



EVALUATION OF MARSHAL STABILITY AND FLOW OF HYBRID MODIFIED ASPHALT CONCRETE

¹Ezemenike, C. S. , ¹Aderinlewo, O. O. , ²Oladele, I. O. and ¹Oyedepo, O. J.

¹Department of Civil Engineering Federal University of Technology Akure.

²Department of Metallurgical Materials Engineering Federal University of Technology Akure.
Ezestan2013@gmail.com .

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Abstract

Highway engineers and researchers are constantly trying to enhance the performance of asphalt concrete pavement, in order to keep up with the global adequate and sustainable highway infrastructure drive. Modification of asphalt concrete could improve certain properties of the mixture and reduce cost of road construction materials. In this research, evaluation of Marshal Stability and flow of hybrid asphalt modified concrete was studied, the wastes from various industries such steel industry, plastic industry and coal-fired power plant industries were combined together to form hybrid composite. Steel slag, fly ash, waste plastic, aggregate and bitumen were used to produce the asphalt concrete in a hybrid manner to evaluate effect of stability and flow properties of asphalt concrete mixture. The physical properties of steel slag, fly ash aggregate, bitumen and waste plastic based polypropylene were determined by carrying out tests such as sieve analysis, moisture content, flakiness and elongation, aggregate impact, aggregate crushing, specific gravity, hygrometer, penetration, softening point, flash and fire point, viscosity, ductility and water-in-bitumen test. Bitumen with penetration grade 60/70 was used and the content varied from 5.0 to 7.0 % at 0.5% interval. A cylindrical sample with the composite mixture of asphalt concrete was produced using varying proportions of hybrid composite which comprises of steel slag (SS) and fly ash (FA) at 2%, 4%, 6% and 8% by weight of the asphalt concrete to partially replace the conventional materials (aggregate and filler) and bitumen which was partially replaced with polypropylene (PP) at 5%, 10%, 15% and 20% respectively. The Marshal Stability test conducted on the hybrid composite asphaltic concrete gives optimum stability values of 10.50 kN, 12.50 kN, 12.30 kN and 13.50 kN and optimum flow values of 3.30 mm, 2.80 mm, 2.80 mm, and 2.70 mm at 2%, 4%, 6% and 8% respectively. Comparing with Asphalt Institute specification, the non-conventional material used as fillers, coarse and fine aggregate can be conveniently used in light, medium and heavy traffic. Based on the findings, the application of these wastes material which constitute higher stability and flow will improve the properties of asphalt concrete, reduce the cost of constituent material and decrease environmental problem that arise from various industries.

Keyword: Asphalt concrete, hybrid composite, waste, stability and flow

Introduction

The traffic volume in Nigeria has increased and this has resulted in higher stresses in asphalt concrete pavement (Jaya, 2015). The rise in private vehicle ownership, poor road usage attitude, bad road maintenance culture, noticeable variation in daily and seasonal temperature of pavement and overloading of trucks have caused major higher traffic density which has consequently led to the development of distresses such as permanent deformation, pot-holes, rutting, fatigue failure, shoveling and raveling in the surface of asphalt (Tomar and Koshta, 2013).

The aim of asphalt pavement is to provide smooth surface over which vehicle can move from one place to another. These asphalt pavements must fulfill the responsibility of transferring the wheel loads to subgrade such that its bearing capacity is not exceeded. However, it is essential to modify the asphalt concrete mixture to make it more resistant to distresses especially permanent deformation and rutting. One of the most important properties of the asphalt

concrete mixture is its ability to resist shoving, rutting and other stresses under traffic. Therefore, stability should be high enough to handle traffic adequately. When stability is low, it causes raveling and flow (which is the ability of a hot mixture asphalt pavement to adjust to gradual settlements and movements in the sub-grade without cracking) of the road surface (Shiva *et al.*, 2012).

The construction and rehabilitation of highway and developments of several expressways exert great pressure on the natural materials being used. Many researchers are trying to explore the suitability of industrial and agro waste for the production of asphaltic concrete. Numerous waste materials result from every aspect of society including manufacturing, service industries, sewage treatment plants, households and mining are enormous. The use of the discarded waste will reduce the environmental pollution caused by these wastes; reduce the dependency on the non-biodegradable waste, which in turn reduce the construction cost. Materials such as fly-ash from

thermal power plants and other coal fired industries, blast furnace slag from steel industries, cement kiln dust from cement related industries, and polypropylene from plastics industry, phosphogypsum from phosphatatic fertilizer industries, and many other solid wastes have already proved to be useful for road construction in many countries (Brajesh and Ravi, 2015).

Debashish *et al.* (2014) explore the use of fly ash, a by-product of a coal based thermal power plant in bituminous paving mixes. They recommended the use of fly ash wherever available, not only reducing the cost of execution, but also partly solve the fly ash utilization and disposal problems. Raval *et al.* (2014) studied Influence of Modify Bituminous Mix with Fly Ash, it was found that Marshall Stability value, which was the strength parameter of bituminous mixes was increased about 25 % by the addition of fly-ash. Sowmya *et al.* (2019) studied Utilization of Copper Slag in Bituminous Concrete with a Stone Dust and Fly ash as a Filler Material; it was found that the Marshall stability was higher for the stone dust as a filler material as compared to the fly ash mix.

Aziz *et al.* (2020) investigated the performance of Steel slag in highway industry; they also concluded that the steel slag aggregate in asphalt mixture resulted in several benefits that outperformed conventional aggregate in terms of stiffness resistance, rutting and fatigue life of the pavement. Also, Muralidhara *et al.* (2020) analyzed the flexible pavement with steel slag as coarse aggregate; the results showed that addition of natural aggregate with SS provides better results in asphalt concrete. The findings of these studies indicate that slag-based asphalt mixtures are ideal for flexible pavement structures and it's better than the traditional asphalt mixtures made with natural aggregates. Adil and Saadoon, (2019) studied the use of cement production waste to enhance the properties of hot mix asphalt concrete, and considered cement kiln dust as non-conventional filler. The result indicated that cement kiln improved fatigue life, rutting, mix cohesion and marshal stability of asphaltic concrete mixture.

In addition Satish and Rajan, (2010) examined the performance characterization of bituminous concrete with industrial waste as a filler in which they used granite, marble dust and fly ash as non-conventional filler and the results showed that fly ash, granite and marble dust could be favourably used as filler in asphaltic concrete mixture. Ogundipe, (2019) considered the use of polyethylene terephthalate (PET) waste for modifying asphalt concrete, the results reveals that the introduction of PET waste improved the permanent deformation resistance of asphalt and reduce fatigue resistance of the mix. Hybrid composite asphalt concrete is defined as the asphalt concrete containing two or three or more kinds of single non-

constitutes or non- conventional material. Although hybrid composite is widely used in cement materials, it is really a new concept applied in asphalt concrete. It has gradually attracted the attention of the researchers and some achievements have been made about this new method (Wang *et al.*, 2007).

The findings of these studies indicate that non-conventional materials such as steel slag, fly ash and waste plastic based polypropylene in a hybrid manner are ideal for flexible pavement structures and they especially outperform traditional asphalt mixtures made with conventional materials. However the use of non-conventional material as alternative replacement to conventional in asphalt concrete will be taken into consideration. The understanding of the composition and physical properties of the specific non-conventional material being investigated is important. It is also necessary to carry out a comprehensive research based on local material and conditions of the feasibility of using SS being generated by steel making factory in Nigeria, FA generated from coal thermal station in Enugu and waste plastic chairs (polypropylene) generated in our environs as partial replacement for conventional aggregate in asphalt concrete mixture. Thus, this research evaluated the performance of asphalt concrete by utilizing steel slag, fly ash and polypropylene as alternative to aggregate, filler and bitumen in the mixture.

Materials and Method

The materials and method used to carry out this research are discussed in subsequent sections;

Materials

Aggregate, Steel Slag (SS), fly ash (FA), Polypropylene (PP) and Bitumen are materials utilized for this study. Aggregate was procured from RCC and JCC quarry, Oba-Ile, Ondo State, Nigeria. Ife Steel and Iron Company located in Ile-Ife, Osun State, Nigeria was where the steel slag (SS) used was sourced from. The 60/70 penetration grade Bitumen was obtained from K.K. Hassan Construction Company in Akure, Nigeria. Fly ash was obtained from burning chambers around the vicinity of the thermal station in Oji river town, Enugu Nigeria, while the waste plastics chairs which are Polypropylene based were collected from Akure metropolis.

Processing of the Constituent Materials

The pulverized SS was sieved to obtain the size range of 150 μ m to 10 mm. This was performed to guarantee steel slag used as aggregate in fine and coarse form to replace conventional aggregate at proportion of 2%, 4%, 6% and 8% by weight of the bitumen. The waste plastic chairs were ground to obtain powdered Polypropylene with particle size passing 0.0015.

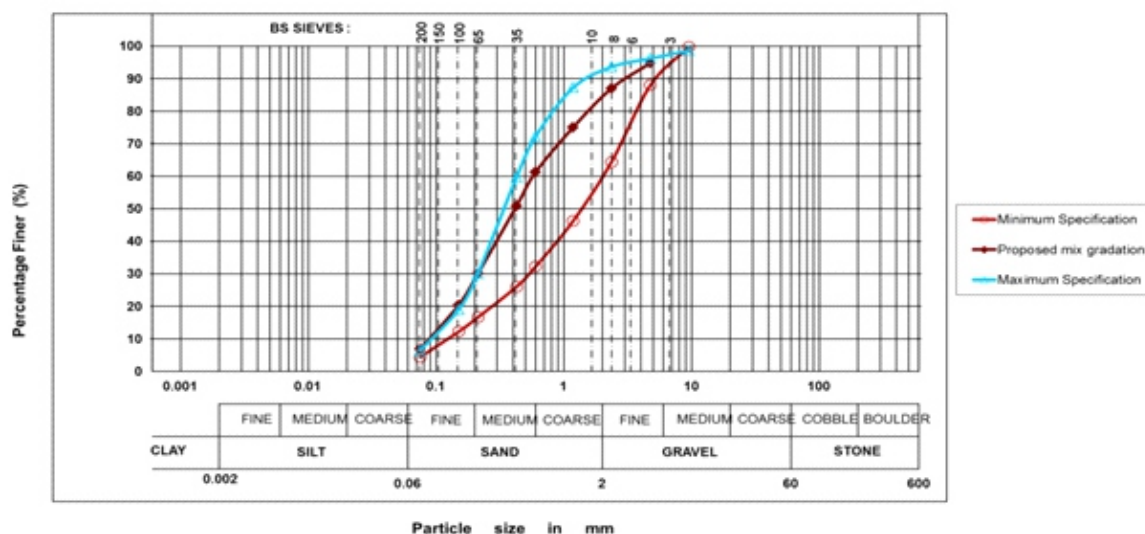


Figure 1: Particle Size Distribution Curve for the Aggregates

From the particle distribution curves in Figure 1, the Uniformity coefficient C_U and Coefficient of gradation C_C can be determined using Equations 1 and 2 according to ASTM D 728-17, 2017

$$\text{Uniformity coefficient } C_U = \frac{D_{60}}{D_{10}} \quad (1)$$

Where D_{60} diameter of aggregate particles is for which 60% are finer and 40% are coarser

D_{50} is the average particle size

D_{30} is the diameter of aggregate particles for which 30% are finer and 70% are coarser

D_{10} is the diameter of aggregate particles for which 10% are finer and 90% are coarser

From Figure 1, $D_{60} = 4$, $D_{30} = 0.7$, $D_{10} = 0.3$

To determine the uniformity coefficient, from Equation 1

$$C_U = \frac{D_{60}}{D_{10}} = \frac{4}{0.3} = 13.33$$

The aggregate sample is a well graded sample because C_U is greater than 4 and poorly or uniformly graded aggregate when it is less than 4.

$$\text{Coefficient of gradation } C_C = \frac{D_{30}^2}{D_{60} \times D_{10}} \quad (2)$$

$$C_C = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.7^2}{4 \times 0.3} = \frac{0.49}{1.2} = 0.588$$

$$C_C = 0.588$$

Based on the coefficient of gradation C_C , the aggregate is classified as well graded because aggregate sample with C_C , in the range of 0.5 to 3 is classified as well graded aggregate.

Characterization of Aggregates, Fly ash and Steel Slag

The result, as shown in Table 1, reveals the physical properties of the aggregates, the steel slag and fly ash used. Based on the Nigeria General Specification for Road and Bridges FGN, (1997) the values obtained for each parameter property falls within the specified range for road surfacing. It can also be observed that the steel slag has lower moisture content, AIV and ACV values as compared to that of the aggregates.

Table 1: Summary of Results on the Aggregates, Steel Slag and Fly ash

S/N	Materials	Moisture Content (%)	AIV (%)	ACV (%)	Gs (g)	Flakiness and Elongation index test (%)
1	Aggregates	0.65	22.20	30.18	3.0	20.64
2	Steel slag	0.46	20.50	28.73	3.32	25.31
3	Fly ash	1.613	-	-	2.305	-
	FMWHM, 2013 Specifications	Max 5	20-30	27-35	-	Max 30

Characterization of Bitumen and Modified Bitumen

The physical properties of bitumen and modified bitumen were determined by carrying out tests such as penetration, softening point, flash and fire point, viscosity, ductility, and water-in-bitumen. Table 2

shows the result of penetration, softening point, flash and fire point, viscosity, ductility and water in bitumen tests. From the result, it is observed that all conform to the standard limit in Table 3 according to ASTM.

Table 2: Result of Physical Properties of Bitumen and Modified Bitumen

Polypropylene (%)	Penetration (dmm)	Softening point (°C)	Flash point (°C)	Fire point (°C)	Ductility (cm)	Viscosity (sec)	Water-in-bitumen (%)
0	62	46	207	252	97	129.4	3.4
5	56	48	216	262	114	135.5	2.8
10	46	52	228	268	134	141.8	2.5
15	38	56	234	276	142	150.1	2.1
20	29	66	247	285	148	159.9	1.8
Standard Limit	60-70	49-56	280 Min	320 Max	100Min	300Min	5 Max

The Marshal Result of the Hybrid Composite

The results of marshal properties of hybrid composite are discussed below:

Marshal Stability of Modified Asphalt

The variation of the stability values is shown in Figure 4; it was found that the stability increases from increasing bitumen content up to optimum content of hybrid composite and thereafter decreases. The improvement of stability in hybrid composite modified asphalt mixture can be attributed to the result of the strength improvement of the combination of steel slag, fly ash, and polypropylene. This will enhance higher fatigue resistance, improved thermal stress cracking, decrease in temperature susceptibility and reduction of rutting. This optimum bitumen content was found to be 6.0% at 2%, 4%, 6% and 8% of hybrid composite respectively. The optimum marshal stability values of 10.50 kN, 12.50 kN, 12.30 kN and 13.50 kN respectively were obtained with 5%, 10%,

15%, and 20% partial replacements with hybrid composite. The percentages were suitable for light, medium traffic and heavy traffic roads in accordance with Asphalt institute (1997) as shown in Table 4.

Flow of Modified Asphalt

The flow results of polypropylene modified asphalt concrete are shown in Figure 5. It was observed that there was a decrease in flow values as increasing in hybrid content. This may be attributed to the reduction in viscosity of the binder with increase hybrid composite content. The optimum flow values of 3.30 mm, 2.8 mm, 2.8 mm and 2.7 mm were obtained with 2%, 4%, 6% and 8% partial replacement with hybrid composite. The flow values conformed to Nigeria general specification for road and bridge (1997) which stated that maximum of 4mm to minimum of 2mm is the acceptable range for wearing course in production of asphalt concrete

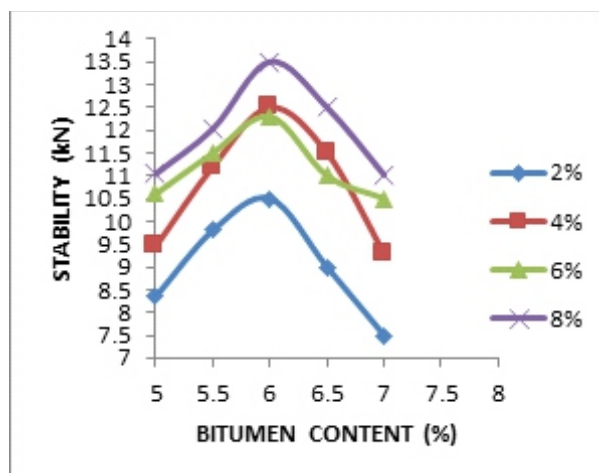


Figure 4: Stability against bitumen content

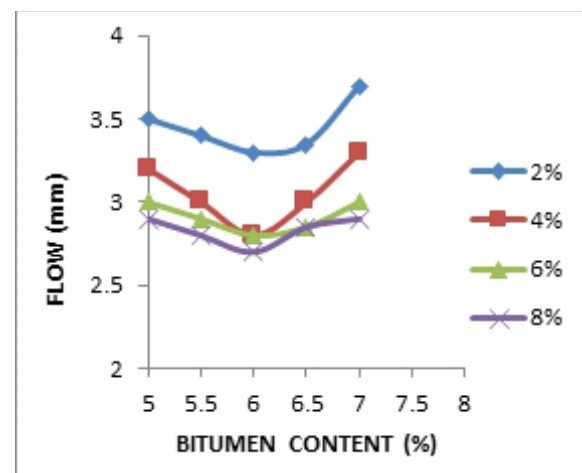


Figure 5: Flow against bitumen content

Table 4: Typical Bituminous Marshall Design Criteria

Mix Specification	Heavy traffic (greater than 10 ⁶ ESALS)		Light traffic (less than 10 ⁴ ESAL)		Medium Traffic (10 ⁴ -10 ⁶ ESAL)	
	Min	Max	Min	Max	Min	Max
Stability (minimum)	6672N	-	2224N	-	3336	-
Flow (0.25mm)	8	16	8	20	18	-
Air voids (%)	3	5	3	5	3	5
Compaction (50 blows each side of specimen)	35	-	50	-	75	-

Note: ESAL is the Equivalent Single Axle Load; Source: Asphalt Institute (1997)

Other Marshal Properties

Figure 6 shows the bulk density against the bitumen content. It can be seen that 8% hybrid composite have optimum values than other percentages, this could be as a result of presence of steel slag which contain iron and steel in the composite mixture. Figure 7 shows the air void against the bitumen content; it can be deduced that varying proportions of 2%, 4%, 6% hybrid composite were 6.0% optimum binder content while 8% proportion of hybrids composite are 6.5% which mean that more percentage of these constitutes that made of hybrid composite could fills voids in asphalt concrete mixture. Figure 8 shows void in mineral

aggregate. It can be seen from result that the optimum bitumen percentage of 6.0 were obtained by varying proportions of 2%, 4%, 6% while optimum of 6.5 were obtained at 8% of hybrid composite. Figure 9 shows the void filled with bitumen against the bitumen content. It can be seen that the voids filled with bitumen increases with increasing bitumen content until it decreased at optimum bitumen content of 6.0% at 2%, 4% 6% of hybrid composite while optimum bitumen content 6.5 also obtained with 8% of hybrid composite. This may be attributed to the improved bonding achieved as a result of asphalt surface modification and the stiffening effect.

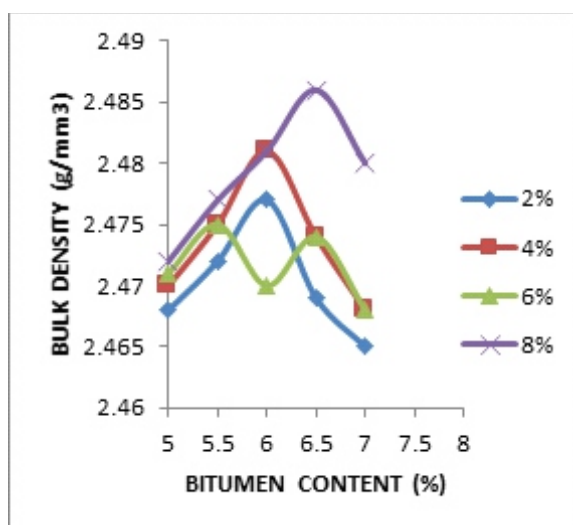


Figure 6: Bulk densit against bitumen content

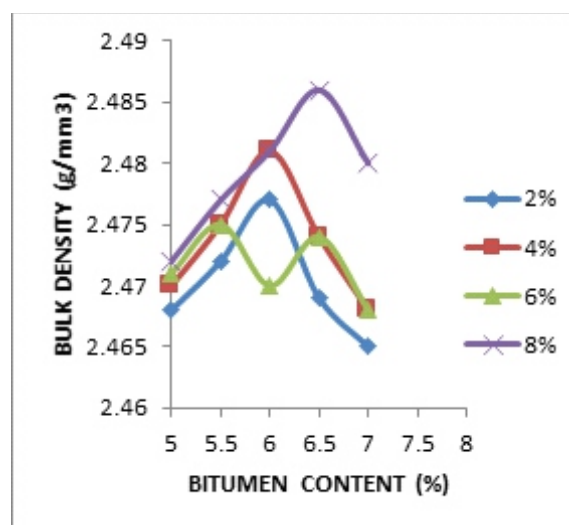


Figure 7: Air void against bitumen content

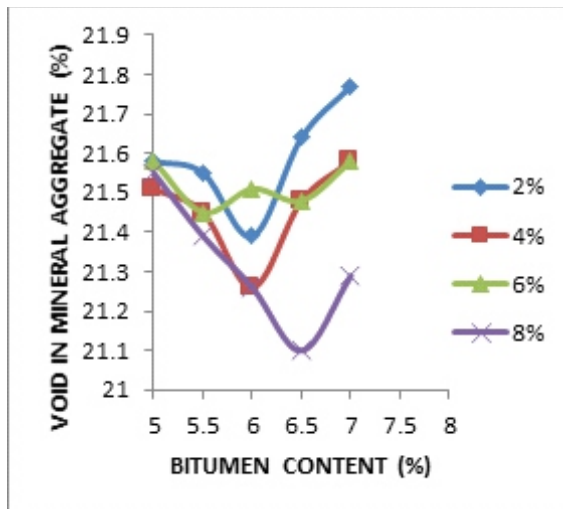


Figure 8: VMA against bitumen content

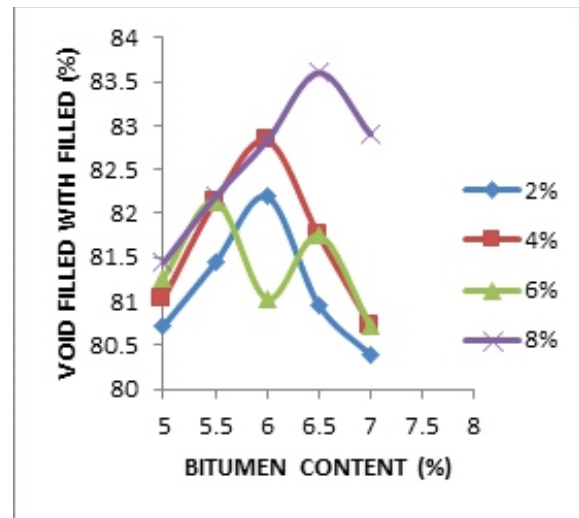


Figure 9: VFB against bitumen content

Conclusion

The experimental study revealed that the varying proportion of 2%, 4%, 6% and 8% of hybrid composite can be suitable for light, medium and heavy traffic when compare with asphalt institute mix design. It is also revealed that optimum bitumen content of 6% were obtained at 2%, 4%, 6% of hybrid composite while optimum bitumen content of 6.5% were obtained at 8% of hybrid composite. This has been conveniently shown that these constituted materials such as steel slag, polypropylene, fly ash that made of hybrid composite can be utilized as aggregate, bitumen and fillers because they improved the performance of asphalt concrete mixture by attaining higher stability and flow.

References

- Adil, A and Saadoon, E. (2019). The use of Cement Production Waste to Improve the Properties of Hot Mix Asphalt Concrete. *Journal of Civil Engineering*, 13(3): 394-404
- ASTM, (2019): Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.
- ASTM, (2013). Standard Test Method for Penetration of Bituminous Material. American Society of Testing and Materials International West Conshohochen.
- ASTM, (2016). Standard Test Method for Flash and Fire Point by Cleveland Open Cup Tester. American Society of Testing and Materials international West Conshohochen.
- ASTM, (2017). Standard Test Method for Ductility of Asphalt Materials. American Society of Testing and Materials international West Conshohochen.
- ASTM, (2017). Standard Test Method for Particle Distribution (Gradation) of Fine-Grained Fillers using Sedimentation (Hydrometers) Analysis. American Society of Testing and Materials international West Conshohochen.
- ASTM, (2005). Standard Test Method of Water in Petroleum Product and Bituminous Materials by Distillation. American Society of Testing and Materials International West Conshohochen.
- ASTM, (2006). Standard Test Method for Marshal and Flow of Bituminous Mixtures. American Society of Testing and Materials international West Conshohochen.
- ASTM, (2010). Standard Test Method for Kinematic Viscosity of Asphalt (Bituminous). American Society of Testing and Materials international West Conshohochen.
- ASTM, (2012). Standard Test Method for Density, Relative Density (Specific Gravity) and Absorption of Coarse Aggregate. American Society of Testing and Materials International West Conshohochen.
- ASTM, (2014). Standard Test Method for Softening Point of Bitumen (ring and ball Apparatus)". American Society of Testing and Materials international West conshohochen
- Asphalt Institute, (1997). Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types (MS2). The Asphalt Institute, 6th Ed
- Aziz, M.M, Shokri, M., Ahsan, A. Liu, H.Y, Tay, L. and Muslim, N.H (2020). An Overview on Performance of Steel Slag in Highway Industry, *Journal of Advanced Research in Materials Science*, 67(1): 1-10.
- Brajesh, M and Ravi, S.M (2015). A Study on use of Industrial Waste in Rural Road Construction, *International Journal of Innovation Research in Science, Engineering and Technology*, 4(11): 10387-10398.

- Debashish, K., Mahabir, P., and Jyoti, P. G. (2014). Influence of Fly-Ash as a Filler in Bituminous Mixes, *ARPJ Journal of Engineering and Applied Sciences*, 9 (6): 895-900.
- FGN, (1997). Government of the Federal Republic of Nigeria, General Specifications (Roads and Bridges), Volume II, 1997
- FMWHM, (2013). Federal Ministry of Work Highway Manuel, General Specifications (Roads and Bridges).
- Jaya, R. S. (2015). Determination of Binder Film Thickness for Bituminous Mixture. *6th International Conference on Structural Engineering and Construction Management*, University of Motunrawa, Kandy, Srilanka, 31-37.
- Muralidhara, R, Varsha .S. D. and Vivek .R. D. (2020). Analysis of Flexible Pavement with Steel Slag as Coarse Aggregate, AIP Conference Proceedings 2204, 020015 (2020), Department of Civil Engineering, MVJ College of Engineering, Bangalore
- Ogundipe, M.O, (2019). The use of Polyethylene Terephthalate Waste for Modifying Asphalt Concrete using Marshal Tests, *Slovak Journal of Engineering and Applied Sciences*, 27 (2): 9-15.
- Raval, N.G, Katara, S.D. and Modiya, C.S (2014). Influence of Modifying Bituminous Mix with Fly Ash, *International Journal of Engineering and Technical Research*, 2(4): 184-186.
- Satish, C. and Rajan, C. (2010). Performance Characteristics of Bituminous Concrete with Industrial Wastes as a Filler, *Journal of Material in Civil Engineering*, 25(11): 1666-167.
- Shiva, P.K, Manjunath, K.R. and Prasa, V.R (2012). Study of Marshal of Stability Properties of BC Mix Used in Road Construction by adding Waste Plastic Bottles, *Journal of Mechanical and Civil Engineering*, 2(2): 12-23.
- Sowmya, N.J, Asad, I, Awais, B. and Shahid, A. (2019). Utilization of Copper Slag in Bituminous Mix, *Pakistan Journal of Engineering and Technology*, 2(2): 30-37.
- Tomar, R. and Koshta, K. (2013). Effects of Fillers on Bituminous Paving Mixes. *International Journal of Engineering Research, Science and Technology*, 2(4): 2391-2397.
- Wang J, Li C, Fan X. and Zhang, M (2007). Flexural Fatigue Behavior of Layered Hybrid Fiber Reinforced Concrete, *Journal Wuhan University of Technology*, 22(3): 560-563.