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Effect of Carbon Black on Adhesion, Wettability, Roughness, Impact, and Hardness of Styrene Acrylic Polymer for Surface Treatment

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Abstract
Styrene acrylic polymer (SAP) coatings protect materials from damage. Their performance can be enhanced by adding microscopic materials such as carbon black (CB), which improves their surface energy and hardness. This research aimed to evaluate the effect of carbon black at concentrations of 5, 10, 15, and 20% using the casting method. SAP films with varying weight percentages of carbon black were prepared. The mixture was magnetically stirred at 25°C for 1 hour, then stirred in an ultrasonic bath for 30 minutes, poured into a 20 cm diameter mold, and dried at room temperature for 24 hours. The adhesion strength peaked at a 5% CB concentration, reaching approximately 590. However, higher concentrations caused a significant decrease in adhesion strength at 15% and 20% concentrations. Contact angles exhibited variable behavior, ranging from 86.93° at 5% to 35.53° at 20%, with a sharp decrease at 10% (54.52°). The surface roughness of pure SAP was 4.92 µm. Upon the addition of CB, the roughness peaked at 5% (9.69 µm), then decreased significantly with higher concentrations, stabilizing between 5.29 and 5.91 µm. Under increasing stress, films reinforced with 15–20% CB withstood the maximum device load (1880 g) without rupture, demonstrating high toughness. Hardness testing showed that CB affected the mechanical properties of the SAP. Hardness was highest at 5% CB (73.5°), with gradual increases and decreases thereafter, reaching 72.6° at 20%. The addition of CB to SAP improves mechanical properties and toughness up to a certain point (especially at 5%), after which further additives lead to decreased performance in adhesion and surface properties.
Keywords: Styrene acrylic polymer, Carbon black, Adhesion, Wettability, roughness, Impact .

1. Introduction

Corrosion of structural elements remains a major challenge in the construction sector. Using paints and varnishes is among the most effective and high-tech protection techniques. With the growing focus on environmental conservation and sustainability, waterborne coatings such as water-based paints and formulations are receiving increasing [1].Materials are now the most important and broadest class of engineering materials after steel in terms of industrial importance and range of applications. This is because: First, materials provide stiffness, strength, corrosion resistance, and light weight. Second, their structural composition can be adapted to suit the device and conditions, giving mechanical properties suitable for performance [1-3]. The construction industry employs acrylic, styrene, and acrylic-based paints and varnishes. Microscopic voids and cracks in concrete facilitate water diffusion through capillary action. The type of environmental exposure determines the nature of its effect on concrete, whether it affects the reinforcing steel or the cementitious matrix, [4,5]Surface coating can be classified as primers or topcoats. The first coats have good adhesion and protection to the concrete, and the topcoat is applied over the primer to protect against corrosion and improve appearance. Coatings treat weak spots in substrates to add properties to them. They were used to preserve wood, ceramics, metals, etc. But modern technology requires more than that and has become increasingly active electrically, biologically, or chemically, such as preventing [6]. Generally, the complex consists of two distinct stages. Composites are used to attain a blend of characteristics not present in a particular material composites are commonly defined as they are formed by combining a matrix with an additive, resulting in a material that possesses at least one distinct property not found in the separate component [7]. Integrating polymers with novel nanoscale fillers such as metals and metal oxides, organic particles, composites, etc., is among the essential factors for enhancing their physicochemical properties to meet practical application demands [8]. Flexible and rigid water-repellent materials represent common categories of waterproofing solutions. Traditional flexible materials, such as membranes and coatings, have demonstrated flexibility and durability in practical use. However, they exhibit poor adhesion, making them unsuitable for moist substrates and ineffective for applications on damp surfaces [9] The range of applications for polymer materials is expanding these days. Their physicochemical, operational, conductive, and other properties need to be improved in this regard. The challenge of developing novel polymer composite materials is becoming increasingly important[10]. Surface water affinity is a crucial parameter in membrane design, particularly for applications such as anti-fouling surfaces, self-cleaning materials, and surface coating[11]

Styrene-acrylic polymers exhibit excellent hydrophobic characteristics, offering enhanced water resistance and a reduced moisture vapour transmission rate (MVTR). Due to the inherently hydrophobic nature of styrene as a monomer, it is possible to synthesis styrene-acrylic polymers with fine particle sizes. These polymers ' high glass transition temperature is another notable feature of these polymers, which contributes to their thermal and mechanical stability [12,13] Black carbon is a unique material because it has numerous technological applications and is attractive to those interested. It has also inspired many fundamental investigations in scientific laboratories worldwide at universities and research institutes [14].

Carbon black is produced from the incomplete combustion of engines. Carbon black has uses such as electronics because it is a good conductor of electricity. It is used as a filler after mixing it with plastics, films, adhesives, paints, and rubber products[15]**.** This study aims to improve acrylic's contact angle, roughness, thermal stability, and mechanical properties. This polymer was developed by incorporating graphene (GR) and carbon fiber (CF) into a flexible acrylic polymer, making it suitable for several applications such as floor coatings and moisture protection. The research used several techniques, including field emission scanning electron microscopy (FE-SEM), thermos gravimetric analysis (TGA), differential scanning calorimetry (DSC), contact angle measurement, impact strength testing, and Shore A hardness evaluation [16.]
We studied the surface modification of epoxy resin and epoxy/aluminum composites using DBD discharges in dry air at 8 and 9 kHz frequencies. They evaluated the thermal effect of plasma on the treated surfaces. First, they conducted a detailed analysis of the optical properties to determine the energy gap [17]. In this study, a novel approach to vibration absorption materials for industrial applications is achieved, and the complementary effects of graphene nanoparticles (GNPs) and carbon black (CB) within styrene butadiene rubber (SBR) will be explored to improve both. Mechanical properties and vibration-damping performance. The SBR hybrid nanocomposite containing a fixed amount of CB (20 phr) and varying amounts of GNP (2, 5, 7.5, and 10 phr) was prepared and compared with neat SBR and a 20 phr CB/SBR composite. The nanocomposites were analyzed for morphology, tensile strength, tear strength, stiffness, and vibration-damping properties using constrained-layer damping (CLD) tests [18]. The work aims to treat cracks in walls and surfaces using Styrene acrylic polymer and improve the polymer's physical and mechanical properties using carbonaceous materials (Carbon Black).

2. Materials and Methods

2.1. Materials

Styrene acrylic polymer (SAP): Styrene Acrylic polymer (with body: Milky white liquid, pH: 8.5 – 9.5, Specific Gravity (wet polymer): 1.06 g/cm3. Was purchased by Shandong Kunhan New Materials Technology Co., Ltd., China. Carbon black (CB): The powder of carbon black (with Product Name: carbon black, molecular weight: 12.01, purity: 99.9%, Melting point: 3550 °C, Density: ~1.7 g/ml at 25 °C). Avonchem Ltd., Wellington House, Waterloo St. West, Macclesfield, Cheshire, SK11 6PJ, U.K. was purchased.

2.2. Preparation of styrene acrylic polymer (SAP) and styrene acrylic polymer/carbon black (SAP/CB) composites

Solution casting method was used to prepare films of styrene acrylic polymer (SAP) with different weight ratio CB (5,10,15, and 20) % at (25°C) for 1 hours under magnetic stirring and by ultrasonic bath for 30 min, then cast into mold with 20 cm in diameter for 24 hours at ambient temperature and left To air dry for 24 hours at room temperature. Determination of SAP and SAP/CB thickness calculated by an electronic digital micrometer used to measure the thickness of films between 1-1.2 mm. **Figure 1:** Pictures of samples SAP and SAP/CB.

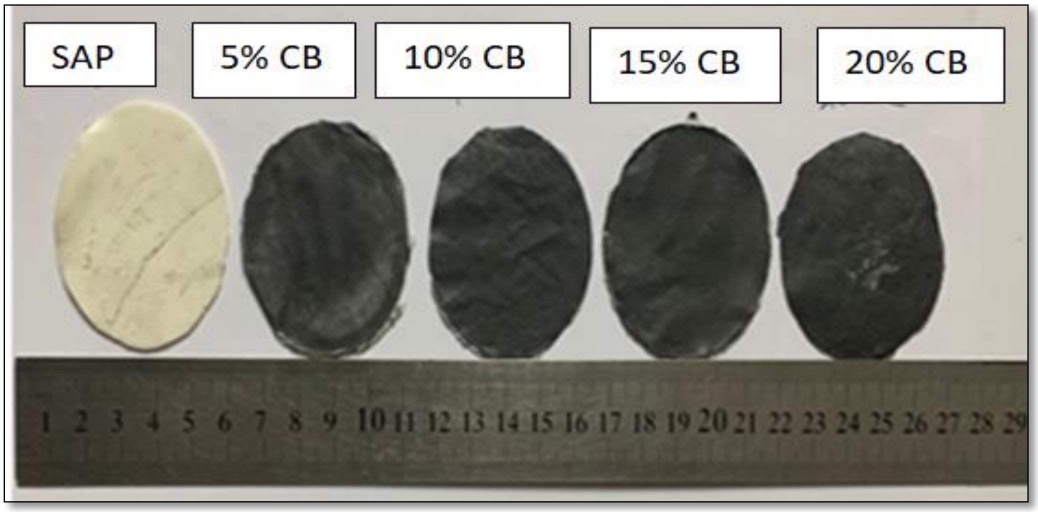

Figure 1. Shows a picture of the samples SAP and SAP/CB.

2.3. Characterization of styrene acrylic polymer/ carbon black composites

The synthesised SAP, SAP/Gr, and SAP/CB morphologies were checked by a scanning electron microscope (SEM) model INSPECT S 50 operating at five kV. Handheld for carrying the pull-off adhesion tester, measures the force required to conduct a specified test coating distance from its substrate, increasing the hydraulic pressure. The contact angle is when a liquid droplet contacts a solid surface; it measures the substrate's (surface) wettability. The sessile drop method is the most commonly used to measure contact angle. It uses a syringe pump to dispense a droplet of liquid (typically water) and a camera to monitor the droplet on a surface. Software linked to the camera is utilized to detect and compute the contact angle of the droplet on the surface. Surface roughness is a measure used to characterize the texture of a surface. It is defined as the vertical deviation of a physical surface from its perfectly smooth form. Roughness is regularly evaluated and crucial in several processes, including friction and adhesion. The arrow impact test method, according to ASTM D1709-04 and ISO 7765, [19] .A circular-tipped arrow (radius of curvature about 18 mm) with a long, thin shank, with cylindrical metal weights attached, is dropped from a height of 1 m vertically onto the surface of a thin polymer film fixed between two rings. Hardness gauge (side A), hardness of the treated material tested for penetration, type "A". Penetration, which is the softest measure of hardness, is tested on a penetrometer.

3. Results

3.1. Scanning electron microscopy (SEM)

SEM images in **Figure 2** of the SAP sample shows a relatively smooth surface with some fine cracks and random protrusions, reflecting the homogeneous nature of the polymer, free of additives or agglomerates**.** SEM image of a SAP surface containing 5% CB shows an irregular surface characterised by roughness, indicating the carbon black's influence on surface morphology. No large aggregates are evident, indicating relatively well-distributed carbon within the polymer matrix. This homogeneous distribution enhances material properties such as mechanical properties, and demonstrates good compatibility between the polymer and additive without noticeable cracks or voids.

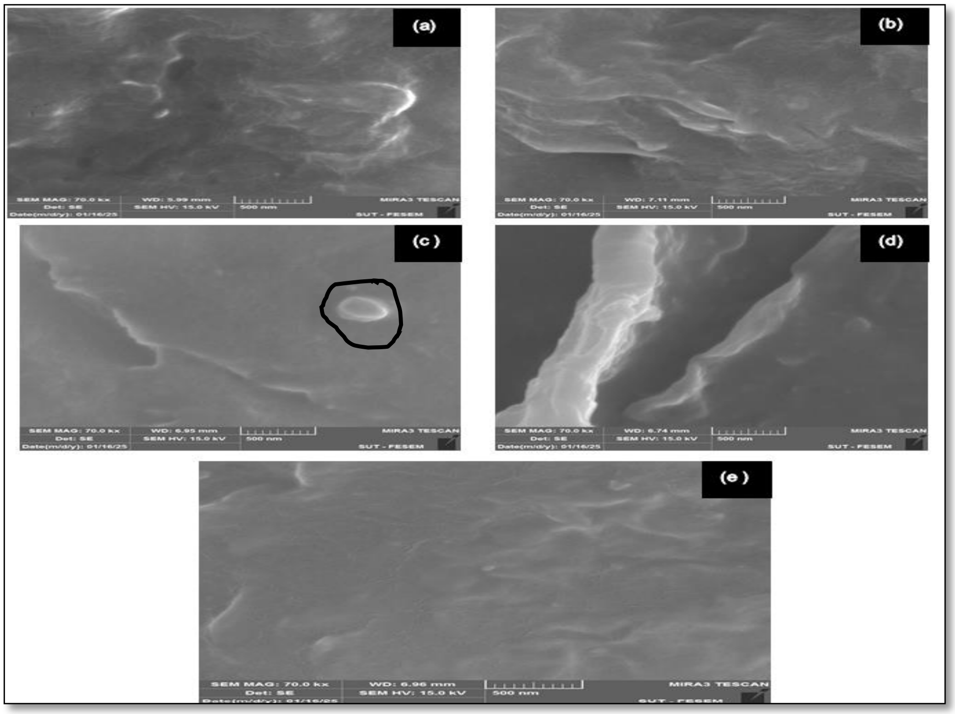

Figure 2. SEM image of (a) SAP , (b) SAP / 5% CB , (c) SAP / 10% CB , (d) SAP/15% CB , and (e) SAP/ 20% CB

3.2. Adhesion strength

In the carbon black reinforced (CB) with SAP, **Figure 3**, the adhesive strength peaked at 5%, reaching approximately 590. However, exceeding this ratio also led to a gradual and sharp decline in performance, with the adhesive strength decreasing significantly at 15% and 20%.

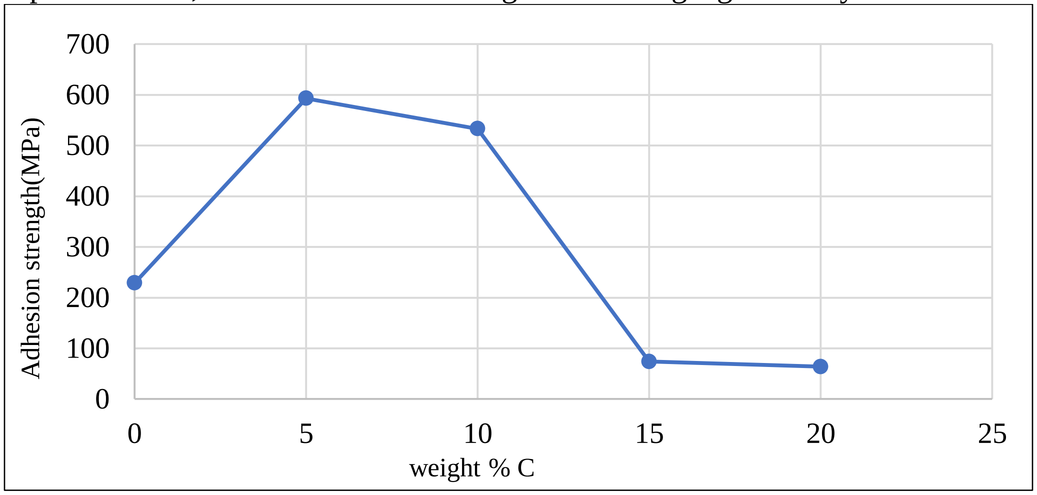

Figure 3. Adhesion strength for SAP/CB composites.

3.3.Water contact angle and Roughness surface

SAP with CB shows in **Figure 4**. The addition of CB exhibited irregular behaviour, with contact angles ranging from 86.93° at 5% to 35.53° at 20%, with a sharp decrease at 10% (54.52°). This indicates that carbon black may increase surface hydrophilicity at certain concentrations. The surface roughness measurement results, measured in micrometers, significantly affected the CB added to the SAP. A roughness value of 4.92 µm was recorded for the pure polymer. In contrast, the carbon black-enhanced samples showed the highest roughness value at 5% concentration (9.69 µm). Still, the roughness decreased significantly as the concentration increased to 10% or higher, with values stabilizing within a range of approximately 5.29–5.91 µm.

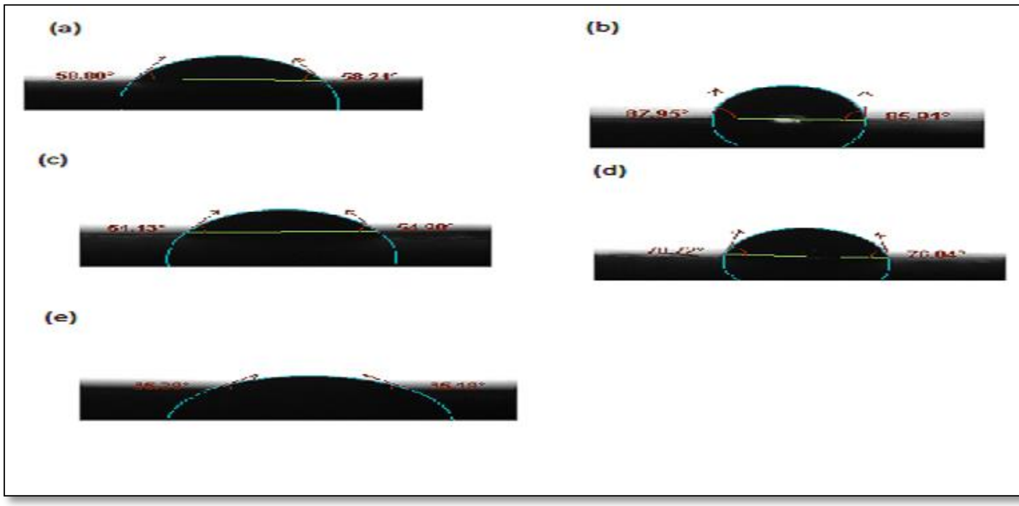

Figure 4. Contact angle values of (a) SAP,(b) SAP / 5% CB, (c) SAP/10% CB, (d) SAP/ 15% CB, and (e) SAP/ 20% CB.

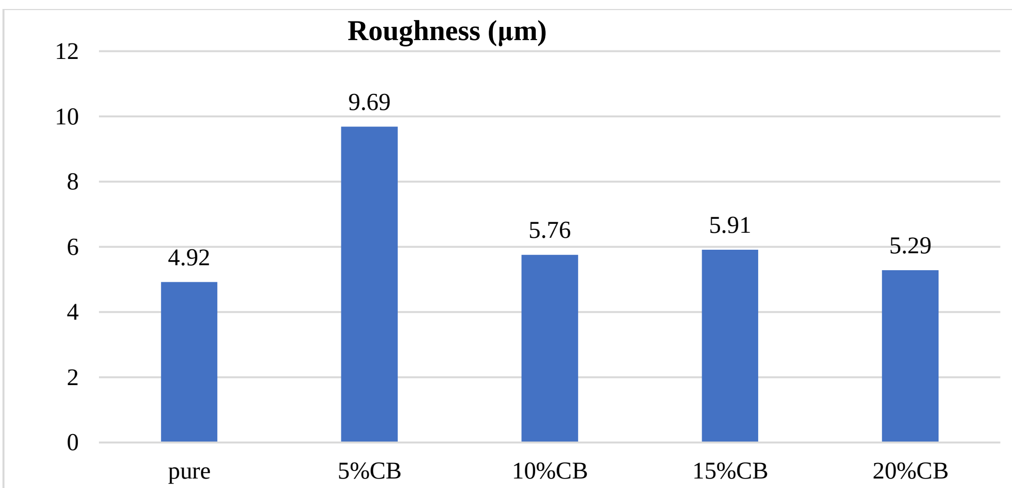

Figure 5. Surface roughness of SAP and SAP/CB.

3.4. Impact Strength and Hardness

The load increases with the increase of the added ratios for both of them until the ratio of 15-20% for CB. This load is the highest in the device, and the amount of 1880 g did not tear the coating shows in **Table 1** . Hardness was at 5%, rising to 73.5. After this concentration, the hardness gradually decreased with increasing CB content, reaching 72.6 at 20%.

Table 1. Impact strength of SAP and SAP/ CB**.**

Samples	Load (gm) 60	Load (gm) 180	Load (gm) 360	Load (gm) 540	Load (gm) 720	Load (gm) 900	Load (gm) 1260	Load (gm) 1440	Load (gm) 1620	Load (gm) 1880
SAP	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	tear			
5% CB	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing
10%CB	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	tear		
15% CB	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing
20%CB	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing	No tearing

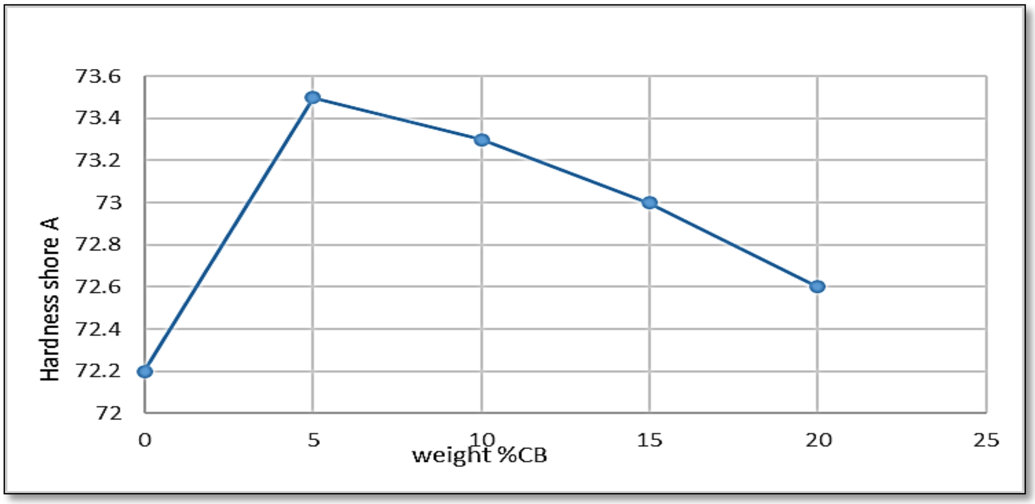

Figure 6. Hardness shore A of SAP and SAP/CB.

4. Discussion

4.1. Scanning electron microscopy (SEM)

The morphology of a polymer with 10% CB added shows a relatively smoother surface compared to the 5% sample, with a clear spherical particle on the right, likely a carbon agglomerate, indicating the beginning of agglomeration at this ratio. The lack of these agglomerations throughout the image shows that the distribution is still acceptable. Still, the higher carbon black ratio is beginning to affect the homogeneity of the surface structure. These changes may improve conductivity but negatively impact mechanical properties if the agglomerate ratio increases. An image of a polymer sample containing 15% CB shows clear cracks and microscopic joints on the surface, indicating increased agglomeration due to the high carbon black content. This may lead to a weakening of the structural cohesion between the polymer and the additive. This high concentration causes significant changes in topography and increases the likelihood of particle separation or poor homogeneity, which may negatively impact mechanical properties. At higher CB content (20%), shows more complex and interwoven surface structure, with a relatively smooth appearance and a blurred distribution of carbon aggregates. This may indicate that the polymer matrix is so saturated with carbon particles that visually distinguishing between the polymer and the additive is difficult. This shows relatively high incorporation or the potential for small, uniformly distributed aggregates. Still, it may also lead to poor structural homogeneity, which could negatively impact mechanical properties, which agrees with the Adhesion strength and hardness test [20,21].

4.2. Adhesion strength

Molecular bonding is the most commonly recognized mechanism for explaining adhesion between two surfaces in close contact. It contains intermolecular forces between the adhesive and the substrate, such as dipole-dipole interactions, van der Waals bonds, and chemical bonds (ionic, covalent, and metallic bonds) [22] . In the carbon black reinforced (CB) with SAP, Figure 3, the adhesive strength peaked at 5%, reaching approximately 590. However, exceeding this ratio also led to a gradual and sharp decline in performance, with the adhesive strength decreasing significantly at 15% and 20%, indicating particle agglomeration. The graphs show that CB improves adhesive strength when added to the polymer at specific ratios. However, this improvement is closely related to the addition ratio. At the same time, CB requires higher ratios (5%) to achieve optimal effect. The sharp decline in performance with increasing ratios indicates the need for careful control of the additive concentration to avoid a negative impact on the polymer's mechanical structure. Surface forces and polar entities influence adhesive joints. Molecular bonding necessitates intimate Interaction between the two surfaces. However, this close contact may sometimes be inadequate for strong bonding at the interface because of imperfections, fractures, or trapped air [23].

4.3. Water contact angle and Roughness surface

Chemical wetting occurs when the polar molecules on a material's surface interact with polar water molecules, increasing adhesion between the surface and the liquid. To reduce this interaction, a hydrophobic coating is used to modify the surface's properties, giving it a nonpolar nature and reducing wettability. Surface hydrophobicity is measured using the contact angle, representing the angle between the water droplets and the material's surface. This measurement relies on images taken with a digital camera connected to a computer. The results are displayed on a graduated screen, which is used to determine the contact angles on either side of the droplet to achieve high accuracy [24]. Figure **4** shows the SAP with CB. The addition of CB exhibited irregular behaviour, with contact angles ranging from 86.93° at 5% to 35.53° at 20%, with a sharp decrease at 10% (54.52°). This indicates that carbon black may increase surface hydrophilicity at certain concentrations. This variation can also be explained by agglomerations or an inhomogeneous distribution of carbon black within the polymer, negatively affecting surface properties. Carbon black additives may be more suitable for applications requiring hydrophilicity or improved adhesion [25] In **Figure 5,** the surface roughness measurement results, measured in micrometers, significantly affected the CB added to the SAP. A roughness value of 4.92 µm was recorded for the pure polymer. In contrast, the carbon black-enhanced samples showed the highest roughness value at 5% concentration (9.69 µm). Still, the roughness decreased significantly as the concentration increased to 10% or higher, with values stabilising within a range of approximately 5.29–5.91 µm. This can be accounted for by the improved homogeneity of carbon black particle distribution within the polymer at higher concentrations, which reduces surface roughness. This trend is supported by the study by [26]. Carbon black at moderate to high concentrations exhibits a more uniform distribution behaviour, improving surface smoothness and reducing agglomerations. This is consistent with water contact angles [27].

4.4. Impact Strength and Hardness

The samples were repeatedly tested under impact at the same location until the mechanical damage obtained in the impact resistance test was restored. However, other samples were not damaged. Adding CB by weight improved the film preparation properties and prevented tearing. However, the addition of CB will also reduce the free expansion of a large polymer chain, decreasing the elasticity of the organic material network. The stock mass can be varied over a wide range by changing the weights on the stock. Typically, the film is tested approximately 10 times with different stock weights until partial or complete tearing occurs, as shown in **Table 1** [28] ,note that the load increases with the increase of the added ratios for both of them until the ratio of 15-20% for CB. This load is the highest in the device, and the amount of 1880 g did not tear the coating, which indicates the strength of the coating. This is due to the good interaction between the styrene acrylic polymer with CB [29]. The mechanical behavior observed during the dart impact test is evident when testing styrene-acrylic polymer films. The central region of the film, measuring 18 cm in diameter, adheres to the curved surface of the dart and stays intact and unstrained throughout the test. In **Figure 6,** the hardness test results showed that (CB) significantly affected the mechanical properties of the polymer, but to varying degrees, when the addition of CB exhibited a different behaviour,its greatest effect on hardness was at 5%, rising to 73.5. After this concentration, the hardness gradually decreased with increasing CB content, reaching 72.6 at 20% [30]. The mechanical properties of these composites depend on several factors, such as particle distribution, their loading ratio, their adhesion to the matrix surface, filler particle size, and their overall composition [31].

5. Conclusion

The structural, physical, and mechanical properties of SAP/ CB composites with CB ratios (5,10,15, and 20) % which conclusions. The SAP sample shows a relatively smooth surface with some fine cracks and random protrusions, reflecting the homogeneous nature of the polymer. 5% CB shows an irregular surface characterised by roughness, indicating the carbon black's influence on surface morphology. No large aggregates are evident, indicating relatively well-distributed carbon within the polymer matrix compared with other ratios (10,15, and 20)%. The adhesive strength peaked at 5%, reaching approximately 590. However, exceeding this ratio also led to a gradual and then sharp decline in performance, with the adhesive strength decreasing significantly at 15% and 20%. The contact angles show the SAP with CB. The addition of CB exhibited irregular behaviour, with contact angles ranging from 86.93° at 5% to 35.53° at 20%, with a sharp decrease at 10% (54.52°). A roughness value of 4.92 µm was recorded for the pure polymer. In contrast, the carbon black-enhanced samples showed the highest roughness value at 5% concentration (9.69 µm). The load of impact strength increases with the added ratios for both until the 15-20% ratio for CB. The hardness test results showed that (CB) significantly affected the mechanical properties of the polymer, but to varying degrees, when the addition of CB exhibited a different behaviour; its greatest effect on hardness was at 5%, rising to 73.5.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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