ADVANCED CONCRETE TECHNOLOGY AND GREEN MATERIALS



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PREFACE

Concrete has vital contribution toward construction technology even building material can be replaced by varies material. However, technology concrete still in trend due to effective development. This book of chapter introduces varies researches to support the sustainable green materials toward a lower cost and green environment such as coconut shell, Palm Oil Fuel Ash (POFA), crushed tires and recycle materials. The significant waste material may contribute to produce high performance concrete in term of strength, durability, and solve related environmental problem. Therefore, it is hoped that this book will provide a body of knowledge toward green material in concrete and construction technology. A special note of acknowledgment is also given to all the author for their invaluable contribution to the chapter of the Advanced Concrete Technology and Green Materials.

Sharifah Salwa Mohd Zuki
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CHAPTER 10

QUANTITATIVE INVESTIGATION OF PHYSICAL AND MECHANICAL PROPERTIES OF DIFFERENT ARTIFICIAL AGGREGATE

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10.0 INTRODUCTION

Concrete is an important construction element because it is plastic and soft when newly mixed, yet strong and tough when hardened. However, when the world technologies are develop year by years, lightweight concrete has been commonly used in several structural element applications and its exploitation increases every year on a global basis [1]. Thus, where lightweight concrete is desirable, raising the need for partial or total replacement of the aggregate with a lighter substitute is needed. Lightweight concrete contains artificial aggregate that is natural or synthetic which weighs less than 1100 kg/m3. Due to the low density of Light Weight Aggregate (LWA), it provides better insulation property and can be used to produce light weight concrete. During this period, various types of aggregates have been used.

The major role of aggregates in concrete is to provide strength. In instances where light weight concrete is required, a lighter aggregate made from plastic can be adopted. Due to the problem in Malaysia, most activities are associated with substantial quantities of non-biodegradable solid waste, which comprise a wide range of plastic waste. Dumping of

waste plastic consumer bags from the domestic has become a main concern to the agencies in the town and cities. The waste plastic bags available in the domestic waste mostly consists of Low Density Polyethylene (LDPE) [2]. The uses of plastic bags not only helps in getting them exploited in concrete but also benefits in dropping the cost of concrete production. Other than that, the numerous indirect benefits of the using plastic bags are reduction landfill cost, saving energy, and protecting the environment from potential pollution effects.

Thus, to ensure the effeciency and its capablity to be used in construction field, this research study to be undertaken intended to investigate the physical and mechanical properties of artificial aggregates that made up basically from plastic bags. This study were carried out by implementing few tests to determine the physical and mechanical properties of different type of artificial aggregate. The results of different properties of artificial aggregate were compared among of them to explore the suitablity of the 100% artificial aggregate to be replaced with normal aggregate (NA) in concrete. In addition, this study also will reveal the microstructure of the different type of artificial aggregate. It is expected that it can give better understanding on the types of proposed artificial aggregate. This approach also can provide fundamental knowledge of different types of these aggregate in terms of their physical and mechanical properties.

10.1 ARTIFICIAL AGGREGATE (LIGHTWEIGHT AGGREGATE)

Lightweight aggregates (LWA) are categorized as conventional or artificial materials, which can be defined as a granular, porous and light in weight. They are categorized as normal LWA, ultra LWA and heavy LWA. The natural materials most commonly applied for their invention are clay (vermiculite, smectite, montmorillonite) and sedimentary rocks (slates, shales). Aggregates are used in concrete mixes, where they can form up 70 to 80% of the concrete compositions, as well as in asphalt mixtures (roadways-hot mix asphalt, cold mix asphalt, surface treatments). The typical properties of LWA are good thermal and acoustic insulation, as well as good fire resistance. [3]. The production of LWA is based on the “bloating” phenomenon at which two situations should happen concurrently: the development of a viscous liquid stage

through firing which is able to deceive the gases formed from the disintegration of minerals. Furthermore, a glassy film on the outside surface should be established through cooling creating the LWA impermeable to water [4].

Numerous wastes have been utilized for the invention of LWA, such as fly ash, bottom ash, red mud, waste glass, zeolites and other [5]. The key objective is to substitute the conventional materials used for the LWA invention by other materials giving comparable chemical content. Consequently, by-products will be used and their disallowed quantity will be reduced with clear environmental profits.

10.1.1 ARTIFICIAL SYNTHETIC AGGREGATE

Study by [6] had a research on synthetic aggregate that form from composite material of recycled plastic which having filler encapsulated in the plastic. The synthetic aggregate includes between 30% and 50% recycled plastic, the balance being filler. The plastic are categorized as linear low density polyethylene (LLDPE), low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene or other type of plastic. The filler can include red sand, fly ash, quarry fines, and silica fume. The synthetic aggregate is best used to make concrete with water to cement ratio of at least 0.5. A method of producing synthetic aggregate comprises the stages of chopping plastic, mixing the shredded plastic with filler to formulate a homogenized mixture, squeezing the homogenized mixture in a mold, melting the plastic in the homogenized mixture to form a composite sheet or slab, and shredding the composite sheet or slab to produce either coarse or fine aggregates for use in mixing concrete. The properties of the materials utilized in concrete have a vital role in defining the quality of the concrete, so it is significant to investigate the physical, chemical and mechanical properties of the materials used. Tests were carried out by comparing the several properties of ordinary concrete, lightweight concrete, and concrete containing a synthetic aggregate prepared as described above. A lightweight concrete is created as a control using a local lightweight aggregate, which is a type of volcanic rock collected from the western region of Saudi Arabia. The properties of this local lightweight aggregate are tabulated in Table 10.1.

Table 10.1: Properties of local lightweight aggregate [6]

Test	Result
Bulk Specific Gravity (OD Basis)	1.41
Bulk Specific Gravity (SSD Basis)	1.67
Apparent Specific Gravity	1.41
Absorption (%)	18.6
Dry Unit Weight (Dense Condition) (Kg/m^3)	697
Voids (Dense Condition) (%)	50
Fineness Modulus	6.5

Recycled plastic was used to substitute coarse aggregates to produce the specimens of concrete with a synthetic aggregate. These synthetic aggregates were produced in different sizes. The properties of these synthetic aggregates are tabulated in Table 10.2. The samples are identified by a sample name of the format RPxFy A, where RPx is the number identifying the recycled plastic type and percentage, Fy is the number identifying the filler type and percentage, and A is aggregate.

Table 10.2: Properties of Synthetic Aggregates Replacing Coarse Aggregates [6].

Test	RP_1F_1A	RP_1F_2A	RP_1F_3A	RP_1F_1A	RP_1F_1A
Bulk Specific Gravity (OD Basis)	1.2	0.81	1.08	1.56	1.19
Bulk Specific Gravity (SSD Basis)	1.24	0.86	1.15	1.59	1.31
Apparent Specific Gravity	1.25	0.86	1.16	1.62	1.35
Absorption (%)	3.55	6.11	5.95	2.72	9.81
Dry Unit Weight (Dense Condition) (Kg/m^3)	600	537.53	510.52	750	529
Voids (Dense Condition) (%)	50	75	52.63	51.8	55.44
Fineness Modulus	6.4	5.87	5.96	6.32	5.84
Type	Crushed	Crushed	Crushed	Crushed	Crushed
Maximum Size	10 mm	10 mm	10 mm	10 mm	10 mm

10.2 MATERIALS AND METHOD

10.2.1 ORDINARY PORTLAND CEMENT (OPC)

Cement is bonding material having cohesive & adhesive properties which makes it capable to mix the different construction materials. The Ordinary Portland Cement (OPC) was used in this research. This cement is a commonly used in Malaysia. Furthermore, this cement should be in dry condition and free from any reaction of moisture. The cement cannot react with the surrounding before used. Concrete produced from Portland cement is one of the most versatile construction materials available

10.2.2 WATER

There are three function of water in the concrete mix that have been identified in this experiment. The first is to be spread the cement particle so that stone covered with cement paste entirely. Second is to give convenience work in the concrete mix. Finally, water is an agent of chemical reaction in the cement matrix to bind all aggregate together in the concrete mix. Water cement ratio is the vital factor to investigate the strength of concrete. For this experiment, water cement ratio was used based on volume method.

10.2.3 AGGREGATE

Aggregates are commonly thought as inert filler within a concrete mix. But a closer look reveals the major role and influence aggregate that plays in the properties of both fresh and hardened concrete. In this exploration, there are two types of aggregate used which are fine aggregate and coarse aggregate. The aggregate is sieved to make sure that the aggregate used is not exceed 20mm and fine aggregate is not more than 5mm.

10.2.4 ARTIFICIAL AGGREGATE PRODUCTION

The artificial aggregate that used in this research are Artificial Polyethylene Aggregate (APEA), Modified Artificial Polyethylene Aggregate (MAPEA) and New Modified Artificial Aggregate (NEMAPEA). The shape and physical view of the aggregate can be seen in Figure 1, Figure 2 and Figure 3. However, the investigation on mechanical properties of NEMAPEA is not included in this study. Basically, the surface texture of APEA is smooth and clean. However, based on previous research by [7], the APEA performed weak in bonding interaction with cement matrix. Thus, some modification had been made to produce rough and uneven surface. In order to improve its surface, APEA were coated with glass dust and cement. The sizes of the aggregates were in the range of 20 to 25 mm.



Figure 10.1: APEA has smooth surface texture



Figure 10.2: MAPEA has rough surface texture after coated by glass dust



Figure 10.3: NEMAPEA also has rough surface texture after coated by cement

10.2.5 ARTIFICIAL AGGREGATE PRODUCTION



Figure 10.4: The main material in production of APEA are from waste plastic bags

APEA was produced from waste Low Density Polythylene (LDPE) plastic as shows in Figure 10.4. The procedure and method to form the artificial aggregate or namely as APEA can be obtained in the following steps as illustrated in Figure 10.5 which the plastic bags made up manually by knotted and compacted it by hand with the help of something rod-shaped like a pen



Figure 10.5: Folded Plastice bag



Figure 10.6: Compacting of plastic bag in oven

After the process of knotting and compacting the plastic bags into aggregate-shaped. The Figure 10.6 shows process of heating in the oven at 180°C for 20 minutes to form the hard condition as normal aggregate.



Figure 10.7: APEA left out for 5 minutes

APEA left out for 5 minutes to cool it down and it slowly become hard like normal aggregate as shown in Figure 10.7. The left hand-side picture is APEA before the heating and the right hand-side picture was APEA after the heating.

10.2.6 MODIFIED ARTIFICIAL POLYTHYLENE AGGREGATE (MAPEA) AND NEW MODIFIED ARTIFICIAL POLYTHYLENE AGGREGATE (NEMAPEA)

The APEA went through modification by coated it with the glass dust. The purpose of this process is to ensure the APEA's surface become rough to increase the friction effect and bonding between the APEA and cement matrix. The smooth surface of APEA contributed to the poor bonding between the aggregate and cement.

The surface of APEA was coated by dust glass, where, the bonding agent that used to bond the glass dust and APEA is specific paint (refer Figure 10.8). This paint would contact and bond the glass dust and APEA perfectly and finally it can produce rough surface. The modification process on APEA has been produced new artificial aggregate namely as MAPEA as shown in Figure 10.9.



Figure 10.8: Paint used as bonding agent between glass dust and APEA



Figure 10.9: APEA coated by glass dust namely as MAPEA

Another production of new type of artificial aggregate is NEMAPEA. As compared to MAPEA, these aggregate namely as NEMAPEA was coated by cement mortar to improve its bonding interaction by providing rough surface of artificial aggregate, see Fig. 10.10. However, this process increase the weight of the aggregate by reducing the lightweight characteristic of the aggregate. In addition, the content of cement mortar

as coating materials will affect the mixture ratio. Due to this effect, the strength of the concrete mix containing NEMAPEA are not considered in this study



Figure 10.10: APEA coated by cement mortar namely as NEMAPEA

10.3 CONCRETE MIX PREPARATION

To examine the mechanical properties of the concrete mix containing different type of 100% artificial aggregates, eighteen (18) specimens were made in accordance to British Standard and Malaysia Standard. In this study, the specimens were casted using mold cylinder with size of 150 mm (diameter) x 300 mm (cylinder height). Then the specimens were cured for 28 days in the water until they reached the required age.

The constituents were used in different portions to define mixture proportions that would yield the strength at the test age of 28 days. The optimum mix proportions include cement, sand, coarse aggregate, artificial aggregate and water to yield a cubic meter of concrete. Table 10.3 and Table 10.4 show the sampling artificial aggregate in concrete mixes that were designed by the volumetric method with the same water cement ratio about 0.5.

Table 10.3: Quantities of material based on Volume Method for per 1m3 [7].

Sample	*Cement (Kg/M³)*	*Sand (Kg/M³)*	*Coarse Aggregate (Kg/M³)*	*Artificial Aggregate (Kg/M³)*	*Water (Kg/M³)*	*Mix Ratio*
NA	*380*	*665*	*1045*	-	*190*	*1:1.75:2.75*
APEA	*380*	*665*	-	*286*	*190*	*1:1.75:2.75*
MAPEA	*380*	*665*	-	*286*	*190*	*1:1.75:2.75*

NA = Normal Aggregate

Table 10.4: Quantities of material based on Volume Method for per trial mix of $5.3x10^{-3}$ m^3

Sample	*Cement (Kg/M³)*	*Sand (Kg/M³)*	*Coarse Aggregate (Kg/M³)*	*Artificial Aggregate (Kg/M³)*	*Water (Kg/M³)*
NA	2.014	3.530	5.540	-	1.012
APEA	2.014	3.530	-	1.520	1.012
MAPEA	2.014	3.530	-	1.520	1.012

NA = Normal Aggregate

10.4 RESULT AND DISCUSSION

10.4.1 PHYSICAL PROPERTIES - SPECIFIC GRAVITY AND WATER ABSORPTION

Water absorption of the different categories of artificial aggregates and normal aggregate were indicative of the proportions of water used in the concrete making procedure. The water absorption percentage of aggregates can be investigated through a test according to BS EN 1097-6: 2000. The results of the water absorption test were presented in Table 10.5. The water absorption of NA was higher than those of the three types of artificial aggregates. It can be seen that NA absorbed more water compared than others. In addition, the specific gravities of the APEA, MAPEA and NEMAPEA were 60% and 55% lower than that of NA, respectively, under the same condition.

Table 10.5: Specific gravity and water absorption

Properties (%)	*NA*	*APEA*	*MAPEA*	*NEMAPEA*
Specific gravity	2.58	1.02	1.14	1.33
Apparent specific gravity	2.89	1.02	1.15	1.32
Water absorption	2.79	0.89	1.25	1.41

NA = Normal Aggregate

10.4.2 MECHANICAL PROPERTIES – COMPRESSIVE STRENGTH AND SPLIT TENSILE STRENGTH

Figure 10.11 and Figure 10.12 illustrated the results of the concrete strength. The highest compressive and split tensile strength was observed for the concrete mix with 100% of normal aggregate compared to those two artificial aggregate. For compressive strength, 100% replacement of APEA has decreases about 67% strength of concrete as compared to normal concrete. Further, it can be also observed that 100% contents of MAPEA as a coarse aggregate has reduce the concrete strength about 58% from normal concrete strength. However, the strength increase for about 26% as compared to concrete containing APEA. Meanwhile, for the tensile strength results, the same pattern are also observed. The concrete mix containing 100% MAPEA decreases the strength about 49% from normal concrete, however, still produce higher strength as compared to concrete containing 100% APEA.

This happened due to the rough surface texture and the irregular shape of normal aggregate had strong bonding with concrete. The low strength of concrete containing APEA could be contributed to the weak bonding interaction between the artificial aggregates and the cement paste due to the smooth surface texture of APEA. Then, the rough surface coated by glass dust for MAPEA slightly increase the strength of concrete. This proved that APEA was not suitable to replace 100% normal aggregate in concrete due to the smooth surface.

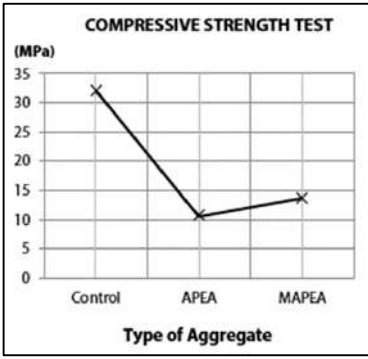


Figure 10.11: Compressive strength for different types of aggregate

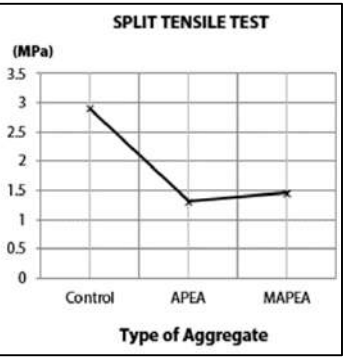


Figure 10.12: Tensile strength for different types of aggregate

10.4.3 MECHANICAL PROPERTIES – POISSON'S RATIO AND MODULUS OF ELASTICITY

Based on Figure 10.13, it can be seen that control sample had the lowest value of poisson's ratio. While, concrete containing MAPEA and APEA produce highest value. This result means that APEA concrete had the largest ratio of the proportional decrease in a lateral measurement to the proportional increase in length. Meanwhile, normal concrete gives the lowest value because it is not easily stretched, even under the high load. It is due to highest density of NA compare to artificial aggregate. Furthermore, the rough surface and irregular shape of NA produce strong bonding with cement and contribute high strength with low poisson's ratio value. On the other hand, smooth surface texture of the APEA causes it to easily detach and had poor bonding with concrete. That was why it easy to break and produce high strain even under low load.

Modulus of elasticity results can be seen in Fig. 10.14. The normal concrete achieved high modulus of elasticity about 36 GPa while APEA as the lowest value of Modulus of elasticity about 22 GPa. This is because the modulus of elasticity depends on the pore structure and the texture of the lightweight aggregate. Therefore, an aggregate with a dense structure and rough and irregular surface texture gives a higher

modulus of elasticity and stiffness than a smooth, clean and light aggregate. This is because the smooth surface of APEA weak on interlocking bonding with cement and resulting low young's modulus value. As compared to normal concrete, a much lower modulus of elasticity would be expected for lightweight concrete.

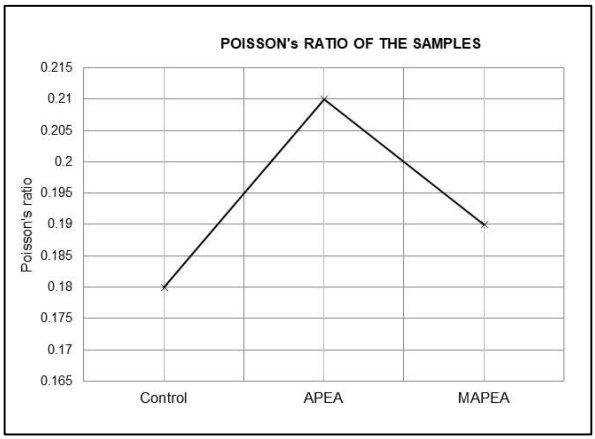


Figure 10.13: Poisson's ratio for concrete containing different type of aggregate

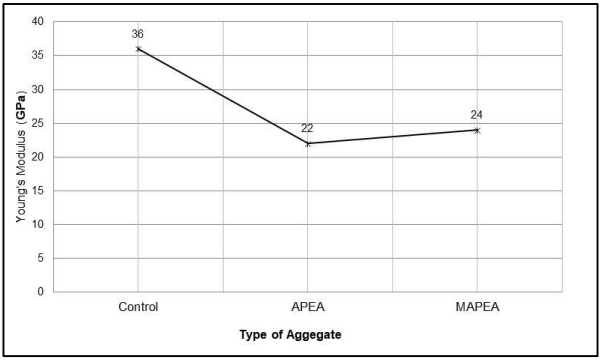


Figure 10.14: Young's Modulus for concrete containing different type of aggregate

10.4.4 SCANNING ELECTRON MICROSCOPE (SEM)

The surface of a concrete specimen containing APEA and MAPEA as a coarse aggregate were observed using Scanning Electron Microscope (SEM) in order to investigate its microstructure performance. In Fig. 10.15, APEA observed to be detached from the concrete and did not bond well with the concrete mixture. It can be concluded that APEA had the lowest strength compared to normal aggregate as well as MAPEA because it is easy to detach from concrete. Further, it can be easily crack under applied.

From Fig. 10.16, the micro crack of concrete containing MAPEA is small ranging from 45 µm to 77 µm and it can be proved that MAPEA bond well with concrete and not detached. This is the reason why MAPEA concrete higher strength compare to concrete containing APEA. The glass dust that coated the APEA has improved the bonding of the artificial aggregate and increases its strength.



Figure 10.15: Microstructure image of the APEA replaced as coarse aggregate in concrete

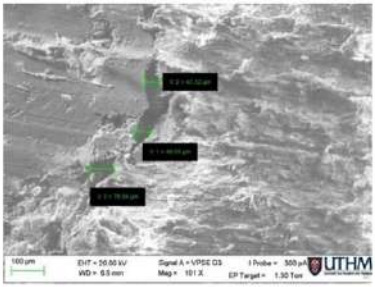


Figure 10.16: Microstructure image of the MAPEA replaced as coarse aggregate in concrete

10.5 CONCLUSION

Based on the results, some conclusion can be summarized as below.

1. The differences between the NA, APEA, MAPEA and NEMAPEA are the surface texture. The surface of APEA improved by the coating process can produce rougher and irregular in shape.
2. For specific gravity and water absorption results, it can be concluded that NA showed the highest percentage than others. This results proved that NA was the most dense material rather than APEA, MAPEA and NEMAPEA. However, the results of specific gravity for artificial aggregate that ranging from 1.02% to 1.33% still meet requirements for lightweight aggregates classification which generally up to a maximum of 2.4.For water absorption test, APEA does not absorb much water compared to the NA due to the properties of the plastic bag that unable to absorb water. However, NEMAPEA got the higher percentage than APEA and MAPEA. Thus, this could be confirmed that cement coating absorbed water well than glass dust coating.
3. Mechanical properties testing of compressive strength and tensile strength show the same trend of the result. Normal concrete produce highest strength under compression and tension zone. It can sustain high load capacity before the sample failed. Lowest strength are produced from concrete consists APEA, however, MAPEA in concrete mix show higher strength than APEA concrete. This happened due to the surface of the APEA smooth and makes it easily detached from concrete and weak interlocking bonding with cement compared to MAPEA.
4. Another mechanical properties test, the modulus of elasticity for lightweight aggregate was comparatively less than that for normal concrete. The value of modulus of elasticity of normal concrete still being the highest among the three samples. Besides that, for Poisson Ratio values, the trends of result were vice versa from other tests. This is due to the highest value belongs to APEA concrete. The ratio of 0.21 mean that the proportional decrease in a lateral measurement to the

proportional increase in length in a sample of APEA was elastically stretched when the load applied.

5. Overall, it can be summarized that APEA is the weakest aggregate. This could be proved by the microstructure image captured by the SEM for APEA sample. APEA could not bond well with the cement paste due to the presence of small gap between concrete and APEA. Further, smooth texture of the aggregate produced weak bonding interaction. The APEA easily detached from concrete and resulting in low strength when load applied. Meanwhile, the image of MAPEA illustrated that, there is small gap between the aggregate and cement matrix. Thus, it is confirmed that the aggregate surface for MAPEA produced good bonding with cement.

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