Effects of Temperature on Resilient Modulus of Dense Asphalt Mixtures Incorporating Steel Slag Subjected to Short Term Oven Ageing

Meor O. Hamzah, and Teoh C. Yi

Abstract**—**As the resources for naturally occurring aggregates diminished at an ever increasing rate, researchers are keen to utilize recycled materials in road construction in harmony with sustainable development. Steel slag, a waste product from the steel making industry, is one of the recycled materials reported to exhibit great potential to replace naturally occurring aggregates in asphalt mixtures. This paper presents the resilient modulus properties of steel slag asphalt mixtures subjected to short term oven ageing (STOA). The resilient modulus test was carried out to evaluate the stiffness of asphalt mixtures at 10ºC, 25ºC and 40ºC. Previous studies showed that stiffness changes in asphalt mixture played an important role in inflicting pavement distress particularly cracking and rutting that are common at low and high temperatures respectively. Temperature was found to significantly influence the resilient modulus of asphalt mixes. The resilient modulus of the asphalt specimens tested decreased by more than 90% when the test temperature increased from 10°C to 40°C.

Keywords**—**Granite, Resilient Modulus, Steel Slag, Temperature.

I. Introduction

THE road construction industry has been consuming naturally occurring aggregates for centuries. Nevertheless, the fast reducing amount of these materials and the ever increasing number of landfill used to dispose industrial waste prompted the road building industry to look for alternative environmentally friendly materials that are compatible or preferably exceeds the performance of naturally occurring aggregates in terms of performance. Steel slag was among the handfuls of waste materials that can be recycled as a construction material. It was stated that steel slag was used as road construction aggregate since decades and the research into the feasibility and suitability of steel slag as road construction materials intensified since the 1970's through studies across Europe and the United States [1], [2]. Recent years had seen researchers throughout Asia and Oceania joined the fray to unearth the potentials and enhance the performance of steel slag as a road construction material. Others reported that steel slag was previously found to perform to the satisfaction of road authorities across Europe, USA, Japan, Singapore and New Zealand [3], [4], [5].

Steel slag asphalt mixes, like the conventional asphalt mixes, unavoidably encounter aged-hardening due to oxidation of the bitumen. The bitumen in asphalt mixes hardens as a result of the ageing process, thus increasing the mix stiffness. The resilient modulus was found to increase after exposure to short term oven ageing (STOA) [6]. Hardening was said to primarily associated with loss of volatiles in asphalt during the construction phase, and progressive oxidation of the in-place material in the field [7]. Both factors caused an increase in viscosity of the asphalt and a consequent stiffening of the mixture. This might cause the mixture to become excessively hard and brittle and susceptible to disintegration and cracking failures.

To enhance the utilization of steel slag as aggregates in asphalt mixture, a proper mix design must be developed and a series of tests carried out to evaluate its performance. In this study, the resilient modulus test was carried out as one of the evaluation method to fulfill the objective of this study. The stiffness of bitumen was known to affect the characteristic of asphalt mixture which contributed towards its performance. It was indicated that the stiffness has also been used as an indicator of mixture quality for pavement and mixture design and to evaluate damage and aged hardening trends of bituminous mixtures in both laboratory and in-situ [8]. At low temperatures, mixes were exposed to increased stiffness and cracking potential. It was found that the resilient modulus of the specimens tested reduced by 85% when the test temperature increased from 25ºC to 40ºC [9].

II. Objective

The objective of this study is to evaluate the effects of temperature on the resilient modulus of dense asphalt mixes incorporating steel slag either fully or partially replacing natural granite aggregates and then subjected to STOA.

III. Materials

Granite and steel slag were used as aggregates while ordinary portland cement was used as filler. A conventional 80/100 penetration grade bitumen was used as binder.

IV. Mix Designation and Preparation

Two mix types designated as SSDA (asphalt mixture incorporating 100% steel slag as aggregates) and SSGDA

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(asphalt mixture incorporating 50% steel slag and 50% granite aggregates) were evaluated to fulfill the above objective. SSGDA is a modification from SSDA where aggregates finer than 3.35mm were replaced by granite aggregates. The aggregates were blended to conform to the Malaysian Public Works Department gradation for ACW14[10] as shown in Fig. 1. Batches of sufficient quantity for each specimen were later weighed and placed in a metal container in an oven set to the desired mixing temperature for at least four hours prior to mixing.

Blending of the dry aggregates was first carried out in an electrically heated paddle mixer for about half a minute. Then the required quantity of binder was added to the aggregates in the same mixer and then further blended for another minute. The loose mixes were then placed in a draft oven at 135ºC for four hours. This procedure simulates the short-term-ageing process of the asphalt mixes. The loose mixes were then removed from the oven and compacted using the gyratory compactor.

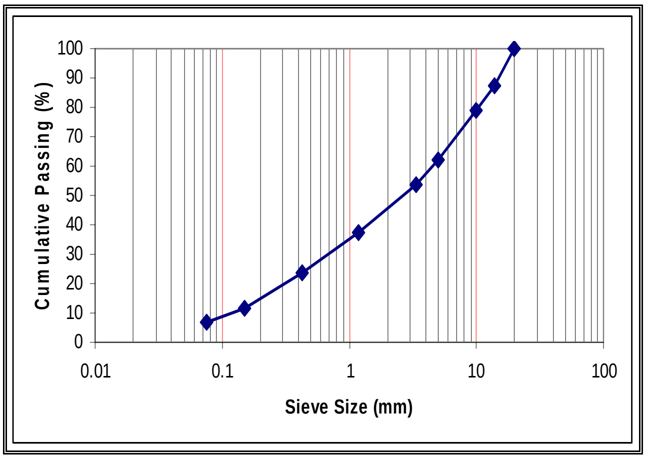

Fig. 1 Aggregate Gradation for SSDA and SSGDA Mixes

V. Test Method

The specimens were divided into three groups, each containing specimens mixed at 4.5% to 7.0% binder content at 0.5% interval. Each group of specimens was tested at 10ºC, 25ºC and 40ºC. In accordance with ASTM D 4123-82 (11), the specimens were conditioned at the selected test temperature for 4 hours prior to testing. Repeated haversine loads with a pulse width of 0.1 second and a pulse repetition period of 3 seconds was used in all resilient modulus testing in order to avoid impact loading to specimens.

VI. Result And Discussion

The test results for all unaged mixes are presented in Tables I and II.

TABLE I
Resilient Modulus of Unaged SSDA Mixes

Binder Content (%)	**Resilient Modulus (MPa)**		
	10ºC	**25°C**	**40°C**
5.0	5314.3	2657.3	612.3
5.5	7050.3	3306.0	767.0
6.0	6110.3	2461.8	537.0
6.5	4804.8	2217.8	511.8
7.0	3971.3	1744.0	409.5

TABLE II
Resilient Modulus of Unaged SSGDA Mixes

Binder Content (%)	Resilient Modulus (MPa)		
	10°C	25°C	40°C
5.0	3183.3	1519.3	345.3
5.5	4390.8	2069.3	419.5
6.0	3270.5	1525.0	375.5
6.5	3122.0	1439.0	331.8
7.0	2586.3	1243.8	296.5

A.. Effects of Binder Content on Resilient Modulus

The relationship between binder content and resilient modulus of aged SSDA and SSGDA specimens are presented in Figs. 2 and 3. Clearly, as the binder content increases, the resilient modulus of the specimens increase up to a maximum, then decreases as the binder content continue to increase. At 25°C, the maximum resilient modulus of aged SSDA and SSGDA mixes are achievable at 5.5% and 6.5% binder content respectively with SSDA and SSGDA mixes respectively recording a maximum value of 3179.5 MPa and 3073.3 MPa. Tests carried out at 10°C and 40°C result in similar trends.

As the bitumen content increases, the inter-aggregate adhesion improves as well and causes the recoverable strain to decrease. However, as the added binder increases beyond the maximum allowable binder content, the excess asphalt replaces the aggregate portion and bulk the mixture. This also causes the greater recoverable strain within the mixes and causes the resilient modulus to decrease.

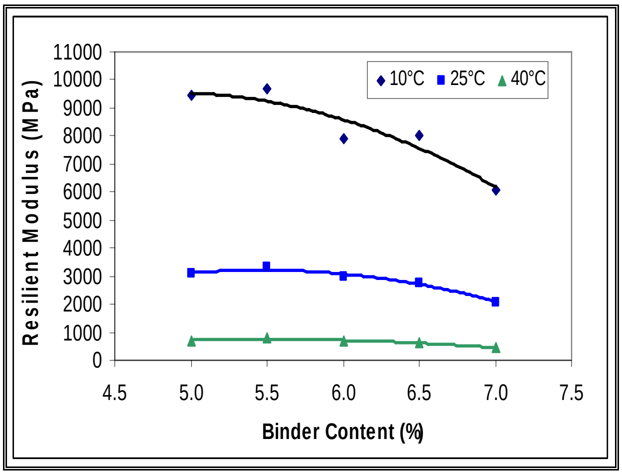

Fig. 2 Resilient Modulus of Short Term Oven Aged SSDA Mixes

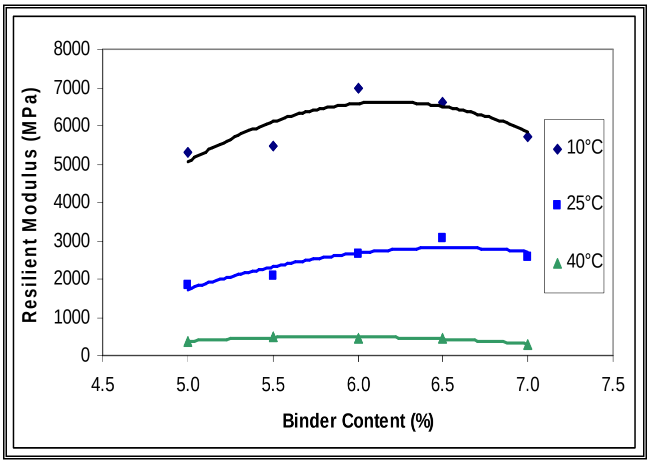

Fig. 3 Resilient Modulus of Short Term Oven Aged SSGDA Mixes

B. *Effects of Temperature on Resilient Modulus*

The resilient modulus versus temperature relationship of aged SSDA and SSGDA mixes at 6.0% binder content is presented in Fig. 4. The resilient modulus of aged SSDA specimens reduces by approximately 66% when the temperature increases from 10ºC to 25ºC. The resilient modulus eventually reduces by as much as 92% when the temperature further increases to 40ºC. The resilient modulus of SSGDA decreases by as much as 65% and 94% when tested under the same condition.

It was stated that bitumen becomes brittle at low temperature and the bituminous mix tended to crack at lower temperature [12]. When an asphalt concrete surface is cooled, stresses are induced in the asphaltic concrete. These stresses can be relieved by the flowing of the asphalt binder within the asphalt mixture. When the temperature increases, the viscosity of the binder decreases thus allowing it to flow within the mix and relieve the stresses. However, bitumen may loose its ability to bind the aggregates together at high temperature. Therefore, as the temperature increases, the recoverable strain needed increases as well resulting in lower resilient modulus.

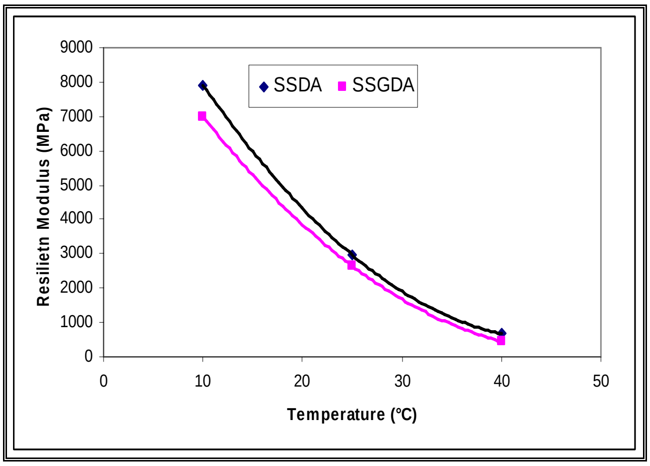

Fig. 4 Resilient Modulus of Short Term Oven Aged SSDA and SSGDA Mixes at 6.0% Binder Content

C. *Effects of Steel Slag Proportion*

In general, the resilient modulus of the mixes decreases when the aggregates below 3.35mm were replaced with granite. Fig. 4 also indicates that at 6.0% binder content, the resilient modulus of SSGDA mixes tested at 10°C, 25°C and 40°C are 11.9%, 10.9% and 32.0% lower respectively when compared to the resilient modulus of SSDA mixes tested at through similar procedures. This indicates that the combination of steel slag and granite as aggregates appears to provide higher flexibility to an asphalt mix compared to the utilization of 100% steel slag.

It was suggested that the susceptibility towards ageing is aggregate dependent [13]. This is in conformity with the findings of this study. The results indicate that SSDA mixes incorporating 100% steel slag is less susceptible towards SSGDA which incorporated 50% granite aggregates. Besides, the percentage change in resilient modulus increases when 50% of the steel slag aggregates were replaced by granite aggregates in STOA mixes. The resilient modulus of SSDA increases between 4% and 25% at 25ºC, and 6% to 24% at 40ºC. The resilient modulus of SSGDA on the other hand increases within a range from 6% to 114% at 25ºC, and 9% to 37% at 40ºC. A hypothesis was suggested [13] indicating that the greater the adhesion, the greater the mitigation of ageing thus inferring that aged SSDA mixes exhibit superior adhesion compared to aged SSGDA mixes.

D. *Effects of Short Term Oven Ageing*

Figs. 5 and 6 graphically presented the relationship between resilient modulus and binder content of unaged and STOA SSDA and SSGDA mixes at 10°C. The resilient modulus of SSDA and SSGDA specimens increase when tested on specimens subjected to STOA. The increasing resilient modulus, as graphically illustrated in Figs. 5 and 6, is more likely due to contribution by binder hardening causing mix to stiffen. At 6.0% binder content and 10°C test temperature, the resilient modulus of SSDA increases by almost 30% while the corresponding value for SSGDA mixes is 114% as a consequence of STOA. Figs. 7 and 8 on the other hand presented a graphical illustration of the resilient modulus versus temperature relationship of unaged and STOA mixes. At 25°C and 40°C respectively, the resilient modulus of SSDA mixes increase by 21% and 24% after STOA while SSGDA mixes exhibit increment of 73% and 20% at 25ºC and 40ºC respectively.

Ageing process causes oxidation and increases the hardening rate of the bitumen, thus resulting in the increasing resilient modulus. It was stated [14] that as the bitumen and the mix become stiffer, the stresses on the underlying layers of pavement were reduced. Regular deflection surveys showed that deflections on heavily trafficked motorways remain relatively constant or, more often, decrease steadily with time, thus increasing the service life span of the pavement. However, age-hardening on the other hand may cause embrittlement and increases the cracking potential of the mixes, especially at low temperature.

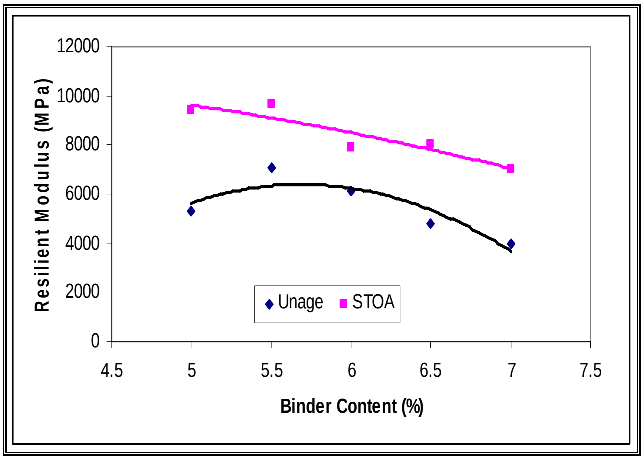

Fig. 5 Resilient Modulus at 10ºC of Unaged and Short Term Oven Aged SSDA Mixes

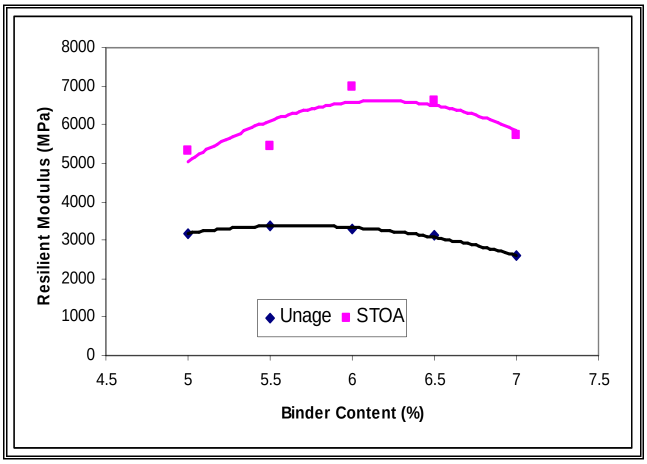

Fig. 6 Resilient Modulus at 10ºC of Unaged and Short Term Oven Aged SSGDA Mixes

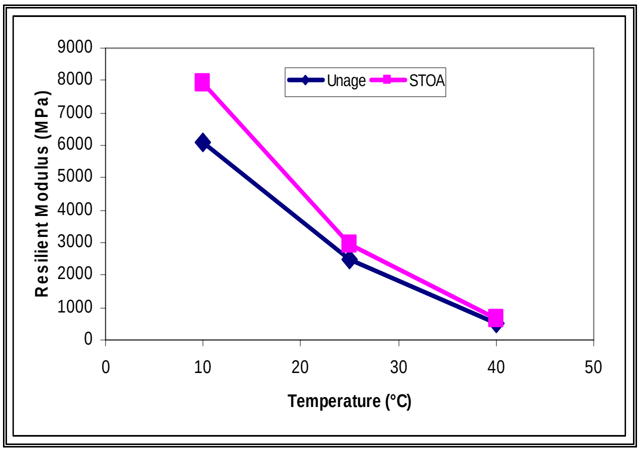

Fig. 7 Resilient Modulus at 10ºC of Unaged and Short Term Oven Aged SSDA Mixes at 6.0% Binder Content

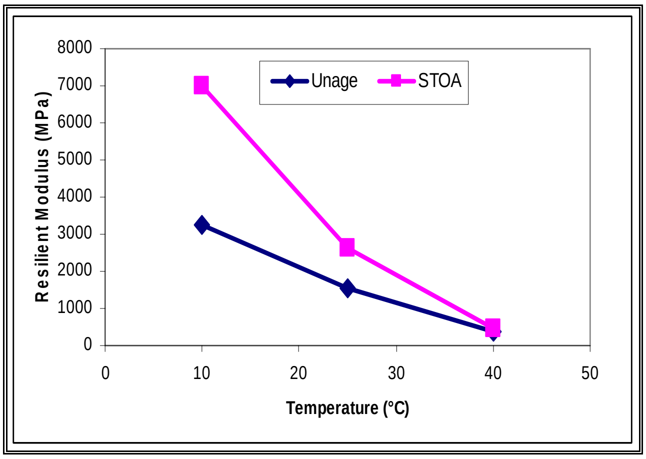

Fig. 8 Resilient Modulus at 10ºC of Unaged and Short Term Oven Aged SSGDA Mixes at 6.0% Binder Content

VII. Conclusion

1) The findings in this study indicated the potential of steel slag to be used as full or partial replacement to naturally occurring granite aggregates in asphalt mixes.
2) The resilient modulus of SSDA and SSGDA increases after STOA due to oxidation of the binder.
3) In general, the resilient modulus of SSDA mixes before and after ageing is higher than SSGDA mixes. However, higher ageing susceptibility is exhibited by SSGDA mixes compared to SSDA mixes.
4) The resilient modulus of SSDA and SSGDA are both sensitive to temperature change. The resilient modulus of SSDA and SSGDA decreases by as much as 90% when the temperature increases from 10°C to 40°C.

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