Investigation into the effect of Aluminium powder on Mechanical, Tribological and Electrical properties of Al-ABS composites

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Abstract: - Nowadays many advanced technological processes require materials with unusual combinations of properties that cannot be provided by the traditional polymers, ceramics, and metal alloys. Because of these the focus is shifted from the pure/traditional material to the composites/hybrid materials for manufacturing the product. In view of this objective of the present study was to investigate the effect of different composition of aluminium (Al) powder on the mechanical properties of the ABS-Al composites. Three different compositions of ABS-Al composite with different weight percentage of surfactant material were prepared using injection molding machine. Mechanical properties such as tensile strength, flexural strength, impact strength and hardness test, tribological properties and electrical resistivity test were performed on these composites as per ASTM standard. Experimental results showed that the mechanical properties of composites are less in comparison to plain ABS. Hardness of Al-ABS composites is low in comparison to plain ABS material. This is due to the fact that the aluminium is soft material and undergoes more deformation resulting in low hardness value. Wear test results showed that the height loss and coefficient of friction of composites is more in comparison to plain ABS. Electrical resistivity of composites is less than the plain ABS and the resistivity decreases as the aluminium percentage increases in the composites. This is due to the fact that ABS is a bad conductor of electricity and aluminium is good conductor of electricity. Thus, this study reveals that based on applications a particular type of Al-ABS composite can be used.

Key-Words: - Polymer composites, Acrylonitrile Butadiene Styrene, Tensile test, Flexural test, Impact test, ABS-Al Composites.

1 Introduction

Synergism of materials combinations have been the focus of attention yielding advanced composites with unique properties. Polymeric matrices are classified in two subdivisions of thermoplastic and thermosetting based on their response to the mechanical forces at elevated temperatures. Metallic fillers have been primarily used to modify and improve thermal and electrical properties as well as increasing the density, inducing magnetism, and thermal stability. Various kinds of metal material used in injection molding process. Gungor [1] studied the mechanical properties of Fe powder fillers in the HDPE polymer matrix based on vol. % (5, 10, 15 vol. %). They concluded that an additional 5 vol. % of Fe reduced the impact strength of HDPE 40% and reduced 90% of elongation respectively. When vol. % of Fe increase of 10 vol. % and 15 vol. %, the impact strength and

% elongation values decrease proportionally. For additional 5 vol. % Fe composite in HDPE, the modulus of elasticity was 31% higher than unfilled HDPE. Nikzad et al. [2] investigated the thermal and mechanical properties of new metal-particle filled acrylonitrile butadiene styrene composites for applications in fused deposition modeling rapid prototyping process. Ahn et al. [3] developed a new polymer matrix composite feedstock material by the injection moulding machine. And they studied the effect of powder loading and binder content on the mechanical properties. Hartwig et al. [4] discussed the specifications for metal injection moulding (MIM) powders and the resulting properties of the materials. Masood and Song [5] developed and discussed the thermal characterization of new metal/polymer composite material for use in fused deposition modelling (FDM) rapid prototyping process with the aim of application to direct rapid tooling. Kumar and Kruth [6] furnished succinct notes on the composites formed by rapid prototyping processes such as selective laser sintering/melting, laser engineered net shaping, laminated object manufacturing, stereolithography, fused deposition modeling, three dimensional printing and ultrasonic consolidation. Moballegh et al. [7] synthesized different feedstocks from gas atomized copper powder and a thermoplastic binder based on paraffin wax. The optimum formulation of 95 / 5 wt (copper powder / binder) was selected from rheological investigation and then the suitable feedstock was injected successfully at low pressure. Nikzad et al. [8], showed 2D and 3D numerical analysis of melt flow behaviour of representative ABS-iron composite through the 90 degree bend tube of the liquefier head of the fused deposition modelling process using ANSYS FLOTRAN and CFX finite element packages. Masood and Song [9] developed a new metal/polymer composite material for use in fused deposition modelling (FDM) process with the aim of application to direct rapid tooling. The material consists of iron particles in a nylon type matrix. The detailed formulation and characterisation of the tensile properties of the various combinations of the new composites are investigated experimentally. Saude et al. [10] studied the hardness and the flexural strength of ABS and copper-ABS. In this study they built up the different samples having the different % proportion of copper material (chemical composition of 99.9% with particle size 17μm to 130μm), ABS and surfactant material. In this composition they varied the copper from 71% to 75%, ABS 19% to 24% and surfactant material 5 to 7 %. After this the flexural and hardness test were performed on 5 samples of copper-ABS composite. The specimen used in hardness test was of duraform type D (ASTM D2240). And they concluded that PMC material gets affected with % of more copper with ABS material and gives better result in break stress with 71 % to 73% of copper in ABS. Saude et al. [11] development a new polymer matrix composite material consisting of iron powder filled in an acrylonitrile butadiene styrene and surfactant powder material. They studied the effect of powder loading and binder content on the mechanical properties of composites. Based on the experimental result it was found that, higher powder loading of iron filler affected the hardness, tensile and flexural strength of PMC material. Akinci [12] had studied the effect of basalt on physical, mechanical and morphological of the injection moulded LDPE. It was found that, the content of basalt filler affected structural integrity and mechanical properties of composites. With increasing the amount of the basalt addition to the LDPE results in a decrease in elongation at break values. Çaliskan et al. [13] investigated the effect of the basalt addition as a filler material on mechanical properties of LDPE and compared the experimental results with finite element simulation results. They concluded that computational design processes is promising one than the experimental procedures which saves and costs. Stabik et al. [14] developed polymeric gradient composites using centrifugal and gravity casting technique. Composites based on epoxy resin and filled with iron, ferrite, graphite, coal powders are fabricated. Influences of casting parameters, concentration and type of filler on composites properties were investigated. They found that higher amount of fillers increased viscosity, which did not allowed casting and preparing acceptable samples. Wear, electrical and magnetic properties are dependent on initial and final filler particles concentration. Szczepanik et al. [15] investigated the effect of graphite powder on electrical properties of polymeric composite material. They prepared composites with epoxy resin as a matrix and with respectively 3, 6, 9 and 12%vol of graphite PV60/65 as a filler using gravity casting method. Surface resistivity was taken as a measure of electrical properties. The experimental results demonstrated that addition of conductive filler (graphite) to epoxy resin caused change of surface and volume resistivity of these materials. Linear decrease of surface resistivity in depth direction of specimens was observed at addition of 3-6%vol. of graphite to epoxy resin. Higher content of filler (9-12%vol) in polymeric composite caused rapid, non-linear with layer depth, decrease of surface and volume resistivity. Aim of the present study is to investigate effect of the different composition of aluminum (Al) powder on ABS-Cu composite material on the mechanical properties of the material in conjunction with tensile strength, flexural strength and impact strength.

2 Material and Methods

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. In this the surfactant material is used to improve the covalent bonding and the flowability between the ABS and the metallic aluminium powder. Aluminium of 220 mesh size was used as a reinforcement material for preparing composites. The table1 shows the composition of the composite materials.

Table 1 Weight percentage of composite compounding

Composition	ABS (wt. %)	Al (wt. %)	Surfactant material (wt. %)
A	100	0	0
B	65	30	5
C	44	50	6
D	23	70	7

Fig. 1 a) Tensile test setup

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 VEEKAY TESTLAB and impact test was conducted on impact testing machine of ADVANCE EQUIPMENTS having least count 0.0001 J. Figure 1 a, b and c shows the setup of tensile, flexural and impact test.

Fig. 1 b) Flexural test setup

Fig. 1 c) Impact test setup

Fig. 2 Injection moulding machine with permanent die

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 2). Figure 3 and 4 shows the plain ABS and Al reinforced ABS composites respectively.

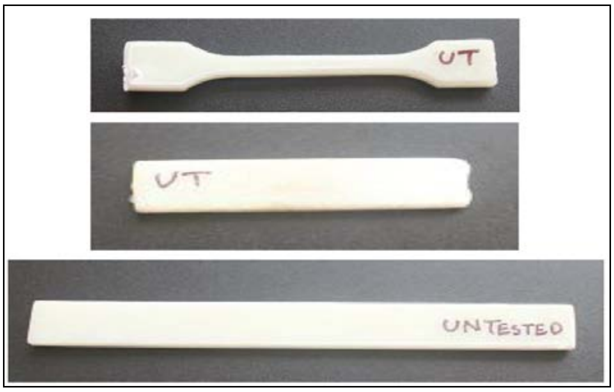

Fig. 3 Plain ABS test specimens

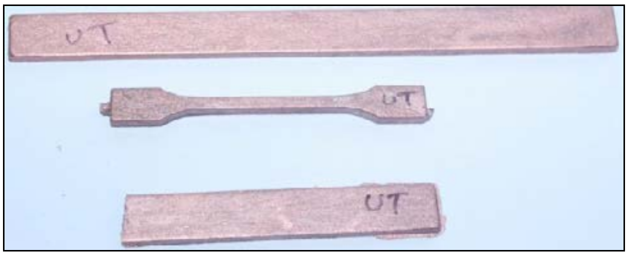

Fig. 4 Al reinforced ABS composites test specimens

Vicker's hardness test was carried out to find the hardness of the plain ABS and Al reinforced ABS. As per ASTM standard 5 kg load is applied for the PMC material and the plain ABS polymer with a dwell time of 20 sec. Vicker's hardness number is calculated by using the formula (equation 1):

$$HV = \frac{1.8544 * f}{d^2} \qquad (1)$$

Where, f = applied load, kgf,
d= average length of the impression diagonals d_1 and d_2, mm.

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 (figure 5).
Electrical resistivity test of plain ABS and composites was carried out using 6.5 digit multimeters and voltage & current measured through specimens. Digital vernier calliper with least count of 0.01mm was used for dimensional measurement.

Fig. 5 Pin on disc tribometer

3 Results and Discussions

This section illustrates the results obtained from the mechanical tests such as tensile, flexural, impact & hardness, tribological test namely coefficient of friction and electrical resistivity test. Then this section discusses the correlation between the experimental data and theory.
The tensile, impact and flexural test data for each type of composite samples are shown in table 2. 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.

Table 2 Mechanical properties of unfilled ABS and ABS-Al composite

Composition	Tensile Test	Flexural Test	Impact Test
A	43.948	75	20.92
B	27.74	62.29	13.15
C	24.25	55.43	7.102
D	13.21	33.82	4.41

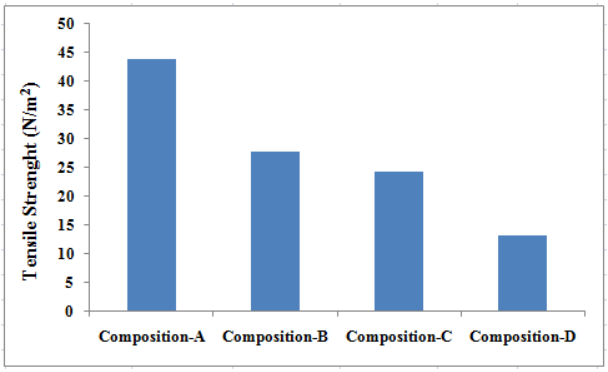

Fig. 6 Tensile strength of unfilled ABS and ABS-Al composites

Figure 6 shows the tensile strength of unfilled ABS and ABS-Al composite. It is seen from the figure that the average tensile strength of ABS-Al composite is less than the pure ABS. With increase in aluminium percentage in the composite, there is a decrease in tensile strength of ABS-Al composite. There is a 52.27 % decrease in tensile strength of ABS-Al composite as compared to pure ABS.

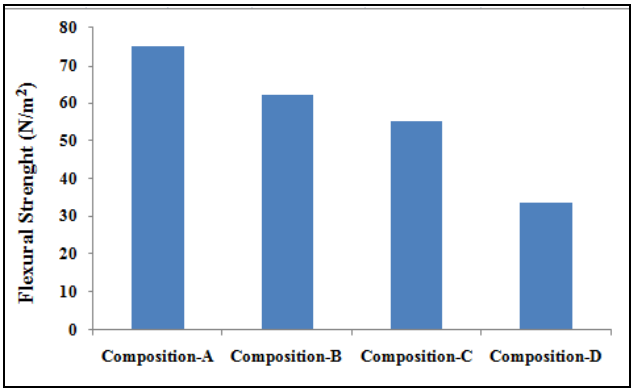

Fig. 7 Flexural strength of unfilled ABS and ABS-Al composites

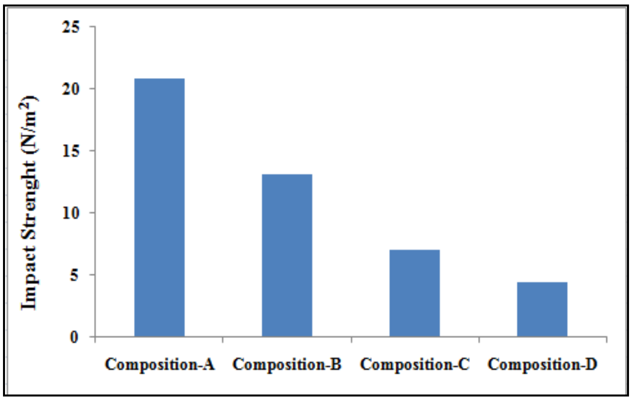

Fig. 8 Impact strength of unfilled ABS and ABS-Al composites

Figure 7 shows the flexural strength of unfilled ABS and ABS-Al composite. It is seen from the figure that the average flexural strength of ABS-Al composite is less than the pure ABS. With increase in aluminium percentage in the composite, there is a decrease in flexural strength of ABS-Al composite. There is a 33.33 % decrease in flexural strength of ABS-Al composite as compared to pure ABS.

Figure 8 shows the impact strength of unfilled ABS and ABS-Al composite. It is seen from the figure that the average impact strength of ABS-Al composite is less than the pure ABS. With increase in aluminium percentage in the composite, there is a decrease in impact strength of ABS-Al composite. There is a 60 % decrease in impact strength of ABS-Al composite as compared to pure ABS.

Table 3 show the hardness test result of unfilled ABS and ABS-Al composite. It can be seen from the results plain ABS has high hardness value in comparison to ABS-Al composites. This is due to the fact that aluminium is comparatively soft material. Another reason may be due to Al reinforcement in the composites creates a kind of atomic gap between the ABS particles and Al particles because of atomic size difference. As any load is applied on the composite material the atoms displace to the empty space thereby leading to more deformation of the composite material under the applied load. Hence the hardness of the Al-ABS is comparatively lower than plain ABS. Hardness of composites decreases as the percentage of aluminium increases in the composites. The percentage decrease in hardness of composites is not as significant because the value of average decrease in hardness of composite is less than 10 %.

Table 3 Hardness test results of unfilled ABS and ABS-Al composite

Type of material	HV1	HV2	HV3	Avg. HV	MPa
ABS (IM)	43.25	42.15	40.16	41.85	410.40
Composition B	42.24	41.53	39.74	41.17	403.80
Composition C	41.18	39.74	38.46	39.79	390.20
Composition D	36.43	30.16	38.19	34.93	342.60

Dry sliding test of plain ABS and Al-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 ϕ8 mm × 32 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 mins duration. Table 4 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 aluminium 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.

Table 4 Pin on disc results

Compositions	Height loss	C.O.F
Plain ABS	65	0.221
Composition B	89	0.313
Composition C	109	0.320
Composition D	146	0.433

In electrical resistivity test voltage difference was created and current was passed through the specimens using 6.5 digital multimeter. As the composite material is made of the ABS and aluminium with different percentage by weight the fluctuation occurs in the result within each composition. ABS is a plastic material hence it is a bad conductor of electricity due to this the electrical resistivity of plain ABS is high. Aluminium is a good conductor of electricity. Thus electrical resistivity decreases with increase in aluminium percentage in composites.

Table 5 Electrical resistivity test results

Materials	Electrical resistivity Ω/m
Plain ABS	1
Composition B	0.4721765
Composition C	0.04820085
Composition D	0.23367882

4 Conclusions

A new polymer matrix composite material has been successfully produced by injection moulding process and tested for the mechanical properties, tribological properties and electrical resistivity. 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 aluminium percentage in the composite, there is a decrease in tensile, flexural and impact strength of ABS-Al composite. There is a 52.27 % decrease in tensile strength, 33.33 % decrease in flexural strength and 60 % decrease in impact strength of ABS-Al composite as compared to pure ABS. There is a marginal change in the hardness value of developed composites. The percentage decrease in hardness of composites is not so significant because the value of average decrease in hardness of composite is less than 10 %. 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 aluminium 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 Al-ABS composite conducts electricity as increase in aluminium 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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