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Research Article

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Investigation of Polypropylene-copper Polymer-matrix Composite

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Abstract

It has been shown that polymer-matrix composites can exhibit excellent mechanical properties. This research reports the dynamic mechanical analysis, scratch, and impact test results of polypropylene-copper polymer-metal matrix composite. The copper powder and polypropylene are taken as the base material for preparing the composite material, and two types of composites are synthesized using 5% and 10% copper. With the help of a magnetic stirrer, ethanol and copper powder are mixed and processed through ultrasonic bath sonication. The twin-screw extruder process blending is carried out for copper and polypropylene. The hot air oven is used for a few hours to remove the moisture content. The result shows that 5% copper mixture composite has less deformation rate than 10% copper mixture composite. Izod and Charpy tests are also carried out to determine the polymer composite's impact strength. Finally, the scratch test using a diamond indenter is carried out to investigate the mechanical properties of the composites. The results show that the deformation rate of the sample of 5% copper is relatively less than 10% copper sample. In the case of the scratch test, when a constant load is applied to the specimen, the traction force is more significant in the 10% sample than in the 5%, but in the ramp load condition, the traction force varies for a short period.

Keywords

Polymer-metal composite, Dynamic mechanical analysis, Impact test, Scratch test

Introduction

Metal Matrix Composites (MMC) are usually reinforced with alternating weaves to improve energy and wear. When there are three or more components, it is referred to as a hybrid composite. The MMCs provide more significant benefits over general monolithic materials in terms of strength, stiffness, and lighter weight [1, 2]. Kaczmar et al. [3] identified the manufacturing techniques and structures of MMCs reinforced with dispersion debris, platelets, and non-continuous and continuous fibers. The widely used methods for manufacturing composite substances and composite elements are based on casting techniques, including the squeeze casting of porous ceramic with liquid metallic alloys and powder metallurgy methods. Dhanunjayarao et al. [4] studied graphite hybrids; the polymer composite structures were manufactured by first hybridizing alkali with jute/e-glass and were further improved over natural laminates by adding graphite to the composite. The composites have shown an impact strength of 19 J and surface hardness of 22 BHN. This paper's main objective is to fabricate polymer-metal matrix composites using an injection molding process with 5% and 10% copper in polypropylene and access the viscoelastic characteristics using the dynamic mechanical analysis (DMA) test of the prepared polymer composite along with scratch and impact strength.

Materials and Methods

The polypropylene $[CH_2CH(CH_3)]_n$ and copper powder of size 14 - 25μm as reinforcement are used to fabricate the samples. The following table 1 gives the properties of the polypropylene and copper powder. Ultrasonic bath process was used to mix ethanol and copper powder. Keep this solution for two hours to get the solution in cleanest form. With a temperature of 1500 °C materials molecules mixed properly using magnetic stirrer to get the material in powder form. Twin screw process is used for mixing or blending of copper and polypropylene materials. Hot air oven instrument is used for drying samples. Finally, samples were prepared using an injection moulding machine.

The properties of composites by mixture rule are calculated as follows:

$$\text{Density } (\rho_c) = V_{pp}\rho_{pp} + V_{cu}\rho_{cu} \quad (1)$$

$$= 0.9583 \times 0.91 + 0.0417 \times 8.96$$

$$= 1246 \text{ kg/m}^3$$

$$\text{Elastic modulus } (E_c) = V_{pp}E_{pp} + V_{cu}E_{cu} \quad (2)$$

$$= 0.9583 \times 1800 + 0.0417 \times 117000$$

$$= 6604 \text{ MPa}$$

$$\text{Poisson's ratio } (\mu_c) = V_{pp}\mu_{pp} + V_{cu}\mu_{cu} \quad (3)$$

$$= 0.9583 \times 0.43 + 0.0417 \times 0.33$$

$$= 0.43$$

Dynamic mechanical analysis test

The DMA machine consists of a furnace that covers the specimen after it is placed on the machine. Software is used to operate the machine in which different parameters, sample affirmation, initial state, and the program are specified. The parameters like testing temperature, force, and frequency are initially specified, choosing the device dry controller. After setting the parameters and starting the machine, the results are acquired from the instrumental wear graphs. Figure 1 shows the DMA test setup and the three-point bending arrangement.

Impact test

Charpy test

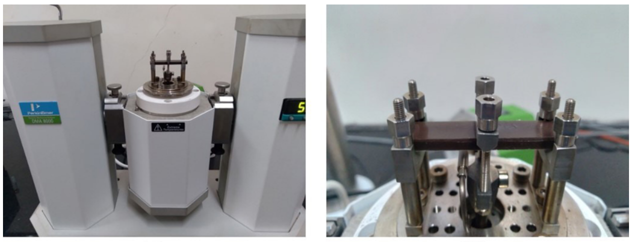
A V-notch specimen is placed across parallel jaws in the impact-testing machine, as shown in figure 2. After the specimen is placed on the impact-testing machine, the pointer is set up to its maximum value (300 J). After the pointer is set, bring the striking hammer to its topmost striking position, and lock it at that position. The hammer is released from the initial height downward towards the sample. Observations and the energy absorbed are recorded and tabulated for the specimens.

Izod test

With the striking hammer in the safe position, the specimen is held in the impact testing machine's vice so that the notch faces the hammer and is half inside and half above the top surface of the vice, as shown in figure 2c. After release, the hammer will fall due to gravity and break the specimen. The energy absorbed by the specimen in the breaking process is known as the breaking energy. The breaking energy is converted to indicate a material's impact resistance.

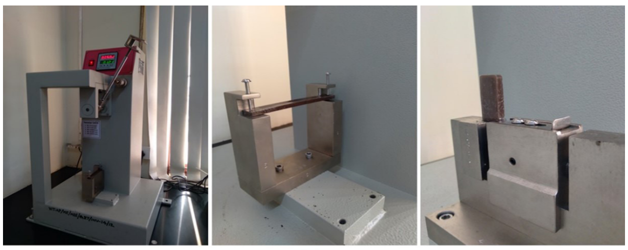
Scratch test

This test uses a diamond Rock Well C-type indenter with a nose radius of 200 microns. The test specimen is polished with a surface roughness of 0.02 to 0.05 m to facilitate measurement and observation of scratch width. In constant load conditions, the indenter is lowered to press against the specimen surface until the normal load is reached; data acquisition begins simultaneously. The specimen is then moved along the Y-axis at the constant load until the scratch distance is reached. After that, the indenter rises, returns to the starting position, and shifts along the X-axis to the pitch value. In the ramp load condition, the indenter moves along the Y-axis



(a) (b)

Figure 1: (a) DMA instrument and **(b)** three-point bending arrangement of the specimen in DMA.



(a) (b) (c)

Figure 2: (a) Impact testing machine for Charpy and Izod test, **(b)** Charpy test specimen fixture, and **(c)** Izod test specimen fixture.

Table 1: Properties of polypropylene and copper powder.

Materials	Density (g/cm³)	Poisson's ratio	Molecular weight (g/ml)	Elastic modulus (MPa)	Melting point (°C)
Polypropylene	0.91	0.43	42.08	1800	170
Copper powder	8.96	0.33	63.55	117000	1085

while the load gradually increases following the loading rate. Data acquisition comes to a halt when the indenter is lifted by 5 mm after reaching the stroke length. The scratch test specimens and machine are shown in figure 3.

Results and Discussion

Dynamic mechanical analysis results

In figure 4a, the black line represents the loss modulus, whereas the red line represents the storage modulus. The storage modulus indicates how much structure there is in a particular material. It means the energy stored in the sample's elastic structure. The material is primarily elastic if it is greater than the loss modulus and the phase shift is less than 45 degrees. The viscous portion, or the amount of energy dissipated in the sample, is represented by the loss modulus. The complex modulus is the sum of the loss and storage modulus. In each given single test, three factors are controlled: frequency of oscillation, amplitude of oscillation, and temperature. A standard test sweep keeps the first two parameters fixed while varying the third. The look at frequency is altered in a frequency sweep to determine the frequency dependency of a fabric. As much as a given applied strain, a fabric's shear moduli are unbiased of pressure amplitude. A textile described as linear viscoelastic falls into this category. Beyond that point, the cloth's form begins to break down, and the elastic modulus decreases. Figure 4b shows the relationship between the modulus and temperature of the sample with a 10% copper percentage.

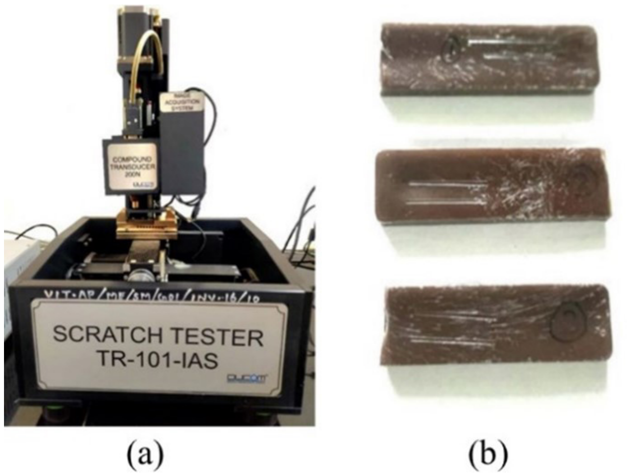


Figure 3: (a) Scratch testing machine and **(b)** Scratch test specimens.

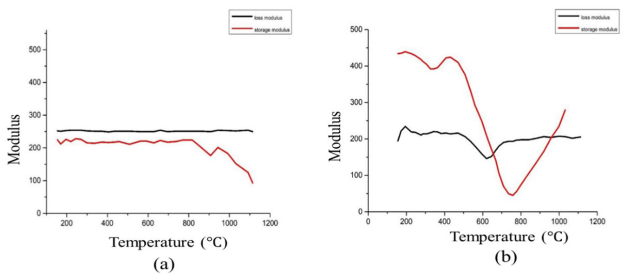


Figure 4: (a) DMA test/5% wt sample and **(b)** DMA test/10% wt sample.

Scratch test results

The scratch test graph is drawn using results from the scratch tester. The X-axis shows the stroke length, while the Y-axis shows the normal load, traction force, and coefficient of friction. The graph shows that two materials with a weight of 10% and a weight of 5% have the same friction coefficient, despite each sample having a different load. The blue line represents the normal load in the graph, the traction force by the orange line, and the coefficient of friction by the green line. The traction force represents the amount of scratching in the material. The material's surface hardness is also represented. Each test is controlled by three variables: normal load, traction force, and force coefficient. The graph depicts how the indenter scratches the material to determine the surface hardness of different materials with different compositions. As shown in figure 5 and figure 6, when a constant load is applied to the specimen, the traction force is more significant in the 10% wt sample than in the 5% wt counterpart. But in the Ramp load, the traction force varies for a short period when a different load is applied to the specimen. The traction force gradually increases as the load increases, while the coefficient of friction remains constant for both loads.

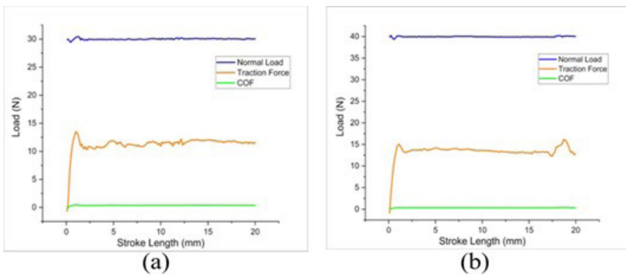


Figure 5: Scratch test results of 5% wt sample under constant load condition.

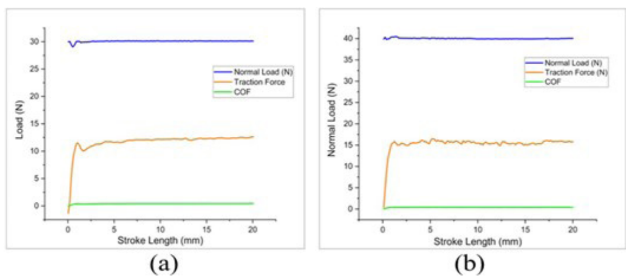


Figure 6: Scratch test results of 10% wt sample under constant load condition.

Impact test results

For the Charpy test, the impact energy applied is 1.38 J. After the test, the Charpy impact strength obtained is 92 J/m which is equivalent to 9.37 kg/cm as per the ASTM standard. Another sample of 10% copper is taken for the test. The impact energy applied is 2.12 J, and the impact strength obtained is 141 J/m, equivalent to 14.4 kg/cm as per the ASTM standard. Figure 7 represents the energy and angular displacement plot where the energy is taken in the form of Joules. In the case of the Izod test of the 5% copper sample, the angular displacement is 130°, and the impact energy and impact strength

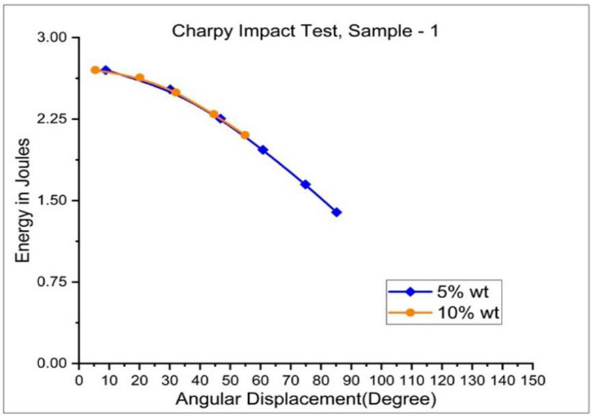


Figure 7: Charpy impact test result of 5% wt and 10% wt copper sample.

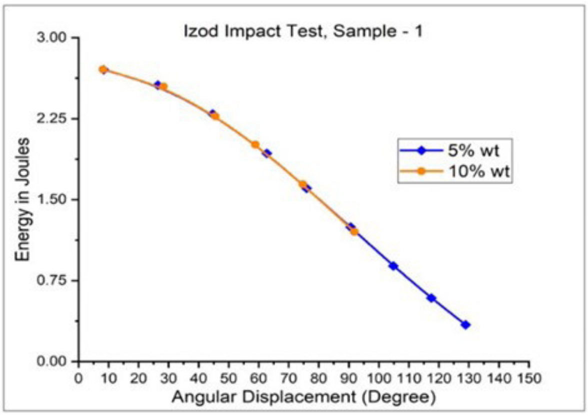


Figure 8: Izod impact test plot of 5% wt and 10% wt copper sample.

as per ASTM standard are 0.34 J and 68 J/m, respectively. For the 10% copper sample, the angular displacement is 95˚ and the impact energy and impact strength are 1.2 J and 240 J/m, respectively, as shown in figure 8.

Conclusion

This research presents the fabrication and dynamic mechanical analysis, impact, and scratch test results of two types (5% wt and 10% wt copper powder) of polypropylene-copper polymer-matrix composites. The DMA test shows that the deformation rate of the sample of 5% wt copper is relatively less and shows less viscoelastic behavior as compared to the sample of 10% wt copper. In the case of the scratch test, when a constant load is applied to the specimen, the traction force is more significant in the 10% wt sample than in the 5% wt, but in the Ramp load condition, the traction force varies for a short period. The impact tests conclude that if the copper percentage is less, the angular displacement will increase. In the case of the Izod test of the 5% copper sample, the angular displacement is 130˚, and the impact energy and impact strength as per ASTM standard are 0.34 J and 68 J/m, respectively. For the 10% copper sample, the angular displacement is 95˚ and the impact energy and impact strength are 1.2 J and 240 J/m, respectively.

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None.

Conflict of Interest

The authors have no conflicts of interest to declare.

Credit Author Statement

Sandeep Bhoi: Conceptualization, Methodology, Formal analysis, Resources, Supervision; Rakesh Ranjan Chand: Writing - original draft preparation; Boddepalli Durga Rao: Software, Writing - review and editing. All the authors read and approved the manuscript.

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