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Waste Paper Ash Pellets as Coarse Aggregate Replacement in Concrete

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Abstract: ***Coarse aggregate is the important constituents in normal concrete (NC) and can be divided into three categories, normal, light and heavy weight aggregate. These aggregates are categorised according to their weight, density and properties. The lightweight aggregate is utilised and essential to reduce the density of concrete because with low density will reduce the dead loads and handling cost. Waste paper ash aggregate (WPAA) is proposed and incorporated in NC as a one of the artificial aggregate type. WPAA has been produced to replace the natural coarse aggregate and due to the environmental impact that occurred from the mining of coarse aggregate. The environmental problem is including a noise and air pollution, landslide, soil contamination, groundwater contamination, loss of biodiversity and erosion. Additionally, the human population growth is produced an industrial waste ash and dust such as wood dust, fly ash and etc. With a lot of problems existed, WPAA is taken from the newspaper industry in ash and then designed with using the ratio of waste paper ash to water of 2:1. The ash is mixed, pelletised, dried and sintered in the oven for 1 day with 200^{0}C. The WPAA is replaced the coarse aggregate in concrete with various percentages by weight. The chemical, physical and mechanical properties of WPAA in concrete are investigated. Lastly, the result shown that the concrete mix with 2.0% replacement of WPAA by weight is illustrated a better compressive strength with a low cost production. WPAA in concrete is recommended to use in non-structural element, masonry industry or industrial building system component.***

Index Terms: ***Waste Paper Ash, Pellets, Coarse Aggregate Replacement, Concrete***

I. INTRODUCTION

Concrete with ingredient of sand, gravel, cement and water is most popular of construction material when compared with others construction material. Concrete with outstanding in versatility and availability is adjusted to propose the special concrete which can reduce cost of production and cost of material, and reduce the energy consumption. Furthermore, concrete with other advantages such as durable, strong, fire resistance and functional is being study broadly in development country. Concrete was divided into three types; there are mass concrete, lightweight concrete, high density concrete and polymer concrete.

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The increment of the waste product either from the industrial, agriculture, construction and residential which established a lot of problem in environment and also the cost of disposal and usage of big area for dumping. From the observation and study, the industrial and construction activity are generated a major waste product in Malaysia. Industrial waste that considered from manufacturing, processing, agriculture and oil and gas industry and factory contribute a large amount of waste. Generally, waste of construction activity is created from the rapid development of the country with constantly demanding of the building and houses. For the reason, a proper way and approach of handling the industrial waste is needed to reduce the negative impacts to the environment, social and economy. In Malaysia, the principle of sustainable waste management is introduced to balance the environment and social to the economy aspects through the concepts of 3R (reduce, recycle and reuse) of the waste. So, it is important for meeting the sustainable waste management principle by identifies the sources of waste and proposes the process for improving the waste management planning. Table 1 is illustrated the method of waste disposal by using several of technique in Malaysia.

Table 1: Method of waste product disposal in Malaysia [18]

Technique of disposal	Percentage of waste disposal (%)		
	2002	2006	Target 2020
Recycling	5	5.5	22
Composting	0	1	8
Incineration	0	0	16.8
Inert landfill	0	3.2	9.1
Sanitary landfill	5	30.9	44.1
Other disposal sites	90	59.4	0

Industrial waste materials are the important issue that must be managed with better plan and strategy for solving the environmental problem and impact. Reference [14] have recommended that the concrete technology can provide some ideas and solutions for recycle and reuse back as cement and aggregate replacement, and additives such as fly ash, silica fume and etc. Normally, the industrial waste materials are used as cement replacement and additives but there are not many study on aggregate replacement especially coarse aggregate. This is because the industrial waste materials with high of fineness is utilised in concrete without any treatment or throughout of additional process that could affected the cost and time of production. In Malaysia, the papermaking and wood pulping industries were disposed a large quantity of a waste paper ash (WPA) in sludge per day that dumping in landfill area. This landfill area was imposed an appreciable load and the lifetime of the facilities in the vicinity to be short (MNI, 1999).

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This practice also effect the environmental impact particularly air pollution and the amount of waste is continues to rise by increasing of paper production and growth of human population. Reference [23] have reported the waste product of paper recycling industry was produced when the process of dewatered waste paper sludge and a by-product of the de-inking and re-pulping of the paper. So, the problem that rise from the papermaking industry was solved by reuse the waste material, WPA as concrete ingredient replacement either cement or aggregate in concrete. There a lot of study on cement replacement but not for aggregate replacement. Finally, the WPA was taken as the aggregate replacement to avoid the problem involved in the papermaking industry.

Nevertheless, concrete with containing the coarse aggregate about 65-75% of total volume of concrete is influenced the hardening of cement and durability of hardened mass. Therefore, coarse aggregate can be reviewed and replaced by industrial waste material and reused back in the large quantity when compared with cement or fine aggregate replacement. Next, this can reduce the discharge of industrial waste material widely and the coarse aggregate replacement from industrial waste is known as lightweight aggregate. Lightweight aggregate was separated into two categories, natural lightweight aggregate such as volcanic ash or pumice, and artificial aggregate such as expanded shale or sintered pulverised-fuel ash [4]. Artificial aggregate is one of the lightweight aggregate that is become more popular at the moment. Reference [5] have mentioned coarse aggregate replacement with the lightweight aggregate is produced to reduce the deadweight of the structure and improved the thermal condition in building. Besides, they can utilise as loose fill material and backfill for pipe beddings material. Reference [14] has stated the artificial aggregate can be formed by processing of the industrial waste through cold forming pelletisation or by sintered. Additionally, by reducing the weight, the coarse aggregate replacement can save time, accumulate the expenses of manufacturing and handling and lastly can be thermal insulation performances of the entire building [4]. Besides, the use of the industrial waste as coarse aggregate can be a solution for the issues of the industrial waste disposal that created a lot of environmental impact and also can be reduced of natural or traditional material sources. The process of mining of the coarse aggregate from natural sources also can create a lot of problem such as pollution and landslide. Reference [12] have reported the utilisation of industrial waste in particular area especially construction activity is the way to diminish the emissions of greenhouse gases and enhance the sustainable development prospects.

Many researchers were studied about the artificial aggregate in mortar, concrete or special concrete. Normally the artificial aggregate was created from the industrial waste product that formed as aggregate by certain process of pelletising. Reference [7] have studied the fresh concrete properties of self-compacting concrete made by cold bonding pelletisation of 90% of fly ash and blended with 10% Portland cement by weight. Reference [11] have also studied the strength and permeability performance of self-compacting concrete with fly ash lightweight aggregate which formed by cold-bonded or process of pelletisation. Reference [8] have reported the relationship of shrinkage crack of lightweight concrete with cold-bonded fly ash aggregate properties such as physical, chemical and mechanical properties. Reference [20] have reported the study on fresh and hardened properties of concrete containing cold bonded of fly ash and quarry dust aggregates and also [21] have considered the waste material of fly ash and quarry dust as coarse aggregate replacement by cold-bonding method for testing of their mechanical properties under elevated temperature. Reference [10] have studied the washing aggregate sludge and sewage sludge that obtained from gravel pit and wastewater treatment plant, respectively as coarse aggregate replacement for checking their physical, chemical properties and strength development. Other example of waste product through the pelletising process was studied for instance water reservoir sediment [17], sewage sludge ash [3], Ground granulated blast furnace slag from iron industry [6], rice husk ash [2] and coal pond ash [22]. Occasionally, researchers were incorporated the artificial aggregate that processed by using fly ash with steel fibre in concrete production such as studied by [13]. From the study and observation, there is little study on the method of pelletisation process by using cold formed and bonded, and lastly sintered. But, all studies is not fully represented the direction and procedure in aggregate pelletisation process. Otherwise there is no information about the waste paper ash as the lightweight aggregate in normal concrete or special concrete. Besides, there are no information of design mix and also the testing procedure from the code or standard. Lastly, the main objective of this paper is to create the artificial aggregate by using WPA and determine the physical and mechanical properties of WPAA in concrete. The process of WPAA production is established to cater the problem involved in industrial waste and environmental impact.

II. MATERIALS AND METHODS

Table 2 is shown the mix design of the concrete with grade of 30 MPa. The WPAA was replaced the coarse aggregate in concrete by using weight in a percentage of 1.0%-4.0%. Mix 1 is known as controls mix which without WPAA and only utilised gravel with 100% proportion. The concrete that proposed in design mix is without any superplasticiser or additives. This is because the study was determined the strength and other properties of the WPAA in normal concrete without additional agent to provide the raw data and information of WPAA before further treatment. The small percentage of the WPAA was selected because the WPAA is predicted having a highly of water absorption. So, the study is utilised the WPAA which without any of surface coating to avoid the water absorption. From the design mix, the prediction of the water absorption of concrete could be discussed to check the reliable percentage WPAA without coating that produced the highest compressive strength of concrete.

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Table 2: Design mix with density of concrete ingredient

Concrete ingredient	Water	Cement	Sand	Gravel
Density (kg/m^3)	190	345	634	1230

Sand that be used for concreting work is size of below 5 mm and gravel with maximum size of 20 mm. Then, cement with type of composite Portland cement that follow the MS EN 197-1:2014 was used. WPAA was formed by a specific new procedure. The WPAA was tested for their physical properties and lastly replaced a coarse aggregate in concrete for mechanical properties testing. The difference of concrete mix with various percentage of the partially coarse aggregate replacement by using WPAA with 1.0%, 2.0%, 3.0% and 4.0% was tested for compressive strength. The workability test of the fresh concrete was tested.

WPA with the total mass of 94.32% was represented a particle size of the range of 150 µm to 2000 µm. The percentage of 1.17% and 2.22% was reported of WPA with the particle size of less 2000 µm and the range of 125-150 µm, respectively. WPA with a highest value of fineness when compared with the cement and sand was reported. Percentage of sand, gravel and quarry dust in range of a particle size with less 4.76mm to 0.075mm as reported by [1] is 99.8%, 0.01% and 98.45%, respectively. The comparison percentage of the WPA with the study of the [1] was noted to have 0.05 of sand, 99.99% of gravel and 1.40% of quarry dust. So, the WPA with the highest fineness was obtained the advantages and disadvantages if the WPA as cement replacement. The main advantage of the fineness cement replacement with highest of fineness is cement reaction in hydration. But, the disadvantage that been discussed briefly nowadays is about the water absorption and effect of the cement replacement with high of fineness. Therefore, the WPA was not suitable to utilise as cement replacement but the idea was shifted to produce the coarse aggregate replacement by pelletizing the coarse aggregate in concrete. The WPA was pelletized to become WPAA and tested their physical properties such as weight, water absorption and density.

A. Production of Waste Paper Ash Aggregate

Waste Paper Ash (WPA) was collected directly and cleaned from the waste paper industry. After that, the WPA was mixed with water in ratio of dust per water of 1:2. The water that used for the mixing is tap water without any chemical or treatment. Then, the WPA paste was pelletised by rounded shape in the size of 18 mm to 20 mm of diameter. WPA aggregate was dried in normal temperature for around two hours and after that, the WPA aggregate was sintered in oven with temperature of 200^{0}C for 24 hours for creating the rapid hardening of the pelletised. The production of the WPA aggregate was reported and established for the contractor and manufacturer as a reference and information as shown in Fig. 1. The process of production of the WPAA was sintered by referring to the study of [15] and being modified according to material and available apparatus. The example of the WPAA is illustrated in Fig. 2.

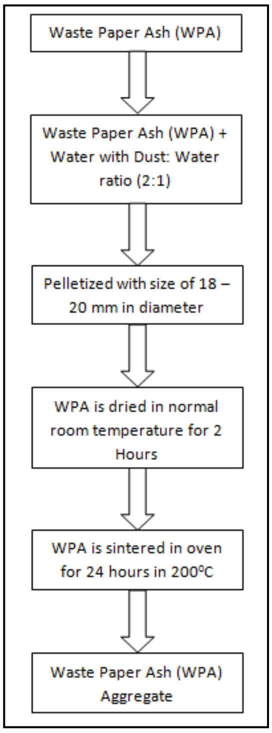

Fig. 1: The production of the waste paper ash aggregate (WPAA)

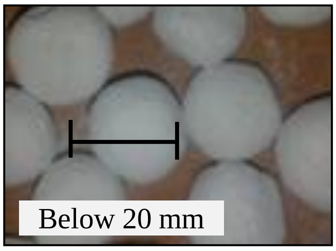

Fig.2: The size and shape of WPAA as coarse aggregate replacement

III. RESULT AND DISCUSSION

WPAA was tested their physical properties such as weight, water absorption, density and specific gravity and compared with other studied of normal coarse aggregate and artificial aggregate from previous study. The workability test of fresh concrete with replacing the coarse aggregate and the compressive strength of the hardened concrete with and without coarse aggregate replacement was experimented.

A. Physical Properties

The surface texture and shape of normal coarse aggregate and WPAA was observed. WPAA is rounded shape whereas the normal coarse aggregate is angular shape. The surface texture of the WPAA is more rough and dusty when compared with normal coarse aggregate. Besides, the WPAA surface also has the small pores around the surface but not for the normal coarse aggregate.

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Reference [19] have mentioned the rounded aggregate is able to assist the workability of concrete and use less of water in concrete mixing but they not provide a good bonding between the concrete ingredients. Physical properties of the WPAA were discussed and compares with other researchers study as tabulated in Table 3. The water

Table 3: The physical properties of the other researchers study

Physical properties	Reference [12]		Reference [16]		Reference [9]	
	Natural coarse aggregate	Fly ash aggregate	Natural coarse aggregate	Fly ash aggregate	Fly ash aggregate through cold-bonded process	Fly ash aggregate through sintered aggregate process
Water absorption (%)	0.5	21.1	0.8	25.5	16.39	1.75
Specific gravity	2.4	1.8	2.71	1.63	1.85	1.57

B. Workability Test

The workability test of the fresh concrete was tested by using slump test equipment which by measuring the height of slump. The height of slump was determined and classified the concrete under true slump condition with the range of slump of 40-60 mm. As a conclusion, the slump condition was decreased when increasing the amount of WPAA in concrete. Low workability of the concrete will affect the strength development and durability. Normally rounded aggregate will promote the better in workability because of less in surface area and voids when compared with normal coarse aggregate. But in the study, the rounded shape of WPAA was contributed a low of workability because of the high water absorption.

C. Compressive Strength

The compressive strength of concrete with WPAA and without WPAA was determined for 7 days and 28 days. The result of the compressive strength is shown in Fig. 3. All mixes were demonstrated to decrease when compared with control mix of Mix 1. Percentage different of 35.06% and 39.52% when distinguished between Mix 1 with Mix 3 and Mix 5, respectively. Mix 3 was observed to have a highest value of mature strength among of the concrete with WPAA and Mix 5 with 2% WPAA was evaluated having a highest of early strength. As conclusion, the concrete compressive strength becomes lowest when the amount WPAA was increased because of the high value of water absorption. Mix 3 and Mix 5 were recommended to be a favourable percentage of coarse aggregate replacement in concrete as indicating the practically and economically factor.

The relationship between the compressive strength with proportion of WPAA in concrete as shown in Fig. 4 was analysed and discussed. From the observation, there are showed difference of the line pattern between 3 days and 28 days. The 28 days line is more linear compared to the early strength (3 days). The result on the 3 days is showed

D. Ultrasonic pulse velocity test

absorption of WPAA and normal coarse aggregate was recorded to have 18.92% and 2.94%, respectively and percentage difference between these two aggregate is 84.46%. Then, if WPAA is compared with fly ash aggregate studied by [12], [16] and [9] through cold-bonded process were noted 10.33%, 25.80% and 13.37%, respectively.

inconsistencies and not linearly achieved, so the early strength of concrete with WPAA could not be a reference for further work. This is because the WPAA is not really react with fresh concrete and not performed into the strong bonding between concrete ingredients. However, after achieved mature or 28 days, the strength is showed the changes quite significantly to become linear relationship from 1% to 4% replacement of coarse aggregate. Thus, the value of 28 days more reliable when compared with the result of 3 days, manifested that the concrete is in mature condition and could be used for concreting. Here, the linear equation for 28 days is established as below;

Range of percentage of WPAA proportion, $1 \le w \le 4$

$$f_{cu} = -1.624w + 24.665 \quad (1)$$

Where, f_{cu} is compressive strength and w is proportion of WPAA

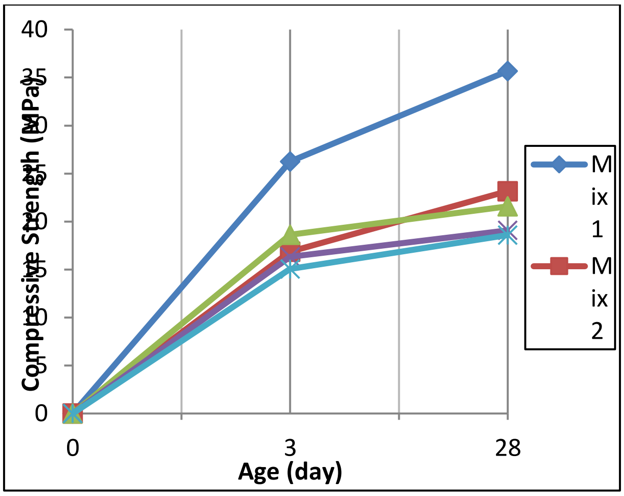

Fig. 3: The compressive strength of the concrete mix

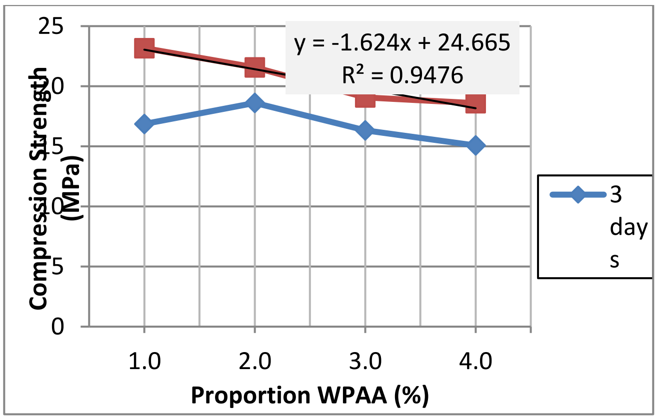

Fig. 4: The relationship of compressive strength of concrete mix with the proportion of WPAA

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The main purpose of the ultrasonic pulse velocity (UPV) test is to check the quality of the concrete without air void or crack and also to investigate the concrete integrity. The mix 1 and mix 5 was selected because the mix 5 with the highest content of WPAA compared to other mixes and mix 1 as normal mix. From the testing, the comparison study could be made to distinguish between mix 1 and mix 5. The result that be recorded is 5353 m/s of mix 1 and 4816 m/s of mix 5 and percentage difference between both mixes is 10.03%. As referred by [11], the concrete is categorised as excellent in quality if the UPV values is 4500 m/s and above. Therefore, mix with 4% WPAA in concrete is showed that the quality of the concrete still consistency, reliable and suited for replacing the coarse aggregate in concrete. The UPV is decreased with increasing the amount of usage of artificial aggregate in concrete and could be proven by the study of [24] and [11].

IV. CONCLUSION AND RECOMMENDATION

From the testing and comparison study, WPAA is recommended as a coarse aggregate replacement in concrete with some adjustment of the production by treating the surface of the WPAA to be smooth surface or resurface it by coating to avoid from the water absorption problem. Besides, the additives or superplasticiser can be utilised to maintain the amount of water in concrete and give a high value of workability and lastly the concrete become more flowable. By using the WPAA as a coarse aggregate replacement, the environmental impact can be solved and supported the sustainable management principle. Furthermore, WPAA can be classified as a low strength concrete that can be used as non structural element or masonry engineering product.

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