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Potential of Shredded Ramie Fibers as Reinforcement in Recycled Polypropylene Composites: Analysis of Tensile and Bending Strength

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Abstract

In the development of composite technology, synthetic fiber reinforcers are gradually being replaced by natural fibers. This shift is driven by growing awareness of environmental issues and the scarcity of petroleum resources, prompting researchers to explore the potential of natural fibers. This study used scraped ramie fiber (SRK) as a reinforcer, with recycled polypropylene (PP) serving as the matrix. The mixture ratios used between PP/SRK (%) were as follows: 90/10, 80/20, 70/30, 60/40, and 50/50. Before use, the scraped ramie fiber (SRK) was subjected to pretreatment with 5% NaOH to improve the mechanical bonding. The hot press technique was used to fabricate the PP/SRK composite. The physical and mechanical properties of the PP/SRK composite were analyzed through weight, thickness, volume, density, tensile strength, and bending strength measurements. The results of physical measurements obtained density values for all samples between 0.73 - 0.76. The tensile test results showed a maximum stress value of 9.91 MPa and a strain value of 7.60% at the PP/SRK ratio 50/50. Then, the maximum modulus of rupture (MOR) was 23.49 MPa, and the modulus of elasticity (MOE) was 1.78 GPa at the PP/SRK ratio of 50/50.

Keywords: composite, matrix, alkalization, reinforcement, ramie, polypropylene

INTRODUCTION

Composites are engineered materials that combine two or more materials to improve their quality and properties. This material combination generally consists of two main components: a continuous matrix and a reinforcer of rigid and strong or fibrous material (Faruk et al., 2012; Harris, 1999). Biofiber or natural fibers are gaining popularity as reinforcement in composite technology. This shift in the trend is due to several factors, including awareness of environmental issues and the scarcity of petroleum resources as raw materials for synthetic fibers. In addition, the use of natural fibers is also considered more environmentally friendly and has a high-density ratio, making it lighter (Diharjo, 2006). Natural fibers are also renewable, have high strength and stiffness, are recyclable, and are biodegradable (Oksman et al., 2003). In Europe, using natural fibers as composite materials in vehicles is increasing by 10% each year (Novarini & Sukardan, 2015). In addition, in Japan, kenaf natural fiber has also been used as reinforcement in the interior of sedan cars, and abaca natural fiber is used in the Dailmler-Bens dashboard composites (Diharjo, 2006). Indonesia’s rich natural resources also support this, as they can be converted into various applications, such as fuel, fertilizer, pharmaceuticals, and biomaterials, in the form of membranes and composites from cellulosic raw materials (Rizkiana et al., 2024). Therefore, the opportunity to use Indonesian natural fibers must be maximized through further research to improve the properties of natural fiber-reinforced composites.

One natural fiber obtained from stalks and found in Indonesia is ramie fiber (Boehmeria Nive). Ramie fiber grows well in Garut, West Java, Wonosobo, Central Java, Lampung, East Nusa Tenggara, and South Sulawesi, and most of the fiber products are used for textile materials, technical textiles, paper, and building materials and exported abroad (Diharjo, 2006; Novarini & Sukardan, 2015). With the development of technology and innovation, the potential utilization of ramie fiber is now broader, one of which is as reinforcement in composites. Structurally, ramie fiber consists of millions of microfibril units that can be used as composite materials. Ramie fiber products consist of ramie stems, ramie ribbon scraping, shredded ramie, and palletized shredded ramie (Putri et al., 2024). The difference between ramie fiber and scraped ramie fiber lies in the part of the fiber that is removed and the process by which it is processed into the fiber. While scraped ramie fiber is generally obtained by scraping the outer skin of the ramie stalk, the fiber properties are stiffer and stronger than the close-cut ramie stalk fiber. However, the use of scraped ramie fiber is still limited to home decoration applications, so the potential use of scraped ramie fiber is not optimal and can be considered a reinforcing material in composite materials.

Polymers are the most widely used materials in composite materials that include matrices. Polypropylene (PP) is a polymer derived from the olefin structure of propylene monomer by additional polymerization to form polymers with long polymer molecules or chains (Maddah, 2016). PP generally has strong mechanical properties, is hard, resistant to chemicals, low-cost, flexible, and can be used as a base material for producing polymer-based composites (Rebia et al., 2022; Sudirman et al., 2002). PP is a thermoplastic plastic. The main characteristic of thermoplastics is that they melt/soften when heated and harden when cooled so that this polymer can be recycled by extrusion and injection moulding (Budiman et al., 2022; Hidayah et al.,). Furthermore, PP has an advantage in the recycling process, where the strength is still considered normal with an increase in flexural strength until the sixth recycling, although the tensile strength is slightly reduced due to the influence of pressure and heat during the extrusion process (Vidakis et al., 2021; Vidakis et al., 2021). Recycled PP also has good dimensional stability, so it can replace raw PP and reduce plastic waste (Galve et al., 2019). Some environmental impacts of plastic waste include blockage of waterways, accumulation at river gates, difficulty in degrading, and air pollution due to carbon emissions when burned (Ningsih et al., 2019; Rafli et al., 2021). So, one solution to the problem is to use recycled plastic or PP in valuable composites.

Previous researchers have manufactured composites using plastic as the matrix and natural fiber as the reinforcer (blending plastic). The results show that natural fiber composites have good stiffness but do not reach strength levels equivalent to glass fiber composites (Ilyas et al., 2022; Oksman et al., 2003). Although not yet able to replace glass fiber, research on PLA/flax composites proves that the composites have high enough mechanical properties to replace conventional thermoplastic composites (Oksman et al., 2003). Polyester composites as matrices and kenaf fibers as reinforcements increased the tensile strength, elastic modulus, and tensile strain by 107.8%, 51.91%, and 37.36%, respectively (Diharjo et al., 2005). In a similar study, higher tensile modulus and tensile strength results were reported for unidirectional kenaf polypropylene composites compared to pure PP, with an increase of 319% and 262%, respectively (Tholibon et al., 2016).

Furthermore, the use of ramie fiber as reinforcement in composites has also been investigated in the research of ramie fiber in polyester composites (Diharjo, 2006), alkalized ramie fiber in polyester matrix composites (Hariyanto, 2015), alkalized ramie fiber in polyester matrix composites (Aesha et al., 2023), composite of ramie fiber and resin as matrix (Setyahandana & Hille, 2006), and ramie and woven ramie fibers in epoxy resin reinforcement composites (Setyahandana & Hille, 2006). From the research that has been done, the most widely used ramie fibers are the ramie fibers resulting from close applicators or shavings in general. In addition, some of the ramie fibers used also do not go through a treatment process to improve the bond between the reinforcement surface and the matrix. This can result in a lack of bond strength between the two composite materials. Thus, combining plastic matrix and natural fibers can be combined with additional chemical treatment. One of the chemical treatments used on natural fibers is alkalization with NaOH (Diharjo, 2006; Hariyanto, 2015).

From the above description, it is clear that ramie fiber has a high potential to be used in composites by adding NaOH chemical treatment to improve its mechanical bond with the polymer as a matrix. However, research on using alkali-treated scrap ramie fiber (SRK) as a reinforcing agent in recycled polypropylene (PP) composites is not yet available and has not been reported. Therefore, this research can provide information about the potential of scrap ramie fiber as a textile fiber with functional value since scrap ramie fiber is only used in decoration or home decor.

The combination of recycled PP as the matrix and SRK pre-treated with 5% NaOH alkali as the reinforcer is made by solid diffusion composite technology using a hot-pressing machine. When the matrix is heated, it melts and then bonds with the reinforcer to form a composite. This study aimed to determine the effect on the physical and mechanical properties of PP/SRK composites at different ratio variables. The analysis carried out mainly focused on the properties of the composite with the increase of SRK as reinforcement.

METHODOLOGY

Materials and Instrumentals

The materials used in this research are recycled polypropylene (PP) plastic seeds provided by PT Surya Indo Utama as the composite matrix. Scrap ramie fiber (SRK) as CV Ramiendo Berkah Persada Sejahtera, Wonosobo, Central Java, provided a reinforcer. In addition, distilled water and technical NaOH are also used for the pre-treatment of SRK to increase the compatibility between the fiber and the matrix. The tools used for the composite manufacturing process include digital scales, composite moulds, iron plates, aluminium, and hot presses.

Methods

SRK pretreatment using NaOH

SRK pretreatment is performed to prepare raw natural fiber materials used as reinforcement in a matrix. The alkaline solution was obtained by dissolving 5% NaOH in distilled water (b/v) at room temperature using a magnetic stirrer until homogeneous. The prepared SRK was then placed in the alkaline solution for ± 120 minutes to remove the elements required for the composite process and to improve the absorbency and compatibility with the polymer matrix (PP). Next, the SRK was thoroughly washed under running water and dried in the sun at room temperature. After drying, the SRK was cut to the length of the composite mould, stored in a closed container, and ready for use in the composite process.

PP/SRK composite manufacturing

Recycled polypropylene (PP) and ramie scrap (SRK) fibers that are already available are weighed according to the predetermined percentage ratio with a total weight of 320g. The ratio between PP/SRK raw materials (%) includes 90/10, 80/20, 70/30, 60/40, and 50/50. Then, SRK and PP were arranged in a 20 cm x 20 cm iron mould and covered with a plate that had previously been coated with aluminium foil to prevent sticking.

A hot press was used to form the PP/SRK composites by applying a temperature of 200°C for a pressing time of 40 minutes and a pressure of 100 bar. After cooling slightly, the composite samples were removed and conditioned at room temperature for approximately seven days before testing.

Data Analysis

Physical Measurement of PP/SRK Composite

Physical measurements were taken of the weight, thickness, volume, and density of PP/SRK composites. The sample was weighed using a laboratory scale scale (Fujitsu FSR-B620). Thickness measurements were made by measuring ten points on each composite sample using an electronic digital calliper. Volume calculation was done by measuring each composite's length x width x height (thickness). While the density measurement is carried out using the formula: $\rho = m$ x V. Where m is the mass (g) and V is the volume.

Tensile Testing of PP/SRK Composites

Tensile test of PP/SRK composites according to ASTM D638 Dog-Bone Standard using a Universal Testing Machine (UTM). The working principle of the tensile test is that the specimen is clamped at both ends and then pulled slowly at a constant speed. Tensile test results are in the form of stress and strain to determine the tensile strength and modulus of the composite.

Bending Testing of PP/SRK Composites

Bending tests or static flexure tests were performed using the modified JIS A5905 standard. An Instron Universal Testing Machine (UTM) was used to obtain modulus of rupture (MOR) and modulus of elasticity (MOE) values. The basic principle of this test is to apply a centred load to the centre of the material/composite supported at both ends.

RESULT AND DISCUSSION

Pretreatment of Ramie Scrap (SRK) Fiber

Pretreatment by using alkaline solvents NaOH up to 3% can reduce lignin content in pine leaf screw fibers (Rizkiana et al., 2024). Furthermore, 5% NaOH treatment of ramie fibers as reinforcement for polyester-matric composites increases bending strength at a two-hour immersion time (Hariyanto, 2015).

Figure 1 shows the scrap ramie (SRK) fibers before (a) and after (b) treatment with a 5% NaOH solution. The alkalization results show a smoother SRK than without treatment. Furthermore, SRK was dried at room temperature, cut into pieces according to the plate size in the hot felt mould, which is 20 cm and used as reinforcement in PP/SRK composites with a predetermined ratio.

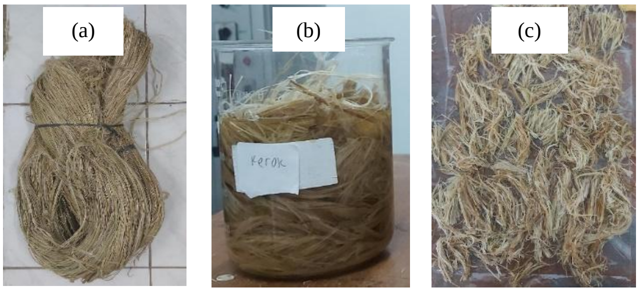

Figure 1. (a) SRK raw materials that have not been pretreated, (b) alkalization process using 5% NaOH solution for two hours at room temperature, and (c) the resulting SRK after being dried at room temperature for two to three days and cut into pieces

Physical Characteristics of PP/SRK Composites

Table 1 shows the measurement of the physical properties of PP/SRK composites after conditioning for approximately seven days. The results show that the weight of the composites with PP/SRK ratios of 90/10, 80/20, 70/30, 60/40, and 50/50 is between 294 - 304 g. The thickness of the composite is 0.96 - 1.07 mm, and the volume is 396 - 400 cm^3. The thickness of the composite is 0.96 - 1.07 mm, and the volume is 396 - 400 cm^3. From these basic measurements, the density is then calculated by dividing the mass by the volume. So, the density value for all samples is between 0.73 - 0.76 g/cm^3. The highest density value was found in the sample with a PP/SRK ratio (50/50) and the lowest with a PP/SRK ratio (90/10).

Adding up to 50% SRK to the PP/SRK composite increased the density of the composite sample by 0.03. This shows that the presence of SRK as reinforcement can also affect the increase in composite density. The increase in composite density can be influenced by the filler composition percentage, which involves the resulting composite board (Ginting et al., 2023). This study's density value follows the JIS A 5908-2023 standard, which is in the medium composite density category with a value between 0.4 - 0.8 g/cm^3.

Table 1. Physical Measurements of PP/SRK Composites

Sample	Variation (PP/SRK)	Mass (g)	Thickness (cm)	Volume (cm^3)	Density (g/cm^3)
R1	90/10	292	0,96	400	0,73
R2	80/20	303	1,00	400	0,75
R3	70/30	300	1,00	400	0,75
R4	60/40	294	0,98	396	0,74
R5	50/50	304	1,07	400	0,76

Tensile Strength of PP/SRK Composite

Tensile strength is used to measure the ductility and toughness of a composite against a given stress and the length increase experienced by the material. Figure 2 shows the fracture of the composite samples after tensile testing, where all samples show almost the same fracture with the position in the middle of the sample. The sample images also show that as the percentage of SRK as reinforcement increases, fewer voids are produced in the PP/SRK composite. This can be due to the higher density, which can affect the density of the composite.

Tensile strength test results regarding stress and strain values of PP/SRK composites are presented in Figure 3 (a) and (b). The stress value produced by PP/SRK composites is between 7.16 - 9.91 MPa. The PP/SRK ratio (90/10) is the sample with the highest strain value of 9.91 MPa. With the increase of filler (SRK) and decrease of matrix (PP) in PP/SRK composites, the stress decreases to a certain extent and then increases slightly. It was found that the stress drop at the PP/SRK ratio (50/50) decreased to 8.56 MPa. Thus, a 13% difference in stress reduction was obtained by adding SRK from 10% to 50% to the PP/SRK composite. The low-stress result is due to the higher ratio of SRK compared to PP polymer as a matrix. In contrast, the strain value increases with the addition of SRK as reinforcement and a decrease in the ratio of PP as the matrix in PP/SRK composites. An increase in strain of 2.58% occurred in the SRK composition from 10% to 50%. The PP/SRK composite strain value increased from 5.02% at (90/10) ratio to 7.60% at (50/50) ratio.

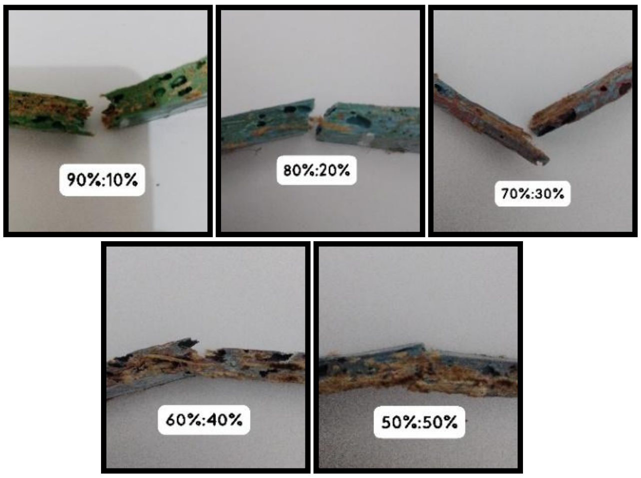

Figure 2. Fracture of PP/SRK composite tensile test samples (%) with 90/10, 80/20, 70/30, 60/40, and 50/50 ratios

In general, the tensile strength test results show a trend of increasing the ratio of SRK as reinforcement in the composite, which shows a decrease in stress value and an increase in strain value. The highest stress value is found in the PP/SRK ratio (90/10), with a value of 9.91 MPa, and the highest strain value is found in the PP/SRK ratio (50/50), with a value of 7.60%. The high-stress results at the PP/SRK (90/10) composite ratio can be due to the PP polymer as a matrix having a higher ratio than SRK. However, the strain tends to be low because PP undergoes more significant deformation before reaching the fracture point. Polypropylene has rigid properties, so the stress value increases, but it makes the composite less flexible/elastic so that the addition of SRK as a reinforcer in the PP/SRK composite shows results in an increase in the strain value from 5.02% to 7.60%, an increase of 13%.

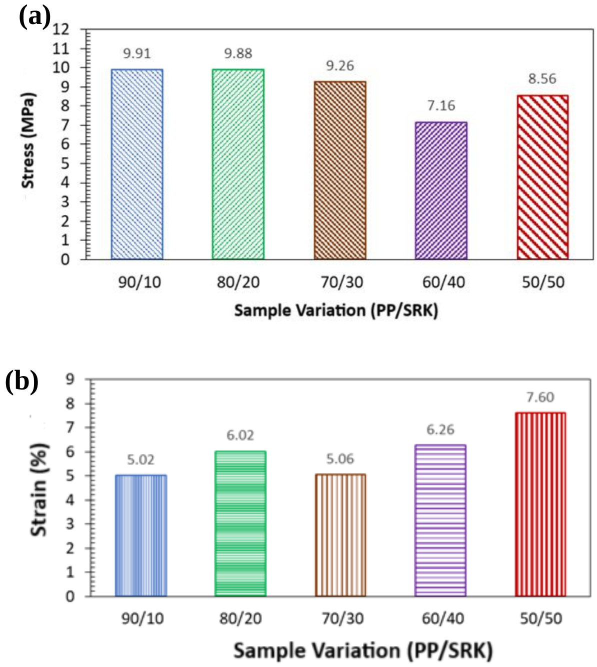

Figure 3. (a) PP/SRK Composite Stress and (b) PP/SRK Composite Strain (%) 90/10, 80/20, 70/30, 60/40, and 50/50

Bending Strength of PP/SRK Composites

Flexural strength is used to measure the strength of the composite in terms of the ability of the material to withstand bending loads until cracking or deformation occurs. The data obtained from flexural strength testing includes the value of the modulus of rupture (MOR) and the modulus of elasticity (MOE). MOR is the ability of an object to withstand the load until it reaches the maximum point (breaks), while MOE is the ability of the material to resist changes in shape or bending that occur up to the limit of elasticity (Yusriani et al., 2022). The MOR and MOE values of the PP/SRK composite are shown in Figure 4 (a) and (b).

The MOR values of the PP/SRK composites ranged from 9.69 MPa to 23.49 MPa. The PP/SRK composite with (50/50) ratio has the highest MOR value, while the (70/30) ratio has the lowest value. Based on the data, the higher the SRK ratio used in PP/SRK composites, the higher the MOR value. The increase in MOR value that occurs with the addition of SRK ratio as reinforcement in PP/SRK composites from 10% to 50% is 29%. In comparison, the MOE value shows that the highest value is found in the composite specimen with a PP/SRK ratio (50/50) of 1.78 GPa. The lowest value is found in the PP/SRK ratio (70/30), where the MOE value is 0.67 GPa. When considering the addition of SRK as reinforcement in PP/SRK composites from a ratio of 10% to 50%, there is an increase in MOE value of 71%.

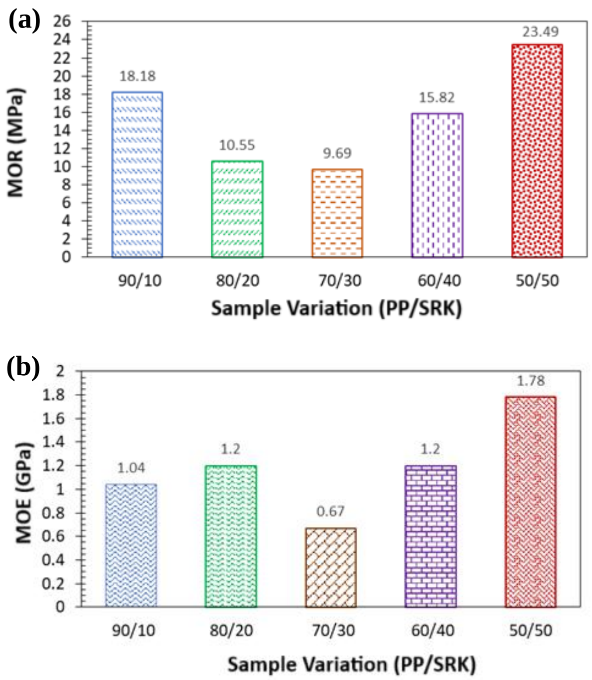

Figure 4. (a) MOR of PP/SRK Composite and (b) MOE of PP/SRK Composite (%) 90/10, 80/20, 70/30, 60/40, and 50/50

The bending test results of PP/SRK composites show an increasing trend in MOR and MOE values with the addition of SRK as a reinforcing agent. This is because SRK acts as a strong mechanical bond between the matrix and the fiber (Hariyanto, 2015). The addition of SRK as a reinforcer in PP/SRK (50/50) composites increased the MOR and MOE values to 23.49 MPa and 1.78 GPa, respectively. Thus, SRK has great potential as a reinforcer, especially to increase the flexural value of composite blends with polymers.

CONCLUSION

The composite of recycled polypropylene and ramie scrap fiber after alkalization pre-treatment with 5% NaOH (PP/SRK) was successfully produced by a hot felting process with a temperature of 200 °C and 40 minutes. Physical measurement results obtained a composite density between 0.73 - 0.76, which is included in the category of medium composite density according to JIS A 5908-2023. Meanwhile, the tensile test shows a trend in which SRK used as a reinforcer in PP/SRT composites shows a decrease in stress value and an increase in strain value. Furthermore, the flexural test showed a trend of increasing MOR and MOE values with the addition of SRK as a reinforcer. From the tensile test, the highest stress value is found in the PP/SRK (90/10) ratio with a value of 9.91 MPa, and the highest strain value is found in the PP/SRK (50/50) ratio with a value of 7.60%. Meanwhile, from the MOR and MOE values, it can be seen that the composite with the highest flexural strength is found in the PP/SRK (50/50) ratio, with a value of 23.49 MPa and 1.78 GPa. Thus, it can be concluded that SRK has a good potential to be used in composite reinforcement, significantly increasing flexibility and flexural strength.

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