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# Novel Method of Cutting Glass Epoxy Laminated Composites by using Lathe Fixture and Comparative Study of Mechanical Properties

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## Abstract

*Experimental studies were carried out on the effect of cutting methods on mechanical properties of E- glass-epoxy laminated composites. Laminates with three fibre weight fractions, namely 0.30, 0.50, and 0.70 were prepared by vacuum bag method. Five cutting methods namely, Diamond cutter, Band saw 14TPI, Band saw 24TPI, Hack saw14TPI and Hack saw32TPI were selected to cut the laminates. Lathe fixture is fabricated and used in the cutting operation along with Diamond cutter. The above-mentioned cutting methods were used to cut Tensile, Compression and Interlaminar Shear strength test specimens as per ASTM standard. To nullify the effect of size variation of the specimen on the strength of the composites, an Accuracy Rating method is introduced and applied in the calculation of Real strength of the specimens. Tests were conducted using UTM and the results were used as base of index to assign grade points to these cutting methods. The mechanical results have been substantiated by the SEM-studies. The results show that, Diamond cutter method is better and hence can be used to cut the glass-epoxy laminated composites.*

**Keywords:** *Composites, Cutting Methods, Glass Fibre Reinforced Plastics, Lathe Fixture, Mechanical Properties, Microscopic Study.*

## 1.0 Introduction

Excellent mechanical properties combined with their low weight; Glass Fibre Reinforced Plastics (GFRP) have successfully substituted the metals in several applications. So far, the main emphasis of the research has been the development of GFRP. But in recent years more attention is drawn to the industrial production of GFRP parts, typically achieved with conventional machining technologies. The conventional method is chosen to reduce the cost of cutting of the laminates. As a consequence, an increase in secondary machining of GFRP's has been observed. However, finishing cutting or secondary machining is often necessary, because of the requirement of high dimensional accuracy of finished parts and securing flexibility during production of small piece numbers.

Thus, an understanding of the effect of different cutting methods on the mechanical properties of composites helps practising engineers in selection of cutting tools and machine tools for efficient manufacturing. Several authors are involved in the investigative work on mechanical

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properties, highlighting the importance of a theory behind the machining of plastics[1]. Two cutting methods, mainly abrasive wheels and circular saw methods were used to cut slabs of polyester and epoxy resins. The cut surfaces produced by these two methods were compared with the help of microscopic images. The results show that, abrasive wheels method is faster and produce good quality surface than circular saw method. Experimental work has been carried out on the effect of cutting speed and width of cut on the machining characteristics of graphite-epoxy composite materials[2]. The Interlaminar Tensile Strength (ILTS) of the machined specimens were measured. Damage in the form of cracks, delamination and fibre–orientation was detected in the machined region. The test results interpret that the depth of affected zone and severity of the damage decreases with an increase in cutting speed. The ILTS of the machined specimen increases with an increase in cutting speed. High Speed Steel tools usually achieve insufficient tool-life for cutting Aramid composites. Aramid fibres require very keen cutting edges and tool geometry. In this direction, the author[3] discussed the good cutting methods for cutting Aramid, Carbon and GFRP materials. Tool-geometry and favourable cutting conditions for Waterjet cutting, Laser cutting and Routing were discussed. Results show that extra fine grain size of Boron or carbide can be used as cutting materials for cutting glass and carbon fibres. Also work shows, the established relationship between cutting process, chips and cutting forces while machining Carbon Fibre Reinforced Plastics (CFRP) through the experiment[4]. Shaping experiments, 'quick stop' experiments and a new chip preparation technique is elaborated. The results show that, machine of unidirectional CFRP perpendicular to the fibres damages the surface edges and cracks measuring approximately 0.3 mm are formed. Machining parallel to the fibres leaves cracks at the front of the tooltip and runs further. The size of the cracks was found to be equal to one or two fibre diameters.

Author explains the effect of cutting operation on the flexural properties of graphite/epoxy laminated composites[5]. Three cutting methods, namely, Abrasive water jet, Circular diamond saw, and shaped planer mounted with polycrystalline diamond tool insert were used. The author reveals that polycrystalline methods produce more microcracks releasing from -$45^0$ ply damage. A contrast result was observed for the other two methods, as very few microcracks were released from the same ply. The author confirmed that there will be no relation between machined surface texture and bending strength of the material selected. There are a good number of works that have been carried out in the field of Ceramic Matrix Composites. One such work involves the study of the effects of yttrium on the mechanical property and the cutting performance of $Al_2O_3$/Ti (C, N) composite ceramic tool material[6]. The author concluded with the statement that there is an improvement in the flexural and fracture resistance of $Al_2O_3$/Ti (C, N) composite, by the addition of yttrium. Also, investigative work has been reported on machining parameters and delamination damage caused by the drilling process on ramie woven reinforced composite material with an unsaturated polyester matrix[7].

From the literature review it is observed that quite few works have been carried out on the effect of machining parameters on the properties of polymer matrix composites. In most of the composite fabrication industry today, Hack saw or Band saw cutting-off operation is followed. But these operations consume large amounts of time and produce rough surfaces, when compared with cutting-off operation using Circular saw cutter. Keeping these key points in mind, a systematic experiment has been designed and executed to study the effect of cutting methods on mechanical properties of Glass-Epoxy composites.

Hence the objectives of the present work are, to know the effect of different cutting methods on the mechanical properties of the laminated FRP composites and to determine the best cutting method for GFRP with less cost. Attempt is also made to find out the cutting speeds of Hacksaw 14TPI (Tooth per inch) and Hacksaw 32TPI cutting methods in order to examine the cutting speed effect on mechanical properties.

## 2.0 Methodology

To meet the set objectives, experimental steps followed are as below.

- E-Glass-epoxy composite laminates are prepared with varied fibre weight fractions, by manipulation of number of fabric layers, matrix content and vacuum pressure. Thus, Laminates with three

Fibre Weight Fractions (FWF), namely 0.30, 0.50, and 0.70 are fabricated.

- Tensile, compression and Interlaminar Shear strength (ILSS) test specimens are prepared by using five cutting methods independently.
- Mechanical tests are carried out to obtain composite strength values, i.e., Tensile, Compression and Interlaminar Shear.
- Real strength values are calculated by considering the size Accuracy Rating (AR). Then ranking index to rank the cutting methods are calculated with the help of AR values.
- SEM studies are carried out to confirm the mechanical test results.

## 3.0 Experimental Details

**Laminate Preparation:** The laminate size is determined based on, trim allowance, local fibre weight allowance and specimen size. Reinforcement used is Bidirectional, E-glass, 2x2 twill, 8mil fabric and resin system (LY556/ HY951) i.e., epoxy and hardener quantity are decided based on the weight fractions using 10:1 ratio. Laminates are fabricated by Hand lay-up and Vacuum bag moulding method. All together 30 specimens each of Tensile, Compression and ILSS respectively are fabricated from the same laminate.

Tensile, Compression and Interlaminar Shear strength test specimens are prepared as per ASTM standards[8-10]. Care is taken to get constant fibre weight fractions, constant thickness of the specimens, same fibre orientation and curing schedule followed by post curing process, in order to get uniform mechanical properties of the specimen. Cutting Speed Calculation: An attempt has been made to check the cutting speed of hack saw blades, keeping the same geometry of the specimen and fibre - matrix ratio. In this case, the forward and return motion of the blade is considered as one stroke. For example, in case of compression test, specimen length is 120 mm and cutting speed calculation of Hack saw blades 14 TPI (HS14) and 32 TPI(HS32) are as shown in Table 1 and Table 2 respectively. The average cutting speed so obtained ranges from 1.2 – 1.37 mm/sec.

Similarly, the cutting strokes and cutting speeds are calculated for Tension and ILSS specimens, respectively and observed the same trend.

**Diamond Cutter and Fixture Details:** Diamond cutter shown in Figure 1 is made of spring steel material having 8 number of teeth and is useful to cut Plastics, wood and soft metals. The saw cutter is classified by

**Table 1.** Cutting speed calculation for HS14

| S No. | Lengthof cut | Number of Cutting Strokes | Cutting Time | | | Strokes per Minutes | Speed, mm/sec |
|---|---|---|---|---|---|---|---|
| | | | Start | End | Time takenin, seconds | | |
| 1 | 120 | 89 | 4.55’0” | 4.56’40” | 100 | 53.4 | 1.2 |
| 2 | 120 | 90 | 5.00’0” | 5.01’40” | 100 | 54 | 1.2 |
| 3 | 120 | 82 | 5.05’0” | 5.06’23” | 83 | 59.27 | 1.44 |
| 4 | 120 | 76 | 5.25’0” | 5.26’24” | 84 | 54.28 | 1.42 |
| 5 | 120 | 81 | 5.30’0” | 5.31’24” | 84 | 57.85 | 1.42 |
| 6 | 120 | 61 | 5.35’0” | 5.36’10” | 70 | 52.28 | 1.71 |
| 7 | 120 | 77 | 5.40’0” | 5.41’25” | 85 | 54.35 | 1.41 |
| 8 | 120 | 88 | 5.55’0” | 5,56’39” | 99 | 53.33 | 1.21 |
| 9 | 120 | 90 | 6.0’0” | 6.01’30” | 90 | 60 | 1.33 |
| 10 | 120 | 81 | 6.05’0” | 6.06’27” | 87 | 55.86 | 1.37 |
| | | | | | Average | 55.46 | 1.37 |

**Table 2.** Cutting speed calculation for HS32

| S No. | Lengthof cut | Number of Cutting Strokes | Cutting Time calculation | | | Strokes per Minutes | Speed,mm/sec |
|---|---|---|---|---|---|---|---|
| | | | Start | End | Time taken in, seconds | | |
| 1 | 120 | 82 | 9.45’ 0” | 9.46’34” | 94 | 52.34 | 1.28 |
| 2 | 120 | 84 | 9.50’0” | 9.51’45” | 99 | 50.91 | 1.21 |
| 3 | 120 | 85 | 9.55’0” | 9.56’39” | 104 | 49.04 | 1.15 |
| 4 | 120 | 99 | 10.00’0” | 10.01’30” | 107 | 55.51 | 1.12 |
| 5 | 120 | 90 | 10.05’0” | 10.06’47” | 101 | 53.47 | 1.19 |
| 6 | 120 | 95 | 10.10’0” | 10.11’24” | 105 | 54.29 | 1.14 |
| 7 | 120 | 97 | 10.15’0” | 10.16’27” | 104 | 55.96 | 1.15 |
| 8 | 120 | 88 | 10.20’0” | 10.21’31” | 95 | 55.58 | 1.26 |
| 9 | 120 | 90 | 10.25’0” | 10.26’25” | 102 | 52.94 | 1.18 |
| 10 | 120 | 81 | 10.30’0” | 10.31’30” | 94 | 51.70 | 1.28 |
| | | | | | Average | 53.17 | 1.20 |

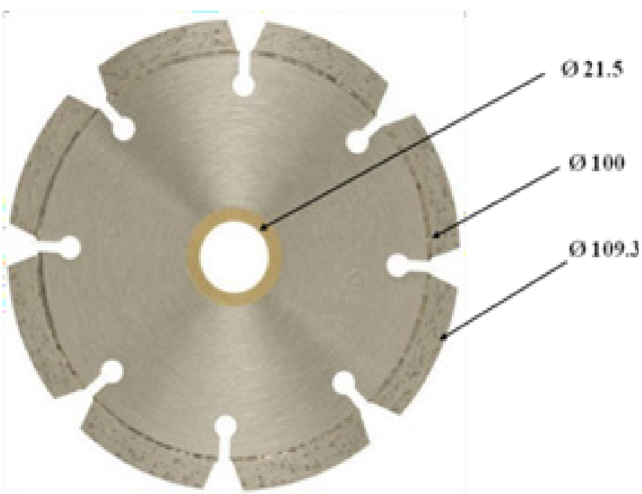



**Figure 1.** Diamond cutter profile.

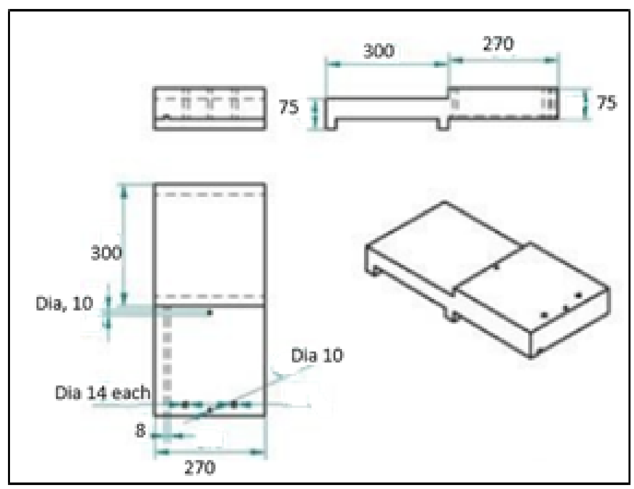



**Figure 2.** Wooden fixture drawing (All dimensions are in mm).

the size of the diamond particles, their concentration and bonding between particles and blade. Particle size is defined in micrometres. In the USA diamond concentration is given as a percentage of the total saw volume. 25% of total saw volume corresponds to 72 carats per cubic inch. As per this standard the cutter used for the present study contains 12.5 % of diamond particles by volume.

A fixture as shown in Figure 2, is designed and fabricated, so that it can be used during DC cutting operation Material requirement for fixture fabrication is as shown in Table 3.

**Table 3.** Material requirements for fixture

| S No. | Material | Size in mm | Numbers |
|---|---|---|---|
| 1 | Plywood | 270 x 270 x 25 | 1 |
| 2 | Plywood | 270 x 570 x 25 | 2 |
| 3 | Plywood | 270 x 25 x 25 | 2 |
| 4 | Screws | M14 | 2 |
| 5 | Screws | M10 | 2 |

Cutter and as well as wood fixture are mounted on the lathe machine. Also, a long steel shaft 21.5 mm diameter is fabricated for mounting the cutter, as the shaft will be fixed into the lathe chuck. The advantage of this wood fixture is laminate can be held in position firmly. Also rotating cutter will be guided to follow the pre-determined grooves in the fixture as shown in Figure 2. Automatic feed can be given to the laminate, so that feed variation will not affect[11] the mechanical properties of the composites. The cutting speed of the lathe machine is 530 RPM and laminate feed of 1mm per sec is fixed. Racker set Band saw blades with 570 RPM is used for the cutting operation of BS14 and BS32. Cutting Performance Evaluation of the Specimen: Aim is to identify the best cutting method among DC (Diamond Cutter), BS14 (Band saw blade 14 TPI), BS24 (Band saw blade 24 TPI), HS14 and H32 also in term of accuracy of cut. To fulfil this aim, the width of the specimen along the length at a constant distance was measured using the digital Micrometre screw gauge 0.01mm accuracy. In the case of tensile specimen, 9 readings per specimen, while for compression specimen, 5 readings per specimen and for ILSS specimen, 3 readings

**Table 4.** Width of DC cut specimen

| Position | Width of DC cut Tensile specimen with 50:50 FWF, in mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Specimen1 | Specimen2 | Specimen3 | Specimen4 | Specimen5 | Specimen6 | Average | Error |
| 1 | 24.87 | 24.80 | 24.93 | 24.95 | 25.05 | 24.90 | 24.92 | -0.08 |
| 2 | 24.86 | 24.88 | 24.91 | 24.96 | 25.06 | 24.94 | 24.94 | -0.07 |
| 3 | 24.90 | 24.78 | 24.91 | 24.94 | 24.90 | 24.87 | 24.88 | -0.12 |
| 4 | 24.80 | 24.72 | 24.89 | 25.00 | 25.20 | 25.01 | 24.94 | -0.06 |
| 5 | 24.84 | 24.79 | 24.91 | 24.92 | 25.14 | 24.92 | 24.92 | -0.08 |
| 6 | 24.88 | 24.80 | 24.91 | 24.95 | 25.26 | 24.99 | 24.97 | -0.03 |
| 7 | 24.89 | 24.70 | 24.89 | 25.00 | 25.29 | 25.04 | 24.97 | -0.03 |
| 8 | 24.87 | 24.77 | 24.95 | 25.05 | 25.45 | 25.09 | 25.03 | +0.03 |
| 9 | 24.97 | 24.81 | 25.00 | 25.02 | 25.45 | 25.01 | 25.04 | +0.04 |
| (Actual width of tensile specimen =25mm) | | | | | | Gross average | 24.96 | -0.04 |

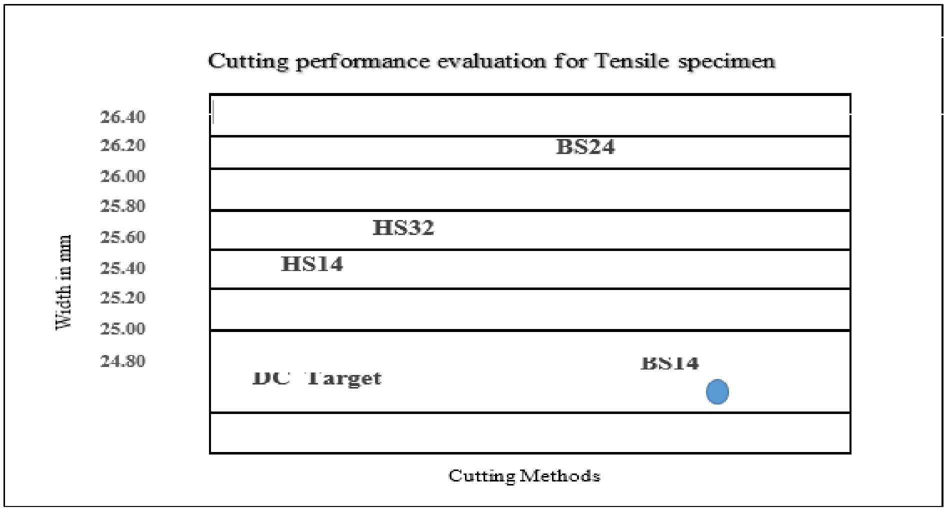



**Figure 3.** Width variation of tensile specimen.

per specimen were taken respectively. The number of measurements of width of the specimen depends upon the length of the tensile, compression and ILSS specimens respectively.

Out of 10 specimens, the best 6 specimens were selected and measured the width as well as the strength of the specimen. For example, width of DC cut tensile specimens with 50:50 FWF is shown in Table 4. FWF of 50:50 is selected for width calculation, because of equal proportion of fibre and matrix. So that the composite constitute should not affect the machinability and thus variation in width will be as small as possible. It is observed that there is a variation in the width of tensile specimen and most of the width spectrum is in the range of 24.7 mm to 25.45 mm. Similarly, the width of HS32, BS14, BS24 and DC cut specimens are measured and tabulated for comparison. Cutting performance of tensile, compression and ILSS specimens with 50:50 FWF are evaluated and one such graph is shown in Figure 3.

In the case of cutting performance evaluation of tensile specimen, 25mm width (Basic size) is the target. It is observed that DC cut specimens have width near to the target, but in negative side of dimension. The average width size of DC cut specimen is 24.96 mm with dimensional inaccuracy -0.04 mm. Whereas BS14, HS14, HS32 and BS24 cut specimens width are on the positive side of dimension. But shows dimensional inaccuracy in that order, respectively. BS24 cut specimen have width on an average 26.15mm with an error of +1.15mm, which is comparatively more inaccurate. Infact, DC cut specimens were of undersize, but comparatively more accurate in width size.

In the case of cutting performance evaluation of ILSS specimen, 10 mm width (Basic size) is the target. It is observed that all of the specimens have width on the positive side of basic size. There is close combat in dimensional accuracy between DC and BS14. The average width size of DC cut specimen is 10.20 mm with dimensional inaccuracy +0.20 mm. Whereas Bandsaw 14 cut specimen have width 10.25 mm with dimensional inaccuracy +0.25 mm. HS32, BS 24 and HS14 cut specimens have dimensional inaccuracy of +0.41, +0.43 and +0.85 mm, respectively. Infact, DC cut specimens are of oversize, but comparatively more accurate in width size.

## 4.0 Results and Discussion

### 4.1 Tensile Strength of Specimens

To nullify the effect of size variation of the specimen on the strength of the composites, an Accuracy Rating (AR) method is introduced and applied in the calculation of Real tensile strength of the specimens. For example, in the case of DC cut tensile specimen, AR value is equals to average width divide by basic size. That is,

**Table 5.** Accuracy rating of GFRP specimens

| | HS14 | HS32 | BS14 | BS24 | DC |
|---|---|---|---|---|---|
| AR of Tensile specimen | 1.02 | 1.026 | 1.006 | 1.046 | 0.998 |
| AR of Compressive specimen | 0.996 | 1.002 | 0.993 | 1.001 | 0.997 |
| AR of ILSSspecimen | 1.085 | 1.041 | 1.025 | 1.043 | 1.02 |

**Table 6.** Real tensile strength of GFRP specimens

| Tensile strength (in N) of specimens with 50:50 FWF | | | | | |
|---|---|---|---|---|---|
| **Specimens** | **HS14** | **HS32** | **BS14** | **BS24** | **DC** |
| 1 | 145.42 | 141.73 | 149.57 | 151.76 | 171.49 |
| 2 | 147.9 | 144.77 | 157.3 | 157.39 | 171.97 |
| 3 | 153.25 | 155 | 162.53 | 166.5 | 175.75 |
| 4 | 146.8 | 146.35 | 152.27 | 155.36 | 161.6 |
| 5 | 149.9 | 149.89 | 148.26 | 160.15 | 169.5 |
| 6 | 144.7 | 145.19 | 155.64 | 155.73 | 166.5 |
| Average | 148 | 147.16 | 154.26 | 157.81 | 169.46 |
| RTS | 145.09 | 143.43 | 153.34 | 150.87 | 169.81 |

**Table 7.** Real compressive strength of GFRP specimens

| Compressive strength (in N) of specimens with50:50 FWF | | | | | |
|---|---|---|---|---|---|
| **Specimens** | **HS14** | **HS32** | **BS14** | **BS24** | **DC** |
| 1 | 72.06 | 68.67 | 70.16 | 66.71 | 78.11 |
| 2 | 70.57 | 67.54 | 71.92 | 67.32 | 84.91 |
| 3 | 75.32 | 64.97 | 65.59 | 71.72 | 85.88 |
| 4 | 74.05 | 63.92 | 72.32 | 70.23 | 77.46 |
| 5 | 72.94 | 64.22 | 70.71 | 66.29 | 77.75 |
| 6 | 74.50 | 65.06 | 73.82 | 69.48 | 78.70 |
| Average | 73.24 | 65.73 | 70.75 | 68.63 | 80.47 |
| RCS | 73.46 | 65.60 | 71.25 | 68.56 | 80.71 |

$$AR = \frac{24.95}{25} = 0.998$$

Similarly, other values are calculated and tabulated as shown in Table 5. Real Tensile Strength (RTS) is calculated by diving the average tensile strength of the specimen by the AR value. For example, in case of DC cut specimen,

$$RTS = \frac{169.46}{0.998} = 169.81$$

Similarly, other values are calculated and tabulated as shown in Table 6.

From the above table it is clear that, tensile property of composite material is better when it is cut through DC method rather than by other method of cutting. RTS of 169.46 N is obtained from FWF = 0.5, DC cut specimen. In fact, tensile property of DC cut specimen is 10% higher than the tensile property of BS14 cut specimen, the next highest value.

## 4.2 Compressive Strength of Specimens

From Table 7, it is observed that compressive strength of DC cut specimen is higher than strength obtained from other cutting methods. Real Compressive Strength (RCS) of 80.71 N is obtained from FWF = 0.5, DC cut specimen.

In this case, compressive strength of DC cut specimen is 9% higher than compressive strength of HS14 cut specimen.

## 4.3 Inter Laminar Shear Strength of Specimens

From Table 8, it is observed that there is a close tie between DC, BS14 and HS14 cut specimens in terms of Real Interlaminar shear Strength (RIS) values. Comparatively, BS14 cutting method gives better strength with highest shear strength values.

As the ILSS specimen size is,10 x 20 mm, the advantage of DC falls shortage because of smaller length of cut. The final matrix of all FWF with mechanical properties is shown in Table 9.

## 4.4 Ranking Index Calculation

The cutting method yielding the highest property for FWF = 0.5, is identified and becomes the datum for the calculation of Ranking Index for all other fibre weight fractions.

**Table 8.** Real ILSS of GFRP Specimens

| ILSS of specimens with 50:50 FWF | | | | | |
|---|---|---|---|---|---|
| **Specimens** | **HS14** | **HS32** | **BS14** | **BS24** | **DC** |
| 1 | 13.61 | 12.90 | 12.78 | 11.83 | 14.03 |
| 2 | 13.13 | 11.70 | 13.67 | 11.80 | 13.74 |
| 3 | 14.47 | 12.81 | 13.85 | 13.12 | 12.47 |
| 4 | 13.98 | 12.04 | 12.48 | 13.21 | 12.73 |
| 5 | 14.98 | 13.05 | 14.67 | 12.26 | 12.56 |
| 6 | 13.89 | 11.51 | 13.61 | 12.89 | 13.99 |
| Average | 14.01 | 12.34 | 13.51 | 12.52 | 13.25 |
| RIS | 12.91 | 11.85 | 13.18 | 12.00 | 12.99 |

**Table 9.** Real strength of GFRP specimen

| FWF | RTS in N | | | | |
|---|---|---|---|---|---|
| | HS14 | HS32 | BS14 | BS24 | DC |
| FWF=0.3 | 90.11 | 97.48 | 94.57 | 99 | 102.2 |
| FWF=0.5 | 145.09 | 143.43 | 153.34 | 150.87 | 169.81 |
| FWF=0.7 | 207.68 | 204.05 | 208.71 | 210.41 | 214.39 |
| FWF | RCS in N | | | | |
| | HS14 | HS32 | BS14 | BS24 | DC |
| FWF=0.3 | 69.31 | 65.16 | 65.45 | 63.36 | 65.38 |
| FWF=0.5 | 73.46 | 65.60 | 71.25 | 68.56 | 80.71 |
| FWF=0.7 | 74.53 | 69.73 | 75.06 | 83.67 | 89.23 |
| FWF | RIS in N | | | | |
| | HS14 | HS32 | BS14 | BS24 | DC |
| FWF=0.3 | 7.24 | 6.75 | 9.59 | 8.09 | 8.97 |
| FWF=0.5 | 12.91 | 11.85 | 13.18 | 12.00 | 12.99 |
| FWF=0.7 | 11.51 | 13.13 | 14.11 | 14.47 | 14.70 |

**Table 10.** Tensile strength ranking index

| FWF | Tensile strength, in N | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HS14 | Ri of HS14 | HS32 | Ri of HS32 | BS14 | Ri of BS14 | BS24 | Ri of BS24 | DC | Ri ofDC |
| 0.3 | 90.11 | 0.53 | 97.48 | 0.57 | 94.57 | 0.56 | 99 | 0.58 | 102.2 | 0.60 |
| 0.5 | 145.09 | 0.85 | 143.43 | 0.84 | 153.34 | 0.90 | 150.87 | 0.89 | 169.81 | 1.00 |
| 0.7 | 207.68 | 1.22 | 204.05 | 1.20 | 208.71 | 1.23 | 210.41 | 1.24 | 214.39 | 1.26 |
| Total | | 2.61 | | 2.62 | | 2.69 | | 2.71 | | 2.86 |

For example, from Table 10, the tensile strength obtained by DC cut specimen with FWF = 0.5 is **169.81 N** and is the highest among the cutting methods. For all fibre weight fractions, Ranking index (**Ri**) of other cutting methods are calculated, by taking 169.81 N as the datum and the final results are tabulated. It is observed that, considering all the factors, cumulatively, Ri of DC cut specimen is the highest with 2.86 followed by BS24, BS14, HS32 and HS14 respectively. DC cut specimens showed 13% higher strength and 17% higher strength than the

**Table 11.** Compressive strength ranking index

| FWF | Compressive strength, in N | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HS14 | Ri of HS14 | HS14 | Ri of HS32 | HS14 | Ri of BS14 | HS14 | Ri of BS24 | HS14 | Ri of DC |
| 0.3 | 69.31 | 0.86 | 65.16 | 0.81 | 65.45 | 0.81 | 63.36 | 0.79 | 65.38 | 0.81 |
| 0.5 | 73.46 | 0.91 | 65.60 | 0.81 | 71.25 | 0.88 | 68.56 | 0.85 | 80.71 | 1.00 |
| 0.7 | 74.53 | 0.92 | 69.73 | 0.86 | 75.06 | 0.93 | 83.67 | 1.04 | 89.23 | 1.11 |
| Total | | 2.69 | | 2.48 | | 2.62 | | 2.67 | | 2.92 |

**Table 12.** ILSS ranking index

| FWF | Compressive strength, in N | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HS14 | Ri of HS14 | HS14 | Ri of HS32 | HS14 | Ri of BS14 | HS14 | Ri of BS24 | HS14 | Ri ofDC |
| 0.3 | 7.24 | 0.55 | 6.75 | 0.51 | 9.59 | 0.73 | 8.09 | 0.61 | 8.97 | 0.68 |
| 0.5 | 12.91 | 0.98 | 11.85 | 0.90 | 13.18 | 1.00 | 12.00 | 0.91 | 12.99 | 0.99 |
| 0.7 | 11.51 | 0.87 | 13.13 | 1.00 | 14.11 | 1.07 | 14.47 | 1.10 | 14.7 | 1.12 |
| Total | | 2.40 | | 2.41 | | 2.80 | | 2.62 | | 2.78 |

FWF = 0.3 Hack saw cut specimens and FWF=0.5 Hack saw cut specimens respectively.

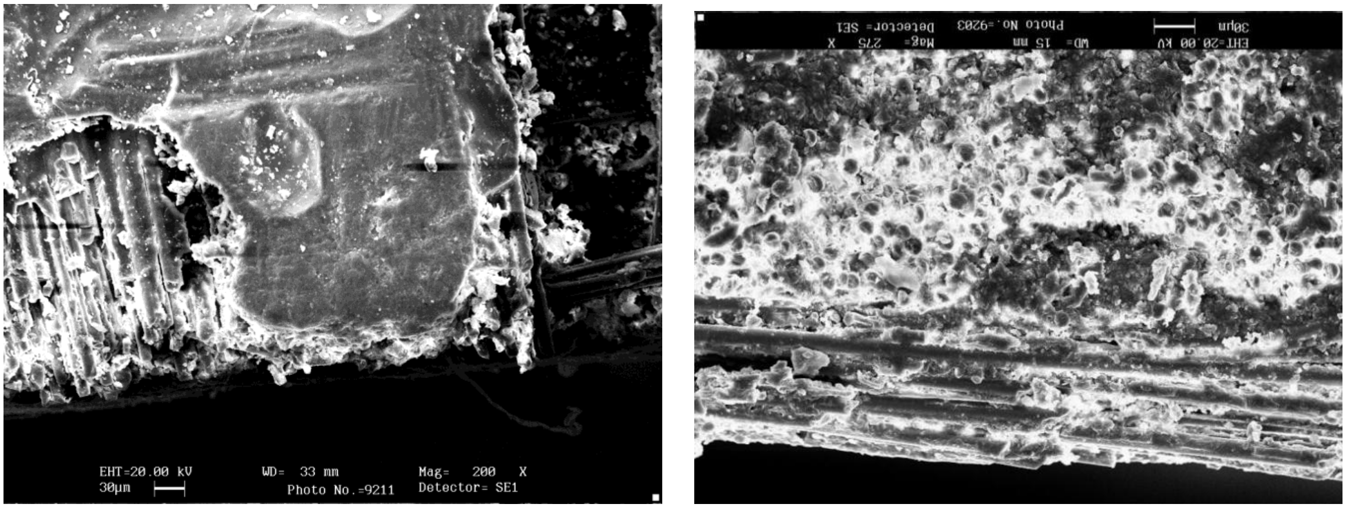
From Table 11 it is observed that, cumulatively **Ri** of DC cut specimen is the highest with **2.92** followed by HS14, BS24, BS14 and HS32 respectively. DC cut specimens showed 23% higher strength and 27.8% higher strength than the FWF=0.5 Hack saw cut specimens and FWF = 0.7 Hack saw cut specimens respectively.

From Table 12, it is observed that, there is a close combat between BS14 and DC cutting methods. Overall, Ri of BS14 cut specimen is the highest with **2.80** followed by DC, BS24, HS32 and HS14 respectively. Note that, rotation speed of DC cutter and Band saw specimen are not taken into account as effect of speed is negligible on the force[12] acting on the laminated composites.

## 4.5 Micro Structural Behavior and Topology of GFRP Composites

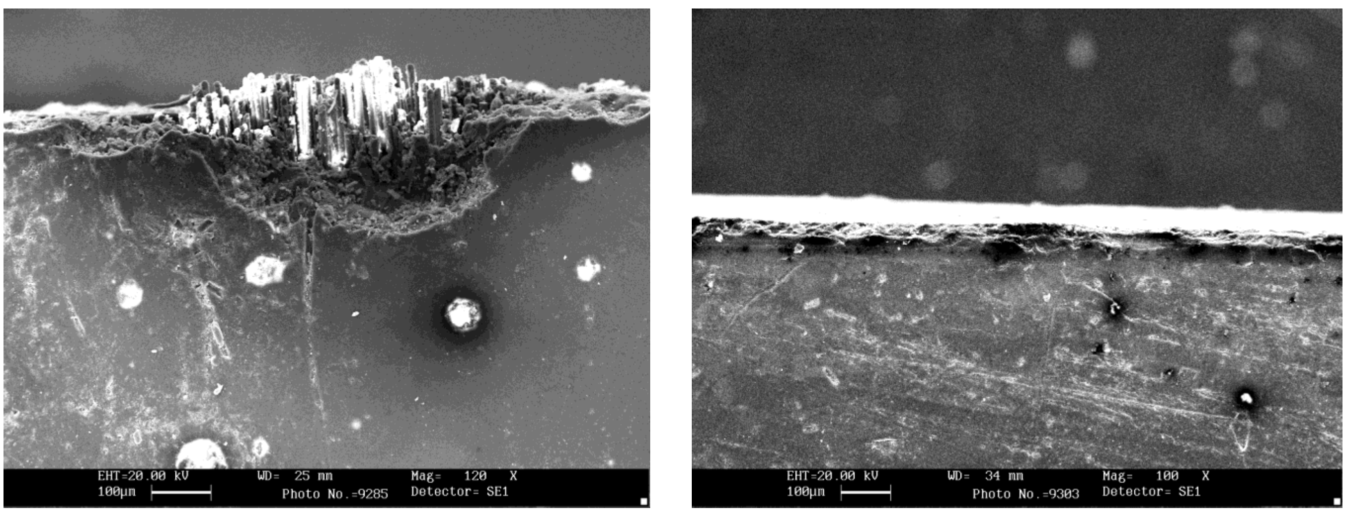
Scanning Electron Microscope (SEM) study have been carried out to substantiate the UTM outcomes i.e., mechanical properties of specimens cut by different cutting methods.

As there are a greater number of specimens with different FWF, specific combinations are selected, and microscopic studies have been carried out. One such example is, FWF = 0.7 HS14- Compressive specimen vs FWF = 0.7 DC -Compressive specimen and the same is as shown in Figure 4(a and b). It clearly shows that HS14 cut specimen have more damage at the edges, due to penetration of hard Hacksaw blade tips. More fibres are




(a) (b)

**Figure 4.** SEM image of compressive specimen with FWF = 0.7 Cut by **a)** HS14 **b)** DC.




(a) (b)

**Figure 5.** SEM Image of Tensile Specimen with FWF=0.3 cut by **a)** BS14 **b)** DC.

exposed to environment without much matrix bonding. Lack of integrity reduces the load carrying capacity of fibres and hence fails early with little resistance. Whereas bonding between fibre and matrix is still intact (Figure 4 (b)), even after the cutting operation by DC method. The microscopic study justifies the results as tabulated in Table 11, where HS14 cut specimen failed at **74.53 N**, load whereas DC cut specimen failed at higher load of 89.23 N.

SEM image with high magnification of BS14 cut specimen shows (Figure 5(a)) that, there is a transverse micro matrix cracks owing to matrix domination[13]. At such cracks, stress concentration is more and therefore, specimen fails to lower loads as there exist less deformation. Also, fibres are exposed out without matrix bonding. SEM image with high magnification of DC cut specimen shows (Figure 5b) that there is a narrow matrix crack. At such cracks, stress concentration is comparatively less and therefore, specimen fails to higher loads. The fibre damages are also reasonable when compared with the damages of BS14 cut specimen. Microscopic study justifies the results as tabulated in Table 10, where BS14 cut specimen failed at **94.57 N**, load whereas DC cut specimen failed at higher load of **102.2 N.**

## 5.0 Conclusions

Experiments were carried out to study the effect of cutting methods, namely Diamond cutter, Band saw 14TPI, Band saw 24TPI, Hack saw14TPI and Hack saw 32TPI on the mechanical properties of E-glass – epoxy laminated composites. Composite laminates of varied fibre weight fractions namely, 0.30, 0.50 and 0.70 were fabricated from which test specimens were prepared as per ASTM standard by the above cutting methods. The Tensile, Compression and ILSS properties were determined and analysed.

- The following are the conclusions drawn from the present work.
- The tensile strength of DC cut specimen possesses higher strength followed by Band saw and Hack saw cutting methods in that order. And tensile strength is proportional to percentage of fibre content.
- Compressive strength was the highest for DC cut specimens, followed by Band saw and Hack saw cutting methods, in that order. Not much appreciable improvement in tensile and compressive strength of FWF = 0.7 and FWF = 0.3 respectively, is observed among the cut specimens. This signifies that, there is an ideal proportion of Fibre and matrix content that enhances the mechanical properties. In fact, 0.65:0.35 fibre–matrix would have been an ideal ratio for better mechanical strength.
- ILSS of Band saw cut specimens shown 40% higher than the strength so obtained from Hack saw cut specimen for FWF = 0.3. Not much noticeable difference in shear strength for FWF = 0.5 and FWF = 0.7 laminates cut by different methods is observed.
- A ranking index procedure was evolved in order to identify the best cutting method among Circular saw, Band saw and Hack saw methods. It can be concluded that, Circular saw is the best cutting method among the Band saw and Hack saw cutting methods.

As composite materials dominated over the metals and alloys, the present work on machining technique of GFRP would enhance the knowledge of material enthusiasts.

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