EFFECTS OF STEEL SLAG AND FLY ASH ON THE PROPERTIES OF ASPHALT CONCRETE

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ABSTRACT

The study focused on the evaluation of effects of steel slag and fly ash on the properties of asphalt concrete. Steel slag and fly ash with conventional materials such as aggregate, fillers and bitumen were used in this study. Experimental test to ascertain the physical properties of these materials were performed. Cylindrical samples of asphalt concrete were produced by mixture of bitumen, aggregate, filler and varying proportions of steel slag and fly ash at 2%, 4%, 6% and 8% to partially replace the conventional materials (coarse, fine aggregate and filler) with different bitumen content of 5%, 5.5%, 6%, 6.5% and 7% respectively. The marshal stability and flow were obtained. The result of steel slag modified asphalt concrete showed that optimum stability of 13.00KN was obtained at bitumen content of 6.0% in varying proportion of 8% while the optimum flow value of 2.8mm was obtained at 6.0% of bitumen content in varying proportion of 8%. The result of fly ash modified asphalt concrete showed that optimum stability of 10.70KN was obtained at 8% varying proportion of fly ash while optimum flow value of 2.8mm was also obtained at 8% varying of proportion of fly ash respectively. The stability and flow values obtained lie within the recommended specifications (Not less 3.5KN for stability and 2mm - 6mm for flow) in accordance with Nigeria General Specification for Road and Bridges (NGSRB), 2016 specification. The study concluded that the two modifiers utilized enhanced the properties of asphalt concrete and showed that the modifiers used have the potential to reduce the cost of road developments.

Keywords: *Steel Slag, Fly Ash, Aggregate, Proportion, Optimum, Stability and Flow*

1.0 INTRODUCTION

Generally speaking, bitumen and aggregates are combined to create asphalt concrete, a composite material commonly used in road pavement. Numerous modifiers and additives have been used to enhance the performance of asphalt concrete. Fly ash, a byproduct of burning coal in power plants, and steel slag, a byproduct of making steel, are two substances that can enhance the qualities of asphalt concrete. Because of its exceptional strength, durability, and density, steel slag is a suitable substitute for aggregates. According to Xie, *et al.*, 2012, the angular shape and rough texture of the asphalt mixture may improve the bonding between the particles and increase the structural strength of the pavement. However, fly ash is known for having pozzolanic properties that improve the asphalt mixture's strength and longevity (Singh and Siddique, 2013).
Fly ash is mostly obtained in Nigeria from coal-fired power stations. Nigeria's coal industry contributes significantly to the nation's energy landscape by helping to produce power. The primary producers of fly ash are the Egbin Power Plant, the Oji River Thermal Power Station, and a number of smaller coal-fired power plants spread across the nation. Nigeria's iron and steel sector is the primary supplier of steel slag. Major steel manufacturing facilities such as Ajaokuta Steel Company, Delta Steel Company, and various smaller steel mills produce a sizable amount of steel slag as a byproduct.
There are some advantages to fly ash production in Nigeria, but there are also environmental risks. When fly ash is handled improperly, it can contaminate the air and water, endangering human health as well as the ecosystem. However, fly ash can also be seen as a beneficial resource for infrastructure and construction industry. Fly ash is being used increasingly frequently in various construction projects to reduce the

environmental effects. It improves the material's strength and durability by taking the place of cement in concrete. This application reduces fly ash's negative environmental effects while saving money on infrastructural development.

Nigeria's steel slag production offers chances for resource usage in addition to environmental challenges. Unmanaged steel slag has the potential to take up enormous tracts of land and release heavy metals into the soil and water. But steel slag's potential as a useful road construction is also acknowledged. Steel slag is being investigated more and more by the Nigerian construction sector as an aggregate for asphalt concrete, road projects, and other infrastructure projects. Steel slag presents a compelling substitute for natural aggregates due to its exceptional density, strength, and durability. Its application promotes sustainable construction methods and lowers the negative environmental effects of disposing of steel slag. In construction projects, using steel slag and fly ash can have a significant positive economic impact. It minimizes the environmental costs involved with waste disposal, lowers the cost of materials, and reduces the reliance on natural aggregates. Long-term cost reductions can stem from the lifetime and enhanced performance of building materials.

The synergistic effects of mixing fly ash and steel slag in asphalt concrete have been studied recently. According to Wu *et al.*, 2015, mixtures that contained both components performed better than mixtures that only contained one of the additives. The overall performance, durability, and resistance to deformation of the asphalt concrete are enhanced by the combination of the pozzolanic activity of fly ash and the mechanical strength of steel slag. The assessment of the marshal stability and flow of hybrid modified asphalt concrete, which includes steel slag and fly ash (Ezemenike *et al.*, 2022). The results indicated an increase in stability and flow, which improved the flexible pavement. Moreover, Li *et al.*, discovered that the incorporation of steel slag and fly ash improved the fatigue resistance of asphalt mixtures, making them more suited for high traffic situations. By reducing the need for natural aggregates and avoiding the disposal of industrial waste, the combined use of these materials resulted in financial savings as well as environmental advantages. Steel slag and fly ash are two such by-products that have garnered attention for their potential benefits when incorporated into asphalt concrete. This study assesses how these materials affect the mechanical and performance characteristics of asphalt concrete while offering a thorough overview of recent findings and real-world applications.

2.0 REVIEW OF RELATED WORKS

The utilization of industrial by-products as building materials is gaining significant attention due to their environmental and economic benefits. Steel slag and fly ash are among the by-products that have shown potential to enhance the mechanical and functional properties of asphalt concrete. This literature review examines studies on the effects of incorporating steel slag and fly ash into asphalt concrete. Recent research has revealed promising outcomes when these two by-products are combined, highlighting their synergistic effects. Various studies have explored the impact of mixing steel slag and fly ash with asphalt concrete.

2.1 Properties of Steel Slag in Asphalt Concrete

Steel slag, a by-product of the steel industry, demonstrates high density, strength, and durability, making it a suitable aggregate substitute in asphalt concrete. According to Xie *et al.*, 2012, adding steel slag to asphalt mixtures improves resistance to rutting and moisture damage. The angularity and rough surface texture of steel slag enhance mechanical interlock between particles, boosting pavement stability and load-bearing capacity. Additionally, the strong affinity between bitumen and steel slag enhances the bond between aggregates and the asphalt binder, contributing to the durability and longevity of steel slag-containing asphalt pavements (Manson *et al.*, 2004). Ahmedzade *et al.*, 2017 found that incorporating steel slag into asphalt mixtures enhances thermal stability, reducing susceptibility to temperature fluctuations and extending pavement lifespan. Zhao, (2018) noted the sustainability of using steel slag as an aggregate in asphalt concrete, emphasizing its durability and stability. Ezemenike *et al.*, 2022 discovered that steel slag with high impact and crushing values enhances the properties of asphalt concrete. Studies by Li, (2018) confirmed that steel slag improves asphalt mixture resistance to rutting and moisture damage. Chen, (2020) highlighted the sustainability benefits of adding steel slag to asphalt concrete, including reduced carbon emissions and promotion of sustainable development. Ogunleye *et al.*, 2017 evaluated the environmental benefits of using steel slag in road construction. Babatunde *et al.*, 2016 reported significant improvements in the mechanical properties of asphalt mixtures containing steel slag. Adedimila *et al.*, 2018 emphasized steel slag's potential to enhance the structural performance of asphalt pavements. Adebisi *et al.*, 2017 confirmed the thermal stability benefits of steel slag in asphalt concrete. Olawale and Ige, (2019) found that adding fly ash and steel slag improved asphalt concrete performance. Okeke *et al.*, 2018 demonstrated improved fatigue resistance in asphalt mixtures containing both components.

2.2 Properties of fly ash in Asphalt Concrete

Fly ash, a by-product of coal combustion, is valued for its pozzolanic properties, which can enhance the binding and durability of asphalt mixtures. Studies have extensively investigated the potential of fly ash to improve asphalt concrete performance. Singh and Siddique, (2013) found that fly ash enhances the workability and compaction of asphalt mixtures, leading to stronger and more durable pavements. The pozzolanic reaction between fly ash and calcium hydroxide in the asphalt binder produces additional cementitious compounds that strengthen the binder. Fly ash's fine particles fill voids in the asphalt mix, reducing permeability and susceptibility to oxidative aging Kim *et al.*, 2008. Jafari and Shafabakhsh, (2016) highlighted that fly ash can lower the environmental impact of asphalt production by reducing greenhouse gas emissions and the need for virgin materials. They also noted fly ash's ability to improve thermal stability and aging resistance of asphalt concrete. Research by Wang *et al.*, 2017 investigated the impact of fly ash on the rheological properties and workability of asphalt binders, showing improved performance. Li *et al.*, 2020 found that fly ash enhances thermal stability and fatigue resistance, extending the service life of asphalt mixtures. Zhang *et al.*, 2021 demonstrated how fly ash and other supplementary materials synergistically enhance asphalt concrete performance in various environmental conditions. Eze-Uzomaka *et al.*, 2017 reported improved workability and moisture damage resistance in asphalt concrete with fly ash. Ezemenike *et al.*, 2022 concluded that fly ash, acting as a filler, enhances the mechanical properties of flexible pavement by filling voids. Ede *et al.*, 2015 found that fly ash improves the workability and compaction qualities of asphalt concrete. Adewale *et al.*, 2017 demonstrated that asphalt mixed with fly ash shows improved aging resistance and environmental benefits. Chukwuma *et al.*, 2018 showed that incorporating fly ash into asphalt concrete increases pavement longevity and structural integrity.

3.0 MATERIALS AND METHODS

3.1 Materials Used and Locations

Aggregates were sourced from the RCC and JCC quarries situated along the Akure-Owo Express Road in Oba-Ile, Akure North local government area, Ondo State, Nigeria. Steel slag was procured from Ife Steel and Iron Company in Ile-Ife, Osun State, Nigeria, while fly ash was obtained from burning chambers near the thermal station in Oji River Town, Enugu State, Nigeria. Bitumen with a penetration grade of 60/70 was acquired from K.K. Hassan Construction Company in Akure, Nigeria.

3.2 Method

3.2.1 Bitumen, Aggregate, Fly Ash, and Steel Slag Processing and Characterization

Fly ash was dried in the sun for two days to reduce moisture content and then used to replace stone dust in varying proportions of 2%, 4%, 6%, and 8%, as illustrated in Plate 1. Steel slag, as shown in Plate 2, was ground and sieved to obtain a particle size range of 150 µm to 10 mm. This was done to ensure its suitability as both fine and coarse aggregate, replacing conventional aggregates in proportions of 2%, 4%, 6%, and 8%. The physical properties of the aggregates, fly ash, bitumen, and steel slag were determined following standard measurement methods. Moisture content was tested according to BS 812-109:1990. Additional tests, including aggregate impact value (AIV) and aggregate crushing value (ACV), were conducted as specified in ASTM D5874-16 and ASTM C131-14, respectively. The elongation index, flakiness test, and specific gravity test were performed in accordance with BS 812: Part 105.1: 1685 and ASTM 854-00, respectively. Bitumen tests, including penetration, viscosity, and ductility, were carried out following ASTM D5/D5M-13, ASTM D36/D36M-14el, ASTM D92-166, ASTM D2170/D2170-10, and ASTM D113-17 standards.

Plate 1: Fly Ash

Plate 2: Steel Slag

3.2.2 Marshall Bituminous Mix Design and Composites Development

A total of 1200 g of aggregates, composed of fractions measuring 8.00, 5.00, and 2.36 mm, along with 4.76 µm of filler (stone dust), were preheated to 160–178°C. The chosen 5% bitumen concentration was heated to 150°C. The bitumen and aggregates were then blended in a steel bowl at a mixing temperature of around 185°C. The mixture was thoroughly mixed and then compacted in a preheated Marshall mold by applying 50 blows to each sample face. Ten (10) samples were prepared by replacing filler (stone dust) with fly ash in varying proportions of 2%, 4%, 6%, and 8%. Another ten (10) samples were prepared by replacing aggregates (both fine and coarse) with steel slag in proportions of 2%, 4%, 6%, and 8%. The samples were tested for Marshall stability and flow using a Marshall Stability Test Apparatus, as shown in Plate 3. Additionally, voids in mineral aggregate (VMA), air voids (AV), bulk density (BD), and voids filled with bitumen (VFB) were measured.

Plate 3: Marshall Stability Test Apparatus

4.0 ANALYSIS AND DISCUSSION OF RESULTS

4.1 Physical Properties of Aggregate, Steel Slag and Fly Ash

4.1.1 Moisture Content (BS 812-109:1990)

The maximum allowable moisture content is 5% (FMWHM, 2013). The average moisture content values obtained for the aggregate, steel slag, and fly ash were 0.65%, 0.46%, and 1.61%, respectively, as shown in Table 1. According to FMWHM (2013), these values confirm that the moisture content of the aggregate, steel slag, and fly ash is within acceptable limits.

Table 1: Summary of physical properties of Aggregates, steel slag, and fly ash

Test	**Obtained Value**			**Specification as FMWHM, 2013**
	Aggregate	**Steel Slag**	**Fly Ash**	
Moisture Content	0.65%	0.46%	1.61%	Max 5%
Aggregate Impact Value	22.20%	20.50%	-	20-30%
Aggregate Crushing Value	30.18%	28.73%	-	27-35%
Specific gravity	3.0g	2.81g	2.31g	2.5-3.09
Flakiness and Elongation Index Test	20.64%	25.31%	-	Max 35%

4.1.2 Aggregate Impact Value (AIV) (ASTM D5874-16)

The AIV results for aggregate and steel slag are shown in Table 1. For the surface course, the required AIV range is 20-30%. The average AIV values for aggregate and steel slag were 22.20% and 20.50%, respectively, which fall within the acceptable range for road surfacing as per ASTM D5874-16. The slightly lower AIV of steel slag compared to natural aggregate indicates its greater resistance to sudden forces.

4.1.3 Aggregate Crushing Value (ACV) (ASTM C131-14)

Table 1 presents the ACV results for aggregate and steel slag. The average ACV values were 30.18% and 28.73%, respectively, which are within the recommended range of 27-35% as specified by ASTM C131-14.

These results indicate that both the aggregate and steel slag have suitable crushing values for their intended use.

4.1.4 Specific Gravity (ASTM 854-00)

The specific gravity results for aggregates, steel slag, and fly ash were 3.00, 2.81, and 2.31, respectively, as shown in Table 1. These values fall within the limits recommended by ASTM 854-00, confirming their suitability for the intended purpose.

4.1.5 Flakiness and Elongation Index (BS 812: Part 105.1: 1685)

Table 1 presents the results of the flakiness and elongation index tests. The flakiness and elongation index for aggregate were 20.64%, while for steel slag they were 25.31%. These values are within the permissible limits, with the maximum flakiness index for a bituminous macadam base course being 35%. Therefore, the obtained values are acceptable.

4.2 Physical Properties of Bitumen

Table 2 shows the physical properties of bitumen: 62 mm for penetration, 46°C for softening point, 207°C for flash point, 252°C for fire point, 148 cm for ductility, 129.4 seconds for viscosity, and 3.4% for water-in-bitumen. All these values are within the specified ranges of the American standard for testing materials.

Table 2: Physical Properties of Bitumen

Test Conducted	**Code Used**	**Specific Limit**	**Test result**
Softening Point (ºC)	ASTM D36-76	Minimum 45	46 ºC
Penetration (mm)	ASTM D5-95	60-70	62mm
Ductility (cm)	ASTM D92-90	Minimum 75	148cm
Fire Point (ºC)	ASTM D92-90	Minimum 240	252 ºC
Flash Point (ºC)	ASTM D92-90	Minimum 200	207 ºC
Water-in-Bitumen (%)	ASTM D95	Maximum 5%	3.4%
Viscosity (sec)	ASTM D92-90	Maximum 300 sec	129.4 sec

4.3 The Marshal Stability of Steel Slag Modified Asphalt

In designing the wearing course, the stability of the asphalt mixture is a critical factor. A high Marshall Stability indicates greater Marshall Stiffness, reflecting the mixture's resistance to permanent deformation. While high stiffness values suggest improved resistance to traffic loadings, they also indicate reduced flexibility, which is necessary for long-term performance due to the potential for future thermal cracking. Plate 4 shows the stability values for various bitumen contents used in this study. The highest optimal stability of 13.00 KN was achieved at a bitumen content of 6.0% with 8% steel slag. Other optimal stability values obtained were 11.50 KN, 12.20 KN, and 10.80 KN for steel slag proportions of 6%, 4%, and 2%, respectively. These stability values comply with the Nigeria General Specification for Road and Bridge (NGSRB, 2016), which specifies a minimum of 3.5 KN.

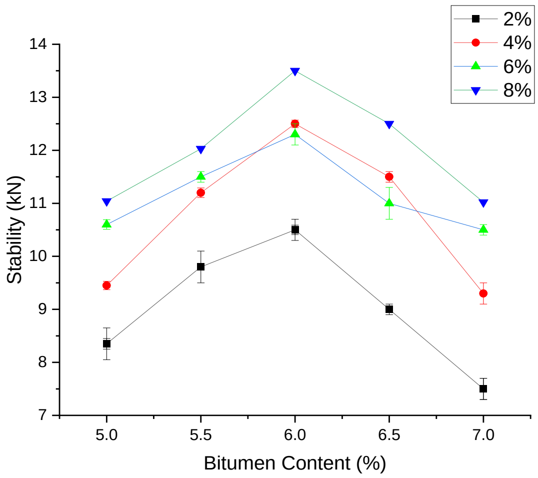

Plate 4: Marshall Stability of Steel Slag Modified Asphalt against Bitumen Content

4.4 The Marshal flow of Steel Slag Modified Asphalt

Low flow values typically indicate a mix with higher void content and insufficient asphalt, which can cause brittleness and premature cracking during the pavement's lifespan. Conversely, high flow values often signify a plastic mix more prone to permanent deformation under traffic loads. Plate 5 shows the flow values for different bitumen contents used in this study. The highest optimal flow value of 3.3 mm was achieved with 6.0% bitumen content and 2% steel slag. Other optimal flow values were 3.10 mm, 3.00 mm, and 2.80 mm for steel slag proportions of 4%, 6%, and 8%, respectively. These flow values meet the Nigeria General Specification for Road and Bridge (NGSRB, 2016), which stipulates a range of 2-4 mm.

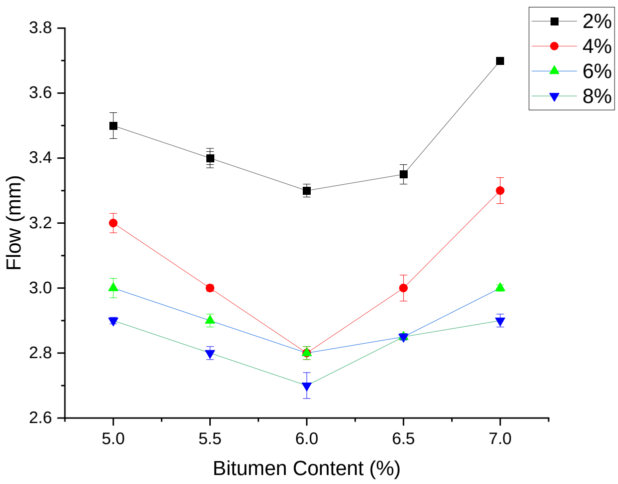

Plate 5: Marshall Flow of Steel Slag Modified Asphalt against Bitumen Content

4.5 Marshal Stability of Fly Ash Modified Asphalt

The stability results for fly ash are presented in Plate 6. Initially, stability increased with rising bitumen content, but it decreased when the bitumen content was further increased. The highest stability values for 2% and 4% fly ash content were 8.3 KN and 8.6 KN, respectively. For 6% and 8% fly ash content, the optimum stability values were 9.5 KN and 10.6 KN. This is likely because fly ash acts as a filler, filling the voids in the asphalt mixture and increasing stiffness and toughness as the fly ash content rises. The high stiffness of the asphalt blend indicates excellent resistance to traffic loads. The optimal bitumen content was found to be 5.5% for 2% and 4% fly ash, and 6.0% for 6% and 8% fly ash. The optimal Marshall stability values of 8.5 KN, 9.0 KN, 9.5 KN, and 10.7 KN were achieved with 2%, 4%, 6%, and 8% fly ash, respectively. These stability values meet the standards set by the Nigeria General Specification for Road and Bridges (NGSRB, 2016).

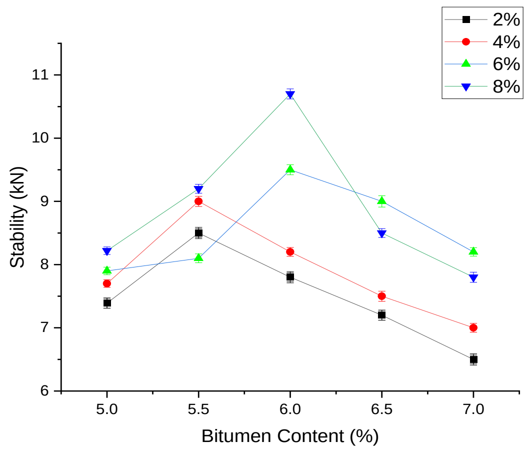

Plate 6: Marshal Stability of Fly ash Modified Asphalt against Bitumen Content

4.6 Marshal flow of Fly Ash Modified Asphalt

The Plate 7 shows the result of fly ash modified asphalt. From the result, it was observed that there was initial decrease in flow value with increase in bitumen content which increased with higher bitumen content. The optimum flow values of 3.50 mm, 3.40 mm, 2.90mm and 2.80 mm were obtained with 2%, 4%, 6% and 8% partial replacement with fly ash. The flow values conformed to Nigeria General Specification for Road and Bridge (NGSRB, 2016) which specify (2-4mm) as standard limit accepted for wearing course in production of asphalt concrete.

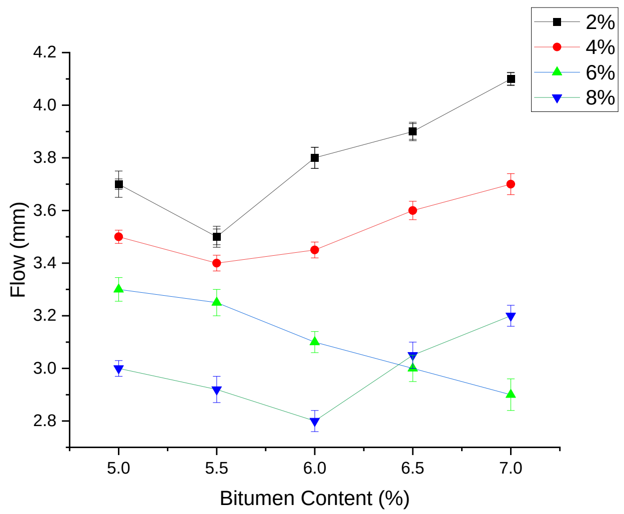

Plate 7: Marshal Stability of Fly ash Modified Asphalt against Bitumen Content

5.0 CONCLUSION

Based on the characterization of materials used, including aggregates, fillers, bitumen, steel slag, and fly ash, the results were evaluated against the Federal Ministry of Works and Highway Manual FMWHM, 2013. The findings met the specified requirements.

The Marshal stability and flow characteristics of steel slag-modified asphalt concrete were assessed against the Nigeria General Specification for Road and Bridge. The results indicated that the addition of steel slag improved the asphalt concrete produced, meeting the specified standards.

Similarly, the Marshal stability and flow properties of fly ash-modified asphalt concrete were compared with the Nigeria General Specification for Road and Bridge. The results demonstrated enhancements in the developed asphalt concrete, aligning with the specified criteria.

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