



Synthesis and Characterization of Cu - Polymer Matrix Composites

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Abstract: In this research work, a full characterization of the newly developed metal/polymer composites including thermal, mechanical, tribological and electrical properties was investigated. Mechanical properties such as tensile strength, flexural strength, impact strength, and tribological properties were carried out as per ASTM standard. Experimental results showed that the mechanical properties of composites are less in comparison to plain ABS. Wear test results showed that the height loss and coefficient of friction of composites is more in comparison to plain ABS. Thus, this study reveals that based on applications a particular type of Cu-ABS composite can be used.

Keywords: Polymer composites, Acrylonitrile Butadiene, Styrene, Tensile test, Flexural test, Impact test, ABS-Cu Composites.

I. Introduction

The polymer matrix material is also called as resin solution which is generally used on commercial level to produce composite. Depending upon the initial ingredients or raw materials there are number of different types of the polymers available in the market. With the so many variations, there are so many categories and common are polyester, vinyl ester, polyether ether ketone (PEEK), polypropylene, phenol, polyimide, polyamide, epoxy and others. The reinforcement materials are common ground minerals but can also be fibers. There are various methods mentioned below which are developed to decreased the resin content in the final output product. As a rule of thumb, hand layup gives output in a product having 60%-40% of resin-fiber, whereas vacuum infusion results in 40%-60% of resin-fiber content. And hence this ratio is the most dependent reason for the strength of product. The polymer matrix, reinforcing element and the fiber/matrix interface are the factors on which basis the response of the composite materials can be explained. To achieve most efficient mechanical properties the strong interfacial adhesion should be there. With help of chemical reaction the matrix molecules can create strong bond with fiber surface, which can show the interfacial adhesion. Through the developments in atomic force microscopy (AFM) and nano indentation devices, facilitation of the investigation of the interface can be done. The mesophase is the alternatively known for this type of interface. Particles don't ever preferred directions, but are firstly used to enhance properties or lower the isotropic material's cost. The reinforcing particles shape is not specified as it can be of any shape like platelet, cubic, spherical or regular as well as irregular structure. In all directions the approximately the proportion of Particulate reinforcements having dimensions are equal. The two subdivisions for the particles reinforced composite are dispersion strengthened and large particle and dispersion-strengthened composites. A laminar composite is composed 2D panels or sheets, which is having the same high strength direction like which one can observed in woods. The orientation with good strength direction different in each oriented layer as they are subsequently cemented and stacked together. Each and every different polymer has their own application with in different manner as well as properties. The main advantages of polymers as matrix are easy processibility, low cost, low specific gravity and good chemical resistance. On the other hand low modulus, low strength and low operating temperatures are limitation for their application. There are some types of polymers are elastomers, thermosetting polymers, thermoplastic polymers and their blends.

II. Literature Review

This section deals with review of past research carried out by researchers in this field. Zhong et al. [1] addressed critical material property issues related to the short fiber reinforced composite used in rapid prototyping and manufacturing. They concluded that by adding short glass fiber as reinforcement in ABS, improves surface rigidity, softening temperature and heat distortion temperature but surface toughness were decreases. To avoid this plasticizer was used (LLDPE at different grade i.e. 7042 and 0209) to improve ductility and flexibility and test it at different % proportion. But to avoid incompatibility at 30% of LLDPE a compatibilizer (hydrogenated

Buna -N) were added and final short fiber composite material formed to suite FDM machine. Kalita et al. [2] shared the knowledge about development and fabrication of controlled porosity polymer-ceramic composite scaffold to boost richer supply of blood, oxygen and nutrients for the growth of bones. For this they developed particulate-reinforced polymer ceramic composite polypropylene (PP) polymer and tricalcium phosphate (TABS) ceramic which improves plasticity and processibility of composite. Masood and Song [3] synthesized the new polymer material for fused deposition modelling in which they used iron/nylon mixture within which P301 nylon matrix is used with different % (by volume) of both in different iron particle sizes like 50-80µm and less than 30 µm. This enhance the strength, toughness and conductivity than existing polymer, but to due to loading of iron powder the viscosity of the mixture increase which result in buckling at entrance of liquefier and to avoid this small amount of surfactant and plasticizer were used. Pandey [4] reviewed on rapid prototyping process and the third generation model making techniques i.e. rapid prototyping in early 1980's which is layer by layer material deposition using CAD/CAM which is better than first and second generation i.e. manual model making by skilled craftsman and prototyping started in mid-1970's using 3-D curves. Jelena et al. [5] explore the use of rapid prototyping in medical application. In this CT scanner or MRI data can be used as the modelling data as it gives the 3-D image data. Using this one can proceed further for surgical planning, training, modelling in tissue engineering Bio-mechanics and approach towards critical operations and much more in medical field. Kurt et al. [6], modify the FDM 1600liquefier subsystem to accommodate the reduced column strength of the soft thermoplastic elastomers (STPE) filament stock with hardness 72 and 78 shore referred as STPE1 and STPE2. These two satisfy the melt process ability and ability to flow with only the addition of heat which is the material requirement for STPE to fabricate custom fit aircrew oxygen masks(CFAOMs) required by U.S. Air force. Nagarjan et al. [7] studied application and the steps involving rapid prototyping in detail in medical field. In this the step like data acquisition, image processing and model production are include for modelling and part production in RP. As well as the different phases in which the rapid prototyping is used like biomedical engineering for complex surgery planning and operations and design and manufacturing of biocompatible and bioactive implant as well as tissue engineering. Nikzad et al. [8] studied the two dimensional and three dimensional flow of the ABS-iron composite material in fused deposition modelling through the liquefier head which is the 90° (liquefier model used in FDM 3000) bent tube to analyse the melt flow behaviour. For this he used the ANSYS FLOTROn and CFX finite element packages with the parameters like temperature, velocity and pressure drop tested. In this composite material 10% of iron and 5% of surfactant material used and experiments are done to characterize the rheological, thermal and mechanical properties. Panda et al. [9] studied the optimization of the process parameters using bacterial foraging techniques and there effects on three responses i.e. tensile, flexural and impact strength of test specimen. In this experiments were conducted using CCD (central composite design) to build a model for each test. In this (FCCCD) face centred central composite design is used to reduce the number of level due to machine constraints as it consider zero level also apart from low level and high level. Parameters of the model over there response values validate using ANOVA. This study shows the functional relationship between process parameters and the strengths (tensile, flexural, impact) for FDM using response surface methodology. Bakar et al. [10] carried out the analysis over the performance of the fused deposition modelling parts. In this they discuss the process parameters of FDM prodigy plus in which six test model were built with the varying parameter like layer thickness, contour width, internal raster, which include the feature like slots, cube, cylinders and ring. Over this the accuracy and the roughness were analysed by using coordinate measuring machine and surface tester respectively. And through they recommend the parameters which improve the dimensional accuracy and the surface roughness of FDM part for the application of the SRM (silicon rubber modelling).Sood [11] studied over the optimization of the process parameters in FDM using (ABSA) principle component analysis. In Taguchi method (L_{27} orthogonal array) he used weighted principle component method to improve or get multi response optimization. In this tensile test, flexural test, impact test on specimen ASTM D638, ASTM D790, ASTM D256 under ABSA using (ABS) P400 as a material. To reduce complexity and uncertainty in Taguchi method MPI (multi-response performance index) used which results in optimal parameter setting for multiple responses in layer thickness, orientation, raster angle, raster width and Air gap. Agnes and Volkart [12] studied the mechanical properties of the fused deposition modelling parts manufactured by Ultem*9085. In this test were perform according to American standard ASTM D638 at an ambient temperature of 23°C and relative humidity of 50% with 5mm/min velocity under 5 KN load cell for tensile test. The specimen was built in all three directions i.e. X, Y, Z direction with raster fill and angle of 45° with thin and thick filament and test were performed. And they conclude that using negative air gap best results were achieved in all direction, thick filament having better mechanical properties in specimen built up in X and Z direction while thinner filament improve strength with specimen built up in Y-direction. Nagnath et al. [13] did the analysis of investment casting using fused deposition modelling. In this the experimentation is carried out to form mathematical model which is completely based on RSM (Response Surface Methodology) theory. The correlation between the response and the variables which is used to development of a model and analyse the temperature (T), with input parameters like volume of RP ABS part, shell thickness and set time and conclude that with the minor modification in pattern design and burn out process one can improve the efficiency, capability and quality of investment casting through

FDM technology. Thus the aim of present studied was to develop polymer metal matrix composite using injection moulding process.

III. Materials & Method

To study the effect of metal powder on mechanical properties of composite material, three different compositions of main material and the metallic powder in weight percentage were taken as shown in table I. In this the surfactant material is used to improve the covalent bonding and the flowability between the ABS and the metallic copper powder. Copper of 50 μm size was used as a reinforcement material for preparing composites. The table1 shows the composition of the composite materials.

Table I Composition of Polymer Matrix

Composition	ABS (Matrix Material)	Metallic Powder (Reinforcing Particle)	Non-inphinoethoxylate (Surfactant Material)
Composition1	100%	0%	0%
Composition2	65%	39% (Cu)	5%
Composition3	44%	50% (Cu)	6%
Composition4	23%	70% (Cu)	7%



Fig. 1 Tensile test machine

Tensile test specimens were prepared as per ASTM D638 standard; flexural test specimens were prepared as per ASTM D790 standard and impact test specimens were prepared as per ASTM D256. Tensile and flexural test was conducted on UTM of DUTECH LAB and impact test was conducted on impact testing machine of ADVANCE EQUIPMENTS having least count 0.0001. Figure 1, 2&3 shows the setup of tensile, flexural and impact test, respectively.



Fig. 2 Impact test setup



Flexural test

setup

Vertical hand operated injection moulding machine is used to fabricate test specimens. Stainless steel multiple cavities mould was used to prepare the three types of specimens to save time as well as the raw material (figure 4). Figure 5 and 6 shows the plain ABS and Cu reinforced ABS composites respectively.



Fig. 3 Injection moulding machine with Stainless steel mould



Fig. 4 Plain ABS test specimens

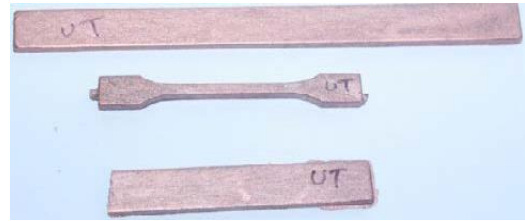


Fig. 5 Cu reinforced ABS composites test specimens

Figure 7 shows the setup of tribological properties test. Dry sliding wear characteristics of the composite and plain ABS specimens were carried out using DUCOM pin-on-disc. The dry sliding wear tests were conducted as per ASTM G99- 95 standards.

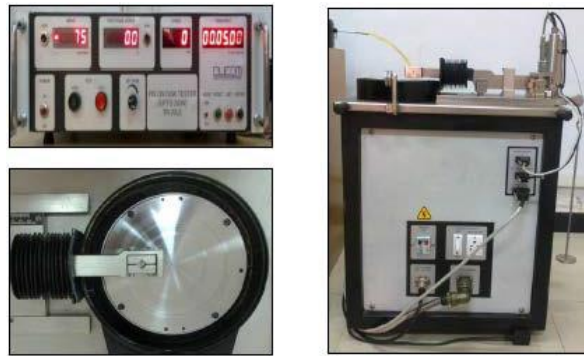


Fig. 6 Pin on disc Tribometer

IV. Results & Discussions

This section illustrates the results obtained from the mechanical tests such as tensile, flexural, & impact, tribological test and electrical resistivity test. Then this section discusses the correlation between the experimental data and theory. As in case of tensile test the load is increased until the specimen gets break. In impact test the hammer of 10 J is used to find maximum energy which can be absorb to break the specimen. And in case of flexural test (three point bending test), load is applied up to deflection of approximately 7.8 mm is observed. Figure 8 shows the tensile strength of unfilled ABS and ABS-Cu composite. It is seen from the figure that the average tensile strength of ABS-Cu composite is less than the pure ABS. With increase in copper percentage in the composite, there is a decrease in tensile strength of ABS-Cu composite. There is decrease in tensile strength of ABS-Cu composite as compared to pure ABS.

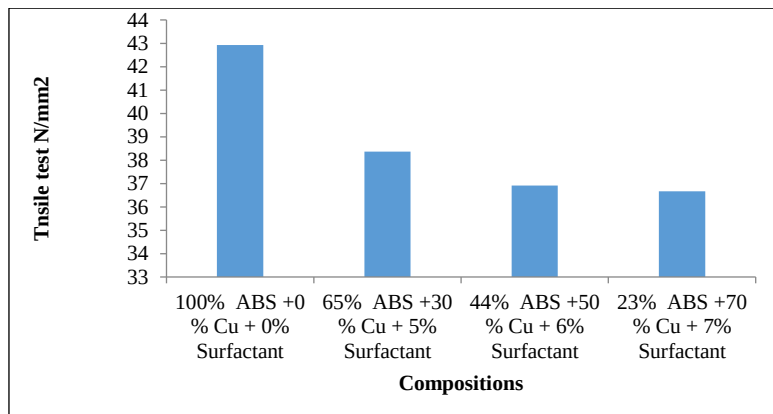


Fig. 7 Tensile strength of unfilled ABS and ABS-Cu composites

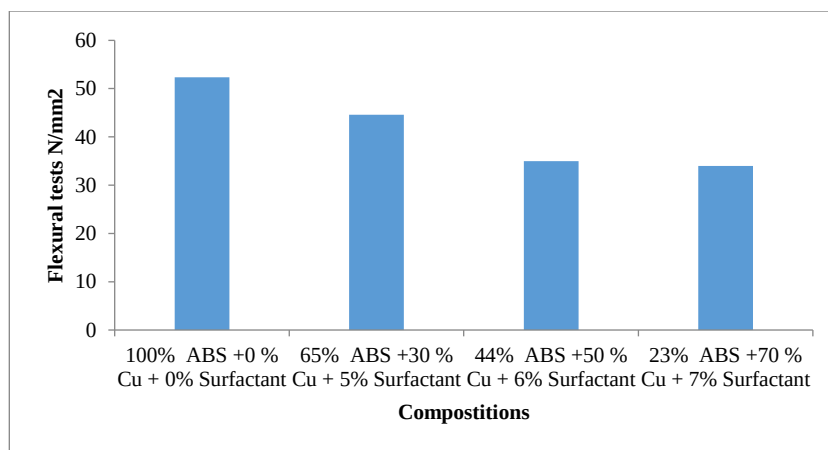


Fig. 8 Flexural strength of unfilled ABS and ABS-Cu composites

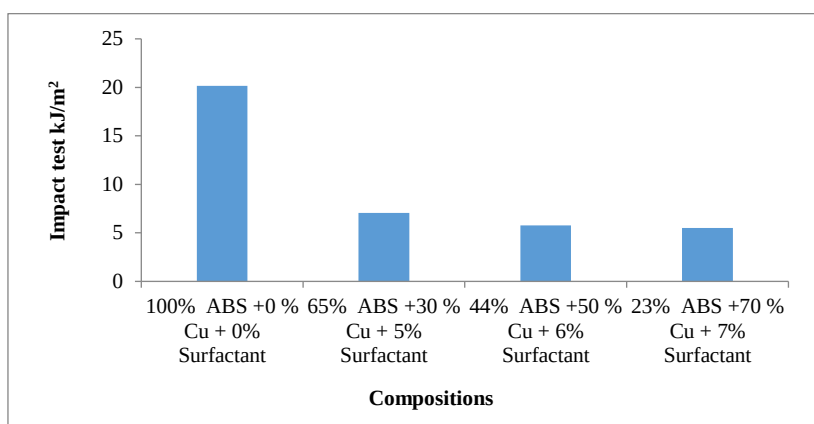


Fig. 9 Impact strength of unfilled ABS and ABS-Cu composites

Figure 9 shows the flexural strength of unfilled ABS and ABS-Cu composite. It is seen from the figure that the average flexural strength of ABS-Cu composite is less than the pure ABS. With increase in copper percentage in the composite, there is a decrease in flexural strength of ABS-Cu composite. There is decrease in flexural strength of ABS-Cu composite as compared to pure ABS. Figure 10 shows the impact strength of unfilled ABS and ABS-Cu composite. It is seen from the figure that the average impact strength of ABS-Cu composite is less than the pure ABS. With increase in copper percentage in the composite, there is a decrease in impact strength of ABS-Cu composite. There is decrease in impact strength of ABS-Cu composite as compared to pure ABS. Dry sliding test of plain ABS and Cu-ABS of was conducted on pin on disc tribometer and coefficient of friction (COF) and height loss was noted down. In this test the standard dimension pin were prepared of $\phi 8 \text{ mm} \times 32 \text{ mm}$ length of cylindrical shape. The test parameters were decided based on the literature review. Such as the normal load was set at 50 N, track diameter was set at 75 mm, sliding speed was set at 350 rpm and all the test were carried out for 5 minutes duration. Fig. 11 and 12 shows the dry sliding wear test results for plain ABS and composites. It can be seen that plain ABS has low coefficient of friction and lesser height loss value due to the fact that ABS material has self-lubricating properties. As the percentage of copper is increased in composites the height loss and COF also increases due to fact that the hardness of the composites is low than the plain ABS material.

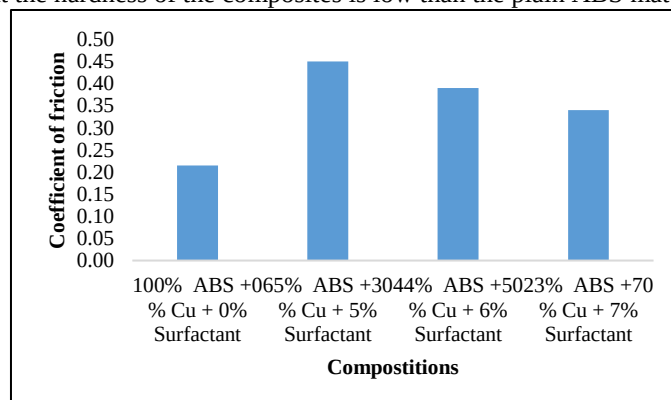


Fig. 11. Dry sliding test results of unfilled ABS and ABS-Cu composite

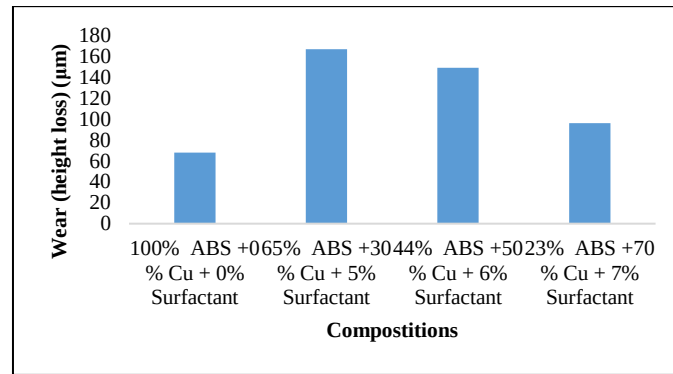


Fig. 12 Dry sliding test results of unfilled ABS and ABS-Cu composite

The electrical conductivity of the composite system was calculated from the impedance data obtained from precision impedance analyzer. Up to 15 vol. % of Cu, the conductivity was gradually increased as compared to matrix polymer but the order was the same as depicted. It shows the dielectric nature of the composite system below 15 vol. %. At 20 vol. % conductivity increased drastically and increased by 4 orders. It is obvious that the percolation phenomenon in the considered system occurred somewhere in between 15 and 20 vol. % of Cu. The percolation is strongly dependent on the aspect ratio of the filler material. The greater the aspect ratio the less will be the required volume fraction of filler for percolation. Recently, a study has achieved the percolation at only 0.04 wt% of silver nanowire with an aspect ratio of 85. It is clear from the SEM image of Cu particles that the particles are almost spherical (with aspect ratio nearly 1). The percolation threshold for the polymer matrix containing spherical conductive particles is reported to be about 16 vol. %, favoring the experimental result. However, in the present case, the presence of cuprous oxide on the Cu particle surface affects the percolation threshold. It is also reported the occurrence of percolation in low density and linear low density polyethylene-based composites filled with Cu at around 18 vol. % which fall within the range as observed in the present case. A brief summary of the percolation threshold values for the Cu-filled polymer composites reported in the literature. It is clear that the percolation is strongly dependent on the matrix, preparation method and particle size.

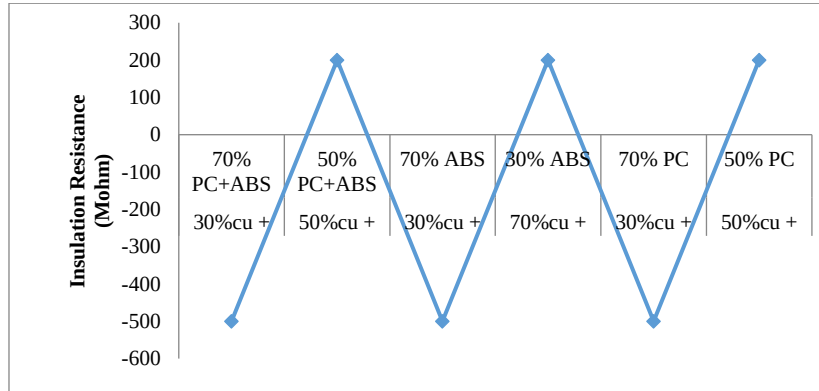


Fig. 13 Electrical Conductivity – Graph

V. Conclusions

A new polymer matrix composite material has been successfully produced by injection moulding process and tested for the mechanical properties, tribological properties, electrical conductivity and thermal expansion. Tensile, impact and flexural specimens were prepared as per the ASTM standard. The specimens made up of pure ABS shows good mechanical strengths within the test observation. With increase in copper percentage in the composite, there is a decrease in tensile, flexural and impact strength of ABS-Cu composite. There is a 52.27 % decrease in tensile strength, 33.33 % decrease in flexural strength and 60 % decrease in impact strength of ABS-Cu composite as compared to pure ABS. Unfilled ABS shows lower coefficient of friction and smaller height loss value due to the fact that ABS material has self-lubricating properties. And as the percentage of copper is increased in composites the height loss and COF also increases due to fact that the hardness of the composites is low than the plain ABS material. Plain ABS material act as an insulator whereas an Cu-ABS composite conducts electricity as increase in copper percentage in the composites decreases the electrical resistivity. This is a useful conclusion which will help in material characterization to users in selecting the best composition of the material for given requirement and create optimal process planning.

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