INCORPORATING MICRONIZED RUBBER POWDER INTO COMPOSITES FOR SUSTAINABILITY IN AUTOMOTIVE APPLICATIONS

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Abstract

In this study, micronized rubber powder (MRP) made from post-manufacturing shoe rubber was tested as a filler in hybrid composites. Several hybrid composites were fabricated containing varying amounts of recycled polypropylene (PP), long glass fiber (LGF), and MRP from material discarded during shoe production. Although glass fibers are a desirable addition to composites due to their superior mechanical properties, the fibers are inorganic and dense. Therefore, they do not provide benefits to the environment or to the fuel efficiency of automobiles. This study analyzes the effect of MRP on the mechanical properties of a composite to create an eco-friendly, lighter-weight, and sustainable alternative for glass-filled composites used in the automotive industry.

1. Introduction

The concept of sustainability and eco-friendly business practices is growing in significance. As individuals and industries realize the importance of reducing waste and protecting the environment, new materials will need to be created that reduce the use of petroleum and single-use plastics. One emerging focus is the use of waste rubber in composites to increase sustainability for the final applications.

Adding sustainable fillers to composites can reduce the waste in the environment, increase the mechanical and physical properties of the composites, and reduce their cost [1]. Significant research has been carried out regarding MRP as a filler due to its elastomeric properties and low cost. Multiple studies have tested varying amounts of MRP in polypropylene and have yielded promising results. These studies proved that increasing the amount of MRP in the composite can improve the mechanical properties such as the impact strength and elongation properties [2, 3]. Additional studies have been conducted with MRP as a filler in epoxy resin. In these studies, the mechanical properties peak at approximately 5-10% MRP filler by weight in the composite, and additional MRP caused the properties to decline [4, 5].

Furthermore, studies of MRP as a filler in a variety of matrices such as polypropylene, epoxy, polyethylene, polyvinyl chloride, and polystyrene have shown a decrease in some of the tensile properties and hardness of the composites as the amount of MRP increases [2, 5, 6, 7, 8, 9]. Therefore, further research is being conducted to find the combination of MRP and glass fiber that optimizes the weight and properties of the composite.

Research has shown the importance of a compatibilizer when using MRP as a filler. Many studies have proven that compatibilizers, specifically PP-g-MA (maleic anhydride grafted polypropylene), will increase the adhesion between the MRP and polymer matrix, therefore significantly improving the mechanical properties of the composites [3, 10, 11, 12, 13]. Moreover, some studies have shown that using smaller-sized MRP filler particles will increase the mechanical properties of the composites [3, 8, 11].

Previously, the MRP used as a filler in polymer matrices largely consisted of waste tire rubber. Recently, there has been growing concern regarding the waste rubber from shoe production. Therefore, new research is emerging using MRP from waste shoe rubber. Each year, about 20 billion pairs of shoes are produced. When the shoe soles are cut from sheets of rubber, 30% or more of the material is discarded [14]. In landfills, this rubber takes 50 to 80 years to decompose [15]. In the meantime, the decomposing rubber emits harmful chemicals, which results in severe environmental issues. These chemicals are absorbed by soil and water, contaminating the environment. When these chemicals are transferred to plants, health issues arise for humans and wildlife consuming those plants [11, 16, 17].

Instead of sending post-manufacturing shoe rubber to landfills, the rubber can be processed into very fine MRP. This research studies the effects of MRP from post-industrial shoe rubber on the properties of polypropylene composites with the hope of decreasing waste sent to landfills and increasing the sustainability of the composites in automobiles.

2. Materials and Methods

Composite hybrids containing various amounts of micronized rubber powder, polypropylene, and long glass fiber were mixed and tested to create the optimal composite for automotive applications. The micronized rubber powder was acquired from the waste supply of a local shoe company. The size distribution of the particles is portrayed in Table 1. The polypropylene consisted of post-consumer carpet fibers, creating a sustainable alternative to standard polypropylene. Finally, differing amounts of long glass fiber were incorporated into the composites. Results were compared against three controls: a polypropylene (PP), a PP with long glass fiber, and a PP with short glass fiber (SGF) composite. The polypropylene and glass fibers were acquired from local suppliers.

Table 1: Size Distribution of Micronized Rubber Powder Particles

Size (X, microns)	Percentage of Particles
$44 \leq X < 63$	0.35
$63 \leq X < 125$	0.72
$125 \leq X < 300$	15.49
$300 \leq X < 425$	26.02
$425 \leq X < 850$	57.23
$850 \leq X$	0.04

3. Experimental

Five test composites with varying amounts of micronized rubber powder, polypropylene, and long glass fiber, as well as three control samples were fabricated to study the effects of MRP on the mechanical properties. The compositions of the test and control samples are listed in Table 2. They were evaluated through flexure, tensile, and impact testing based on ASTM D790, D638 and D256, respectively.

3.1 Preparation of Composite Specimens

To create the composites, the micronized rubber powder was first placed in an oven for about 18 hours at 80°C to remove moisture. It was then mixed with polypropylene using a twin-screw extruder. The mixture also included a PP-g-MA coupling agent for increased adhesion between the materials. This process created a masterbatch consisting of 30% MRP, 67% PP, and 3% PP-g-MA. The masterbatch was re-extruded to ensure even dispersion of MRP, PP, and PP-g-MA in the sample. The masterbatch was diluted by adding long glass fiber and additional polypropylene to create five samples with varying compositions (Table 2). Unfortunately, the MRP produced a strong foul smell during the compounding that should be taken into consideration during future testing.

To create control samples, separate mixtures of polypropylene, long glass fiber, and short glass fiber were dried out to remove moisture. They were then extruded to create three control samples with varying compositions.

Table 2: Compositions of Control and Test Samples

	Sample Number	MRP (%)	LGF (%)	SGF (%)	PP (%)
Control Sample	1	0	0	0	100
	2	0	30	0	70
	3	0	0	30	70
Test Sample	1	5	10	0	85
	2	5	25	0	70
	3	10	20	0	70
	4	15	15	0	70
	5	30	0	0	70

After all the samples had been extruded, they were dried out and then injection molded into ASTM standard specimen using a BOY 80M Injection Molding Machine.

3.2 Flexural, Tensile, and Impact Testing

Flexural and tensile tests were performed using an Instron Dual Column Universal Testing System, Model 3366, with 6 replicates per formulation. The flexural tests were carried out in accordance with ASTM D790 and yielded the flexural modulus and maximum flexural stress of each composite. The tensile testing was performed on Type V specimens in accordance with ASTM D638. This yielded the tensile stress and strain at maximum load, as well as Young's modulus for each sample.

Additionally, the samples underwent notched Izod impact testing. Ten standard Type V notched specimens were created using a Model TMI 22-05 notch cutter. The tests were carried out on these specimens using a Model 43-02-03 pendulum arm impact tester in accordance with ASTM D256. This yielded the impact strength of each sample.

4. Results and Discussion

The flexural, tensile, and impact test results demonstrated that among the four samples with LGF and MRP combinations, the one with the least amount of LGF (5% MRP/10% LGF) was the most sustainable choice and showed promising results. However, these results were much lower than the 30% LGF and 30% SGF control samples, which have strong mechanical properties and are currently used in automotive applications. Many of the mechanical properties of the 5% MRP/10% LGF composite decreased by over 50% compared to the 30% LGF control sample and over 40% compared to the 30% SGF control sample.

4.1 Flexural Testing

Incorporation of 30% MRP into the polypropylene matrix decreased both the flexural strength and modulus compared to the neat polypropylene. This was expected, as according to research by Speri and Patrick (1975), increasing the amount of micronized rubber powder in a polypropylene matrix decreases the flexural properties, specifically the flexural modulus, of the composite [18]. To account for this decrease and to adhere to the automotive industry's standards for the mechanical properties of the composites, long glass fiber was added to the composite due to its strong mechanical properties. In general, addition of fillers with better mechanical properties and high aspect ratios results in an increase in mechanical properties. For instance, Lee and Jang (1999) found an increase in the flexural modulus and strength of composites with the addition of glass fibers [19].

To find a good balance between sustainability and the mechanical property requirements for automotive applications, the amount of MRP in the composites was decreased while simultaneously increasing the amount of LGF. This resulted in an increase in both the flexural modulus and maximum flexural strength of the composites. The 5% MRP/10% LGF composite showed favorable results with an 89% increase in the flexural modulus compared to the 100% PP control sample. However, it also showed a 56% decrease in the flexural modulus compared to the 30% LGF control sample and a 50% decrease compared to the 30% SGF control sample (Figure 1).

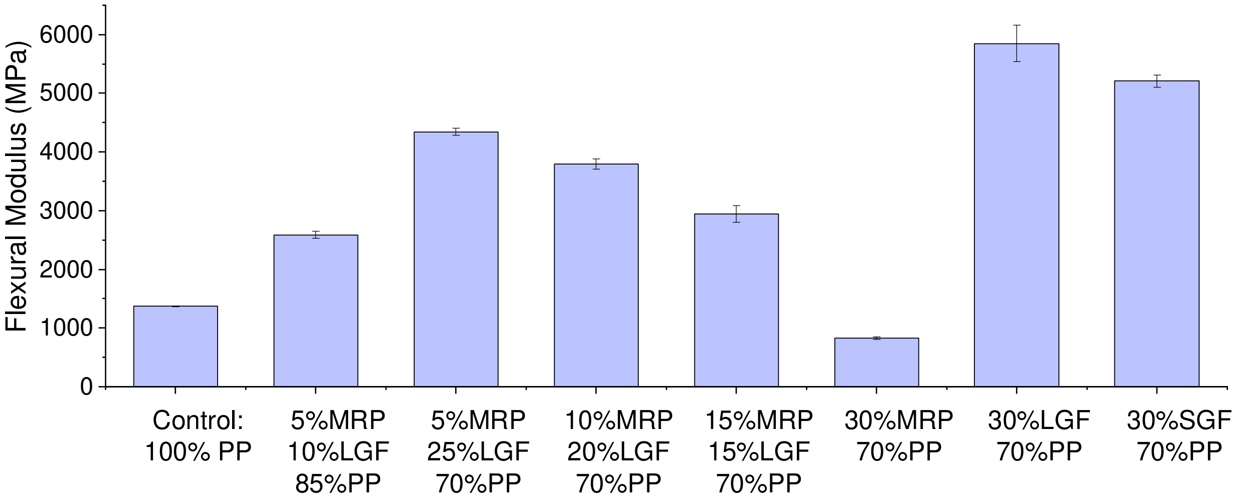

Figure 1: Flexural modulus of hybrid composites and control samples

In addition, the 5% MRP/10% LGF composite showed a 56% increase in the maximum flexural stress compared to the 100% PP control sample. However, it showed a 51% decrease in the maximum flexural stress compared to the 30% LGF control sample and a 42% decrease compared to the 30% SGF control sample (Figure 2).

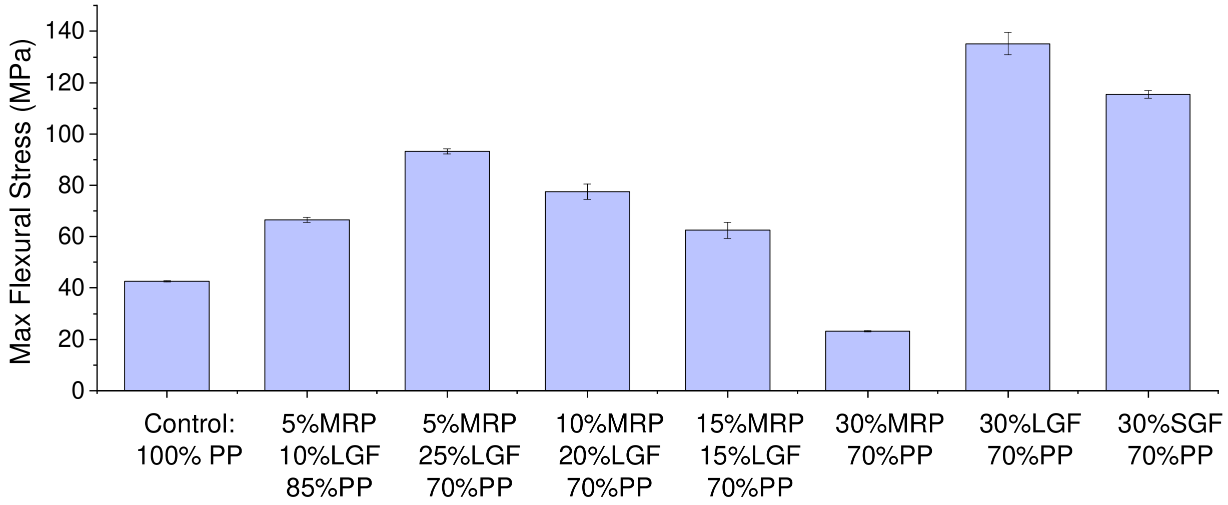

Figure 2: Maximum flexural stress of hybrid composites and control samples

4.2 Impact Testing

Impact strength increased significantly (129%) with the addition of 30% MRP into the polypropylene matrix compared to the 100% PP control sample. This was expected, as according to Sienkiewicz et. al (2017), studies show the impact strength of a polypropylene matrix composite reinforced with MRP can be up to 100% greater than neat polypropylene with only 20% MRP filler, let alone 30% [3]. Impact strength was further improved with the addition of LGF, in accordance with studies by Lee and Jang (1999) that state that impact strength increases upon addition of LGF and peaks at about 20% LGF by volume [19]. The impact strength of the MRP/LGF/PP composites peaked at between 20% and 25% of LGF filler by weight and then began to decrease.

Once again, the 5% MRP/10% LGF composite showed favorable results, with a 191% increase in the impact strength compared to the 100% PP control sample. Despite these favorable results, it still showed a 51% decrease in impact strength compared to the 30% LGF control sample and a 33% decrease compared to the 30% SGF control sample (Figure 3).

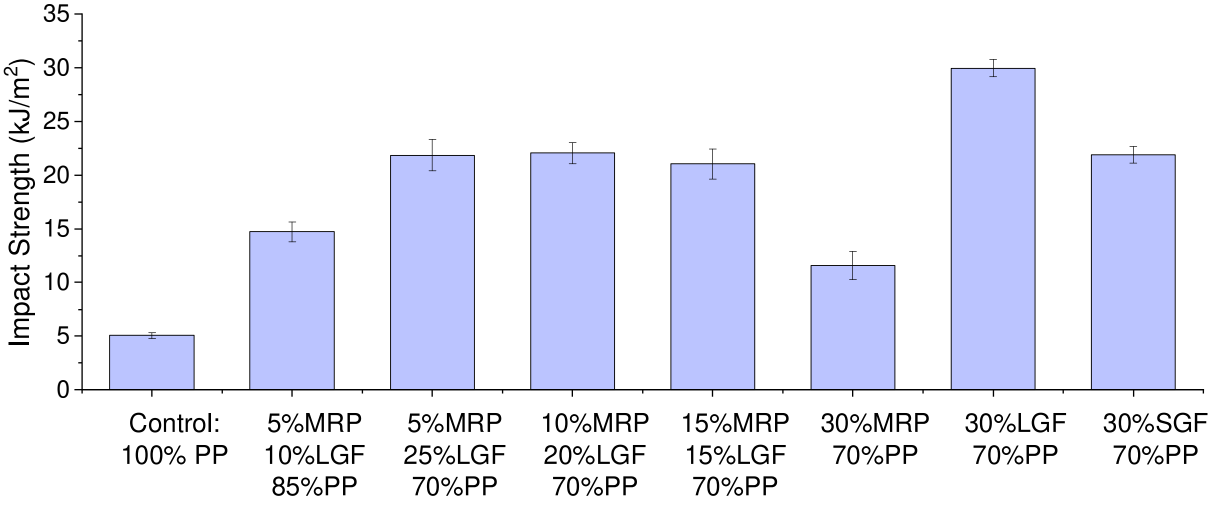

Figure 3: Impact strength of hybrid composites and control samples

4.3 Tensile Testing

Tensile testing showed that incorporating MRP into a polypropylene matrix, specifically 30% MRP, caused a 44% decrease in the tensile stress at maximum load and a 40% decrease in Young's modulus compared to neat polypropylene. This was predicted, as numerous studies by Egodage et al. (2008), Speri and Patrick (1975), Ismail and Suryadiansyah (2002), and Ismail et. al (2006) show that increasing the amount of MRP in a polypropylene matrix decreases the tensile strength and modulus of the composite [2, 18, 20, 21].

The addition of LGF into the composites improved the tensile stress at maximum load and Young's modulus. The values increased as the amount of LGF in the composite increased and the amount of MRP decreased. Research supports this trend, and Lee and Jang (1999) show an increase in the tensile strength and modulus of the composites with an increase in glass fiber [19].

The 5% MRP/10% LGF composite showed favorable results, as it had the least amount of MRP and a significant amount of LGF. The composite had a 60% increase in the tensile stress at maximum load compared to the 100% PP control sample. However, this value is a 51% decrease compared to the 30% LGF control sample and a 43% decrease compared to the 30% SGF control sample (Figure 4).

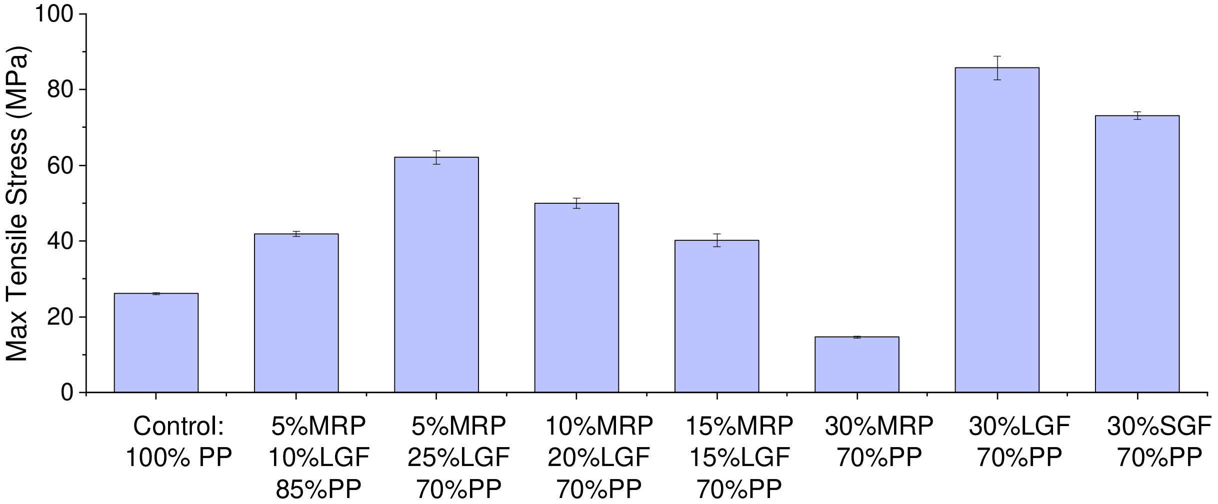

Figure 4: Tensile stress at maximum load of hybrid composites and control samples

Additionally, the 5% MRP/10% LGF composite showed a 77% increase in the Young's modulus compared to the 100% PP control sample, which is a 52% decrease compared to the 30% LGF control sample and a 48% decrease compared to the 30% SGF control sample (Figure 5).

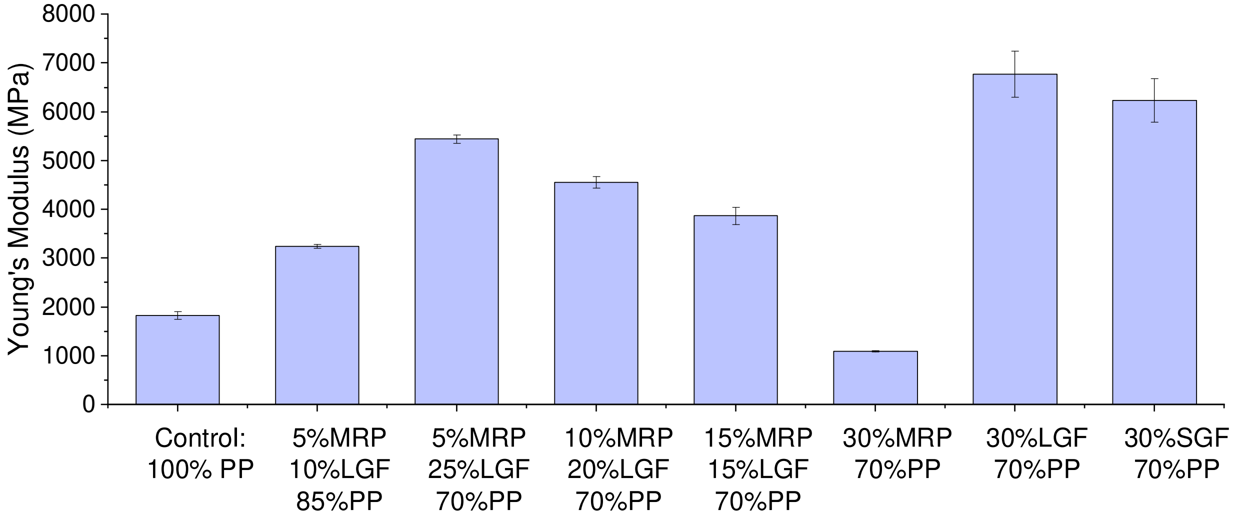

Figure 5: Young's Modulus of hybrid composites and control samples

However, tensile testing also showed that adding LGF and decreasing the amount of MRP in the composites decreased the tensile strain at maximum load. This is expected, as the elastomeric characteristic of the MRP gives it strong elongation properties, whereas the LGF is much more brittle [3]. The 5% MRP/10% LGF composite showed the most favorable results, as it had the least amount of LGF compared to the other MRP/LGF/PP composites. Although the 5% MRP/10% LGF composite had a 54% decrease in the tensile strain at maximum load compared to the 100% PP control sample, the 5% MRP/10% LGF composite performed better than the other two control samples, contrary to the previous tests. It had a 19% increase in tensile strain at maximum load compared to the 30% LGF control sample and a 7% increase compared to the 30% SGF control sample (Figure 6).

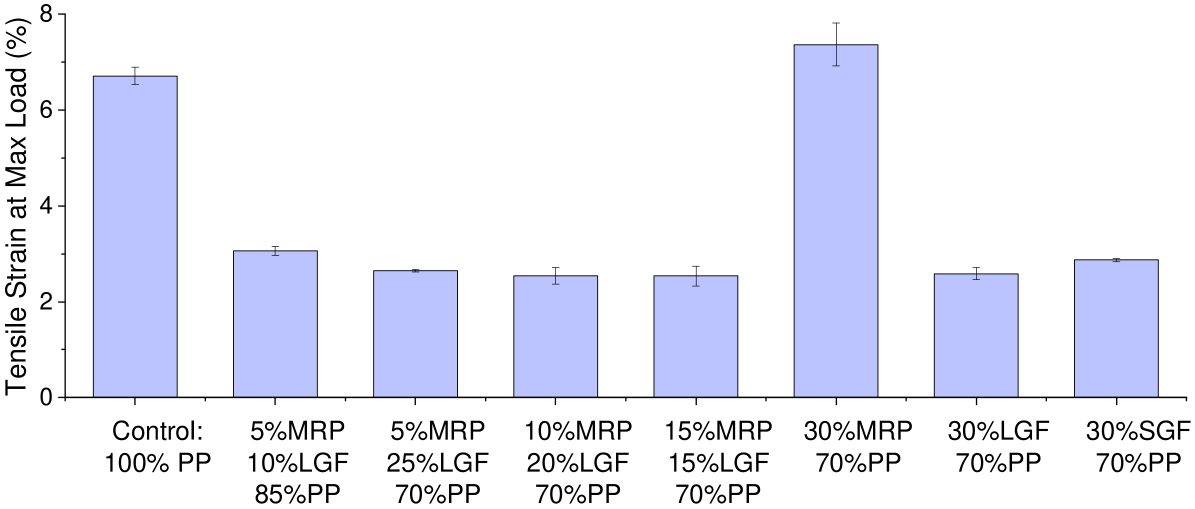

Figure 6: Tensile strain at maximum load of hybrid composites and control samples

5. Conclusions

In summary, MRP is an advantageous filler due to its low cost and sustainability. However, as the amount of LGF increased and the amount of MRP decreased, the mechanical properties all showed improvement, with the exception of the tensile strain at maximum load. Therefore, composites with the least amount of MRP filler, such as 5%, were most favorable.

The 5% MRP and 10% LGF composite had the most promising results. It had the least amount of total filler, besides the 100% PP control, compared to the other samples. It only had 15% filler, whereas the other samples had 30%. Additionally, among the samples with LGF, it contained the least amount of that material. LGF has a much higher density than MRP and polypropylene so this composite would be the option with the least weight, which is an important attribute to help with fuel efficiency [22, 23]. This composite could be used for under the hood applications in automobiles, as it showed favorable results and its strong odor would not be an issue.

Further testing can be performed such as thermal testing, scanning electron microscope analysis, and rheology testing to continue to analyze the composites. Additionally, smaller MRP particles can be used to improve mechanical properties. Finally, in future studies, researchers should address the odor produced during compounding with MRP to adhere to regulations.

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