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Investigation on the effect of moisture induced damage on asphaltic concrete mix incorporating waste concrete aggregates

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Abstract. Recycling waste materials, such as partial replacement of WCA for natural aggregates in hot-mix asphalt, could be an option for addressing problems such as environmental pollution and the increasing demand for natural resources. Due to continual development and renovation in the construction industry, the generation of concrete waste has become one of the major challenges. Consequently, the purpose of this study was to develop an asphalt mix design utilizing waste concrete aggregate (WCA) as a partial substitute for natural aggregates (NA). The ratios of WCA10:NA90 and WCA30:NA70 are utilised to design the asphalt mixtures. In this study, asphalt mixtures containing 10 and 30 percent WCA are referred as WCA10 and WCA30, respectively. The density-voids analysis enables the determination of the optimum asphalt content that satisfies the criteria of the Malaysian Public Works Department (PWD). Results indicates that the criteria and design parameters of both mix conforms to the PWD specifications. The optimum asphalt content determined for both WCA10 and WCA30 asphalt mix is 5.7 and 5.8 percent respectively. The moisture sensitivity test is then performed on both WCA10 and WCA30 asphalt mixtures to determine how susceptible these mixtures are to moisture-induced damage. The tensile strength ratio (TSR) for WCA10 and WCA30 asphalt mixtures is 83.6 and 97.4 percent, respectively, which is greater than the minimal requirement of 80%. This investigation revealed that the use of WCA in hot-mix asphalt satisfies the moisture susceptibility requirements.

1. Introduction

One of Malaysia's most significant economic pillars continues to be the building sector, and Malaysia, like many other nations, is aggressively addressing the issues of environmental sustainability. Environmental contamination and the demand for natural resources by the construction sector are two current challenges. Construction and building activities are expected to utilise 40 percent of total energy and 50 percent of total natural resources. [1]. Concrete can be reused as recycled concrete aggregate, prepared through the crushing and grading of waste concrete, which can be wholly or partially used as a raw material in new concrete mixtures [2]. The construction industry generates approximately 900 million tonnes of building and demolition wastes. Concrete demolition waste constitutes about 65 to 75 percent concrete, mortars, ceramic bricks, tiles, and other materials that can be reused in the construction life cycle [3]. Recycling these waste products, such as using waste concrete aggregates, can help protect the environment and reduce the energy required for natural aggregates in the road construction industry. The concrete waste materials have equivalent geotechnical engineering properties to that of typical quarry granular materials [4]. However, further evaluation must be conducted to determine the general engineering properties and performance of the concrete waste materials. These concrete waste differ significantly from natural aggregate due to the cement mortar that is bonded to the surface of the aggregate, which causes higher water absorption, higher crushing characteristics, and microstructure of the interfacial zones [5]. On this basis, the overall properties of waste concrete aggregates are not as good as natural aggregates which may lead to poor engineering performances especially in pavement wearing course [6][7]. Waste concrete aggregates can be used in hot-mix asphalt as a partial replacement for natural aggregates to address these problems while maintaining environmental sustainability. The environmental objective is to reuse and recycle these materials which could generate beneficial economic activities with proper treatment [8].

The WCA can potentially replace NA in applications for asphalt pavement based on the findings from physical, mechanical, and chemical investigation [9]. In addition, the use of RCA in asphalt mix was comparable to that of traditional HMA mixtures, but the recycling and reuse of waste concrete aggregates offered better environmental advantages and possible cost savings [10]. Furthermore, previous research has shown that asphalt mixes including WCA are not prone to moisture-induced damage and are profitable, contributing to sustainable growth [11][12]. The main purpose of this study is to assess the feasibility of incorporating concrete waste aggregate (WCA) into an asphalt mixture. The asphaltic mixture volumetric properties are analysed to determine the Marshall properties and optimum bitumen content. The indirect tensile test is performed to evaluate the sensitivity of the asphalt mix at 10 and 30 percent WCA by weight of aggregate to moisture-induced damage.

2. Materials and Methodology

The materials used in this study comprise natural aggregate (NA) as well as waste concrete aggregate (WCA) from construction demolition, as shown in Figure 1. Initially, the demolition waste was crushed to a smaller size using a crusher jaw and then sieved to the required aggregate size based on the target gradation. The gradation of the WCA asphalt mix conforms to the requirements of the Public Works Department (PWD) specification, designed using the Marshall mix method. The physical properties of both aggregates and WCA are determined and presented in Table 1. Based on the LA abrasion loss test results, the percentage wear for natural aggregates was 22.4 percent, which is within the range defined by the AASHTO T 96. The flakiness and elongation indices are 7.5 and 22.2 percent, respectively, and results comply with MS 30. The percentage wear value obtained for recycled concrete aggregates was 67.4 percent, which was above the range. The AIV for WCA materials is 43.9 percent and 14.5 percent for NA materials, which indicates that WCA is weak for road surfacing. These results indicate that the overall properties of WCA are not as favorable as those of NA. The loss, however, can be compensated for by combining WCA and granite aggregates.

Figure 2 shows the aggregate gradation of the WCA asphalt mix is within the upper and lower gradation limits and meets PWD criteria [13]. The test and analytical parameters for asphalt mixes must satisfy the PWD criteria in order for the mix design to be accepted as tabulated in Table 2. In this study, asphalt mixtures containing 10 and 30 percent WCA are referred as WCA10 and WCA30, respectively.

Figure 1. Construction demolition waste

Table 1. Properties of WCA and Granite aggregate

Test	Aggregate	Results	Specification Limits
Los Angeles Abrasion Test	WCA	22.4	<25%
	Granite	67.3	
Aggregate impact value	WCA	43.9	>35% (Weak)
	Granite	14.5	10-20% (Strong)
Flakiness	WCA	7.5	<25%
	Granite	8.8	
Elongation	WCA	22.2	<35%
	Granite	34.1	

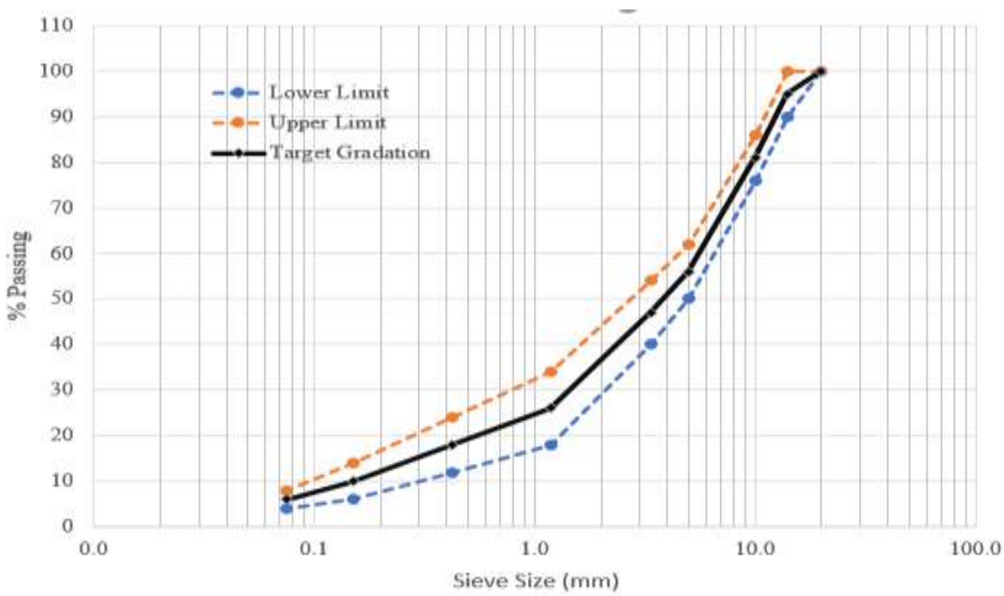

Figure 2. Aggregate gradation

The decrease of strength and durability caused by the presence of water is referred to as moisture susceptibility in asphalt mixes [14]. Understanding moisture susceptibility and assessing the performance of anti-stripping agents are essential for extending the lifespan of pavements. The moisture infiltrating the asphalt mix may cause detachment of the aggregates and weaken the binder adhesion under heavy traffic and elevated temperature conditions [15]. The WCA asphalt mixtures used in the Indirect Tensile Strength (ITS) test are evaluated for their moisture sensitivity and stripping resistance using the Modified Lottman test (AASHTO T283). In dry, room-temperature conditions, three compacted specimens were tested. Three additional specimens were saturated between 70 and 80 percent and conditioned for 24 hours in a 60°C water bath. The samples were removed after 24 hours and conditioned again at 25°C for two hours before testing. Tensile stress is obtained by placing the specimen between two loading strips that are vertical to the cylindrical diametrical plane, as shown in the schematic diagram in Figure 3. The ITS is calculated using the following equation:

$$ITS = \frac{2T}{\pi t d} \tag{1}$$

where,
T is the failure load (kN)
t is sample thickness (mm)
d is sample diameter (mm)

Table 2. Test and analysis parameters (PWD Specifications, 2008)

Parameter	Wearing Course
Stability, S	> 8000 N
Flow, F	2.0 - 4.0 mm
Stiffness, S/F	> 2000 N/mm
Air voids in the mix (VTM)	3.0 - 5.0%
Voids in aggregate filled in asphalt (VFA)	70 - 80%

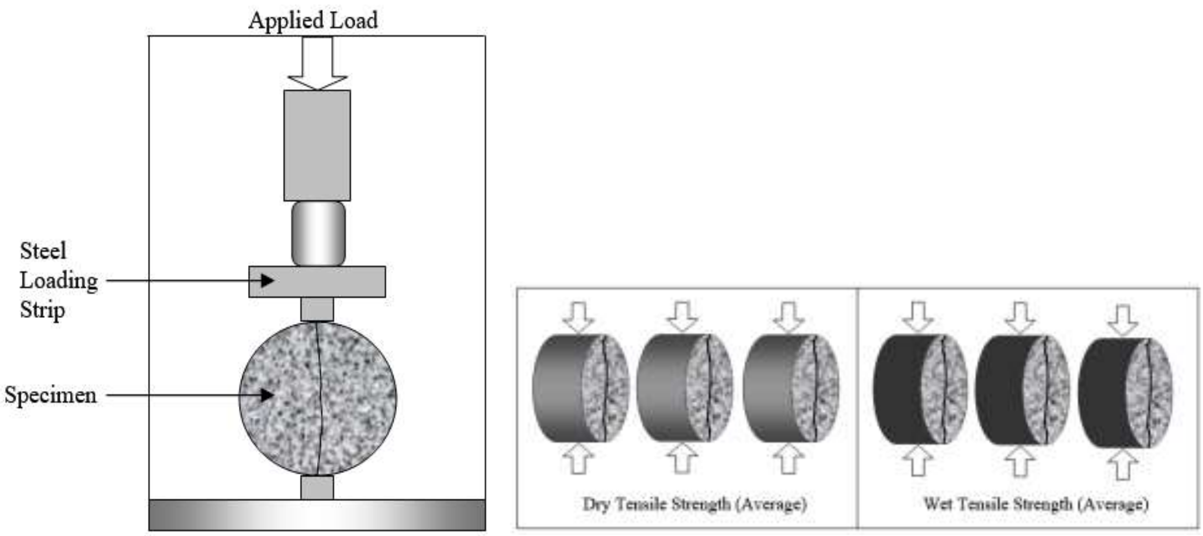

Figure 3. Schematic diagram of Indirect Tensile Strength test

3. Results and Discussion

3.1 Optimum Bitumen Content

The density-voids analysis of the asphalt mix is calculated to estimate the volumetric properties. All the specimens prepared at different bitumen content are also evaluated for the Marshall Stability and Flow values. These values are then plotted to determine the optimum asphalt content (OAC) of WCA10 and WCA30 mixtures. Figure 4 and Figure 5 presents the individual plots of the voids in total mix (VTM), void filled with asphalt (VFA), density, Marshall stability and flow graphs versus asphalt content for asphalt mix with WCA10 percent and WCA30 percent asphalt mixtures. The optimum asphalt content determined for both WCA10 and WCA30 asphalt mix is 5.7 and 5.8 percent respectively. The OAC for WCA30 mix is slightly higher than WCA10 due to the higher percentage of cement mortar. The Marshall properties of both WCA asphalt mixtures comply with the specifications and design parameter of Public Works Department, Malaysia as tabulated in Table 3.

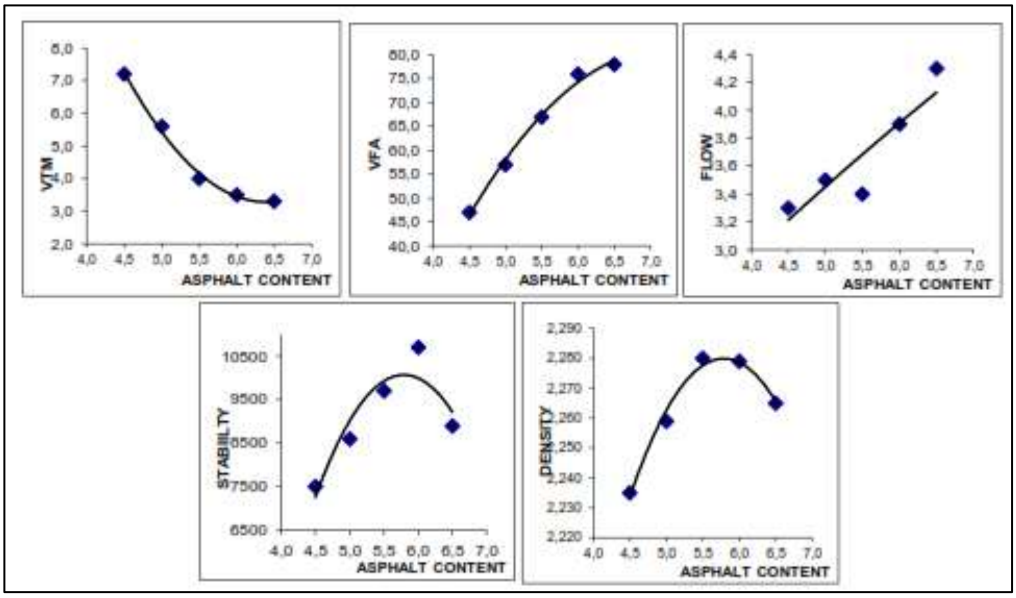

Figure 4. Marshall properties of WCA10 asphalt mix

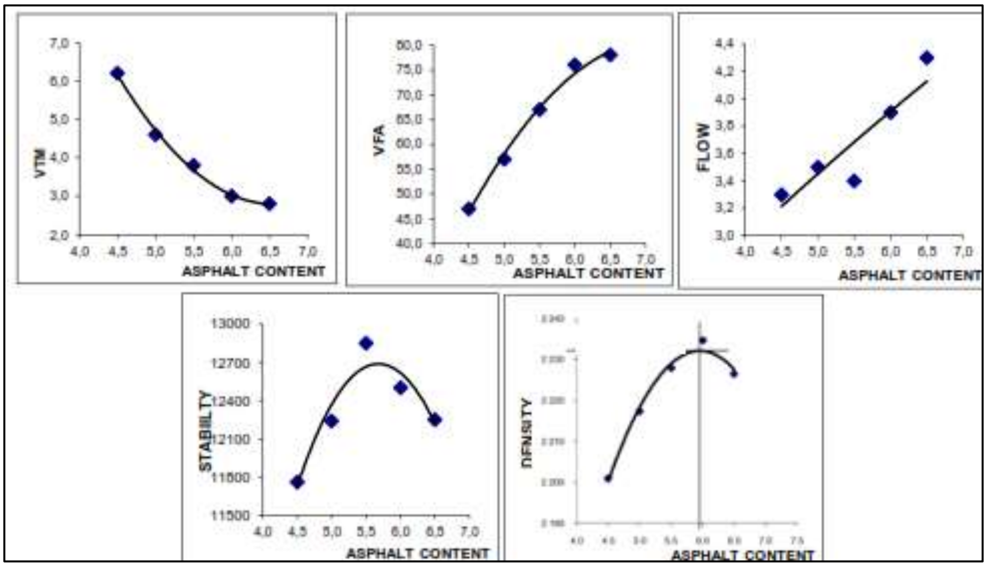

Figure 5. Marshall properties of WCA30 asphalt mix

Table 3. Criteria and design parameters (JKR/SPJ/2008)

Parameters	WCA10	WCA30	Criteria	Remarks
Voids in Total Mix (VTM)	3.9 %	3.4 %	3 % - 5 %	Comply
Void Filled Asphalt (VFA)	75 %	72 %	70 % - 80 %	Comply
Stability, S	10100 N	12700 N	>8000 N	Comply
Flow, F	3.9 mm	3.8 mm	2 - 4 mm	Comply

3.2 Moisture Susceptibility Test

Figure 6 presents the results of the ITS between wet and dry specimens for WCA10 and WCA30 asphalt mix. The tensile strength of the dry specimens of both asphalt mixture types is higher than the tensile strength of the saturated wet specimens, which is evident due to low load strength of the saturated specimens. From the ITS test, the tensile strength ratio (TSR) is determined by dividing the wet ITS values of the specimens by the dry ITS values, and it must be greater than 80 percent for the asphalt mixture to be considered not susceptible to moisture induced damage.

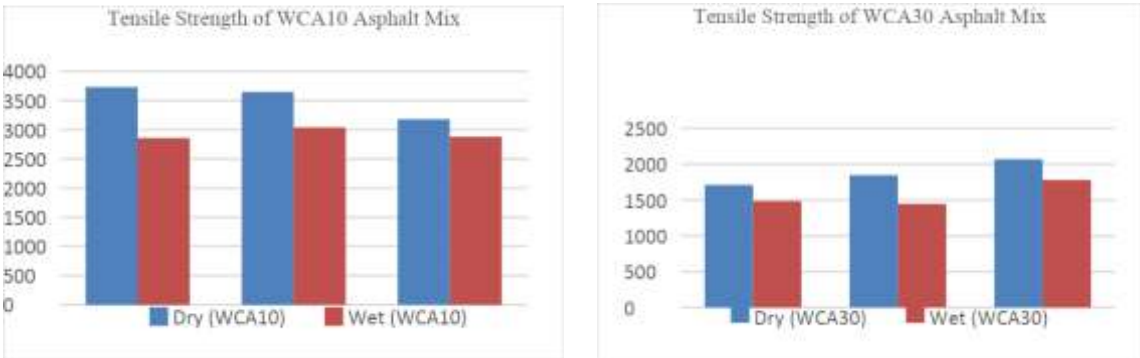

Figure 6. Indirect Tensile Strength of dry and wet specimens of WCA asphalt mix

Based on the above results, WCA10 asphalt mix has a stronger tensile strength than WCA30 asphalt mix in both dry and wet conditions. This is because the mix contains a higher percentage of WCA, resulting in higher mastic content in the asphalt mix, which adds to the lower strength. Figure 7 demonstrates that the tensile strength ratio obtained is 83.6 percent and 97.4 percent respectively, which is higher than the minimum requirement of 80 percent for both mix. This indicates that neither WCA asphalt mixture is susceptible to moisture-induced damage.

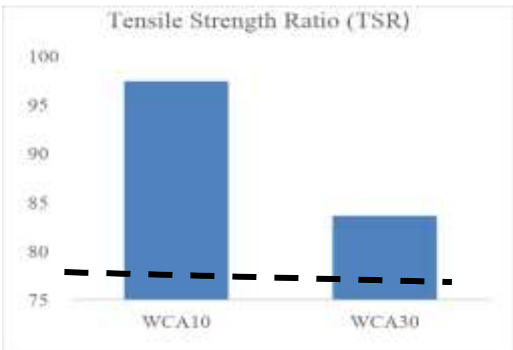

Figure 7. Tensile strength ratio of WCA asphalt mix

4. Conclusions

The WCA made from demolition waste has a significant potential for use in road construction, which promotes environmental sustainability. Waste concrete aggregates can be used with natural aggregate in an asphalt mixture. The findings of this study demonstrated that the use of waste concrete aggregates in HMA satisfies the Malaysian Public Works Department. Standard specification for road works. Both WCA10 and WCA30 asphalt mixtures are resistant to moisture-induced damage and satisfies the AASHTO T283 test requirement. Furthermore, recycling waste materials, such as replacing waste concrete aggregates with natural aggregates in hot-mix asphalt, may be an alternative to address concerns such as environmental pollution and the construction industry's increasing demand for new, unexplored natural resources. Utilizing waste concrete aggregates can also reduce the overall cost of road construction.

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