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The effect of tire rubber particles on the mechanical and physical properties of polyester

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Abstract. In this work, a novel composite of polyester with rubber particles -obtained from recycled wasted car tires -was developed. Worn tires generate a large amount of wastes that do not derogate resulting in environmental problems. This has the advantage of producing useful product that is economical and eco-friendly. The effect of the volume fraction of the rubber particles in the composites on the physical and mechanical properties of the composites was studied. Varying the volume fraction from 0-60% resulted in an increase in the impact properties. The addition of rubber particles had also the effect of reducing the density of the composites which is a desirable property

1. Introduction

1.1. Solid waste management

Solid waste management is one of the most significant issues now a days. Waste tires are one of the top issues as they do not derogate resulting in environmental problems. Consumption of rubber was 26.166 ton in 2012[1]. This material is used to produce many products mainly tires [2]. In USA 300,000,000 tires are turned to scrap tires annually, some are used as a fuel in ovens for about 40 % of the scrap tires, some are shredded and ground into particles which is about 26 % of the scrap tires, the rest are in landfills or used in some civil applications [3]. Waste tire rubber is representing a big part in waste disposal. This is considered as a huge problem in all over the world. In USA and Japan, they have a high environmental standard that lead to the need to dispose the waste tire rubber in an efficient way. Many countries now are developing and putting law to face the environmental hazards resulting from wastes and on the top of that is the waste tire rubber. USA and Japan were the leaders to put the laws in place to face these issues. That makes them now the leaders in waste tires recycling [4]. As for now the way to dispose the waste tire rubber in landfills is not accepted anymore because the landfills sites are now fully occupied [5, 6]. European union direction now is to implement a time schedule to solve this problem, so new disposal ways for waste tire rubber is an urgent need to face this huge waste problems [7].Also, the waste tire rubber is used as a fuel in cement factories, as a source of carbon black, and a source to create reefs in marine[9, 10]. In order to use it as a fuel it is technically applicable but economically expensive, as to get the carbon black from the tires, they need shredding and grinding process which is costly, even to get it from pyrolysis is more costly and produces lower quality compared to normal producing from petroleum [11, 12]. For civil engineering applications the waste tires are cut and shredded to be used in leachate landfills in dams. Also, it is used as a filler and modifier in asphalt mixture and as an additive in cement [13, 14]. Several research efforts were directed during the last decades to develop composite materials. While some of these composites had metal matrices [15,16], some others had ceramic or polymeric matrices [16-20]. The reinforcing phase varied from synthetic to natural fibers or particles. In this work, waste rubber tire particles are inserted into polymeric matrix to develop a novel composite material that can have useful engineering applications [21] Waste tire rubber

Tires are fundamental things in vehicles that forms the point of contact between wheel and the road. They provide the friction between wheel and road so that they can accelerate and brake and provide proper handling and in order to do this tire had to with stand wear, tear and impact [22]. Tires are manufactured from vulcanized rubber, natural rubber, synthetic rubber, fiber and steel wires. The two major components used in the manufacturing of tires are natural rubber and synthetic rubber [23]. By analyzing rubber, it is a high molecular weight, amorphous polymeric material. As per application the manufacturing of rubber differs according to the properties needed. Car tire is consisting of 58.6 wt.% rubber, 29.2 wt.% carbon black, 2.9 wt.% zinc, 1.8 wt.% stearic acid, 1.2 % sulfur, 5.85 % extending oil, and 0.4 wt.% accelerators [18]. Rubber can be oxidized in the amorphous regions. Attacking the tire by chemicals and microbes can results in decreasing in the mechanical properties and decreasing the working life of tire [24]. Natural rubber is sticky in nature and can be deformed under heat and can be turned to brittle when cooled under glass transition temperature. As a raw material it cannot be used to have products with needed elasticity, and this is because un-vulcanized rubber is consisting of long chains that can move independently. The vulcanization process is done by adding Sulphur, cross linking is formed and that results in the elasticity which means that by applying stress, deformation happens and when remove stress, the rubber goes back to its initial [25].

Many ways are now used for reuse, recycle and reclaim of waste tires such as retreading and can also be used as floaters [2]. In engineering applications, the ground tire rubber is used in civil engineering, asphalt, cement and composites. The waste tire rubber particle is used in composite mixtures.

1.2. Waste tire rubber in polymer blends

Waste tire rubber can be recycled by using them in polymeric composites. Polymeric composites can be divided into two types; thermoset and thermoplastic rubber composites. Waste tire rubber could be blended with the two types to obtain blends. The market use of polymers is huge, only 10 wt.% of waste tire rubber is blended with polymers, particularly thermo plastic [26]. Thermoset and thermoplastic can use these waste tire rubber as a filler in form of particles to increase the toughness and to reduce the cost of final product.

Polyethylene, Polypropylene and polyvinyl chloride are the most used in composites materials due to their competitive cost and easy blending processing. These composites are done to have thermoplastic elastomer composite to be a solution to utilize the waste tire rubber in thermoplastics. There are many factors that affect the mechanical properties as the influence of particle size of waste tire rubber. Particle size of waste tire rubber has a noticeable effect on the mechanical properties, also the properties may vary according to the processing as injection molding or pressurized molding. Ismail et al. [27] reported that particle size <500 μm has better mechanical properties compared to bigger size. Colom et al. [28] reported a decrease in tensile strength at 20 wt.% Waste tires rubber containing HDPE blend with <200 μm particle size whereas when bigger particle size (>500 μm) was used the decrease was 51%. Same results were noted by Mujal-Rosas et al. [29] in their study, they used three different particle sizes (<200, 200–500, >500 μm). Sonnier et al. [30] also used three different waste tire rubber particle sizes which were all >500 μm and did not results in significant effect of particle size on the mechanical properties. Tantayanon and Juikham [31] reported the impact strength of PP/Waste tire rubber blend comprising 420 µm, 1.2 mm and 2.4 mm sized particles and found only the smallest particle size results in an tangible improvement in impact strength (20%) whereas the other two bigger particle size composites results in only slight improvement.

Tensile properties generally decrease with addition of waste tire rubber. This was accompanied with poor adhesion between waste tire rubber and polymer matrix at interface. Poor interface results in high interfacial tension, making the waste tire rubber particles agglomerate and creating voids around waste tire rubber. Clear indication of lack of interfacial adhesion can be concluded from the easy removal of waste tire rubber particle from the polymer. Colom et al. [28] observe a decrease in tensile modulus of approximate 25%when only 20 wt.% Waste tire rubber was added to HDPE. Recycled HDPE/ Waste tire rubber blends properties were studied by Sonnier et al. [32] and they observe all tensile properties decrease considerably with increasing Waste tire rubber content. At 50 wt.% GTR content, tensile properties showed decrease of 40–80%. Study using PP/ Waste tire rubber also showed similar pattern where the tensile modulus decreased by 20%at 30 wt.% Waste tire rubber loading [27].

2. Methodology

2.1. Materials
Polyester were supplied by SUNPOL with density 1.2 gm/cm3, Recycled rubber particles were supplied by HOPPEC Company, the used average rubber particle size is2.5 mm of density 0.4 gm/cm^3.

2.2. Composite preparation
Polyester/ rubber particles composite is prepared as follows:

1. Calculate volume required for sample size
2. Divide the volume calculated according to the required volume fraction for rubber and polyester.
3. Polyester is mixed with waste tire rubber particles and stirred till homogeneity at Room Temperature.
4. Hardener is added at 2.5 wt.% to the mixture and stirred for 2 min
5. The mixture is placed in a vacuum chamber for 5 min at -0.8 bar.
6. The mixture is poured in a silicon rubber mold with required sample size

2.3. Physical testing.
Density tests were conducted on Aczet CY (0.1 mg & 0.001ct) as shown in Figure 1 according to standard ASTM D792-00 to measure the density of the waste tire rubber particles, polyester and the composite. Samples of density were prepared with the dimensions as shown in Figure 2

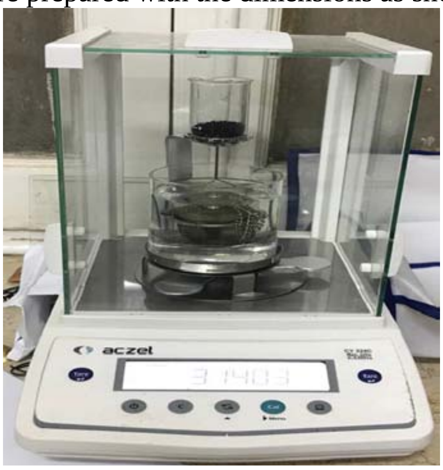

Figure 1 Aczet CY (0.1 mg & 0.001ct)

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Figure 2 Density sample size

2.4. Mechanical testing

Tensile tests were conducted on LLOYD universal testing machine-30 ton according to ASTM D 3039/D 3039M – 00 as shown in Figure 3, with crosshead speed 5 mm/min in order to determine the ultimate and yield tensile strength. Impact tests are carried according to ASTM D 6110-04 using XJJU-5.5/50J Izod & Charpy Impact Tester as shown in Figure 4

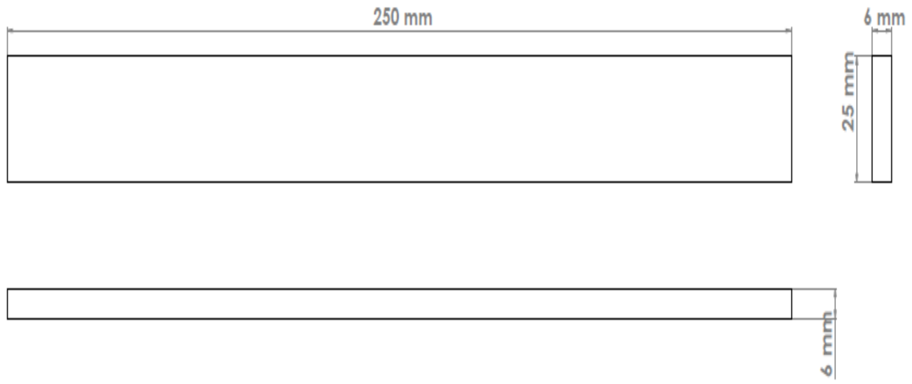

Figure 3. Tension Test sample size

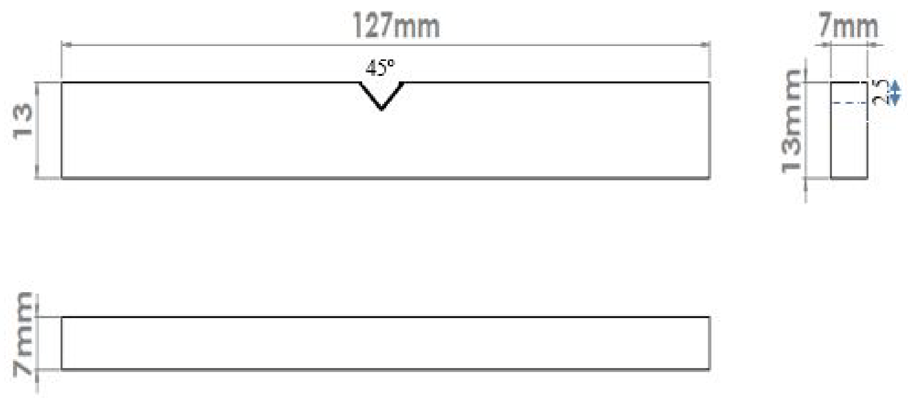

Figure 4 Impact sample size

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2.5. Scanning electron microscopy
The fracture surface of the specimens that underwent impact test was studied to assess the mechanical adhesion and the interface of rubber particles with the polymer in the composite. Field emission scanning electron microscope Leo Supra 55was used.

3. Results and discussion

3.1. Physical properties
The effect of the waste tire rubber particles size on the density of the Polyester composites is shown in Figure 5. The density decreases as the vol% of waste tire rubber particles increases because of the lower density of the waste tire rubber particles than that of polyester, and this agrees with what was mentioned in Scrap Tires - Material Description [33]. The theoretical density was calculated using simple mixture rule and compared to the practical measured density. It was observed that there is an error gap between theoretical density and practical measured one, this error is increasing with the increase of waste tire rubber vol.%. The error is stabilized from and after 50 vol.% as shown in Figure 5.

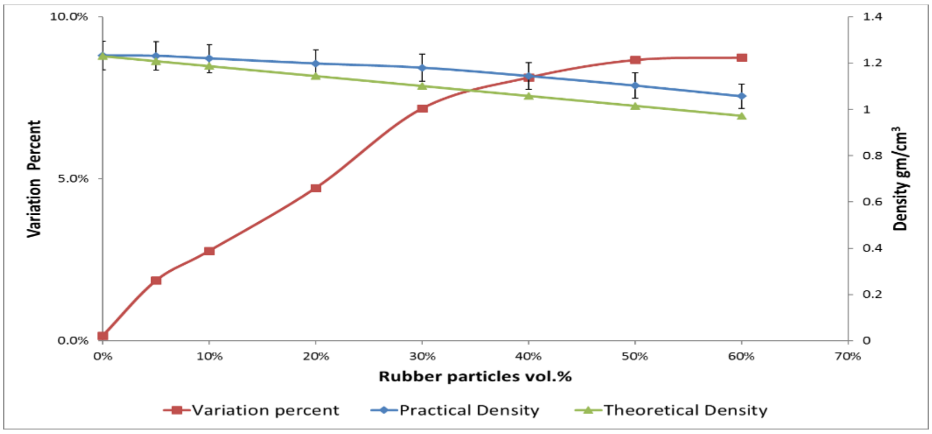

Figure 5. Theoretical density vs Practical density ofwaste tire rubber particles polyester composite.

3.2. Mechanical properties
3-2-1 Tensile Test

Some mechanical properties of composite material composite are obtained as shown in Figure 6 to Figure 11typical stress strain curve shows the decrease of strain rate up to failure with the increase of waste tire rubber vol% as shown in Figure 6.

The stress strain curve shows that the ultimate tensile strength decreases with the increase of waste tire rubber vol.%. and this is expected to be due to the lower strength of rubber particles compared to polyester.

Area under stress-strain curve which is known as the toughness was calculated. The toughness of the composite decreases with the increase of waste tire rubber vol.%. yield tensile strength was also obtained from tension test as shown in Figure 7.Yield strength decreases up to 5 vol.% of waste tire rubber particles. However, it shows an increase compared to the value of yield strength for 0vol.%at 10 vol% of waste tire rubber particles. This can be explained as up to 10 vol.%, the rubber particles act as a barrier that block the crack propagation and act as a reinforcement particle inside the matrix. Yield strength decreases with the increase of waste tire rubber particles after the 10 vol.% and up to 60 vol.% and this can be explained as the vol.% of particles increases the agglomeration of particles-so, particle to particle contact effect, is more than the effect of stopping the crack propagation that leads to decrease in yield strength and this is can be verified with SEM as shown in Figure 12 and Figure 14.

The ultimate tensile strength decreases with the increase of waste tire rubber particles vol.% as shown in Figure 8. and this can be due to the form of the rubber as ductile particles can’t stand tensile stress unlike fibers.

The toughness was calculated form the area under curve of stress-strain. The toughness decreases with the increase of waste tire rubber particles vol % as shown in Figure *9* with agreement with previous researches [34]. This is due to the decrease both of ultimate tensile strength and strain to fracture.

The strain up to yield was measured and calculated form from the stress-strain curve. The strain up to yield increase with the increase of waste tire rubber particles vol.% up to 10 vol %. After 10 vol % the strain up to yield decrease with the increase of waste tire rubber particles vol.% as shown in Figure *10*. and this can be explained as in the phase of elastic deformation the matrix transfer the load to the rubber particle in which the particle has already high stain property but when the load goes beyond to the elastic phase the load transfer and cracks increase by amount more than that the rubber can absorb inside the matrix and crack propagation cannot be any more stopped by rubber particles.

3-2-2 Impact test

Impact strength was obtained from Charpy impact test and the results are shown in Figure 11. The specific impact strength is calculated by dividing impact value by density value. The impact strength decreases with the increase of waste tire rubber particles up to 10 vol %. with agreement with previous research [17],[344],[35]. then the impact strength starts to increase with the increase of waste tire rubber vol.% till reach the highest at 50 vol.%. and this may be explained by the high impact properties of waste tire rubber as this is the main property that tire rubber was manufactured for. The impact strength after 50 vol.% decreases with the increase of waste tire rubber particles vol.% as shown in Figure 11. and this can be explained from the agglomeration and particle to particle contact [36].

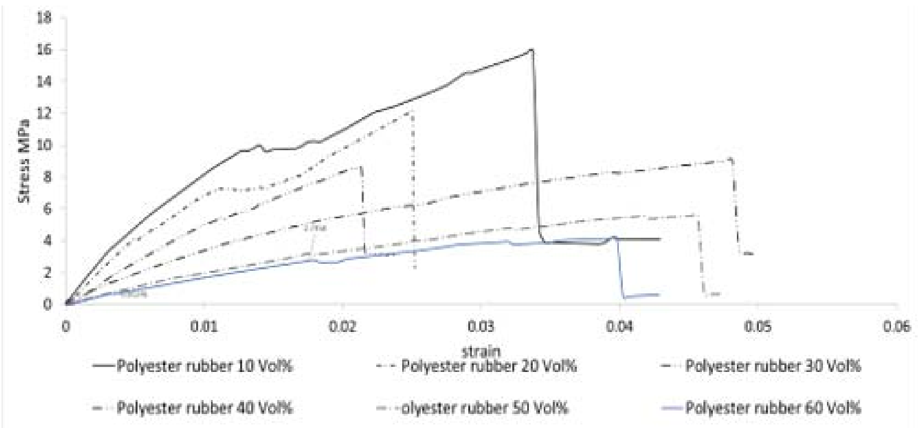

Figure 6. Typical Stress-Strain of waste tire rubber particles polyester composite.

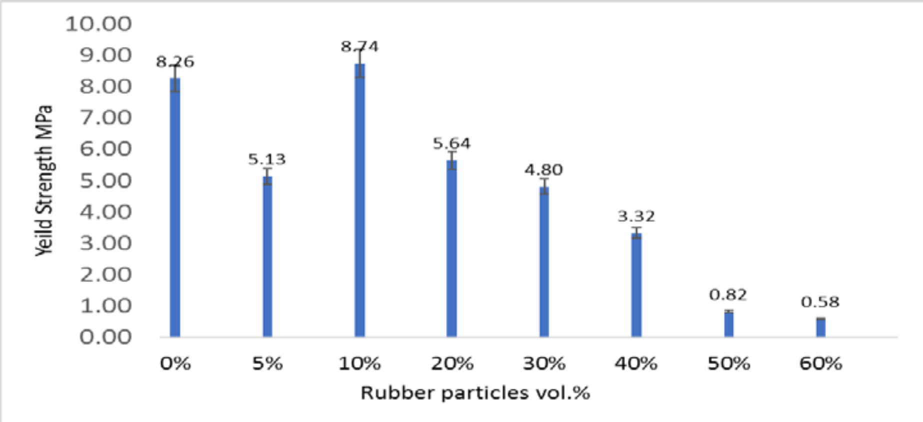

Figure 7. Yield strength vs waste tire rubber particles polyester composite vol.%.

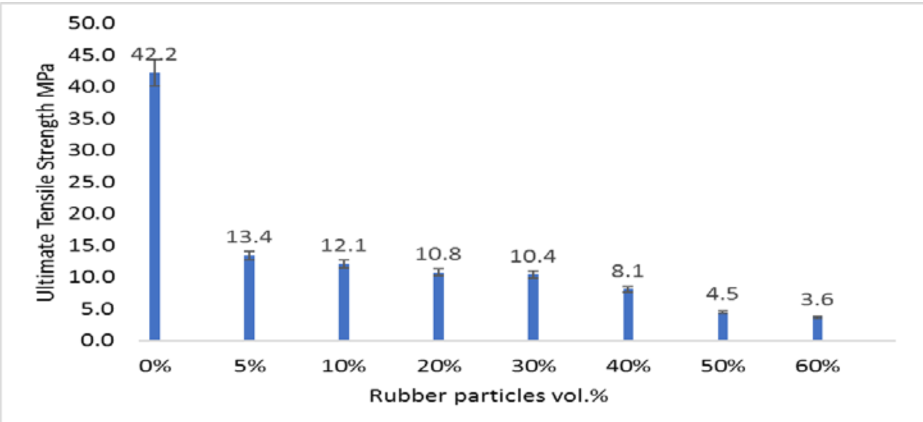

Figure 8. Ultimate tensile strength vs waste tire rubber particles polyester composite vol.%.

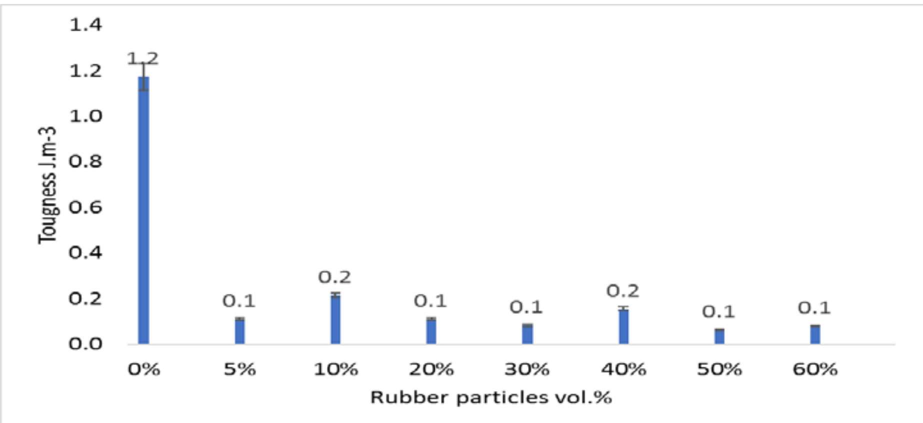

Figure 9. Toughness vs waste tire rubber particles polyester composite vol.%.

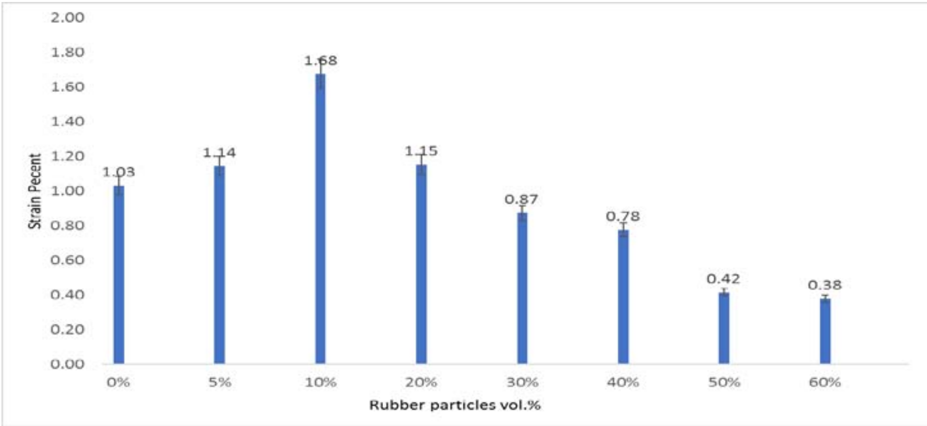

Figure 10. Strain up to Yield vs waste tire rubber particles polyester composite vol.%.

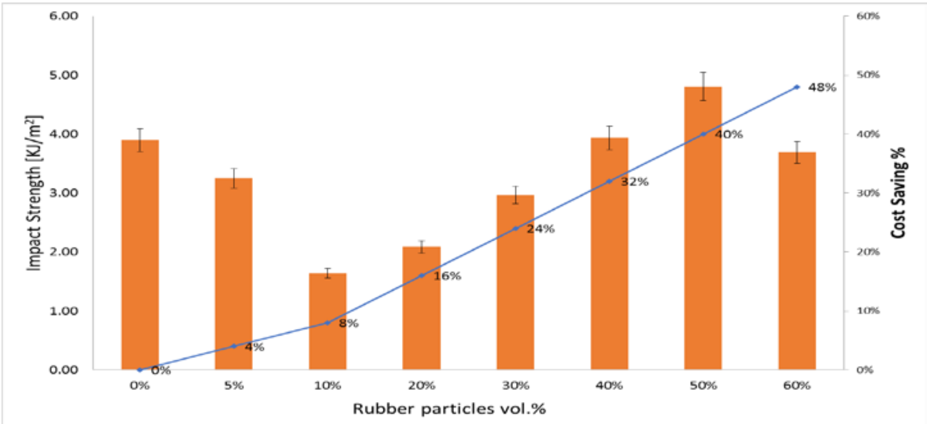

Figure 11. Specific impact strength vs waste tire rubber particles polyester composite vol.%. -cost saving % vs waste tire rubber particles polyester composite vol.%.

3.3. Morphology

SEM micrographs of impact fractured surface of polyester waste tire rubber particles composites are shown in Figure 12 to Figure 14. The surfaces of samples were gold sputtered and then examined under the SEM. The surface of waste tire rubber particles is fractured which confirms the contribution of particle in the impact fracture test as shown in Figure 12. There were cracks in matrix, debonding between matrix and particle. On the surface there are tearing in rubber particle. This morphology shows the weak adhesion between the waste tire rubber particle and the polyester resin as shown in Figure 12 with magnification 30X. and agrees with previous researcher [17].the particle surface was examined by SEM Figure 13 with magnification 422X and this shows that the particle is smooth and this may be the reason of the debonding and to increase the bonding surface of rubber need to be treated so the surface can have more roughness to bond and increase the interfacial forces between rubber and matrix. For 60 vol.% of waste tire rubber particles, a particle to particle contact is observed as shown in Figure 14.

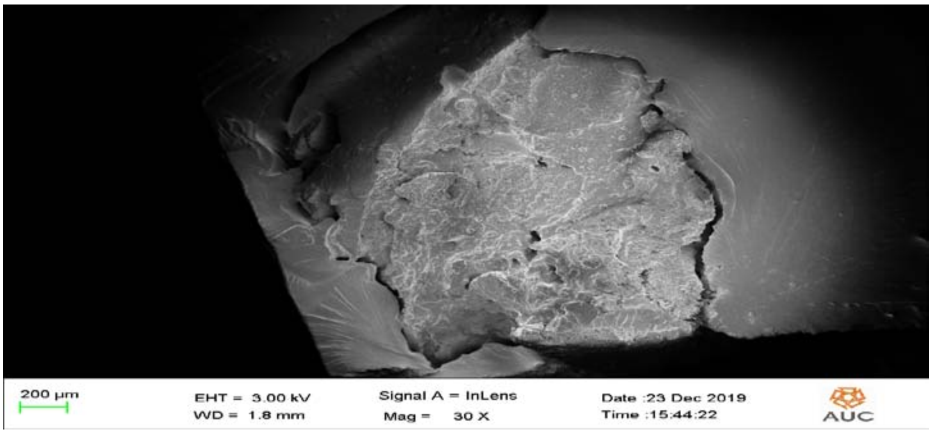

Figure 12.SEM of the fractured surface illustrating poor interface

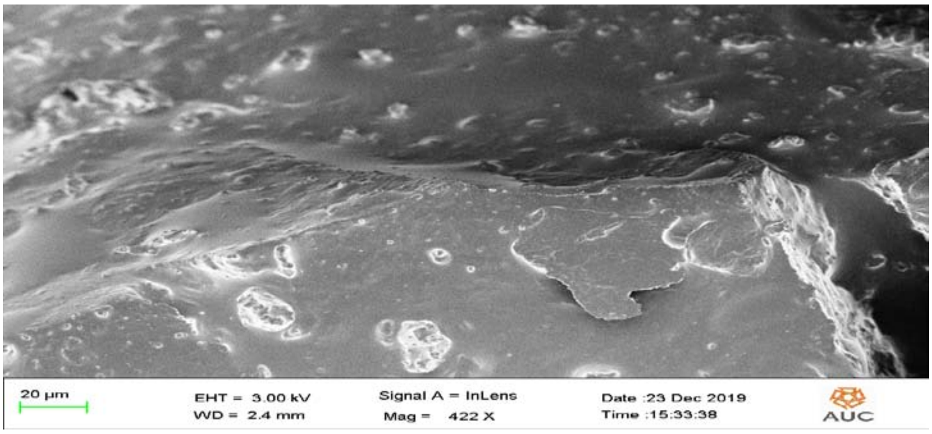

Figure 13 SEM rubber particle with magnification 422X

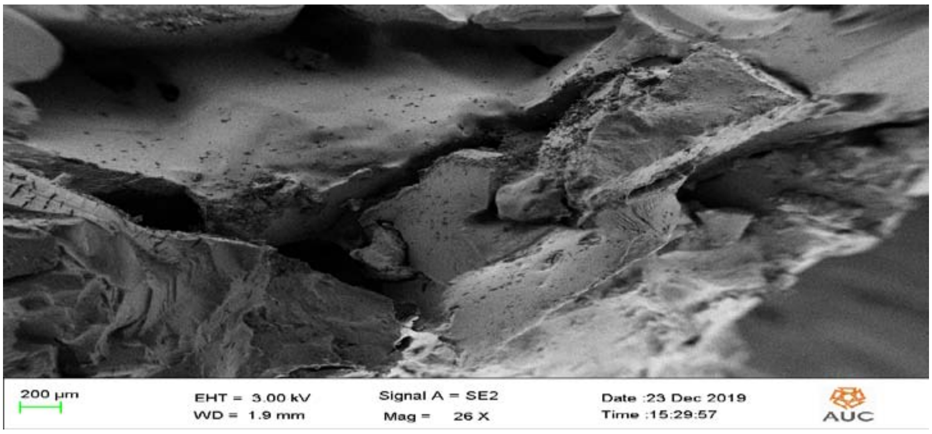

Figure 14 SEM particle to particle contact

4. Conclusions

In this study, the following can be concluded;

The developed rubber composite present a considerable improvement in its Mechanical Properties. The Impact strength increased by 23% at 50 vol.% of waste tire rubber particles while the yield strength and strain up to yield increased by 10% and 63 % at 10 vol.% of waste tire rubber particles respectively. Moreover, the developed composites became lighter with a density decrease with the increase of waste tire rubber particles vol.% which is a desirable property. On the other hand, the ultimate tensile strength decreased with the increase of waste tire rubber particles vol%. These results were also verified using field emission scanning electron microscope.

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