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Adhesion, Roughness, Wettability, and Dielectric Strength of Elastomers Liquid Bends for High-density Fiberboard Wood Adhesive

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Abstract

In the present study, the physical characteristics of an elastomer (EL) blend with natural polymers such as polyvinyl alcohol (PVA), Dexrin (D), Arabic gum (AG), and corn starch (CS) based on high-density fiberboard wood adhesives were investigated. The EL blends were made by dissolving AG, D, PVA, and CS in deionized water at 70 °C for 1 hour while magnetic stirring continuously until the solution was clear. The blends had a weight of 60/40 (w/w), and they were then poured into a 20-cm-diameter mold and left at room temperature for 24 hours to make sure all the water was gone and the samples were dry. The prepared EL and EL blend structures, adhesion strengths, roughness, wettings, and dielectric strengths were investigated. The modified EL blend reveals 144 MPa for pull-off strength and 770.8 N for shear strength for high-density fiberboard (HDF) wood as a substrate for the EL and AG, respectively. The surface roughness and contact angle of the EL/PVA mixture were found to be high, measuring 4.57 µm for roughness and showing the water contact angles for the samples. An increase in the contact angle of the El/AG blend, which reached 83.94˚, was observed due to the decrease in the COOH and OH groups present in the backbone of the arabic gum. The greatest dielectric strength for EL/AG was reported to be 18.62 kV/mm at 0.5 kV/s and 22.77 kV/mm at 5 kV/s, and an optical microscopy image of the break-down region showed carbonization in the break-down point as a result of carashing polymer chains, as well as microcracks occurring for specimens and these cracks extending directly from the breakdown region.

Keywords: Elastomers Liquid, Blends, Adhesives, Roughness, Wettability, dielectric strength

1. Introduction

A substance in a liquid or semi-liquid condition that attaches or binds objects together is referred to as adhesive (or glue), and adhesives can be made from either natural or manmade sources. Primarily manmade and naturally occurring polymeric *i.e.*, polymers, are used as adhesive source materials [1]. As a result of the necessity to develop and comprehend new varieties of plastics, rubber, adhesives, fibers, and coatings, Polymer blends provide a variety of industrial uses by improving properties and providing financial advantages. Any mixture of two or more polymers that results from a shared processing step is known as a polymer blend [2]. Blending different types of polymers with other polymers can considerably increase their adhesion capability [3]. Casting method, It was observed that the method used to combine polymer mixes affected the adhesion strength [4]. Homogeneous or heterogeneous mixes of at least two polymers or co-polymers are known as polymer blends or polymer mixtures. Depending on their structural characteristics, these polymers can interact chemically or physically, and their physical characteristics diverge from those of their parent components [5]. There are five basic categories of polymer blends, all of which have undergone substantial research: thermoplastic-thermoplastic blends, thermoplastic-rubber blends, thermoplastic-thermosetting blends, rubber-thermosetting blends, and polymer-filler blends [6]. Polymers that, at typical ambient temperatures, are above their glass transition temperatures and are amorphous in their unstretched condition [7] They often have low glass transition temperatures, which fall between −50 and −70 °C. A network of cross-links holds the irregularly shaped chain molecules that make up EL together, preventing the chains as a whole from moving around but allowing individual chain segments to move locally. The network of cross-links may result from physical connections between chain molecules or covalent bonding [8].

Wood has been used as a building, house, and other structures, furniture, tools, vehicles, and ornamental items since the dawn of time due to its distinctive properties (the physical properties of wood are strength, hardness, stiffness, and density). Dense types of wood are usually hard and strong. The term strength covers a number of different properties. Strength varies greatly with seasoning and with the direction of the grain; wood is much stronger when cut along the grain than when cut across it. (Toughness is a measure of strength against sudden, repeated stress.) For engineers, architects, and carpenters to use wood more effectively, more accurate knowledge of wood variation is essential [9]. High-density fiberboard (HDF) wood is prepared when natural wood has a high density and a low amount of chemical additives [10]. HDF is a scientific word that is also used informally since the wood is of high quality and hence expensive. [10]. High-performance starch-based wood adhesives were made using Hydrogen peroxide (H_2O_2), a silane coupling agent, and an olefin monomer as an oxidant, a cross-linking agent, and a comonomer, respectively [11]. PVA is one of the relatively low-cost adhesives that the wood industry has used for decades [12].

Xiaojian C. et al. (2022) A high-performance, environmentally friendly starch-based glue have synthesized using cassava starch as the primary raw ingredient [13]. The plywood with modified starch adhesive demonstrated the maximum wet shear strength, 1 MPa, at pH 4.50 to 5.50, which was 163% greater than that with modified starch adhesive.

The objective of this study is to improve the elastomer liquid mix polymer's shear strength, pull-off adhesions, roughness, wettings, dielectric strength, and color intensity so that it may be used in HDF wood coatings and adhesives. Several methods, including shear-strength adhesives, pull-off adhesives, roughness, wettings, dielectric strength, and color intensity, were used in the investigation.

2. Experimental details

2.1. Materials

The adherent is an HDF wood that was used as the substrate, and its thickness is 3 cm. Meanwhile, the adhesives are EL, AG, D, AG, PVA, and CS. The EL polymer was utilized in this investigation and had the following characteristics: strong, waterproof, flexible, chemically resistant, and temperature-resistant from 40 to 120 °C. It also had a density of 1.1 g/cm^3 and was a clear liquid. The EL polymer was purchased from Sika Gulf, which manufactures products in Bahrain. AG is a complex blend of macromolecules with a variety of sizes and compositions, with a high percentage of carbohydrates (D-galactose and L-arabinose) and a negligibly low percentage of proteins (~3%). In comparison to other gums, AG has a comparatively low viscosity and a high water solubility. The D is white or yellow powder dextrin employed in this investigation, which had a density of 1.8 g/cm^3 and a boiling point of 865.2 °C. Both the AG and G were purchased from the Chinese company Shanghai Clinical Research Center. PVA is a synthetic polymer that dissolves in water. Its idealized chemical structure is $[CH_2CH(OH)]_n$, a density of 1.19 g/cm^3, and colorless (white). The PVA polymer was manufactured in Spain by Panreac Corn Co., Ltd. CS has no color (clear) and is an industrial-grade corn starch that was acquired from the Spanish company Panreac Corn Co., Ltd.

2.2. Preparation of Elastomers and polymers blends

Films of EL/AG, D, PVA, and CS blends were produced with weight ratios of 60/40 (w/w). Around 1 g of AG, D, PVA, or CS was dissolved in 10 mL of deionized water at 70 °C for 1 h while being continuously magnetically stirred until the solution became transparent. Then, 40% of the formed solutions were mixed separately with 60% of the EL polymer, and the mixture was stirred again at room temperature (25°C) for 30 min. To ensure full water removal and drying, the samples were then placed into a mold with a 20-cm diameter and kept at room temperature for 24 hours. The thickness of films was measured using an electronic digital micrometer, which is also used to calculate the thickness of pure EL and mixtures, which is estimated to be 2 mm. The procedures for synthesizing polymer mix adhesives are shown schematically in **Figure 1**.

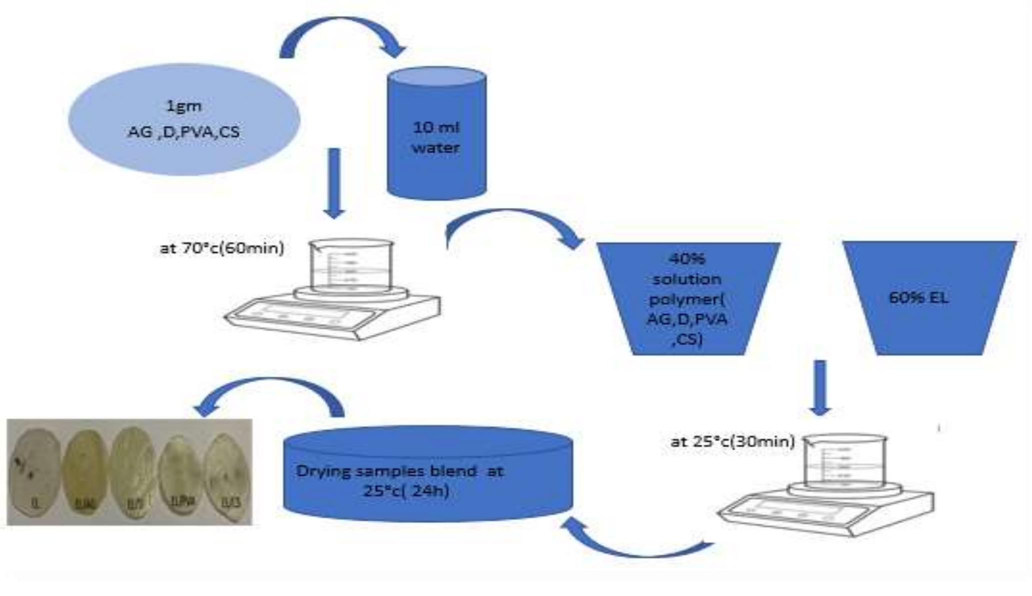


Figure 1. A schematic shows The procedures for preparing polymer blend adhesives

2.3. Characterization of Elastomers and polymers blends

Fourier transform infrared spectroscopy (FTIR) is a technique for obtaining an infrared spectrum, primarily of a solid's absorption and emission. FTIR is frequently employed to examine chemical bonding. Shimazu's FTIR-8400S is utilized in research.

The portable, manually operated PosiTest pull-off adhesion tester measures the force required to separate a certain test diameter of the coating from its substrate as the hydraulic pressure increases. According to ASTM D4541, D7234, and ISO 4624, the pressure shown on a digital LCD shows how effectively the coating clings to the substrate. **Figure 2** displays the sample mixtures for pull-off adhesion.

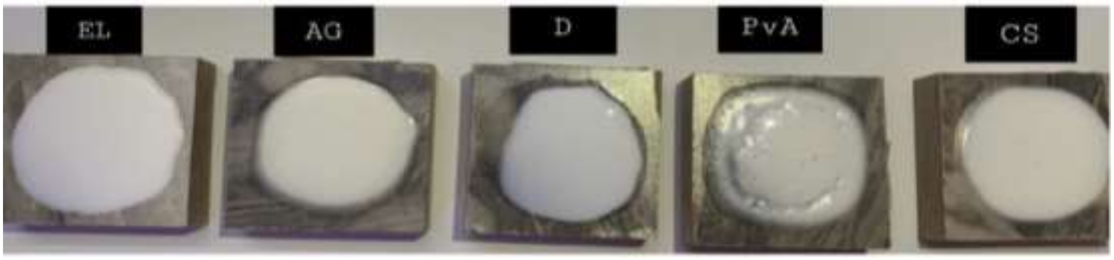


Figure 2. EL, EL/AG, EL/D, EL/PVA, and EL/CS blends of pull-off adhesion for HDF wood

An Intron 4502 electromechanical tensile testing apparatus was used to test single-lap joints mechanically in almost static conditions. In compliance with the ASTM D 1002 standard, crosshead speed was set at 1.3 mm/min. Each sample was subjected to at least six evaluations, and room temperature was used for all testing. A single-lap joint may exhibit stiff adhesion and act as a solid with linear elastic properties, according to a theory. Following these hypotheses, the adhesive experiences pure shear stress, which is constant across the whole overlapping region. **Figure 3** presents the illustration blends for HDF wood.

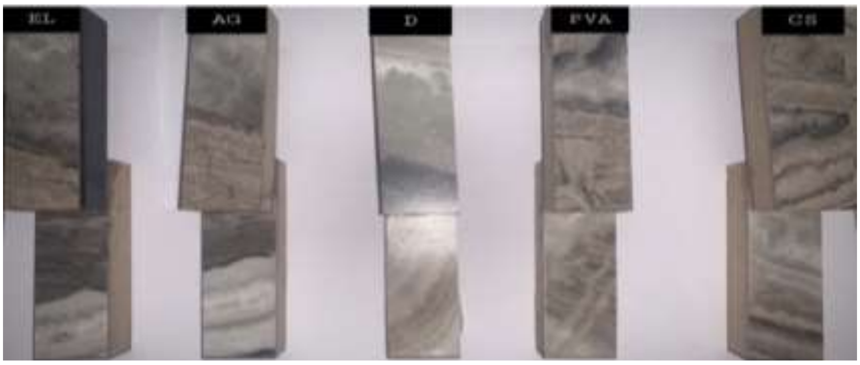


Figure 3. samples of EL, EL/AG, EL/D, EL/PVA, and EL/CS blends for HDF wood

The contact angle is the angle at which a liquid drop makes contact with a solid surface. It gauges the wettability of a substrate (surface). The sessile drop method is by far the most commonly utilized to determine contact angle. The liquid droplet (typically water) is produced with a syringe pump, and it is then examined using a camera on a substrate. Using software connected to the camera, the contact angle of the droplet on the substrate is recognized and computed. Surface roughness is a metric for characterizing surface texture. It is described as a physical surface's vertical departure from its uniform ideal shape. The crucial function that roughness plays in numerous processes, including friction and adhesion, is frequently measured.

The electrical insulation type (BAUR, PGO, and S3), which is of German origin and is made up of a system of pieces, was tested for durability. having a voltage and functioning between 0 and 60 kV and a frequency (50 Hz), a substance with a high dielectric constant, and used oil (8.40 mm/kV) for this purpose to prevent unintentional spark transfer (Flashover). To prevent ionization and guarantee precise readings, this oil must be changed. Brass electrodes with a 2 mm diameter are spherical and well-conductive. The test specimen is positioned between the electrodes; both the electrodes and the test specimen must be submerged in oil.

3. Results and discussion:

Figure 4 depicts the FTIR spectra used to describe the structure of the EL and polymer mix. The main observed peaks in the FTIR for EL are located at 3440.8 and 3431. 1 cm^{-1} corresponding to sp C-H stretching, at 2999. 1 cm^{-1} is due to a long chain of $–CH_2$- group, at 2879 cm^{-1} is due to C=C group, and at 646,1012.5 cm^{-1} is due to C-O, which is commonly used as the fingerprint region of LR, which agrees with [14].

The main peaks were observed for the EL/AG blend in the FTIR the band O-H..O stretching at 3436.9, and 3286.4 cm^{-1}, sp² C-H stretching corresponding to 3213.1 cm^{-1}, sp³ C-H stretching corresponding to 2960 cm^{-1}, C-H stretching at 2341 cm^{-1}, C=C at 1413.7, and 1639.3 cm^{-1}, C-O-C bending vibrations at 1170, 800.4, 642.2, and 522 cm^{-1}. These observed peaks represent the fingerprint area for EL/AG which agrees with [14].

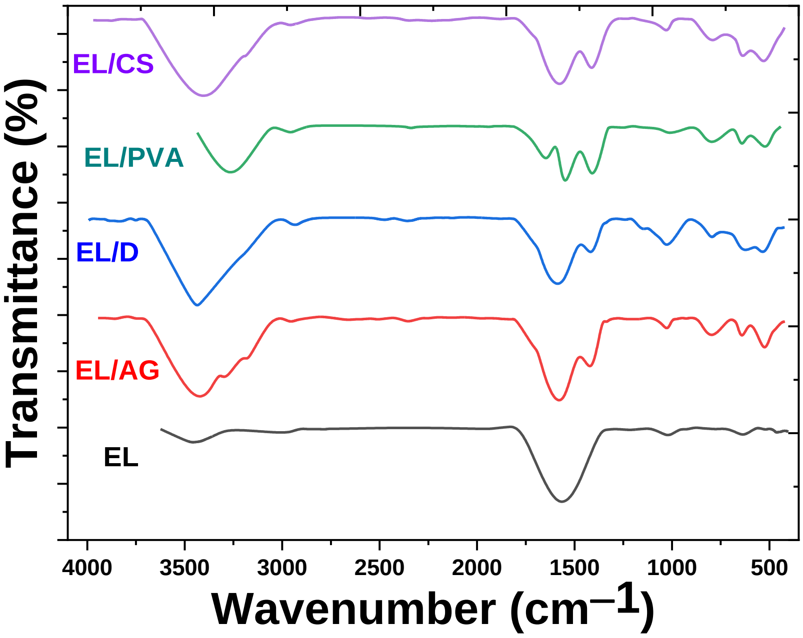


Figure 4. FTIR spectra of EL, EL/AG, EL/D, EL/PVA, and EL/CS blends.

For the EL/D polymer, peaks at 3438.8 cm^{-1} are related to the OH group’s stretching vibrations in the dextrin molecules. Moreover, peaks at 2925.8 cm^{-1} belonged to the CH bond’s stretching vibrations. Other peaks at 1639.3, and 1413.7 cm^{-1} are related to the bending vibrations of the CH3 and CH2 groups, and peaks at 1155, and 929 cm^{-1} are related to the stretching vibrations of the C-O-C glycoside bond and the stretching vibrations of the C-O bonds. Peaks at

524.4 and 422 cm^{-1} are related to the bending vibrations outside the plane of the hydroxide groups, which agree with [15].

For the EL/PVA, the main peaks of PVA were observed at 3434.9, 3284.5, 2960.5, 1639.3, 1556.4, 1413.7, 1166.8, 804.2, 642.2, and 516.6 cm^{-1}. These peaks are assigned to the O–H stretching vibration of the hydroxy group, CH_2 asymmetric stretching vibration, C=O carbonyl stretch, C–H bending vibration of CH_2, C–H deformation vibration, C–O stretching of acetyl groups, and C-C stretching vibration, respectively, which agree with [16]. These high points are caused by the O-H stretching vibration of the hydroxy group, the CH_2 asymmetric stretching vibration, the C=O carbonyl stretch, the C-H bending vibration of CH_2, the C-H deformation vibration, the C-O stretching vibration of acetyl groups, and the C-C stretching vibration.

For EL/CS, the main peaks of CS were observed at 3429.2 cm^{-1} belonging to the O-H stretching, the C-H stretching was assigned at 2960.5 cm^{-1}, CH2 symmetric deformation was assigned at 1554.5 cm^{-1}, CH2 symmetric scissoring was assigned at 1413.7 cm^{-1}, the C-O-C asymmetric stretching was observed at 1166.8 cm^{-1}, and the C-O-C ring vibration of carbohydrate was observed by peaks at 800.4, 642.2, and 522.6 cm^{-1} which agree with [17].

The shear strength and pull of adhesion of wood bound with various adhesives are shown in **Figure 5**. Both the shear strength and the pull of adhesion are increased by the mixing of various additives into the EL polymer. The maximum values for the shear strength (770.8 N) and the pull of adhesion (144 MPa) were observed for the EL/AG polymer. Adding polymers to the elastomer and mixing them together to make a homogeneous mixture also changes the characteristics of the adhesive and makes it work better mechanically. The best-formed polymer with high mechanical strength and adhesion is EL/AG and AG could be the ideal mix. Such observations could be attributed to the characteristics of AG as compared to pure EL polymers. Besides, strong binding and stabilizing qualities are seen in adhesives of high quality and strength [18]. Due to its particular adhesive qualities and rapid drying time (15 min), dextrin shows good adhesion and strength after the AG [19]. Additionally, the combination produced cross-linking between them that increased the shear strength of wood joined with various adhesives. The shear strength data show a significant difference between aluminum and wood, with wood showing a significant and discernible rise. The qualities of the wood are to blame for this variation in the outcomes. The lumens of their cells are big enough to provide a suitable channel for the flow of liquid resin, and interconnecting pits are frequently sufficient to promote resin flow. Hardwood species have high porosity and include vessel and longitudinal fibers. The effectiveness of the bonding between wood pieces depends significantly on how much adhesive reaches the porous network of interconnected cells. Since adhesive bonds move under stress from one component to the next through the interphase area, the interphase geometry also affects the bonding performance [20]. The maximum adhesion value of the material was obtained on the substrate from the EL/AG mix, as shown in **Figure 5**. Due to the characteristics of D and PVA, it is followed by EL/D and EL/PVA, (92 and 90 MPa) respectively, with extremely similar values. In addition to drying fast (15 minutes), dextrin exhibits unique adhesive properties [21]. PVA is a polymer that is water-soluble, biodegradable, and has exceptional adhesion properties. It is one of the most promising water-based adhesives [22].

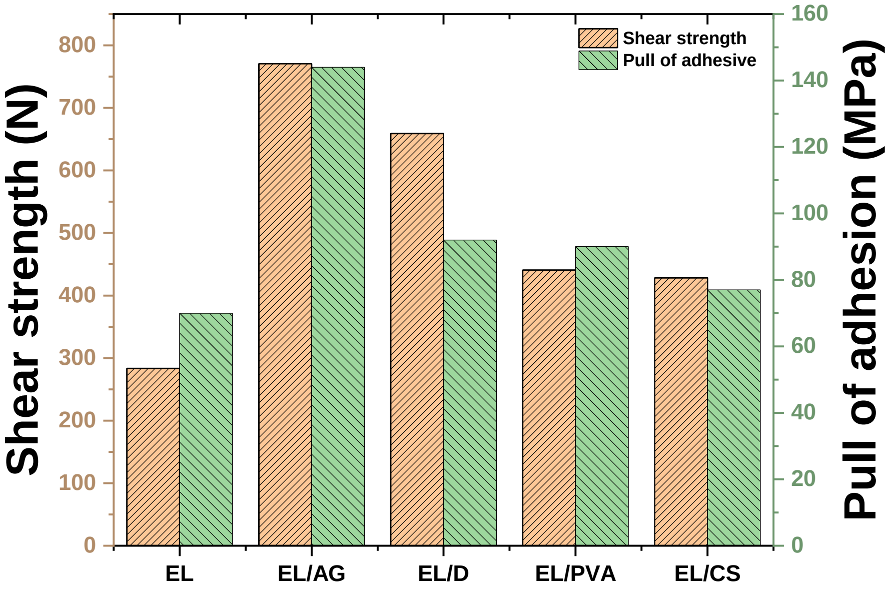
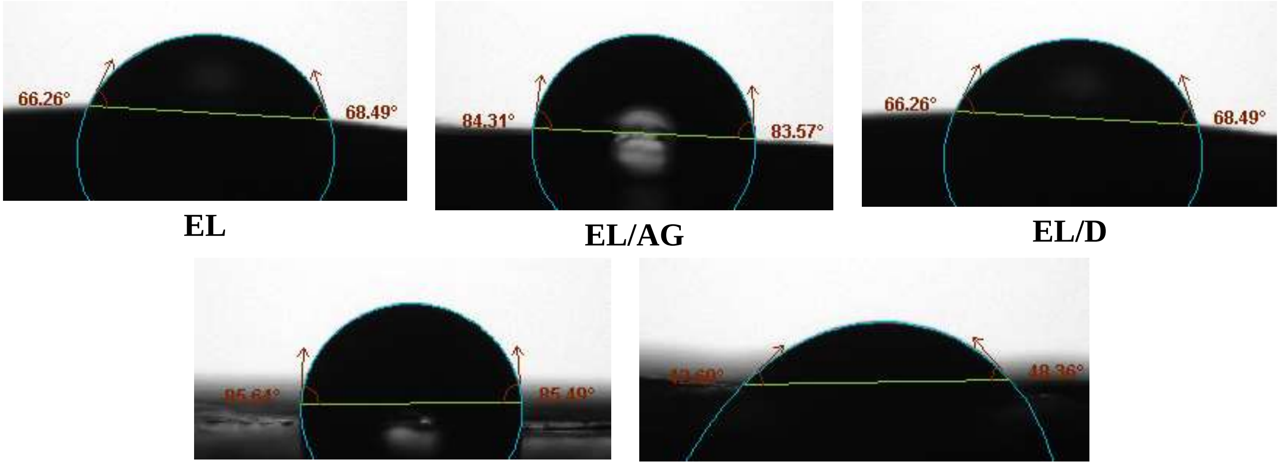


Figure 5. shear strength and pull-off adhesion for EL, EL/AG, EL/D, EL/PVA, and EL/CS blends.

The hydrophilic or hydrophobic character of the sample's surface was evaluated by measuring the contact angle. The table displays the samples' water contact angles. The backbone of the AG had fewer COOH and OH groups, which increased the contact angle of the El/AG combination. The elastomer reduced the AG polar groups, which caused it to change from being a hydrophilic substance to a hydrophobic one. As a result of their combination with the elastomer groups, these groupings decreased. The AG content causes higher water contact angle (WCA) values. The amphiphilic nature of the AG composition might be to blame for this anticipated trend. The arabinogalactan-protein part of AG's structure that has both hydrophobic polypeptide chains and hydrophilic polysaccharide blocks may be what makes it work so well because they give the substance great properties at the interface [23]. Similar thoughts apply to PVA, which is a hydrophilic polymer [24]. We were able to create a slightly hydrophobic adhesive by mixing PVA and elastomer. As the contact angle increased to (85.56°), the elastomer enhanced the PVA's characteristics, as illustrated in **Figure 6** and **Table 1**. **Figure 7** depicts adhesive droplets on a wood surface. Dextrin and AG have the lowest contact angles with the wood's surface, which means that they will permeate the wood and provide the best adhesion since, as was noted in the shear strength test, the wood is porous.

Table 1: left contact angle (Θ_1), right contact angle and (Θ_2), and average contact angle ($\bar{\theta}$) of EL and blends

Samples	Θ_1	Θ_2	$\bar{\theta}$
EL	72.82	70.75	71.78
EL/ AG	84.31	83.57	83.94
EL /D	66.26	68.49	67.37
EL/ PVA	85.64	85.49	85.56
EL/ CS	42.60	48.36	45.48



EL **EL/AG** **EL/D**

EL/PVA **EL/CS**

Figure 6. contact angle for EL, EL/AG, EL/D, EL/PVA, and EL/CS blends.

The contact angle and surface roughness are correlated, meaning that as the contact angle rises, so does the surface roughness. The elastomer and polymer mixes' surface roughness is seen in **Figure 8**. We see that the EL/PVA mix had the greatest roughness value at (4.57 µm), which is consistent with the high value we observed for the same blend in the contact angle test. Although the surface roughness of pure PVA was modest, it rose when blended with elastomer, indicating that the elastomer enhanced the characteristics of this polymer. This is in line with [25]. After being blended with elastomer, AG's characteristics have also improved, and its surface roughness is now equivalent to (4.36 µm). The EL/D mixture's roughness ratio was (4.13 µm) and the EL/CS mix had a value of (3.5 µm), which agree with [26].

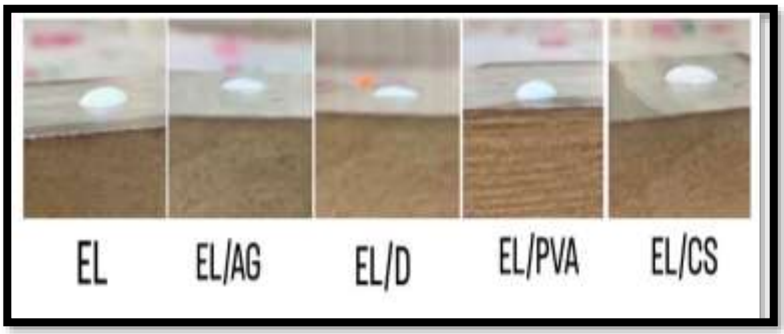


Figure 7. pictures of droplets of adhesive on wood for EL, EL/AG, EL/D, EL/PVA, and EL/CS blends.

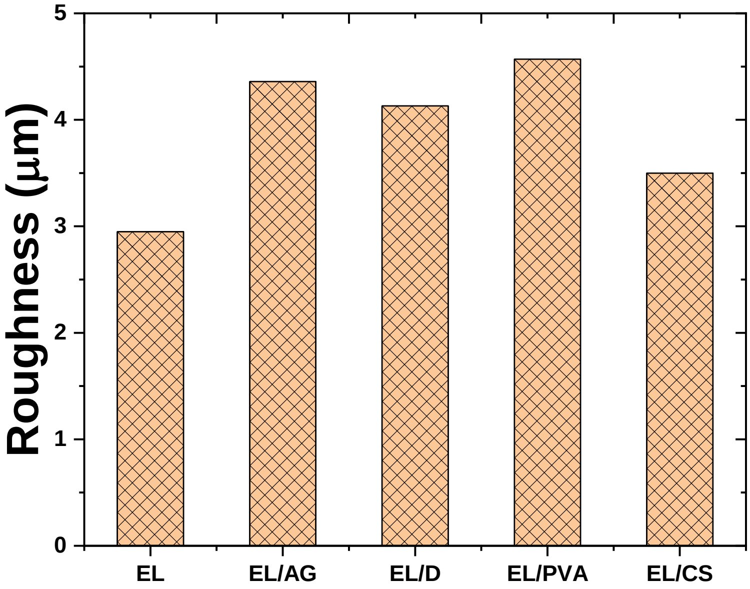


Figure 8. surface roughness of EL, EL/AG, EL/D, EL/PVA, and EL/CS blends.

The effect of fusion, penetration, and cracking on the dielectric depends on the frequency of the voltage and the time of the effect. When a voltage is applied to the dielectric, it causes the release of heat from the dielectric as a consequence of the loss of insulation owing to leakage currents. The lowest voltage (0.5 kV) and maximum voltage are used to determine the dielectric strength (5 kV). The dielectric strength of the prepared blends is better than that of pure elastomers, and the EL/AG blend exhibits the highest dielectric strength to withstand the electrical stress before it collapses and loses the insulation property, as shown in **Figure 9** dielectric strength for EL and blends. The EL/PVA mix has a lower dielectric strength than the other prepared samples because heat arises at the site of contact between the electrodes and the sample and does not equally diffuse to other portions of the sample, causing separation and change at this location. Air bubbles in the prepared sample also cause faults, which lead to electrical failure in the sample. A carbonized zoon was formed as a result of the manufactured blend's thermal breakdown, as seen by the photos in **Figure 10**, which were captured under a light microscope. Photos taken under an optical microscope of the breakdown site showed that the polymer chains intersected at the breakdown point, causing carbonization. The images also showed that the specimens had microcracks that extended directly from the breakdown spot.

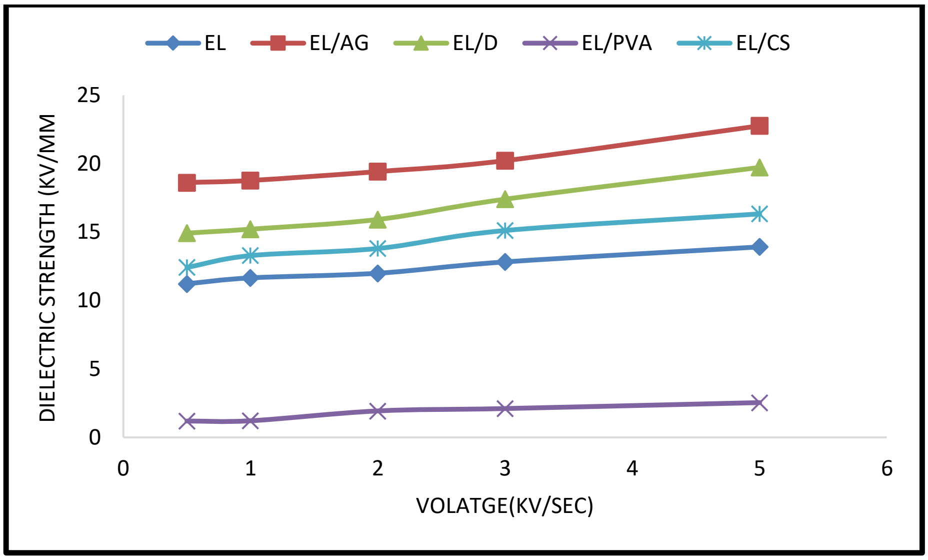


Figure 9. dielectric strength for EL, EL/AG, EL/D, EL/PVA, and EL/CS blends.

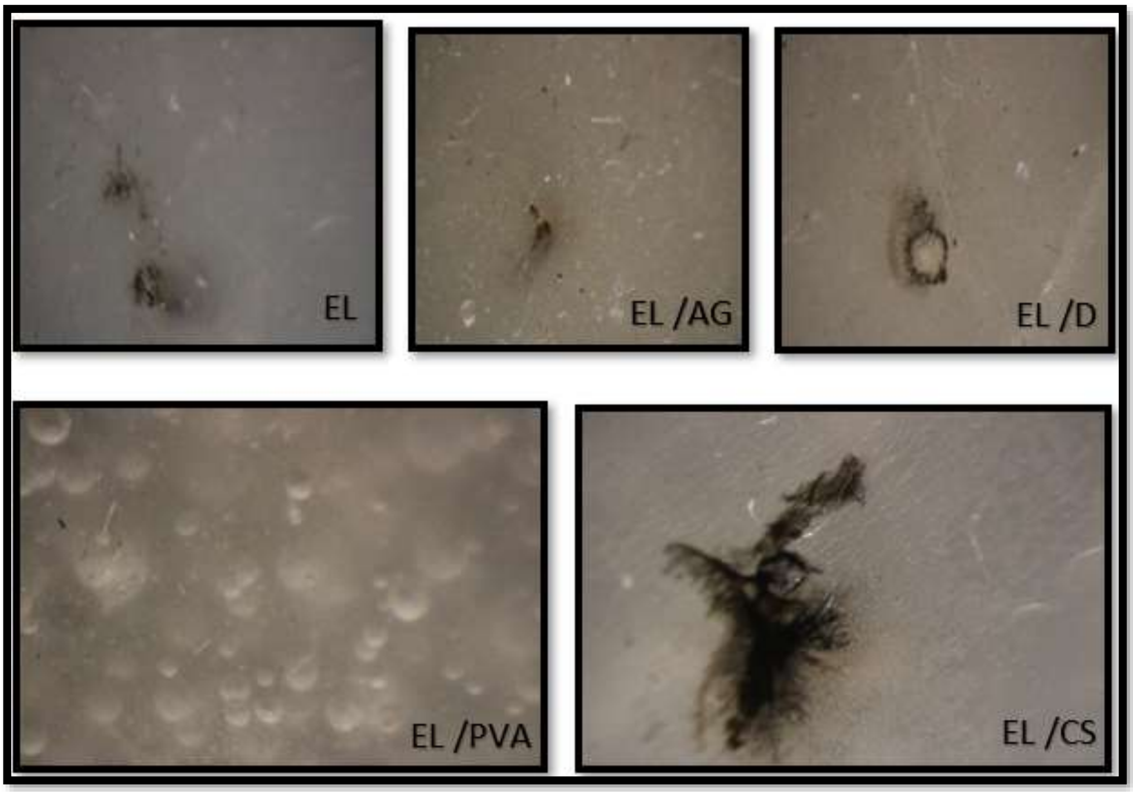


Figure 10. optical microscopy image for breaking down the region for EL, EL/AG, EL/D, EL/PVA, and EL/CS blends.

4. Conclusion

Ablends have been prepared for use in coatings and adhesives for HDF wood. Elastomers Liquid (LE) are integrated with the adhesive polymers (such as AG, D, PVA, and CS) to increase the dielectric strength, pull-off strength, roughness, and wettings. High pull-off strength was recorded (144 MPa) and a higher shear strength of 770.8 N for HDF wood as a substrate for the EL/AG. The surface roughness and contact angle of the EL/PVA mixture were found to be high, measuring 4.57 µm for roughness and 85.56° for contact angle, respectively. The greatest dielectric strength for EL/AG was discovered to be 18.62 kV/mm at 0.5 kV/s and 22.77 kV/mm at 5 kV/s.

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Conflict of Interest

The authors declare that they have no conflicts of interest

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