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RESEARCH ARTICLE

FABRICATION, MODELING AND ANALYSIS OF THE EROSIVE WEAR PROPERTIES OF MULTI-WALLED CARBON NANOTUBE REINFORCED PMMA COMPOSITE USING TAGUCHI APPROACH

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ABSTRACT

In this paper, an attempt has been made to study the erosive wear property of CNT reinforced poly methyl methacrylate (PMMA) composites. Carbon nanotubes are (CNTs) applied widely as reinforcing fillers due to their exceptional stiffness and strength, high aspect ratio. The composites have been prepared with different weight percentage of CNT like 0.1, 0.3, 0.5, 0.7 and 1%. The erosion rates of these composites have been evaluated experimentally with regard to their wear rate at three different impingement angles (30^0, 60^0, 90^0) and at three different pressures (1, 2, 3 bar). The particles used for the erosion measurements were sand particle with diameter of 400µm. From the results, it is revealed that with increase of fiber content the erosion rate of the composites decreases. The effect of impingement angle and velocity of impact has a significant effect on the erosive wear behavior of the PMMA-CNT composites. To evaluate the test data obtained, an experimental design method based on taguchi has been used.

INTRODUCTION

Now a days, a worldwide level have been distinguished meaningful changes regarding the use of composite materials in different industrial branches, from household objects to aero spatial parts of high mechanical resistance. Composites, the wonder material with light-weight, high strength-to-weight ratio and stiffness properties have come a long way in replacing the conventional materials like metals, wood etc. Continuous advancements have led to the use of composite materials in more and more diversified applications. Composite materials represent a category of engineering materials that present special scientific and technical interest. These are the first materials that have the internal structural disposal conceived by the human that confers them favorable resistance. From the discovery of carbon nanotubes in 1991, they have been focused for considerable research [1]. A number of researchers have reported the physical and mechanical properties of CNT reinforced composites [2-5]. The potential of nano composites reinforced with CNTs having excellent mechanical and thermal properties make them a suitable material for advanced applications. Future applications demand materials having extraordinary mechanical, thermal and chemical properties which must sustain the different environment conditions and in the same time available easily at reasonable prices. The carbon nano tubes (CNT) reinforced functionally graded composite materials (FGCM) is expected to be the new generation material having a wide range of unexplored potential applications in various technological areas such as aerospace, defence, energy, automobile, medicine, structural and chemical industry. They can be used as gas adsorbents, templates, actuators, catalyst supports, probes, chemical sensors, nano pipes, nano-reactors etc. Although there are many reports in the literature on the mechanical, thermal properties of the CNT composites [6-10], the tribological properties are yet to be revealed. A variety of researches on the erosive properties of synthetic fiber composites have been reported [11-15]. In this context, an attempt has been made to evaluate the erosive properties of the CNT composites to make it available for use in erosive environments.

MATERIALS AND METHODS

Raw Material

The materials used in this experimental work are Carbon nanotube (CNT) and poly methyl methacrylate (PMMA). CNT are allotropes of carbon with a cylindrical nano structure. Nano tubes have been constructed with length to diameter ratio. Carbon nano tubes are molecular scale tube of graphitic carbon with outstanding properties. They are stiffest and strongest material having strength upto 100 GPa. Nano tubes are members of fullerene structural family. Poly (methyl methacrylate) (PMMA) is a transparent thermoplastic, often

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used as a lightweight or shatter-resistant alternative to glass. It is sometimes called acrylic glass. Chemically, it is the synthetic polymer of methyl methacrylate. PMMA is an economical alternative to polycarbonate (PC) when extreme strength is not necessary.

Functionalization of CNT

Functionalization of the CNT surface can not only lead to increased dispersibility of the CNTs in various organic solvents and polymers, but also to increase the strength of the interface between the CNT and the polymer matrix. 500 mg of CNT was treated with the concentrated H_2SO_4 and HNO_3 in ratio of 3:1 by volume. Then the hydrophobic MWCNTs are taken in a beaker (borosil of 250 ml capacity) and stirred to mix on disperse of MWCNTs completely by magnetic stirring instrument of normal room temperature or temperature of the solution with a low speed stirring.

Preparation of composite material

MWCNT are functionalized to separate acid and base. After that the cryo milling of MWCNT was done to reduce the particle size. Thermoplastic polymers (PMMA) are initially pre dried at 100^0C for 2 hour in the oven to avoid absorption of moisture.

Procedure for micro-compounding

The batches of 10gm of each (0%, 0.1%, 0.3%, 0.5, 0.7 % and 1 %) sample are prepared. The barrel is heated of around 220^0C that is above the melting point temperature of the polymer. Material is poured inside the compounder slowly through which it moves towards the barrel and allowed to melt before they reach bottom of the barrel. Inside the barrel the mixing screws are rotating at a speed of (100rpm) i.e. the compounding speed. However the operation time has been kept at 10 min in which the polymer get mixed into reinforcing material at high temperatures and as result a high viscous solution is prepared. At the end of the compounding time, turn the flow director valve has been turned to out flow position (front) and the compounded material was collected from the exit port. After the material has been extruded from the compounder; the motor has been stopped and the barrel has been cleaned. DSM Micro 10cc injection moulding machine is intended for injection moulding small quantities of materials. The molten materials is forced out of micro compounder and collected inside a cylinder (nozzle). A compressed air cylinder forces the hot polymer into a heated mould; as a result test specimen is prepared.

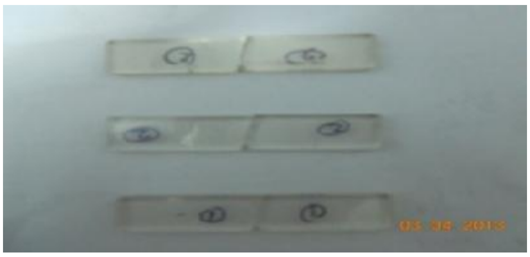

Fig.1 a Neat PMMA

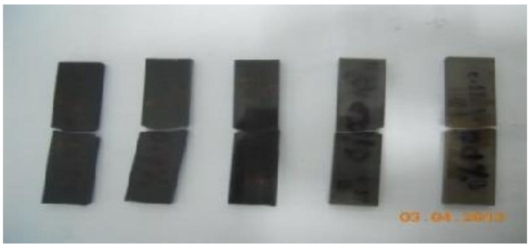

Fig.1b Different percentage of CNT and PMMA

Erosion Study

To study about material it is needed to conduct many physical, chemical, mechanical and tribological properties to suggest the material in any fields of applications. In the main part of tribology the material removal by any means called as wear. Depend up on different mean they were named in different types such as Abrasion, Adhesion, Erosion, chemical, fretting wear and corrosion. Erosive wear can be defined as the process of metal removal due to impingement of solid particles on a surface. Erosion is caused by a gas or a liquid, which may or may not carry, entrained solid particles, impinging on a surface. When the angle of impingement is small, the wear produced is closely analogous to abrasion. When the angle of impingement is normal to the surface, material is displaced by plastic flow or is dislodged by brittle failure.

Test parameters

Test parameters are the main input values to any experimental procedure. The erosion test parameters are listed below.

Table 1 Parameters for erosion test

Erodent	Silica sand
Erodent size(μm)	300μm
Impingment angle(α⁰)	30, 60, 90
Impact velocity(m/s)	48, 69, 82
Erodent feed rate(gm/min)	8
Test time(min)	2
Nozzle to sample distance(mm)	10
Nozzle diameter	8

Erosion wear test

The solid particle erosion experiments were carried out as per ASTM G76 standard on the erosion test rig. The test rig consist of an air compressor, an air drying unit, a conveyor belt type particle feeder, an particle mixing and accelerating chamber. The compressed air coming from the compressor was pressurized by the pressure transducer. The dried and compressed air is mixed with silica sand and was fed constantly by conveyor belt feeder into the mixing chamber. The pressurized sand passes through the nozzle and impinges on the sample holder. The composite of different percentage (0, 0.1, 0.3, 0.5, 0.7 and 1) is eroded at different impact angles (i.e., at 30^0, 60^0, 90^0), at different pressure (1, 2 and 3 bar) when converted to velocity (i.e., at 48, 69, 82 m/s) with the erodent Particles size of 300μm. The impact velocity of the erodent particle was determined using standard double disc method. A precision electronic balance with 0.001 mg accuracy was used for weighing. Erosion rate is calculated as the mass loss per unit erodent mass (gm/gm). The inputs for the erosion test are 3 pressures, 3 angles, 6 percentage of CNT. So the number of experiments are more. To minimize the set of experiments a standard Taguchi experimental plan with notation L18 was chosen and the details of the erosion results are listed in Table 2 .

The erosion wear rate of a material was calculated by the equation:

$Er = \Delta W/We$ …………..(1)

Where ΔW is the loss of weight of the material and We is the weight of the erodent used. ΔW is determined by weighting the sample before and after each experiment on a weighting balance having an accuracy of 0.001mg.

RESULTS AND DISCUSSION

Taguchi method is used to minimize the experimental time, cost and also optimal parametrical design for various parameters and their interactions. This experimental procedure has been successfully applied by many researchers [16-18].

Table 2 Experimental layout, erosion rate and S/N ratio of different test conditions

percentage	angle	pressure	in put	out put	wt. loss	Erosion rate	SNRA1
0	30	1	1.533	1.528	0.005	0.000294	70.6296
0	60	2	1.517	1.506	0.011	0.000647	63.7811
0	90	3	1.556	1.542	0.014	0.000824	61.6864
0.1	30	1	1.502	1.498	0.004	0.000235	72.5678
0.1	60	2	1.463	1.454	0.009	0.000529	65.5241
0.1	90	3	1.437	1.424	0.013	0.000765	62.3301
0.3	30	2	1.473	1.468	0.005	0.000294	70.6296
0.3	60	3	1.543	1.525	0.018	0.001059	59.5035
0.3	90	1	1.550	1.544	0.006	0.000353	69.046
0.5	30	3	1.517	1.505	0.012	0.000706	63.0254
0.5	60	1	1.485	1.479	0.006	0.000353	69.046
0.5	90	2	1.511	1.498	0.013	0.000765	62.3301
0.7	30	2	1.488	1.483	0.005	0.000294	70.6296
0.7	60	3	1.555	1.5409	0.0141	0.000829	61.6246
0.7	90	1	1.520	1.516	0.004	0.000235	72.5678
1	30	3	1.575	1.565	0.01	0.000588	64.609
1	60	1	1.527	1.5219	0.0051	0.0003	70.4576
1	90	2	1.500	1.488	0.012	0.000706	63.0254

The S/N ratio for CNT-PMMA composites were calculated using MINI-TAB for all the three factors given in table 2. The calculated S/N ratio for three factors on the specific wear rate in CNT-PMMA composite for each level is plotted in figure 2. From the figure it is concluded that the best optimum conditions for the specific wear resistance are (a) 0.7%, fiber percentage (b) 30^0, impingement angle (c) 1 bar, pressure. And conditions for maximum erosion are (a) 0.5%, fiber percentage (b) 90^0 impingement angle (c) 3 bar, pressure. So the material behaves as brittle material because the maximum erosion exists at 90^0. If the maximum erosion exists at 30^0 then the material behaves as ductile material.

Figure 3 shows the 3D graphs between erosion wear rate vs. impingement angle and percentage. From the figure it is clear that the erosion wear rate is less at 30 and start decreasing in the range of 30 -60 . Maximum erosion exists at 90 . In general α_{max} for ductile material remains in the range 15° – 30° and α_{min} 90° while for brittle material the behavior is opposite.

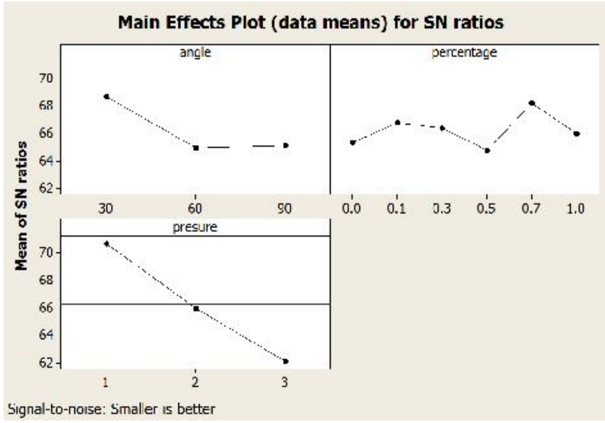

Fig.2 Main effects plot of S/N ratio for CNT-PMMA composite

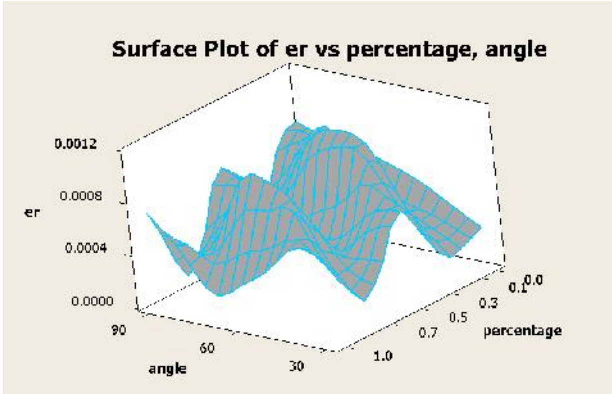

Fig.3 3D graphs of erosion wear rate vs. angle and percentage

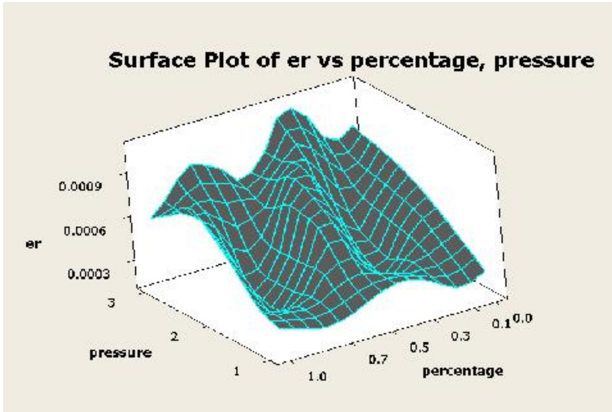

Fig.4 3D graphs of erosion wear rate vs. pressure and percentage

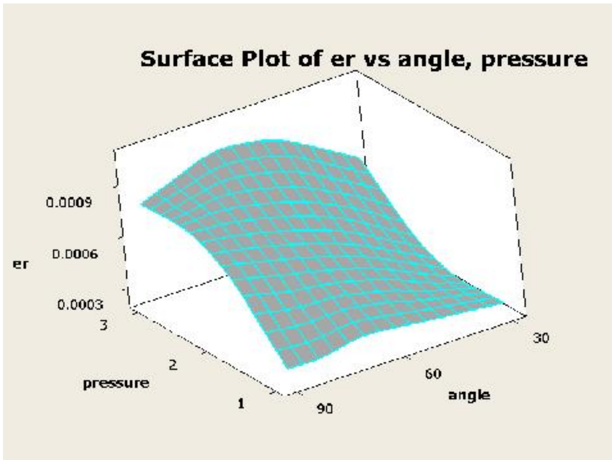

Fig.5 3D graphs of erosion wear rate vs. pressure and angle

It is available in the literature that, there are no fixed trends available which correlates ductility or brittleness of materials with α_{max} or α_{min}. It is found that some polymers erode in a ductile manner; some show evidence of both ductile and brittle characteristics [19-21]. Based on this the material prepared with the CNT-PMMA shows maximum erosion at 90 , so the material behaves as brittle material. Based on the percentage, the erosion wear rate is equal or not change in the range from 0-0.1% because the bonding between PMMA-CNT is varies. Erosion wear rate is little bit more at 0.3% but it decreases in the range of (0.5- 0.7%), then after that further increases from (0.7- 1%). Optimum conditions for best erosion wear resistance are at 0.7% and 30 . Figure 4 shows the 3D graphs drawn between erosion wear rate vs. pressure and percentage. From the figure it is clear that the best erosion wear resistance exists at 0.7% and 1 bar and maximum erosion exist at 3 bar pressure. Figure 5 shows the 3D graphs drawn between erosion wear rate vs. pressure and angle. From the figure it is clear that the erosion wear rate increases as the pressure increases.

CONCLUSION

Experiments were carried out to study the erosion behaviour of different percentage of carbon nanotube reinforced PMMA composite with sand particle as erodent. Based on the studies the following conclusions are made.

1. Different percentage of CNT-PMMA composite was successfully prepared.
2. The S/N ratios for CNT-PMMA composite were calculated using Taguchi approach for all the three factor.
3. Even if the reinforcement is in nano scale, the effect has been reflected on micro level on the erosion behavior of the composites as the load on the composites has been transferred to the nano tubes.
4. The incorporation of nano tubes increases the wear resistance of the materials.
5. From all the graph (S/N ratio and 3D graph), the erosion rate increases with increasing in pressure and maximum erosion occurs at 90^0, 0.5% and 3 bar pressure. This shows that the material behaves as a brittle in nature. Best condition for erosion wear resistance are 30^0, 0.7%, 1 bar.

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