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# Experimental Studies on Axial Bolted Joint between E-Glass Epoxy Flat Laminate and Steel Flat Plates Subjected to Uni-Axial Tensile Repeated Loading for 15 Cycle

C. Sharada Prabhakar[*,#], Dilikeswar Das[#], and P. Rameshbabu[@]
[#]*DRDO-Advanced Systems Laboratory, Hyderabad - 500 058, India*
[@]*University College of Engineering, Osmania University, Hyderabad - 500 007, India*
[*]*E-mail: chavalisp_hyd@dataone.in*

## ABSTRACT

Axial bolted joint between EN-31 steel flat plates and E-Glass Epoxy thick, flat laminate consisting of helical winding layers with ±30° helical angle of winding and fabric prepreg layers, was realised with 3 number of M10, 12.9 property class steel fasteners on each side and assembly was tested under uni-axial tensile repeated loading and unloading up to 8.1 ton proof load and to 0 respectively, for 15 cycle. Aim of the experiment was to study the damage induced if any and further increased, in E-Glass epoxy laminate near joint regions, under tensile repeated loading and unloading for 15 cycle. Total length, width and thickness of metal composite axial bolted joint test assembly were 700 mm, 150 mm, and 22 mm, respectively. Longitudinal and transverse strain was monitored at 31 strain gauge locations in composite laminate near joint regions, in all the 15 cycle. For first cycle, longitudinal strain was plotted during loading up to proof load of 8.1 ton and unloading to 0, to check the linearity of strain variation with increase and decrease in load, respectively. It was observed that strain at all strain gauge locations was varying linearly. Maximum strain measured was 4035 micro strain in 1st cycle. Residual strain at all strain gauge locations was observed very less. No defects were induced in composite laminate after 15 cycle.

**Keywords:** E-Glass epoxy; Steel plates, Axial bolted joint; Tensile load test; Strain

## 1. INTRODUCTION

Fibre reinforced composite materials are used in many structural applications because of high specific strength and stiffness[1-4]. For realising complete large structure, sometimes, composite sections have to be joined with other composite or metallic sections by adhesive joints or bolted joints. There are two type of bolted joints: overlap joints (shear loaded joints) and axial butt joints (tension loaded joints). In shear-loaded joints, primary loads are applied at right angles to the axes of the fasteners. In tension-loaded joints, primary loads are applied more or less parallel to the axes of the fasteners[5]. Metal composite axial bolted joint is considered for present studies. T-bolt joint used in blades application is very similar to present configured joint. T-bolt, bearing strength and damage accumulation in E-Glass epoxy blades application is studied by Briggs[6]. Strength of bolted joint depends on geometrical parameters, material properties and fabrication parameters[1].

In metal-composite bolted joint, under tensile load, failure modes of composite laminate are: bearing failure, net tension failure, cleavage failure and shear out failure[1,3,7,8]. Fibre orientation and lay up sequence affects the bearing failure of composite laminate[1,9,10]. There will be very high stress and strain concentration near the drilled hole[1, 3,11], and will reduce the mechanical properties[12]. High stress concentration will be cause of tension failure in composite laminate. Shear out failure occurs because of less edge distance[13] and low shear strength and transverse tensile strength. In metal composite joint, bearing damage only produces progressive failure[2] and bearing failure is more desirable than other failure modes[1].

There is requirement (functional) to test large size, steel E-glass epoxy cylindrical section's axial bolted joint assembly, under internal hydraulic proof pressure, for 15 cycle, to check whether any defects are induced and further increased in composite cylindrical section and in composite portion near metal-composite axial bolted joint. Tensile load will be exerted on joint, due to internal hydraulic pressure. There will be stress concentration near holes. Bearing failure (crushing) at the loading side of radial pockets in the composite section will be initiated under tensile loading and further will be increased with increase in tensile loading. Steel-E-Glass epoxy axial bolted joint assembly was tested under tensile loading for 15 time, on laminate level, before testing on cylindrical section's large size assembly under internal hydraulic pressure, for 15 time. However hoop load generated due to internal hydraulic pressure cannot be simulated in this laminate level test.

Polymeric laminated composite product development and realisation of metal-composite joints are very critical. Quality of these composites is highly process oriented. Component is made layer by layer. Processing of composite laminate including drilling of axial holes and radial pockets, metallic plates, assembly and testing details are briefed in this paper.

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## 2. MATERIAL AND METHOD

### 2.1 E-Glass Epoxy-Steel Axial Bolted Joint

Two flat plates of EN-31 steel were joined to E-Glass Epoxy laminate on both ends of it with the help of 3 number of axial fasteners, on each side as shown in Fig. 1.

### 2.2 Details of Joints

Total length of metal-composite axial bolted joint assembly test specimen = 700 mm

Length of composite laminate = 400 mm
Length of each metallic plate = 150 mm
Width of test assembly = 150 mm
Thickness of joint = 22 mm
Number of fasteners selected = 3 (on each side)
Size of fasteners = M10
Material of fasteners = EN-24, 12.9 property class.

### 2.3 Preparation of E-Glass Epoxy Steel Axial Bolted Joint Assembly, Test Specimen

#### *2.3.1 E-Glass Epoxy Composite Laminate Test Specimen*

Composite laminate was consisting of both, E-Glass epoxy filament winding helical and hoop layers and E-Glass fabric epoxy layers. Thickness of composite laminate = 29 mm (total structural thickness of cylindrical composite section at joint portion, including 15 mm filament winding layer and 14 mm fabric layers), however, effective thickness at joint portion of the laminate is 22 mm.

Helical winding of 1.0 mm thickness with ±30° as helical winding angle was followed by one hoop winding of 0.5 mm thickness on mandrel surface and these layers were cut and stacked in metallic mould. Such type of few windings of helical and hoop layers were wound, cut and stacked on mould to achieve 15 mm thickness of filament winding.8 fabric epoxy layers of 0.25 mm thickness of each layer (layup thickness = 2 mm) were interspersed in between filament wound layers which is followed by lay up of 48 fabric epoxy layers to get 12 mm thickness and to achieve total thickness of laminate as 29 mm.

Lay-up was cured in mould, under hydraulic load of 25 ton at 150 °C for 4 h. Curing of laminate was confirmed by measuring Barcol hardness[14]. It was 72 B to 78 B. Laminate specimen of size: 400 mm x 150 mm x 29 mm was cut from moulded laminate.

No major defects were found in the laminate. Fibre volume fraction of filament wound layer portion and fabric layer portion were measured as 60.8 per cent and 42.63 per cent, respectively. Criticality in drilling of long axial holes on the face of composite laminate is that they have to be drilled, along the layers, without delamination and with geometrical accuracies. 3 number of axial holes with 11 mm diameter and 44 mm depth were drilled on face and blind radial pockets of 22 mm diameter and 22 mm depth were drilled on surface of the composite laminate on both sides. All required dimensional accuracies were achieved.

#### *2.3.2 Metallic Plates*

EN-31 steel plates were machined and axial holes and radial holes were drilled as per requirement.

#### *2.3.3 Metal-Composite Axial Bolted Joint Assembly*

Metallic inserts were placed in blind pockets and studs were tightened. Metallic plates were joined to composite laminate test specimen at both ends with the help of three number of washers and nuts. 60 NM torque (estimated torque for tightening of fasteners in actual cylindrical sections assembly, to not to open the joint up to 1.5 time of working pressure) was applied.

## 3. EXPERIMENTAL WORK

E-Glass epoxy steel axial bolted joint assembly test specimen is subjected to uni-axial tensile loading, for 15 time. Details of experiment are briefed as follows.

### 3.1 Test Set up and Testing

E-Glass epoxy steel axial bolted joint assembly test specimen is loaded in test jig. Assembly was tested under uni-axial tensile load up to proof load of 8.1 ton for 15 cycle. In each cycle, assembly was loaded up to 8.1 ton, held for 3 minutes and then unloaded to zero. 15 cycle were tested in two days. On first day, 6 cycle and on second day, 9 cycle were tested with 20 min gap between each cycle. At any time, 3 or more cycles were tested at a stretch.

Strain was monitored at 31 strain gauge locations, during loading and unloading for each cycle. Axial holes and radial pockets were drilled on fabric side of the laminate, hence 27 strain gauges were bonded on fabric surface side and only 4 strain gauges were bonded on winding surface side. Strain gauge locations are shown in Fig. 1. Strain recording was continuous.

### 3.2 Strain Measurement for First Cycle

#### *3.2.1 Longitudinal Strain in Strain Gauges, Located in Stress Concentration Zone, at Joint Region*

Strain gauges 5, 7, 23, 25, 9, 10, 11, 12, 17, 18, 20 and 21 (joints at top and bottom) are located near radial pockets in stress concentration zones and near metallic inserts. More strain is expected at these locations. For first cycle, longitudinal strain in these strain gauges were plotted during loading up to proof load of 8.1 ton and unloading from 8.1 ton to 0, to check the linearity of strain variation with increase and decrease in load respectively. Strain at locations 5 and 7 (bottom) are compared with strain at locations 23 and 25 (top). Strain plots at these strain gauges, during loading and unloading are as shown in Figs. 2 and 3, respectively. Strain plots at strain gauges, 9, 10, 11 and 12 (bottom), during loading and unloading are as shown in Figs. 4 and 5, respectively. Strain plots at strain gauges, 17, 18, 20 and 21 (top), during loading and unloading are as shown in Figs. 6 and 7, respectively. 1545 strain readings are plotted during loading and 1190 strain readings are plotted during unloading.

At all the strain gauge locations, strain variation during loading and unloading was observed as linear. Maximum strain was measured as 4035 micro strain at strain gauge 21.

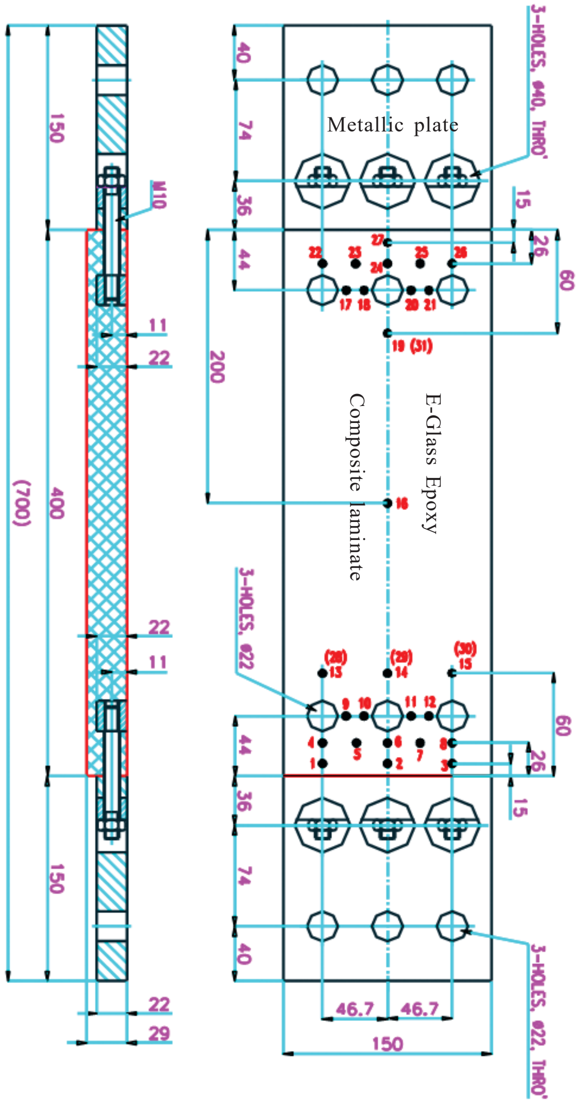

**Figure 1. E-Glass epoxy steel axial bolted joint assembly.**

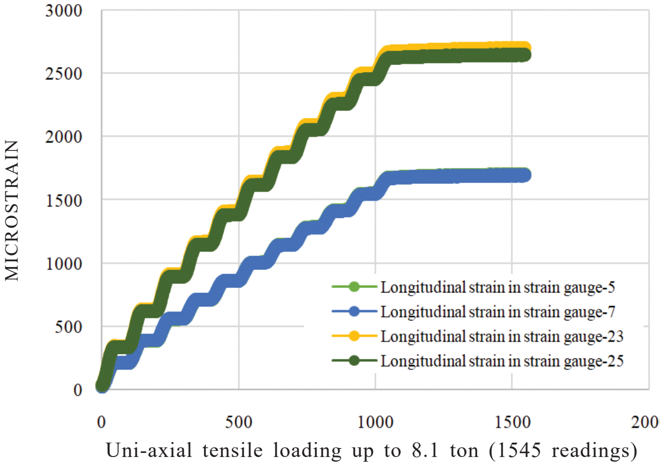

**Figure 2. Longitudinal strain plots in strain gauges 5, 7, 23, and 25, during loading up to 8.1 ton, for 1st cycle.**

## 3.3 Max. Longitudinal Strain in all 15 Cycle

### *3.3.1 Max. Longitudinal Strain in Strain Gauges 5, 7, 23 and 25 for all 15 Cycle*

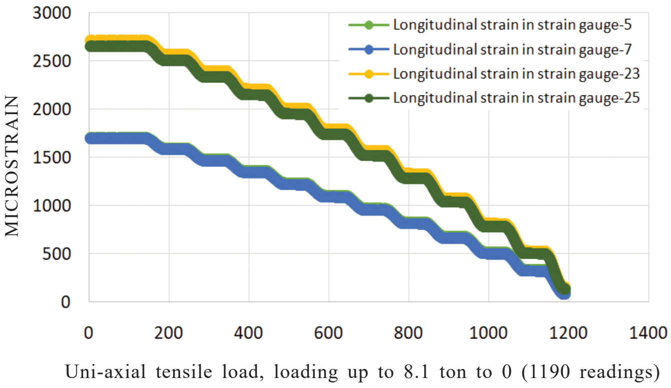

**Figure 3. Longitudinal strain plots in strain gauges 5, 7, 23, and 25, during un-loading from 8.1 ton, for 1st cycle.**

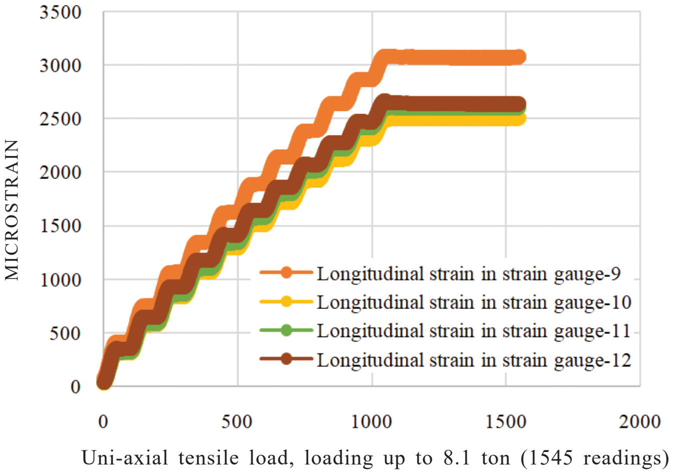

**Figure 4. Longitudinal strain plots in strain gauges 9, 10, 11, and 12, during loading up to 8.1 ton, for 1st cycle.**

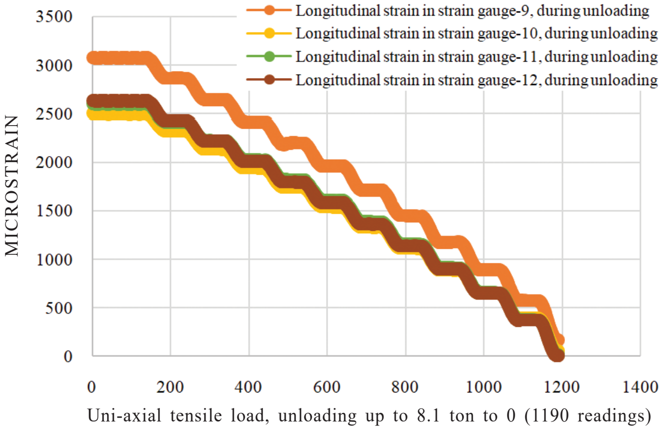

**Figure 5. Longitudinal strain plots in strain gauges 9, 10, 11, and 12, during un-loading from 8.1 ton, for 1st cycle.**

Strain gauges 5, 7, 23, and 25 were located at same distances from the edges of the composite laminate test specimen at both ends. Hence strain in theses strain gauges were compared for all 15 cycle. Maximum longitudinal strain values at strain gauges 5, 7, 23, and 25 at 8.1 ton uni axial tensile load, for all 15 cycle are given in Table 1.

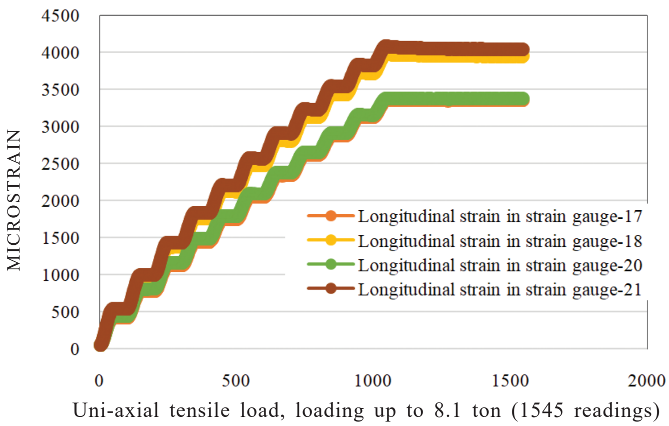

**Figure 6. Longitudinal strain plots in strain gauges 17, 18, 20, and 21, during loading up to 8.1 ton, for 1st cycle.**

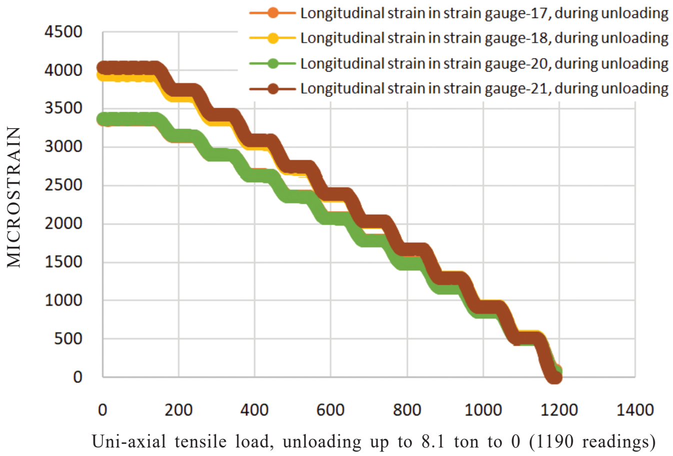

**Figure 7. Longitudinal strain plots in strain gauges 17, 18, 20, and 21, during un-loading from 8.1 ton, for 1st cycle.**

### 3.3.2 *Max. Longitudinal Strain in Strain gauges located near Metallic Inserts*

Strain gauges 9, 10, 11, 12 and 17, 18, 20 and 21 were located near metallic inserts, at same distances from the edges of the laminate test specimen at both ends. Hence strain in theses strain gauges were compared for all 15 cycle. Maximum longitudinal strain values at strain gauges 9, 10, 11, 12 and 17, 18, 20 and 21 at 8.1 ton uni-axial tensile load, for all 15 cycle are given in Table 2 and Table 3, respectively.

It can be seen from Table 2 that maximum variation in maximum longitudinal strain, with in 15 cycle is observed at strain gauge-9, as 1168 micro strain. This is maximum variation among 4 strain gauges 9, 10, 11, and 12. Only in cycle-6, strain recorded was less as 2792 as compared to other cycles. However compared to ultimate strain, recorded strain are very less.

It can be seen from Table 3 that maximum variation in maximum longitudinal strain at 8.1 ton load for 15 cycle was only 208 micro strain at strain gauge 21.

## 3.4 Residual Strain

Longitudinal and transverse residual strain, at all 31 strain gauge locations for every cycle were monitored and found to be

**Table 1. Max longitudinal strain in strain gauges 5, 7, 23, and 25 for all 15 cycle**

| Tests | Strain at strain gauges located in stress concentration zones (micro strain) | | | |
|---|---|---|---|---|
| | SG-5 | SG-7 | SG-23 | SG-25 |
| 1 | 1706 | 1699 | 2709 | 2655 |
| 2 | 1746 | 1742 | 2742 (max) | 2678 |
| 3 | 1757 | 1757 | 2576 | 2689 (max) |
| 4 | 1629 | 1660 | 2528 | 2475 |
| 5 | 1620 | 1651 (min) | 2519 | 2467 |
| 6 | 1614 (min) | 1672 | 2509 (min) | 2462 (min) |
| 7 | 1784 | 1811 | 2549 | 2498 |
| 8 | 1784 | 1811 | 2552 | 2500 |
| 9 | 1796 | 1822 | 2565 | 2511 |
| 10 | 1800 (max) | 1824 (max) | 2570 | 2516 |
| 11 | 1771 | 1806 | 2539 | 2489 |
| 12 | 1762 | 1793 | 2527 | 2477 |
| 13 | 1755 | 1786 | 2521 | 2470 |
| 14 | 1746 | 1781 | 2509 | 2459 |
| 15 | 1791 | 1820 | 2559 | 2505 |
| | Variation in maximum longitudinal strain in 15 cycle | | | |
| | 186 | 173 | 233 | 227 |

*Maximum variation in maximum longitudinal strain is found 233 micro strain, at strain gauge location 23 among 4 strain gauges 5; 7; 23 and 25, at 8.1 ton load for 15 cycle.*

**Table 2. Max Longitudinal Strain in strain gauges 9, 10, 11 and 12 for all 15 cycle**

| Tests | Strain at strain gauges located near metallic insert (bottom), (micro strain) | | | |
|---|---|---|---|---|
| | SG-9 | SG-10 | SG-11 | SG-12 |
| 1 | 3075 | 2505 | 2604 | 2634 |
| 2 | 3492 | 2535 | 2608 | 2661 |
| 3 | 3617 | 2540 | 2611 | 2663 |
| 4 | 2937 | 2465 | 2599 | 2624 |
| 5 | 2928 | 2453 | 2587 | 2613 |
| 6 | 2792 (min) | 2445 (min) | 2580 (min) | 2606 (min) |
| 7 | 3167 | 2668 | 2808 | 2832 |
| 8 | 3027 | 2665 | 2804 | 2829 |
| 9 | 3485 | 2669 | 2810 (max) | 2834 (max) |
| 10 | 3736 | 2671 (max) | 2809 | 2834 (max) |
| 11 | 3960 | 2644 | 2782 | 2810 |
| 12 | 3117 | 2631 | 2768 | 2797 |
| 13 | 3109 | 2661 | 2768 | 2790 |
| 14 | 3062 | 2653 | 2755 | 2778 |
| 15 | 3466 | 2667 | 2807 | 2833 |
| | Variation in max longitudinal strain in 15 cycle | | | |
| | 1168 | 226 | 230 | 228 |

**Table 3. Max longitudinal strain in strain gauges 17, 18, 20 and 21**

| Tests | Strain at strain gauges located near metallic insert (top), (micro strain) | | | |
|---|---|---|---|---|
| | SG-17 | SG-18 | SG-20 | SG-21 |
| 1 | 3357 | 3950 (max) | 3374 | 4035 (max) |
| 2 | 3367 | 3940 | 3381 | 4018 |
| 3 | 3368 (max) | 3928 | 3378 (max) | 4000 |
| 4 | 3189 | 3799 | 3198 | 3867 |
| 5 | 3179 | 3787 | 3189 | 3851 |
| 6 | 3169 (min) | 3776 | 3179 | 3841 |
| 7 | 3222 | 3840 | 3232 | 3906 |
| 8 | 3217 | 3832 | 3228 | 3898 |
| 9 | 3220 | 3834 | 3231 | 3901 |
| 10 | 3223 | 3834 | 3234 | 3900 |
| 11 | 3203 | 3811 | 3210 | 3869 |
| 12 | 3188 | 3793 | 3195 | 3849 |
| 13 | 3181 | 3784 | 3185 | 3841 |
| 14 | 3169 (min) | 3770 (min) | 3174 (min) | 3827 (min) |
| 15 | 3220 | 3833 | 3229 | 3899 |
| | Variation in maximum longitudinal strain in 15 cycle | | | |
| | 199 | 180 | 204 | 208 |

very less. Longitudinal residual strain in all other strain gauges was observed maximum up to 258 micro strain except at strain gauge-9 location. At strain gauge-9, maximum residual strain of 841 micro strain was recorded, may be because of slight undulations at outer surface at this location as shown in Fig. 8 but further in 12th to 15th cycle, residual strain recorded were less (100 micro strain). No other visual defect was seen at this location.

## 4. RESULTS AND DISCUSSION

- Longitudinal and transverse strain at all 31 strain gauge locations were monitored, for all cycles, during loading up to 8.1 ton and unloading from 8.1 ton to 0.

Figure 8. Location of strain gauge-9.

- For 1st cycle, longitudinal strain were plotted in strain gauges 5, 7, 23, 25, 9, 10, 11, 12, 17, 18, 20, and 21 located near radial pockets in stress concentration zone and near metallic insert. Recorded strain in all these strain gauge locations, located in E-Glass epoxy composite laminate test specimen were very less compared to its ultimate strain. Maximum longitudinal strain observed was only 4035 micro-strain, at strain gauge 21, which is much less than ultimate strain of this composite material. Ultimate strain of this composite material is 20,000 micro strain.
- Strain were varying linearly with increase in uni-axial tensile load up to proof load of 8.1 ton and decrease in load from 8.1 ton to 0.
- Strain gauges located at top portion, at same distances from the edges of laminate at bottom portion have recorded slightly more strains, may be because of alignment problem.
- Variation in maximum longitudinal strain within 15 cycle, at all the strain gauge locations was observed very less, except one location, at strain gauge-9 and it was 1168 micro strain.
- Maximum residual strain was also recorded at gauge-9 and it 841 micro strain at cycle-11, however residual strains for cycles 12 to 15 were less than 50 micro strain.
- There was no torque relaxation in fasteners.
- Only 4dB increase was found at strain gauge-9 location in Ultrasonic inspection.

## 5. CONCLUSIONS

Metal-composite laminate, axial bolted joint assembly was tested under uni-axial tensile load up to proof load of 8.1 ton by loading and unloading for 15 cycle. Strain near joint region were monitored. Maximum strain in all 15 cycle of experiments was found as 4035 micro strain and it is very less. Not much variation in strain was found, between cycles. Residual strain at the end of every cycle were also found very low except in strain gauge-9 location, which is near metallic insert. It was found that no defects were induced and increased with repeated loading and unloading up to proof load, for 15 time of test.

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## CONTRIBUTORS

**Ms C. Sharada Prabhakar**, has received MTech (Mechanical Engineering) from IIT Madras, Chennai. She is working as scientist ‘G’, Deputy Technology Director, Advanced Composite Centre, DRDO-Advanced Systems Laboratory, Hyderabad. She is working in the area of development of polymeric structural and ablative composite products and mechanical and thermal characterisation of polymeric composite materials used in missile application.

In the current study, she has planned the development of metal-composite axial bolted joint assembly for uni-directional tensile load testing for 15 cycle. Generated helical winding program with ±30° helical winding and developed E-Glass epoxy composite laminate, metallic plates, metallic fasteners and metal composite axial bolted joint assembly. She has written the manuscript.

**Mr Dilikeswar Das,** has received BTech (Mechanical Engineering) from IGIT, Sarang, Utkal University, in 2002. He is working as Scientist ‘E’ at Advanced Composite Centre, DRDO-Advanced Systems Laboratory, Hyderabad. He is working in the area of development of polymeric structural and ablative composite products, and mechanical and thermal characterisation of polymeric composite materials used in missile application.

In the current study, he has developed E-Glass epoxy composite laminate and he has carried out precise drilling of axial holes and blind radial pockets on composite laminate and arranged for testing.

**Dr P. Rameshbabu,** has received PhD (Composites) from IIT Kharagpur. Presently working as Professor in Mechanical Engineering Department, College of Engineering, Osmania University, Hyderabad, India. His area of specialisation is composite materials. He is teaching, composite materials and finite element analysis to under graduate students and post graduate students. Also, he taught the subject Theory of Elasticity to post graduate students.

In the present work, he was involved in analysis of all the test results.