

Influence of Euphorbia Balsamifera Gum as a Bio-Modifier on the Volumetric and Marshall Characteristics of Asphalt Mixtures [†]

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Abstract

This study evaluates the effect of Euphorbia Balsamifera Gum (EBG) as a green bio-modifier on the volumetric and mechanical properties of asphalt mixtures. EBG was added in proportions from 0 to 8%. Results show that 6% EBG yielded optimal performance, reducing air voids from 4% to 3% and increasing Marshall stability to 14.1 kN from 12 kN in the control mix. Voids filled with bitumen rose to 81.07% at 6% EBG. Flow values and moisture susceptibility also improved, indicating enhanced durability. EBG demonstrates strong potential as a sustainable, efficient additive for asphalt pavement modification.

Keywords: Euphorbia balsamifera; asphalt mixtures; Marshall characteristics; volumetric; bio-modifier

1. Introduction

The increase in global road infrastructure development has enhanced the rate of production and usage of asphalt mixtures, culminating in high usage of non-renewable resources, thereby increasing impacts on the environment [1,2]. Asphalt mix production is extremely energy-intensive and therefore contributes greatly to global warming effects, hence presenting a significant barrier to achieving sustainable construction of roads [3,4]. As a result, the incorporation of the United Nations Sustainable Development Goals (UN SDGs) into pavement engineering has become increasingly relevant for ensuring sustainable construction materials [3,5]. In light of these recent advances in pavement engineering technology, the trend towards employing bio-based modifiers for sustainable pavement solutions has gained considerable momentum compared to traditional polymer-based modifiers [3,6]. Bio-based materials provide several benefits over traditional synthetic polymers, such as reduced carbon dioxide emissions, sustainability, and resource efficiency [1,4,6]. Nevertheless, there is still a scarcity of research work that has been carried out on less-exploited plant-based gums from an engineering perspective. In this regard, Euphorbia balsamifera (EB) can be considered an under-utilized, but attractive biological material. The gum produced from the EB is from a drought-resistant plant endemic to arid and semi-arid areas of Africa, exhibiting adhesive properties, which indicate that it may find applications



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for asphalt modification [7–9]. While the use of EB gum (EBG) has been explored elsewhere in the literature, its application in asphalt modification has not yet been attempted [10,11]. Furthermore, there is a lack of sufficient literature that has explored the effect of bio-gum on the aforementioned performance parameters, such as volumetric properties (air voids, VMA, and VFB) and Marshall properties (stability and flow). This is clearly an important knowledge gap pertaining to the mechanical and volumetric properties of EBG-modified asphalt mixture. Thus, the primary objective of this research is to test the influence of EBG on the volume and Marshall properties of asphalt concrete mixtures through experimentation. Various mixes using different amounts of EBG have been formulated, prepared, and analyzed in conformity with relevant guidelines, with one control mix being used as the base for comparison. The unique aspect of this study is that it is the first systematic investigation into the application of EBG as a bio-modifier in asphalt mixture, especially concerning its adhesive and viscoelastic qualities. Thus, the results of this study will aid in furthering pavement materials sustainability and help in infrastructure projects aligned with SDGs using environmentally friendly additives in asphalt mix design.

2. Materials and Methods

The study employed crushed granite aggregate that met the requirements for a dense-graded mixture, and an asphalt mixture wearing course with a nominal maximum aggregate size of 14 mm was used. Additionally, the research employed a 60/70 Penetration Grade asphalt binder. EBG was collected in Badariya, Argungu L.G.A, Kebbi State, Nigeria, from the stem part of mature EBG trees, cleaned, dried in the open air, and then processed. Figure 1a,b show EBG before and after heating, which was utilized in the study. The modification of the bitumen with EBG was done through the wet process. In the wet process of modifying the bitumen, the bitumen employed was initially heated to the range of 120–130 °C. Following this, the liquid EBG 0, 2, 4, 6 and 8 wt.% of bitumen, covering the weight fraction of the coming bitumen, was steadily added to the steadily stirred liquid bitumen at rates of up to 600 rpm for 35 min at 120 °C to ensure even distribution within the stated temperature limits. The control mixture of optimum bitumen content (OBC) was determined to be 5.16 in this study. EBG-modified samples with similar OBC to the control mixture were prepared, in order to compare the control mix and modified mixtures without considering bitumen as a different factor according to ASTM D1559 [12]. All lab analyses on the base binder were carried out on EBG to determine its suitability as a modifier. Testing was conducted on the specimens 24 h after curing. They were conditioned to a temperature of 60 ± 1 °C before being tested for stability and flow in accordance with the ASTM D6927 [13] standard. The volumetric properties of air voids (AVs) in mixtures, voids in mineral aggregate (VMA), and voids in mineral aggregate filled with bitumen (VFB) were found from the sample unit weight (UW) test as per the ASTM D2726 [14] standard specification test. Also, the Retained Marshall stability (RMS) is evaluated by taking the ratio of immersed sample stability to the dry sample stability. RMS is an indicator that can assess a mixture's resistance to moisture damage. Figure 2 shows the study flowchart.

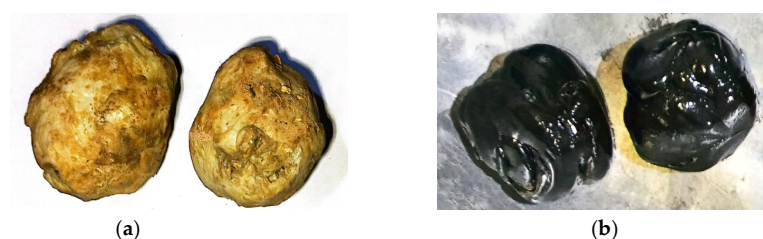


Figure 1. EBG (a) before and (b) after heating.

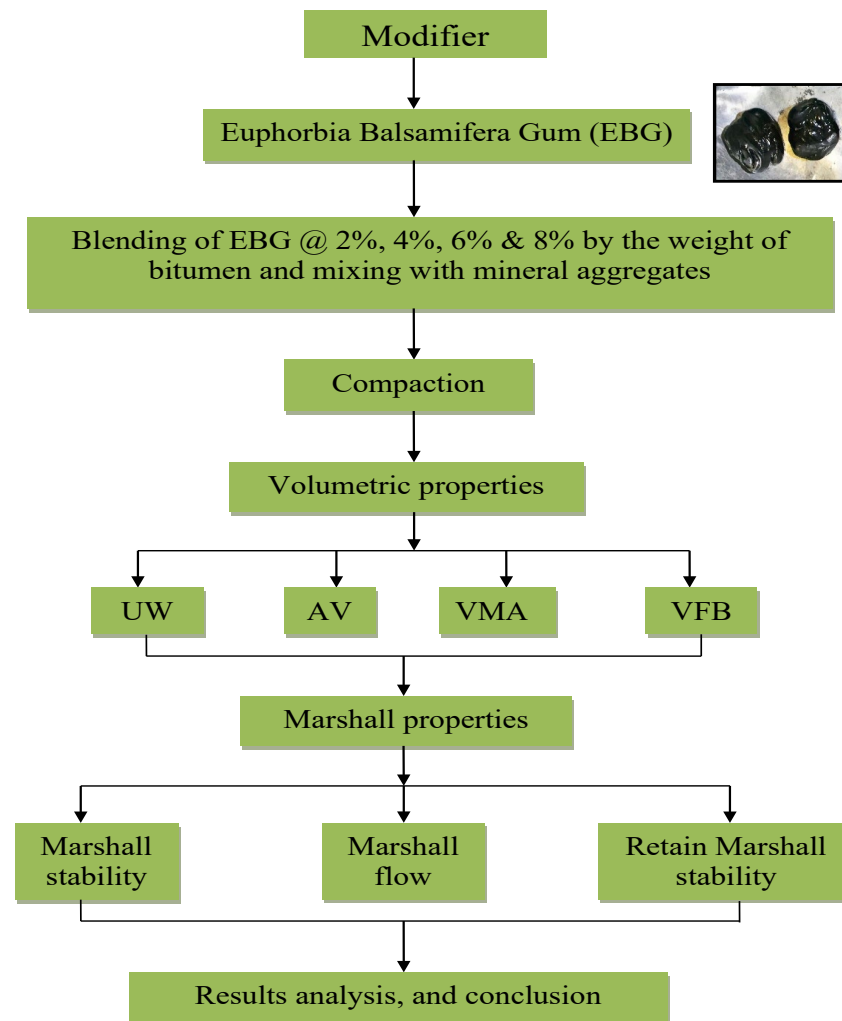


Figure 2. The study flowchart.

3. Results and Discussion

3.1. Sample Unit Weight

Figure 3a shows the effect of EBG on the asphalt mixture UW. It was found that the control mix without EBG possessed the maximum value of 2.341 g/cm^3 . However, with the addition of 2% EBG, the value slightly reduced to 2.319 g/cm^3 due to the dispersion of the biomaterial in the binder. This is because the EBG added in a very small amount reduces the stiffness of the binder, thus improving its workability. With an increase in the content of EBG to 4% and 6%, the unit weight similarly moved to 2.322 g/cm^3 and 2.332 g/cm^3 . This represents greater interactivity between the aggregate and the binder such that the aggregate is fully coated, leading to fewer voids and greater degrees of compaction [15]. For 8% EBG, a slight decrease was observed in the unit weight to 2.316 g/cm^3 , probably due to an overly saturated mixture relative to the addition of the EBG. The EBG overly coated mixture causes a thick binder and an under-interlocked aggregate during compaction; hence, a slightly lower density was observed.

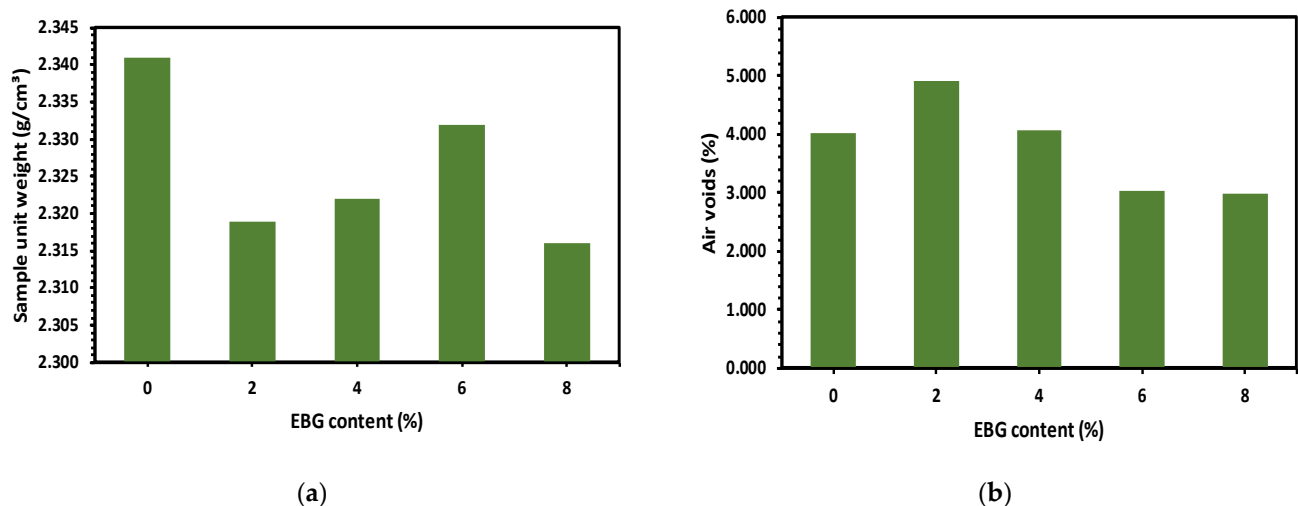


Figure 3. Influence of EBG content on asphalt mixtures: (a) UW and (b) AV.

3.2. Air Voids

Figure 3b shows the effect of EBG content on the asphalt mixtures AV. It was observed that the mixture without the incorporation of the above additives, which could be considered a control, had a 4% content of AV, which is a standard value in the asphalt mixture. The AV value increased slightly, noted as 4.91%, while the dosage of 2% EBG was incorporated, due to some degree of dispersion observed in the asphalt material. This is due to the presence of the additives, which slightly reduce the coating efficiency of the mixture, thus failing to achieve a more compact aggregate. It was also observed that as the EBG content increased to 4 and 6% compositions, the air void content correspondingly decreased to 4.08 and 3.03% compositions. This decrease reflects an increased interaction of the modified bituminous binding agent and aggregates, as well as the increased coating of aggregates and efficiency of compaction. A similar trend was observed when the bio-binder was also used in asphalt mixtures [16]. The minimum void was observed at 6% EBG and slightly stabilized at 8%. This indicates that a point of saturation is reached at which the EBG does not have an influence on the reduction in AV in the asphalt mixture.

3.3. Void in Mineral Aggregate

Figure 4a shows the influence of EBG content on the VMA of the asphalt mixtures. It was observed that a VMA of 17.71% was measured for the control mixture (no EBG). However, for the 2% EBG dosage, VMA increased to 18.79%, which is attributed to the partial dispersion of the EBG in the binder at low dosage. At this level, the binder film thickness increases slightly, without achieving an optimal degree of aggregate packing, resulting in a temporary dilation of inter-aggregate void space, as often observed for bio-binder-modified mixtures [15]. Also, at 4% EBG, the VMA remained relatively consistent at 18.68%, indicating an enhanced distribution of the EBG and a degree of improvement in the efficiency of compaction. As the proportion of EBG increased to 6%, the VMA dropped considerably to 16.01%, which is attributed to better binder–aggregate interplay, showing an improvement in aggregate coating and compaction efficiency [17]. At 8% EBG, VMA was increased to 17.48%, implying that over-saturation of the aggregate with the modifier materials can result in marginal decreases in aggregate interlocks. This trend is consistent with the literature on the utilization of natural bio-modifiers in asphalt mixtures.

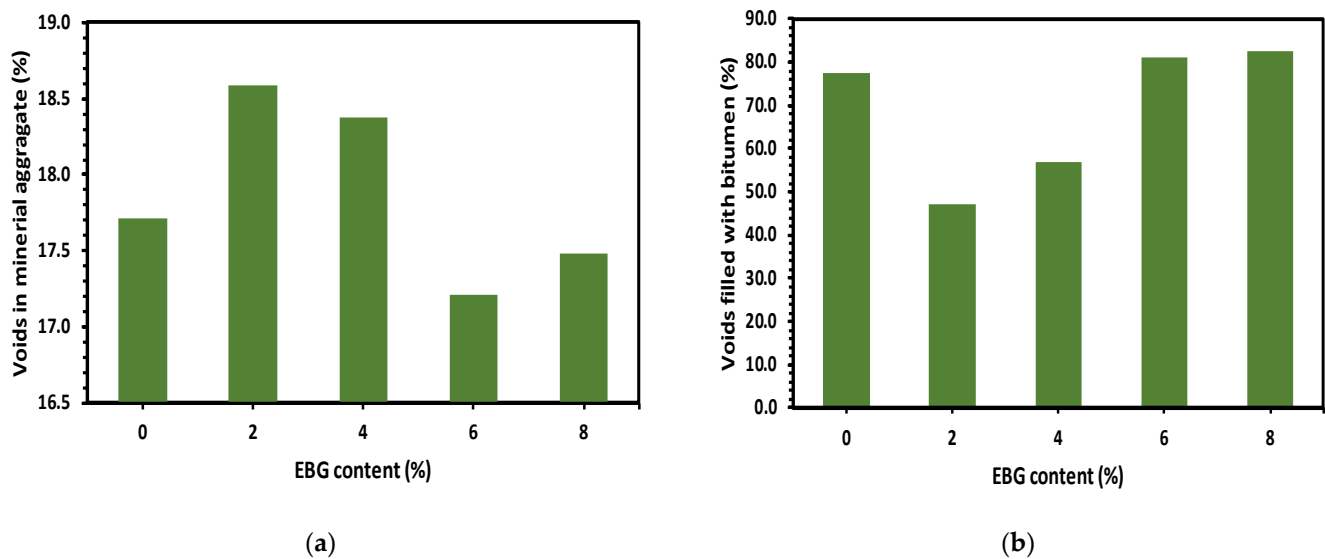


Figure 4. Influence of EBG content on asphalt mixtures: (a) VMA and (b) VFB.

3.4. Voids Filled with Bitumen

Figure 4b depicts the influence of EBG content on the asphalt mixtures VFB. For the control mix sample, the VFB was found to be 77.4%. This represents the binder content within the mineral aggregate voids. However, at 2% EBG, the VFB was significantly lowered to 47.26%. This indicates that the binder could not fill the voids in the asphalt mixtures, a quality often experienced in bio-binders within asphalt mixtures using low amounts of EBG as the bio-modifier binder. As the EBG content increased to 4%, VFB also increased to 56.75%, indicating an improvement in the distribution of the binder material and the coverage of aggregate material voids [15]. Also, at 6% EBG, there was an increase in VFB to 81.07%, showing that EBG is optimally used to completely coat the aggregate materials. However, at 8% EBG, the VFB was observed to increase slightly to 82.7%, implying that an excess modifier slightly improves the binder film, which tends to have a saturation point where extra EBG has a limited effect in filling the formed voids.

3.5. Marshall Stability

Figure 5a shows the influence of EBG content on the Marshall stability of asphalt mixtures. The control mixture was observed to have a stability value of 12 kN, representing the intrinsic ability of the mix to handle load resistance. However, it was observed that as the EBG content increases, the values also increase, with a maximum value of 14.1 kN at 6% EBG. This can be attributed to the increased adhesion of the asphalt mix aggregates due to the EBG additive's reaction with the asphalt binder. Also, it could be due to EBG's ability to improve the asphalt mix's capability to distribute the stresses within the mix, hence increasing resistance to deformation when a load is applied. The maximum value of Marshall stability, which is 14.1 kN, when using 6% EBG, is attributed to enhanced interface bonding between EBG and the asphalt matrix. EBG consists of polar groups, which are able to react with polar compounds such as asphaltenes and resins in bitumen, resulting in stronger adhesion due to hydrogen bonding and dipole interaction. When the dosage of EBG is increased to 6%, the dispersing ability of EBG reaches its optimum, and hence, it forms a reinforced network in bitumen, facilitating stress transmission and deformation resistance. However, at 8% EBG content, there is a minor reduction in stability to 13 kN. This indicates that excessive additive content may cause the oversaturated state of the binder, resulting in a reduction in effective binder content [18]. In such instances, the binder may exhibit unacceptable viscosity and/or heterogeneity, resulting in reduced cohesive

strength. Thus, the analysis proves that EBG does indeed have the potential to attain better structural properties in asphalt mixtures, wherein the content produces an optimum level that maximizes the Marshall stability.

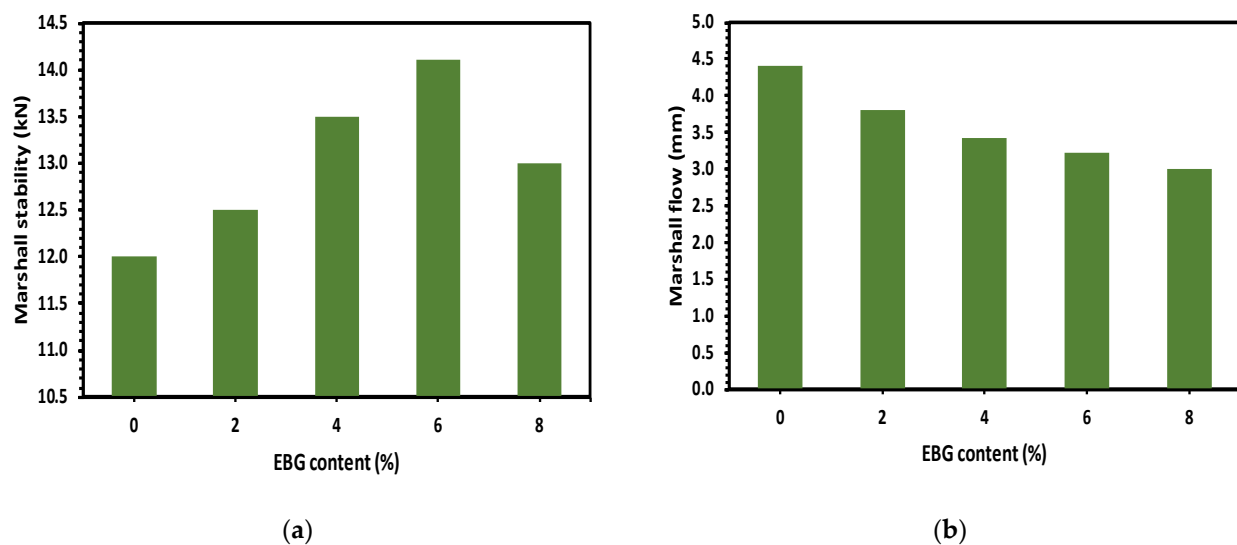


Figure 5. Influence of EBG content on asphalt mixtures: (a) Marshall stability and (b) Marshall flow.

3.6. Marshall Flow

Figure 5b shows the influence of EBG content on the Marshall flow of asphalt mixtures. The control mixture recorded a varied average flow of 4.4mm, implying a deformed mix in a native state. As more *Euphorbia balsamifera* is added to an asphalt mix, decreasing values are obtained in a trend that reaches 3 mm with a maximum content of EBG added to the mixtures. This trend could mainly be attributed to the impact exerted by EBG on the pavement, which ensures that the binder is cohesive as well as viscoelastic when subjected to shear deformation forces. Moreover, the improvement in the aggregate binder interaction due to the incorporation of EBG into the pavement leads to a reduction in the mix mobility, such that the flow value is decreased in the pavement [16]. The opposite relationship between Marshall stability and flow observed can be attributed to the stiffness–deformation equilibrium in the blend. At 6% EBG, the maximum stability shows that there is adequate cohesion and stress transmission, whereas at 8% EBG, the minimal flow of about 3 mm is caused by over-stiffening and low plasticity due to high binder viscosity. Hence, maximal stability is not necessarily associated with minimal flow, implying that maximal performance is achieved when the modifier content is balanced at 6% EBG.

3.7. Retained Marshall Stability

Figure 6 shows the influence of the EBG content on the RMS of asphalt mixtures. The RMS values for all the mixes were observed to decrease with an increase in the immersion period from Day 1 to Day 7. The control mixtures showed a large reduction in RMS over the period of immersion. Its value dropped from 85.36% after the first day to 69.98% after day 7.

EBG-modified mixtures, however, demonstrated a constant improvement in RMS values over all immersion periods. While at low concentrations (2–4% EBG), relatively good developments were recorded, as Day 7 RMS improved to 70.82% and 73.07%, respectively. The improvement implies an enhancement in adhesion between aggregates and binders due to the use of EBG, the nature of which is cohesive and thus improves water resistance [15]. Also, the best mix performance was observed at 6% EBG, with a 91.74% improvement during Day 1 immersion and 75.78% improvement during Day 7, which

meets the stimulated standard of 75% according to AASHTO T 165-86 [19]. By contrast, at 8% EBG, a small reduction in RMS values is observed, which is attributed to excess EBG in the binder, which reduces aggregate coating efficiency as well as moisture resistance.

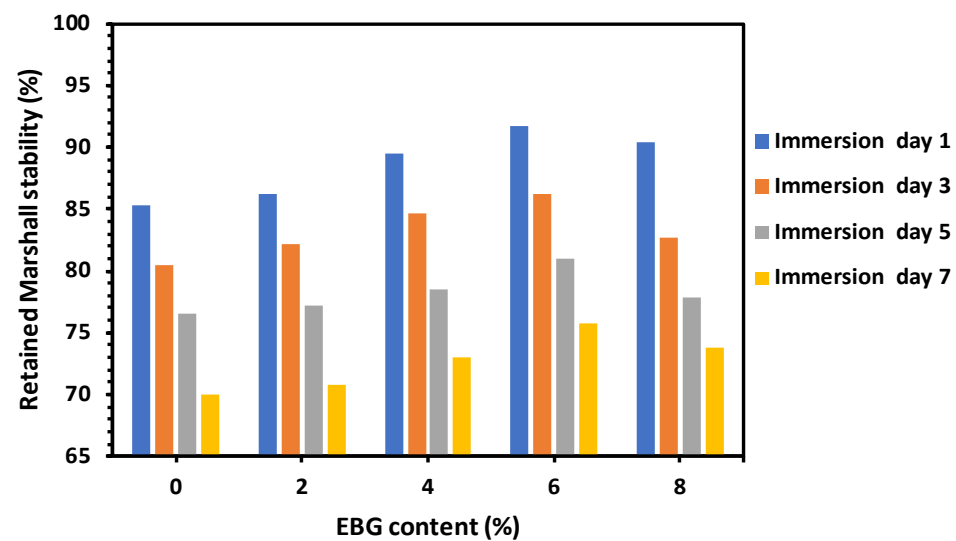


Figure 6. Influence of EBG content on asphalt mixtures' RMS.

The outcomes obtained from the Marshall tests conducted in this study have been compared to Marshall mix design criteria like those in ASTM D6927. The acceptability ranges of asphalt mixtures normally involve high Marshall stability beyond structural sufficiency; reasonable workability indicated by flow value (2–4 mm depending on traffic); and desirable volumetrics, such as air voids (3–5%) and VFB. This research shows that all the tested mixtures (control and EBG-modified) complied with the standards. The control mixture had a Marshall stability of 12 kN, whereas EBG-modified mixtures had a high stability level, with a maximum value of 14.1 kN achieved at a ratio of 6%. This implies that EBG-modified asphalt was more effective in bearing loads than the control asphalt used in comparable bio-modified asphalt. Similarly, the flow value of both mixtures remained within an acceptable level, with the optimal mixture having a 3.23 mm flow value. Results from the volumetric analysis revealed that the requirements had been met since there were no more air voids, and VFB rose to 81.07% at 6% EBG usage. Based on a comparison of this result, it can be stated that the efficiency of EBG is a green modifier.

4. Conclusions

This study investigates the influence of EBG as a bio-modifier on the volumetric and Marshall properties of asphalt mixtures. As revealed by the study, the air void content was progressively reduced upon an increase in the EBG content. In terms of VFB, it is noteworthy that there was a non-linear trend in the data. This is shown by the fact that the VFB decreased to 47.26% with 2% EBG due to partial dispersion but then rose to 81.07% with 6% EBG due to good filler action in the process of bitumen coating and void filling within the mixture. It was also observed that the highest value for Marshall stability was reached at the level of 14.1 kN using 6% of EBG. At the same time, the Marshall flow was reduced from 4.4 mm to 3.23 mm. Moreover, moisture resistance was the best with 6% of EBG as well. The paper shows the viability of incorporating EBG as an environmental bio-modifier in sustainable pavement construction.

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