Correlation for Determining Elastic Modulus of Asphalt Concrete Mixtures Blended with Void Fillers using Timoshenko and Hondro's Models.

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Abstract: Having a safe and durable pavement, that will satisfy demands of irregular traffic loading and various frequencies, plus temperatures variances and oxidation problems resulting from moisture intrusions has been a long time natural malady. Thus, the need for pavement modification, proper characterization of pavement materials such that design properties shall not be compromised within service life is critical. The problem however is that one of the major input parameters in design of flexible pavements-elastic modulus as proposed by various researchers and agencies always have variations in their results, and seemed not to converge. On this basis, the present study sought to develop models that will satisfy the correlation for determining elastic modulus of asphalt concrete mixtures blended with void fillers using Timoshenko and Hondro's Models. The methodology involved determining mechanical and elastic properties of modified Asphalt concretes using waste granite dust and white cement from indirect tensile splitting test. The results obtained showed that the addition of waste granite dust up to 20% by weight of the mix produced better performance with respect to elastic properties of the concrete. Similarly, the addition of white cement up to 10% by weight of the mix produced better performance with respect to elastic properties of the concrete. Finally, the correlation between elastic modulus determined from Timoshenko and Hondro's models for the modified asphalt concretes produced R values of 0.976 and 0.836 for waste granite dust and white cement modifications respectively.

Index Terms: Correlation, waste granite dust, white cement, asphalt concrete modified, mechanical and elastic properties, Quadratic Polynomial, Linear Regression.

1.0 INTRODUCTION

Flexible pavements which are major infrastructural component in most developed nations is a special type of concrete binder having different structural layers. These different layers work as a single, conglomerate strata to satisfy the demands of irregular traffic loading and environmental conditions, such as temperature, oxidation and moisture, (Igwe, et al., 2009).

Thus, proper evaluation of the performance and behavior of the asphalt concrete when modified with mineral fillers become imperative; Hence performance model of asphalt concrete provides the required link among various processes associated with asphalt mix design, pavement structure design, construction and rehabilitation. These properties of asphalt mixtures are very complicated and sometimes difficult to predict (You, 2003; You and Buttlar, 2004; Xiao et al 2007; Xiao et al 2011). However, these properties of its constituents are relatively less complicated and easier to characterize individually.

Therefore, if the microstructure of asphalt mix can be obtained, its properties can be evaluated from the properties of its constituents and microstructure (Wang et al, 2004; Xiao et al., 2006). Thus proper characterization of pavement materials such that design properties shall not be compromised within service life became critical. The problem however is that one of the major input parameters in design of flexible Parameter (elastic Modules) as proposed by various researchers and agencies always have variations in their results, either underestimate or overestimate the design parameters. Hence this study is aim at correlating and determining elastic modulus of asphalt concrete mixtures blended with void fillers using Timoshenko and Hondro's models.

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2.0 Materials and Methods

2.1 Material Sampling

The materials used for the preparation of the asphalt concrete simulating actual flexible pavement under investigation in this study were collected from different sources. The coarse and fine aggregate were both obtained from commercial source within Port Harcourt.

The bitumen used was sourced from Mobil Oil Producing Nigeria Plc. The modifiers used: waste granite dust (WGD) obtained from MCC Nigeria Limited, Ikwerre road and white cement obtained directly from the market dealers at mile 3, Diobu Port Harcourt, Nigeria.

2.2 Laboratory Tests

The materials were prepared using Marshall mix design procedure (Asphalt Institute, 1956). The procedure entailed the preparation of series of test specimens for a range of bitumen contents such that data curves showed well defined optimum values. For each binder proportion ranging of 5%- 25% at increment of 5%, two specimens were prepared to provide adequate data. Approximately 1200g of aggregate and asphalt binder put together and heated to a temperature of 160^0c – 170^0c.

The heated aggregate and bitumen were thoroughly mixed at that temperature. The mix is placed in a preheated mould and compacted with a hammer of weight 6.5kg, falling freely from a height of 450mm giving 75 blows on either side to compact the specimen to a thickness of 63.5+3mm.

2.3 Sample Preparation

Compacted specimens were subjected to bulk specific gravity test, stability and flow, density and voids analysis at that given temperature. The results obtained were used to determine optimum asphalt content of the unmodified asphalt concrete. Waste granite dust (WGD) and white cement (WC) which are non-hazardous secondary materials, finely divided mineral matter passing through B.S. No. 200 mesh or 75μm sieve size were then added on fillers at varying amount (5%-25%) by weight of the asphalt at optimum Asphalt content. Then the modified samples were subjected to the indirect split test and the result obtained were imputed into Timoshenko and Hondro's model to obtain the Mechanical and Elastic properties both in tension and compression.

2.4 Model Used

2.4.1 Mechanical Properties

i. Tensile Strength σ_t

For Solid Cylinder

$$\sigma_t = \frac{2p}{\pi td} \qquad (2.1)$$

ii. Compressive Strength σ_c

For Solid Cylinder

$$\sigma_c = \frac{-6p}{\pi td} \qquad (2.2)$$

2.4.2 Elastic Properties

A. Timoshenko and Goodier, 1951 models

i. Elastic Modulus in Tension, E_t

For Solid Cylinder

$$E_t = \frac{1}{\varepsilon_t}(\sigma_t - \mu\sigma_c) \qquad (2.3)$$

ii. Elastic Modulus in Compression, E_c

For Solid Cylinder

$$E_c = \frac{1}{\varepsilon_c}(\sigma_c - \mu\sigma_t) \qquad (2.4)$$

iii. Poisson's Ratio

$$\mu = \frac{\varepsilon_t}{\varepsilon_c} \qquad (2.5)$$

Where;

E_t and E_c = Elastic modulus in tension and compression respectively (N/mm^2)

ε_t and ε_c = Tensile and compressive strain respectively

σ_t = Horizontal tensile stress (N/mm^2)

σ_c = Vertical compressive stress (N/mm^2)

μ = Poisson's ratio

P = Load of failure

t = Thickness of specimen

d = Diameter of specimen

B. Elastic Properties using Hondro's Model (Hondro's, 1959)

i. Elastic Modulus in Tension, E_t

$$E_t = \frac{8w}{\pi R^2 (3\varepsilon_t + \varepsilon_c)} \quad (2.6)$$

ii. Elastic Modulus in Compression, E_c

$$E_c = \frac{8w}{\pi R^2 (3\varepsilon_t + \varepsilon_c)} \quad (2.7)$$

iii. Poisson's Ratio:

$$\mu = \frac{3\varepsilon_t + \varepsilon_c}{3\varepsilon_c + \varepsilon_t} \quad (2.8)$$

Where;

E_t and E_c = Elastic modulus in tension and compression respectively (N/mm^2)

W = Load of failure

ε_x = Horizontal tensile strain

ε_y = Vertical compressive strain

R = Radius of sample (mm)

μ = Poisson's ratio

3.0 Results (Tables and Figures)

Table 1:
Laboratory Test Results of Material Classification

Material	Waste Granite Dust (WGD)	White Cement (WC)	Asphalt	Sand	Gravel
Specific Gravity	2.75	2.94	1.02	2.51	2.93
Grade of Binder Material			60/70		
Mix Proportion %				62	38
Viscosity of Binder (seconds)			69.3		
Softening Point			49.5		
Penetration Value (mm)			66.7		

Table 2
Elastic Properties of Asphalt Concrete-Timoshenko (*White Cement*)

White Cement (%)	Failure Load (kN)	Poisson Ratio (μ)	Tensile Modulus (N/mm^2)	Compressive Modulus (N/mm^2)
0	11.6	0.46	247	152
5	15.59	0.40	393	156
10	17.05	0.40	415	170
15	15.85	0.40	404	161
20	10.67	0.40	397	154
25	10.54	0.40	330	128

Table 3
Elastic Properties of Asphalt Concrete-Hondros' (*White Cement*)

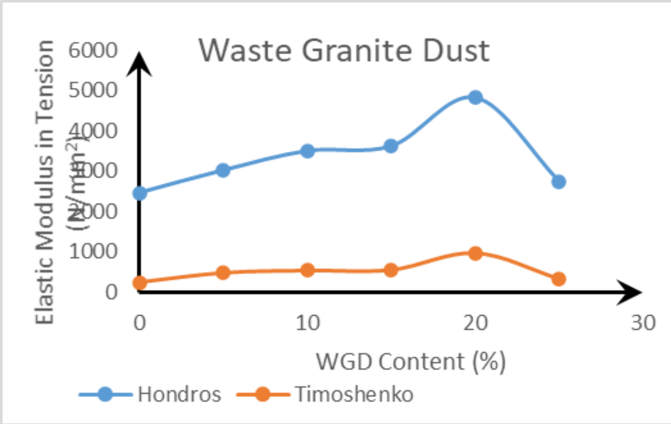
White Cement (%)	Failure Load (kN)	Poisson Ratio (μ)	Tensile Modulus (N/mm^2)	Compressive Modulus (N/mm^2)
0	11.6	0.46	2470	1700
5	15.59	0.40	5370	8300
10	17.05	0.40	5670	8800
15	15.85	0.40	5530	8500
20	10.67	0.40	5430	8400
25	10.54	0.40	4510	7000

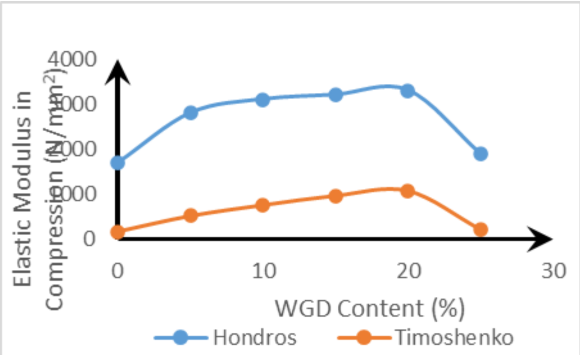
Table 4
Elastic Properties of Asphalt Concrete-Timoshenko (*Waste Granite Dust*)

Waste Granite Dust (%)	Failure Load (kN)	Poisson Ratio (μ)	Tensile Modulus (N/mm^2)	Compressive Modulus (N/mm^2)
0	11.6	0.46	247	170
5	17.9	0.45	484	320
10	19.9	0.45	542	360
15	20.15	0.46	557	370
20	20.6	0.45	580	380
25	11.55	0.45	330	220

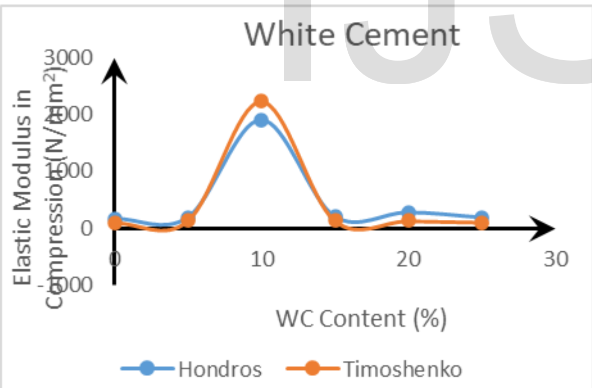
Table 5
Elastic Properties of Asphalt Concrete-Hondros' Moduli (*Waste Granite Dust*)

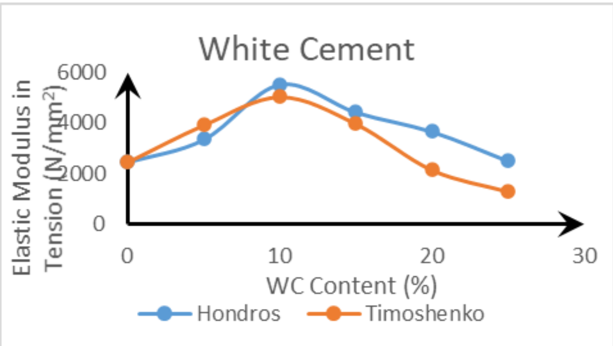
Waste Granite Dust (%)	Failure Load (kN)	Poisson Ratio (μ)	Tensile Modulus (N/mm^2)	Compressive Modulus (N/mm^2)
0	11.6	0.46	2470	1700
5	17.9	0.45	4030	2800
10	19.9	0.45	4510	3100
15	20.15	0.46	4630	3200
20	20.6	0.45	4830	3300
25	11.55	0.45	2750	1900





Figures 1: Graph of Elastic Modulus in Tension and Compression for Waste Granite Dust





Figures 2: Graph of Strain in Tension and Compression for White Cement

4.0 Developing a Model Fit between Timoshenko and Hondro's Model

The correlation models were anchored on testing a non-linear model that can be best used to describe the model fit between Timoshenko and Hondro's models. The models used in testing the correlation includes;

4.0.1 Quadratic Polynomial Model

- **Correlation between Timoshenko and Hondros' Model for Elastic Modulus for Waste Granite Dust (WGD) Modified Hot Mix Asphalt Concrete.**

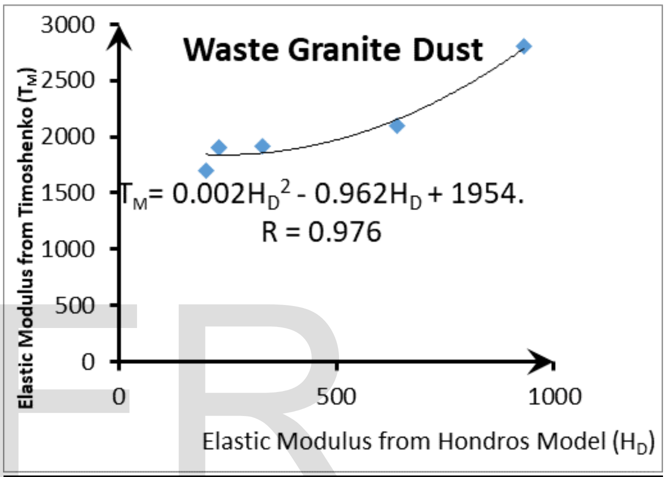


Figure 3: Elastic Modulus Correlation between T_M and H_D Waste Granite Dust

From figure 3, the results of correlation between Timoshenko and Hondros model for elastic modulus for Waste Granite Dust (WGD) shows a Quadratic relationship with an R-value of 0.976.

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4.0.2 Linear Regression Model

- **Correlation between Timoshenko and Hondros' Model for Elastic Modulus for White Cement (WC) Modified Hot Mix Asphalt Concrete.**

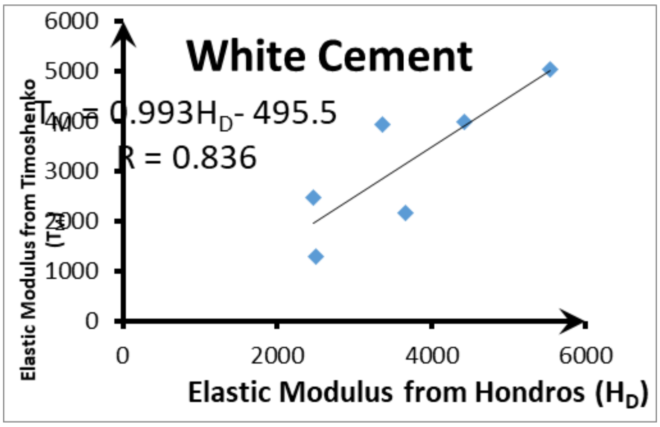

Figure 4: Elastic Modulus Correlation between T_M and H_D White Cement

From figure 4, the results of correlation between Timoshenko and Hondros model for Elastic modulus for White Cement (WC) shows a linear relationship with an R-value of 0.836.

Where;
Tm = Timoshenko model, H_D = Hondro's model

5.0 Discussion of Result

5.0.1 Elastic Properties in Tension and Compression Waste Granite Dust

As illustrated figure 1 above tensile modulus of the asphalt concrete mix for both Timoshenko and Hondro's model showed almost identical set of values for waste granite dust (WGD) contents in tension and compression. Tensile modulus increased by 49% from 247 x 10^4N/mm^2 for the control sample, to 484 x 10^4N/mm^2 at 5% Waste granite dust (WGD) content. This value further increased by 10.7% to 542 x 10^4N/mm^2 at 10% WGD content; by 2.7% to 557 x 10^4 N/mm^2 at 15% waste granite dust (WGD) content; by 4% to 580 x 10^4N/mm^2 at 20% waste granite dust (WGD) content where it peaked. However, the value of tensile modulus dropped by 75% to 330 x 10^4 N/mm^2 at 25% Waste granite dust (WGD) content, indicating that further addition of Waste granite dust (WGD) filler would cause a corresponding decrease in the value of elastic modulus of the mix. It is instructive to note that, the behaviour of waste granite dust (WGD) content in terms of its moduli properties for tension and compression are similar. Which maximizes at 20% filler content, indicating that further addition of waste granite dust (WGD) into the mix will have negative consequences on the hot mix asphalt concrete

5.0.2 Elastic Properties in Tension and Compression for White Cement

As it is shown in figure 2 above, tensile modulus of the asphalt concrete mix for both Timoshenko and Hondro's model for white cement modified hot mix asphalt concrete in tension and compression. Tensile modulus increased by 2.9% from 247x10^4 N/mm^2 for the control sample, to 393 x 10^4 N/mm^2 at 5% White cement (WC) content. This value further increased by 31.1% to 415 x 10^4 N/mm^2 at 10% WC content; begins to decrease by 15.3% to 404 x 10^4 N/mm^2 at 15% white cement (WC) content; by 16.1% to 397 x 10^4N/mm^2 at 21% white cement (WC) content. However, the value of tensile modulus continues to drops to 330x10^4 N/mm^2 at 25% white cement (WC) content, indicating that further addition of white cement (WC) filler would cause a corresponding decrease in the value of elastic modulus of the mix. Interestingly, for white cement the maximum value of threshold was at 10% white cement (WC) content as illustrated at figure above for both tension and compression. The import of this is that further addition of white cement into the mix will have negative consequences on the hot mix asphalt (HMA) concrete.

6.0 Conclusion

i. The waste granite dust modified asphalt concrete in tension and compression performed better at 20% addition with respect to elastic properties, similarly, white cement modified asphalt concrete in tension and compression performed better at 10% addition with respect to elastic properties.

ii. The correlation between elastic modulus from Timoshenko and Hondro's models for elastic modulus for waste granite dust

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modified hot mix asphalt concrete shows a quadratic relationship with an r-value of 0.976.

iii. While the correlation between elastic modulus for Timoshenko and Hondro's model for elastic modulus for white cement modified hot mix asphalt concrete showed a linear relationship with a r-value of 0.836.

iv. The results from the research works therefore has shown that the addition of waste granite dust and white cement can produce a better asphalt concrete with respect to elastic behavior.

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