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Article

Liquid Smoke Treatment for Natural Fibers: The Effect on Tensile Properties, Surface Morphology, Crystalline Properties, and Functional Groups of Banana Stem Fibers

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Abstract: This study aims to investigate the effect of banana stem fibers (BSFs) treatment with liquid smoke on changes in the micro-mechanics properties of BSFs, the tensile strength of single fibers, morphology, crystalline properties, and functional groups. The research used four model specimen variations, namely fiber without treatment and immersion in liquid smoke for 1, 2, and 3 hours. The BSFs with treatment was dried in an oven with a temperature of 40ºC for 30 minutes. Several tests were conducted, including a tensile test of single fiber capacity of 50N standard ASTM 3379-02, SEM observation, XRD, and FTIR test. The results showed that the highest increase in fiber strength was P2J, which was 264.21 MPa, and the lowest was TP fiber at 148.54 MPa. Fibers treatment with liquid smoke can form strong C-C elemental bonds caused by the H_2O degradation process in BSFs, hence carbon atoms (C) are dense, and in conditions of excessive H_2O degradation, the fiber strength will become brittle and the liquid smoke can increase the tensile strength of the fiber. The morphology of the fiber changed where the untreated fiber was covered with lignin, while the treated fiber had an elongated rectangular line pattern, porous, and the lignin was eroded. Crystalline properties in the X-ray diffractogram pattern differ between untreated and treated fibers. At an angle of 2θ, the lowest diffraction peak is around 160 in untreated wool, and the highest is 230 in treated fiber. The functional group of the fiber has changed where there is a difference in the wave crest between untreated and treatment fiber. The longer immersion time, the element of Carbon (C) will increase. In conclusion, treating BSFs with liquid smoke can change the physical, mechanical, and chemical properties, hence becoming a choice of composite reinforcement material in the future which is lightweight and environmentally friendly.

Keywords: Banana stem fiber; tensile strength; morphology; crystalline properties; functional groups; light weight; environmentally friendly

1. Introduction

The importance of utilizing environmentally friendly natural materials nowadays is widely considered worldwide. The environment is currently affected by human activities that cause losses, mainly from processed agricultural waste, and this attracts researchers to convert the waste into composite reinforcement materials containing natural fibers that are environmentally friendly, easy to obtain, and inexpensive [1].

Indonesia is a country that has abundant natural wealth. Many natural fibers have not been utilized optimally, one of which is fiber from the banana plant. Almost all agricultural land owned by the community is planted with banana plants. This plant leaves waste in the form of banana stems in the harvest process. Indonesian people generally use fiber from banana stems as a binder.

BSFs are one of the natural fibers derived from banana trees. This material contains high lignin, hemicellulose, and cellulose so it is widely used by the community as a rigging material because it has unique properties, namely as a binding material before the synthetic binder used today. Therefore, Banana Stem fiber becomes interesting to be studied experimentally by examining several parameters such as the physical, chemical, and mechanical properties of the fiber [2].

Multiple methods have been done to increase Banana Stem Fiber as a composite filler material, like soaking with NaOH, $KMnO_4$, H_2O_2, seawater, heating with turmeric, liquid smoke, silane, fumigation, and to expose the micromechanical characteristics of the fiber such as physical, chemical and mechanical properties by testing and observations such as single fiber tensile test, SEM, XRD, and FTIR.

Other methods of fiber treatment conducted by several researchers include the treatment of sago midrib fiber with liquid smoke changing the texture and pores of the fiber [3][4], changing the morphology and increasing the tensile strength of single fibers [5], changing the thermal properties, and changing the properties of the fiber. chemistry[6]. Treatment of king pineapple fiber with liquid smoke increased morphology, tensile strength of single fibers, and changes in functional groups [7]. Treatment of coconut belt fiber with liquid smoke can change the tensile strength and morphology of the fiber [8].

Treating king pineapple fiber by fumigation increases the morphology of the tensile strength of the single fiber [9,10]. The fumigation of king pineapple leaf fibers affects the contact angle of less than 30^o and increases the interlocking capability of the fiber matrix. The interfacial shear stress increases by 282.8 % with smoking for 15 hours [11,12]. The increase in the strength of the fiber reinforcing composite is due to seawater treatment [13,14]. The morphology and surface roughness of the fibers increased during immersion and the fiber-matrix bond [15][16]. Fiber will increase mechanical properties due to turmeric treatment [17].

Fiber treatment with NaOH increased density, fiber mechanical properties, changes in O-H and C-H groups at 3330 cm^{-1} and 2918 cm^{-1}, reduced lignin, more excellent thermal stability, and a rougher surface after treatment [18]. Corn husk fiber treated with NaOH showed better mechanical properties than fiberglass [19]. Fiber with NaOH treatment changed the mechanical properties better, and the absorption increased due to changes in the roughness and lumen structure [20]. Coir fiber with NaOH treatment changes the surface of the fiber, which is much cleaner and rougher, improves the tensile and flexural properties of the composite, increases the interfacial adhesion of the fiber and matrix, and effectively increases the compressive strength, flexural strength, and toughness [21]. The alkaline effect is evident from the changes seen on the surface of the Abaca fibers [22]. Pandanus tectorius fiber with alkaline treatment can strengthen the fiber hence the pandanus tectorius fiber-reinforced composite is an environmentally friendly fiber alternative [23]. The H_2O_2/CH_3COOH and HNO_3 treatment of removed lignin, pectin, waxes and They also increased cellulose crystallinity in the fibers, especially for HNO_3 treatment [24].

Many processing materials are not environmentally friendly, then environmentally friendly processing materials such as liquid smoke is needed [4]. Liquid smoke contains phenolic compounds, carbonyl compounds, and acids that change the fiber's chemical, physical and mechanical properties. Therefore, it is necessary to research natural fibers, especially BSFs, to determine the effect of liquid smoke immersion treatment on physical (morphological), chemical (crystal index and functional groups), and mechanical properties (single fiber tensile strength) BSFs as a composite reinforcement, lightweight and environmentally friendly.

2. Materials and Methods

2.1. Material and Treatment Methods

The material used is gray BSFs, and the treatment method consists of two methods, including the treatment of fiber immersion with liquid smoke by various immersion time

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that is 1,2,3, hours, and without treatment. After that, the fiber was dried in a memmert oven UN 55 Cap 53L at 40°C for 30 minutes.

Table 1. Treatment notation on BSFs.

No	Notation	Code	Treatment
1	Without treatment	TP	Without
2	1 hour treatment	P1J	Liquid smoke
3	2 hours treatment	P2J	Liquid smoke
4	3 hours treatment	P3J	Liquid smoke

2.2. Testing and Observation

Before testing, The specimen was made according to ASTM 3379-0 standard and tested with a single fiber tensile tester with a capacity of 50 N. For morphological observations, the coating process was carried out and then observed with the JEOL JCM 6000 SEM tool. In the crystalline and functional group tests, the fibers were shaped into folders and then tested with XRD type Rigaku miniflexll and FTIR type Shimadzu prestige-21 model 8400S tolls.

2.3. Single Fiber Tensile Test

In the single fiber testing stage, the specimen is made according to the ASTM 3379-02 standard, as shown in Figure 1. Then the diameter of the specimen is measured, and conducted a tensile test to obtain the tensile strength of the single fiber Banana Stem Fibers.

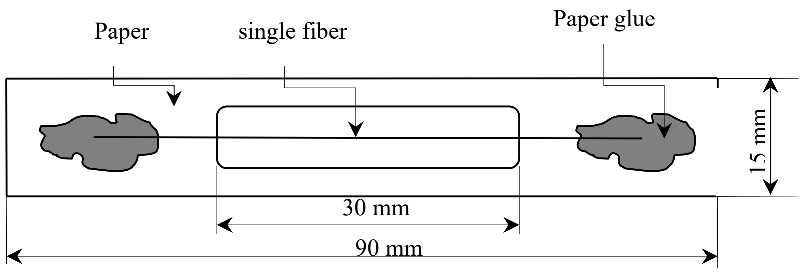

Figure 1. A tensile test specimen ASTM 3379-02.

2.4. SEM Observation

The scanning electron microscope (SEM) observations test was to see the morphology of the coated test material by placing the specimen on the preparat. The SEM test equipment then operated and observed until the surface of the specimen was visible, then photographed and stored.

2.5. FTIR and XRD Test

In this test, the pulverized fiber sample that becomes a folder is installed on the preparat and inserted into the testing tool. The result of this test is the graphs that informs whether the fiber is amorphous or crystalline and fiber functional group.

3. Results and Discussion

3.1. Effect of Liquid Smoke Treatment on Tensile Strength of Single Fiber

The study on fiber treatment with liquid smoke showed the micromechanics properties of BSFs had increased, and the trend of fiber strength was different without and with the treatment. The tensile strength of TP fiber was 148.54 MPa, while P1J, P2J, and P3J increased by 219.19 MPa, 264.21 MPa, and 239.46 MPa. A significant increase occurred in P2J, which was 264.21 MPa. This change is influenced by changes in fiber composition, whereas in previous studies conducted by [5][7], the changes in fiber composition could increase fiber strength.

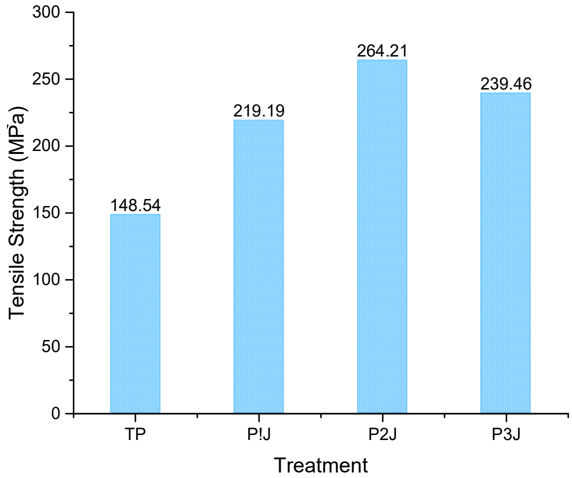

Figure 2. Single fiber strength test (TP, P1J, P2J, dan P3J).

Figure 2 shows that BSFs with 2 hours of treatment have a higher tensile strength single fiber, where the shape of the cross-section does not break brittle or change the shape of the fiber before breaking. Following previous research conducted by [6][7], Fiber treatment with liquid smoke can form strong C-C elemental bonds caused by the H_2O degradation process in BSFs, hence carbon atoms (C) are dense, and in conditions of excessive H_2O degradation, the fiber strength will become brittle and the liquid smoke can increase the tensile strength of the fiber.

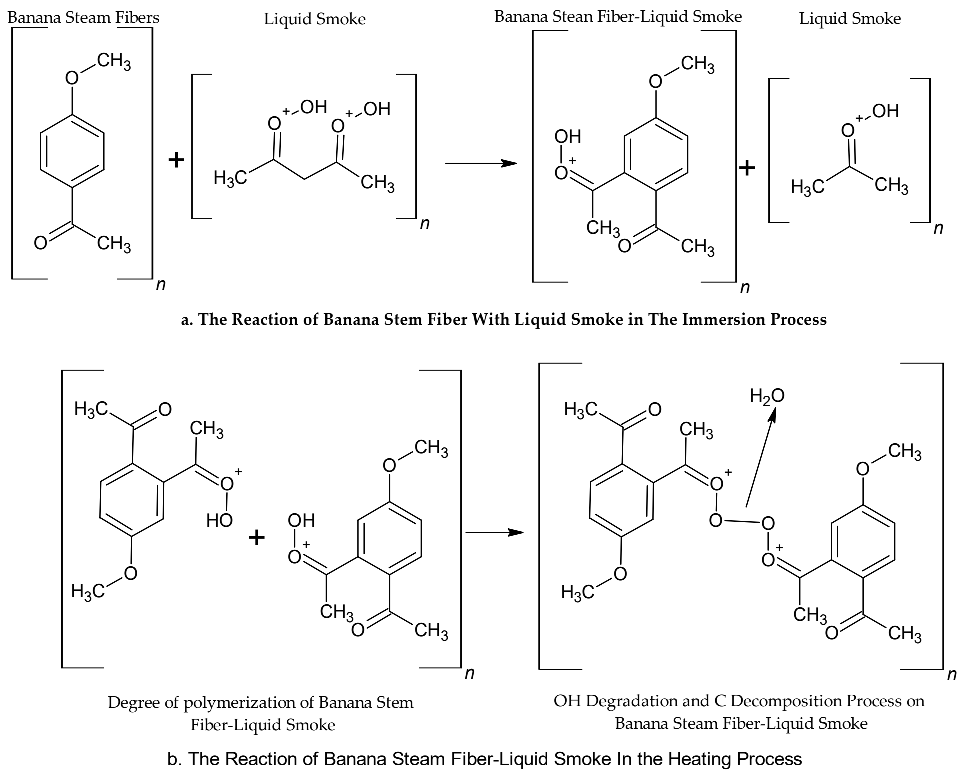

Figure 3. The Concept of Reaction Fiber Treatment Method with Liquid Smoke.

3.2. Effect of Liquid Smoke Treatment on Fiber Morphology

The surface shape of BSFs from SEM observations is shown in Figure 4. Figure 3a is the morphology without treatment, Figures 3b, 3c, and 3d are the morphology of the fiber with treatment.

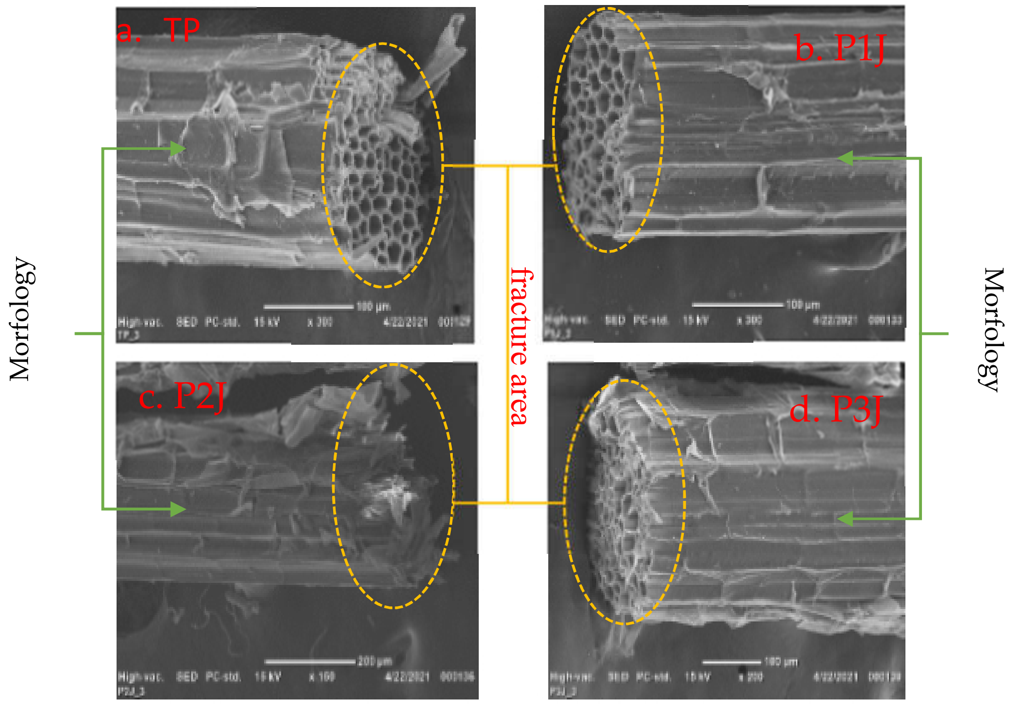

Figure 4. The surface of BSFs with SEM Photo of TP, P1J, PJ2 and P3J.

Figure 4. shows differences in fiber morphology, where TP fiber has a pattern of longitudinal rectangular lines that are still coated with lignin, while P1J, P2J, and P3J fibers show that the lignin in the rectangular line pattern is elongated, and the fiber pores begin to be eroded by liquid smoke. According to previous research [5][7], liquid smoke can affect the process of lignin drying and roughness at the fiber surface. The longer the immersion time, the more lignin becomes eroded; hence the morphology of the fiber forms an elongated pattern, and the pores are more clearly visible.

In addition, there is also a difference in the cross-sectional pattern of breaking during the single-fiber tensile test where the BSFs fiber at TP, P1J, and P3J shows a brittle fracture pattern, while the BSFs fiber at P2J shows that the cross-sectional surface is not brittle. It indicates that the liquid smoke affects changes in tensile strength which will increase the micromechanics properties of the fiber.

3.3. Effect of liquid smoke treatment on fiber crystalline properties

The XRD test was conducted to see the effect of liquid smoke treatment on BSFs crystalline level. The XRD test generates graphic information on different treatments of BSFs, as shown in figure 5.

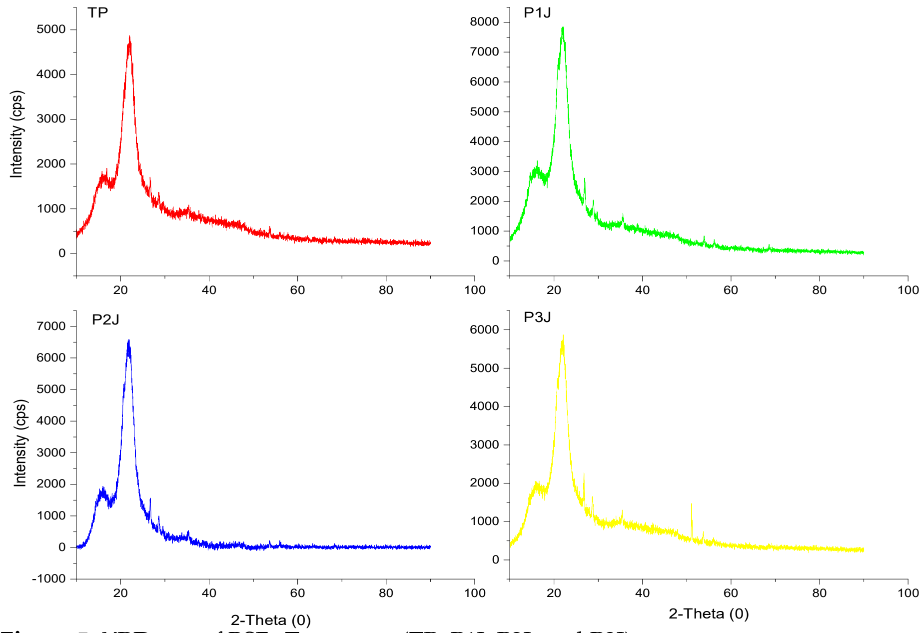

Figure 5. XRD test of BSFs Treatment (TP, P1J, P2J, and P3J).

The XRD test results show that the crystal intensity in the fiber has changed where P1J, P2J, and P3J fibers have increased compared to TP fibers, as shown in Figure 6.

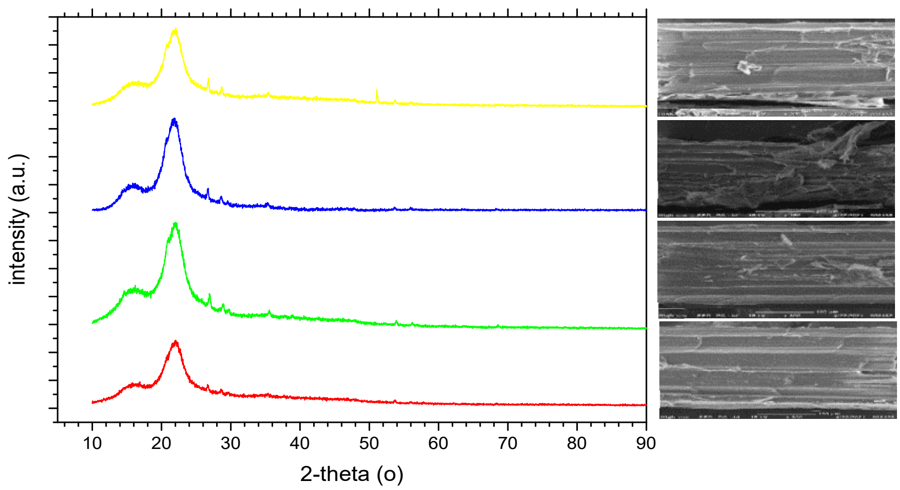

Figure 6. Intensity comparison of the XRD test of BSFs (TP, P1J, P2J, and P3J).

Figure 6 shows fiber testing at TP, P1J, P2J, and P3J, having an X-ray diffractogram pattern with three peaks at 2θ angles of 160, 220, and 350. These peaks are related to the crystal plane (011), (022), and (400), where the peak changes in the graph occur after the liquid smoke treatment. The diffraction peak of 230 occurred in the P1j treatment.

The changing trend of TP, P1J, P2J, and P3J fibers increased the crystallization index in the fiber along with treatment time. A longer treatment time makes the fiber crystalline index were higher. The fiber crystallization index increases due to changes in the structure of the fiber, and it can change the micromechanics properties of the fiber.

3.4. Effect of Liquid Smoke Treatment on Fiber Functional Groups

Changes in fiber functional groups with liquid smoke treatment can be analyzed by performing FTIR testing. Figure 6 shows the result of fiber FTIR testing on TP, P1J, P2J, and P3J.

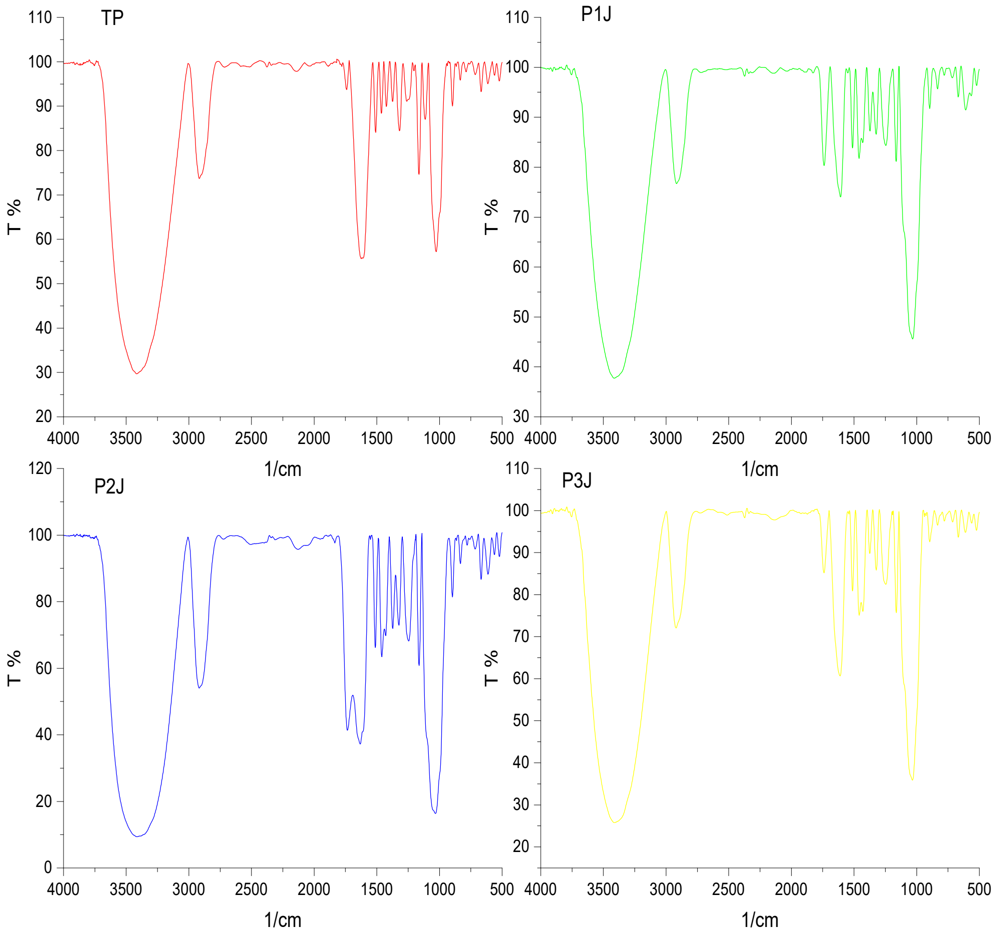

Figure 7. FTIR test of BSFs (TP, P1J, P2J, and P3J).

The graph of the FTIR test results shows differences in the composition of fiber compounds where the functional groups O-H, C-H, C=O, C=C, and CH_3 look different, and this indicates that the treatment of fiber with liquid smoke affects the change in wave crest.

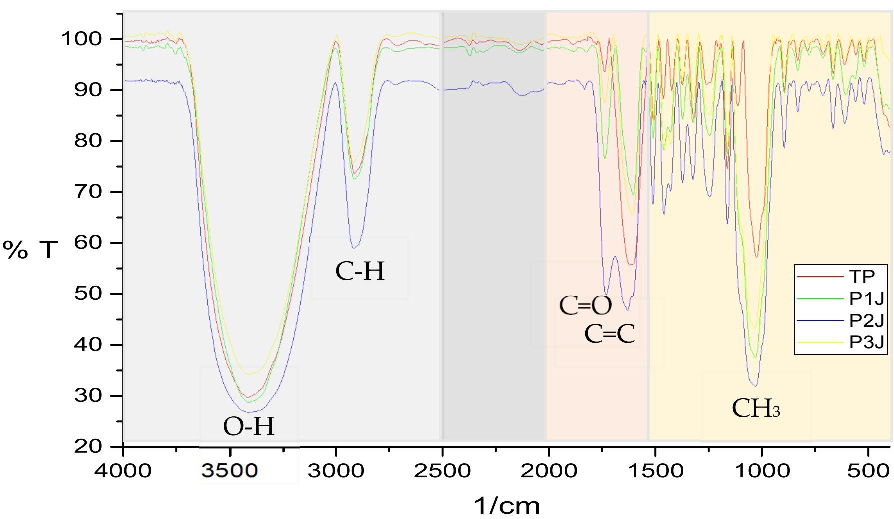

Figure 8. Transmittance comparison of FTIR test (TP, P1J, P2J, and P3J).

Figure 8 is a combination of the FTIR BSFs transmittance pattern TP, P1J, P2J, and P3J, where the shape of the peak on the graph changes due to the liquid smoke treatment. The constituent molecules in the FTIR Spectrum show that the wave peaks numbered from 2500-4000 cm^{-1} are in the O-H and C-H spectra and caused a significant addition of P2J BSFs composition. The peak wave number 1500-2000 cm^{-1} is in the spectrum C=O and C=C, which indicates that the BSFs compound increased in intensity after treatment, and the compound content was more significant than BSFs without treatment. Therefore the liquid smoke can add C=O and C=C compounds to the chain of BSFs compounds such as lignin and hemicellulose, and the high carbon composition of BSFs can increase their strength of BSFs. While at the peak of the wave number 500-1500 cm^{-1} is in the CH_3 spectrum, which indicates the addition of CH_3 composition, P2J BSFs become the most significant increase in functional groups.

From the liquid smoke treatment done by this study, P2J fiber was the most optimal fiber with a significant increase in tensile strength, crystalline intensity, functional groups of BSFs, and changes in morphology. Hence P2J BSFs became the latest property findings as a material solution, lightweight and environmentally friendly composite reinforcement for the future.

4. Conclusions

Treatment of BSFs with liquid smoke formed fiber morphology with elongated, porous patterns, and the tensile strength of single fibers increased. P2J fiber is the most optimal fiber, increasing tensile strength by 264.21 MPa. In addition, it also increased crystal intensity, functional groups, the composition of BFs compounds, and significant morphological changes. Thus, liquid smoke is an essential ingredient for treating BSFs, where this treatment can change the physical, mechanical, and chemical properties as a lightweight and environmentally friendly choice for composite reinforcement in the future.

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