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Hardness assessment of novel waste tire rubber-polypropylene composite

Khan Zahir Ahmed *, Mohammad Faizan, Farooque Azam, Abdul Faheem

Department of Mechanical Engineering, A.M.U, Aligarh, India

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ABSTRACT

As the manufacturing and use of vehicles are increasing globally, the disposal and recycling of waste tire have become a major environmental issue when they are out of service life. One of the potential recycling processes is to turn the waste tire into a useful composite material that may have domestic and industrial applications where hard materials are required. In the present study, hardness of novel Waste Tire Rubber-Polypropylene (WTR-PP) composite is evaluated using analog Rockwell hardness tester. Since WTR is a soft material and elastic in nature, the addition of WTR in composite materials affects the properties of the resulting novel WTR-PP composite including the hardness. It is observed from the test that the hardness of the WTR-PP composites decreases with the increase of WTR % due to lower hardness of WTR as compared to PP. Results reveal that upon addition of 20%, 40%, 60% and 80% WTR in the composite the hardness of composite decreased by 42.5%, 61.8%, 84.09% and 93.18% respectively.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Advancements in Materials and Manufacturing.

1. Introduction

Tire rubber is a complex blend of natural and synthetic rubbers and various other chemicals and construction materials. Tire rubber is usually a blend of styrene-butadiene rubber polymer, butadiene rubber, natural rubber, and other additives such as zinc oxide, carbon black, etc. As the tires are bulky and non-biodegradable, they consume valued space in landfills, and the increasing number of waste disposal lands creates a severe danger to human health and a high risk of fire hazards [1–3]. There are various techniques to recycle waste tire rubber. One of the methods is to create composite blends of waste tire rubber (WTR) with other waste materials like polypropylene with the help of an extruder machine.

The recycled composite and WTR market has grown significantly in recent years, thanks mainly to the automation industries contributing to more waste tires and expanding construction which has a considerable potential to recycle waste tire rubber in many applications. Polyvinyl chloride, polypropylene and (HDPE) high-density polyethylene are the three thermoplastics most frequently utilized for WTR composite [4].

WTR-PP composites are a mixture of rubber and thermoplastics. It is a high molecular weight material that surrounds rubber components forming a continuous matrix. These materials are typically low-cost common thermoplastics that can flow under various load condition to be shaped into required products. Thermoplastics can act as an effective barrier to prevent moisture from getting to the mixture since they swell and shrink but very marginally absorb moisture. Compared to other comparable materials, polymer composite often has relatively high strength and stiffness, good durability and less costly. WTR-based composites can also be an excellent alternative for low-cost thermal insulating materials. They may be utilized for various outdoor applications and are weather and water-resistant. The nature of composites is greatly influenced by their constituent element's nature and distribution [5–7].

As the waste tire rubber contains natural rubber and synthetic rubber, which makes it elastic and soft in nature but has high level of weather resistance, it can be utilised for construction material and for minimizing impact damage. Whereas polypropylene has Rockwell hardness on R scale around 110 which places the polypropylene on the high end of the softer materials measure on that scale. This means the polypropylene is semi-rigid and more likely to flex, deform and bend under the application of load [8]. Blending these two materials to create a novel composite material

* Corresponding author.
E-mail address: kzahir@myamu.ac.in (K. Zahir Ahmed).

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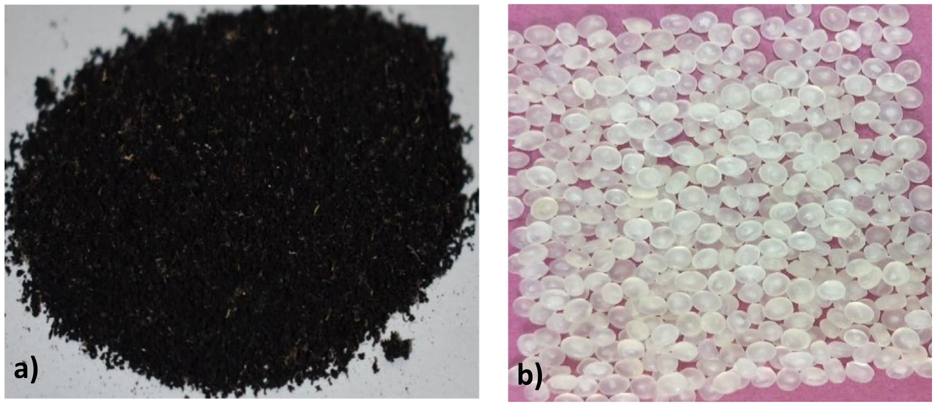


Fig. 1. A) wtr powder b) virgin polypropylene.

that can be molded into tiles/bricks and successfully used in playground surfaces, pedestrian blocks, elastic flooring, and other applications where impact loads are common.

Plesuma et al. [9] investigated a few functional properties of scrap tire-based composite material, including hardness. it was concluded that the size and composition of the rubber crumb used to create the composite material have a significant impact on the material's properties and characteristics. Ruzaidi et al. [10] studied the effect of waste tire dust of different sizes (150 μm, 300 μm, 600 μm) on the wear rate and hardness of Palm slag composite that contain polyester, alumina, and graphite as well. Results discovered that friction composite with a palm slag/waste tire dust ratio of 30/10 and the highest filler with size > 600 μm provide a reasonable hardness with an improved wear rate. Besides that, the filler's large particle size also influences the composite's hardness and wear behavior. Atakan et al. [11] studied the morphological and tensile properties of waste tire rubber–polyester composite. The result reveals that adding waste tire rubber to polyester resin decreases the tensile and yield strength. The study indicated that waste tire rubber granule/polyester composites could be used for non-structural applications. Carlos et al.[12] studied flexible tiles made of polyurethane resin and waste tire rubber; furthermore, developed tiles were successfully applied in industry. Results reveal that as polyurethane resin content drops, hardness also reduces proportionally. Hejna et al. [13] looked into the interaction between the WTR and the polymer matrix to enhance the performance of polymer-rubber composites. researchers proposed an in-situ reaction for the filler and the matrix during the formulation of construction and engineering materials. Sienkiewicz et al. [14] investigated the morphology and specific surface area of the WTR particles and the properties of the rubber-asphalt binder, illustrating that the inclusion of rubber to the asphalt binder alters the proportion of asphalt fractions and the molecular weight distribution of the rubberized asphalt binder. Li et al. [15] studied WTR thermo-mechanically devulcanized in the presence of waste engine oil, thereby enhancing the storage stability and easy processing of rubber-modified asphalt.

This research aims to determine the effect of various concentrations of WTR on the hardness of PP-based novel WTR-PP composite material. WTR-PP composite was made using a single screw extruder machine. The preparation of WTR-PP composite materials and the test performed are detailed, which include material specifications, material mixing strategy, and Rockwell hardness test. The developed composite reduces pollution created by WTR and is also a promising product for domestic and industrial applications.

2. Material and methods

2.1. Waste tire rubber and virgin polypropylene

Materials used for this study are shown in Fig. 1. Blending materials were virgin polypropylene procured from Reliance Industries Limited (RIL) and a raw waste tire rubber material procured from a local waste tire rubber supplier as shavings of used car/truck tires containing unknown composition and non-uniform grain size. WTR powder (425 μm) was prepared by mechanical shredding, and grading was determined using sieve analysis ASTM C136 for fine and coarse aggregate [16].

Moisture content and density of WTR powder (425 μm) were evaluated using the dry oven method and density bottle experiment, and the properties of PP and WTR are reported in Table 1.

2.2. Sample preparation

WTR and PP were melted blended for various WTR-PP ratios: 20/80, 40/60, 60/40, and 80/20. Melt blending was performed using an in-house fabricated single screw extruder with an L/D ratio of 12 with a 5 mm circular die to extract the extrudate. The extruder was operated at 50 rpm with a throughput rate of 2.467 kg/hr, and a temperature profile of 170 °C (metering zone) was maintained as the melting point of PP is 170 °C. A homogenous and continuous extrudate free of air bubbles was obtained. However, extrudates may have varied flow characteristics because of the various cooling rates in different areas of the extrudate due to shear heating induced by the molten material passing through a die or by the friction created by materials as they pass over one another, resulting in some regions of the extrudate to be hotter than others.

2.3. Density variation and void formation

The density of any composite is determined by the relative quantity of matrix and reinforcing components, and it is one of

Table 1
Characteristics properties of the materials.

Properties	WTR	Polypropylene
Color	Black	White
Melting point	–	170 °C
Density (gm/cm^3)	0.793	0.95
Thermal conductivity (W/mk)	0.32	0.2
Water absorption	0.95 % [17]	0.03 %
Rockwell Hardness	–	89–110

the most critical parameters influencing composite qualities. As density plays a significant role in composite materials, a water immersion test is used to determine the actual density of the developed composite. Density variation and void formation in the composite can occur for various reasons, such as mechanical air entrapment during resin flow, temperature variations during the blending in a filament screw extruder, or insufficient pressure to fill the part/gaps [18]. The deviation in the actual and theoretical density of the developed composite is very minute, and void formation is less than 4%, as shown in Fig. 2.

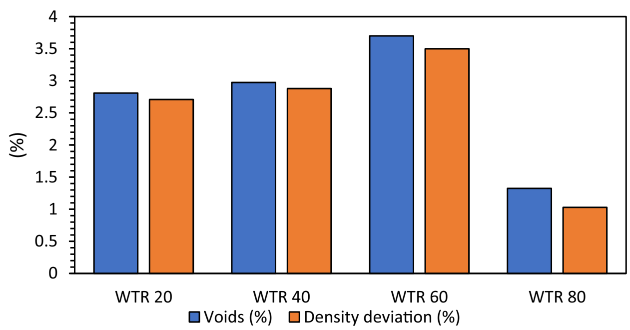


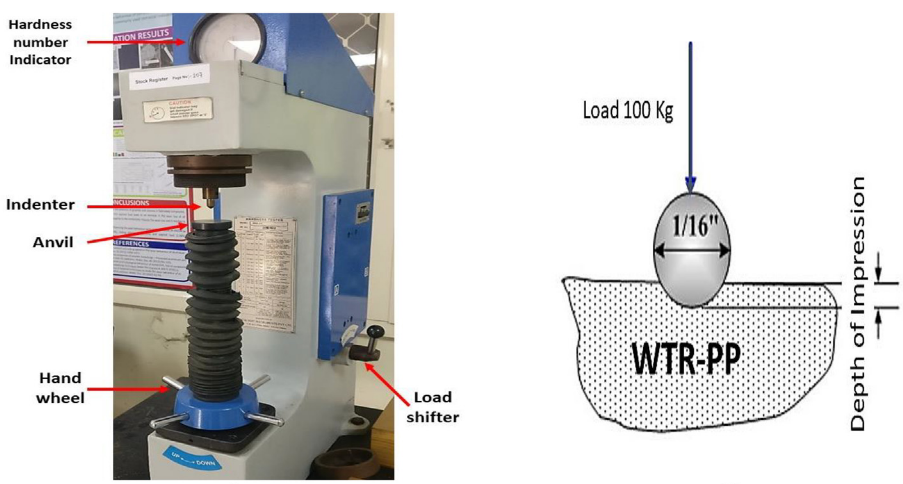
Fig. 2. Voids and Density deviation.

3. Rockwell hardness test

The Rockwell hardness scale is one of the most widely used and reliable hardness testing procedures in industry. The resistance of a material to indentation and abrasion is defined as its hardness. It is a material quality as various applications require hard materials, and the hardness of that material characterizes that property. The higher the hardness value, the harder the material and the more challenging it is to make an indentation under a specific load. Rockwell hardness method is used to measure the hardness of the sample by the depth of penetration of the indenter under a large load (major load) compared to the penetration made by a preload (minor load). The penetration depth on the specimen is inversely proportional to the hardness of the material. Scale B with load 100 kgf and 1/16'' ball indenter was used for performing tests on WTR-PP composite material. Tests were repeated for four repetitions for each composite sample.

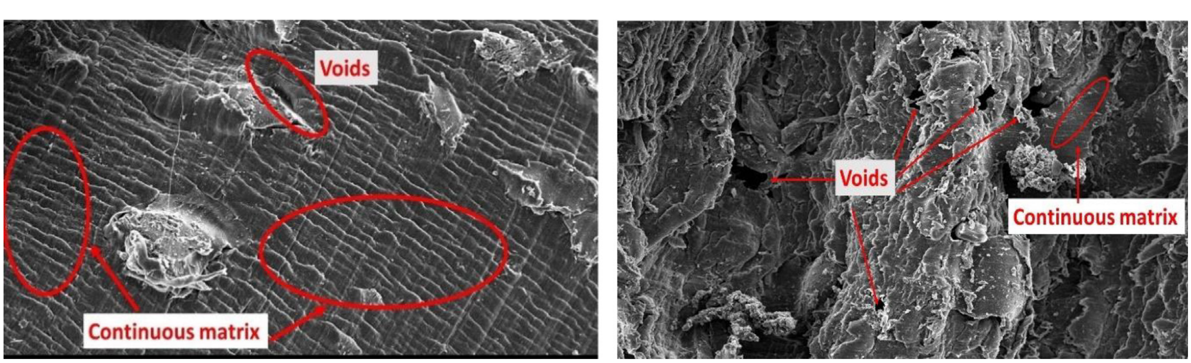
3.1. Experimental procedure

All the contacting surfaces were cleaned, and the WTR-PP specimen was kept on an anvil. 1/16'' ball indenter fixed in a jig above the anvil, and the selected load was 100 kgf. The test specimen was elevated to bring the indenter point and sample into contact, and the hand wheel was turned, forcing the WTR-PP sample against the indenter, which ensured the minor load was applied. The hard-



a) b)

Fig. 3. A) rockwell hardness setup b)1/16'' Ball indenter arrangement.



a) 20% WTR-PP b) 80% WTR-PP

Fig. 4. SEM images for WTR-PP composites at 70x magnifications.

ness indicator dial was adjusted to the proper setting, and the major load was applied gradually using a load shifter, as shown in Fig. 3 (a). Once the pointer reached rest, a major load was released, the pointer rotated, and Rockwell hardness was measured.

4. Result & discussion

4.1. Microstructure

The microstructure of the 20% WTR-PP and 80% WTR-PP composite with 70 × magnification is shown in Fig. 4. SEM graph for 20% WTR-PP composite shows tiny voids and a large continuous matrix compared to 80% WTR-PP composite resulting in good adhesion between WTR and polypropylene for 20% WTR-PP composite. Good adhesion between PP and WTR is due to the higher quantity of PP and good adhesive properties of PP.

4.2. Hardness

A novel WTR-PP composite were tested for various concentration of WTR for four repetitions, as reported in the following Table 2.

Polypropylene is a semi-rigid material with a Rockwell hardness value of around 110, whereas the WTR used as a filler is soft and elastic. The novel developed composite is expected to have a lower hardness than the pure PP, and it is quite evident from Fig. 5. that hardness of WTR-PP is inversely proportional to the WTR content. Therefore, the hardness result for WTR-PP may be correlated with WTR % as:

$y = 0.0125x^2 - 2.2562x + 108.27$.

The hardness results reported in Table 2. for novel WTR-PP composite materials are satisfactory and in accordance with the published literature. A similar trend for hardness was reported by M. Izwan et al.[19] for polypropylene-based composite. Elenin et al. [20] reported similar findings for rubber particle-based composite.

Table 2
Hardness of WTR-PP composite (4 repetitions).

Sample	1	2	3	4	Hardness Value (Avg.)
20 % WTR-PP	61	61.5	68	63	63.25
40 % WTR-PP	44	39	40	45	42
60 % WTR-PP	16	17	19	18	17.5
80 % WTR-PP	7	8	9	6	7.5

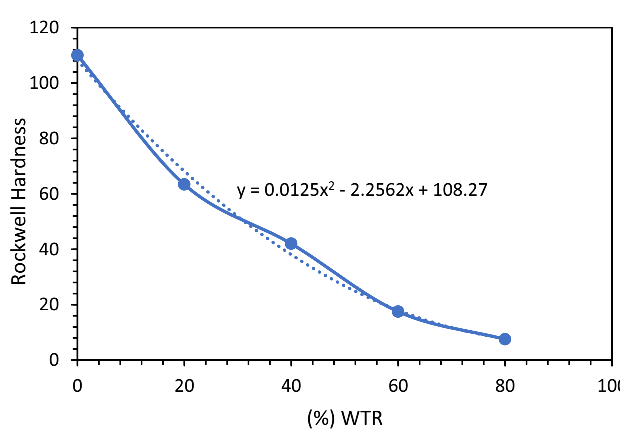


Fig. 5. Rockwell hardness for WTR-PP for various concentration.

5. Conclusion

The present study used waste tire rubber powder and pure polypropylene to obtain a novel WTR-PP composite that may have useful domestic and industrial applications, the following conclusion can be drawn.

1. Microstructure study revealed a good adhesion between WTR and PP for 20%WTR-PP composite as it has less void formation due to the good adhesive capability of PP, whereas 80%WTR-PP composite has more void formation resulting in less adhesion between WTR and PP.
2. As the PP is semi-rigid had a greater hardness value than soft and elastic WTR. The newly developed composite was expected to have a lower hardness value than pure PP, which was established by the test result as reported in Fig. 5.
3. Hardness of the composites decreases with the increase of WTR % due to the lower hardness of WTR compared to PP.
4. Upon addition of 20%, 40%, 60%, and 80% WTR in the composite, the hardness decreased by 42.5%, 61.8%, 84.09% and 93.18% respectively.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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