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RESEARCH ARTICLE OPEN ACCESS

Suitability of Using Waste Polystyrene and Granite Dust Blend in Bituminous mixes in flexible Pavement Construction

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Abstract:

This investigation focuses on enhancing the performance of asphalt concrete mixes for road construction through the incorporation of granite dust (GD) and waste polystyrene (WPS) as modifiers. This research paper seeks to utilize (GD) and (WPS) as filler in asphaltic mixture by adopting the dry process to evaluate the effect of (GD) and (WPS) mix interaction on asphaltic concrete physical properties. Laboratory investigation using varying percentage quantities (between 0% to 10%) of GD-WPS modified asphalt mixture. The mixtures were subjected to Marshall Stability Tests where the stability, flow, percentage air void, density and void in mineral aggregate were determined. The results obtained shows an increase in stability and density at 4% GD,- 2% PS mix for the different blends and then a gradual decrease as the Percentage of WPS increases. While flow and VMA (MDD) decreases at 4% GD,- 2% PS mix for the different blends and then gradually increases as the Percentage of WPS increases. The 4% GD - 2% PS Mix of the different blend investigated gave the optimal stability, flow, air void, density and VMA results and these values fall well within the recommended range for asphalt mixtures designed for heavy traffic conditions.

Keywords: Asphalt concrete, Waste Polystyrene, Marshall Stability, flexible concrete, Optimal

1. INTRODUCTION

In Nigeria, road transport is the major mode of transportation, and most roads are being constructed with bituminous or asphaltic flexible pavement, taking a large portion of the annual budget of River state. Flexible pavement usually consists of asphalt concrete mixtures placed on granular base layers supported by compacted soil foundation. To achieve safe and durable flexible pavements, asphalt concrete mixtures are carefully designed to possess essential qualities such as resistance to rutting, fatigue cracking, moisture damage, and low-temperature cracking, as well as good skid resistance and workability. Asphalt or bituminous materials blended with aggregates (both coarse and fine) are the most used pavement surfacing materials today. These are generally referred to as flexible or asphalt pavements. A typical flexible pavement structure is made up of several layers: the subgrade, subbase, base course, and surface (wearing) course. It is important to note that flexible pavements are affected by four primary factors moisture, oxidation, temperature fluctuations, and traffic loading. The effect of moisture is often underestimated because pavements are assumed to have adequate drainage systems. However, especially in developing countries over 70% of asphalt pavements are constructed with inadequate or no drainage facilities, making them more vulnerable to moisture-related damage. (Igwe and Amadi-Oparaeli 2018).

Major contributors to pavement surface failure in terms of fatigue are traffic load and axle configuration effects and climate effects (temperature, moisture, and oxidation problems). These maladies upon contact with asphalt pavement surfacing re-arrange the material properties such that pavement life is compromised. For example, excess oxidation in the pavement leads to early aging and fracture of the pavement. Similarly, high exposure temperatures result in bleeding and flushing of the asphalt binder from the aggregates. Lastly, excessive submergence of pavement surfacing result in stripping of the materials that make up the asphalt concrete surface due to separation of binder from aggregates. On this basis the present study seeks to modify asphalt pavement surfacing to resist the above maladies using polystyrene and granite dust blend.

2. Materials and Methods

2.1 Materials

Asphalt Cement was obtained from HCC asphalt plant in Emohua, Emohua Local Government Area of Rivers State. Coarse Aggregates used was gravel obtained from dealers at Mile 3 Market in Port Harcourt City of Rivers State, Nigeria. Fine Aggregate used was sand obtained from dealers at Mile 3 Market, in Port Harcourt City. Granite Dust was obtained from Fuhua Quarry at Njahachang, Akamkpa Local Government Area of Cross Rivers State, Nigeria. Polystyrene used was obtained at Iloabuchi axis of Port Harcourt as waste from electronics packages.

2.2 Methods

2.2.1 Classification and Characterization of Materials

Sieve analysis provides the particle size distribution, it is required in classifying the aggregates and also used in the blending of aggregates. Sieve analysis was carried out on the coarse and fine aggregates in accordance with BS 1377 (1990)**.** The specific gravity test was conducted in line with ASTM D 70 for asphalt cement and Polystyrene While ASTM C-127 (2015) and ASTM C-128 (2001) were used for coarse and fine aggregates respectively. Table 1 shows the specific gravity of materials used. The penetration test involve the depth in tenth of mm of a bitumen sample at 25^{o}C temperature with a standard needle under a load of 100g for 5 seconds. The test procedure was in accordance with AASHTO-T49. The viscosity test involved the measurement of time it will take fluid (bitumen) flowing through an orifice at a given temperature to fill a 50ml receiver. The Standard tar viscometer was used as specified by AASHTO-T50. The softening point of the specimen was measured using the ring and ball softening point test as specified by AASHTO-T52.The result of physical property tests of asphalt cement used is shown in Table 2.

2.3 Blending of Aggregates/ Mix Proportions

For specification and classification requirements of aggregate gradation to be met, the particle size distribution of each aggregate was obtained and recorded. The Excel Solver method of aggregate combination was adopted to get the blending proportion for the aggregates. The specification limits are provided in accordance with ASTM (1951: C136). Table 3 gives the particle size distribution of the gravel and sand with their mix proportion to meet the specification used. While Figure 1 shows the specification envelope and the mixed material particle size distribution.

2.4 Sample Preparations

The method used in preparing the test specimen was in accordance with ASTM D-I559.

The total weight of one specimen is 1200g. The sample was prepared by heating the aggregates and bitumen before mixing them. The specimen was compacted by subjecting it to 75 blows on both top and bottom (corresponding to heavy volume traffic category on wearing course) by a hammer 6.5 kg rammer in weight, dropped from a height of 450 mm manually. The specimen was extruded from the mould and allowed to cool overnight before testing. The testing method used involved the application of load to the specimen in compression, to failure in the Marshall Stability testing machine. The Marshall Stability test was carried out on varying amount of asphalt cement and optimum asphalt cement was obtained which was then used in the specimen preparation

Similar procedure was carried out, for the preparation of modified asphalt concrete mixes with varying percent (2%, 4%, 6%, 8% and 10%) granite dust and waste polystyrene blend content as modifiers at optimum binder content (O.B.C) in accordance to the matrix combination shown in Table 4. Marshall Stability, flow, air voids, density and voids in mineral aggregates of the specimen were then determined.

3. RESULTS AND DISCUSSION

3.1 Preliminary Tests

The result of laboratory tests to determine the specific gravity and physical properties of asphalt cement are presented in Table 1 and Table 2 respectively.

Table 1: Specific Gravity of Material

Material	Specific Gravity
Coarse aggregate (gravels)	2.75
Fine aggregate (sand)	2.60
Filler (Granite Dust)	2.69
Polystyrene	1.005

Table 2: Physical Properties of Asphalt Cement

Physical Properties	Value
Specific Gravity	1.02
Penetration	66.7
Viscosity (sec)	69.3
Softening Point (°C)	49.5

Table 3: Mix blend for coarse and fine aggregate

Sieve Size (mm)	Specification Limit		% Passing Aggregate A (Gravel)	% Passing Aggregate B (Sand)	The Blend A=.65.3% B =.34.7%
	Lower	Upper			
19.0	100	100	100.00	100.00	100.00
12.5	86	100	85.15	100.00	90.49
9.6	70	90	61.30	100.00	75.23
6.7	45	70	40.37	100.00	61.84
4.75	40	60	18.20	97.33	46.69
2.36	30	52	9.99	96.66	41.19
1.18	22	40	6.49	96.19	38.78
0.600	16	30	5.38	70.26	28.74
0.300	9	19	5.28	34.95	15.96
0.150	3	7	5.20	1.17	3.75
0.075	1.2	4	5.14	0.70	3.54

The mix proportion of 63.7% of gravel and 34.7% of sand meet the specification requirement for particle size distribution see Table 3 and figure 1 for particle size distribution curve.

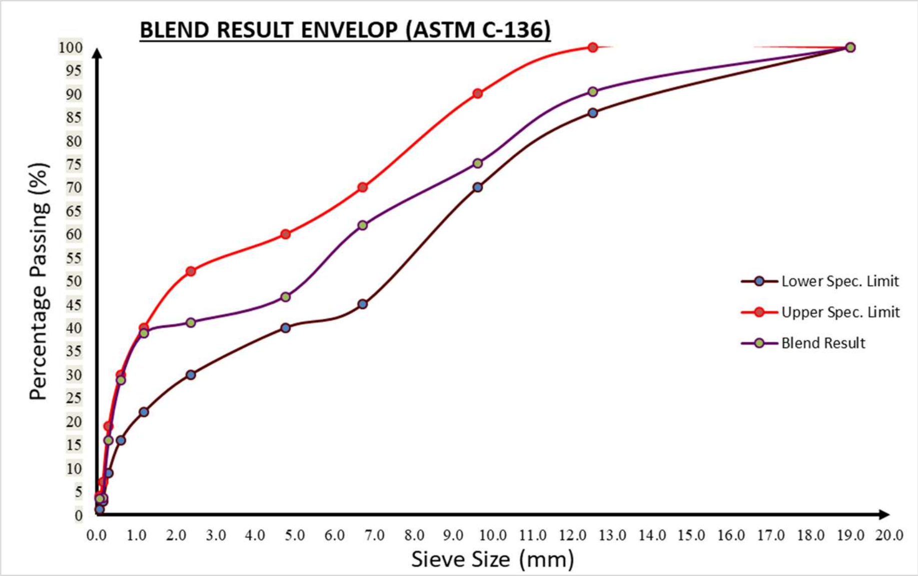

Figure 1. Gradation curve of blended aggregate

Table 4: Blending Schedule for Granite Dust (GD) and Waste Polystyrene (WPS) - Blends

WPS (%)	Granite Dust (GD) %				
	Blend A	Blend B	Blend C	Blend D	Blend E
	2	4	6	8	10
0	0 : 0	0 : 0	0 : 0	0 : 0	0 : 0
2	2 : 2	4 : 2	6 : 2	8 : 2	10 : 2
4	2 : 4	4 : 4	6 : 4	8 : 4	10 : 4
6	2 : 6	4 : 6	6 : 6	8 : 6	10 : 6
8	2 : 8	4 : 8	6 : 8	8 : 8	10 : 8
10	2 :10	4 : 10	6 : 10	8 : 10	10 : 10

Table 5: Trial Mix Design Properties

Asphalt Content (%)	Stability (N)	Flow (mm)	Density (kg/m^3)	Air Void (%)	VMA (%)	VFA (%)
4.0	12,760	2.18	2345	7.18	16.38	56.16
4.5	19,020	3.09	2362	5.81	16.23	64.2
5.0	23,080	2.9	2410	3.14	14.85	79.01
5.5	24,390	3.48	2407	2.54	15.52	83.64
6.0	22,240	2.91	2396	2.25	16.35	86.23

Optimum Binder Content (OBC) of 5.25% was gotten when the combined results of stability, flow, density, and air void analysis for all trial mixes were analysed see Table5 and OBC determined satisfies the design criteria see Table 6.

Table 6: Results at Optimum Binder Content (OBC)

Asphalt Content (%)	Stability (N)	Flow (mm)	Density (kg/m^3)	Air Void (%)	VMA (%)	VFA (%)
Results from graph based on OBC	24,160	3.35	2,413	3.5	15.06	78

3.2 Result of GD-WPS mix on Stability of Asphalt Concrete

The stability result for unmodified and GD-PS modified Asphalt Concrete mixes are shown in figure

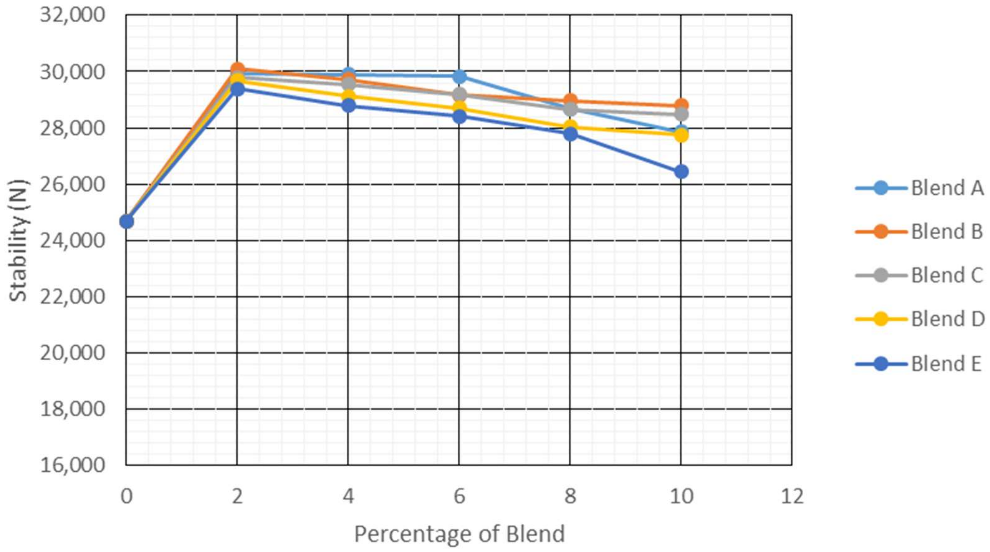

Figure 2: Result of varying quantity of GD-WPS mix on Stability of Asphalt Concrete

From Figure 2, it was observed that an optimal Marshall Stability value was achieved in Blend B (4% GD, 2% PS) at 2 % blend. The result suggests that this combination offers an optimal balance in void-filling capacity and structural reinforcement within the asphalt matrix. The synergistic effect of mineral fillers and polymer modifiers enhances the internal structure of the mix, resulting in improved load-bearing capacity.

The high stability value indicates a significant reduction in interconnected air voids, which are typically pathways for moisture intrusion an essential factor in prolonging pavement service life (Brown & Kandhal, 2001; Hicks, 1991). Moreover, the obtained stability significantly exceeds the minimum requirement of 8 kN for mixes intended for heavy traffic conditions, as recommended by ASTM D6927, Roberts et al. (1996) and the Transportation Research Board (TRB, 2000). These findings are consistent with (Read & Whiteoak, 2003; Airey, 2002; Choudhary et al., 2007) that demonstrated the beneficial impact of polymer modification and mineral fillers on the mechanical performance asphalt mixes.

3.3 Result of GD-WPS mix on flow of Asphalt Concrete

The flow result for GD-WPS modified Asphalt Concrete mixes at varying percentages are shown in figure 3

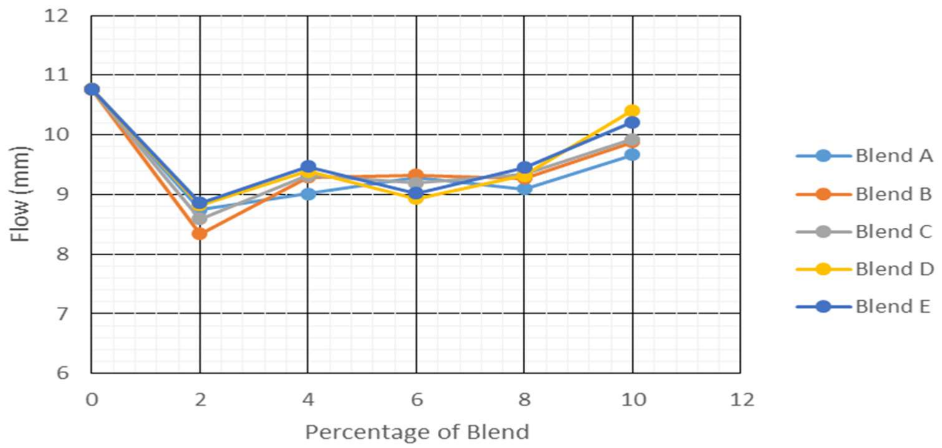

Figure 3: Result of varying quantity of GD-WPS mix on Flow of Asphalt Concrete

This minimum flow value was recorded at 4% GD and 2% PS Blend B (4% GD, 2% WPS) at 2 % blend see Figure 3, suggesting that this specific combination offers the best balance of stiffness and flexibility within the mix. The low flow value at this composition indicates a significant reduction in internal voids and plastic deformation under loading, reflecting an improved load-distribution capability and increased pavement resistance to external forces such as traffic and environmental stressors (Brown & Kandhal, 2001; Bahia & Davies, 1994). The obtained flow value falls within the recommended range of 8 to 16 mm for asphalt mixtures designed for heavy traffic (ASTM 6927; Roberts et al. (1996); TRB, 2000). These findings align with earlier research highlighting the benefits of incorporating mineral fillers and polymers to control flow characteristics and enhance overall mix performance (Choudhary et al., 2007; Al-Hadidy & Yi-Qiu, 2009).

3.4 Result of GD-WPS mix Air Voids on Asphalt Concrete

The air void result for GD-WPS modified Asphalt Concrete mixes at varying percentage quantities are shown in figure 4

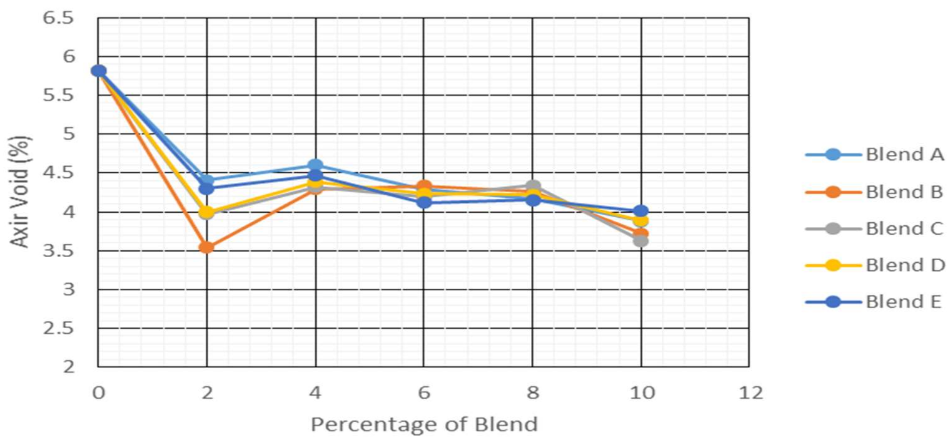

Figure 4: Result of varying quantity of GD-WPS mix on Air Void of Asphalt Concrete

An optimal air void content of 3.54%, which occurred at Blend B (4% GD, 2% WPS) at 2 % blend see Figure 4. This represents the lowest air void value across all tested combinations, indicating a maximized densification of the mix due to the effective void-filling and stabilizing characteristics of the mix. Lower air void content at this optimal blend implies improved structural integrity, as it reduces the potential for tensile strain development under load and enhances resistance to moisture infiltration, a key factor contributing to pavement deterioration (Brown & Kandhal, 2001; Hicks, 1991). Additionally, minimizing internal voids reduces the likelihood of oxidation and aging of the bitumen binder, thereby extending the service life of the pavement (Bahia & Davies, 1994; Airey, 2002). The obtained air void content of 3.54% falls well within the recommended range of 3–5% for asphalt mixtures designed for heavy traffic conditions, as specified by Transportation Research Board (TRB, 2000). These findings are consistent with other studies that worked on mineral fillers and polymer modifiers (Read & Whiteoak, 2003; Al-Hadidy & Yi-Qiu, 2009; Choudhary et al., 2007).

3.5 Result of GD-WPS mix on Density of Asphalt Concrete

The Density result of varying percentages of GD-WPS modified Asphalt Concrete mixes are shown in figure 5

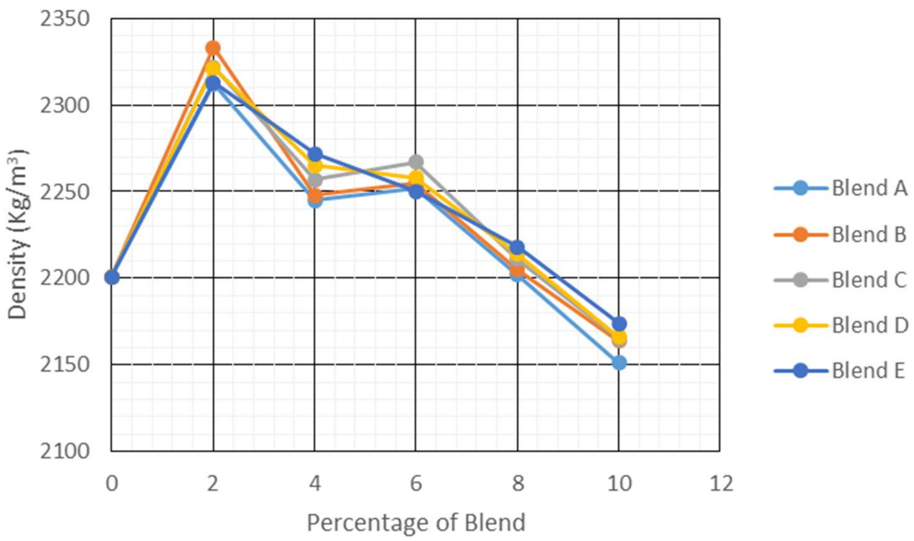

Figure 5: Result of varying quantity of GD-WPS mix on Density of Asphalt Concrete

From Figure 5, the maximum density value occurred at Blend B (4% GD, 2% WPS) at 2 % blend, indicating the most efficient void-filling capacity and densification level within the asphalt concrete matrix. The observed improvement can be attributed to the synergistic interaction between the mineral and polymer modifiers, which contribute to better particle packing and reduced air void content (Bahia & Davies, 1994; Airey, 2002). According to mix design guidelines such as AASHTO T 166-20, achieving high density ensures improved resistance to moisture damage and permanent deformation under heavy traffic loads. The density value of 2333 kg/m³ recorded in this study exceeds the minimum requirement of 2200 kg/m³ for heavy traffic applications, as recommended by Transportation Research Board (TRB, 2000). This result in in line similar investigation (Read & Whiteoak, 2003; Choudhary et al., 2007).

3.6 Result of GD-WPS mix on Voids in Mineral Aggregate (VMA) of Asphalt Concrete

The VMA result for varying percentages of GD-WPS modified Asphalt Concrete mixes are shown in figure 6

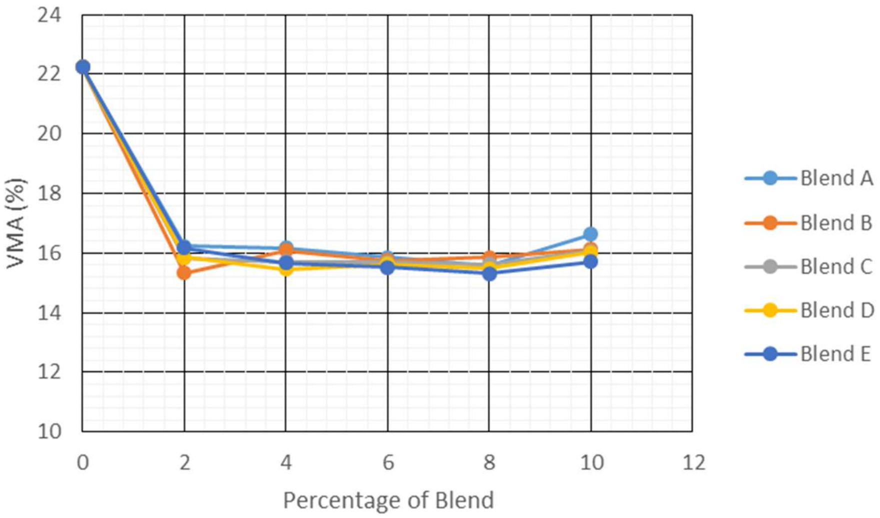

Figure 6: Result of varying quantity of GD-WPS mix on VMA of Asphalt Concrete

The optimal Voids in Mineral Aggregate (VMA) value of was recorded at Blend B (4% GD, 2% WPS) at 2 % blend, indicating the most effective combination for internal void filling and volumetric efficiency of the asphalt concrete mix. The reduction in VMA at this composition implies that the mixture attained a high level of compaction and particle interlock, largely due to the synergistic effect of the mineral and polymer additives (Brown & Kandhal, 2001; Airey, 2002). Since VMA represents the volume of intergranular void space between aggregate particles, it is directly influenced by both the bitumen content and the air voids in the mix. A lower VMA value typically suggests lower air voids and higher density and reduced potential for oxidation and aging (Hicks, 1991; Roberts et al., 1996).The observed VMA value of 15.33% exceeds the minimum specification of 14% recommended for asphalt mixtures designed for heavy traffic conditions, according to Superpave mix design guidelines (AASHTO R 35; Roberts et al., 1996; TRB, 2000). These findings are also in agreement with earlier studies that demonstrates the effectiveness of mineral fillers and polymer (Bahia & Davies, 1994; Choudhary et al., 2007).

4. Conclusions

From the laboratory investigation and analysis carried out to determine Marshall Stability, flow, air void, density and void in mineral aggregate of GD-WPS mix modified asphalt concrete, the following conclusions were reached: The use of a GD-WPS blend as a partial replacement for conventional filler in asphalt concrete notably improved the Marshal stability, flow, air void, density and void in mineral aggregate of the mix with 4% GD and 2% WPS as the optimal mix demonstrating compliance with recognized industry standards, including AASHTO T 283 and ASTM D6931

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