

# **ADVANCED SIMULATION OF FIBER-REINFORCED AUTOMOTIVE RADIATOR END TANKS BY CAPTURING ANISOTROPIC MATERIAL PROPERTIES**

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## **Abstract**

Fiber-reinforced plastics applications such as radiator end tanks used in automotive industry exhibit highly anisotropic behavior due to random orientations of fibers in the plastic matrix. Traditionally these components are analyzed by considering the plastic material to be homogeneous and considering equivalent properties obtained from standard tensile strength test on a fiber reinforced plastic specimen. Based on experience sometimes equivalent properties obtained from tensile strength test on cross fiber specimen are used for analysis. However this approach does not completely account for the anisotropic properties introduced due to complex fiber orientation in the part, resulting from plastic injection molding process. Present study aims at capturing the realistic anisotropic properties of the plastic material in the structural analysis. Moldflow Plastics Insight (MPI) software has been used to obtain the fiber orientation details for the plastic tank. This fiber orientation output data has been transferred to the structural analysis software (Abaqus) using commercially available interface software (DIGIMAT from eXstream Engineering). The process involves generating element specific material data card by combining basic nonlinear material data for unidirectional fiber reinforced plastic and the fiber orientation data for each element. This integrated simulation technique involving modeling of anisotropic properties of fiber reinforced plastic tank helps us in accurate prediction of burst pressure strength of tank. Comparison of results obtained by using tensile stress strain data with fibers along flow and cross flow directions has been presented.

## **Introduction**

Injection molding of glass reinforced plastics process results in a typical flow pattern resulting in non-uniform distribution of short fibers in plastics. This non uniform fiber orientation is the primary cause of anisotropic behavior of fiber reinforced plastic components. These fiber orientations essentially depend on the flow conditions during mold filling. Shear and longitudinal flow forces fibers to be aligned in flow direction and transverse to it, respectively. Figure 1 indicates the process of fiber orientation development during the injection molding process. Hence, a changing orientation distribution can be observed over the wall thickness of an injection-molded part. Complex geometric features like ribs, brackets, bends etc. present in the injection molded components further adds to significant variations in the fiber orientation. Accurate and realistic analysis of fiber reinforced plastic components thus calls for development of advanced simulation techniques to account for the anisotropy introduced through injection molding process and complex geometry of the plastic component.

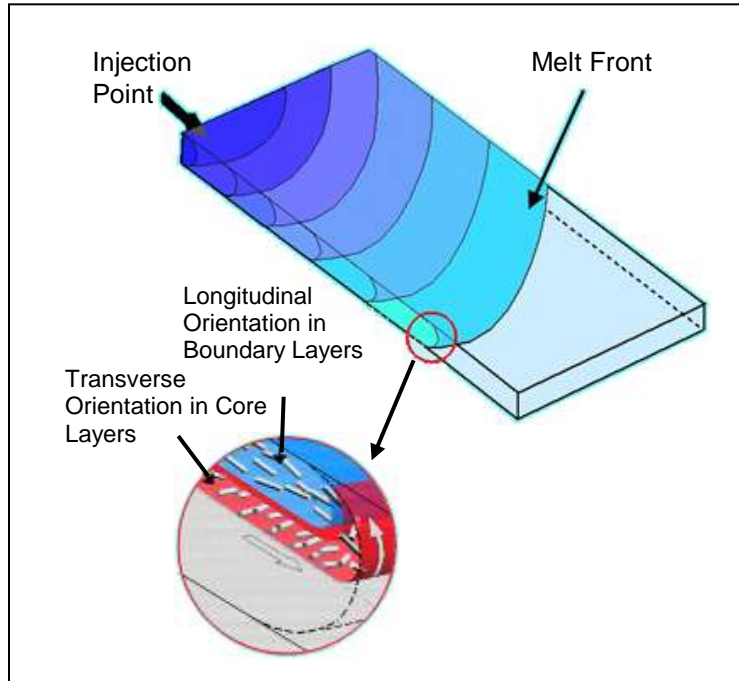


Figure 1: Fiber orientation in injection molding process

## Design and Analysis of Fiber Reinforced Plastic Tank

In the present study advanced simulation of a typical fiber reinforced plastic tank employed in an automotive radiator tank assembly has been performed. Three dimensional geometry of this radiator end tank has been presented in Figure 2. The injection molding process for this complex geometry consisting of several ribs, bracket and pipe junction results in a great deal of anisotropic material properties. Design of this radiator tank requires various structural analyses and physical tests.

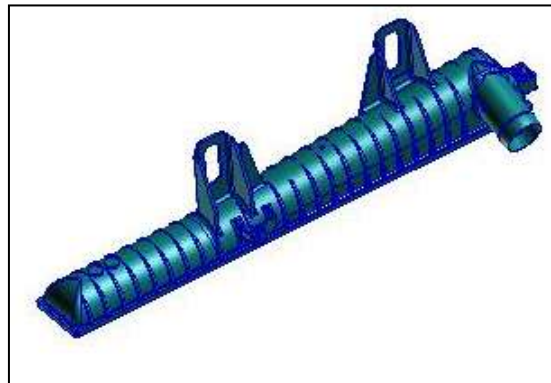


Figure 2: Three-dimensional geometry of fiber reinforced plastic radiator tank

## Plastic Tank Performance Tests

Fiber reinforced plastic radiator tanks are subjected to several physical tests to ensure quality and performance over the stipulated life time of the radiator assembly. These tests include pressure cycle test, burst strength test, thermal cycle test and vibration test. Here in this study we are mainly investigating the burst pressure test as we feel it is the key test showing the effect of fiber orientation on part performance. The primary focus however remains on the accurate analysis of fiber reinforced plastic tanks by capturing the anisotropic material properties.

### Burst Pressure Estimation from Laboratory Test

The burst pressure test on fiber reinforced plastic radiator end tank has been conducted by applying uniform pressure through the inlet pipe of the tank. Figure 3 shows a typical setup of the burst pressure test being conducted on radiator assembly at Delphi Technical Centre, Lockport, NY. The design value of the burst pressure is 40 psi or 276 kPa. For confidentiality of the product related information the actual burst pressure noted in laboratory test has not been specified in this paper.



*Figure 3: Radiator assembly burst pressure test setup at Delphi Technical Centre, Lockport, NY*

### Numerical Simulations of Burst Pressure Test

The phenomenon of bursting of these tanks is quite complicated since the failure of radiator assembly partially contributes to the leakage and crack initiation process. For simplicity of investigation and to limit the computational effort only tank geometry has been considered for FE model.

### FE Model

A finite element model of the plastic tank has been created by using tetrahedral solid elements (C3D10M) in abaqus v6.7 software. Figure 4 illustrates the FE mesh generated for this structure. Total number of nodes \ elements required to model this complex geometry are 1105331 \ 711967 respectively.

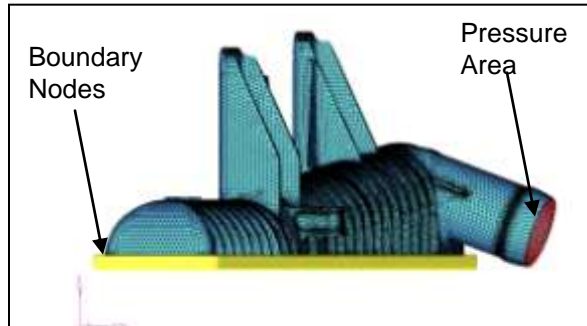


Figure 4: FE model of fiber reinforced plastic tank

### Boundary Conditions

All the nodes on the bottom surface and side walls of the tank have been fixed in all degrees of freedom to ensure leak proof fixed conditions of the tank for burst pressure test. A uniform pressure has been applied on internal surface of the tank as indicated in Figure 4 above.

### Material Testing

In general the fiber orientation and material properties at any section in the structure will vary between the properties of specimen with fibers oriented along flow direction and cross flow direction. At Delphi Research Laboratory (DRL) standard tensile test specimens were prepared from an injection molded plaque with three injection points as indicated in Figure 5. Independent tensile tests have been conducted on the ISO specimens shown in Figure 5 below with fibers in flow direction and cross flow direction. The material constants and stress-strain data obtained from these tests have been accepted as the best possible flow and cross flow material data for the fiber reinforced plastic tank under consideration.

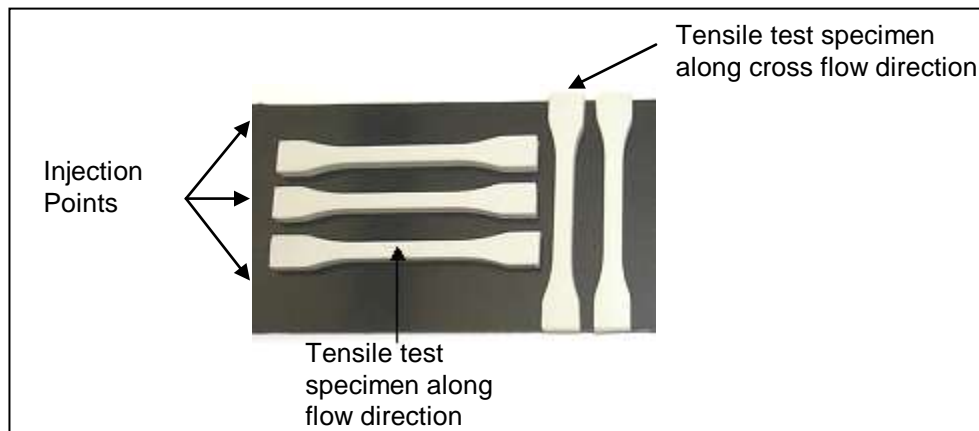


Figure 5: Tensile test specimens with fibers along flow and cross flow direction

The average values of Young's Modulus of Elasticity for a glass fiber reinforced plastic (GFRP) material with fibers along flow and cross flow directions have been presented in Table I

below. Tensile stress-strain curves obtained from tests have been presented in Figure 6. Flexural modulus of elasticity for these test specimens have been observed to be as follows:

Table 1: Young's modulus of elasticity for a typical GFRP material with fibers oriented along flow and cross flow direction

Young's modulus of elasticity constants for GFRP plate	
Fiber Direction in Test Specimen	Modulus of Elasticity
Flow	8100 MPa
X - Flow	5949 MPa

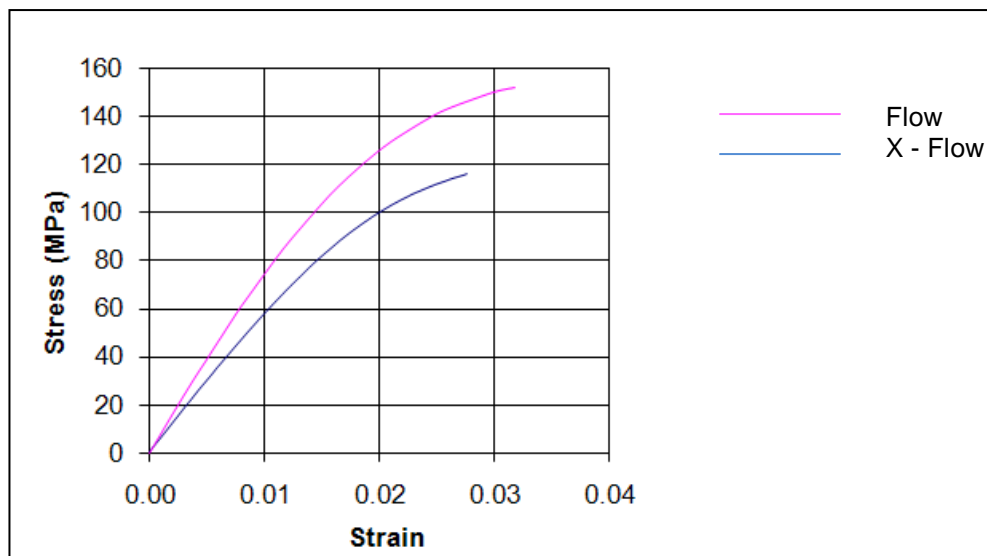


Figure 6: Average nominal stress-strain curves for tensile test specimens with fibers along flow and cross flow direction

### Nonlinear Material Model

The elastic-plastic model has been used in abaqus v6.7 software to capture the material nonlinearity of fiber reinforced plastic material. The tensile stress strain curves shown in Figure 6 represent nominal engineering stress strain values. This stress-strain data is converted to true stress strain data using following formulae

True Stress:  $\sigma_t = \sigma_e (1 + \epsilon_e)$

True Strain:  $\epsilon_t = \ln (1 + \epsilon_e)$

Plastic Strain:  $\epsilon_p = \epsilon_t - (\sigma_t / E)$

where  $\sigma_e$  = Engineering (nominal) stress

$\epsilon_e$  = Engineering (nominal) strain

E = Young's Modulus of Elasticity

For the nonlinear analysis purpose the material data is divided into elastic and plastic components. The plastic component is represented by true stress and corresponding plastic strain data. Specific values true stress - plastic strain data pertaining to the GFRP material with fiber orientation along flow and cross flow direction has been presented in Table II.

Table II: True Stress - Plastic Strain Data for a typical GFRP Material with Fiber oriented along flow and cross flow direction

True stress - plastic strain data for GFRP Material			
Flow		X - Flow	
$\sigma_t$ (MPa)	$\epsilon_p$	$\sigma_t$ (MPa)	$\epsilon_p$
30.3594	0.000000	44.7921	0.000000
58.02374	0.000309	62.5380	0.000253
75.0665	0.000683	78.6572	0.000765
90.3027	0.001176	91.7327	0.001591
112.8250	0.002437	101.4335	0.002657
124.0297	0.003510	108.7487	0.003956
141.4359	0.006256	114.2583	0.005425
154.3331	0.010506	118.4669	0.007052
156.4674	0.011989	119.1781	0.007320

### Accurate Modeling of Anisotropic Material Properties using DIGIMAT Software

An advanced analysis software DIGIMAT from eXstream company has been used to capture anisotropic material properties all along the geometry of the radiator end tank. This software captures the fiber orientation data generated by the moldflow simulation of the structure into the structural mesh. DIGIMAT interface software works as pre compiled libraries to enable accurate and efficient nonlinear structural modeling at element/integration point.

### Moldflow Simulation of Plastic Tank

Injection molding process for the short glass fiber reinforced plastic radiator tank has been simulated using 3D module of MPI v6.0 software. An independent mesh has been created in MPI software for this particular analysis. A single central injection point has been considered in the simulation and all parameters as per actual injection molding tool design have been employed. For brevity of the paper details of moldflow simulation have not been presented over here. Figure 7 shows the results obtained from Moldflow simulation of the plastic tank.

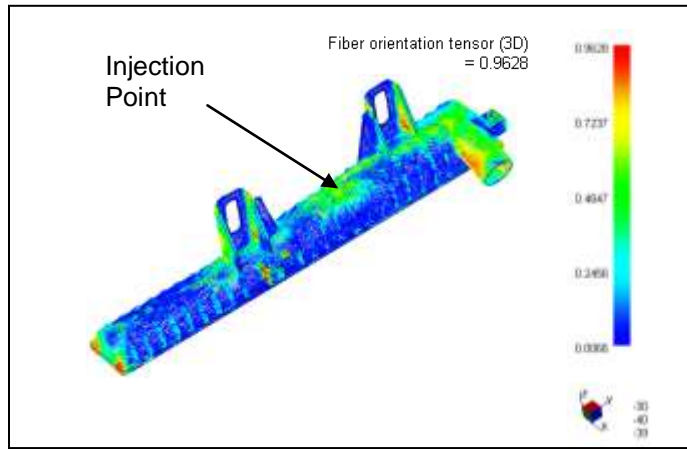


Figure 7: Fiber orientation results from Moldflow simulation of fiber reinforced plastic tank

### Capturing Fiber Orientation from Moldflow Simulation to the Plastic Tank

Fiber orientation results obtained from the moldflow simulation of the plastic tank are imported from moldflow output (.xml) file to the abaqus input (.inp) file by DIGIMAT software. The fiber orientations mapped on to the structural mesh can be seen in Figure 8.

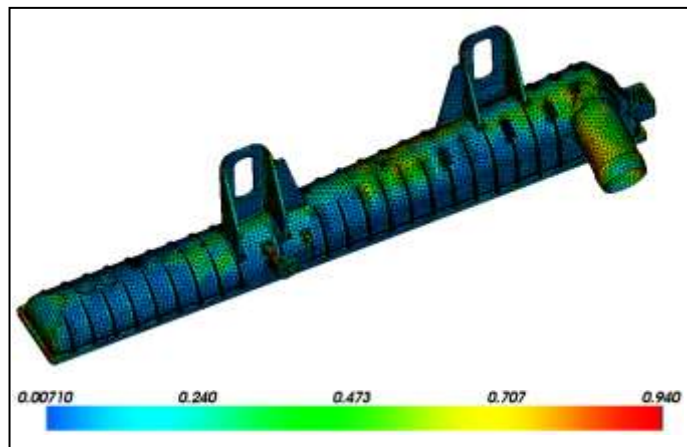


Figure 8: Fiber orientation results mapped on to the structural mesh of fiber reinforced plastic tank

### Numerical Results

Preliminary analysis has been performed on glass fiber reinforced plastic tank by applying 40 psi pressure (design burst pressure) on the internal surface of tank with material properties along flow and cross flow directions. Results obtained for both cases have been presented in Figures 9-10.

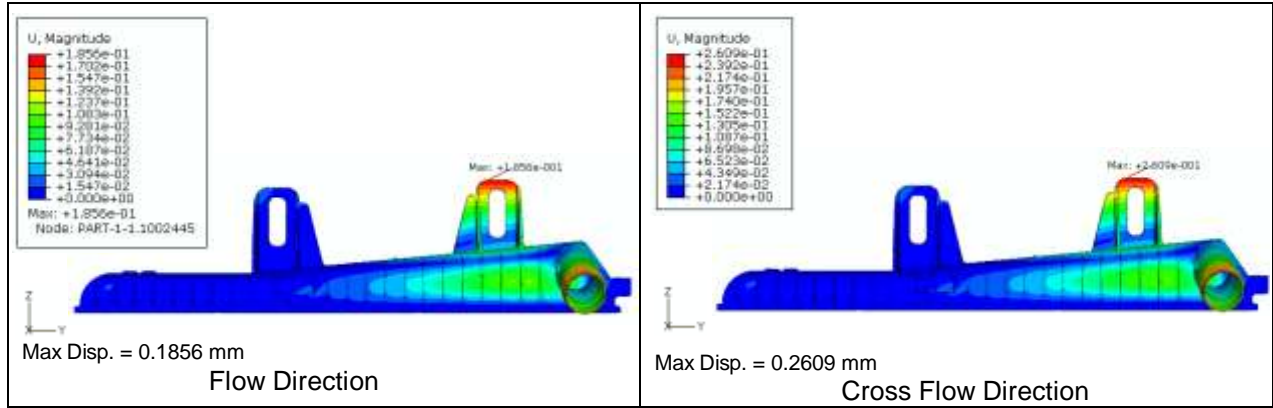


Figure 9: Displacement contours for tank modeled with fibers along flow and cross flow direction and subjected to 40 psi internal pressure

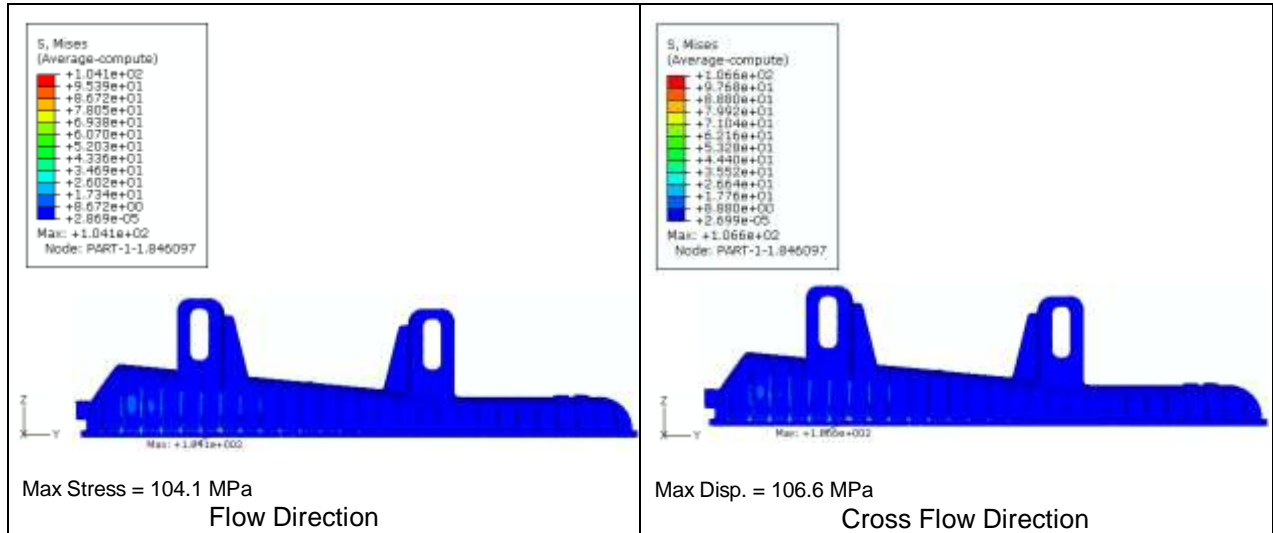


Figure 10: Stress contours for tank modeled with fibers along flow and cross flow direction and subjected to 40 psi internal pressure

The fiber orientation obtained from moldflow simulation of the fiber reinforced plastic tank was captured in the FE model by using DIGIMAT software and the analysis performed for internal pressure of 40 psi. Results obtained from this accurate analysis have been presented in Figures 11-12.

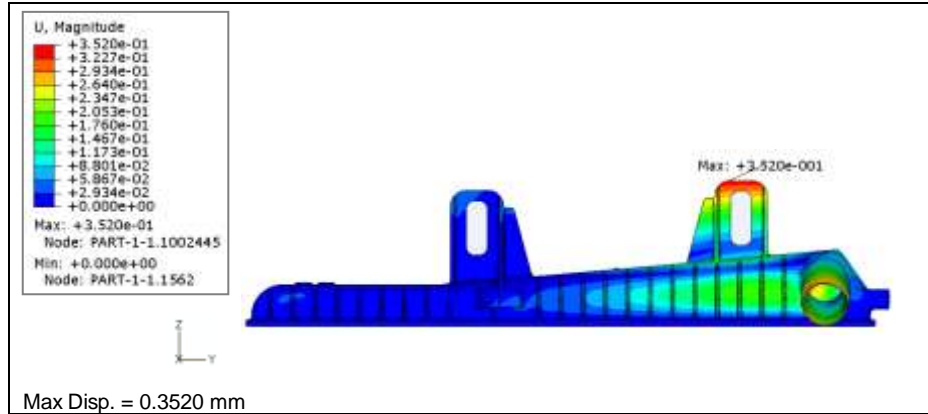


Figure 11: Displacement contours for tank modeled through DIGIMAT software and subjected to 40 psi internal pressure

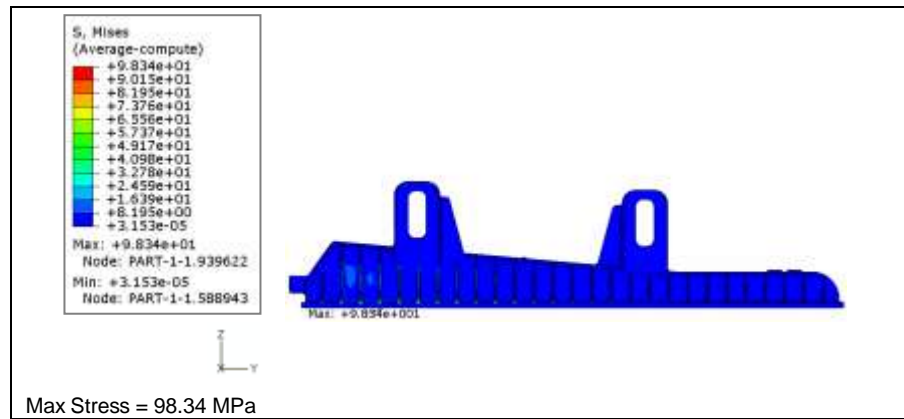


Figure 12: Stress contours for tank modeled with modeled through DIGIMAT software and subjected to 40 psi internal pressure

In the present investigation numerical simulation results obtained for a burst pressure test with traditional homogeneous material properties and with accurate anisotropic material properties have been compared.

## Summary and Next Steps

Results presented above indicate that by assuming uniform distribution of fibers along the flow direction for the glass fiber reinforced plastic tank structure there is an underestimation of displacements in the tank structure. Maximum total displacement obtained by analysis with fibers along cross flow direction has been observed to be 40% higher than the displacement from analysis with fibers along flow direction. Whereas with accurate modeling of anisotropic properties of the tank using DIGIMAT software maximum total displacement has been observed to be 89% higher. The maximum von mises stress observed in analysis with fibers along cross flow direction is 2.4% higher than that obtained with fibers along flow direction. Similar analysis with accurate material modeling using DIGIMAT software has provided maximum von mises stress 5.5% lesser than that obtained with fibers along flow direction. Thus it can be observed that with conventional material modeling using material properties with different angle of fiber orientation provides inconsistent results. Also with conventional material modeling there is a

finite overestimation of the stiffness of the plastic tank structure. It can be concluded that incorporation of fiber orientation data in structural analysis is necessary for accurate prediction of structural performance.

A more detailed study is currently in progress wherein a three-point bend test on simply supported GFRP radiator end tank is being performed as seen in Figure 13. At various critical locations on the tank structure accurate measurements of deformation will be measured. Numerical simulation of this bend test will be performed with similar sets of material models in flow and cross flow direction and by using DIGIMAT software. Comparison of results obtained from these simulations with experimental readings is expected to provide more realistic validation of this simulation effort to capture anisotropic properties of short glass fiber reinforced plastic tank.



Figure 13: Experimental setup for three-point Bend test on radiator end tank

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