Effect of Ground Tire Rubber on Mechanical Properties of Low Density Polyethylene

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Abstract: This research explores the effect of ground tire rubber (GTR) on the mechanical properties of LDPE. This thermoplastic-elastomer blend sets the composition of ground tire rubber and low-density polyethylene (LDPE/GTR). The blend was prepared in different proportions and was processed in a compression molding machine. The optimum operating conditions of the blend set to be 220℃ temperature and pressure varied from 150-200 bars. Different parts per hundred rubber (phr) samples were obtained under these conditions, including 1 phr, 2 phr, 3 phr, 4 phr, and 5 phr. After that, the mechanical properties of the blend were examined concerning various compositions. Different testing methods were used to determine the mechanical properties of the thermoplastic-elastomer blend, which include tensile strength, flexural strength, and Izod impact. The results obtained from these tests show that tensile strength and modulus decreases by increasing the rubber content. However, impact strength and percentage elongation increase by increasing the rubber content. This enhancement in impact and percentage elongation may be suitable for the applications in gymnasium mat and automobile industry.

Keywords: Ground tire rubber, Izod strength testing, Low-density polyethylene, Thermoplastic elastomer, Percentage elongation.

INTRODUCTION

As the necessity of population increases, the manufacturing level additionally increases, which means the use of plastic is also rapidly increasing. It is employed for numerous purposes. In the same way, over the past several years, the uses of vehicles have increased tremendously, largely due to transportation which raises tire production. This worldwide scrap tire occupies huge amounts of landfill area globally. In Colorado, for illustration, there was a scrap tire site with 60 million tires weight approximately 550,000 tons of scrap thrown away on the land. Furthermore, more than two-thirds of the billions of tires used worldwide every year are discarded in the permitted or unauthorized waste areas [1, 2].

Waste tires stacked up like that attract disease-carrying rodents, make the land useless, and release harmful substances to the atmosphere as they decay slowly. Waste tire scraps usually catch fire because of their size and the combustibility of tire materials. Sometimes waste tire fires could last up to several months; as millions of tires piled together. There must be a proper way to get rid of these millions of waste tires and develop a good technique to overcome this global issue [3, 4].

The polymer waste represents a considerable portion of all waste materials. With the quick improvement of the vehicle business, waste tires contribute to the expanded polymer waste volume. A polymer mix like elastic thermoplastic mixes, when elastic rich, creates delicate thermoplastic elastomers, while plastic-rich mixes produce elastic hardened thermoplastic. Rubber hardened thermoplastics that display adaptable and high-sway properties will be utilized as economical alternatives to standard plastic materials.

The mechanical behavior of RR/SBR (reclaimed rubber/ styrene-butadiene rubber) and RR/NBR (reclaimed rubber/ nitrile butadiene rubber) blends studied reveal that arise within the strength, tear strength, elongation at break occurs with a decrease within the resilience. In the past few years, the concept to include the end of life tires into the low-density polyethylene has been proposed to overcome environmental pollution and other economic factors. The dynamic, static properties and morphology of the GTR/LDPE blend are studied [1, 4]. The reusing of end-of-life tires has become another solution for the energy recovery process utilized in Poland. The quantity of tires, which pollute the environment per one year, has increased by 200,000 tons p.a. in Poland [5, 6].

The influence of polarity of elastomer on the blend of HDPE/GTR was also explained [5, 6]. Two

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E-ISSN: 2410-1869/21

copolymers, namely polar ethylene-(vinyl acetate) and nonpolar ethylene-octene copolymer, are tested. The result shows that the nonpolar ethylene-octene copolymer has greater mechanical properties than the polar one simply because of higher homogeneity. The compatibilization of various blends of GTR-PP/PE grafted via maleic anhydride with compatibilizing agents like butadiene-styrene or styrene-ethylene copolymer grafted via maleic anhydride were studied [7, 8]. The results of the elastomeric material and dynamic vulcanization on the properties of the LDPE/GTR blend were examined. Effects of EPDM, SBR, and NR on the blend of LDPE/GTR were explained. The most effective was the one by the EPDM on the GTR/LDPE blend as described within the data published concluding that the dynamic vulcanization ends up in a positive result as increased within the elongation at break. It had been observed that the decrease in the lastingness of ethylene-vinyl acetate 23MPa on the introduction was 10% by weight GTR and 12.7MPa having particle size but 200 µm. Using the particle size 200-500 µm or quite 500 µm, even lower values 10.4 MPa and 84 MPa respectively [7, 8].

In general, when the quantity of GTR is increased within the polymer composition, its mechanical properties decrease. Better substrates are introduced to extend the interference between the polymer and GTR to induce better mechanical properties. In one of the articles, it was examined that the compatibility of the thermoplastic/GTR using peroxide does not create a material that has thermoplastic elastomer properties [9]. However, the fresh elastomers are required within the blend of GTR/thermoplastic to accomplish the properties as by thermoplastics elastomer. Natural rubber rather than GTR was partially used with active filler within the variety of carbon. The application of GTR within 40% weight has increased the strength and hardness, and elongation at break decreased. It was seen that reclaimed elastic (RR) upgraded the effect strength of polypropylene (PP). When the RR is blended in with thermoplastics, it's relied upon to pass on the ascent to thermoplastic elastomers (all the more explicitly TPEs), and comparable examinations on piece elastic powder/LLDPE mixes are accounted for before. Thermoplastic elastomers got from WPE and RR, and their composites with new and Si-69 treated FA are read for their mechanical, dynamic mechanical properties. As morphological attributes these composites are utilized for making esteem added items like vibration dampers in industry, guards, light posts, floor tiles, and afterward on [9, 10].

In 2017 Lukasz Piszczyk *et al.* researched the likelihood of using polyurethane (PU) with GTR to supply compression-absorbing buoys and floating trays. Also stated is that incorporating GTR into the polyurethane increases the static mechanical properties and thermal stability. They studied the acoustic absorption of the blend of PU/GTR, which significantly increases the insulation properties of the blended foam [11].

The properties of elastic thermoplastic mixes are accounted for the sort of elastic/thermoplastic utilized, the synthesis, and bond between the stages by R. Scaffaro *et al.* [10]. Further, the grip between the materials relies upon the dissolving thickness of the lattice stage, the structure and size of the scattered particles, and in this way, the handling conditions. Moreover, mix properties additionally fluctuate with the molding methods acquainted with test examples [10].

In 2020 Marín-Genescà *et al.* reported that due to lack of adhesive between two phases, the blend's mechanical characteristics are weakening. It is because of GTR's large particle size, crosslinking and surface properties, which resist the molecular entanglement with polymers. Numerous effort has been made to make them homogeneous and to produce a composition with better properties [6, 7].

In 2021 Ali Fazil and Denis Rodrigue; reported that larger GTR particles increase the possibilities of larger voids, and tiny particles of GTR increase small cracks. It introduced the 20% by weight GTR (200 µm) have decreased the enduringness by 25% (from 24% to 18%). But on acid treatment (sulfonitric), the durability decreased by 13%. The acid treatment increases the surface roughness by which the interaction of GTR with the matrix phase increases [12].

Regarding the environmental issues of ground tire rubber, when the tires are wasted, the chemicals and heavy metals are leached into the environment. These chemicals are carcinogenic and mutagenic, which cause cancer and gene mutations. The leaching of ground tires also affects the soil around the old tires; if the tires are moved from that place, the soil is still a toxin. So the toxins in the soil are transferred to the groundwater, and the water becomes harmful for living things when they come in contact with water. The hollow portion of the tires will contain rainwater and if the tires are left open to the atmosphere and the tires are undisturbed for a long period. It will create a breeding ground for mosquitoes. There is also a problem with the combustibility of tires. If the tires are burned, the chemicals are released to the surrounding, become harmful to human health. Also, the landfills problem is associated with the ground tires' rubber [12, 13].

The scope of research is to utilize the grounded tires in low-density polyethylene (LDPE) to produce LDPE/GTR blend. And secondly, to increase the impact strength of the LDPE by incorporating ground tire rubber (GTR) powder in it. The main objective of the research is to explore the effect of GTR on the mechanical properties of LDPE. LDPE is not a particularly strong polymer in comparison to others; it is primarily used for packaging. So using GTR as a filler in LDPE to observe its mechanical properties is aimed. As GTR has outstanding impact strength, and it's also an elastomer, when the composition of LDPE/GTR is set, we propose that it will probably improve its impact strength as well as percentage elongation.

METHODOLOGY

Raw Materials

The raw materials which are used are low-density polyethylene (LDPE), ethylene propylene diene monomer (EPDM), natural rubber (NR), styrene-butadiene rubber (SBR). Polyethylene is made by an additional polymerization reaction of ethylene monomers, as shown in Figure **1**. The functional group of polyethylene (PE) is hydrogen. PE contains only carbon and hydrogen, generally high molecular weight, so it is pretty unaffected to most solvents. PE belongs to the polyolefin family of polymers and is categorized by its density and branching [12, 13].

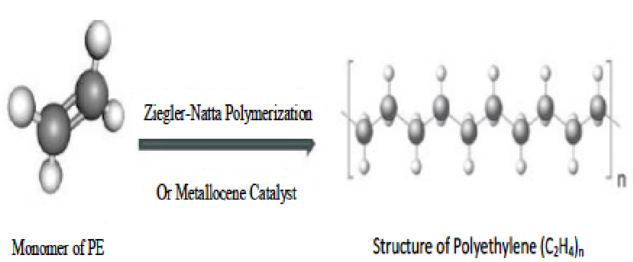

Figure 1: Polymerization reaction of polyethylene.

High-density polyethylene (HDPE), low-density polyethylene (LDPE), and linear low-density polyethylene (LLDPE), the main focus is on LDPE. It is formed when high pressure and high temperature via free radical polymerization reaction takes place. It is a semi-rigid and translucent polymer as compared to HDPE. It has a higher degree of long and short side-chain branching. The density is low because that it rises the construction of many relatively long branches and avoid the molecules from packing close together to form crystal structures. It has low crystallinity (below 40%). The LDPE consists of 4000 to 40000 carbon atoms, with many small branches. A highly amorphous nature structure affects the physical properties of LDPE. The melting temperature ranges from 105^{o}C to 115^{o}C, and density ranges from 0.91-0.94 g/cm^3. Good chemical resistance to a dilute alkali, acids, and alcohols and limited resistance to hydrocarbons, aliphatic, oxidizing agent. Low water absorption (% by wt. <0.01), clear in thin-film form, electrical insulating properties are excellent, good processability, and low cost. The disadvantages of LDPE are; low tensile strength, low stiffness, poor ultraviolet resistance, high flammable and vulnerability to stress cracking [11, 14-16].

EPDM

Ethylene propylene diene monomer (EPDM) comes from chemicals like monomers, which are mixed in different proportions to get it. It includes ethylene, propylene, and diene. Commonly 45% to 75% ethylene content is present. While diene monomers are only a minor component of EPDM, they offer the crosslinking that provides remarkable resilience, flexibility, and durability. EPDM's exceptional material characteristics are due to its molecular mesh structure, making it unique in terms of elasticity and aging resistance. EPDM rubber is a synthetic rubber material. Because it is highly flexible and durable, it has a broad range of uses, containing automobiles (used for door/window seals and cooling system hoses), non-slip coatings for decks and playgrounds, cold-rooms, and many more. The significant advantages of EPDM are; it has excellent weather resistance. It has the most waterproof rubber available; it can withstand abrasion, UV radiation, ozone, age, and weather. EPDM is also resistant to steam. It was operating at temperatures as high as 392 degrees Fahrenheit (200 degrees Celsius) without air and chemicals, including polar fluids. Its susceptibility to solvents, hydrocarbon oils, and certain lubricants, all of which can cause damage. Furthermore, unlike silicone, it is not flame resistant and is not suggested for food applications [14, 17].

Natural Rubber

It is natural rubber obtained from the latex of rubber trees. It can often be called cis-1,4 poly (isoprene). By cutting the bark to reach the latex vessels, it is collected in a cup installed on each tree. Rubber provides about 30-40% of the weight of this latex liquid. The assemblage of the latex sap, the natural rubber, is prepared to make it useable. At first, acid was added to the latex, making the sap solidify like jelly. The subsequent latex jelly was leveled, wrapped into elastic sheets, and hung to dry. Normal elastic consolidates solid malleable and tears strength with extraordinary exhaustion obstruction. It has extraordinary green strength and tack, implying it can append to itself and different materials, making it simpler to develop. One of its weaknesses is unassuming protection from natural corruption brought about by warmth, light, and ozone. Normal elastic bonds well to metal-plated steel wire, making it ideal for elastic tires. Lower hysteresis brings about diminished heat generation, preserving new tire service integrity, and broadening retread capacity. Natural rubber offers low moving opposition and further develops mileage. It is amazingly impervious to cutting, chipping, and tearing [18, 19].

Styrene-Butadiene Rubber

SBR is created by combining petroleum and natural gas. It is a synthetic rubber composed of styrene 25% and butadiene 75% monomers; it is sometimes used to replace natural rubber. Either emulsion polymerization or free-radical polymerization can be used to generate it. The most common general-purpose synthetic rubber is styrene-butadiene rubber (SBR). It may be utilized in applications comparable to NR / IR elastomers, except for strong dynamic applications due to the poorer fatigue resistance. Drive couplings, haul-off pads, conveyor belts, shoe bottoms and heels, adhesives, roll covers, and automobile tires are examples of typical uses (but not truck tires) and a variety of additional molded rubber products. For static sealing, the normal operating temperature range is -25°C to +100°C. It has better abrasive resistance, heat resistance; it is better than natural rubber, has excellent corrosion resistance, low temperature flexibility, and tensile strength [20, 21].

Process Equipment

A grinding machine is one of the power tools commonly used for grinding and cutting the material. The grinding machine had different types of blades for different purposes. In this process, the angle grinder tool using. The abrasive disc is placed in a grinder which grinds the rubber in the form of uniform powder. The speed of the grinder plays an important role in the grinding of rubber. To ensure the speed of the grinder, and must be set according to the requirement. Ensure that there would be no crack on the disc while using the grinding machine.

Compression molding is a process in which a material acquires a restricted shape (according to the mold) by applying temperature and pressure. A compression molding machine is also called a laboratory hot press. This process consists of five major steps; set the optimal temperature according to the material requirements. I was preheating the mold and filling the material. Applied pressure according to the required conditions. The curing of the material.

Preparation of Sample

The experimental samples were being prepared by grinding the tire surface into powder form with the help of a grinding machine and filer. It incorporates low-density polyethylene (LDPE), which is also in powdered form. Samples were prepared by setting the composition of LDPE/GTR in phr form 1phr - 5phr and prepared 15 samples of each composition of LDPE/GTR. Initially observed the formation of the sample by varying temperature and finally got the optimal temperature 220°C. The powder form of LDPE/GTR was placed between hot plates of the compression molding machine at a constant temperature of 220°C and varying pressure (150-200) bar. Dumbbell shape samples were made to examine the mechanical properties of LDPE/GTR at different phr. The composition of LDPE/GTR was named as pure LDPE, 1phr, 2phr, 3phr, 4phr, and 5phr, where phr refers to gram of GTR with 30 gram of LDPE. The samples were prepared at 0g, 0.3g, 0.6g, 0.9g, 1.2g, and 1.5g of GTR. The samples were prepared as shown in Table **1**.

Table 1: LDPE/GTR Samples Composition

Samples	LDPE (g)	GTR (g)	Number of Samples
Pure LDPE	30	0	15
1 phr	30	0.3	15
2 phr	30	0.6	15
3 phr	30	0.9	15
4 phr	30	1.2	15
5 phr	30	1.5	15

The LDPE and GTR, both in powder form, were first weighed with the help of weight balance. Then mixed them and made a composition of LDPE/GTR according to the required phr. Set the machine at an optimal temperature of 220°C. Firstly, preheat the mold, and after that filled the mold with the material. Then place the mold between two heat plates at a temperature of 220°C and different pressure (150-200) bar. Under the set, the condition material is melted and takes the shape of the mold. Mold is heated continuously for 3 min to give the samples a proper shape. After that, mold was taken out and continued to cool down for 10 minutes at room temperature. In the end, the dumbbell shape part is separated from the mold. Repeat the process until you prepare 15 samples of each phr.

Sample Testing

Different samples were tested at different phr. The basic objective of sample testing is to explore the mechanical properties of the low density of polyethylene with ground tire rubber. Tensile strength, flexural strength, and impact strength testing are done on prepared samples.

Izod Impact Testing

Izod impact testing can measure the impact energy that is the toughness of the sample. The hammer is raised at a specific height and then released it which hits a sample and absorbs the energy in it-using the US-based company manufacture of Ray-Ran testing equipment. The samples were prepared according to ASTM D256. The result from these tests mainly depends upon the materials. The velocity was set to 3.46m/s, and the standard weight of the hammer was 0.905 kg. The mean thickness of the samples was 3.3mm, and their mean width was 12.7mm.

Flexural Strength Testing

Flexural strength is also called bending strength. The flexural test can be performed on a Universal Testing Machine with samples standard according to ASTM D790. The core purpose of the flexural test was to find out the behavior of the sample when stress is located when the load is applied. In this testing, the sample is placed horizontally between the two fixed jaws while a movable jaw applies a force from the top until a sample bends. This test measures the maximum bending stress that the test sample can maintain before it fails. The speed of the machine was set at 50mm/min, and also the span length of the specimen was 50mm. The mean thickness of the sample was 3.3mm, and their mean width was 12.2mm.

Tensile Testing

The tensile force is applied to a sample and measures the response of the sample. It defines how strong a material is and how much it can be stretched-using Universal Testing Machine (UTM), which German company Zwick/Rowell manufactured. The samples were prepared according to ASTM D638. UTM was used for testing the sample by applying tensile stress. The speed of the machine was set at 50mm/min, and also the span length of the specimen was 50mm. The mean thickness of the samples was 3.3mm, and their width was 12.38mm.

RESULTS AND DISCUSSION

Five samples of each composition of LDPE/GTR, which was in phr, have been tested, and the results and their mean width, thickness and IZOD, flexural strength, tensile strength, modulus, and percentage elongation have been recorded. Similar results were achieved when testing 5 samples of each composition of LDPE/GTR.

IZOD Test

The impact energy will increase as the GTR content in the composition of the LDPE/GTR blend increases, as shown in Figure **2**. It is found that as the rubber content in a composition LDPE/GTR increases, the impact strength of the sample gradually increases because the rubber can absorb the energy. After all, it is an elastomer, and they are cross-linked, and also they are above glass transition temperature *Tg* at room temperature that is why they are flexible. The good impact strength was achieved because of the fracture toughness behavior of GTR [7, 12, 20, 21].

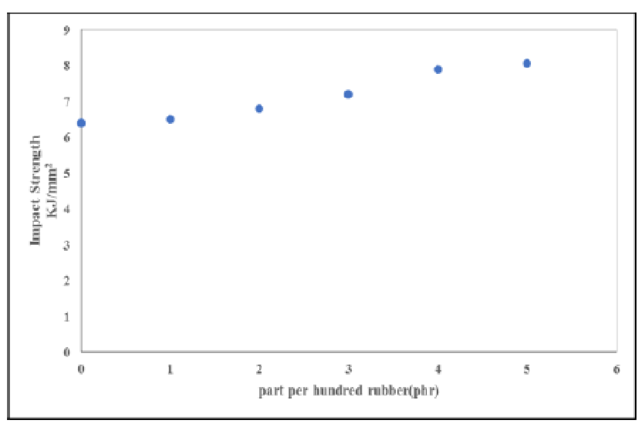

Figure 2: Effect of rubber content on the impact strength of LDPE/GTR blend.

Flexural Test

From Figure **3**, it is observed that as the rubber content in a composition LDPE/GTR increases, the flexural strength of the sample decreases. It may be due to the low stiffness of LDPE compared to other thermoplastic materials and maybe due to void or defect inside the blend. Also, rubber can resist when the load is applied. Further, adding the rubber material to it will significantly affect its stiffness and reduce its flexural strength. The flexural strength at break cannot be calculated as the sample was not broken during applied load. So the flexural strength was calculated at 25 % deformation. The blended material shows good flexibility by reducing the stiffness of the overall composition [11, 15, 16, 19, 22].

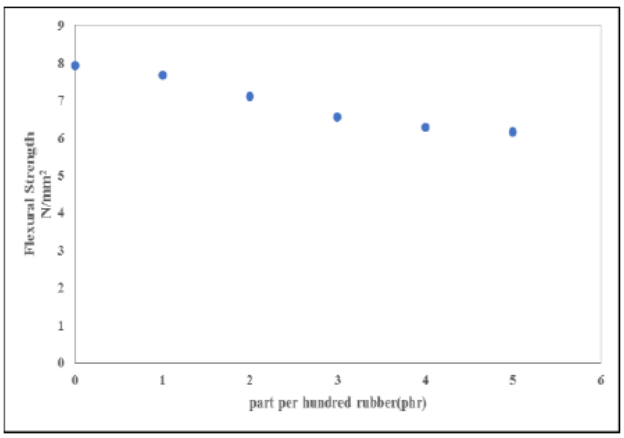

Figure 3: Effect of rubber content on the flexural strength of LDPE/GTR blends.

Tensile Test

From Figure **4**, the effect of the rubber content on the modulus of LDPE/GTR blends is observed. The elastic modulus decreases by increasing the rubber content in LDPE/GTR blend, due to poor compatibility between GTR and LDPE. The rubber molecules did not get sufficient freedom to entangle with LDPE molecules to form strong bonding between GTR/LDPE. The rubber has a low modulus compared to the thermoplastic material [3, 4, 7, 18].

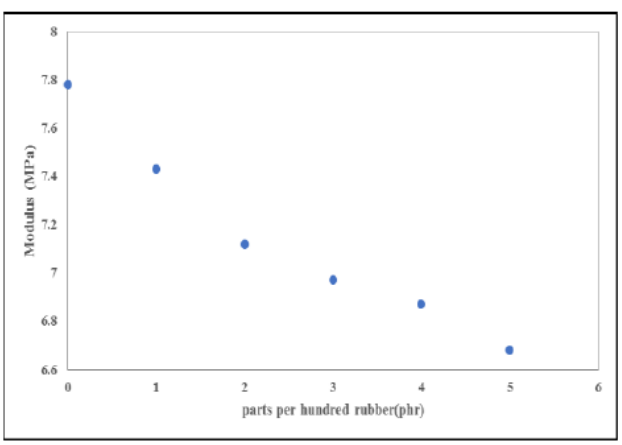

Figure 4: Effect of rubber content on the modulus of LDPE/GTR blends.

In Figure **5**, the trend shows that as the GTR content increases from pure LDPE to 5phr, the tensile strength decreases from 111 to 79.21 N/mm^2. This decrease is not only due to weak affinity between blends, but also due to degradation of recycling GTR by exposure to the atmosphere or during their use while processing and grinding.

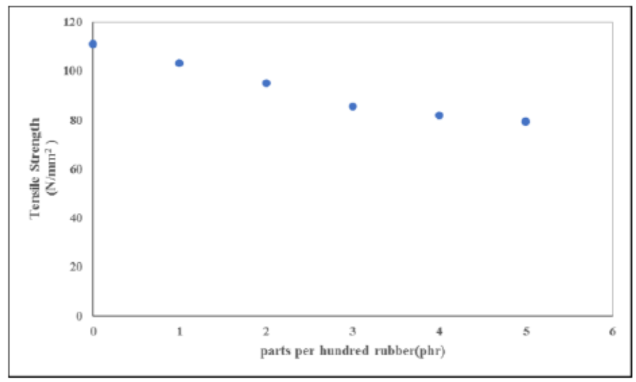

Figure 5: Effect of rubber content on the tensile strength of LDPE/GTR blends.

In Figure **6**, it is observed that as the rubber content increase, the percentage elongation increases because of the slight increase in plastic deformation due to the presence of elastic phase, which persuading higher elasticity in the samples. According to the tensile results, it was observed that the rubber content is showing its effect by increasing elongations as we have

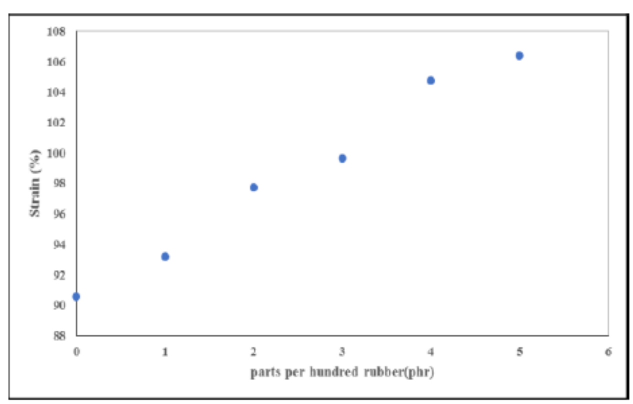

Figure 6: Effect of rubber content on the elongation of LDPE/GTR blends.

more elastic properties in rubber and decreasing the modulus and tensile strength of the blend. The blend has good energy absorption capabilities with mechanical balance properties compared to pure rubber material [9, 11, 16, 17].

CONCLUSION

Thermoplastic-elastomer blend was prepared from ground tire rubber (GTR), and low-density polyethylene (LDPE) on a hot press compression molding machine, and its properties were examined in detail. It was noticed that percentage elongation and impact strength increases when the rubber content is increased in the blend as compared to virgin LDPE. The percentage elongation of pure LDPE is 90.56%, and the percent elongation was increased in phr, and at 5 phr, it is found to be 106.39%. Similarly, the flexural strength of pure LDPE is 7.93 N/mm^2, and its strength decreases in phr, and at 5 phr, it is found to be 6.146 N/mm^2. Similarly, the impact strength of pure LDPE is 6.4 KJ/mm^{2,} and its impact strength is increased in phr, and at 5 phr, it is found to be 8.06 KJ/mm^2. Furthermore, tensile strength, and modulus decreased with the incorporation of rubber content in the blend. The decrease in tensile and modulus was from 111 N/mm^2 to 79 N/mm^2, and 7.78 MPa to 6.68 MPa, respectively, in a 5 phr blend. Better mixing would be obtained while using an extruder which may give a good uniformity of the LDPE/GTR blend. Homogeneity of the GTR/LDPE blend can be observed by scanning electron microscopy. From previous studies [ref], it can also deduced that GTR can be incorporated with other polymer matrices for better enhancement in properties. The thermal properties of the GTR/LDPE blend can be analyzed.

NOMENCLATURE

SBR	Styrene-butadiene rubber
NBR	Nitrile butadiene rubber
FA	Fly ash
PE	Polyethylene
PP	Polypropylene
NR	Natural rubber
PU	Polyurethane
UV	Ultraviolet
UTM	Universal testing machine
PHR	Parts per hundred rubber
GTR	Ground tire rubber
LDPE	Low-density polyethylene
HDPE	High-density polyethylene
EPDM	Ethylene propylene diene monomer
TPE	Thermoplastic elastomers
RR	Reclaimed rubber
LLDPE	Linear low-density polyethylene
ASTM	American standard testing material

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Received on 27-11-2021 Accepted on 13-12-2021 Published on 16-12-2021

DOI: https://doi.org/10.15379/2410-1869.2021.08.02.07