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Performance of Glass and Steel Slag Mixtures as a Partial Replacement for Fine Aggregate in Asphalt Concrete

*[1]Oluwatobi A. Ogunsanya, [2]Oluwasegun O. Aluko and [3]Olumide M. Ogundipe
Department of Civil Engineering, Ekiti State University, Ado-Ekiti, Nigeria
{tobiopi28|alukosegun}@gmail.com|olumide.ogundipe@eksu.edu.ng

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ORIGINAL RESEARCH ARTICLE

Abstract- Solid waste management is a significant challenge particularly in developing countries for example Nigeria. The waste disposal technique is inadequate as negative effects from improper solid waste dumping can be easily visible in the environment. Recycling and reuse of waste as aggregate in asphalt production may be an economic way to reduce these problems. This research evaluates the viability of crushed waste glass combined with steel slag (GSS) as fine aggregate in asphalt wearing courses. The Marshall mix method was used in production and evaluation of samples. GSS mixtures in the ratio 70:30 (steel slag: glass) were substituted for fine aggregate at varying percentages of 0 to 50 %. This mix ratio was adopted so that the glass content does not exceed 10%. Five samples of GSS content (10%, 20%, 30%, 40%and 50%) were prepared and their Marshal stability, Voids in Mineral Aggregates, Voids filled with Bitumen and bulk density were evaluated and compared to nominal asphalt mix. While a 10% GSS replacement in modified asphalt resulted in a greater peak stability value of 16.21 kN compared to the standard mix peak stability value of 12.68kN. The 20% GSS replacement resulted in a lower flow value and a significantly higher Marshall quotient of 5.11KN/MM was recorded at 20% replacement, making it preferable. As a result, a 20% replacement is advised for heavily trafficked highways, whereas up to 30% replacement is permissible on lightly travelled roads.

Keywords- asphalt, concrete, glass, steel slag

1 INTRODUCTION

Waste is described as any undesirable substance majorly from a production process and home activities. With the continued growth of the economy and industrialization, waste materials are being generated at an increasing rate. Disposal of solid waste has been a significant problem in both urban and rural areas of developing and under-developed countries (Hussein and Mona, 2018). Solid waste dumps are negatively impacting the environment in these places. The negative environmental effects of inappropriate solid waste disposal may be seen all across the developing world. Nigeria as a whole is facing some major solid waste management challenges (Ike *et al*.,2018) which has worsened the environmental condition and adversely affected the ground water condition (Ogwueleka, 2003).

Increasing amount of production is also generating a large amount of garbage with increasing negative impact on the environment (Binici*et al*.,2008). The risk from ineffective solid waste management system will continue to increase the negative environmental impacts such as including, land and water pollution (Ejaz *et al*., 2010). The need for innovative management methods of waste is therefore important. On the other hand, there is the problem of high rate of depletion of natural aggregates, Pavement construction takes the higher part of the natural aggregates market.

*Corresponding Author

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Aggregates forms about 100% sub-base and base courses, 85% of cement concrete pavements and 95% of bituminous pavements (Mallick *et al*., 2008). According to the National Stone Sand and Gravel Association (NSSGA, 2013), research shows that nearly two billion metric tons of aggregates are used yearly for construction and other purposes. The average amount of aggregate required for 1km pavement of bituminous concrete usually ranges from 14, 000 tons or above depending on the design specification. Due to construction, and rehabilitation of roads there have been huge demands for natural aggregates and this has begun to take its toll on the availability of natural aggregate material.

Aggregates sometimes have to be transported over hundreds of kilometres as materials are no longer easily accessible having been depleted over time. This depletion of natural aggregates also has a big effect on cost including the cost of transporting them over long distances. The magnitude of this problems makes it a good idea to look into other sources of raw materials in order to find alternative materials as well as reduce dependence on depleting natural aggregates (Farrell *et al*.,2006). Looking for alternative sources of highway materials in other to cut down on high exploration of natural aggregates as well as recycling/reusing waste to reduce the need for landfills in waste management has become necessary. The use of some appropriate solid waste as partial replacement for natural aggregates will reduce the amount of waste requiring disposal and thus reduce the pressure on landfills. It will also reduce the need for of exploration (Huang *et al*., 2007), enhance the sustainability of natural aggregates as well as preserve the environment.

Several waste materials are now used as substitutes for highway materials. The use of steel slag (Ahmedzade and

Sengoz 2009; Crisman *et al*., 2019; Hassan *et al*., 2021), waste glass has been studied by various authors. In countries such as Germany, slag applications particularly in pavement construction and concrete exceeds 75% of total slag produced (Huang *et al*., 2007). Steel slag has been used in subgrades, subbase as unbound material, and road embankments (Behiry, 2012). Ibrahim *et al*. (2021) investigated the efficacy of steel slag in improving the engineering properties of conventional asphalt concrete mixes. Limestone was used as coarse aggregate and was replaced at varying percentages of 0%, 25%, 50%, 75%, and 100%. The samples' mechanical characteristics, such as resilient modulus, tensile strength, rutting resistance, creep modulus, and resistance to stripping, improved significantly. It also found that using SSA to replace up to 74% of the coarse aggregate improved the mechanical characteristics of the mixes.

Similarly, Ahmedzade and Sengoz (2009) assessed the effect of using steel slag as aggregate. Marshall flow and stability, creep stiffness, tensile stiffness modulus and indirect tensile strength tests were used to determine the mechanical characteristics of all mixtures. The study found that, using steel slag as aggregate enhanced the mechanical characteristics of asphalt mixtures. Additionally, the results indicated that the combined mix of steel slag and limestone had a higher electrical conductivity. Some researchers have also investigated the use of crushed glass as a replacement for aggregate in asphalt mixes. According to Issa (2016), glass is a good modifier for asphalt and could be utilized without the need to alter its composition. Moreover, HMA pavements incorporating 10% to 15% crushed glass in the wearing surface mixes have demonstrated satisfactory performance.

Countries such as Japan, the USA and some countries in Europe have utilized crushed waste glass as a substitute for fine aggregate in asphalt concrete (Alhassan *et al.*, 2018). Moreover, studies on waste glass have offered robust results. Issa (2016) worked on the properties of asphalt mix containing crushed waste glass. Comparing the flow and stability results for glassphalt mix with the conventional mix, there was an improvement at 10% glass especially at low bitumen percentage (less than 5%). Similarly, Sajed (2014) experimented on the characteristics of glassphalt at different temperatures and by using different sizes of glass at different fine aggregate replacement proportions. The results showed that adding glass improved the mechanical behaviour and the stiffness of asphalt mixtures. Furthermore, glassphalt possess lower temperature sensitivity compared to conventional mixtures. The aim of this research is to study the effect of crushed glass and steel slag mixtures as replacement for fine aggregate to modify asphalt using the Marshall mix method and to evaluate the performance of the modified asphalt mix.

2 Materials and Methods

The materials used in this study were crushed granite stone, stone dust, bitumen, crushed waste glass and crushed steel slag. The type of material used, source and processing carried out on these materials are described in Table 1. All tests carried out on materials used are presented in Table 2. The Los Angeles abrasion machine was used in milling the Waste glass (Figure 1a), and steel slag (Figure 1b). The sizes used were fractions passing through 4.75mm (sieve no 4) and retained on sieve (sieve no 200).

Table 1. Raw Materials used in the study and their sources

Raw materials	Coarse Aggregate		Fine Aggregate			Filler	Bitumen
Type	½ inch	3/8 inch	River Sand	Crushed Glass	Steel Slag	Stone dust	60/70 penetration grade
Source	Quarry (KOPEK along Ikere-Ise road-Ekiti-State Nigeria)			Dump site in Omu-aran, Kwara State, Nigeria)	Steel Company (Pukit-Alloy steel company in Ikorodu, Lagos)		FERMA, Ibadan, Oyo state
Processing				Milling and Sieving	Milling and Sieving	Crushed stone passing through sieve 75 μm	

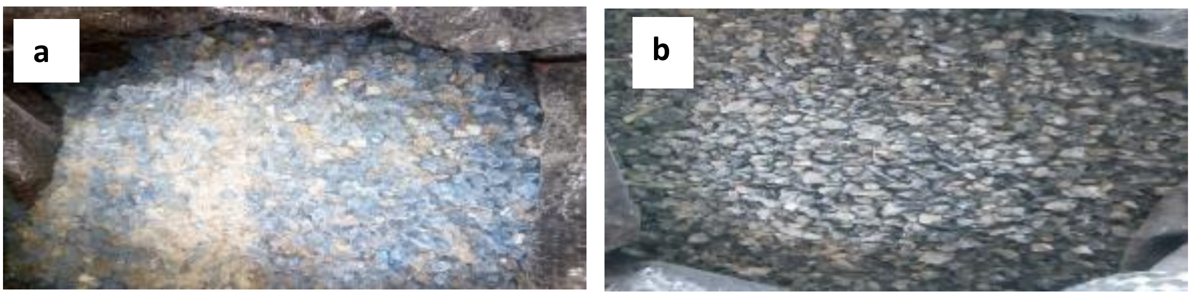

Fig. 1: (a) Crushed waste glass and (b) steel slag

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Table 2. Summary of various tests were carried out according to specifications

Type	Test carried out	Specifications	Standard
Test on Aggregate	Particle size distribution	ASTM C 125	
	Specific gravity	ASTM C127 (coarse), ASTM C128 (fine), ASTM C854 (mineral filler)	
	Water absorption	BS 812:2	< 3%
	Aggregate Impact value	BS EN 812: Part 112	30% maximum
	Aggregate abrasion value	ASTM C131	45% maximum
Test on Binder	Penetration test	ASTM D5	50 to 70
	Softening point test	ASTM D36	46 - 56
	Marshall stability	FMWN	>3.5KN
	Marshall flow	FMWN	2 to 4 (mm)
	Voids in the mineral aggregate (VMA)	ASTM C29	Minimum 13%
	Voids filled with asphalt (VFA)		70 – 80
	Voids in the total mix (Air voids)	ASTM D3203	2.5 to 4.5

2.1 MARSHALL MIX DESIGN

Marshall mix design is one of the conventional ways of testing how asphalt concrete will perform under service. The main aim is to design a pavement which is resistant to permanent deformation, low temperature cracking, good skid resistance, possesses good fatigue resistance and durable (Asphalt Institute Handbook2007). Parameters used to determine how good an asphalt mix are: the Marshall Stability, Voids in Mineral Aggregates (VMA), Voids filled with Bitumen (VFB), void ratio. The Federal Ministry of Works and Housing, Nigeria stipulates a value greater than 3.5kN for wearing course as shown in Table 2.

3 RESULTS AND DISCUSSION

3.1 INDEX PROPERTIES

The chemical constituent of the waste material was analysed using X-Ray Diffraction Analysis (XRD). The mineral constituent of steel slag is dominated by iron and magnesium oxides, which accounts for its hardness and increased density, which agrees with the research of Hassan *et al.* (2021). In the case of crushed glass, silica is the most dominant. The results are shown in Table 3. Figure 2 compares the specific gravity of material used.

Table 3. Oxide Composition of Steel slag and Crushed glass

Steel Slag		Crushed glass	
Constituent	%	Constituent	%
CaO	28 to 30	SiO_2	70
SiO_2	13 to 20	CaO	7.02
MnO	0.8 to 2.0	MgO	5.03
TiO_2	0.9 to 1.5	Fe_2O_3	0.3
MgO	9 to 12	TiO_2	0.08
V_2O_5	0.7 to 1.3	Al_2O_3	0.12
Al_2O_3	5 to 7	Na_2O	13
FeO	30 to 40	K_2O	0.51

The Aggregate Abrasion Value (AAV) indicates the aggregate toughness and abrasion characteristics. Lower values of AAV indicate an aggregate have high toughness to resist crushing and degradation. Typically, ASTMC535 specification limit the abrasion value of coarse aggregates for Hot Mixed Asphalt (HMA) use to ranges of 25 to 55 % while General Specifications (Road and Bridges 1997) specifies max of 35% for wearing course. Table3 shows that glass and steel slag possess lower toughness. Aggregate with Aggregate Impact Value (AIV) values of less than 10-20 are considered exceptionally strong while values between 20-30% are satisfactory for road surfacing. From Table3, it can be seen that glass and steel pass as regard AIV standard for wearing course. All the characteristics of glass and steel slag in Table 4 meets the specification for the FMWN and ORN 31 comparing the water absorption value with BS 8007 and BS812-2 which specifies a value of less than 3 for wearing course, all the aggregate used satisfies the required specification. Steel slag water absorption value is higher than that (Rondi, 2016) which gave a value of 2.4%.

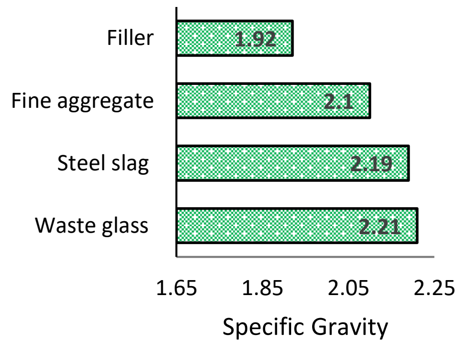

Fig. 2: Aggregate Specific gravity

Table 4. Properties of aggregate used

Aggregates	AAV	AIV	Water Absorption
Glass	43	26.8	0.74
Steel Slag	29	25	2.96
Fine aggregate	26.3	21	1.2

Particle size distribution: Figure 3 shows particle size distribution for glass and steel slag. It can be seen that the materials are well graded since **C_c** values for both steel slag and crushed glass falls within the range of 1 to 3., Therefore both aggregates are suitable for design and in accordance to BS 812:part 103.

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Penetration test carried on the bitumen shows that the penetration grade of bitumen is within 60mm minimum to 70mm maximum penetration grade (Table 5). The specific gravity which is 1.03 shows that it belongs to the grade 60/70 bitumen. The test values conform to the Nigerian general specification (1990).

Table 5. Properties of bitumen used

Tests	Result obtained
Specific gravity at 25 °C	1.03
Softening point	48
Penetration at 25°C - 0.1mm	63
Ductility at 25 °C (cm/mm)	99

3.2 Marshall Test Results

Table 6 shows Marshall Values at optimum bitumen content (OBC) while Figure 4 shows details of Marshall mix graphs used to determine the OBC.

Table 6. Optimum parameters for asphaltic mixtures and the binder content

Parameters	Value	Optimum binder content (%)
Stability (kN)	12.68	6.0
Air void	4.9	6.0
Bulk density (g/cm^3)	2.92	6.0
Flow (mm)	3.87	6.5
Average Binder Content (%)		**6.1**

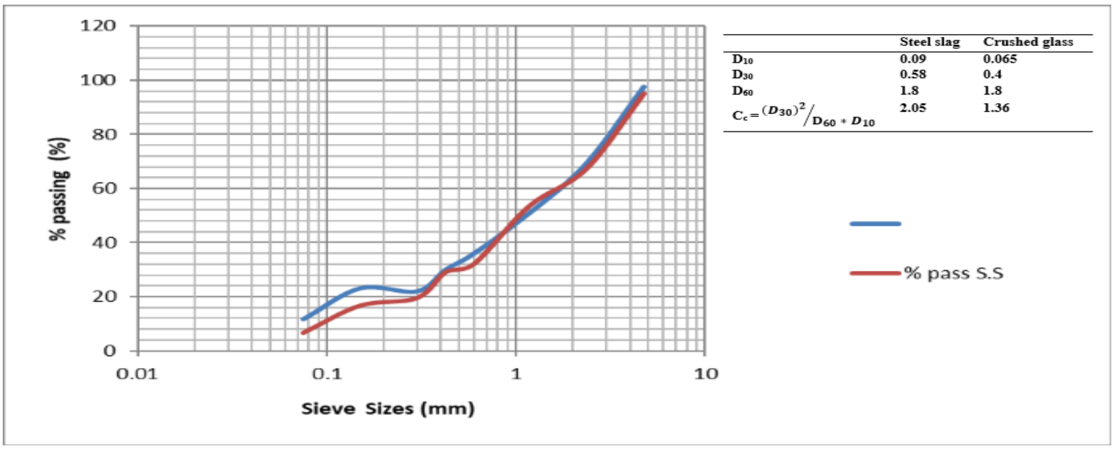

Fig. 3: Particle size distribution of steel slag and crushed glass

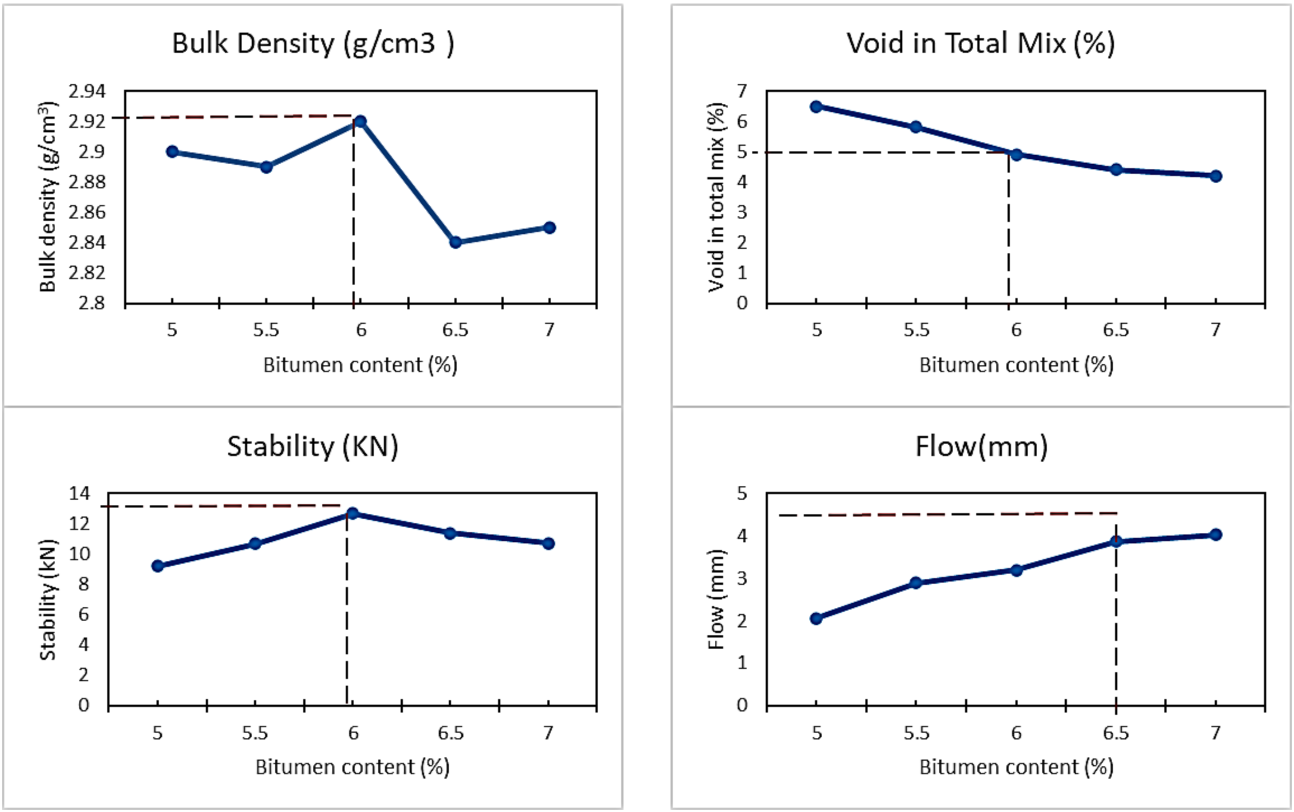

Fig. 4: Marshall Optimum Bitumen Graphs

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3.3 Marshal Results of Partial Replacement of Fine Aggregate with Steel Slag Combined with Glass (GSS)

GSS Asphalt Mix: Result shown in Table 7, the modified asphalt mixtures were produced using GSS at different percentages (10%, 20%, 30%, 40%, 50%) for fine aggregate replacement. The optimum bitumen content (6.1%) obtained from the Marshall mix design was used.

Bulk Density: The bulk density can be seen in figure 5a, the GSS modified samples are higher than the control sample. The results obtained in this study are relatively higher than those obtained by (Maharaj *et al*., 2017). This is due to the fact that increase in specific gravity of aggregate increases the density of the asphalt composite.

Void in Total Aggregate: For all traffic conditions, the target air void content of a bituminous mix is typically between 3% and 5% of the total volume of the mix. As illustrated in Figure 5(c), the design mix is within specification except for the 50% replacement. Additionally, the air void content of a mix tends to increase as GSS is used to replace sand. This increase in air voids indicates a change in particle packing in the mixes as a result of the angularity of GSS and the aggregate grading differences between GSS and the corresponding natural sand. The GSS air voids values are slightly higher than (Magdiet *al*, 2017) and Zaydoun *et al.*, 2017) which ranges from 3 to 4.4.

Void in Mineral Aggregate: The volume occupied by air voids in mineral aggregates (VMA) is defined as the sum of the volume occupied by air voids and the amount of binder not absorbed into the aggregate's pores (ASTM International, 2016). Establishing an enough VMA during mix design and field application will assist in establishing an adequate film thickness without using an excessive amount of asphalt, which will result in bleeding or flushing. GSS content between 10% and 50% increased the VMA slightly over the control figure 5(d) with a maximum of 16.18% at 50% replacement. A minimum VMA of 15% is required (Maharaj *et al.*, 2017). Therefore, except for the control sample, all samples met this criterion. A higher VMA indicates that the aggregate can accept a greater amount of binder, resulting in a more impermeable and thus more durable pavement.

Voids Filled with Bitumen: The VFB is the bitumen-filled void space in the mineral aggregate. This parameter indicates the richness of a bituminous bound mix and is related to the number of air voids, the volume of bitumen absorbed, and the effective bitumen content (the portion that is not absorbed by aggregates). There is a slight increase in effective bitumen content as more GSS aggregate is added. This increase may be a result of different water absorption values. This agrees with (Dhir*et al*., 2017) who found that glass absorbs less water compared to fine aggregate and thus increases the effective bitumen content. (GSS values (74.5% to 80.42%) were similar to (Magdi*et al*, 2017) which has its values ranging from 71% to 80 %

Marshal Stability: By considering Marshal stability in Figure 5 the entire asphalt mixes have a stability higher than the specification limit given by the American Asphalt Institutei.e7.5 KN, the stability increases with increasing GSS content. All GSS stability values satisfies the FMWN specified standards which stipulates values >3.5KN. Progressive addition of GSS from 10% to 50% improves the stability values with the highest value occurring at 16.21 KN at 10% replacement. GSS stability values are a little bit lower compared to (Perviz and Burak, 2009) steel slag aggregates which has values from 17.46KN to 19.54KN but higher than (ISSA 2016) glassphalt values of 11.92KN to 13.65KN.

Marshal Flow: In a bituminous bound mix, the elastic and plastic deformation is described by its marshal flow at stability test. The flow rate is determined by the properties and content of the bitumen used, as well as the presence of filler with a particle size of less than 75 microns. Values ranging from 3.0 to 4.2 mm were achieved with the 10% GSS having the lowest deformation and the 50% having the highest deformation. GSS flow values were in the range of 3.0 to 4.2 (mm) which is higher than (ISSA 2016) 2.6 to 2.80(mm) and (Magdi *et al*., 2017) values of 3.2 to 3.5(mm).it can be deduced that the increase in GSS content gave rise to higher deformation as depicted in Figure 5.

Table 7. Marshal Properties of HMA Partially Replaced with GSS

GSS (%)	Bulk Density (g/cm³)	Void in Total Mix (%)	Void in Mineral Aggregate (VMA)	Void Filled with Bitumen (VFB %)	Stability (kN)	Flow (mm)
10	2.52	3.0	15.87	76.26	16.21	3.76
20	2.49	3.46	15.20	80.24	15.32	3.0
30	2.51	3.92	15.29	79.69	9.38	3.1
40	2.49	4.37	15.25	79.96	12.93	4.18
50	2.48	5.16	16.18	74.5	10.97	4.20

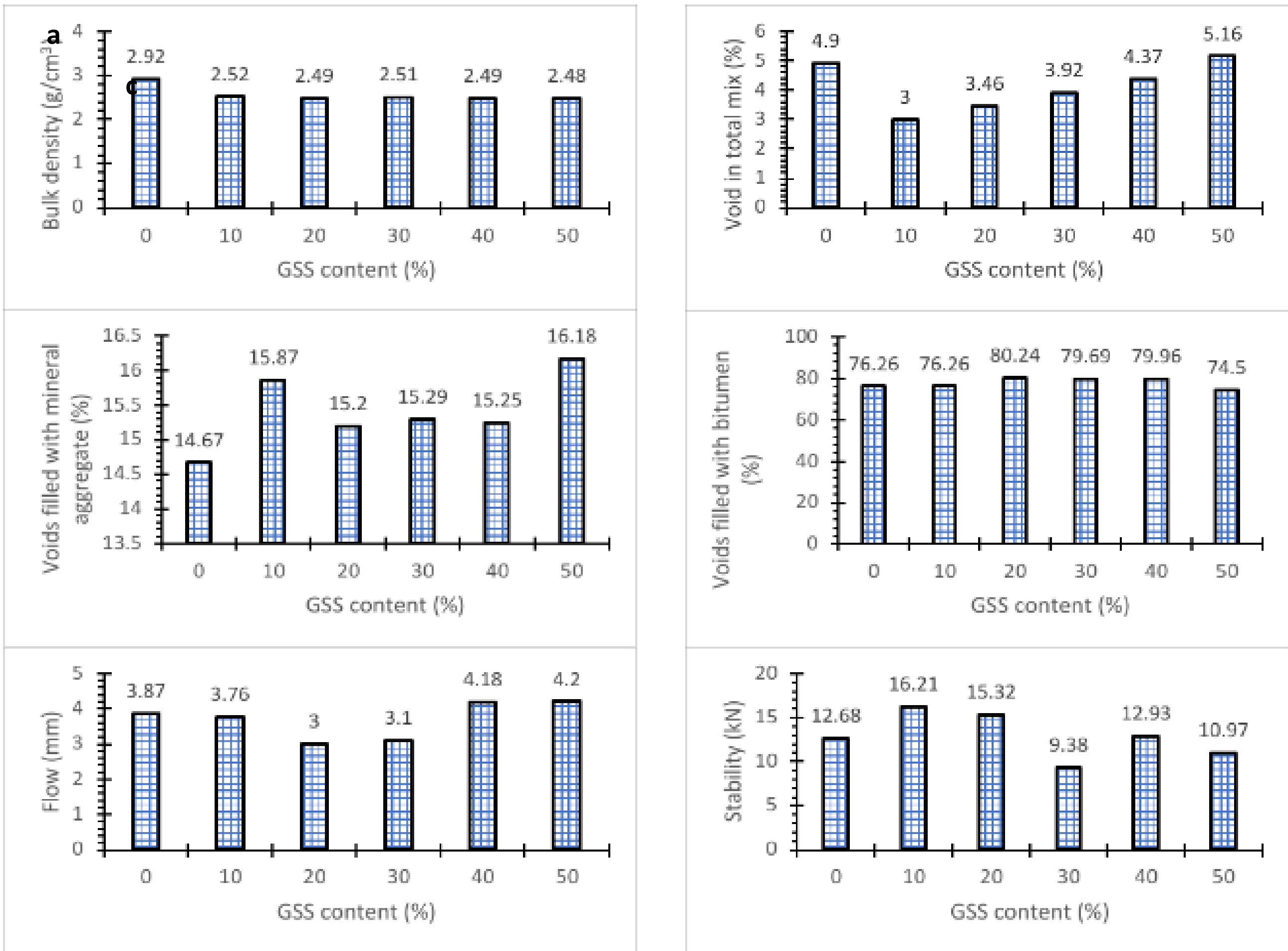

Fig. 5: Marshal properties of GSS Modified Asphalt

Marshall Quotient: Additionally, the Marshall quotient (MQ) (kN/mm) is determined as the stability to flow ratio. MQ can be used to determine a material's resistance to persistent deformation during use. A greater MQ value suggests a stiffer combination and, therefore, a more resistant mixture. A Marshall Quotient of greater than one indicates that the asphalt mixture is more stable and has a lower flow rate. In this study, the peak MQ is recorded at 20% replacement. All MQ values are stated in table 8.

Table 8. Marshall Stability, Flow, and Quotient values

GSS (%)	Stability (KN)	Flow(mm)	Marshall Quotient
0	12.68	3.87	3.28
10	16.21	3.76	4.31
20	15.32	3	5.11
30	9.38	3.1	3.03
40	12.93	4.18	3.09
50	10.97	4.2	2.61

4 Conclusions

In this study, the natural aggregate used in road paving was replaced by repurposed waste materials GSS made up of 30% waste glass and 70% steel slag. The effectuality of replacing the natural aggregate with GSS was measured by changes the physical and mechanical properties attributes of the various blends. Marshall mix method was used to obtain the optimum bitumen content which was determined as 6.1%. The study then proceeded to look into the effect of GSS as partial replacement for fine aggregate in varying mixes (10%, 20%, 30%, 40%, and 50%). Addition of GSS showed better results with improved Marshall stability, flow, VMA and VTA compared to conventional asphalt mix. Although a 10% GSS replacement in modified asphalt gave better peak stability value (16.21 KN) compared with the conventional mix (12.68 KN). The 20% GSS replacement had a lower flow value and much higher Marshall Quotient value which makes it preferable. Hence, a20% replacement is recommended for heavily trafficked roads while a replacement of up to 30% can be done for lightly trafficked roads. Use of crushed waste glass and steel slag in asphalt concrete will help in solving pollution and environmental problem. It will also ensure sustainability of natural aggregate and decrease cost of treating and disposing existing massive stockpiles of steel slag and glass waste.

References

AfkhamyMeybodi, P., KhaniSanij, H., Hosseini, S. H., & Olazar, M. (2019). Effect of Crushed Glass on Skid Resistance, Moisture Sensitivity and Resilient Modulus of Hot Mix Asphalt. *Arabian Journal for Science & Engineering (Springer Science & Business Media BV)*, *44*(5).

Ahmedzade, P., &Sengoz, B. (2009). Evaluation of steel slag coarse aggregate in hot mix asphalt concrete. *Journal of hazardous materials*, *165*(1-3), 300-305.

Alberici, S., de Beer, J. G., van der Hoorn, I., &Staats, M. (2017). *Fly ash and blast furnace slag for cement manufacturing* (No. 2017/19). BEIS Research Paper.

Alexandria, V. (2013). The aggregates handbook. *National Stone Association, Alexandria*.

Alhassan, H. M., Yunusa, G. H., & Sanusi, D. (2018). Potential of glass cullet as aggregate in hot mix asphalt. *Nigerian Journal of Technology*, *37*(2), 338-345.

Ameri, M., Hesami, S., &Goli, H. (2013). Laboratory evaluation of warm mix asphalt mixtures containing electric arc furnace (EAF) steel slag. *Construction and Building materials*, *49*, 611-617.

Arabani, M. (2011). Effect of glass cullet on the improvement of the dynamic behaviour of asphalt concrete. *Construction and Building Materials*, *25*(3), 1181-1185.

Asphalt Institute. (1981). *Thickness Design--asphalt Pavements for Highways and Streets* (Vol. 1). Asphalt Inst.

ASTM (2001) C136. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregate.

ASTM (2004) C127. Standard Test Method for Specific gravity and water absorption of Fine and Coarse Aggregate.

ASTM (2018). Aggregates Characteristics and Use. Specification For Asphalt Materials.

Behiry, s., &Narendra (2012). The use of steel slag in construction of flexible pavement.

Binici, H., Aksogan, O., Görür, E. B., Kaplan, H., &Bodur, M. N. (2008). Performance of ground blast furnace slag and ground basaltic pumice concrete against seawater attack. *Construction and Building Materials*, *22*(7), 1515-1526.

British Standards Institution. (1983). *British Standard Specification for Aggregates from Natural Sources for Concrete*. British Standards Institution.

BS 812: 1975, 1982, British Standard Specification for aggregates from natural sources for concrete.

Dhir, R. K., Brito, J. D., Mangabhai, R., & Lye, C. Q. (2017). 7-use of copper slag in road pavement applications". *Sustainable Construction Materials: Copper Slag*, 247-277.

Ejaz, N., Akhtar, N., Hashmi, H., & Naeem, U. A. (2010). Environmental impacts of improper solid waste management in developing countries: A case study of Rawalpindi city. *The sustainable world*, *142*, 379-387.

Farrell, A. E., Farrell, A. E., &Jäger, J. (Eds.). (2006). *Assessments of regional and global environmental risks: designing processes for the effective use of science in decision making*. Resources for the Future.

Federal Ministry of Works and Housing (1997). General Specification for Roads and Bridges, Volume 11, Federal Highway Department, FMWH: Lagos, Nigeria.

Finkle, I., &Ksaibati, K. (2007). *Recycled glass utilization in highway construction* (No. MPC Report No. 07-192).

Hasanuzzaman, M., Rafferty, A., Sajjia, M., &Olabi, A. G. (2016). Properties of glass materials. *Reference Module in Materials Science and Materials Engineering*, 1-12.

Hassan, K. E., Attia, M. I., Reid, M., & Al-Kuwari, M. B. (2021). Performance of steel slag aggregate in asphalt mixtures in a hot desert climate. *Case Studies in Construction Materials*, *14*, e00534.

Huang, Y., Bird, R. N., & Heidrich, O. (2007). A review of the use of recycled solid waste materials in asphalt pavements. *Resources, conservation and recycling*, *52*(1), 58-73.

Ibrahim, M. R., Alnadish, A. M., Aman, M. Y., &Katman, H. Y. B (2021). Characteristics of Warm Mix Asphalt Incorporating Coarse Steel Slag Aggregates. *Applied Sciences*, *11*(8), 3708.

Ike, C. C., Ezeibe, C. C., Anijiofor, S. C., & Daud, N. N. (2018). Solid waste management in Nigeria: problems, prospects, and policies. *The Journal of Solid Waste Technology and Management*, *44*(2), 163-172.

Issa, Y. (2016). Effect of adding crushed glass to asphalt mix. *Archives of Civil Engineering*, *62*(2), 35-44.

Japan Asphalt Pavement Association (JAPA). (2002). Waste Glass Bottles for Pavement. Clean Japan Center. 32-38.

Kateryna, K., Prentkovskis, O., Bieliatynskyi, A., &Junevičius, R. (2012). Use of steel slags in automobile road construction. *Transport*, *27*(2), 129-137.

Madhu, P. L., Choudhary, R., & Kumar, B. (2018). Clogging evaluation of open graded friction course mixes with EAF steel slag and modified binders. *Construction and Building Materials*, *159*, 220-233.

Maharaj, C., White, D., Maharaj, R., & Morin, C. (2017). Re-use of steel slag as an aggregate to asphaltic road pavement surface. *Cogent Engineering*, *4*(1), 1416889.

Mallick, R. B., & El-Korchi, T. (2008). *Pavement engineering*. CRC Press, NY.

Ogwueleka, T. (2003). Analysis of urban solid waste in Nsukka, Nigeria.

Perviz, B., Burak, S. (2009). Utilisation of LD Slag as Aggregate in Construction Industry.

Rondi, L., Bregoli, G., Sorlini, S., Cominoli, L., Collivignarelli, C., &Plizzari, G. (2016). Concrete with EAF steel slag as aggregate: A comprehensive technical and environmental characterisation. *Composites Part B: Engineering*, *90*, 195-202.

Sajed, G. S. S. M. Y. (2014). Investigation of Dynamic Behaviour of Hot Mix Asphalt.

TRL. (1993). Overseas Road Note 31. A Guide to the Structural Design of Bitumen-surfaced Roads in Tropical and Sub-tropical Countries.

Twesigye, N., Twinamatsiko, M., &Tumwesigye, W. (2022). Utilisation of Biodegradable Solid Waste to Boost Crop Production Among Farmers in Mbarara City, South Western Uganda. *American Journal of Agriculture*, *4*(1), 47-57

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