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Mechanical behaviour of rubber hybrid composites

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Abstract. Recently, a lot of researches are directed to recycling of waste materials such as waste tires and marble and granite dust (GM). The management of solid wastes is essential to prevent the harmful effects and hazards associated by the contamination of these wastes. Waste tire rubber particles (WTRP) are added to high density polyethylene (HDPE) matrix to increase the impact strength of HDPE, while it results in the decrease of other mechanical properties. GM is added to this mixture to modify some mechanical properties such as hardness and compressive strength, this mixture results in a novel hybrid composite. The effect of using different GM wt.% on different mechanical properties of the composite is studied. Mechanical testing such as three-point bending, Charpy impact, compression and shore D hardness is implemented according to ASTM standards and Scanning electron microscopy examination of the microstructure of WTRP-HDPE-GM hybrid composite is used to support the explanation of the results.

Keywords. Recycled tire rubber; impact strength; HDPE composite; Marble and Granite dust; SEM

1. Introduction

Waste tire rubber particles (WTRP) are used to get rubber composite material. WTRP are added to a virgin rubber or a composite thermoplastic material [1]. The objective of using WTRP with polymeric matrix is to enhance toughness and other elastic properties of the particulate composite [2,3]. Recycling of rubber depends mainly on the waste tires and about 70 % of the consumption of natural and synthetic rubbers is directed to tire manufacturing [1,4,5]. Tires consist of rubber, carbon black and silica, metals, fibers, Sulphur, stearic acid, Zinc oxide, additives and Aromatic oils [6].

Marble and granite dust (GM) is the waste resulting from marble and granite industry and represents 20 to 25% of the marble and granite total waste [7]. About 70% of the marble and granite factories are located in Shaq Al-Thu`ban situated in Katameyya close to Maadi suburb of Cairo [8]. The marble and granite dust resulting from Shaq Al-Thu`ban is around 800, 000 tons/year. The dust is dumped in Wadi Degla and the neighboring area thus increasing soil alkalinity and reducing soil fertility [7]. Research efforts were directed towards the usage of GM as reinforcement in cement or natural rubber as it may enhance some mechanical properties of the resultant composite. GM consists of $CaCO_3$, Silica (SiO_2), Fe_2O_3, Alumina (Al_2O_3), Phosphoric acid, Potassium oxide (P_2O_5),

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$MgCO_3$, Soda (Na_2O), Lime, Iron (Fe_2O_3), Iron (FeO), Magnesia (MgO), Titina, Water (H_2O) and impurities such as SiO_2, Fe_2O_3, limonite, manganese, Al_2O_3, and FeS_2 (pyrite) [9].

The combination of WTRP and thermoplastic material combines the toughness of rubber with the high strength and stiffness of thermoplastics (Polypropylene, Polyvinylchloride, Polyethylene…etc.). The new composite material holds the material characteristics of the WTRP and the ease of manufacturability of the thermoplastic. The usage of large size WTRP shows better mechanical properties of the resulting composite compared to small WTRP size [10]. This may be due to the effect of thermal degradation and less crosslinks associated with the production of small sizes WTRP [11]. Also, the effect of WTRP wt.% on the mechanical properties of composites containing cement and concrete as a matrix has been studied. This shows that bending and compressive strength decreases by increasing WTRP wt.%. Also, it is observed that, the value of toughness is higher than that of matrix but remains constant at different WTRP wt. % in the composite material [12]. In other researches, it is observed that when adding marble and granite dust to polymeric matrix, the bending and compressive strength will increase. The idea of adding GM to WTRP-HDPE mixture to produce WTRP-HDPE-GM hybrid composite is very convenient due to the availability of such a waste in Egypt.

Hybrid polymeric systems consist of fillers which may take different forms such as fiber or particle. Therefore, polymeric hybrid system consists of polymeric matrix with fiber and fiber, fiber and particle or particle and particle fillers. The commercial manufacturing process for polymer composites is suitable to produce these polymeric hybrid composites. Fiber-fiber polymeric hybrid composite such as kenaf fibers and pineapple fibers with HDPE matrix used the compression moulding technique for processing [13,14]. Fiber-particle polymeric hybrid composite such as fiber glass and $CaCO_3$ particles with polypropylene used the injection moulding technique [15], while particle-particle polymeric hybrid composite such as marble slurry particles and silica particles with natural rubber matrix used the compression moulding technique [16].

The effect of fillers on the mechanical properties in different cases were studied. Tensile strength shows a decrease by the addition of GM and decrease of silica extracted from rice husk in GM-Silica particle-natural rubber hybrid composite at a selected wt.% of natural rubber of 40wt.%. This means that by increasing GM wt.%, there is a deterioration in tensile strength. GM acts as a stress concentration point in the matrix which will affect load carrying capacity of the sample [17].
Tensile strength shows a decrease by the addition of $CaCO_3$, which is a main component in GM, in glass fiber-$CaCO_3$ particle-polypropylene hybrid composite. $CaCO_3$ acts as a stress concentration point in the matrix which will affect load carrying capacity of the sample. Also, toughness decreases, and this may be attributed to the decrease in both the strength and strain up to failure [15].

In this study, GM is also used with WTRP-HDPE mixture aiming to add good mechanical properties and managing waste by useful utilization. The effect of addition of GM to WTRP-HDPE mixture on the mechanical properties of the resulting novel hybrid composite material are evaluated. The results are compared to WTRP-HDPE composite (RPC) without the addition of GM.

2. Methodology

2.1. Materials
HDPE of density 952 Kg/m^3 is supplied by SAPIC Company. Recycled tire rubber particles of size 1-3 mm are supplied by HOPPEC Company. Marble and granite dust is supplied from Misr El-Nour factory.

2.2. Preparation of materials.
HDPE, GM and WTRP are dried in oven for 24h at 100°C.

2.3. Preparation of hybrid composite
First, a specified amount of dried polymer granules was fed to the thermal mixer for about 20 min at a temperature of 180°C for achieving a plasticized phase. Then, the predetermined amount of rubber

particles was added to the HDPE in the mixer and left for about 15 min to guarantee a good homogeneity between the rubber particles and HDPE. Then GM of size less than 0.25 mm was added to the mixture by the required amount. The selected wt.% of WTRP was 40wt.% based on series of previous studies [18,19] which gives the highest impact strength of RPC. The weight portions of marble and granite dust with respect to the weight of the mixture were taken as 5%, 10%, 15% and 20%. Then, the mixture was hot pressed in a mold to get 200 mm × 200 mm WTRP-HDPE-GM hybrid composite plate. Finally, the standard test specimens were cut from the WTRP-HDPE-GM hybrid composite plate according to ASTM standards.

2.4. Mechanical testing.

In this study, the implemented mechanical tests were three-point bending, impact, compression and shore D hardness. These tests were carried out according to ASTM standards. Three point bending test was carried out according to ASTM D790, on bending test specimen on the WDW-1universal testing machine of capacity 1 ton and cross head rate of 2mm/min. Load displacement was drawn and bending strength, young's modulus and toughness were determined. Charpy impact test was done according to ASTM D6110 on impact test specimens on XJJU-5.5/50J Izod & Charpy Impact Tester. Compression test was also carried out according to ASTM D695 on compression test specimen in order to get the compressive strength at a specific strain. Compressive strength at a specific strain such as 5% is reported for materials that do not rupture like plastics [20-22]. The specimen is set on the WDW-1universal testing machine of capacity 1 ton and cross head rate of 2mm/min. Hardness test was carried out according to ASTM D 2240 on test specimens on Shore D Durometer Scale Digital Hardness Tester.

2.5. Scanning electron microscopy

Field emission scanning electron microscope QUANTA FEG 250 is used to examine the test specimens.

3. Results and discussion

3.1. Mechanical properties

3.1.1. Impact test results. The effect of GM wt.% on impact strength of WTRP-HDPE-GM hybrid composite is studied and shown in figure 1. The addition of GM up to 5wt.% shows an increase in impact strength and this may be attributed to the increase of WTRP wt.% relative to HDPE wt.% in WTRP-HDPE-GM hybrid composite than RPC, with the neglected effect of the small GM wt.% on impact strength of WTRP-HDPE-GM hybrid composite.
Further addition of GM wt.% decreases the wt.% of HDPE in WTRP-HDPE-GM hybrid Composite to the extent that increases the probability of different particle to particle contact such as GM-GM, GM-WTRP, WTRP-WTRP contact.

3.1.2. Compression test results. The effect of GM wt. % on compressive strength at 5% strain of WTRP-HDPE-GM hybrid composite is studied and shown in figure 2. The addition of GM up to 5wt.% shows an increase in compressive strength at 5% strain and this may be due to the increase in the strength of GM particles relative to the strength of WTRP and HDPE. It is thought the increase in compressive strength at 5% strain may be attributed to the behaviour of brittle GM as it forms a weak adhesion zones in which cracks can travel easily through, but under compression load, the crack changes its direction in direction of load and its growth stops as discussed by Neville J. Price [23]. Further addition of GM wt.% decreases the compressive strength due to the decrease of HDPE wt.% in WTRP-HDPE-GM hybrid composite and increases the probability of GM-GM, GM-WTRP, WTRP-WTRP contact as shown in the SEM of figures 7-9 respectively.

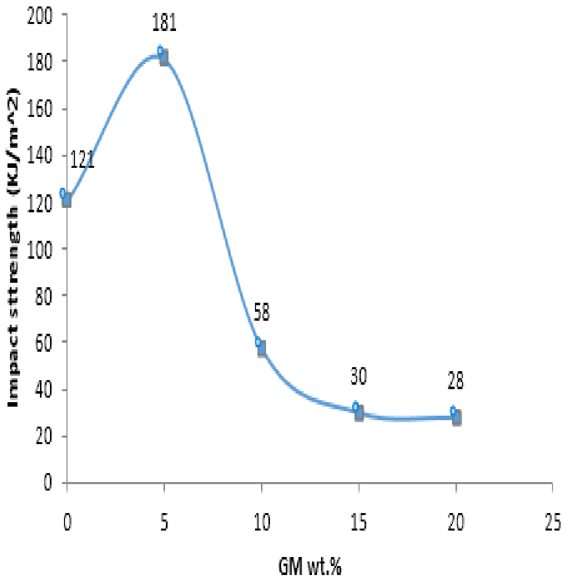

Figure 1. The effect of GM wt.% on the impact strength of WTRP-HDPE-GM hybrid composite (with max. deviation ±5%)

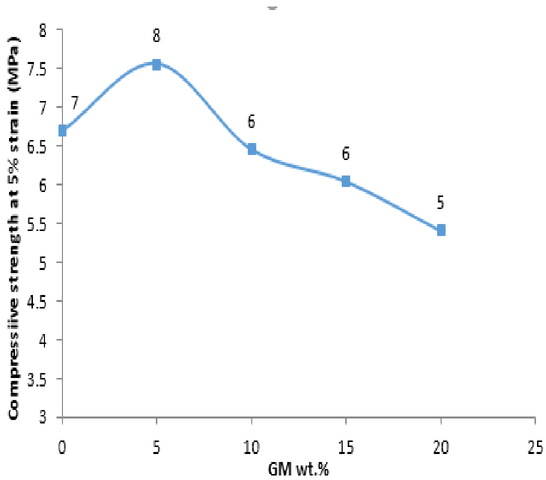

Figure 2 The effect of GM wt.% on the compressive strength at 5% strain of WTRP-HDPE-GM hybrid composite (with max. deviation ±5%)

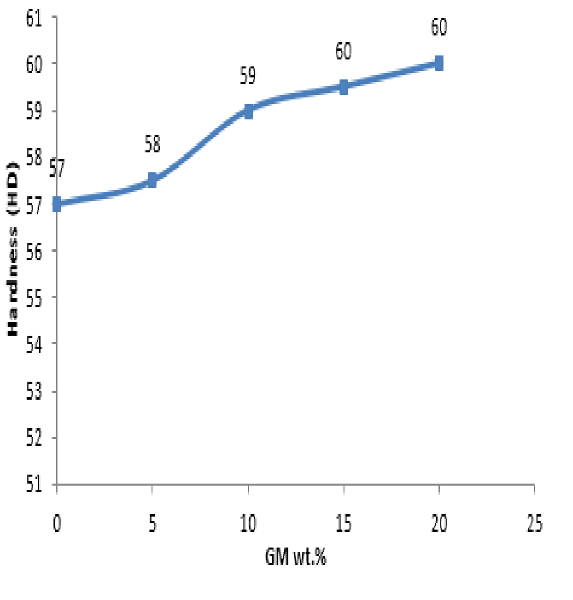

Figure 3. The effect of GM wt.% on the hardness of WTRP-HDPE-GM hybrid composite (with max. deviation ±5%)

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3.1.3. Hardness test results. The effect of GM wt.% on hardness of WTRP-HDPE-GM hybrid composite is presented in figure 3 and shows a slight improvement in hardness with increasing GM wt.%. This may be due to the decreased flexibility and plasticity of WTRP chains by the incorporation of GM in WTRP-HDPE-GM hybrid composite resulting in more rigid and harder hybrid composite material as discussed by Khalil Ahmed [24].

3.1.4. Bending test results. The effect of GM wt.% of size less than 0.25mm at 40wt.% untreated WTRP of size 1-3mm on bending strength, modulus of elasticity and toughness of WTRP-HDPE-GM hybrid composite are studied.

The values of bending strength and modulus of elasticity show a slight decrease with the increase of GM wt. %, figures 4-5. This may be due to the increase in brittleness of WTRP-HDPE-GM hybrid composite with the increase of GM wt. % and/or stress concentration at the dust particles sites [17] and/or the particle to particle contact as shown in figures 7-9.

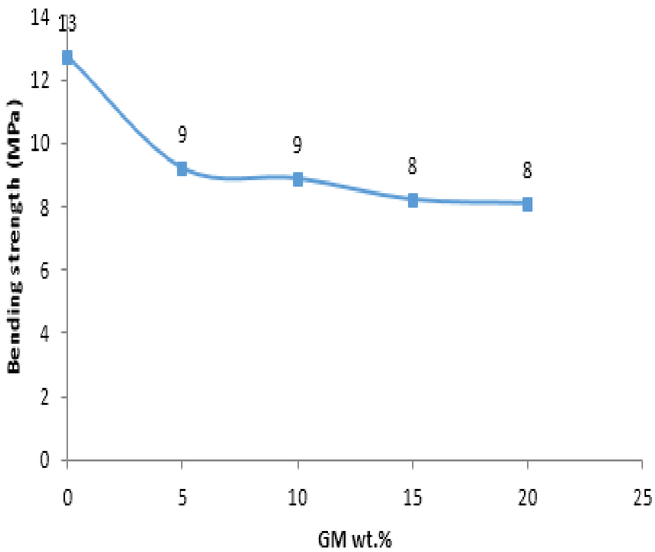

Figure 4 The effect of GM wt.% on the bending strength of WTRP-HDPE-GM hybrid composite (with max. deviation ±5%)

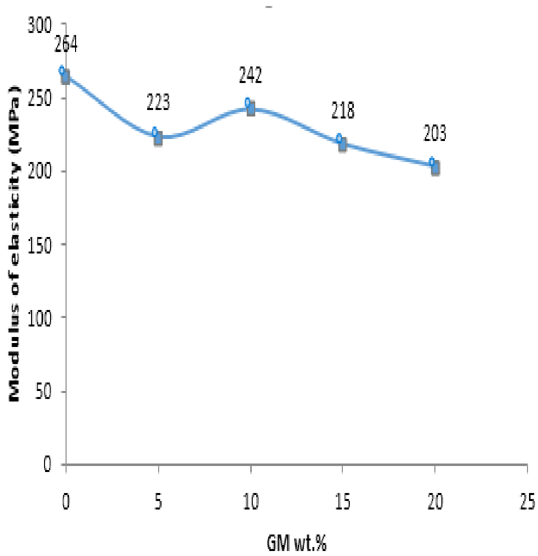

Figure 5. The effect of GM wt.% on the modulus of elasticity of WTRP-HDPE-GM hybrid composite (with max. deviation ±5%)

The decrease in toughness may be attributed to the decrease of strain up to failure associated with the addition of GM in the WTRP-HDPE-GM hybrid composite. When GM wt.% increases, weaker adhesion zones may be formed, and cracks can travel more easily through the weaker adhesion zone so the hybrid composite fractures at a lower strain in agreement with other researchers [25].

3.1.5. Scanning electron microscopy. SEM examination of the microstructure of WTRP-HDPE-GM hybrid composite supports this explanation of the above results. Figure 7 clearly shows marble and granite dust particles in contact, figure 8 shows direct contact between rubber particles (WTRP) and marble and granite dust particles and figure 9 shows rubber to rubber particle contact.

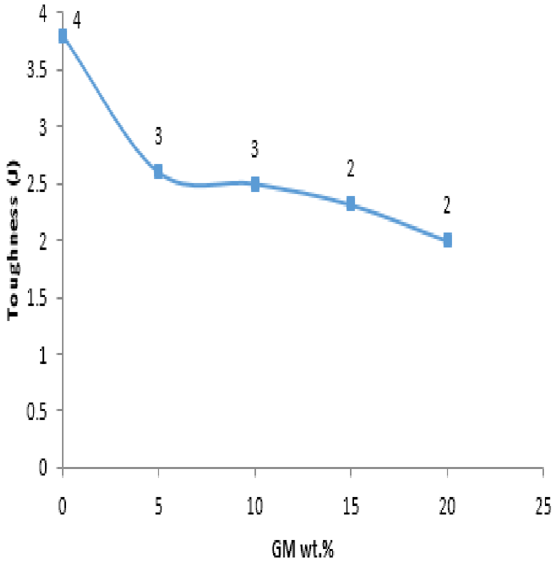

Figure 6. The effect of GM wt.% on the toughness of WTRP-HDPE-GM hybrid composite (with max. deviation ±5%)

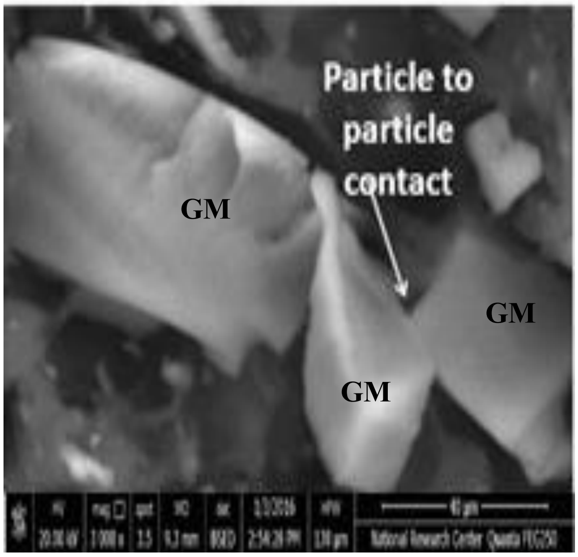

Figure 7. SEM for GM-GM contact of WTRP-HDPE-GM hybrid composite

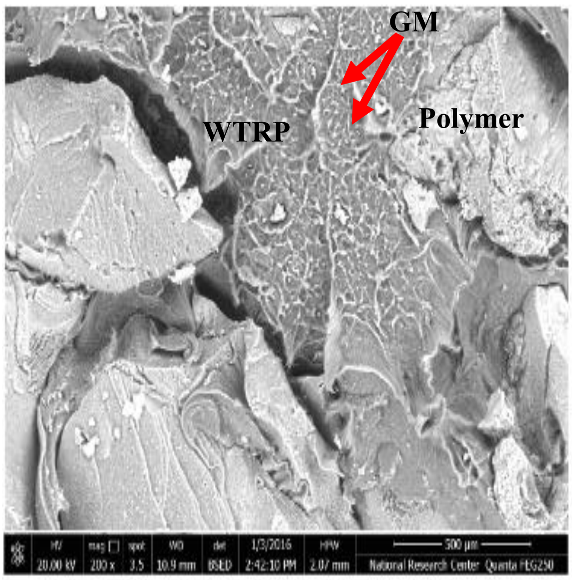

Figure 8. SEM for GM-GM contact of WTRP-HDPE-GM hybrid composite

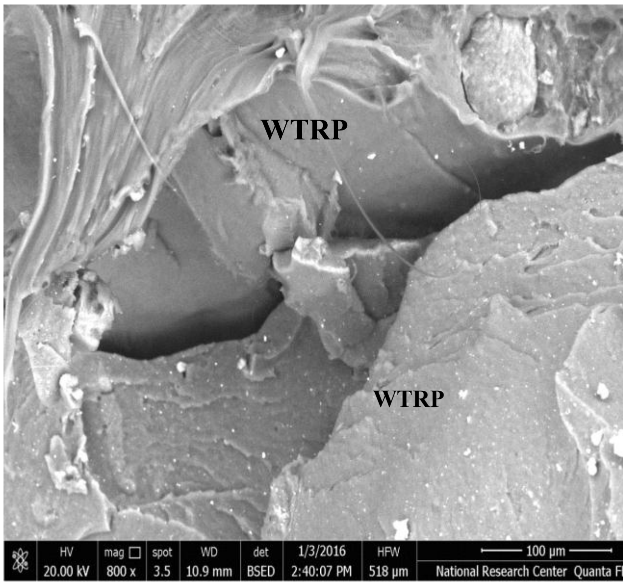

Figure 9. SEM for GM-GM contact of WTRP-HDPE-GM hybrid composite

4. Conclusions

Referring to the above study, we can draw the following conclusions:

- The addition of GM decreases the bending strength and Young's modulus of WTRP-HDPE-GM hybrid composite. This may be attributed to the effect of GM as it acts as stress concentration points in the matrix which will affect the load carrying capacity of the composite.
- The addition of GM decreases the toughness of WTRP-HDPE-GM hybrid composite. This may be attributed to the decrease of strain up to failure associated with the addition of GM in the WTRP-HDPE-GM hybrid composite.
- By adding GM up to 5wt.%, the impact strength of WTRP-HDPE-GM hybrid composite increases by 50% compared to RPC (0wt.% GM). Also, this value represents about 12 times that of HDPE. This may be attributed to the increase of WTRP wt.% relative to polymer wt.% in WTRP-HDPE-GM hybrid composite than RPC.
- By adding GM up to 5wt.%, the compressive strength at 5% strain of WTRP-HDPE-GM hybrid composite increases by 10% compared to RPC. This may be attributed to the brittle behaviour of GM.
- By adding GM more than 5wt.%, the impact strength and compressive strength at 5% strain decreases. Further addition of GM wt.% decreases the wt.% of HDPE in WTRP-HDPE-GM hybrid composite that encourage the possibility of GM- GM, GM- WTRP, WTRP-WTRP contact
- The increase in GM wt.% shows a slight increase in hardness of WTRP-HDPE-GM hybrid composite. This may be due to the decreased flexibility and plasticity of WTRP chains by the incorporation of GM in WTRP-HDPE-GM hybrid composite resulting in more rigid and harder hybrid composite.

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