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The influence of the alkali-treated bamboo particles on the rubber blend properties for medical applications

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HIGHLIGHTS

- Alkali treatment is an effective way to enhance the natural fillers.
- A chemical agent is used for an immiscible blend.
- Grafted PUR/RTV-SIR binary blend systems are miscible up to 25%.
- Bamboo particles develop the mechanical properties of the PUR/RTV-SIR blend system.
- The composite rubber blend system is a suitable alternative to manufacturing the SACH prosthetic foot.

Keywords:

Binary rubber blend
Alkali treatment
Bamboo particles
Mechanical properties
Silicone rubber

ABSTRACT

This study investigates the effect of chemical treatment on the mechanical properties of bamboo particle-reinforced grafted binary rubber blend systems (RTV-SIR/PUR), particularly for medical applications such as Solid Ankle Cashion heel (SACH) prosthetic feet. The Grafted binary rubber blend composite is consisting of Polyurethane (PUR) with (10, 20, and 30 wt.%) of Room temperature vulcanized silicone rubber (RTV-SIR) with presence of 0.1% of Tetraethoxysilane (TEOS) as coupling agent to more compatibility, and added different percentage of treated bamboo particles (3, 6, and 9 wt.%) that treated by 5% of Sodium Hydroxide (NaOH). The effectiveness of the alkali treatment in eliminating contaminants, enhancing the surface appearance of natural bamboo particles, and improving the bonding between the particles and blend constituents was verified using field emission scanning electron microscopy (FE-SEM). The molecular composition of the samples was assessed using Fourier transform infrared spectroscopy (FTIR). Samples were made utilizing vacuum desiccators. The Mechanical properties, including tensile, tear, compression, and hardness, were measured by a material testing system. The results show that a grafted binary blend composite exhibits better mechanical properties when containing less than 30% RTV-SIR. In contrast, increasing the loading of treated bamboo particles to 9 wt.% results in the best properties of the samples. This grafted composite rubber blend is supported by the results presented in this study, which demonstrate a new composition for SACH feet that replaces traditional materials (polyurethane foam) and is feasible due to the use of liquid materials.

1. Introduction

Blending polymers is a powerful method for creating new materials with enhanced properties, often at a lower cost than designing unique monomers and/or developing specialized polymerization routes [1-3]. Another benefit is that a broad range of properties can be created by varying the composition of blends, sparking considerable interest in several practical applications [4-5]. Therefore, the selection of a binary blend system was novel and significant for the manufacture of prosthetic feet, as it offers multiple options that allow the foot to be manufactured with the required characteristics. The exceptional properties of polyurethane include high mechanical strength and good abrasion resistance. These unique properties arise from the molecular structure of urethane compounds (-NH-COO). Consequently, many polyurethane-based materials have been produced in various forms, such as resin, fluids, and cross-linked elastomers for various commercial applications, including high-performance aerospace, adhesives, pharmaceuticals, and advanced biomedical devices [6]. However, these materials exhibit poor thermal stability and limited weather resistance [7]. In contrast, silicone rubber demonstrates exceptional resistance to ozone, chemicals, and flame [8]. All these advantages led to the creation of blends of silicone rubber with polyurethane to form Interpenetrating Polymer Networks (IPNs) [8]. Gao et al. [9], studied the modified silicon rubber by adding different polyurethane content (0, 1, 2, 3, 4, 5, 7, and 10 phr) to form IPNs. The results showed that the addition of polyurethane improves the tensile strength by 32.5%, hardness, and volume resistivity by 200%. Karekar et al. [10], fabricated a 50/50 rubber blend of natural rubber (NR)

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and styrene-butadiene rubber (SBR) and then subjected it to different periods of accelerated weathering. The consequences showed that the blend was more resistant to tests and weathering than its constituent elastomers, due to the increased cross-link density of the blend structure. In addition, Chiu et al. [11], studied the aggregation structure and mechanical properties (tensile, compression, tear, and shear strength) of silicone rubber (S), polyurethane (P), and epoxy (E) blends. The blends composition was as (SPE100, SPE010, SPE001, SPE730, SPE721, SPE712, and SPE703). The outcomes indicate that the characteristics of silicone rubber and polyurethane blends exhibit greater flexibility and adhesion than those of the epoxy mixture.

However, silicon rubber's lack of reactive functional groups limits its use in this field of blending. Therefore, to develop a polar functional group in the silicon rubber backbone, Tetraethoxysilane (TEOS) was utilized as a grafting agent, which can react with the functional group of polyurethane. Still, PUR is generally miscible with silicone rubber up to 25% by weight of SIR, even with the addition of TEOS [7,11]. Maity et al. [12], compared grafted and non-grafted blends of polyurethane and silicone rubber. The findings demonstrated that the grafted blends exhibit greater thermal stability and enhanced mechanical properties compared to their un-grafted counterparts, attributed to the formation of inter-chain crosslinking.

In recent years, the composite industry has shifted its focus to using natural fillers in resins, rather than synthetic fillers, in various applications due to their biodegradable properties, low cost, ease of processing, low density, and eco-friendliness. Natural fillers are produced from sisal, flax, straw, wood, wheat, rye, bamboo, grass, hemp, etc., [13-14]. Bamboo fillers are one of the most promising alternatives to synthetic fillers. In addition to its strength and stiffness combined with low density, it is available, has a short growth cycle, is environmentally friendly, flexible, easy to develop, and biodegradable [15]. However, a significant problem when using natural fillers as reinforcement in resin is the poor adhesion between them. Therefore, numerous studies have been conducted to enhance the adhesion between natural fillers and the matrix by modifying the natural fillers using physical or chemical methods [16]. These treatments result in a reduction in moisture absorption and changes to the surface of the filler. The conditions of modification reactions affect the properties of fillers, including their chemical composition, morphology, and thermal stability. Chemical treatment is the most common procedure used to improve the adhesion with a resin, such as Alkali treatment by sodium hydroxide (NaOH). This method is low-cost and effective in modifying the natural filler's surface to enhance interfacial adhesion with the resin [17-18]. Most studies have confirmed the efficacy of natural filler treatment using a NaOH solution, as determined by IR spectroscopy [19-22].

Maheswari et al. [23], studied the effects of alkali (5% of sodium hydroxide) and silane (1% of 3-aminopropyltriethoxysilane) treatment of different weight fractions (5, 10, 15, 20, 25, and 30%) of tamarind fibres on the mechanical properties of epoxy composites. The mechanical results showed that the alkali and silane treatment significantly improved the flexural, tensile, and impact properties of tamarind fiber epoxy composites. Additionally, the SEM results indicate that the surface modifications enhanced fibre/resin adhesion. Manalo et al. [24], found that the alkali treatment (sodium hydroxide 4–8% by weight) of bamboo fillers affected the mechanical properties of polyester composites, where the best concentration of NaOH was 6% to enhance the tensile, bending, and compression strength by 10, 7, and 81% respectively. In addition, Martijanti et al. [25], aimed to make composite materials, from (polyester, polypropylene) as matrix reinforced by bamboo particles with different volume fraction (10, 20, and 30%), powder size (50, 100, and 250 mesh), and type of bamboo (SBT, alkali treated with 6% NaOH and SBH, alkali treated with 4% NaOH). The results exhibited that the maximum. Tensile and flexural strength were 30.85 MPa and 91.03 MPa, respectively, belonging to composite materials with SBT bamboo particle (treated by 6% NaOH, particle size 250 mesh, and volume fraction of 30%). Additionally, numerous studies have clarified the materials, properties, and factors that influence prosthetic feet. Oleiwi and Hadi [26], and Abdulradi et al. [27], thoroughly studied the biomechanics, materials, and concepts of prosthetic feet. Flexibility, long-lasting durability, corrosion resistance, tensile strength, rust resistance, shear resistance, and a reasonable price were all critical factors in a prosthetic foot. The qualities of the material used, the design of the feet, and the manufacturing method all affect the previously listed factors. In comparison to other types of feet, the SACH foot's forefoot is incredibly durable due to its rubber (polyurethane) sole and superior mechanical qualities. One way to determine how long something lasts is to do a fatigue test.

Several previous studies have developed a blend structure of materials and their mechanical properties, and other studies have focused on bamboo-reinforced polymer materials. The primary concern of this study is to fabricate a cost-effective, easy-to-manufacture, and environmentally friendly grafted rubber blend using PUR with varying concentrations of RTV-SIR (10, 20, and 30%) and reinforcing it with different contents of alkali-treated bamboo particles, which have not been previously reported in this context. The current offering of the composite rubber blend system provides fewer failures, a low cost, easy manufacturing, and various properties, allowing for the selection of the most suitable one for the prosthetic SACH foot, rather than the traditional rubber prosthetic SACH foot.

2. Experimental

2.1 Materials

Polyurethane Rubber (PUR) from Shenzhen Rongxingda Polymer Material Co., Ltd., China, was used. PUR consists of two components: Part A (a polyol (R-(OH) n) as soft segment) and Part B (an isocyanate (R'-(N=C=O) n) as hard segment), as shown in Figure 1, Room-temperature vulcanized Silicone Rubber (RTV-SIR) Parts (A &B) were purchased from Shenzhen

Rongxingda Polymer Material Co., Ltd, China. Figure 2a shows the chemical structure of RTV-SIR, Tetraethoxysilane (TEOS), with a chemical composition (C8H20O4Si) as indicated in Figure 2b, was obtained from Alfa Aesar GmbH & Co. KG, Germany, as a coupling agent, Bamboo Powder (BP) was obtained from SIP India in the form of sticks, and its chemical composition is presented in Table 1, as previously documented [28], and Sodium Hydroxide (NaOH) was obtained from Scharlab Spain Ltd. as a pellet for chemical alkali treatment of bamboo particles.

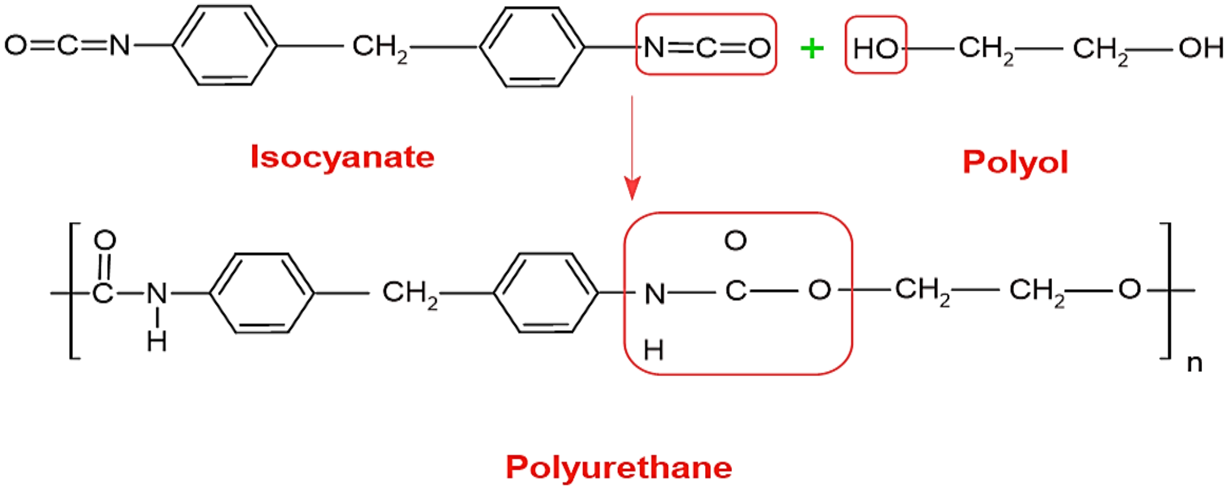


Figure 1: The chemical reaction for producing PUR

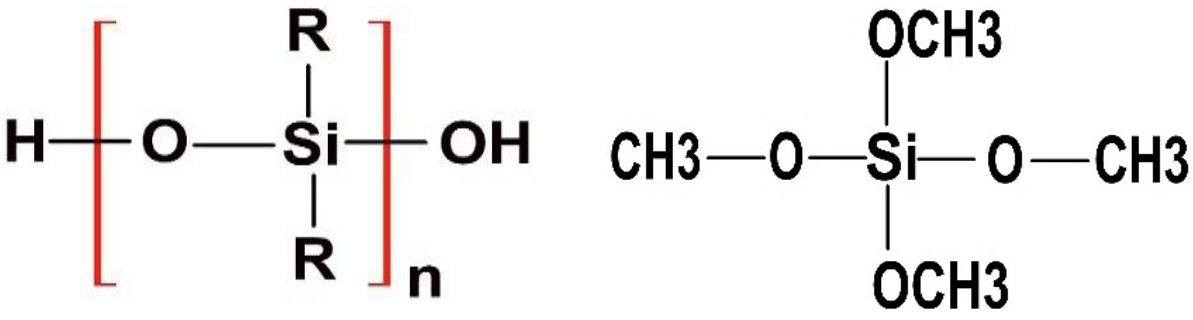

(a) (b)

Figure 2: a) RTV-SIR structure, b) TEOS structure

Table 1: Chemical composition of bamboo [28]

Chemical composition	Percentage %
Cellulose	40
Hemicellulose	29
Lignin	26
Aqueous Extract	4
Pectin	1

2.2 Chemical treatment of bamboo

The bamboo sticks were cut into smaller parts and dried in the sunlight for several weeks to eliminate the moisture. Small bamboo parts were crushed by a jaw crusher machine and followed by a ball mill for further refinement into particulate bamboo particles. Then, the bamboo particles were sieved using a sieve frame mesh of <150 µm size. Chemical treatment of bamboo particles was treated with (5%) of NaOH solution for two hr. at 50 °C [29], under a stirrer device with model MSH-420 (BOECO), Germany. The alkalization treatment of BP was carried out to facilitate the removal of specific quantities of wax, lignin, and oils that cover the external surface of the powder. After chemical treatment, the BP was rinsed and washed multiple times to become neutral, and then the powder was dried for 24 hours at 60 °C. Figure 3 shows the stages of bamboo preparation in this study.

The composite rubber blend samples were fabricated by mixing part A of RTV-SIR at different weight fractions (10, 20, and 30%) with 0.1 wt. % of TEOS. Afterward, part A of PUR was added and then BP at (3, 6, and 9 wt.%) to the mixture at the mechanical mixer device for 5 min, at 150 rpm. After that, part B of both PUR and RTV-SIR was added, the percentage of resin to hardener ratio (A: B) was (100:100) and (100:2) of PUR and RTV-SIR, respectively. Finally, according to the manufacturer's recommendations, the mixture was placed in vacuum desiccators at -10 bars for 10 min. Finally, the mixture is poured into a mold and cured at room temperature (25 ± 1 °C) for 24 hours. Afterward, it is cut according to the test standards. The samples were coded to PSB913, PSB916, PSB919, PSB823, PSB826, PSB829, PSB733, PSB736, and PSB739. Figure 4 and Table 2 illustrate the fabrication and composition techniques used in this study, respectively.

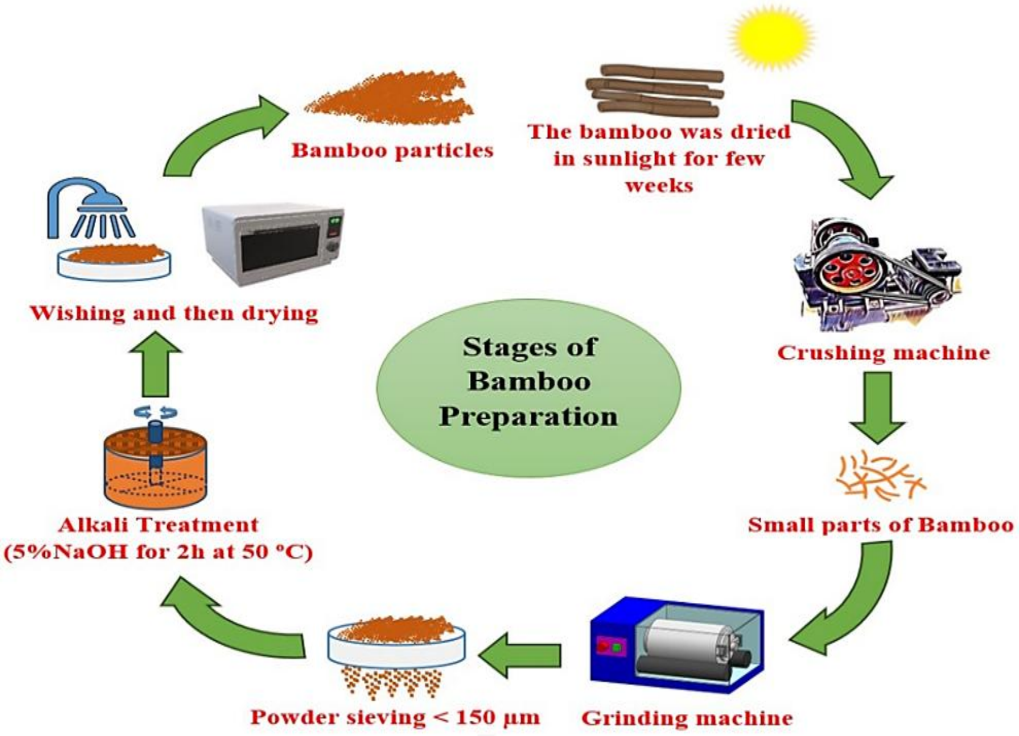


Figure 3: Stages of bamboo preparation

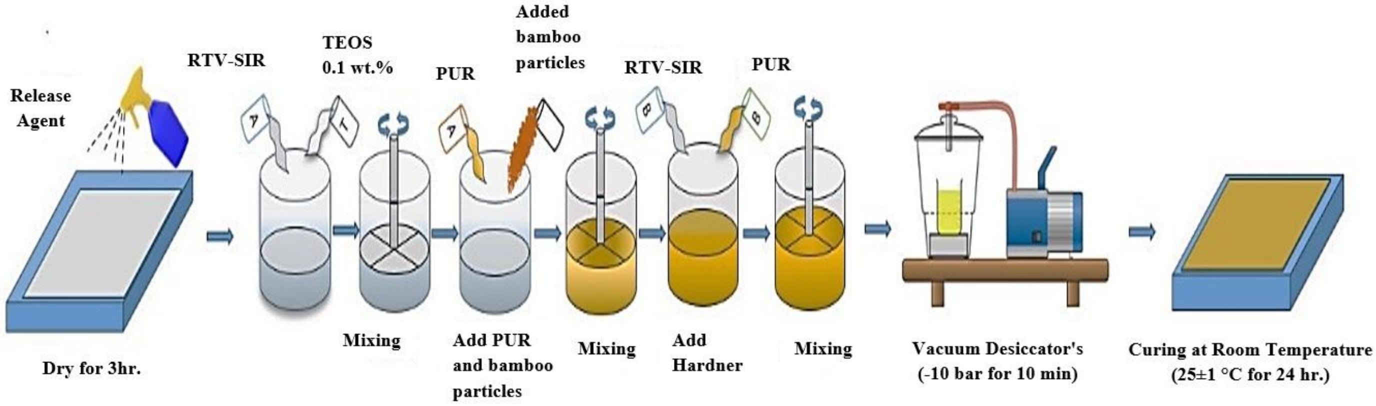


Figure 4: Fabrication of rubber blend composites

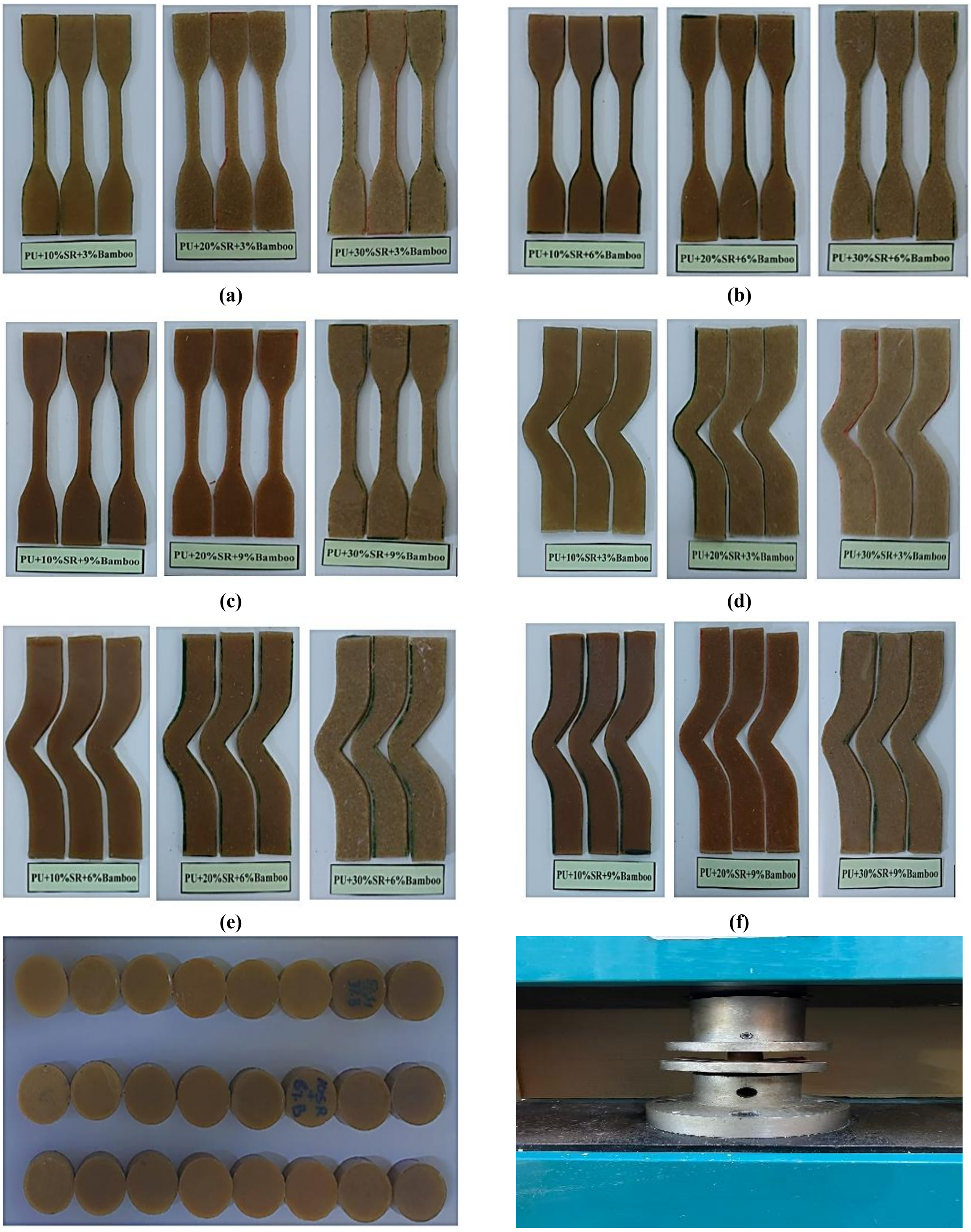
Table 2: Composition of specimens in this study

Sample code	Materials (wt.% %)		
	Polyurethane (P)	RTV-silicon rubber (S)	Bamboo powder (B)
PSB913	90	10	3
PSB916	90	10	6
PSB919	90	10	9
PSB823	80	20	3
PSB826	80	20	6
PSB829	80	20	9
PSB733	70	30	3
PSB736	70	30	6
PSB739	70	30	9

2.3 Characterization

The surface morphology of BP was studied using an FEI INSPECT F50 FE-SEM (Field Emission-Scanning Electron Microscopy) with a magnification of 5 µm and an accelerating voltage of 30 kV. Infrared spectra of samples were collected using the (FTIR) Fourier Transform Infrared spectrometer, based on ASTM E 1252 [30], with a Bruker Optics Tensor 27 spectrometer, Germany. Infrared spectra of the samples were recorded at a resolution from 4000 cm^{-1} to 600 cm^{-1}, and mixed with KBr to obtain pellets for FTIR analysis.

The rubber blend composite's tensile, tear, and compression strength is evaluated using a matrix of polyurethane with 10, 20, and 30 wt.% of RTV-silicon rubber, along with different contents of bamboo particles: 3, 6, and 9 wt.%. The tensile properties of the samples were determined from the stress-strain curve, as per ASTM D-638 Type IV [31]. The tear strength of the samples is determined by dividing the maximum force by the sample thickness, as per ASTM D-624 Die C [32]. The compression samples were prepared with a thickness of (12.5 ± 0.5 mm) and a diameter of (28.6 ± 0.1 mm) according to ASTM D-575 Method A [33]. The samples shown in the figure are mounted on a Universal Tensile Testing Machine, type LARYEE-UE34300 (China), with a crosshead speed of 50 mm/min for tensile and tear tests, and a crosshead speed of 12 ± 3 mm/min for compression tests. In addition, a Shore A Durometer hardness test was used to evaluate the samples' scratch resistance, based on ASTM D 2240 [34], using a device type ZWICK-Bc100 (Germany). The information on tests was presented as average values, along with at least three independent measurements and the standard deviation (SD). Figure (5a-h) shows the samples in this study.



(a) (b)

(c) (d)

(e) (f)

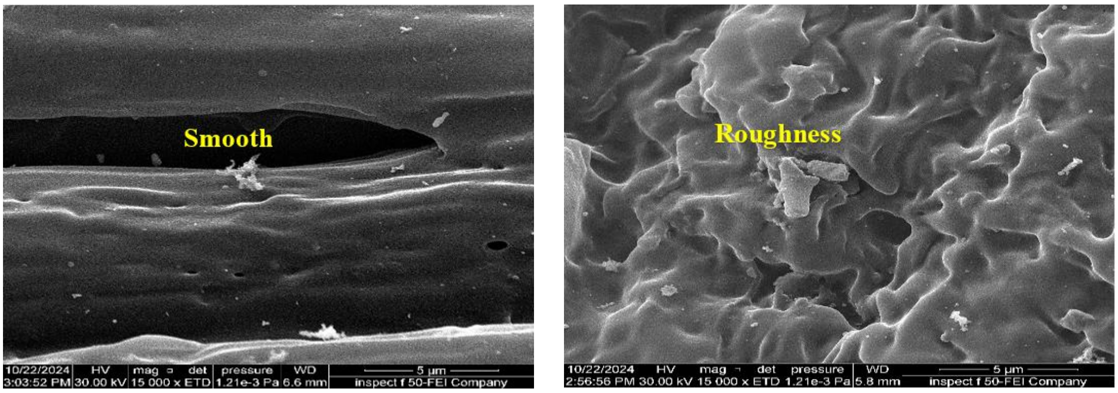
(g) (h)

Figure 5: (a, b, and c) Tensile samples of (10, 20, and 30 wt.% RTV-SIR/PUR) with (3, 6, and 9 wt.% %) Bamboo particles, respectively. (d, e, and f) Tear samples of (10, 20, and 30 wt.% RTV-SIR/PUR) with (3, 6, and 9 wt.% %) Bamboo particles, respectively. (g and h) Compression samples and device, respectively

3. Results and discussion

3.1 Field Emission-Scanning Electron Microscopy (FESEM)

SEM images of untreated and treated Bamboo Particles are shown in Figures 6a and b, respectively. As shown in Figure 6a, BP has a smooth surface due to the presence of wax, lignin, and pectin, among other components. The white flecks within the figure of BP may be impurities present on the surface of BP, as well as holes. Comparing Figure 6b with 6a, BP has a rough surface after chemical treatment with 5% NaOH, due to the partial removal of non-cellulosic components [18]. The roughness of the treated surface of bamboo particles increases the surface area and provides more sites for interlocking between the bamboo particles and the matrix [25].



(a) **(b)**

Figure 6: FESEM of Bamboo particles (a) without alkali treatment, (b) with alkali treatment

3.2 Fourier Transform Infrared Spectrometry (FTIR)

Figure 7a shows the NaOH-treated bamboo revealed low intensity peaks from 1180 cm^{-1} to 1515 cm^{-1}; these vibrations indicated that a large amount of lignin was removed. Another peak was shifted to 1640 cm^{-1}, revealing the carbonyl group of the acetyl ester in hemicellulose and the carbonyl group of the aldehyde in lignin [19]. The intensity of the peak at 2910 cm^{-1}, corresponding to the low (C-H) stretching vibration from the (-CH2) group of cellulose and hemicelluloses, was lower than that of non-treated bamboo particles, which reveals the reduction or removal of this component [20]. The broad band ranging from 3000 cm^{-1} to 3700 cm^{-1}, which indicated the cellulose structure's hydrogen-bonded (-OH) vibration, was slightly absent due to the removal of the cellulose structure. These chemical treatments helped reduce the water absorption of bamboo fillers at 1640-1650 cm^{-1} (H-O-H). Alkali treatment with NaOH was more prone to attack the hemicellulose in natural fillers than it was to lignin. It is assumed that the absence of lignin, hemicellulose, and wax-containing chemicals on the filler surface enhances the compatibility between fillers and resin matrix, and it will not affect the mechanical strength of fillers [19].

IR spectra of RTV-SIR, TEOS, and PUR are shown in Figures 7 b, c, and d. It is known that the absorption peak of silicone rubber reaches 3600 cm^{-1} (Si-OH), 1080 cm^{-1} (Si-O-Si), and 2960, 1257, and 795 cm^{-1} ($Si-CH_3$). For TEOS, the absorption peak reaches 3550 cm^{-1} (Si-OH), 1077 cm^{-1} (Si-O-Si), 786 cm^{-1} (Si-O), and 962 cm^{-1} (Si-OH). The absorption peak of PUR reaches 3350, 1729, 1223 cm^{-1} for stretching (N-H, C=O, and C-O), respectively, and the absorption peak 1528 cm^{-1} for bending (N-H), which agrees with [35]. The PSB919 and PSB733 blend system's IR spectra are shown in Figures 7e and 7f. The PSB919 blend exhibited a new peak at 2273 cm^{-1}, corresponding to the isocyanate (-N=C=O) linkage, which was absent in the case of the PSB733 blend. This spectrum indicates that interchain crosslinking reactions occurred through the PUR and the grafted RTV-SIR by TEOS, indicating the diisocyanate reaction, and the vulcanization process is completed in PSB919 [12]. At the same time, the PSB733 blend exhibits no new observed absorption peak due to the lack of compatibility between PUR and 30 wt.% % of the RTV-SIR blend, as reported in [1].

3.3 Mechanical properties

The tensile strength and elongation at break of rubber blend composite samples were tested at room temperature (25 °C), and the stress-strain results are shown in Figure 8. Table 3 shows the mechanical properties of the samples in this study. With the increase in silicon rubber content, the samples' tensile strength decreases. When the silicon rubber content is 10 to 30 wt.%, the tensile strength of SPB919 reaches its highest value of 10.1 MPa, which is 145% higher than that of SPB739, at 4.11 MPa. This indicates that the tensile stress of silicone rubber is lower than that of polyurethane. However, the elongation at break shows different trends, depending on the ability of composite rubber blend samples to resist the stretching before fracture. When subjected to external load, the rubber blend of PUR and RTV-SIR molecules intertwine into a whole and form a load compatibility effect of the interpenetrating network IPN with the presence of TEOS, which makes it difficult for the molecular chains to untangle, resulting in an enhancement in tensile strength. At the same time, increasing the degree of cross-linking and enhancing the interaction between PUR molecules diminishes the mobility of the molecular segments to a certain extent, resulting in a decrease in the elongation at break, which agrees with the findings of Gao et al., [9]. In addition, when the treated bamboo particle content increases from 3 to 9 wt.%, the tensile strength of the samples reaches the highest value. Due to the superior characteristics of bamboo particles and their use as reinforcement in many studies [14-15,36], the alkali treatment of these particles can remove wax and pectin, resulting in a rougher surface topography and fibrillation, as shown in FESEM images. This enhances the effective surface area accessible for wetting by the matrix resin, resulting in improved adhesion between the particles and resin, as well as increased mechanical properties. The tensile strength and tensile modulus are essential parameters to determine when designing composite applications. Variation in tensile modulus M100 (stress at 100% elongation) and M200 (stress at 200% elongation), which measures material stiffness, is shown in Figure 9. M100 and M200 increase with a decrease in RTV-SIR content and an increase in bamboo loading up to 9 wt.% %. The most important contribution to the modulus arises from: 1) the percentage of blend composition, 2) the cross-linking density of the blend, and 3) polymer filler interaction, which can increase when the density of cross-linking is increased, and with a good dispersion of the filler, which is achieved with polymer [37]. Alkali treatment enhances the tensile modulus values of the samples, as is also the case with tensile strength.

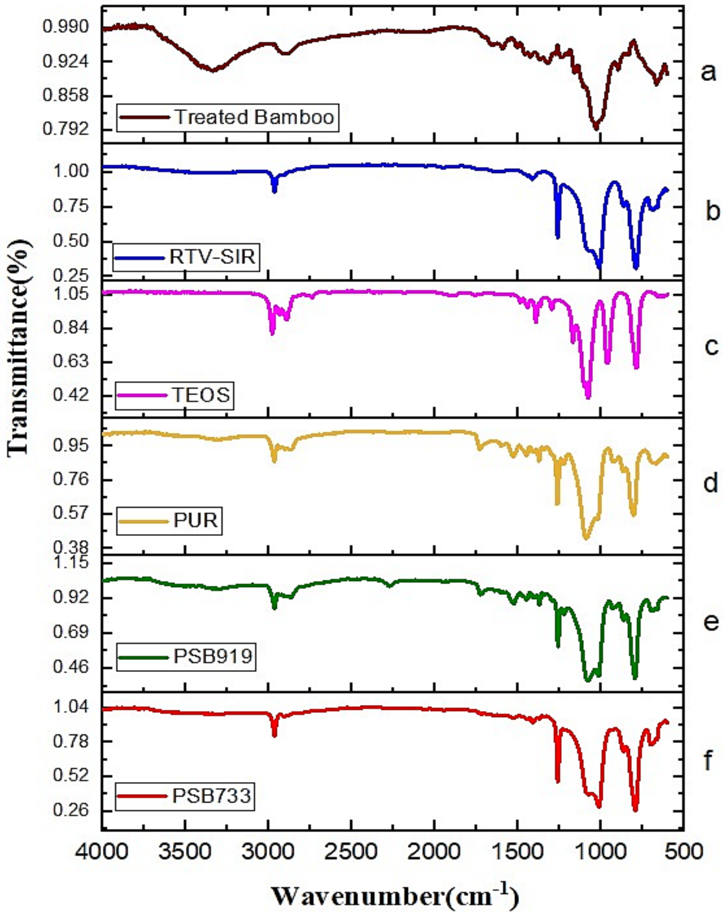


Figure 7: FTIR spectrometer of materials and blends

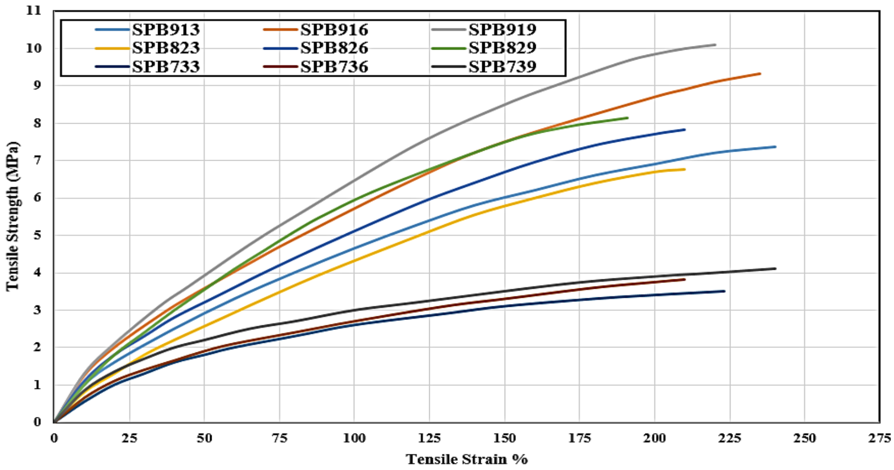


Figure 8: Stress-strain curve of rubber blends composites

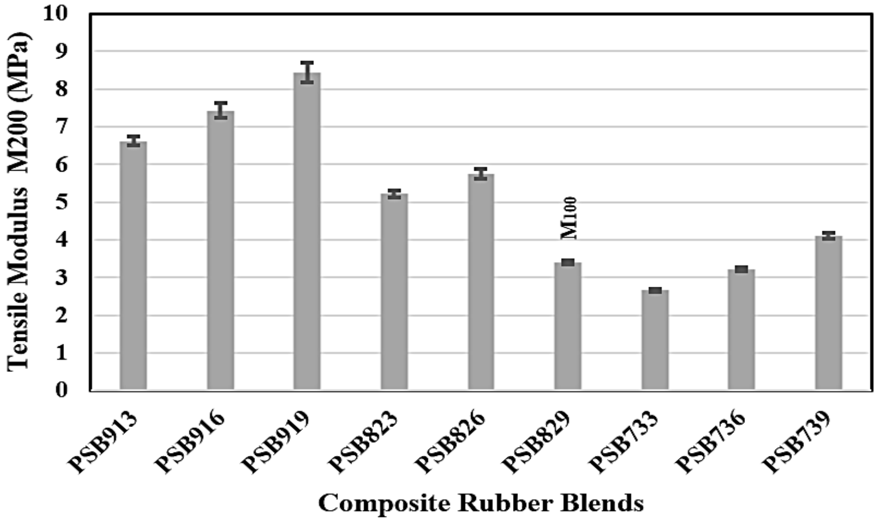


Figure 9: Tensile modulus values of rubber blends composites

Table 3: Mechanical properties of composite rubber blends in this study

No.	Code of Sample	Tensile Strength (MPa)	Tensile Modulus at 200% M_{200}(MPa)	Elongation (%)	Tear Strength (N/mm)	Compression Strength (MPa)	Hardness (Shore A)
1	PSB913	7.36 ± 0.17	6.62 ± 0.12	240 ± 3	44.32 ± 1	8.51 ± 0.2	70
2	PSB916	9.32 ± 0.28	7.43 ± 0.2	235 ± 3	47.1 ± 1.1	8.8 ± 0.2	72
3	PSB919	10.1 ± 0.27	8.44 ± 0.25	220 ± 5	52.78 ± 1.2	10 ± 0.25	77
4	PSB823	6.77 ± 0.15	5.22 ± 0.1	210 ± 2	35.2 ± 0.7	7 ± 0.18	61
5	PSB826	7.82 ± 0.2	5.75 ± 0.13	210 ± 2	38.8 ± 0.6	7.22 ± 0.15	64
6	PSB829	8.15 ± 0.22	M_{100}=3.4	191 ± 2	41.5 ± 0.7	8.21 ± 0.2	66
7	PSB733	3.5 ± 0.08	2.66 ± 0.04	223 ± 3	22.5 ± 0.4	2.5 ± 0.12	31
8	PSB736	3.82 ± 0.1	3.21 ± 0.05	210 ± 1	25.1 ± 0.4	2.77 ± 0.1	33
9	PSB739	4.11 ± 0.1	4.1 ± 0.08	240 ± 4	27.78 ± 0.5	3.3 ± 0.2	33

The tear strength values are shown in Figure 10 and Table 3. Similar to tensile strength, the tear strength of the PSB919 is higher (52.78 N/mm) than that of other samples, and the PSB733 has the lowest value (22.5 N/mm).

The amount of silicone rubber and bamboo filler of the samples influences the difference in tear strength values. Tear strength is directly related to the bonds between molecules and the density of cross-linking that forms the rubber blend [38]. In addition, the ratio of PUR and RTV-SIR, as well as the bamboo fillers, greatly determines the binding capacity between molecules, which ultimately determines the nature of the composite rubber blend. In the composite rubber blend system, the tear is initiated and propagates through the interface between two rubber components of the blend. The lowest tear strength exhibited by the PSB733 can be attributed to the easy propagation of an initiated crack through the weak interface, resulting from weak interfacial crosslinking and poor interfacial adhesion of the blend compound, which agrees with the findings of Perera et al., [39].

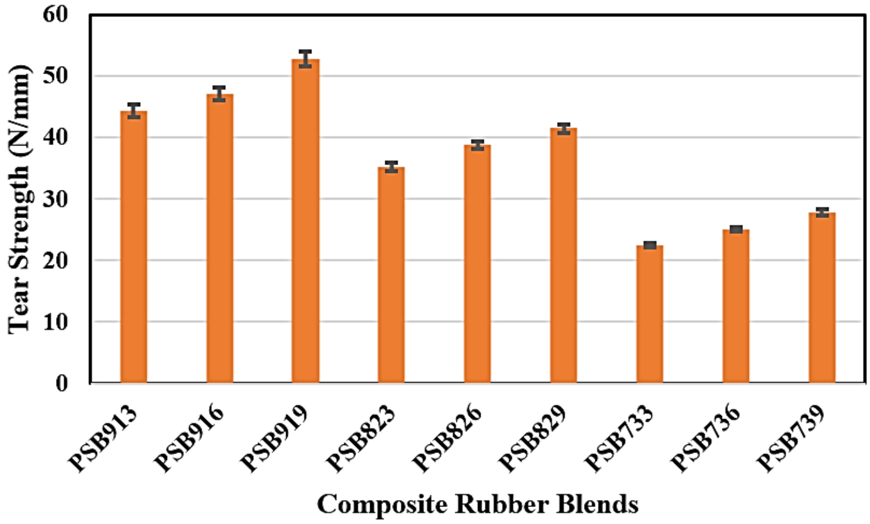


Figure 10: Tear strength values of Rubber Blends Composites

From the compression test results shown in Figure 11 and Table 3, the samples with 10 wt. The percentage of RTV-SIR (PSB913, PSB916, and PSB919) showed the highest values (8.51, 8.8, and 10 MPa, respectively), indicating the highest stiffness value. This property was further decreased for samples with 20 wt%. % and 30 wt.% RTV-SIR, as the latter displayed the lowest stiffness property (2.5, 2.77, and 3.3 MPa) of PSB733, PSB736, and PSB739, respectively. The structure of the binary rubber blend is complex due to the rigid nature of polyurethane and the soft nature of silicone rubber, which is compatible with up to 25% silicone rubber [8]. Therefore, the 30 wt.% RTV-SIR samples have an immiscible blend structure and lower properties.

In addition, the effect of the treated bamboo content on samples with 9 wt. % is the highest in terms of compressive load, followed by the six wt. % samples, and then the three wt. % samples. This indicates that the addition of particles to the rubber blend enhanced the compressive properties of the samples, enabling them to withstand the compressive load and resist deformation under the applied load [40]. This could also be attributed to better filler-matrix interaction, as the particles are well distributed. With this, the stress distribution and deformation of the samples will be uniformly transferred due to the manufacturing process using the vacuum technique [41]. Thus, the ultimate compressive performance of the samples can be achieved [42]. However, adding bamboo particles to a binary blend of polyurethane and silicon rubber yields several properties that can be utilized in medical prostheses.

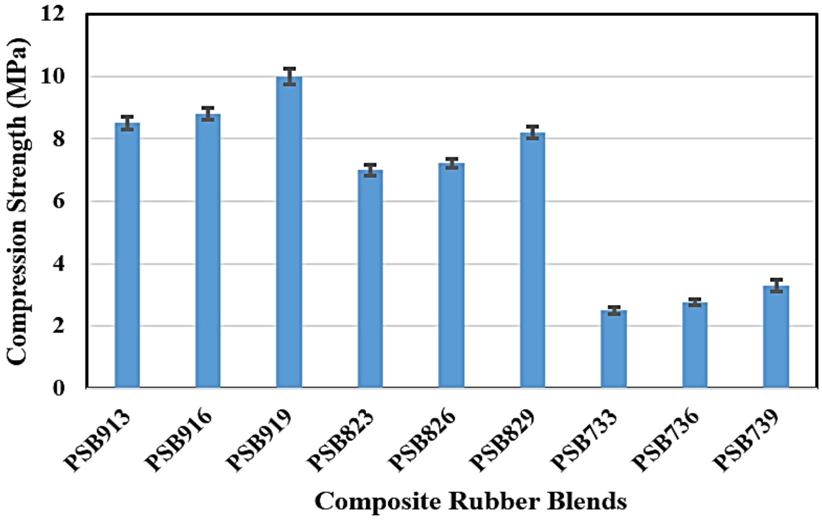


Figure 11: Compression strength of Rubber Blends Composites

The hardness test results of the binary blend with treated bamboo particle composite samples are shown in Figure 12 and Table 3. The samples with 10 wt. % content of RTV-SIR has the highest hardness value (70, 72, and 77 shore A) of PSB913, PSB916, and PSB919, respectively, compared to the other contents of RTV-SIR. Meanwhile, the lowest hardness test result (31 Shore A) was obtained for PSB733. The hardness value of a binary blend system is influenced by the ratio of components and the density of bonds between the material and treated bamboo particles, with loading up to 9 wt%. % causes increased hardness value and further decreases with loading to 6 and 3 wt. % leads to a deterioration in hardness by (10%). This was because the fillers with particle size <150 µm have a larger surface area, mostly in contact with the matrix by physical bonds, than large particles [43]. Composites with strong bonds are more complex to construct and have good surface properties [44]. In addition, the efficiency of the treated bamboo is further supported by the improvement in hardness, which is attributed to the high filler properties and better interfacial interaction between the treated bamboo particles and the matrix [45,46].

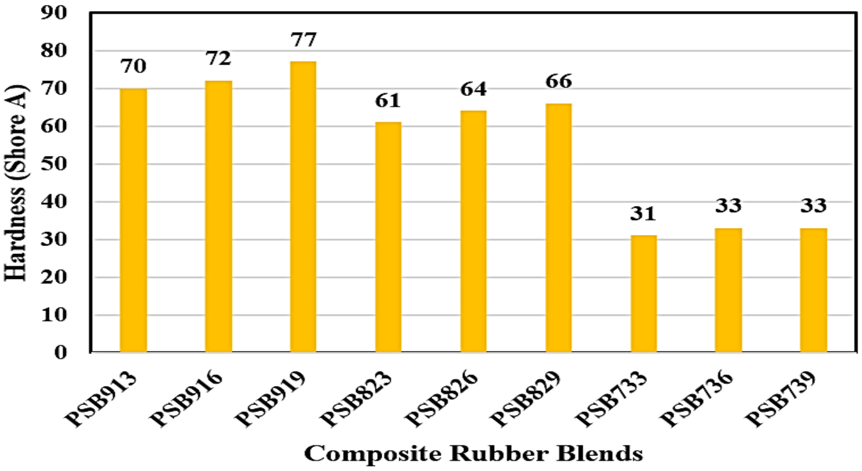


Figure 12: Hardness shore A values of Rubber Blends Composites

4. Conclusion

Based on the experimental evidence, the conclusions are as follows:

1) This study provides many selections for choosing the most suitable for the SACH prosthetic foot from a composite rubber blend system reinforced by bamboo natural particles instead of using traditional materials (polyurethane or polyurethane foam) that suffer from many problems.
2) The state of miscibility for (10 and 20 wt. % RTV-SIR/PUR with 0.1% TEOS) blend constituents is good, but the blend of (30 wt. % RTV-SIR/PUR with 0.1% TEOS) is immiscible, as shown by properties.
3) Alkali-treated bamboo particles provide better phase morphology, more interaction sites, and interfacial adhesion with the blend matrix. The best mechanical properties are obtained for treated bamboo particle loading samples at 9 wt%.
4) FTIR spectra show that treating bamboo particles with NaOH reduces their hydrophilic characteristics. Additionally, the IR analysis confirms that the PUR can crosslink with RTV-SIR in the presence of TEOS up to 20% RTV-SIR.
5) Finally, considering all results, the PSB919, PSB916, and PSB913 samples exhibit the highest tensile modulus, tear, compression, and hardness properties compared to the other samples. The samples of PSB 739, PSB 736, and PSB 733 have the lowest properties and compatibility between components.

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Author contributions

Conceptualization, **S. Ahmed**, **J. Oleiwi**, and **Q. Hamad**; data curation, **S. Ahmed**; formal analysis, **S. Ahmed**; investigation, **S. Ahmed**; methodology, **S. Ahmed**; project administration, **J. Oleiwi**, and **Q. Hamad**; resources, **S. Ahmed**; software, **S. Ahmed**; supervision, **J. Oleiwi**, and **Q.Hamad**; validation, **J. Oleiwi**, **Q. Hamad**, and **S. Ahmed**; visualization, **S. Ahmed**; writing—original draft preparation, **S. Ahmed**; writing—review and editing, **S. Ahmed**, **J. Oleiwi**, and **Q. Hamad**. All authors have read and agreed to the published.

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Data availability statement

The data supporting this study's findings are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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