

DURABILITY OF CONCRETE CONTAINING RECYCLED ASPHALTIC CONCRETE AGGREGATE AND HIGH CALCIUM FLY ASH

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ABSTRACT: In this research, the durability of concrete containing Recycled Asphaltic Concrete (RAC) aggregate and fly ash were studied. The concrete was made from Ordinary Portland Cement (OPC), fly ash, water, sand and combination of natural limestone and RAC aggregates. The RAC aggregate was obtained from the discarded asphaltic pavement. The RAC aggregate was used to replace natural limestone aggregate at the replacement levels of 0, 10, 20, and 30 % of the total weight of aggregate. In addition, the high calcium fly ash from Mae Moh power station in the north of Thailand was used to partially replace OPC at the dosages of 0, 20, and 40 % by mass. The compressive strength, water absorption, porosity, flexural strength, modulus of elasticity and resistance to sulfuric acid were tested. The results showed that concretes with 28-day compressive strengths between 22.5 and 33.0 MPa, water absorption between 5.3-5.9 %, porosity between 12.2 and 13.5 %, flexural strength between 4.4 and 5.5 MPa, modulus of elasticity between 25.6 and 30.0 GPa were obtained. The replacement levels of RAC at 10 % and fly ash at 20 % gave the optimum compressive strength and mechanical properties of concrete for use as pavement concrete. In addition, the using of RAC aggregate together with fly ash in concrete work improved water absorption, porosity and sulfuric acid resistance and the use of RAC and high calcium fly ash will also increase the sustainability of the construction industry.

Keywords: Fly ash, Concrete, Durability, Recycled asphaltic concrete, Surface abrasion

1. INTRODUCTION

The economic development and urban growth increase the utilization of energy and natural resources in the industrial, agricultural and transportation sector. The energy consumption in industrial sector is around 36 percent, and the transportation sector is around 35 percent with the majority is in the road transport (87 percent). The consumption of energy causes air pollution and environmental problems,

The road transportation usually consists of good networks and facilities. The highways in Thailand cover a distance of over 71,470 kilometers per 2 traffic lanes and are mostly (92 percent) asphalt road. These roads require maintenance and restoration to stay in good condition for convenience, speed and safety. The restoration of asphalt concrete pavement is done using the Reclaim Asphalt Pavement (RAP). The original pavement was recycled by mixing with cement and used for the pavement layer. The new asphalt concrete is then laid to replace the original pavement. A large amount of RAP materials are obtained from the scraping off the original pavements to maintain the pavement level, scraping of from the bulging of original pavement due to the wheel track,

or from the construction of new pathway. These RAP materials are piled up as discarded asphalt as shown in Fig. 1. Some of this RAP material are reused by mixing with asphalt cement to repair road, or mixed with cement to make concrete products in the pathway, such as concrete curb, concrete barrier, but there are a lot of RAP materials waiting to be utilized.

In the construction industry, Portland cement is used as the main binding material and a large amount of cement production is thus required each year [1]. The manufacturing process involves rock blasting, digesting, conveying, burning and fine grinding. This results in large amount of carbon dioxide emissions and thus increases the greenhouse effect, which affected the environment negatively [2]. Moreover, the Portland cement production process consumes enormous energy. Previous researched had shown that class C high calcium fly ash with some cementing property could be used successfully as partial replacement of Portland cement [3,4] and as starting material in geopolymer [5].

This research, therefore, aims to investigate the reuse of RAP materials as a coarse aggregate in the concrete mixture and also the use of high calcium fly ash to partially replace Portland cement. The RAP



Fig.1 Discarded asphalt pavement storage area.

material was sorted to obtain the required size and is called Recycle Asphalt Concrete Aggregate (RAC aggregate). It was used to replace natural coarse aggregates. High calcium fly ash was also used to partially replace Portland cement to improve the concrete quality. The suitable proportions for concrete pavements were obtained with cost saving due to the use of RAC aggregate and fly ash with the reduced amount of natural aggregate and Portland cement. It is also a conservation of the environment, reduce the amount of waste and reduce the use of natural resources.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Materials used in this research consisted of Ordinary Portland Cement (OPC), river sand, crushed lime stone aggregate, water, Fly Ash (FA) and RAC aggregate. The FA was a class C high calcium from Mae Moh power station in Lampang province, northern Thailand. The RAC aggregate with the particle size between 4.75-19.10 mm and 3.5 % asphalt was from reclaimed asphalt pavement as shown in Fig.2. The physical properties of materials are shown in Table 1. The morphology of FA by SEM as shown in Fig. 3 indicated that the shape of FA was spherical with smooth surface. The chemical compositions of FA are shown in Table 2. The specific gravity of FA was 2.66 with median particle size of 18.6 μm . The FA consisted of a high content of 36.20% SiO_2 , 15.52% Al_2O_3 , 14.25% Fe_2O_3 , and 22.57% CaO with the Loss On Ignition (LOI) of 0.88%. The high calcium content in fly ash gave its cementing property. The XRD of FA as shown in Fig. 4 indicated the high amorphous content with relatively large hump around $22-38^\circ 2\theta$.



Fig.2 RAC aggregate.

Table 1 The physical properties of materials

Materials	Sand	OPC	FA	RAC agg.	Natural coarse agg.
Specific gravity	2.61	3.15	2.66	2.39	2.7
Median particle size (μm)	-	14.6	18.6	-	-
Fineness modulus	2.65	-	-	-	-
Unit weight (kg/m^3)	1360	1440	-	1266	1598
Abrasion Loss (%)	-	-	-	29.5	22.4
Water absorption (%)	1.17	-	-	0.36	0.46

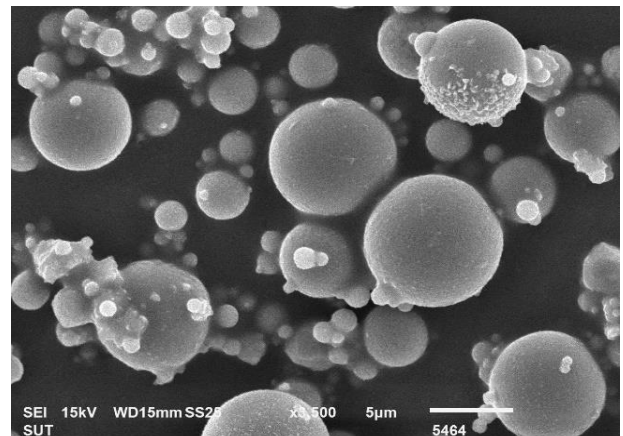


Fig.3 The morphology of FA by SEM

2.2 Mix Proportion

2.2.1 FA and RAC aggregate contents

To study the durability of concrete containing Recycled Asphaltic Concrete (RAC) aggregate and high calcium fly ash, the OPC was replaced with FA at the levels of 0, 20, and 40 % by weight and the natural lime stone aggregate was replaced with RAC aggregate at the replacement levels of 0, 10, 20, and 30 % by weight. The compressive strength, water absorption, porosity, modulus of elasticity, flexural strength and sulfuric acid resistance of concrete containing RAC aggregate and FA were determined. In order to obtain adequate data, three series of mixes totaling 12 mixes as shown in Table 3 were tested.

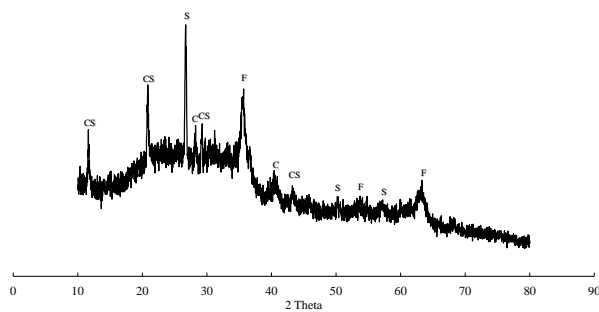


Fig.4 The XRD of FA. F-Maghemite: Fe_2O_3 ; Fe_2O_3 ; C-Anhydrite; CS-Gypsum: CaSO_4 ; S-Quartz: SiO_2 .

Table 2 Chemical composition of materials (by weight)

Chemical compositions (%)	FA	OPC
SiO_2	36.20	20.8
Al_2O_3	15.52	4.7
Fe_2O_3	14.25	3.4
CaO	22.57	65.3
K_2O	1.63	0.4
Na_2O	0.33	0.1
SO_3	8.9	2.7
LOI	0.88	0.9

2.3 Details of Mixing

For mixing, OPC and FA were firstly mixed together until the mixture was homogenous. Next, sand was added and mixed for 5 min. Next, crushed lime stone aggregate and RAC aggregate were added and mixed for 5 min. Finally, water was added and mixed for another 5 minutes to obtain a homogenous mixture.

The fresh concrete was placed into 150x300 mm cylindrical molds, 100x100x100 mm cube molds and 150x150x500 mm prism molds. The specimens were demolded at 1 day and stored in water.

2.4 Details of Test

2.4.1 Compressive strength

The cylindrical specimens size 150x300 mm were tested to determine the compressive strength in accordance with ASTM C39/C39M-18 [6]. The reported compressive strength was the average of three samples.

2.4.2 Porosity and water absorption

The cube specimens size 100x100x100 mm were tested to determine the porosity and water absorption in accordance with ASTM C642-13 [7]. The reported

Table 3 Mixture of concrete by weight. (kg/m^3)

Mix	Cement	FA	Fine Agg.	Coarse Agg.	RAC	Water
0F - 00R	394	-	590	1138	-	213
0F - 10R	394	-	590	1024	114	213
0F - 20R	394	-	590	910	228	213
0F - 30R	394	-	590	797	341	213
20F-00R	315	79	590	1138	-	213
20F-10R	315	79	590	1024	114	213
20F-20R	315	79	590	910	228	213
20F-30R	315	79	590	797	341	213
40F-00R	236	158	590	1138	-	213
40F-10R	236	158	590	1024	114	213
40F-20R	236	158	590	910	228	213
40F-30R	236	158	590	797	341	213

0F-00R = fly ash of 0 % and RAC aggregate of 0 %,

Fine Agg. = fine aggregate, Coarse Agg. = coarse aggregate.

porosity and water absorption were the average of three samples.

2.4.3 Modulus of elasticity

The cylindrical specimens size 150x300 mm were tested to determine the modulus of elasticity in accordance with ASTM C469/C469M-14 [8]. The reported modulus of elasticity was the average of three samples.

2.4.4 Flexural strength

The prism specimens size 150x150x500 mm were tested to determine the flexural strength in accordance with ASTM C293-02 [9]. The reported flexural strength was the average of three samples.

2.4.5 The resistance to sulfuric acid

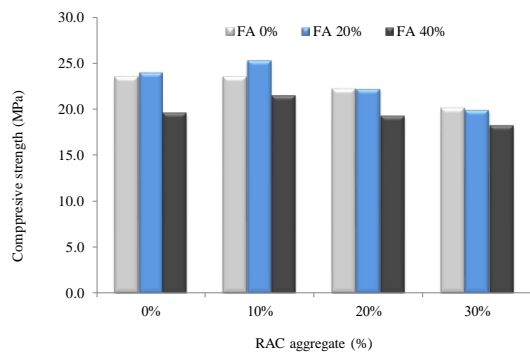
The cube specimens size 100x100x100 mm were tested to determine the resistance to sulfuric acid in accordance with ASTM C267-01 [10]. The reported resistance to sulfuric acid was the average of three samples.

3. RESULTS AND DISCUSSIONS

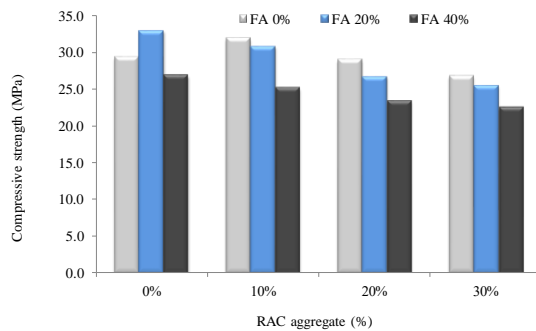
3.1 Compressive Strength

The results of compressive strength of concrete containing RAC aggregate and fly ash are shown in Fig.5.

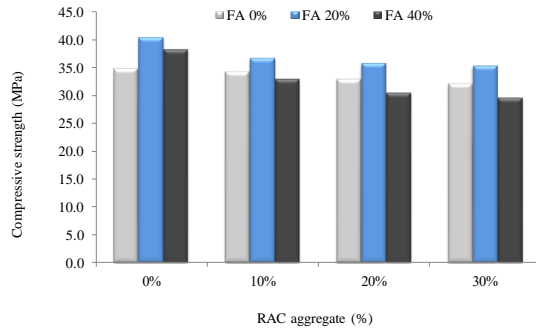
The compressive strength decreased with increasing RAC aggregate content. For example, the compressive strength at 28 days of mixes with 20 % FA by weight with 0, 10, 20, and 30 % RAC



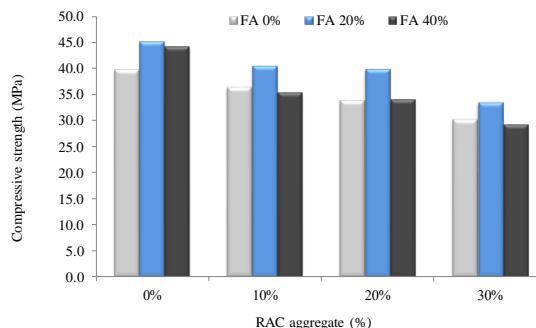
a. 7 days



b. 28 days



c. 56 days



d. 90 days

Fig.5 Compressive strengths at 7, 28, 56 and 90 days

aggregate were 32.9, 30.8, 26.7, and 25.5 MPa, respectively.

The RAC aggregate was partly covered with asphalt and its use thus resulted in the reduced bond between cement paste and RAC aggregate compared with that of natural lime stone aggregate. This negatively affected the aggregate bonding and reduced the strength of concrete.

With regards to the effect of fly ash content, the compressive strength development of concrete containing fly ash was quite good. The general trend was that the replacement level of 20% improved the compressive strength of the mixes. This was in line with the reported result that normally the strength of concrete with proper amount of fly ash could slightly increase compared with that of normal concrete [3,4]. The incorporation of fly ash increased the workability of the mix and also resulted in the increases in pozzolanic reaction and filling of the void [11,12]. Especially when the concrete age was more than 28 days, the pozzolanic effect was more noticeable as indicated by the increases in compressive strengths at 56 and 90 days as shown in Fig. 5(c) and 5(d). For example, the compressive strengths at 56 days of mixes with 10 % RAC aggregate and 0, 20, and 40 % FA were 34.2, 36.6, and 32.9 MPa, respectively.

3.2 Porosity and Water Absorption

The results of water absorption and porosity of concrete containing RAC aggregate and fly ash are shown in Figs.6 and 7. With regards to the effect of content of fly ash, both water absorption and porosity at 28 days increased with the increasing content of fly ash. The use of fly ash to partially replace OPC resulted in changes in paste content, pore size and pore structure. However, the early reactions depend on OPC, as a result the pore of fly ash cement paste was increased compared to that of the mixture without fly ash. But the distribution of the pore was improved because the fly ash with circular particles made the dispersion better in cement paste. This resulted in the smaller average size of pore with increasing amount of fly ash [13]. This affected directly and increased the porosity of the samples at the early age. For example, the porosities of mixes with 10 % RAC aggregate and 0, 20, and 40 % fly ash were 12.88, 13.26, and 13.54 %, respectively. In contrast, the increase in RAC aggregate improved the water absorption characteristics and reduced the porosity of concrete. This was due to the fact that the surface of RAC aggregate was partially coated with asphalt (Fig.1) and this lowered its water absorption (Table 1). For example, the water absorptions of mix with 40 % fly ash and 0, 10, 20, and 30 % RAC aggregate were 5.91, 5.92, 5.88, and 5.66 %, respectively.

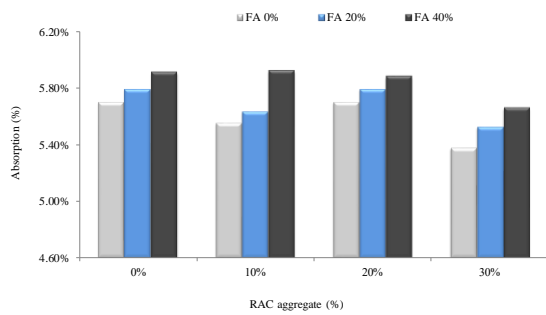


Fig.6 Water absorption at 28 days

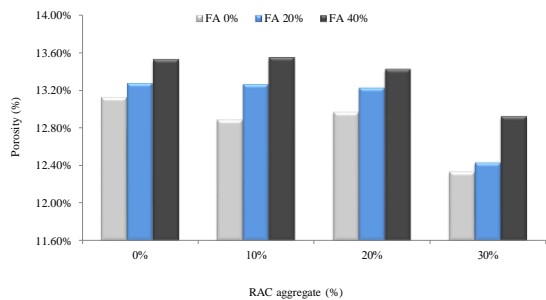


Fig.7 Porosity at 28 days

3.3 Modulus of Elasticity

The results of modulus of elasticity of concrete containing RAC aggregate and fly ash are shown in Fig.8.

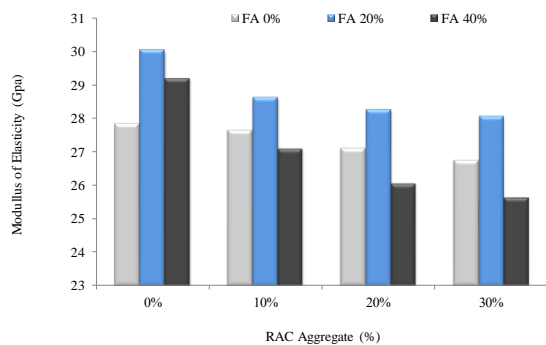


Fig.8 Modulus of elasticity at 28 days

The modulus of elasticity tended to decrease with the increasing in the content of RAC aggregate and this trend was similar to the reduction in compressive strength. For example, the moduli of elasticity at 28 days of the 40 % fly ash mix with 0, 10, 20, and 30 % RAC aggregate were 29.20, 27.10, 26.05, and 25.65 GPa, respectively. The modulus of elasticity is affected by the properties of aggregate, water to binder ratio and compressive strength [14,15].

Normally, a higher value of modulus of elasticity for a given concrete strength indicates the better quality.

3.4 Flexural Strengths

The results of flexural strength of concrete containing RAC aggregate and fly ash are shown in Fig. 9. With regards to the effect of content of fly ash, the flexural strengths increased with the incorporation of fly ash at the 20 % replacement levels but at the content of fly ash beyond 20 %, the flexural strengths started to decrease. In general, the increase of flexural strength was due to the increase in the reaction products from OPC and fly ash. This was associated with the improvement of compressive strength and modulus of elasticity of fly ash concrete which led to the improvement in flexural strength [3,16]. For example, the flexural strength at 28 days of the mixes with 20 % RAC aggregate and 0, 20, and 40 % fly ash were 4.66, 4.99, and 4.61 MPa, respectively. With regards to the effect of RAC aggregate content, the flexural strength decreased with increasing RAC aggregate content due to the increase in the amount of weak bond between the RAC aggregate and the matrix. For example, the flexural strengths at 28 days of mixes with 40 % FA and 0, 10, 20, and 30 % RAC aggregate were 4.64, 4.63, 4.61, and 4.40 MPa, respectively.

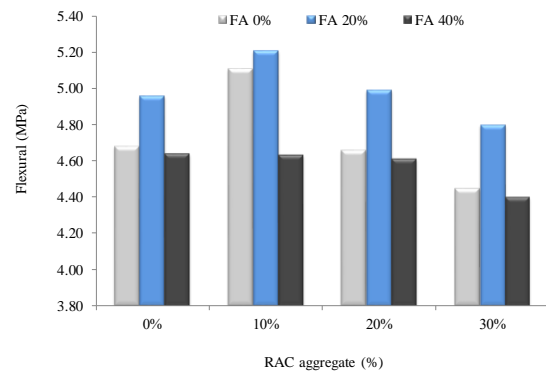
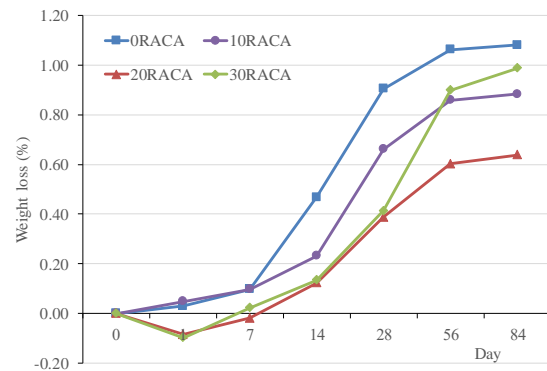


Fig.9 Flexural strengths at 28 days

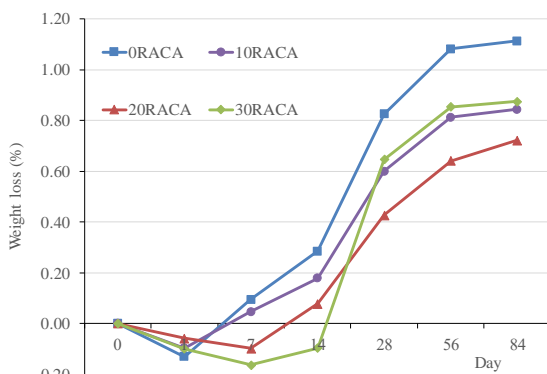
3.5 Sulfuric Acid Resistance

The results of weight losses in sulfuric acid of concrete containing RAC aggregate and fly ash are shown in Fig.10. All concrete specimens were immersed in the 1 % sulfuric acid solution for 84 days to study the durability in an acidic environment. The results indicated that the resistance to acid increased slightly with the increasing fly ash content, which was in line with previously reported results [17].

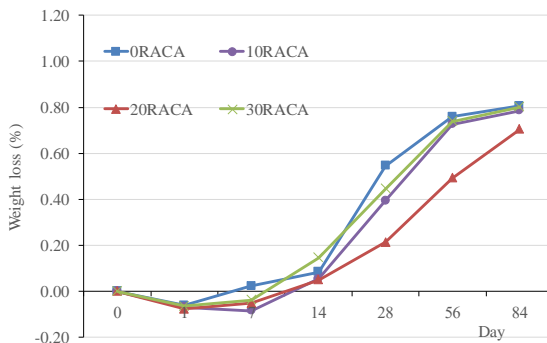
The increase in fly ash reduced the amount of calcium hydroxide in the mix. The reduced calcium hydroxide and the resulting calcium silicate hydrate with low calcium made the sample more durable in



a. FA 0 %



b. FA 20 %



c. FA 40 %

Fig.10 Sulfuric acid resistance at 28 days

the acid environment [17]. In addition, the acid resistance of the cement paste was shown to be dependent on the continuous pore and the acid neutralization capacity of matrix [18]. At the low content of fly ash, the weight loss was high due also to the presence of a large amount of continuous pore in the concrete (Fig.9a) which were conducive to the attack from sulfuric acid. For example, the weight losses after 84 days in sulfuric acid of the mixes with 10 % RAC aggregate and 0, 20, and 40 % fly ash were 0.88, 0.84, and 0.79 %, respectively. However, the increase in porosity was associated with the pore

refining resulting and the reduction in the average pore size of paste [13]. The high replacement level of fly ash also resulted in the strength reduction. The resistance to sulfuric acid attack was, therefore, increased but only slightly due to some of the negative effect as well.

The results also indicated that the resistance to sulfuric acid increased with the incorporation of RAC and the optimum RAC content was 20%. The weight losses after 84 days in sulfuric acid of the mixes with 20 % fly ash and 0, 10, 20, and 30 % RAC aggregate were 1.11, 0.84, 0.72, and 0.87 %, respectively. Although the incorporation of 20% RAC resulted in a slight reduction in strength of sample, the porosity and water absorption were reduced and this increased the resistance to acid attack as opposed to the reduction in strength and modulus of elasticity of the samples.

The increase in the resistance to acid attack of concrete containing RAC was thus due to the reduced porosity of the sample as a result of the presence of asphalt adhered to the aggregate surface. But the excessive amount of RAC aggregate at 30 % resulted in the increased weight loss due to the adverse effect on the compressive strength.

However, the use of RAC aggregate can improved some of the important engineering properties including impermeability, flexibility, and resistance against erosion as also reported by other researchers [19].

4. CONCLUSIONS

Based on the obtained data, the following conclusions can be drawn:

1. The replacement of natural limestone aggregate with RAC aggregate at the level of 0-30% resulted in the reduction in compressive strength, modulus of elasticity and flexural strength due to the decrease in the bonding of cement paste and aggregate as a result of the attached asphalt at the surface of aggregate.

2. The incorporation of RAC aggregate resulted in the improvement of water absorption, porosity and sulfuric acid resistance of concrete.

3. The weight losses from the attack of sulfuric acid decreased and the optimum content of RAC aggregate was 20 % replacement level. The replacement beyond this level resulted in the high weight losses due to the reduction in the strength of the sample.

4. The results showed that the concrete containing 10 % RAC aggregate and 20 % fly ash had 28-day compressive strength of 31.0 MPa, flexural strength of 5.2 MPa and modulus of elasticity of 28.6 GPa with improved water absorption, porosity and durability in terms of acid resistance. It can be used to make concrete pavements in areas with low and light traffic. It can also be used to make simple

concrete structures such as concrete barrier and barrier curb.

Moreover, it has also been shown that the use of RAC and fly ash can increase the waste material utilization, reduce the cement usage and increase the sustainability of construction industry.

5. ACKNOWLEDGEMENT

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