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Electric Insulators Performance Improvement with Cutting Force Optimization

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Abstract: The research work is carried out to improve the performance of conventional insulators made from glass fibre and ceramic because they are not durable and under high voltage they failed or flash over. To replace conventional insulators of glass fibre or ceramic with some economical material needed extra advantage in manufacturing and processing. Glass epoxy material was chosen for this purpose, The study deals not only with checking the properties of this material but from manufacturing point of view the process parameter are also analysed and then optimized for optimum performance. The insulators manufacturing involves different machining and drilling operation and cutting forces is used as critical parameter for optimum performance. Experiment work has been done to manufacture the insulator washer with glass epoxy material on standard lathe and drill machine. Hence after manufacturing of washer, test have been conducted for checking insulator electrical properties which shows that washer made of glass epoxy are not only durable but they also have better electrical properties and performed under high voltage flash over test. An integrated effort in design, composition, process, tooling, quality and manufacturing is essential to become competitive with metals.

Index Terms **- Cutting Force, Tool Dynamometer, Electric Insulators, Breakdown voltage, Composite glass epoxy material.**

I. INTRODUCTION

Use of composite materials is important in today's modern life. Fibre glass is the first modern composite material used for boat hulls, sports equipment, building panels and electric insulators etc. Composite materials are replacing normal engineering materials due to their outstanding properties such as high strength to weight ratio, high specific stiffness, improved fatigue resistance and creep resistance. A composite material is a combination of two or more chemically distinct material. The plastic matrix helps to holds the glass fibres together and also protects them from damage by sharing out the forces acting on them. Manufacturing of composite is important to obtain the desired performance. Composites can be designed to be far stronger than aluminium or steel. The composites can be engineered and designed to be strong in a specific direction also.

Composite epoxy materials (CEM) are a group of composite materials typically made from woven glass fabric surfaces and non-woven glass core combined with epoxy synthetic resin. Some advanced composites are developed by using carbon fibres instead of glass due to lighter weight and stronger than fibreglass but on expense of cost. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated applications. Composite have good fabrication characteristics and properties. They utilizes for wide variety of electrical and mechanical application such as relays, switches, bus-bars, washers, arc shields, transformers and screw terminal strips etc. as in figure-1.

FIG-1 Electrical Applications of Composite Material

Figure-1 Different electrical applications of composite materials

It is essential that there be an integrated effort is needed and even programme management for composites to become competitive with metals in different applications. The current challenge is to make them cost effective and same time to improved mechanical properties. Composites can be designed to be far stronger than aluminium or steel. Machining of a composite depends on the properties and relative content of the reinforcement and the matrix materials and on its response to the machining process. Good surface roughness and optimum cutting parameters are required to get the desired performance of insulators. Cutting force is the most sensitive indicators of machining performance and surface finish. Cutting forces can be measured by using suitable dynamometers mounted on the machine tool. Force can also be calculated from the amount of power consumption that occurs during cutting, often measured by a power monitor and provides that the mechanical efficiency of the machine tool can be determined.

Accuracy performance and efficiency of composite depend on optimum cutting parameters. Cutting parameters like feed, speed and depth of cut are varies and set to obtain optimum output. The output performance is checked by breakdown high voltage. Full factorial experiment was performed to determine optimum parameters. The washer made from epoxy material have shown superior electrical properties over the conventional washer made from fiber glass like high resistance and better life when tested with A.C breakdown test set of 100 Kv.

Composites are mixture of materials such as metal and alloys and ceramics, metals and consist of more than one kind of material [15]. Composites are used as multifunctional materials having unprecedented mechanical and physical properties which can be improved to meet the requirements of a particular application [10]. Different composites also exhibit great resistance to wear, corrosion, and high-temperature working [12]. Machining glass epoxy material is challenging task for good electrical properties for the manufactures. Different researcher suggested using Composite to reduce their Weight [2, 7, and 9]. The influence of drilling parameters on thrust, force and torque of silica (SiO_2) and Alumina (Al_2O_3) filled into glass fabric reinforced epoxy (G-E) composites are analyzed for good insulator properties [1, 3, 4].

To study the effects of different cutting parameters like increasing cutting speed on different composite materials required planned experiments [18]. Many works have been done on optimizing the machining parameter such as work on the complex tool geometry and cutting conditions of metal cutting and some unknown factors and stresses [5, 6, and 8]. The analytical cutting force calculations may not give the accurate results and hence the experimental measurement of cutting forces is essential [14 and 16].

From the literature, it can be concluded that researchers are mainly focusing on optimization of machining parameters, based on different criteria such as insulating properties, surface roughness, production and final cost, tool wear, working life etc. [11, 13]. No work is found to replace glass fiber composite by glass epoxy composite in different industrial applications [17, 19].

II. PROBLEM DEFINITION:

In this research work machining of composite insulating material e.g. glass epoxy is performed to optimize the cutting process. Almost 90% of the engineering components are subjected to some kind of machining during manufacture. It is very important to design those parts in such a way that would lead to the increase in efficiency of the machining process, enhancement of the tool life and reduction of the overall cost of machining. The effect of machining parameters can be determined by measuring final out put or performance. The insulating composite material are used in different applications like, washers, printed circuit boards, screws, bolts, nuts, switches, threaded rod and transformers etc. For the insulator the high voltage resistance and working is very important for expected safe life.

Figure-2 Different electrical insulators parts of composite materials for experiments

The different experiments are performed on lathe and drill machine. Figure-2 indicates different electrical insulators parts of composite materials for insulator manufacturing and experiments. The development of composite materials and the related design and manufacturing technologies is one of the most important works in the history of materials [20]. Machining of composite materials is difficult to carry out due to the anisotropic and non-homogeneous structure and high abrasiveness of their reinforcing constituents. Resulted in damage being introduced into the work-piece and very rapid wear development in the cutting tool. Conventional machining processes such as turning, drilling or milling can be applied to composite materials, provided proper tool design and operating conditions. Machining of composite has influence on final performance and life of part, economy of machining, life of cutting tools and damage to work material. The objective is to improve the surface finish and accuracy of machining process on glass epoxy material and to minimize the cutting force for optimum performance.

III. EXPERIMENTATION:

The main cutting or machine parameters are cutting speed, depth of cut and feed. The tool dynamometer is used for cutting force measurement in all direction. The material selected for insulating cup washer and experiment is cut from glass epoxy sheet of 5mm and 10mm. To obtain cup washer the epoxy sheet is cut in different pieces. A mandrel is also developed for ease of job mounting for the bore development for outer machining.

Figure-3 A.C breakdown voltage test set **Figure-4 Before flash-over** **Figure-5 After flash-over**

The developed insulators are than tested at high voltage in college laboratory for insulating properties. For this a special washer is required for uniform current applications in the set up. The experimental set-up for the insulating properties testing is available at the high voltage lab at Electrical department of SGSITS. The Figure-3 shows a general set-up of A.C breakdown test set, Figure-4 and 5 shows setup before and flash-over test set respectively.

The raw material selection for insulator different parts are developed from epoxy sheets around 5mm. thick. Selection of tool depends upon machining process and final selection of cutting parameters is on process optimization. At first work-piece machining done on lathe and for cutting force measurement tool dynameters are used. Pillar type drilling machine used for work-piece drilling. Cutting force measurement on drill is also done by drill dynamometer. Optimum cutting parameter selection depends on work-piece finish. High voltage and flash testing of work-piece will determine the optimum performance at actual working conditions. Based on test results optimum work-piece material selection is done.

IV. DATA COLLECTION AND ANALYSIS:

The various data of experiments on lathe machine and drill machine and high voltage performance test at different voltage are collected in different tables below. The various cutting parameters on different machine are set before the measurement. Cutting speed depth of cut and feed rate are the input variables. Vertical force, feed force and radial force are the response variables. The data is collected from the Drilling machine and centre lathe machine of the Central Workshop of SGSITS Indore. Table-1 indicates comparison between glass epoxy and fibre material.

Table-1 Comparative analysis of glass epoxy material and glass fiber material

S. N.	PROPERTIES	GLASS EPOXY	GLASS FIBER
1.	Density (g/cm^3)	1.850	2.58
2.	Tensile strength (MPa)	430	1950
3.	Compressive strength (MPa)	410	1080
4.	Thermal conductivity W/(m.K)	0.29	0.05
5.	Young's modulus (GPa)	21	81
6.	Price (Rs./kg)	210	160
7.	Applications and uses	Relays, switches, standoff, bus bars, washers, arc shields, transformers and screw terminal strips.	boats, automobiles, bath tubs and enclosures, swimming pools, hot tube, septic tanks, water tanks, roofing, pipes, cladding, casts, surfboards, and external door skins.

The data is collected from the centre lathe machine are in Table-2.

Table-2 Experimental data collecting table for Centre lathe Machine

S. N	Parameters	1	2	3	4
1	Cutting speed (m/min) RPM	315	315	500	500
2	Feed (mm/rev)	0.048	0.102	0.102	0.048
3	Depth of cut (mm)	1	1	1	1
4	CH1 (Vertical Force)	008	013	013	012
5	CH2 (Feed Force)	009	013	013	012
6	CH3 (Radial Force)	009	012	011	012

The data of cutting forces different component (vertical and horizontal) are measured by help of tool dynamometer. The experimental set-up is same for different cutting parameters like feed, depth of cut and speed. The tool dynamometers used on drill and lathe machine are different. And hence these dynamometers measured different forces. Lathe machine dynamometer measure Feed force, radial force and vertical force whereas drilling dynamometer measured radial force and thrust force only. The

cutting experiments are performed on insulator to get optimum cutting parameters. The data collected from the drilling machine are in Table-3.

Table-3 Experimental data collecting table for pillar type Drilling Machine

S.N	Parameters	1	2	3	4	5	6	7	8
1	Cutting speed (m/min)	600	600	600	852	852	852	1260	1260
2	Feed Rate (mm/rev)	0.0083	0.0041	0.0124	0.104	0.211	0.315	0.0124	0.0124
3	Depth of cut (mm)	10	10	10	10	10	10	10	10
4	Dia. of Drill bit (mm)	5	5	10	10	5	10	5	10
5	CH1 (Thrust Force)	550	322	594	565	698	1026	768	1016
6	CH2 (Radial Force)	11.5	11.2	39.9	09.2	17.3	38.8	22.6	50.4

V. BREAKDOWN VOLTAGE STRENGTH TEST (BREAKDOWN VOLTAGE TEST)

Single phase A.C control penal supply voltage (maximum-220 kv) is supplied to autotransformer where we can vary the voltage according to the requirement and send voltage supply to the primary side of the high voltage transformer convert this small voltage into the very high voltage up to (100 kv) at the secondary side of the transformer. Now this high voltage supply can be further use to check to breakdown voltage strength test of the different insulator material as in Table-4.

Table-4 Insulator Performance of optimum condition and normal condition

Sr. No.	Material	Flash over in normal condition	Flash over in optimum condition
1.	Glass fiber	5 Kv	6-7 Kv
2.	Glass epoxy	11 Kv	13-14 Kv

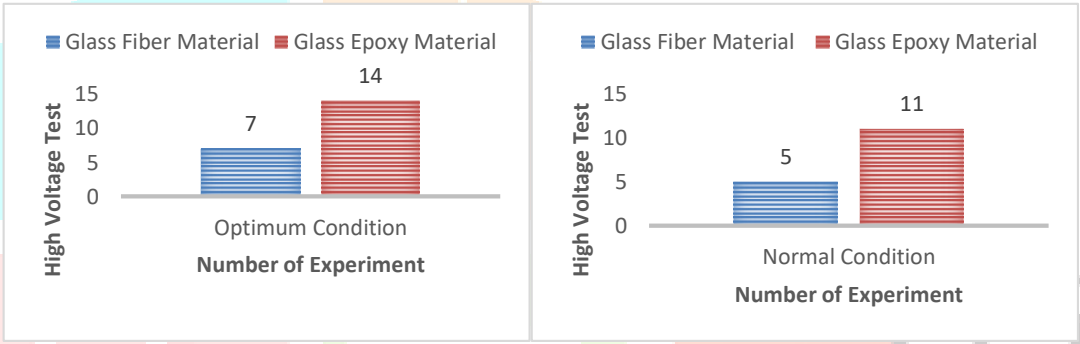

Figure-6 Graph Insulator Performance of optimum condition v/s normal

VI. COST COMPRESSION OF GLASS FIBER AND GLASS EPOXY MATERIAL

Economical cost between glass epoxy and glass fiber material
Glass epoxy material price (Rs. /kg) = 210
Glass fiber material price (Rs. /kg) = 160

$$\text{Cost analysis} = \frac{210 - 160}{210} = \frac{50}{210} \times 100$$

$$= 23.80\ \%$$

VII. RESULTS AND DISCUSSION:

From the above experiment it can be stated that it is convenient to replace the glass fiber with glass epoxy but the cost of glass epoxy is about 20-25 % higher than glass fiber. The 12-14 Kv resistance of glass epoxy is about double than glass fiber which favours the use of glass EPOXY and glass epoxy also has better durability. Effect of machining on delamination, fiber pull out and surface finish of composite was also determined and optimized.

VIII. CONCLUSIONS AND FUTURE SCOPE OF WORK:

It may be concluded that machining properties of glass epoxy composite material are far better than that of glass fiber. Washers made out of glass epoxy have better electrical resistance when compared to glass fiber. Hence it may be concluded that glass epoxy material can be used to make electrical insulator. Further it may be concluded that washer made out of glass epoxy have more durability. We can further extent this optimization study with other important factor like lubrication, change in drill bit, design etc. This study further may use to develop more economical and physical process parameter.

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