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Evaluation of the Stability and Flow of Asphalt Concrete Produced with Waste Brick Tile Powder as a Filler

John Ayibatunimibofa TrustGod[1], Ebuka Nwankwo[2,*]

[1] Department of Civil Engineering, Faculty of Engineering, Niger Delta University, Amassoma, Nigeria
[2]Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Nigeria
johntrustgod@ndu.edu.ng[1], ebuka.nwankwo@uniben.edu.ng [2]

ABSTRACT

The utilization of recycled brick tile powder as a replacement for conventional filler in the asphalt concrete mix has been studied in this research. This research evaluates the effectiveness of recycled brick tile powder and determines its optimum replacement level. Using recycled brick tile powder is significant from an environmental standpoint as it is a waste product from construction activities. Sixteen asphalt concrete samples were produced, and eight were soaked for a day. Samples contained 5% Bitumen, 2% to 5% brick tile powder, and conventional stone dust filler. The properties of samples were evaluated using the Marshall test. It was observed that the resistance to stiffness and deformation of asphalt concrete was increased by 99% when the conventional filler was replaced with brick tile powder. The resistance to deformation decreases as the percentage of brick tile powder increases while Marshall stability values increase significantly. At an optimum content of 4% recycled brick tile powder as filler, the Marshall stability is increased by 123%. Based on this investigation, it is established that brick tile powder can be effectively used in asphaltic concrete as a filler. This presents a sustainable solution to waste utilization and pavement performance.

Keywords: Stability, Flow, Recycled, Brick tiles, Stone dust, Fillers, Asphalt concrete.

*Corresponding author
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تقييم استقرار وتدفق الخرسانة الإسفلتية المنتجة بمسحوق قرميد نفايات الحشو

جون ايباتونيميبوفا ترست كاد[1] ، إبوكا نوانكو[2]، *

[1] قسم الهندسة المدنية، كلية الهندسة، جامعة بنين، نيجيريا
[2] قسم الهندسة المدنية، كلية الهندسة، جامعة دلتا النيجر، نيجيريا

الخلاصة

دُرِسَ استخدام مسحوق بلاط القرميد المعاد تدويره كبديل للحشو التقليدي في خليط الخرسانة الإسفلتية في هذا البحث. يُقَيِّم هذا البحث فعالية مسحوق بلاط القرميد المعاد تدويره ويحدد مستوى الاستبدال الأمثل له. يعد استخدام مسحوق بلاط القرميد المعاد تدويره أمرًا مهمًا من وجهة نظر بيئية لأنه ينتج نفايات من أنشطة البناء. تم إنتاج ستة عشر عينة من الخرسانة الإسفلتية ، ونقع ثمانية منها لمدة يوم واحد. احتوت العينات على 5٪ بيتومين ، 2٪ إلى 5٪ مسحوق قرميد ، وحشو غبار تقليدي. تم تقييم خصائص العينات باستخدام اختبار مارشال. لوحظ أن مقاومة الصلابة والتشوه للخرسانة الإسفلتية زادت بنسبة 99٪ عندما تم استبدال الحشو التقليدي بمسحوق القرميد. تقل مقاومة التشوه مع زيادة النسبة المئوية لمسحوق بلاط القرميد بينما تزداد قيم استقرار مارشال بشكل كبير. في المحتوى الأمثل من مسحوق بلاط القرميد المعاد تدويره بنسبة 4٪ كمواد مالئة ، يزداد استقرار مارشال بنسبة 123٪. بناءً على هذا التحقيق ، ثبت أنه يمكن استخدام مسحوق القرميد بشكل فعال في الخرسانة الإسفلتية كمواد مالئة. يقدم هذا حلاً مستدامًا لاستخدام النفايات وأداء الرصف.

الكلمات المفتاحية: الاستقرار ، التدفق ، اعادة التدوير ، قرميد الآجر ، غبار الحجر ، الحشو ، الخرسانة الإسفلتية.

1. INTRODUCTION

The continuous dumping and accumulation solid waste, for instance, bricks, glass, concrete, stones, steel, plastic, etc., is one of the most alarming environmental threats. Waste disposal has to be expanded in accordance with the precipitous rise in waste production caused by infrastructure development **(Ghasemi and Marandi, 2013)**. Effective management of these wastes is essential for improving the quality of life. The majority of solid waste is generated from demolition and construction waste. Disposing of that volume of solid waste has become an alarming issue in developing nations. To have effective management of these waste materials, several investigations have been conducted to evaluate the usefulness of various wastes as alternative materials in asphalt concrete, such as demolition and construction waste **(Taha et al., 2002; Mahyar and Alireza, 2012; Sutradhar et al., 2015; Souliman and Eifert, 2016).**

Recycling construction waste into suitable building materials has emerged as the primary method for solving waste management problems. As a result, an investigation into novel and state-of-the-art applications for construction waste is strongly supported. Several transportation and highway authorities are carrying out different research projects to assess the environmental condition, feasibility, and strength properties of employing waste materials in road development. Identifying an application for construction waste is both economically and environmentally beneficial. Using waste materials in road development can help save natural resources and minimize environmental threats. Construction and demolition waste materials can be employed in road pavement, such as surface course, sub-base, and base. The practicality of applying construction waste materials in road development has been examined for lower layers of road pavement **(Molenaar and Van, 2002; Xuan et al., 2012; Basha et al., 2020; Poon and Chan, 2012).**

The application of different waste materials, such as waste lime, fly ash, brick blocks, waste glass, and waste cement dust, has been studied to substitute conventional filler in asphalt concrete production. It has recently been established that these wastes can enhance the strength properties of asphalt concrete and have no adverse effect on the mix. **(Serkan, 2008; Hwang et al., 2008; Chen et al., 2011; Arulrajah et al., 2012).** According to **(Chen et al., 2011),** the performance of an asphalt mix with brick powder as a filler was considered better than that of asphalt concrete containing limestone filler in terms of stiffness, fatigue, water sensitivity, and creep. **(Ahmed et al., 2006)** examined the option of employing waste cement powder instead of stone dust in the mix proportions of 0, 25, 50, 75, and 100% by weight. The test includes the evaluation of strength properties by the Marshall test. The findings demonstrate that flow decreases and stability increases as the amount of waste cement dust in the mix increases. The authors reported that the optimum replacement level was 100%, meaning cement completely replaces the stone dust. **(Khaled and Ahmed, 2009)** investigated waste white cement power as a substitution for stone dust in asphalt concrete in the percentages of 0, 2, 4, 6, and 8 % by weight. The samples were subjected to Marshall testing. The authors reported that 4 % of waste white cement dust is an optimum substitution for stone dust. **(Sutradhar et al., 2015)** reported that asphalt concrete with brick powder as filler shows practically the same strength properties as asphalt concrete with stone dust, according to the Marshall test. The authors concluded that recycled brick powder of up to 0.075 mm in size could be considered as a substitute for filler. **(Taherkhani and Bayat, 2016)** reported that the stability of asphalt concrete with brick powder as a filler is more significant than conventional filler, with the maximum stability for asphalt concrete with 25% of the brick powder.

In this work, the stability and deformation of asphalt concrete mixes, in which the conventional filler has been substituted with recycled brick tile powder, have been studied to evaluate the effectiveness and the optimum replacement level.

2. MATERIALS AND METHOD

2.1 Materials

The materials used in this study area were asphalt binder, brick tile powder, fine aggregate, and coarse aggregate. In addition, the following materials were used:

2.1.1 Bitumen

A Bitumen of 60/70 penetration grade supplied by Ringardas Nigeria Limited was used in this study. The asphalt binder was subjected to laboratory tests according to **(ASTM D5, 2006; ASTM D36/D36M, 2012; and ASTM D92, 2018)**.

2.1.2 Aggregates

Fine and coarse aggregates of bulk specific gravity of 2.67 and 2.72, respectively, were considered in the production of the asphaltic concrete samples. This study's adopted coarse aggregate gradation confirms **(BS EN 933-1, 2012)**. Tests carried out on the aggregates are Size and gradation **(BS 812-2, 1995)**, aggregate specific gravity **(ASTM, C128, 2022)**, and water absorption **(BS 812-2, 1995).**

2.1.3 Filler

Waste brick tile powder (BTP) was considered a mineral filler and was used as a percent of 0, 2, 3, 4, and 5 % of limestone. As a reference, conventional filler (stone dust) of 0, 2, 3, 4, and 5 % was used as a standard. Tests were conducted to appropriate codes on the BTP used to examine their properties: fineness test **(BS EN 196-6, 2018)** and specific gravity. The chemical properties of the BTP filler used in this research are given in **Table 1.**

Table 1. Significant components of clay bricks **(Osarenmwinda and Abel, 2014)**

Oxide	Weight (%)	Oxide	Weight (%)
Al_2O_3	17.75	MgO	0.6
CaO	0.72	MnO	0.03
Cr_2O_3	0.04	Na_2O	0.8
Fe_2O_3	11.8	SiO_2	53.9
K_2O	3.3	ZnO	0.9

2.2 Methodology

Sixteen (16) asphaltic concrete samples based on the design proportions of materials i.e., Bitumen (5%), filler (ranged between 2 to 5%), coarse and fine aggregates (ranged between 90 to 95%) by weight, were produced with BTP and stone dust (STD), respectively. The fine and coarse aggregates were proportioned in a ratio of 2:3 in the asphaltic concrete mix. The asphaltic concrete samples were produced separately in 2, 3, 4, and 5% proportions of BTP and STD. **Fig. 1** shows the sample configurations and waste brick tile powder, respectively. Eight (8) samples: BTPS2, BTPS3, BTPS4, BTPS5, STDS2, STDS3, STDS4, and STDS5, as shown in **Table 2,** were soaked in water for 24 hours to investigate the stability and flow in a situation where the pavement is submerged in water. The remaining 8 samples were not submerged in water and are described as unsoaked. All the samples were produced according to **ASTM D6926-15**. Applying 75 blows on each side of the specimen was carried out. The stability and flow properties of the specimen containing BTP and STD were examined by conducting a Marshall stability test according to **ASTM D6927-15**. The compacted asphalt samples were conditioned in a water bath at 60 ^{o}C for 30-35 minutes and placed in a Marshall breaking head. The Stability and flow were measured during the test.

Figure 1. Waste brick tile power

Table 2. Sample configurations (distribution of mixture by weight)

Sample ID	Configuration	Filler content %	Bitumen content (%)	Aggregate (fine and coarse) (%)
BTPU2	unsoaked	2.0	5.0	93
BTPU3	unsoaked	3.0	5.0	92
BTPU4	unsoaked	4.0	5.0	91
BTPU5	unsoaked	5.0	5.0	90
BTPS2	soaked	2.0	5.0	93
BTPS3	soaked	3.0	5.0	92
BTPS4	soaked	4.0	5.0	91
BTPS5	soaked	5.0	5.0	90
STDU2	unsoaked	2.0	5.0	93
STDU3	unsoaked	3.0	5.0	92
STDU4	unsoaked	4.0	5.0	91
STDU5	unsoaked	5.0	5.0	90
STDS2	soaked	2.0	5.0	93
STDS3	soaked	3.0	5.0	92
STDS4	soaked	4.0	5.0	91
STDS5	soaked	5.0	5.0	90

3. RESULTS AND DISCUSSION

The laboratory test results of the stability and flow of asphaltic concrete produced with waste brick tile powder as filler are discussed below**.**

3.1 Results of Test on Bitumen

The results of the tests conducted on the unmodified Bitumen are given in **Table 3.** Referring to **Table 3**, the penetration result fails within the specification for paving grade as 60/70 penetration grade Bitumen by the **(Federal Ministry of Works and Housing, 2016)**. **Table 3** also includes the results of a flash point test. The average flash and softening points are between 230 to 300°C and 46 to 54°C, respectively. Test results of ductility, solubility, and specific gravity are also shown in **Table 3**, and the results are within the range specified by the codes. This implies that the selected Bitumen is suitable for the production of asphalt concrete.

Table 3. Results of Tests on Bitumen

Test	Unit	60-70 Grade		Result
		Min	Max	
Softening point	**°C**	46	54	49.8
Flash point	**°C**	230	300	278
Penetration Grade @25 °C	0.1mm	60	70	65
Solubility in trichloroethylene	%WT	99		100
Specific gravity @ 25 °C		1.01	1.06	1.038
Ductility @ 25 °C	CM			Greater than 100

3.2 Results of Test on Aggregates

Specific gravity and water absorption tests were performed on the aggregates to examine their suitability in an asphaltic mix. The test outcomes on fine and coarse aggregates and specification limits are given in **Table 4**. **Figs. 2 and 3.** performed the test outcomes on the aggregates and are shown in **Table 5.**

Table 4. Physical Properties of Aggregates

Test conducted	Results	Code referenced	Code Specification	Remark
Coarse Aggregate				
Specific gravity	2.72	**(ASTM C128, 2022)**	2.55 - 2.75	Ok
Water absorption (%)	0.46	**(BS 812-2, 1995)**	< 3.5%	Ok
Fine Aggregate				
Specific gravity	2.67	**(ASTM C128, 2022)**	2.55 - 2.75	Ok
Water absorption (%)	8.9	**(BS 812-2, 1995)**	< 15%	Ok

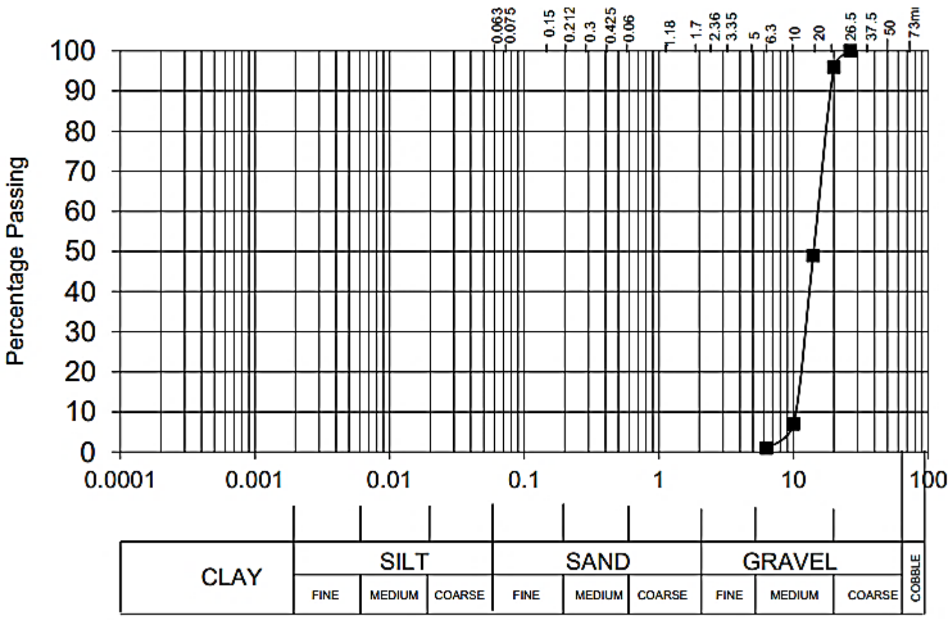

Figure 2. Particle size distribution of coarse aggregate

Table 5. Physical Properties of BTP and STD Filler

Tests conducted	Results	Code referenced	Code Specification	Remark
BTP				
Fineness (%)	3.0	BS EN 196-6:2018	< 5%	OK
Specific gravity	3.3	ASTM C188, (2017)	≥ 3.15	OK
STD				
Fineness (%)	3.5	BS EN 196-6:2018	< 5 %	OK
Specific gravity	3.18	ASTM C188: 2017	≥ 3.15	OK

The results of water absorption and specific gravity are within the specified limits of ASTM guidelines. Also, the particle size distribution graphs confirm that the coarse and fine aggregates are well-graded.

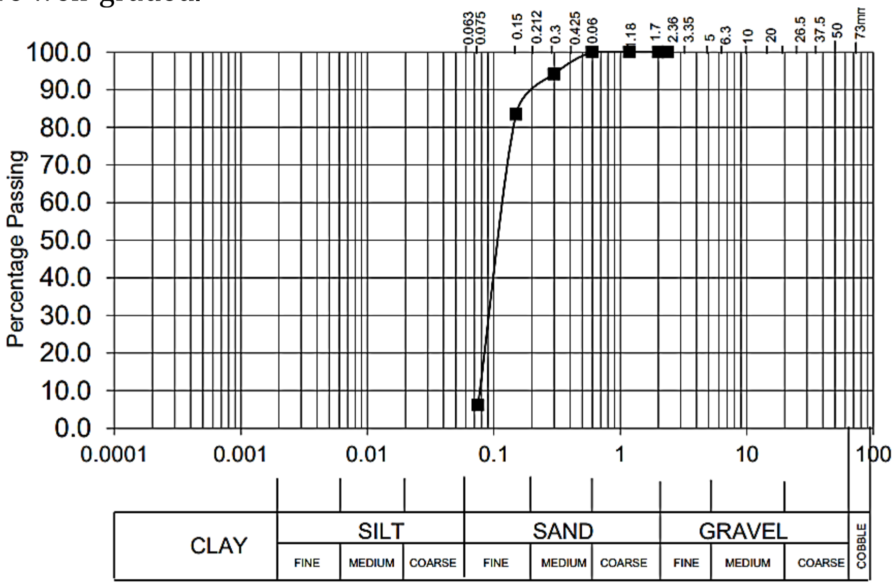

Figure 3. Particle size distribution of fine aggregate

3.3 Results of Test on Mineral Filler

The outcomes of the physical properties test on the BTP and STD considered are given in **Table 5.** It is clear from Table 5 that BTP and STD have fineness values of 3% and 3.5%, respectively, which is within the code specification. This indicates that the ground BTP and STD are appropriate for asphaltic concrete production.

3.4 Void Filled with Bitumen (VFB) and Void in the Mineral Aggregate (VMA)

The results of VFB and VMA with STD and BTP contents are presented in **Figs. 4** and **5**. It is apparent from **Fig. 4** that VMA is reduced by introducing BTP or STD to the asphalt concrete mixtures, subsequently exhibiting an increased VMA.

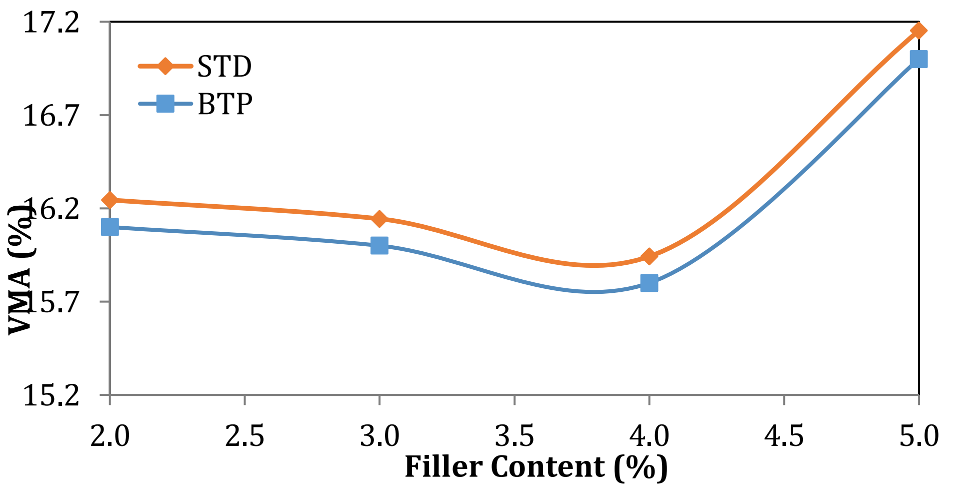

Figure 4. Alteration of VMA with filler-content

BTP as filler mixture has a lower VMA relative to STD. This pattern was similarly reported by **(Chen et al., 2011)** when the recycled brick powder was considered a mineral filler. **Fig. 5** shows that the VFB of the asphaltic concrete samples increased at first and attained maximum VFB, then decreased with increased BTP or STD content. The trend was similar to that **(Chen et al., 2011).**

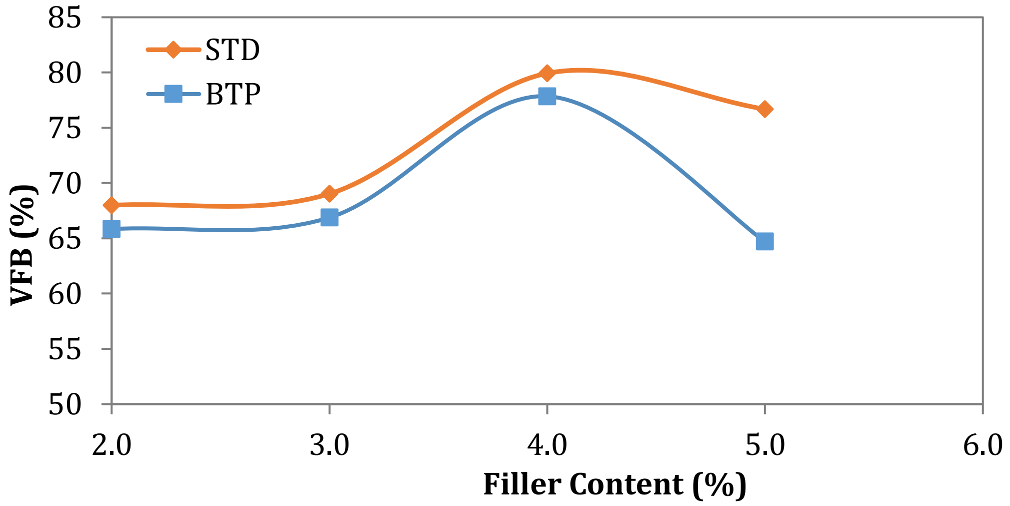

Figure 5. Alteration of VFB with filler content

3.5 Stability Results of STD for the Evaluation of Optimum Filler Content

The trend of stability results of asphalt concrete with different STD content is depicted in **Table 6**. The optimum filler content is 4% with a corresponding stability value of 8.4 kN, but when soaked, the optimum filler content, which remains 4%, has a corresponding stability of 8.1 kN. It is clear that as the filler content increases to 4%, the stability increases progressively. However, stability reduces as the content exceeds 4% in both the samples submerged and not submerged in water.

Table 6. Stability performance for STD

Sample ID	Marshall Stability (kN)	Flow value (mm)	Marshal Quotient (kN/mm)
STDU2	5.6	2.4	2.33
STDU3	5.8	3.3	1.76
STDU4	8.4	3.8	2.21
STDU5	8.2	3.6	2.28
STDS2	5.3	2.6	2.04
STDS3	5.6	3.6	1.50
STDS4	8.1	4.0	2.03
STDS5	7.8	3.7	2.11

The stability results of BTP samples are shown in **Table 7**. The stability values increase with increasing BTP content, with an ultimate stability value of 12.2 kN obtained at 5% BTP content. This result is similar to the work of (**Alves et al., 2014)**, which reported that as the waste foundry sand increases, the stability increases as well. The stability results of all the BTP samples exceed the 3.5 kN recommended by the **(NGSRB,1997),** which specifies 3.0 kN stability values for wearing surfaces**.** The study also shows that the stability of the BTP-soaked asphaltic concrete samples increases at first, reaches ultimate stability, and then reduces with an increase in BTP content.

Table 7. Stability performance for BTP

Sample ID	Marshall Stability (kN)	Flow value (mm)	Marshal Quotient (kN/mm)
BTPU2	4.6	2.2	2.09
BTPU3	9.6	3.04	3.16
BTPU4	11.8	3.50	3.37
BTPU5	12.5	3.70	3.38
BTPS2	6.2	2.28	1.84
BTPS3	9.5	3.29	2.89
BTPS4	9.7	3.28	2.96
BTPS5	9.2	3.96	2.32

3.6 Comparison of Stability and Flow Properties for STD and BTP

The stability and flow of asphalt concrete produced with STD and BTP as filler are shown in **Tables 6 and 7**. The stability of the asphalt concrete containing BTP is higher than that of the STD, with the highest stability of 12.5 kN with 5% of BTP. This finding agrees with earlier studies by **(Taherkhani and Bayat, 2016)** that investigated the properties of asphalt concrete with waste brick powder as a filler**. Fig. 6** and **Tables 6 and 7** show that at 2% BTP as filler, the Marshall stability value decreases by 17% relative to the corresponding 2% STD, while at 3, 4, and 5% BTP as filler, the Marshall stability value increases by 65, 40.5, and 52.4%, respectively, relative to the corresponding 3, 4, and 5% STD. Furthermore, at 2, 3, 4, and 5% BTP as filler, the Marshall stability increases by 16.9, 41, 17, and 17.9%, respectively, relative to the corresponding 2, 3, 4, and 5% STD when soaked for a day.

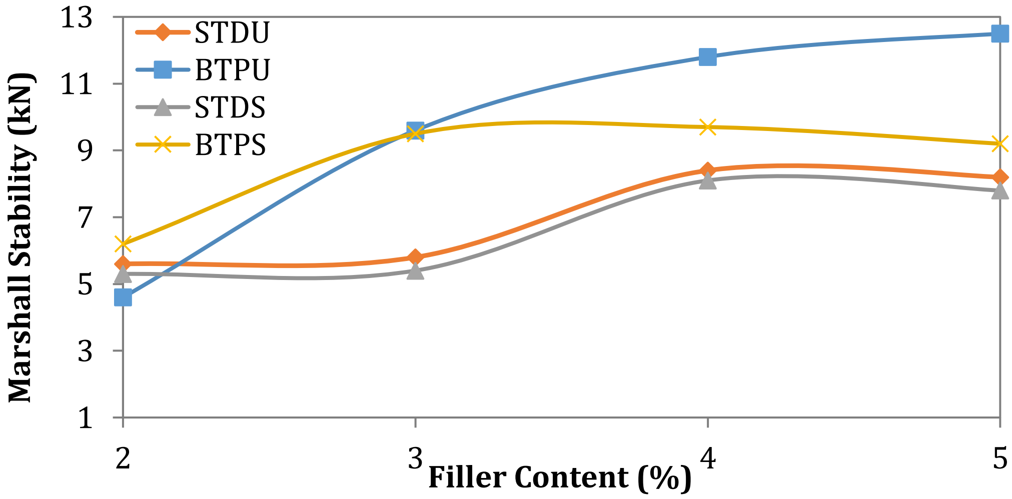

Figure 6. Stability versus filler content

It is also clear from **Tables 6 and 7** and **Fig. 7** that the flow of the samples with STD is higher than those with the BTP at 2, 3 and 4% filler content. At the same time, the flow values of the samples containing BTP are higher than those with STD at 5% filler content. Implying that the resistance to deformation decreases with an increase in the percentage of BTP in the asphalt concrete.

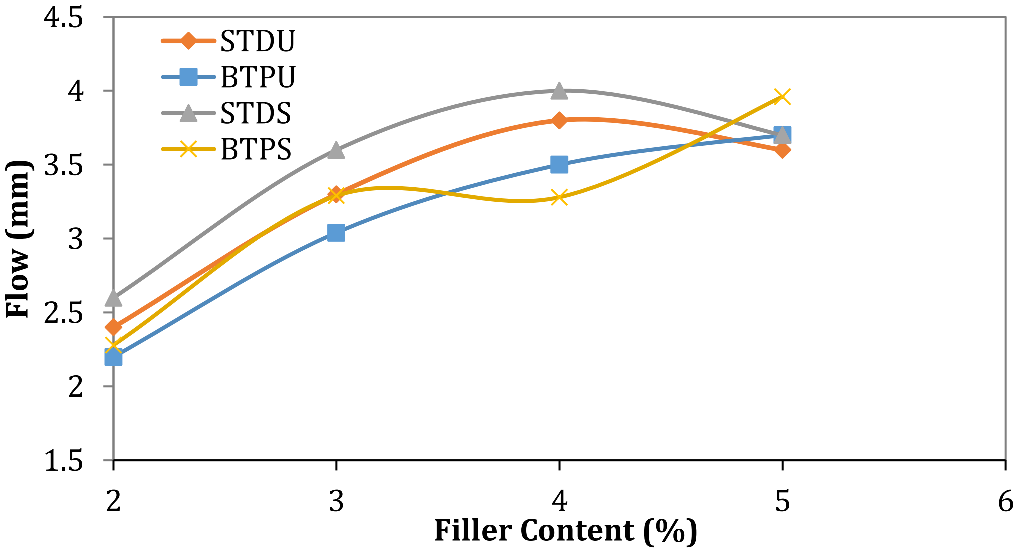

Figure 7. Flow versus filler content

Though the reduction of flow is not always advantageous, as it possibly leads to fracture at very low temperatures, the flow values recorded for all the samples exceed the minimum requirement specified by the **(Asphalt Institute, 1997)**, which is 2 mm. The maximum flow was recorded at 5% BTP content, with a flow value of 3.7 mm. However, when soaked for a day, the flow reduces by 12, 8, and 18% at 2, 3, and 4% BTP content, respectively, while it increases by 7% at 5% BTP content compared to the corresponding STD contents. The Marshall Quotient, which measures the stiffness of asphalt concrete and its resistance to deformation, is estimated as the ratio of stability to flow. Referring to **Tables 6 and 7**, BTP, it is clear that in terms of resistance to stiffness and deformation, BTP as a filler is much better, both soaked and unsoaked.

3.7 Flow Results of STD and BTP for the Evaluation of Optimum Filler Content

The flow results of asphalt mixtures containing different STD contents are shown in **Table 6 and Fig. 7**. As observed, the optimum filler content is 4%, with a corresponding flow of 3.8 mm and 4.0 mm when soaked for 24 hrs. Referring to **Table 6**, as the filler content increases, the flow increases at first reaches a maximum flow value and then decreases with an increase in STD, both soaked and unsoaked. Nevertheless, the flow results shown in **Table 6** are within the recommended range (2-4 mm) by the **(NGSRB, 1997).**

The flow results of BTP are depicted in **Table 7 and Fig. 7**. It is clear that flow increases with increasing BTP content, with an ultimate flow of 3.7 mm at 5% BTP content and 3.96 mm at

5% BTP content when soaked. This finding is in agreement with **(Alves et al., 2014)**. The study also shows that the flow value of the BTP-soaked samples does not differ much.

4. CONCLUSIONS

The evaluation of the stability and flow of asphaltic concrete produced with waste brick tile powder as the filler has been studied, and the following conclusions are drawn:

1) Results suggest that waste BTP as a filler material in asphaltic concrete can significantly increase its resistance to stiffness and deformation. Specifically, the increase in resistance is reported to be around 45%.
2) Results indicate that as the amount of BTP in asphaltic concrete increases, the resistance to deformation decreases. In other words, the more BTP is added, the less resistant the asphaltic concrete becomes to deformation.
3) Using BTP as a filler material in asphaltic concrete can significantly increase the Marshall stability value by 52%. This improvement can lead to long-lasting and more resilient roadways.
4) Careful consideration and testing should ensure that the addition of waste BTP does not negatively impact other properties of the asphaltic concrete mixture, such as workability and flexibility.
5) The optimum amount of BTP that should be used as filler material in asphalt concrete production is 4%. This means that if the amount of waste BTP used in asphalt concrete production is less than 4%, it may not significantly impact the mechanical properties of the mixture.
6) The strength properties of the asphalt concrete with waste BTP conform to the Asphalt Institute (1997) specifications. This makes the material suitable for road pavement.

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