
EFFECT OF POLYCARBONATE PLASTIC ON THE MECHANICAL PROPERTIES OF ASPHALT CONCRETE

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ABSTRACT

In Nigeria, plastics are indiscriminately discarded endangering man and the entire ecosystem. There is need for development of alternative ways in combating challenges of plastic waste disposal. These challenges have necessitated its adoption in asphalt concrete production. This study examined the use of polycarbonate plastic waste as an additive and the effect on strength properties of hot mix asphalt. Polycarbonate is a polymeric material. Fourier Transform Infrared analysis on polycarbonate revealed the presence of aromatic, methyl, carbonyls, amine, and alkene. Scanning electron microscopy and Energy dispersive x-ray spectrometry analysis showed that polycarbonate has spongy shape and the predominant elements are silicon, oxygen, carbon, and aluminum. For the experiment, Marshall method was adopted for mix design and testing. Polycarbonate plastic was introduced into the mix by means of dry process from 0 - 3% (at interval of 0.5%). The bitumen content used was varied from 6 – 7.5% (at intervals of 0.5%). The introduction of polycarbonate plastic improved the Marshall stability by 20% from 4.67 kN (Threshold) to 5.59 kN (Modified) at 2.5% addition of polycarbonate. Although flow did not improve, other volumetric properties recorded an improvement. This study concludes that an optimal dosage of 2.5% polycarbonate plastic will increase the strength of hot mix asphalt and consequently improve the service life of flexible pavement.

Keywords: Polycarbonate Plastic; Mechanical Properties; Asphalt Concrete; Waste

I. INTRODUCTION

Plastic is a group of synthetic or semi-synthetic material produced from hydrocarbons through polymerization. Polymerization is a sequence of chemical reactions chiefly on crude oils and natural raw materials (Luckscheiter & Ebii, 2020; Adogame, *et al.*, 2021). Plastic is the general name for polymeric materials that may contain other materials for enhanced performance or colour (Yalwaji, *et al.*, 2022). Nigeria is among the largest importer and consumer of plastics in Africa, it is estimated that between 1996 and 2014 over 23 million tons of plastics were imported into Nigeria (Luckscheiter & Ebii, 2020; Dibia, *et al.*, 2023). Polymers used in production of plastics includes the following; High Density Polyethylene (HDPE), Polyethylene Terephthalate (PET), Polycarbonate (PC), Low-Density Polyethylene (LDPE), Polylactic acid (PLA), Polypropylene (PP), Polyhydroxyalkanoates (PHA). Expanded polystyrene (EPS), Polystyrene (PS), Polyvinyl Chloride (PVC) Adogame, *et al.*, (2021; Yalwaji, *et al.*, (2022). According to IHS Chemical, (2013) polycarbonate chemical is the highest consumed chemical in plastic industries, it reported that world-wide demand for polycarbonate surpasses 4.2 million tons annually. Million tons of plastic are littering the streets and harming our environment. Within this experiment Polycarbonate (PC) plastic waste was incorporated as an additive to improve the strength of asphalt concrete. Polycarbonate plastics used from home, offices, industries, food and packaging companies are non-biodegradable and cannot be recycled as such are dumped in the open site and eventually burnt openly on dumpsites causing the release of dioxins and furans into the atmosphere. This method of disposing plastic waste poses public health challenges and are great concern for residents and waste management authorities (Federal Ministry of Environment, 2020). This calls for alternative method of waste disposal that are economical and environmentally friendly.

Asphaltic concrete comprises of fine and coarse aggregate with bitumen as binder. Aggregate function as the structural framework for flexible pavement and bitumen serve as adhesive for the asphaltic mixture. About 90–95% of volume of asphaltic concrete mixtures are aggregates including mineral filler and bitumen is approximately 5 - 8%. Strength properties of asphaltic concrete directly impact the performance of flexible pavements. Asphaltic concrete is typically used in pavement construction due to its excellent performance in providing stability, driving comfort, water resistance and durability (Bakare, 2017). When a flexible pavement is to be constructed, a sample or representative of the mix design is prepared to test the consistency of the properties in compliance with specification. The mechanical properties of asphalt concrete to be tested are stability, durability, skid resistance and workability (Cesare, *et al.*, 2019). These properties make hot mix asphalt desirable for pavement. Flexible pavement develops defects during its service life. Road defect according to Okigbo, (2012) is any portion of a road, highway that deviates from the prescribed standard for safety and comfort of the rider. However, the service life of flexible pavement and rider's comfort by can be increased by incorporating different materials into asphalt mixes either in form of modifier, filler or admixture. In recent literatures, it is a common practice in highway engineering to improve the properties of asphalt binder and asphalt concrete with locally available waste material such as locust bean pod ash (Murana, *et al.*, 2024), pulverized burnt brick (Ibedu & Murana, 2024), polyvinyl chloride (Murana, *et al.*, 2024), high density polyethylene (Murana *et al.*, 2024; Murana *et al.*, 2023), Bentonite clay (Ibedu & Asaolu, 2026), coconut shell ash and reclaimed asphalt pavement (Murana, *et al.*, 2023), Soybean husk ash (Ibedu & Asen, 2026). These waste from industries and domestics products serves as an economical option in the search for material to improve for road construction. However, polycarbonate (PC) plastic possesses superior mechanical properties such as good toughness, high impact and crack resistance, high temperature resistance (Sisodia & Arora, 2022; Kumar & Raj, 2021). These properties, make polycarbonate (PC) plastic a suitable additive polymer material for asphalt production.

There are limited studies on the effect of polycarbonate plastic waste on asphalt concrete, despite the good mechanical properties of polycarbonate plastic. Therefore, this study is aimed at investigating the mechanical properties of asphalt concrete admixed with polycarbonate plastic and to obtain optimal dosage of polycarbonate needed to improve the performance of asphalt mixtures. Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectrometry (EDS) were used for microstructural examination and elemental analysis of the polycarbonate plastic. This study bridges the knowledge gap in previous studies on plastic waste in asphalt concrete

2. METHODOLOGY

2.1 Materials

Materials used in this research were bitumen, aggregates and waste polycarbonate plastic. The aggregate and bitumen were sourced from Zeberced Group Limited along Kaduna – Zaria Road in Kaduna State, and Ringadas Nigeria Limited/ASCA Bitumen Company Abuja. The waste polycarbonate plastic was sourced from open refuse disposal dump in Samaru area of Zaria L.G.A. Kaduna State.

2.1.1 Polycarbonate

The polycarbonate was sourced from open dumpsite situated within Ahmadu Bello University, Zaria. The initial step in material involved the washing of polycarbonate waste with ethanol to strip away dirt, the material was spread out and allowed to air-dry 72 hours under ambient conditions to remove residual moisture. The dried polycarbonate was then cut into pellets forms and further reduced to a powdered form through pulverization using a laboratory grinding machine.



Plate I: Processing of polycarbonate waste (a) pellet polycarbonate (b) pulverized polycarbonate (c) dry mixing of polycarbonate (d) asphalt concrete admixed with polycarbonate

2.2 Methods

Test on Polycarbonate

- i. Fourier Transform Infra-Red (FTIR)
Fourier Transform Infra-Red (FTIR) spectroscopy was employed to identify the functional groups present in the polycarbonate in accordance with ASTM D6348-12 (2020).
- ii. Scanning Electron Microscopy and Energy Dispersive Spectroscopy (SEM/EDS)
Scanning Electron Microscopy and Energy Dispersive Spectroscopy (SEM/EDS) is a technique that uses a high-energy beam to create an image resolution surface and to identify elemental composition of a material's surface. The test was conducted in accordance with ASTM E2809-22, (2022).

Test on Aggregate

- i. Sieve Analysis of Aggregates
Sieve analysis of aggregates was done by manual sieving. The sieving of aggregates was conducted to determine the distribution of different sizes of aggregate in a given batch aggregate. The test was conducted in accordance with ASTM C136/C136M-19 (2019)

Test on Asphaltic Concrete

- i. Marshall Stability and Flow Test
Marshall stability is the maximum load that a compacted asphalt specimen can withstand before a deformation at a standard temperature of 60°C with a load applied at a constant rate of 50mm/min. The stability and flow are read from the dial gauges. The flow which is measured in 0.25mm units is the deformation that the specimen has undergone at the maximum load. The test was conducted in accordance with ASTM D6927-15 (2015).
- ii. Production of Asphaltic Concrete Admixed with Polycarbonate Waste Plastic
For each bitumen content and replacement level, three replicate specimens were produced and tested. Approximately, 1200g of aggregates (including admixture) were blended and preheated to 140°C. Varying percentages of bitumen 6%, 6.5%, 7% and 7.5% by weight of the total mix, polycarbonate was then added to the aggregates. The mixture was thoroughly mixed to achieve homogeneity. The hot mix was immediately transferred to a mould (101.6mm diameter x 63.5mm height) and compacted with 75 blows per side. After compaction, the briquette sample was allowed to cool for 25 minutes before extraction. This procedure was applied to both threshold mixtures (0%) and mixtures containing 0.5 –3% polycarbonate at 0.5% increments. The prepared samples were subsequently subjected to Stability-flow tests and density-voids analysis in the laboratory in accordance with ASTM standard (ASTM D6926-20, 2020; ASTM D6927-15, 2015).

3. RESULTS AND DISCUSSIONS

3.1 FTIR Analysis of the Polycarbonate Plastic Material

The FTIR analysis was carried out on the polycarbonate plastic was recorded Figure 1 and tabulated in Table 1. The polycarbonate plastic gave characteristics absorption peaks in both functional groups and finger print region. The result of the infra-red spectrum in Figure 4.1 shows that the polycarbonate plastic gave peak due to O-H_{str} at 3753.4 and 3693.8^{cm-1} due to alcohol, C-H_{str} vibration band due to amine appeared at 3507.4^{cm-1}, C-H_{str} vibration band appeared at 3041.5^{cm-1} due to Aromatic, C-H_{str} absorption peak due to Methyl appeared at 2967 and 2922.2^{cm-1}, C-H_{bend} vibration

band due to Aromatic appeared at 2072.4cm^{-1} , $\text{C}=\text{O}_{\text{str}}$ vibration band appeared due to Anhydride at 1897.2cm^{-1} , $\text{C}=\text{O}_{\text{str}}$ absorption peak due to Carbonyls appeared at 1770.8cm^{-1} , $\text{N}-\text{H}_{\text{bend}}$ vibration band appeared due to Amine, $\text{N}-\text{O}_{\text{bend}}$ absorption peak due to Nitro appeared at 1502.1cm^{-1} , $\text{C}-\text{C}_{\text{str}}$ vibration band due to Carboxylic appeared at 1408.9cm^{-1} , $\text{C}-\text{H}_{\text{str}}$ vibration band appeared due to Aromatic amine at 1289.7cm^{-1} . At the fingerprint region, peak at $\text{C}-\text{O}_{\text{str}}$ appeared at 1218.8cm^{-1} due to Carbonyl, $\text{C}-\text{O}_{\text{str}}$ vibration band due to Ester appeared at 1185.3cm^{-1} , $\text{C}-\text{O}_{\text{str}}$ vibration band appeared due to Alcohol at 1103.8cm^{-1} , $\text{C}-\text{O}_{\text{str}}$ absorption peak due to Carbonyl appeared at 1159.2 , 1013.3 and 1080.9cm^{-1} , $\text{C}=\text{C}_{\text{str}}$ vibration band appeared at 887.5cm^{-1} due to Alkene. $\text{C}-\text{H}_{\text{bend}}$ vibration band appeared at 827.1 , 764.1 and 704.1 . A similar results was obtained by Haghighi-Yazdi & Lee-Sullivan, (2015).

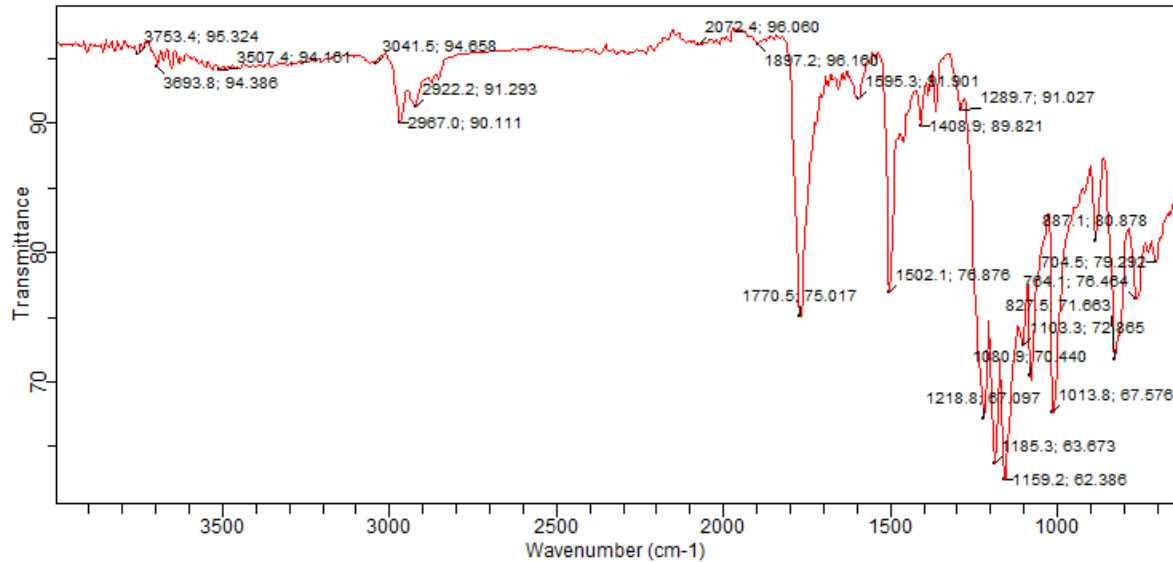


Figure 1: FTIR Spectrum of Polycarbonate

Table 1: Functional group, wavenumber and Vibration type of polycarbonate plastic

Functional Group	Wavenumber (cm^{-1})	Vibration Type
OH (Alcohols)	3753.4	Medium O-H Stretching
OH (Alcohols)	3693.8	Medium O-H Stretching
C-H (Amine)	3507.4	Strong C- H Stretching
C-H (Aromatic)	3041.5	Strong C - H Stretching
C-H (methyl)	2967	Weak C- H Stretching
C-H (methyl)	2922.2	Weak C- H Stretching
C-H (Aromatic)	2072.4	Weak C- H Bending
$\text{C}=\text{O}$ (Anhydride)	1897.2	Strong $\text{C}=\text{O}$ stretching
$\text{C}=\text{O}$ (Carbonyls)	1170.8	Strong $\text{C}=\text{C}$ stretching
N-H (Amine)	1595.3	Medium N-H bending
N-O (Nitro)	1502.1	Strong N-O bending
O-H (Carboxylic)	1408.9	Weak C-C stretching
C-H (Aromatic amine)	1289.7	Strong C-H stretching
C-O (Carbonyl)	1218.8	Strong C-O stretching
C-O (Ester)	1185.3	Strong C-O stretching
C-O (Alcohol)	1103.8	Strong C-O stretching
C-O (Carbonyl)	1159.2	Strong C-O stretching
C-O (Carbonyl)	1080.9	Strong C-O stretching
C-O (Carbonyl)	1013.3	Strong C-O stretching
$\text{C}=\text{C}$ (Alkene)	887.5	Strong $\text{C}=\text{C}$ stretching
CH_3	827.1	Strong C-H bending
C-H	764.1	Strong C-H bending
C-H	704.1	Strong C-H bending

3.2 Results of SEM and EDS on Polycarbonate

The SEM and EDS results from polycarbonate plastic is shown in Figure 2a and Figure 2b respectively. The morphology examination shown in Figure 2a was done using Scanning Electron Microscopy (SEM) technique with a magnification of 10,000x, it can be seen that polycarbonate appears to have a sponge-like shape rough texture, it was apparent that polycarbonate plastic was pulverized with size greater than 10 μ m. The elements contained in the polycarbonate was measured with EDS. The results obtained from the EDS spectrum is shown in Figure 2b, the major elements detected are namely; Silicon (Si) detected at 65.2%, Oxygen (O) detected at 15.2%, Aluminium (Al) detected at 7.2%, other elements detected are Carbon (C), Copper (Cu), Na (Na), Magnesium (Mg), and Potassium (K) at 3.2, 5.2, 1.5, 1.3, and 1.2% respectively, summation of the different elements normalized to total of 100%.

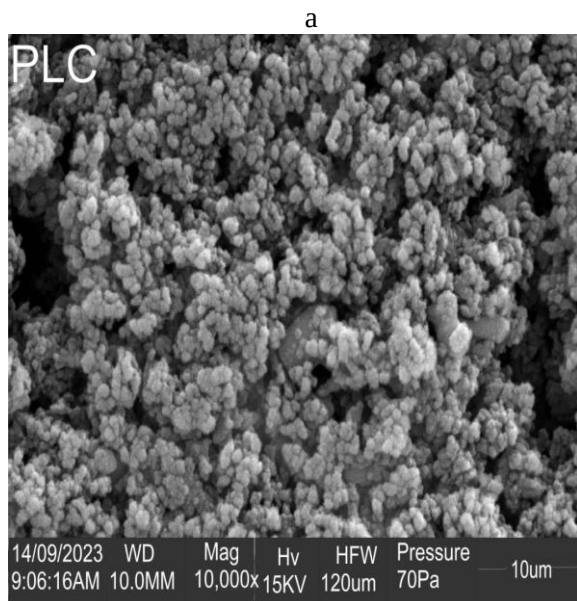


Figure 2a: SEM of Polycarbonate

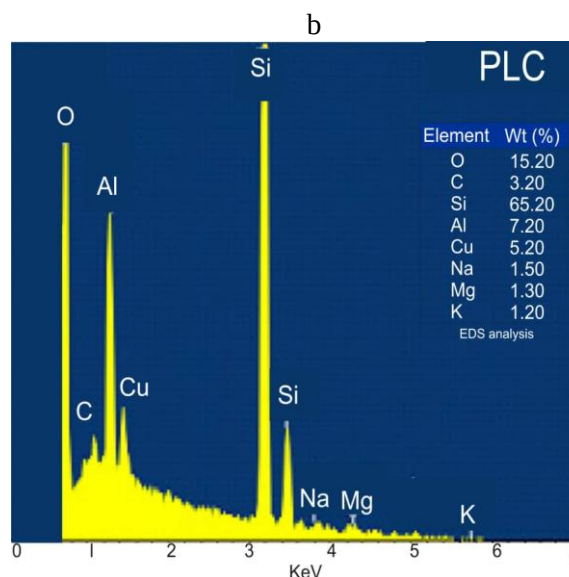


Figure 2b: EDX of Polycarbonate

3.3 Sieve Analysis on Aggregates

The particle size distribution for combined coarse aggregate, fine aggregate and mineral filler is shown in Figure 3. The results obtained satisfied the upper limit and lower limit boundary condition as specified by FMWH (2016). The proportioning was done to determine the volume of each aggregate by weight of the entire hot mix asphalt. Particle size distribution is important because they aggregates are the major determining factors in the density and interlocking ability of the mixture. Aggregate serve as the skeleton of hot mix asphalt and distributes stresses from wheel loads. Aggregate gradation also imparts on the finishes of the flexible pavement, i.e., the smoothness or roughness of road surfaces.

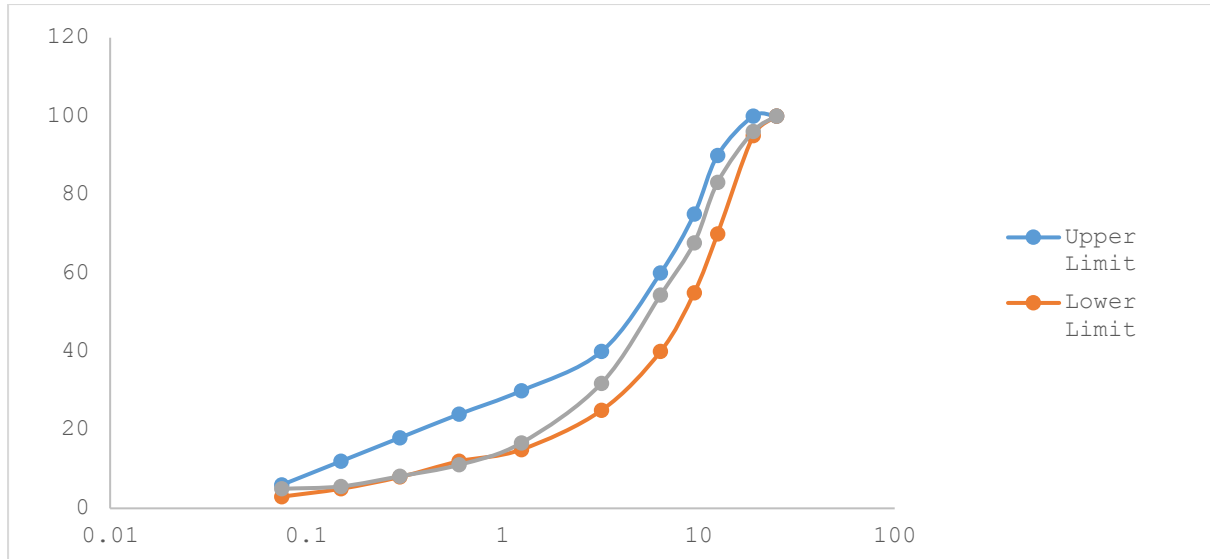


Figure 3: Particle size distribution

3.3.1 Marshall Stability

Figure 4 illustrates the variation in Marshall stability with bitumen content and polycarbonate addition. The stability values increased by an average of 8% when the bitumen content rose from 6% to 6.5% across all polycarbonate replacement levels. However, a notable 18% decrease occurred at 7% bitumen content, followed by a 7% recovery when the bitumen content was further increased to 7.5% across all polycarbonate content. The highest Marshall stability of 5.59 kN was achieved at 6.5% bitumen content with 2.5% polycarbonate addition. This represents a 20% improvement over the maximum stability of 4.67 kN recorded at the same bitumen content without polycarbonate. Higher stability values signify improved resistance to rutting and shoving (Awan, *et al.*, 2022). All mixtures satisfied the Federal Ministry of Works and Housing (FMWH, 2016) minimum requirement of 3.5 kN. A similar trend was reported by Ibedu and Murana (2024).

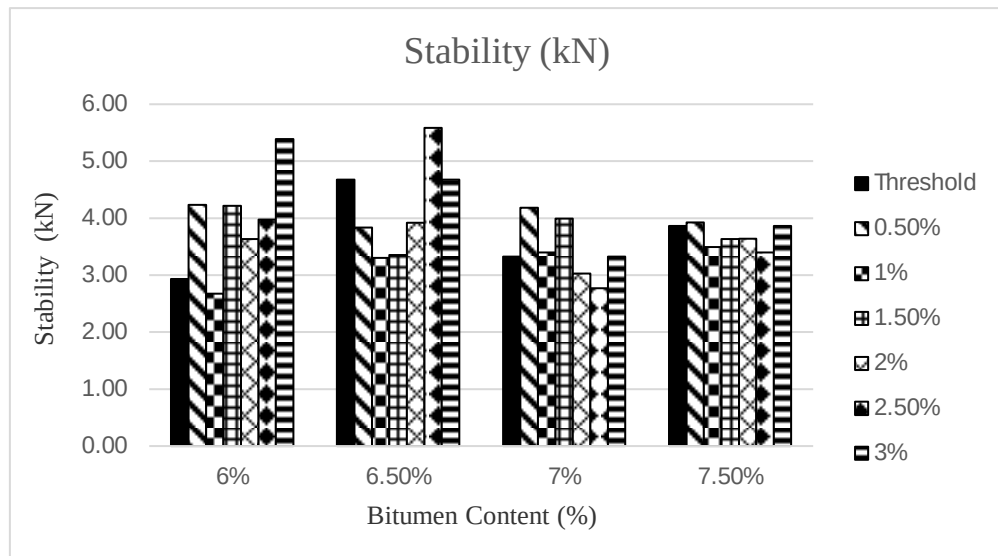


Figure 4: Variation of Stability with Polycarbonate Content

3.3.2 Marshall Flow

Figure 5 presents the variation in Marshall flow value with bitumen content and polycarbonate addition. Marshall flow measures the elasticity and plasticity of the asphaltic mixture. The flow values obtained ranged from 2.47 mm to 5.5 mm. The minimum flow of 2.47mm was observed at 6.5 bitumen

content and threshold polycarbonate content while the maximum Marshall flow was observed at 6% bitumen and 3% polycarbonate content. All mixtures satisfied the Federal Ministry of Works and Housing (FMWH, 2016) specification for base course, which requires flow values between 2 mm and 6 mm. However, the observed increase in flow with higher bitumen content and polycarbonate addition indicates greater plasticity of the mixture, implying an increased susceptibility to permanent deformation under traffic loading.

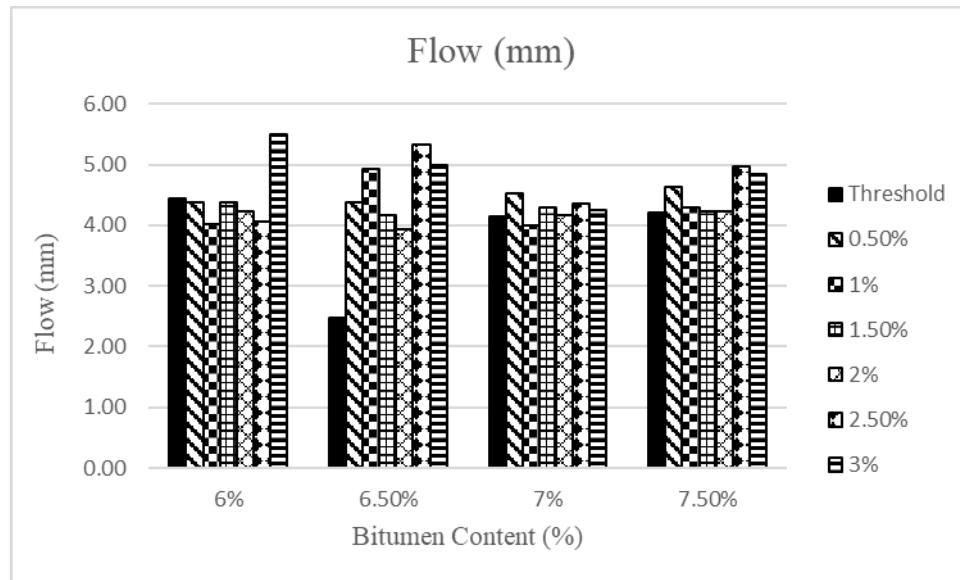


Figure 5: Variation of Flow with Polycarbonate Content

3.3.3 Unit Weight

Figure 6 shows the variation in unit weight (bulk density) of the asphalt mixtures with bitumen content and polycarbonate addition. Volumetric properties of asphalt concrete are strongly influenced by unit weight, which in turn significantly affects the overall durability of the pavement (Murana *et al.*, 2023). As shown in Figure 6, at 6% bitumen content, the unit weight decreased with increasing polycarbonate content relative to the control mixture. The decrease may be attributed to inadequate chemical bonding between the polycarbonate waste plastic and the bitumen matrix particularly at 6% bitumen content which likely resulted in the formation of large voids within the mixture after compaction. In contrast, at higher bitumen contents (6.5%, 7%, and 7.5%), the unit weight increased progressively with higher polycarbonate levels. The increase can be attributed to the elevated viscosity and improved coating efficacy of the bitumen influenced by polycarbonate waste plastic, which facilitates better lubrication and rearrangement of aggregate particles, thereby more effectively filling inter particle voids.

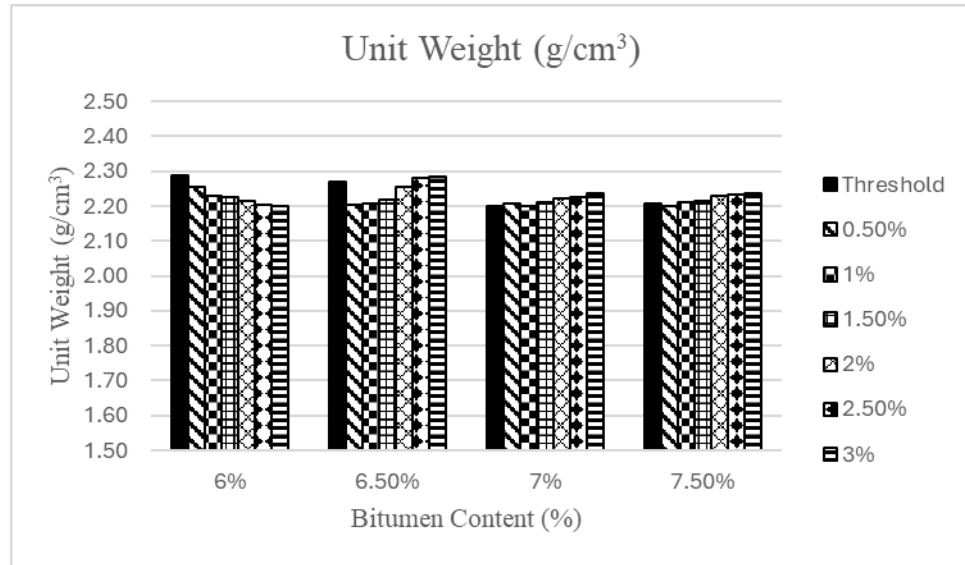


Figure 6: Variation of Unit Weight with Polycarbonate Content

3.3.4 Voids in Mineral Aggregate (VMA)

Figure 7 presents the variation in Voids in Mineral Aggregate (VMA) with bitumen content and polycarbonate addition. The results showed that VMA generally increased with increasing polycarbonate content. This trend is attributed to the sponge-like structure of the polycarbonate particles, which were not adequately coated by the bitumen, thereby creating additional voids within the mix and reducing inter-particle bonding.

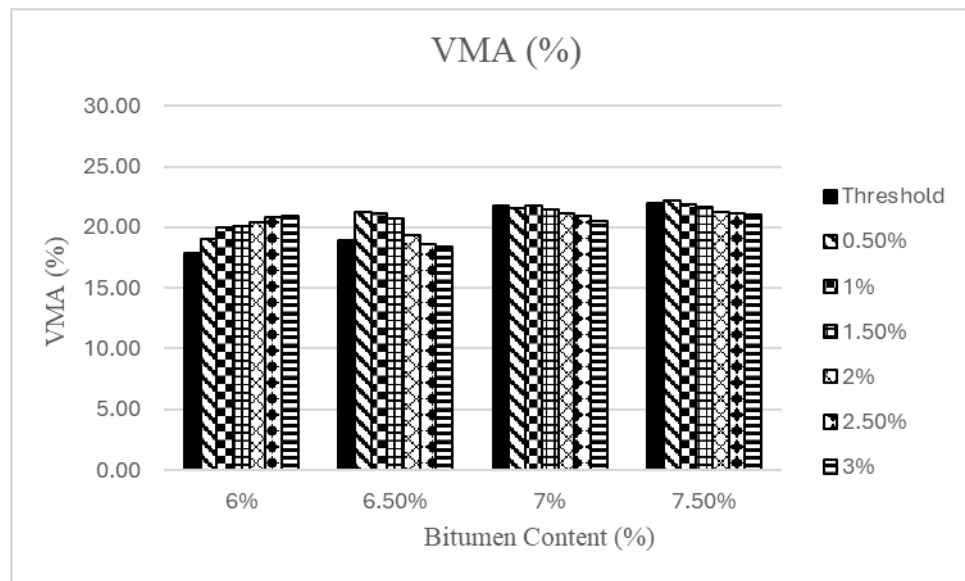


Figure 7: Variation of VMA with Polycarbonate Content

3.3.5 Voids in Total Mixture (Pa)

Figure 8 shows the variation in voids in the total mixture (Pa) with bitumen content and polycarbonate addition. The voids in the total mixture are directly related to the voids in mineral aggregate (VMA). All tested mixtures achieved Pa values within the Federal Ministry of Works and Housing (FMWH, 2016) acceptable range of 3% to 8%. Maintaining an adequate level of air voids is critical for durable asphalt performance. Excessive voids (due to insufficient bitumen to coat the

aggregates) can lead to premature cracking and moisture damage, while insufficient voids may result in rutting and bleeding under traffic loading.

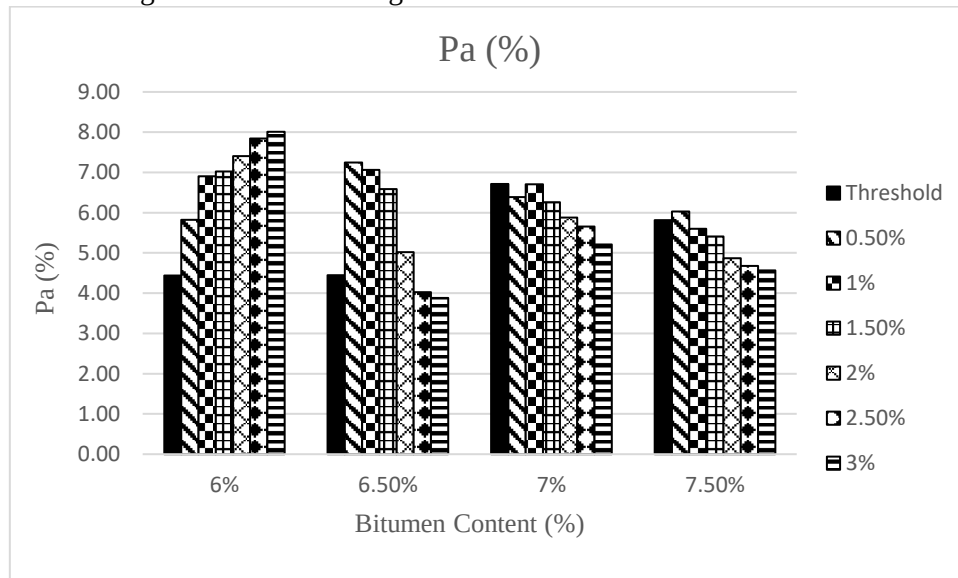


Figure 8: Variation of Pa with Polycarbonate Content

3.3.6 Voids Filled with Bitumen (VFB)

Figure 9 illustrates the variation in voids filled with bitumen (VFB) with changes in bitumen content and polycarbonate addition. As expected, VFB is inversely related to the voids in the total mixture (Pa). At 6% bitumen content, VFB generally decreased with increasing polycarbonate content compared to the control mixture. In contrast, at higher bitumen contents (6.5%, 7%, and 7.5%), VFB increased with higher polycarbonate replacement levels. This indicates that sufficient bitumen was available to effectively coat and bind the aggregates, thereby reducing the air voids in the mixture. Notably, the mixture containing 6 - 7.5% bitumen content and 0.5 - 1.5% polycarbonate content satisfied the requirement of 65 - 72% VFB range for base course compacted asphaltic concrete as stipulated by the Federal Ministry of Works and Housing (FMWH, 2016).

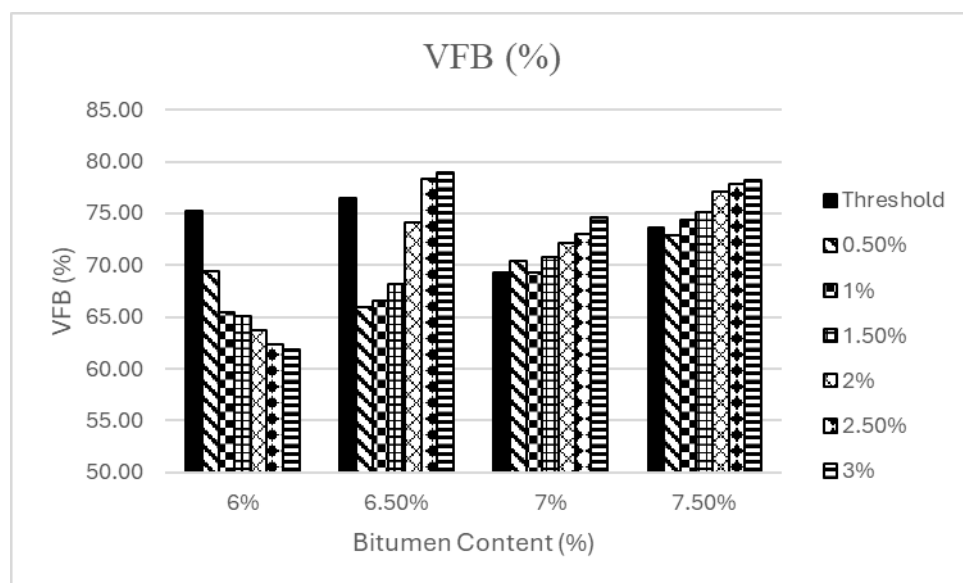


Figure 9: Variation of VFB with Polycarbonate Content

4. CONCLUSION

Based on the results of this study, the following conclusions can be drawn:

- i. FTIR analysis of the polycarbonate revealed the presence of key functional groups, including methyl aromatic, anhydride, amine, carboxylic, aromatic amine, carbonyl, and alkene groups, confirming its polymeric nature
- ii. The incorporation of polycarbonate into hot mix asphalt improved the mechanical properties (Marshall stability) by up to 20% at 6.5% bitumen content and 2.5% polycarbonate content, compared to the threshold mixture. The performance of polycarbonate as an admixture in Marshall stability of asphalt concrete meets and, in some cases, exceeds the requirements of 3.5kN stipulated by the Federal Ministry of Works and Housing (FMWH, 2016). Similarly, the Marshall flow values satisfied 2 - 6mm requirement with optimum 5.5mm at 6% bitumen content and 3% polycarbonate content. Furthermore, the results of unit weight, voids in mineral aggregate (VMA), total voids in mixture (Pa) and voids filled with bitumen (VFB) indicated improvement. These results showed that polycarbonate waste enhances both mechanical and volumetric properties of asphalt concrete.

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