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Erosive Behavior of Polypropylene Fiber Based Needlepunched Nonwoven Reinforced Laminated Composites

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Abstract: This study aim to investigate the needlepunched nonwoven textile material based composites. Epoxy as a bonding agent and polypropylene based needle-punched nonwoven fiber mat (PP600gsm) as a reinforced component of composites were used. The solid particle erosion and mechanical properties of needlepunched nonwoven fiber mat reinforced composites were investigated. The solid particle erosion wear behavior of needlepunched nonwoven polypropylene composites was evaluated using irregular shape silica sand particles with the size of 250, 350 and 450μm.These sand particles were accelerated along a 50mm long nozzle of 3 mm diameterat a varying impact velocity, angles of impingement and stand of distance. Taguchi analysis was carried out on the basis of Design of experiments (DoE) approach to establish the inter-dependence of operating parameters. Analysis of variance (ANOVA) and S/N (signal-to-noise) ratios have been performed on the measured data. Eroded surfaces of composite samples were examined by scanning electron microscopic (SEM) to see the effect of impact velocity and impingement angle on the surface of composites.

Keywords: Needle punched Nonwoven, Epoxy, Solid particle erosion.

I. INTRODUCTION

Nonwoven are a manufactured sheet, web or batt of directionally or randomly orientated fibers, bonded by friction, cohesion or adhesion. The most common fiber type in nonwoven fabrics for composite structural applications is E-glass fiber which is strong and inexpensive. Needlepunched fabrics are another type of nonwovens, in which arrays of barbed needles punch through the web, effecting fiber entanglements and 3D fiber orientation.

Different fibers and fiber blends can be used for needle punched fabrics, and the process is especially suitable for tough fibers such as aramids and extended chain polyethylene, polypropylene fibers [1-4]. Flexibility and the compressibility of the nonwoven fabrics make them easier to mould into different shapes. Composite laminates with needle-punched nonwoven fabric mat offer much greater resistance to delamination due to the structure of fabric, in that the fibers are intertwined in all three directions improving cohesion between the laminates.

Nonwoven fabric mat absorb resin easily because of the high void volume of the fabric and this leads to composites with uniform distribution of fibers and resin throughout, resulting in excellent mechanical properties. Needle-punched nonwoven fabric mat reinforced composites also offer good inter-laminar, shear and compressive properties [5-9].

II. EXPERIMENTAL DETAILS

A. Materials & Composite Fabrication

Polypropylene based needle-punched nonwoven fiber mat (mass per unit area: 600 g/m^2). The low temperature curing epoxy resin (LY 556), corresponding hardener (HY951) as recommended by the supplier.Composites are fabricated by hand lay-up technique using mixture of epoxy and hardener in a ratio of 10:1 as a matrix material, and a polypropylene based needle-punched nonwoven fiber mat (PP600gsm) as a reinforcement.

Three types of fiber mat percentage were used for fabrication of composites in a size of 150×150 mm^2. These samples cut into different proper sizes for solid particle erosion test and mechanical characterization.

B. Erosion wear test rig (Figure 1)

The room temperature test facility used in the present investigation. Fig.1 shows the schematic diagram of the test apparatus, which is composed of an air compressor, erodent feeder, mixing chamber, accelerating chamber, nozzle and sample holder. Dry compressed air mixed with the particles, which are fed at a constant rate from a conveyor belt type feeder in the mixing chamber and then accelerated through a tungsten carbide material nozzle of 1.5mm inner diameter and length 50mm. These accelerated particles impact the specimen, which can be held at various angles with respect to the impacting particles using an adjustable sample holder. The feed rate of the particles can be controlled by monitoring the distance between the particle feeding hopper and the belt drive carrying the particles to the mixing chamber. The impact velocities of the particles can be varied by varying the pressure of the compressed air. The velocity of the eroding particles is determined using a rotating double disc method [10-13].

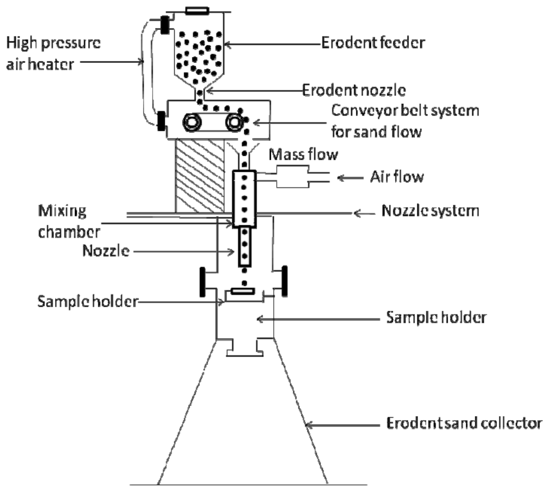

Fig. 1. A schematic diagram of air jet erosion test rig.

In the present study, dry silica sand of different particle sizes was used as an erodent and square sample of composites (size 30mm × 30mm × 3 to 5 mm) were utilized for erosion test. The samples were cleaned in acetone, dried and weighed to an accuracy of ± 0.01 mg accuracy using a precision electronic balance machine of **Denver Instruments**, **Model No. TB215D.** These samples are eroded in the erosion test rig for 15 minutes and weighed again to determine the weight loss. The erosion rate is the ratio of this weight loss to the mass of the erodent particles on impacting samples. The erosion test conditions are shown is Table 1.

TABLE I EROSION TEST CONDITIONS

Test parameters	
Erodent	Silica sand
Erodent size (μm)	250, 350, 450
Density of erodent (g/cm^3)	2.5
Impingement angle (degree)	30°, 45°, 60°,75°, 90°
Impact velocity (m/s)	45, 55, 65
Test temperature	RT
Stand of distance (mm)	65, 75, 85
discharge rate (g/min)	10

III. RESULTS AND DISCUSSION

A. Steady state erosion (Effect of Impingement Angle and Impact velocity)

The impingement angle has a great influence on the particle erosion. In order to monitoring the effect of impingement angles, experimental results are illustrated in Fig. 2. The angle of impingement is usually defined as the angle between the composite surface and the trajectory of particle immediately before impact. The most important factors influencing the erosion rate of materials are the impact angle, impact velocity, the size, shape and hardness of the eroding particles [14-17]. When the erosive particles hit the target at oblique impact angles, the impact force can be divided in two constituents: one tangential (F_t) to surface of the material and other normal (F_n). Ft controls the abrasive and F_n is responsible for the impact phenomenon. As the impact angle shifts towards to 90◦, the effects of F_t become marginal. It is obvious that, in the case of normal impact (90°), all available energy is dissipated by impact and kinetic energy loss [16]. It is generally believed that for brittle materials such as hard polymers a maximum erosion rate occurs at 90°, where as for ductile materials this occurs at oblique impact angles. For semi-ductile materials the erosion rate occurs at 45° to 60° angle of impact [16, 17].

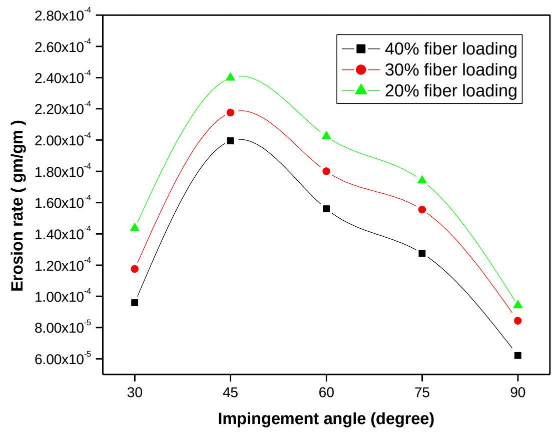

Fig. 2. Variation of erosion rate with impingement angle at constant Impact velocity 45m/s, Stand of distance 75mm and Erodent particle size 450μm.

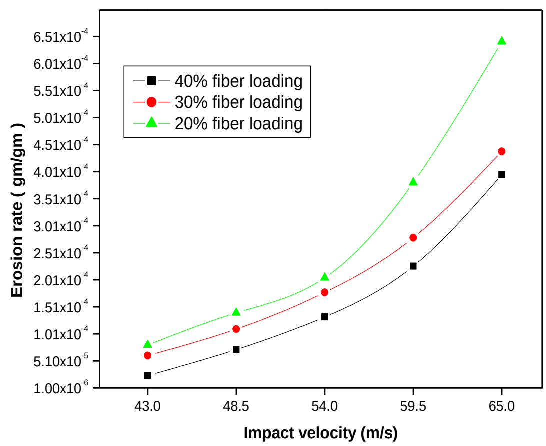

Fig. 3. Variation of erosion wear rate with impact velocity at constant Impingement angle 60°, Stand of distance 75mm and Erodent size 450μm.

Fig. 2 shows the wear rate as a function of impingement angle (α). All the three percentage of nonwoven composites shows the maximum erosion rate at α = 45°, constant impact velocity 45m/s, Stand of Distance 75mm and sand particle size 450µm. The erosion rate higher on 45° impingement angle is the evidence of the semi ductile nature of the needle punched nonwoven composites. This is due to the ductile behaviour of needle punched nonwoven fiber mat and brittle behaviour of epoxy resin. It is also shown in Fig. 2 higher fiber percentage composites shows less erosion rate compared to lower fiber percentage composites. The erosion rate of the PP600gsm composites are decreasing compared to PP400gsm and PP200gsm composites. It is seen by comparing the present research work with the last research work [17, 18] had done, that the increase in weight of polypropylene fibers per unit area (g/m^2 - gsm) the erosion rate is decreasing, it is may be due to the higher thickness of the fiber mat made of polypropylene fibers and due to the high dense structure of higher gsmfiber mat. PP600gsm and PP400gsm composites shows less erosion rate on 40wt% fiber loading composite compare to PP200gsm, in which 20wt% fiber loading shows the less erosion rate in impingement angle-steady state erosion [20,21].

To study the effect of particle velocity on erosion rate, erosion rate were performed by varying the particle velocity from 43 to 65 m/s and fiber content from 20wt% to 40wt% for constant impingement angle (60°), stand of distance (75mm) and constant erodent size (450µm). Erosion mainly dominated by fracture of fibers due to impact of solid particles with varying impact velocities.

Fig. 3 shows the typically steady state erosion rate dependence of needle punched nonwoven fabric and these composites for different impact velocities. It shown in figure that steady state erosion rate of 600gsm needle punched nonwoven composites increase with increase in impact velocity due to the increase in kinetic energy of the impacting particles; this describes the strong effect of impact velocity on erosion rate. Erosion rate is decreasing with increase in fiber percentage due to the higher volume fraction of fibers in composites. As compared to pp400gsm composites the erosion rate of all the three compositions is decreased in pp600 gsm composite. A slightly difference is seen that the pp200gsm composites shows highest erosion rate on 40wt% fiber loading, on the other hand pp400gsm compositions shows the highest erosion rate at steady state erosion on 30wt% fiber loading. But in present work pp600gsm composites show the higher erosion rate on 20wt% fiber loading [19-24]. This is a very important phenomena show in polypropylene fiber based needle-punched nonwoven composites. This shows that the increase in mass per unit area (gsm) in fiber mat, the higher erosion rate is shifted to lower percentage composites [25-30].

IV. CONCLUSIONS

Experiments were carried out to study the effect of fiber content, impact velocity and impingement angle on the erosion rate, following conclusions are drawn:

1. Experimental parameters such as sand particle size, impact velocity, impingement angle, material properties like type of fiber and fiber content, types of matrix have a strong effect on the erosion wear behaviour of composites.
2. The polypropylene based needle-punched nonwoven fiber mat reinforced polymer composites have semi ductile erosive wear behaviour during solid particle erosion; due to composites have a maximum erosion rate at 45° impingement angle. Particle speeds, and angle of impingements has a close relationship for the particle erosion rate of the material.
3. The fiber content has a strong influence on the erosion rate of needle-punched nonwoven reinforced epoxy resin composites. The erosion rate is higher in higher percentage composites on all impact velocities and impingement angles. Whereas 40% needle-punched nonwoven fiber mat reinforced composites shown better erosion resistance as compared to 20% and 30% fiber composites.

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