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The Application of Waste Marble as Coarse Aggregate in Concrete Production

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ABSTRACT

The massive growth of construction industry especially in the developing countries results in extensive quarrying activities which ultimately would lead to the depletion of natural resources. Apart from extensive extraction of the natural granite from the earth for concrete production, marble production industry is also majorly contributing to the quarrying activities. In addition, high volume of waste is generated by the marble production industry as 70% of marble is wasted during the production such as quarrying, cutting, processing and others which is environmental unfriendly. In a way to achieve sustainable construction, the present study is to utilise the waste marble in replacing the coarse aggregate in concrete production. The engineering performance including workability, compressive strength, ultrasonic pulse velocity (UPV) and chloride penetration were analysed. The raw waste marble obtained from the industry were crushed and sieved into maximum size 20 mm and used to replace the coarse aggregate at the level of 20%, 40%, 60%, 80% and 100% respectively. Results show that 60% of the replacement level has yield to optimum result by achieving the highest compressive strength and UPV at approximate 5% higher than the control. Meanwhile, the effect on chloride penetration resistance is more significant, i.e. approximate 19% better than the control. However, increasing the replacement level of waste marble has no significant effect on workability, although an increasing trend was observed.

Keywords: *waste marble, coarse aggregate replacement, concrete, environmental*

INTRODUCTION

Due to the continuous development, the quarrying activities are increasing to cater the demand of coarse aggregate for concrete production. Although the earth is rich in natural resources, the extensive and endlessly quarrying of coarse aggregate can cause depletion of available resources and ecological problems to the environment. Besides, marble production is not an environmental friendly activity. Approximately, 70% of marble were wasted during the production such as quarrying, processing and polishing [1]. Even though the waste marble is not hazardous, it destroys plants and causes pollution [2]. On the other hand, disposal of waste marble is not viable as it may reduce the permeability of soil and the fertility of soil will be affected as it increases its alkalinity [3]. Therefore, the aim of this study is to study the engineering performance of the crushed waste marble when use as coarse aggregate replacement in concrete production. This measure can be viewed as a sustainability measure as it reduces the solid waste disposal and slows down the pace of resources depletion.

Shirule *et al.* [4] and Vaidevi [5] reported that the replacement of cement with marble powder up to 10% by weight increase the compressive strength. Moreover, Aliabdo *et al.* [6] investigated in another study and found that 10% of cement replaced by marble dust enhances the mechanical properties of concrete. Nonetheless, the results show that 15% replacement of sand by marble dust is the optimum replacement level to provide the highest compressive strength. Another study reported by Corinaldesi *et al.* [7] shows that 10% replacement of fine sand by waste marble powder possessed higher compressive strength with similar workability properties. Hebhoub *et al.* [1] studied the use of waste marble aggregates as fine and coarse aggregate replacement materials in concrete. The study elucidates that the substitution of natural aggregates by waste marble is beneficial to the concrete performance. From the review on the current literatures, it is found that the majority of the studies are exploring on the effects of substituting the fine aggregate with waste marble. The crushed waste marble that acts as replacement material for coarse aggregate in concrete production is scarcely reported. Substituting the coarse aggregate could be more economically viable as the amount of energy and cost to spend on crushing the waste marble is greatly reduced.

EXPERIMENTAL PROGRAMME

In this study, the Portland composite cement manufactured by YTL Cement in accordance with BS EN 197-1:2000 [8] was used as the binder in concrete. Meanwhile, the filler part consist of natural granite as coarse aggregate and mining sand as fine aggregate in concrete. The waste marble was collected from Sri Martek Marble Industries Sdn. Bhd. in Perak, Malaysia. The waste marble was crushed to coarse aggregate size with not more than 20 mm. The crushed waste marble is shown in Figure 1 and the physical properties of the natural granite and crushed waste marble is shown in Table 1.

Figure 1: Crushed Waste Marble (source by author)

Table 1: Physical Properties of Coarse Aggregates Used

Physical Properties	Natural Granite	Crushed Waste Marble
Specific gravity	2.62	2.66
Fineness modulus	7.97	7.90
Average flakiness index (%)	18	13
Water absorption (%)	0.35	0.30
Moisture content (%)	0.15	0.05

In this study, conventional normal concrete was used as the control mixture and the replacement ratio of coarse aggregate is 20%, 40%, 60%, 80% and 100% while the water-to-cement (W/C) ratio was maintained at 0.4. The concrete mix design is summarised in Table 2. Several tests were carried out to assess engineering performance, including slump, compressive strength, ultrasonic pulse velocity, and chloride penetration. The slump test was performed in accordance with BS EN 12350-2 [9] while the compressive strength of concrete was tested up to 90 days in accordance with BS EN 12390-4 [10]. The ultrasonic pulse velocity (UPV) was carried out in accordance with BS EN 12504-4 [11] while chloride penetration depth were performed according to the method used by Guneyisi, Ozturan and Gesoglu [12]. The specimens for chloride penetration test were cured in normal water for 28 days and then immersed in 4% sodium chloride solution until the testing age. At the testing age, the cube specimen was cut into half and the freshly cut surfaces were then sprayed with 0.1 N silver nitrate solution.

Table 2: Crushed Waste Marble Concrete Mix Design

Mix	Cement (kg/m3)	Fine Aggregate (kg/m^3)	Natural Granite (kg/m^3)	Crushed Waste Marble (kg/m^3)	W/C ratio
CM	422	980	980	0	
M1	422	980	784	196	
M2	422	980	588	392	0.4
M3	422	980	392	588	
M4	422	980	196	784	
M5	422	980	0	980	

RESULTS AND DISCUSSION

Slump Test

Figure 2 shows the workability of all concrete mixtures. The result shows that the replacement level of crushed waste marble has no significant effect on workability as all of them were still categorised as medium slump. Besides, it shows that the workability is slightly increasing with the replacement ratio of crushed waste marble but this is contradicted with other researches [13-14]. This could be probably due to different sources of marble were used. However, from the flakiness index and water absorption data in Table 1, the values of crushed waste marble were slightly lower than the natural granite in both properties. These would contribute to better workability properties in fresh concrete [15].

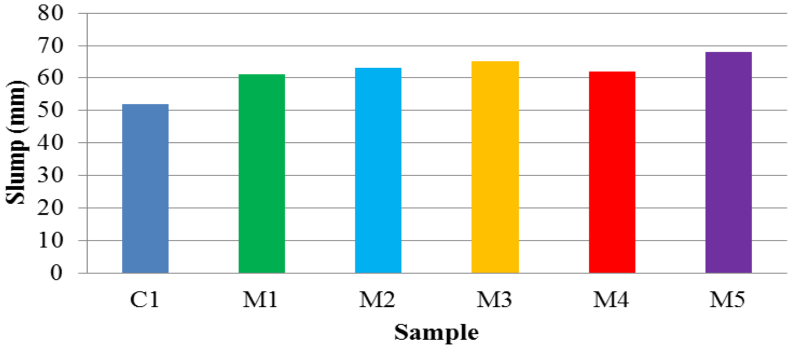

Figure 2: Slump Values of Various Specimen

Compressive Strength

The compressive strength of various concrete specimens was examined at 7, 14, 28 and 90 days. Figure 3 illustrates the strength development are similar in the control mixture (CM) and other mixtures containing crushed waste marble. This can be concluded that the replacement of crushed waste marble would not affect the strength development of concrete matrix. The result also shows concrete containing 60% crushed waste marble in the coarse aggregate (M3) obtained higher compressive than control mixture (CM). The recorded strength of the M3 at 90 days was 39.95 N/mm^2, approximate 5% higher than the control specimen. This could be explained that the more rounded crushed waste marble helped to create better particles formation in the concrete matrix and consequently it yields better bonding among the binder and filler which ultimately render a denser matrix [1].

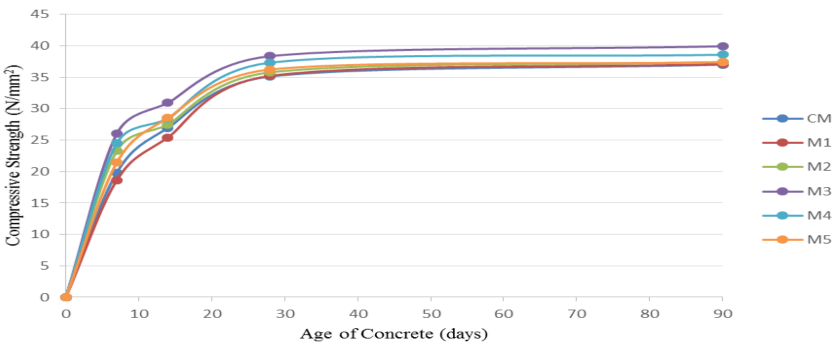

Figure 3: Compressive Strength of Specimens at Different Level of Marble Replacement

Ultrasonic Pulse Velocity (UPV)

Ultrasonic pulse velocity test is a non-destructive test that used for determination of the speed velocity of propagation of pulses of ultrasonic waves through hardened concrete. It can be used to determine the quality of the concrete in term of the amount of the voids or cracks presence in the concrete. The pulse velocities of concrete specimens are shown in Figure 4 and the results show that the concrete specimens' quality was excellent as the pulse velocities are above 4.5 km/h in accordance with the UPV assessment guidelines. Among all specimens, M3 is the best as it exhibits the highest value, i.e. 4.78 km/h. This is consistent with the compressive strength analysis where the M3 specimen has obtained the highest strength at all testing ages. Hence, it leads to a conclusion that M3 mix has produced better microstructure formation than the other specimens.

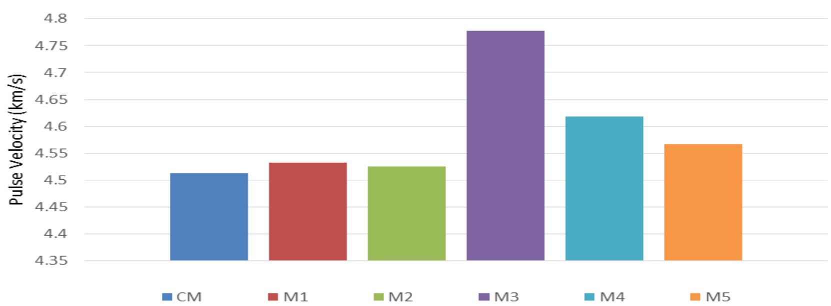

Figure 4: UPV Values of Various Specimen

Chloride Penetration Depth

The durability of the reinforced concrete depends on the capability of concrete cover to prevent the reinforcement from corrosion within the concrete. The corrosion of reinforcement in the concrete structure is the most common factors causing structure deterioration in the long term [12]. Hence, chloride penetration depth of the specimens was determined in this study. The chloride penetration depth was determined after immersion in 4% sodium chloride solution for 7, 14 and 28 days. M3 has the lowest chloride penetration depth at 28 days, i.e. 12.6 mm at approximate 19% lower than that of the control specimen. The better resistance against the chloride penetration could be due to better microstructure formation. Neville [15] explains that higher compressive strength is a result of lower porosity in the concrete matrix and this was also justified in the UPV test.

Table 4: Average Chloride Penetration Depth

Specimen	Average Chloride Penetration Depth (mm)		
	7 days	14 days	28 days
CM	9.6	11.4	15.5
M1	9.1	11.8	14.8
M2	9.0	11.4	15.6
M3	8.7	9.5	12.6
M4	9.3	11.4	15.2
M5	9.0	12.0	15.0

CONCLUSION

Based on the results and discussion, few conclusions are drawn as below:

i. The workability of concrete was not affected by the replacement of crushed waste marble and it gave slightly higher workability than normal concrete.

ii. The optimum mixture is the concrete with 60% replacement of crushed waste marble (M3) as it has the highest compressive strength compared to the other concrete mixes. Besides that, the strength development trend is in line with the conventional concrete.

iii. The quality of concrete specimens was excellent as the UPV values were above 4.5 km/h. Besides, M3 has the highest value which is 4.77 km/h, which indicates that it has lesser amount of voids and micro cracks.
iv. The concrete with 60% replacement of crushed waste marble (M3) has highest resistance against the chloride penetration as the penetration depth was 12.6 mm.

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