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Study on the Characterization of Fillers and Different Rubber Crumb Ratio for Car's Bumper

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Abstract

This study investigates the development of sustainable composite materials using recycled rubber crumb and PVC pipe fillers for automotive bumper applications. Composites were prepared using epoxy resin and hardener, with rubber crumb incorporated at 20%, 40%, 60%, and 80% weight ratios to assess the influence on mechanical performance. Standardized mechanical tests were conducted in accordance with ASTM D638 (tensile), D790 (bending), and D6110 (impact). The 20% rubber crumb composition exhibited the highest tensile strength at 33.73 MPa and a maximum force of 1214 N, while the 40% composition demonstrated the best bending strength at 147.39 MPa. The 80% composition absorbed the highest impact energy at 0.13 J, indicating its suitability for applications requiring high energy absorption. These results highlight the potential for optimizing mechanical properties through tailored rubber crumb content. The 20% composition was identified as the most balanced option for bumper applications, offering strength, stiffness, and impact resistance. This work also promotes environmental sustainability by repurposing end-of-life tire materials into cost-effective, eco-friendly automotive components.

1. Introduction

The automotive industry is under pressure to replace synthetic composites with eco-friendly alternatives due to environmental and sustainability concerns. Traditional composites made from fossil fuels contribute to high carbon emissions and waste problems. One viable alternative is rubber crumb derived from waste tires, which can serve as a filler in composite materials, offering both environmental and performance benefits [1]. This study investigates the mechanical behavior of composites made with recycled rubber crumb and PVC, focusing on their suitability for use in car bumpers. Key mechanical properties such as tensile, bending, and impact strengths are evaluated to identify optimal rubber crumb ratios for automotive use.

PVC is commonly used in polymer composites due to its flexibility and compatibility with plasticizers, making it ideal for automotive fillers [2]. Recycled PVC and bio-based plasticizers further enhance sustainability [3]. Rubber crumb from waste tires offers excellent shock absorption and mechanical properties, especially when devulcanized to improve bonding with resin matrices [4]. Natural rubber provides superior elasticity, while synthetic rubber, such as SBR and NBR, adds oil and temperature resistance [5].

Mechanical tests such as tensile, bending, and impact are essential to assess composite performance. Tensile strength tests evaluate load resistance, bending tests assess flexibility, and impact tests measure toughness—critical for components like bumpers [6]. Composites with varying rubber crumb ratios are expected to show differences in these properties, guiding the selection of the best composition for real-world applications.

2. Methodology

The methodology outlines the systematic process of producing and testing rubber crumb and PVC crumb composite for car's bumper. This section details the steps involved in preparing the samples, ensuring safety during handling, and conducting mechanical tests to evaluate their performance. It begins with preparing raw materials, including measuring, and mixing epoxy resin, hardener, PVC crumb and rubber crumb in different ratio.

2.1 Material

Rubber crumb and PVC crumb were employed as raw materials, with samples produced using two types of chemicals which is epoxy resin and hardener. Waste rubber tyres and PVC pipes were mixed into a crumb shape. Waste rubber tyre obtained from rubber factory and PVC pipe obtained from hardware store. Waste rubber crumb has the flexibility to modify its mechanical properties, such as elasticity and PVC pipes can have a good impact. Its diverse mechanical qualities make it suitable for a wide range of applications. Epoxy resin and hardener collaborate to make lasting, strong test samples by generating a solid substance via a chemical reaction, allowing for precise mechanical testing of qualities such as strength and durability. Epoxy resin and hardener obtained from a polymer laboratory.

2.2 Preparing Mould

The producing process included multiple steps. First, the epoxy resin and hardener were evaluated at a 2:1 ratio, followed by the rubber crumb and PVC crumb at varying ratios. Table 1 indicates the number of samples with the appropriate rubber crumb to PVC ratios. Figure 1 illustrates that the mixture was placed in a moulding plastic storage container, and the resin and hardener were completely stirred with a stirrer until it was smooth and free of streaks or lumps. Resin hardener mixture was stirred frequently to ensure that the rubber and PVC additives were evenly distributed. This method was performed with rubber crumb compositions of 20%, 40%, 60%, and 80%. All created mixes were allowed to dry for 24 hours.

Table 1: Number of Samples with Respected Ratios of Rubber Crumb and PVC

Rubber Percentage (%)	Rubber Weight (g)	PVC Percentage (%)	PVC Weight (g)	Epoxy Resin Weight (g)	Hardener Weight (g)	Total Weight (g)
20	8	80	32	60	30	130
40	16	60	24	60	30	130
60	24	40	16	60	30	130
80	32	20	8	60	30	130

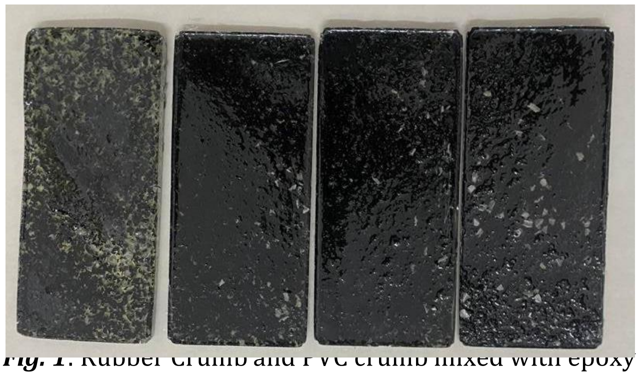


Fig. 1: Rubber Crumb and PVC crumb mixed with epoxy

2.3 Preparing Sample

After drying, the moulds were removed from their plastic storage containers. Before beginning, a workshop coat, safety shoes, safety gloves, safety glasses, and a mask were worn to protect against dust, strong odours, moving machinery, sharp instruments, and cutting disc debris. Each mould was carefully removed from the moulding container and marked with a marking pencil and elbow L according to the ASTM measurement criteria illustrated in Figure 2. To fulfil the desired measurements, the piece was further shaped with a cutter and saw. Figure 3 shows how the samples were finished, including trimming or sanding rough edges and applying additional coatings or finishes as needed.

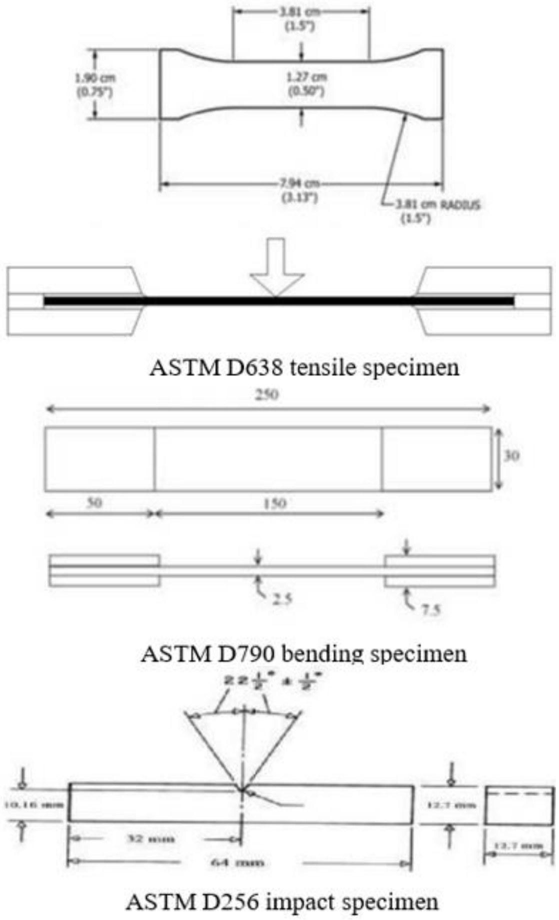
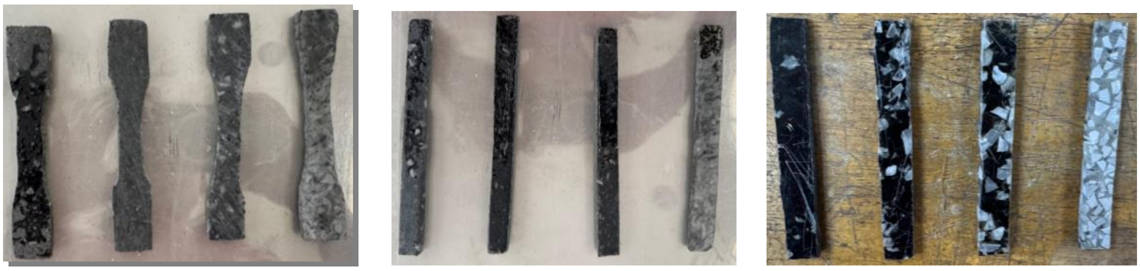


Fig. 2: Dimensions for all specimens



(a) **(b)** **(c)**

Fig. 3: Samples (a) Tensile Test; (b) Bending Test; (c) Impact Test

2.4 Mechanical Testing

Every single sample underwent mechanical testing, including the tensile test (ASTM D638 Type 4), to assess tensile strength, which is the maximum pulling force that can be applied to samples before they break. The bending test (ASTM D790) was used to determine its flexural strength, which is the greatest stress that a sample can bend before breaking. Impact tests (ASTM D256) were used to assess the sample's impact strength, which is the maximum energy absorbed. The finishing procedure was repeated for all compositions, including rubber crumb samples of 20%, 40%, 60%, and 80%. The resulting specimens were prepared for testing to determine their mechanical characteristics and performance in car bumper applications. Characterisation refers to a thorough examination of the rubber crumb and PVC crumb composite automobile bumpers created in this study. It entails assessing the key physical, mechanical, and environmental qualities to establish the appropriateness of various rubber crumb compositions for automotive applications. The main characteristics analysed were tensile strength, bending strength, and impact resistance.

3. Result and Discussion

The results and discussion section displays and evaluates the findings from the manufacture and testing of a rubber crumb and PVC crumb composite cars bumper. This section describes the mechanical parameters of the samples, such as tensile strength, bending strength, and impact resistance, for four different rubber crumb compositions (20%, 40%, 60%, and 80%). The findings are compared against industry standards and past studies to determine the composites' performance and appropriateness for automotive applications.

3.1 Tensile Test

Figure 4 presents a graph of Tensile Strength (MPa) versus Rubber Crumb Ratio (%), highlighting the effect of varying rubber crumb content on tensile strength. The Y-axis represents the tensile strength in MPa, while the X-axis shows the rubber crumb ratio in percentage. The sample with a 20% rubber ratio shows the highest tensile strength at 33.73 MPa, indicating strong resistance to tension. As the rubber content increases to 40%, the strength drops to 26.67 MPa, and further declines to 18.75 MPa at 60%. Interestingly, the 80% rubber crumb sample shows a slight increase in strength to 20.72 MPa, though still much lower than the 20% and 40% samples. This trend suggests that increasing rubber content generally reduces tensile strength, but minor improvements may occur at higher ratios due to complex material interactions. Overall, the graph demonstrates that lower rubber crumb ratios, especially at 20%, offer better tensile strength performance.

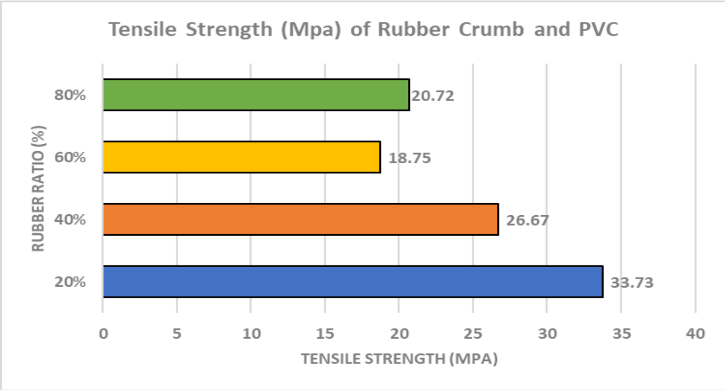


Fig. 4: Graph Tensile Strength (MPa) against Rubber Crumb Ratio (%)

Figure 5 shows four shattered samples arranged from left to right, each reflecting a different percentage of rubber crumb content following a tensile test in accordance with ASTM D638 standard. The samples have an increasing rubber crumb ratio which is 20%, 40%, 60%, and 80%, respectively, from left to right. Each sample is shown in two different pieces, demonstrating the point of failure during the tensile test. The visual discrepancies in the fracture surfaces and overall look of the samples are due to variations in mechanical properties and failure processes caused by varied rubber crumb concentrations.

Fig. 5: Sample After the Tensile Test

3.2 Bending Test

The bending strength of Rubber Crumb and PVC composites, as shown in Figure 6, exhibits a clear dependence on rubber crumb content. The highest value, 147.39 MPa, was recorded at a 40% rubber crumb ratio, suggesting this as the optimal composition for maximizing strength. At 20%, the strength was still considerable at 130.11 MPa, indicating that a moderate amount of rubber crumb enhances the composite's structural performance. However, further increases to 60% and 80% resulted in a noticeable decline in bending strength to 83.59 MPa and 94.33 MPa, respectively. This trend suggests a point of diminishing returns, where too much rubber crumb may lead to issues such as poor dispersion or weak interfacial bonding with the PVC matrix, ultimately reducing the material's ability to bear bending loads effectively.

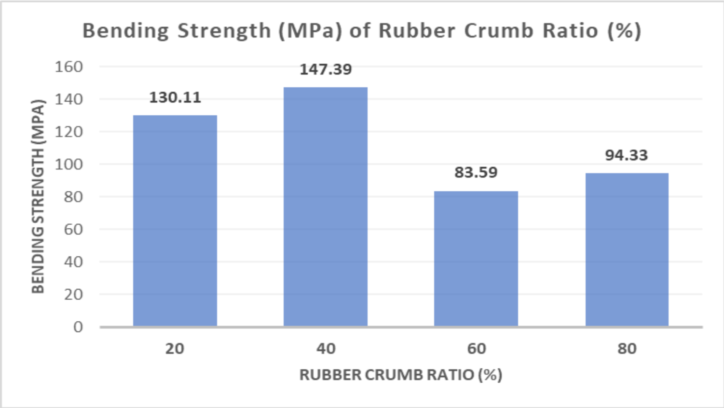


Fig. 6: Graph Rubber Crumb Ratio (%) against Bending Strength (MPa)

Figures 7 display a series of samples, all of which have undergone a bending test according to ASTM D790, resulting in breakage across all specimens. Starting from the left, the samples represent increasing ratios of rubber crumb: 20%, 40%, 60%, and 80%. The leftmost sample, containing 20% rubber crumb, appears to have fractured into two distinct pieces. All samples exhibiting fracture after the bending test suggests that when the rubber crumb content varies, the material's ability to withstand the applied bending force to the point of complete failure is have a different across these tested ratios.

Fig. 7: Sample After the Bending Test

3.3 Impact Test

Figure 8 illustrates the graph of Energy Absorbed (J) versus Rubber Crumb Ratio (%), showing the energy absorption capabilities of rubber crumb and PVC composite samples from an impact test. The trend reveals that higher rubber crumb content leads to increased energy absorption. At 20% rubber crumb, the sample absorbed only 0.07 J, rising to 0.1 J at 40%, and 0.11 J at 60%. The highest energy absorption was observed at 80%, reaching 0.13 J. These results indicate that increasing the rubber crumb ratio enhances the material's ductility and ability to absorb impact energy, making it more suitable for applications that demand high toughness and impact resistance.

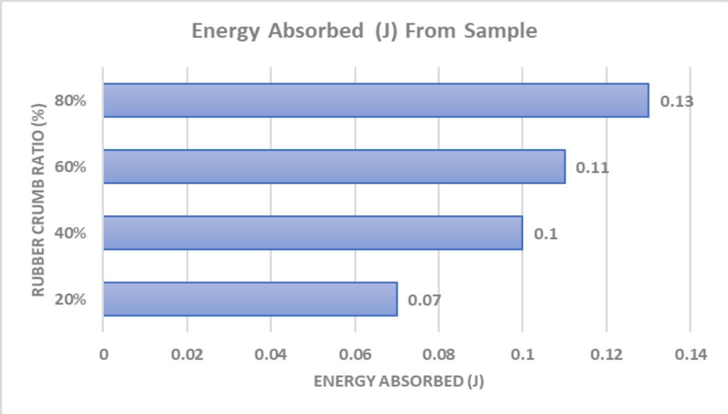


Fig. 8: Graph Energy Absorbed (J) against Rubber Crumb Ratio (%)

Figures 9 show a succession of samples organised from left to right, with increasing quantities of rubber crumb at 20%, 40%, 60%, and 80%, respectively. All of these samples underwent a manual Charpy impact test. As shown in the figure, each sample split into two different pieces as a result of the impact test. This breakage across all samples, independent of rubber crumb level, suggests that the impact force delivered was sufficient to cause total failure in each specimen.

Fig. 9: Sample After the Impact Test

4. Conclusion

To conclude, all research objectives were successfully achieved. This study evaluated rubber crumb and PVC crumb composites for automotive use, particularly bumpers, using four composition ratios: 20%, 40%, 60%, and 80%. Samples were moulded and tested for tensile, bending, and impact strength. Objective 1 was met by producing the composite samples. Objective 2 was fulfilled by analyzing the mechanical performance, where the 20% rubber crumb composite showed the highest tensile strength (33.73 MPa), the 40% ratio had the best bending strength (147.39 MPa), and the 80% ratio showed the best impact resistance (0.13 J). Objective 3 was achieved by identifying the optimal formulation. The 20% rubber crumb composite provided the best overall balance of strength, stiffness, and impact resistance, making it the most suitable for durable and eco-friendly bumper applications. The study also highlighted that higher rubber crumb content improves energy absorption, indicating greater ductility and toughness, which is ideal for impact-prone components.

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