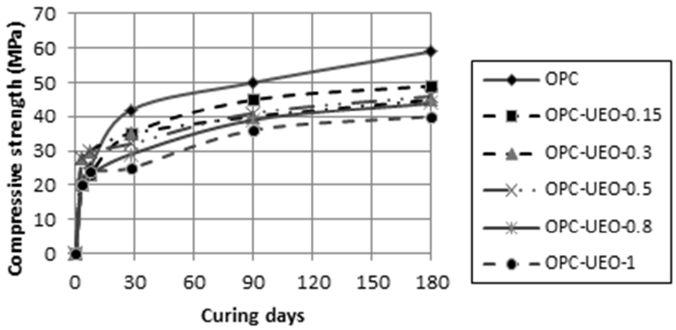

Fig. 4. Strength development of OPC concrete containing used engine oil.

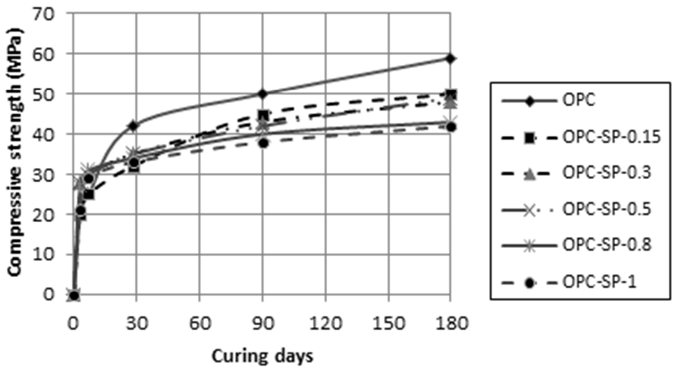

Fig. 5. Strength development of OPC concrete containing superplasticizer.

At the age of 28 days, control mix showed the highest value of compressive strength as compared to mixes containing used engine oil and superplasticizer. At 28 days, compressive strength of OPC concrete was 42 MPa. Furthermore concrete containing set of 0.15, 0.3, 0.5, 0.8 and 1% of used engine oil and superplasticizer acquired set of compressive strength of 35, 35, 32, 29 and 25 MPa and 32, 35, 35, 34 and 33 MPa respectively as tabulated in Table 4.

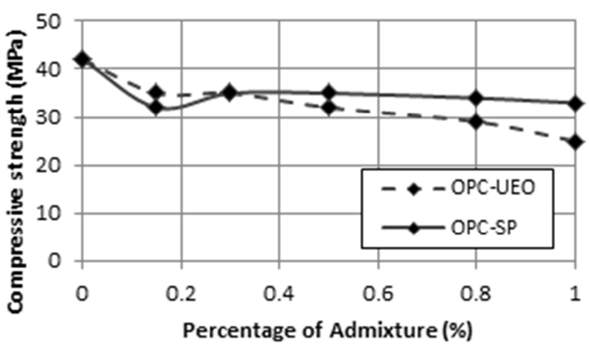

Fig. 6. Compressive strength of OPC concrete at 28 days.

Table 4. Compressive strength of OPC concrete and MIRHA concrete at 28 days.

Mix	Compressive Strength (MPa)
OPC-UEO-0.15	35
OPC-SP-0.15	32
OPC-UEO-0.3	35
OPC-SP-0.3	35
OPC-UEO-0.5	32
OPC-SP-0.5	35
OPC-UEO-0.8	29
OPC-SP-0.8	34
OPC-UEO-1	25
OPC-SP-1	33
MIRHA-UEO-0.15	45
MIRHA-SP-0.15	48
MIRHA-UEO-0.3	48
MIRHA-SP-0.3	50
MIRHA-UEO-0.5	49
MIRHA-SP-0.5	55
MIRHA-UEO-0.8	34
MIRHA-SP-0.8	53
MIRHA-UEO-1	29
MIRHA-SP-1	40

It can be seen from Figs. 4 and 5 that at the age of 28, 90 and 180 days, control mixes showed the higher value of compressive strength as compared to mixes containing used engine oil and superplasticizer. Based on observations of the results, for constant w/c of 0.55, used engine oil concrete showed a decrease in compressive strength of up to 32% compared to OPC control mix at 180 days, whereas the reduction was 29% of strength in the case of using superplasticizer. Although there is no significant improvement in the compressive strength of both used engine oil and superplasticizer as compared to control mix, however, they showed almost similar behavior. In addition, both used engine oil and superplasticizer did not show any harmful effects over time by giving 49 and 50 MPa compressive strength respectively at 180 days which exceeded the target strength of 30-40 MPa. Compressive strength of concrete containing 0.15-0.5% used engine oil give almost similar result and started to decrease at 0.8% of usage. The decreasing of compressive strength was due to the heavy metal content. The result also proved the result obtained by Murat et al. (1996) [16] who stated that the presence of heavy metal in concrete delayed setting and lower the strength.

Figures 7 and 8 show that MIRHA concrete with incorporation of lower than 0.8% used engine oil and superplasticizer significantly enhanced the strength performance. This was due to the effects of used engine oil and superplasticizer in deflocculating the agglomeration or lumps of cement grains. With adequate water, pozzolanic reaction was improved and hence increased the formation of C-S-H gel. Results of MIRHA concrete mixes at 28 days are shown in Fig. 9. Compressive strength of MIRHA concrete containing 0.15, 0.3, 0.5, 0.8 and 1% of used engine oil were 45, 48, 49, 34 and 29 MPa respectively. Whilst, compressive strength of MIRHA concrete containing 0.15, 0.3, 0.5, 0.8 and 1% of superplasticizer were 48, 50, 55, 53 and 40 MPa respectively also tabulated in Table 4. Thus, it showed that the performance of used engine oil MIRHA concrete in terms of compressive strength was comparable to the ones with superplasticizer. The compressive strength of MIRHA concrete containing superplasticizer was higher than MIRHA control concrete up to 1% usage but MIRHA concrete containing 1% used engine oil is lower that MIRHA control concrete.

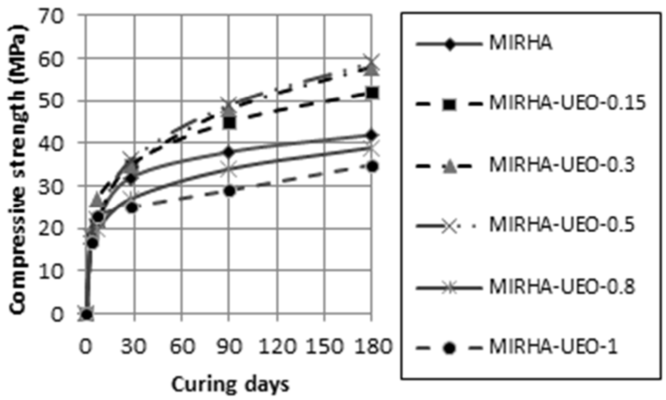

Fig. 7. Strength development of MIRHA concrete with used engine oil.

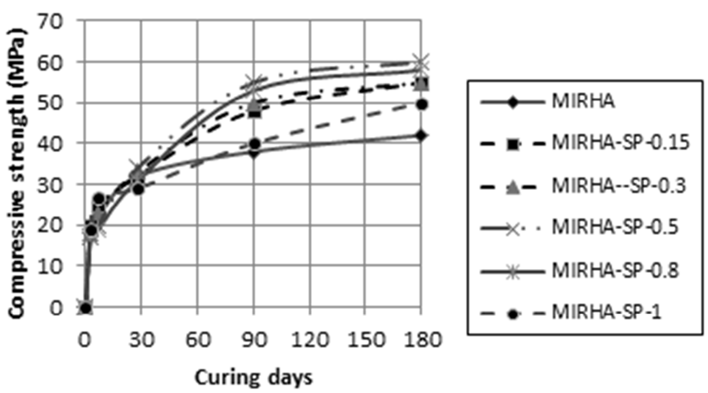

Fig. 8. Strength development of MIRHA concrete with used engine oil.

Figures 7 and 8 also showed that at 28 days, 90 days and 180 days, compressive strength MIRHA concrete containing 0.15%-0.5% of used engine oil and superplasticizer is higher as compared to MIRHA control mix. MIRHA concrete containing 0.8-1% used engine oil and superplasticizer did not give significant effects to compressive strength development. It is evident that high dosage of superplasticizer of more than 0.5% significantly increased workability but it is counterproductive in term of compressive strength as it contributes to the increase of water cement ratio.

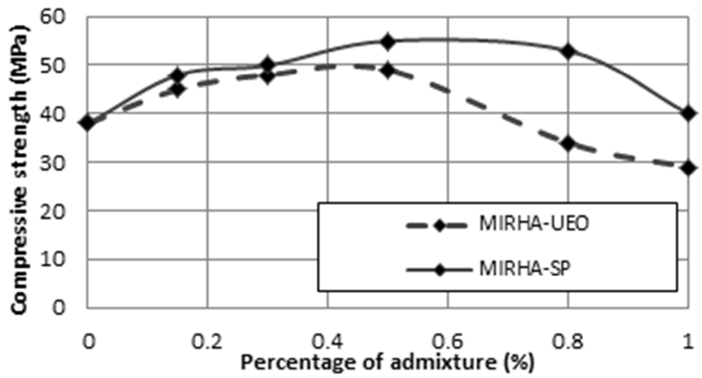

Fig. 9. Compressive strength of MIRHA concrete at 28 days.

The strength increment of MIRHA concrete was due to the 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 was instrumental in creating good quality MIRHA concrete. The role of MIRHA in the improvement of concrete's strength is achieved via the pozzolanic reactivity of MIRHA that consume excessive calcium hydroxide and produce additional calcium silicate hydrates (C-S-H) gels.

From the analysis, it was found that the OPC control mix and MIRHA control mix give performed a different compressive strength at all ages. Overall, the compressive strength of control OPC is higher than MIRHA control mix. This is due to the absorptive characteristic in MIRHA. Therefore, MIRHA control mix need more water to complete the hydration process compared to OPC control mix.

4. Conclusions

From the tests that have been conducted, it can be concluded that:

- Used engine oil can act as a chemical plasticizer similar to superplasticizer to improve workability, air content and strength of OPC and MIRHA concrete.
- 0.5% inclusion of used engine oil demonstrated better or same concrete performance with compared concrete with superplasticizer at the same percentage. The results of 0.5% inclusion of chemical admixtures in both OPC and MIRHA concrete can be concluded in the statement below:

(i) The slump value of OPC concrete containing UEO and superplasticizer was 3.9 time and 4.4 times as OPC control mix, while MIRHA concrete containing UEO and superplasticizer was 3.3 times and 2.8 times compared to MIRHA control mix respectively.

(ii) The entrained air generated in OPC concrete containing UEO and superplasticizer was 2.2% and 0.8% than OPC control mix, while MIRHA concrete generated 1.9% and 1.7% entrained air respected to OPC control mix respectively.

(iii) Compressive strength at 28 days of OPC concrete containing UEO and superplasticizer gave 19% and 14% lower than OPC control mix respectively. Compressive strength of MIRHA concrete containing UEO and superplasticizer showed increment of 26% and 45% respectively compared to MIRHA control mix.

- The trend of used engine oil in improving workability of MIRHA concrete was similar with that of superplasticizer in deflocculating the cement grains. Beside it acted as a lubricant in improving workability of concrete hence and not gives any harmful effects on MIRHA as cement replacement material.
- It can be concluded that used engine oil can be used as free chemical plasticizer to enhance concrete performance thus opens the door for new approaches to conventional construction to make concrete structure more sustainable.

References

1. Mehtra, P.K.; and Folliard, K.J. (1995). Rice husk ash - A unique supplementary cementing material: Durability aspects. *ACI Special Publication*, 154.
2. Cook, D.; and Cook, D.J. (1984). Rice-husk ash cements: Their development and applications. *United Nations Industrial Development Organization.*
3. Nuruddin, M.F.; Kusbiantoro, A.; and Shafiq, N. (2008). Microwave incinerated rice husk ash (MIRHA) and its effects on concrete strength. *International IMS Conference on Applications of Traditional and High Performance Materials in Harsh Environments, American University of Sharjah*, 23-24.
4. Nuruddin, F.; Shafiq, N.; and Kamal, N.M. (2008). Microwave incinerated rice husk ash (MIRHA) concrete: A new material in the construction industry. *United Kingdom Malaysia Engineering Conference*.
5. Utah Department of Environment Quality. Retrieved December 28, 2009, from http://www.deq.utah.gov.
6. El-Fadel, M.; and Khoury, R. (2001). Strategies for vehicle waste-oil management: A case study. *Resources, Conservation and Recycling*, 33(2), 75-91.
7. Mindess, S.; and Young, J. F. (1981). *Concrete*. Prentice Hall. Englewood Cliffs, NJ, 481.
8. Hamad, B.S.; Rteil, A.A.; and El-Fadel, M. (2003). Effect of used engine oil on properties of fresh and hardened concrete. *Construction and Building Materials*, 17(5), 311-318.
9. U.S. Environmental Protection Agency. Retrieved May 15, 2010, from http://www.epa.gov/

10. Princeton University. Retrieved May 15, 2010, from http://www.cs.princeton.edu/
11. Du, L.; and Folliard, K.J. (2005). Mechanisms of air entrainment in concrete. *Cement and Concrete Research*, 35(8), 1463-1471.
12. Wilson, M.L.; and Kosmatka, S.H. (2011). Design and control of concrete mixtures. *Portland Cement Association: USA*.
13. Kurniawan, A. (2010). *Performance of self compacting concrete containing fly ash and MIRHA: Optimum mix design and structural behavior*. Doctoral Dissertation, Universiti Teknologi PETRONAS.
14. Ramachandran, V.S. (1996*). Concrete admixtures handbook: Properties, science and technology*. Cambridge University, Press, 211.
15. Zhang, M.H.; Lastra, R.; and Malhotra, V.M. (1996). Rice-husk ash paste and concrete: Some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste. *Cement and Concrete Research*, 26(6), 963-977.
16. Murat, M.; and Sorrentino, F. (1996). Effect of large additions of Cd, Pb, Cr, Zn, to cement raw meal on the composition and the properties of the clinker and the cement. *Cement and Concrete Research*, *26*(3), 377-385.
17. Hill, R.L.; Sarkar, S.L.; Rathbone, R.F.; and Hower, J.C. (1997). An Examination of fly ash carbon and its interactions with air entraining agent. *Cement and Concrete Research*, *27*(2), 193-204.