Experimental Study on Spring-in Deformation for L-shape CFRP Components

Tushar Gajjar¹, Dhaval Shah²*, S J Joshi² and K M Patel²

¹Mechanical Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat – 395 007, India.
²Mechanical Engineering Department, Institute of Technology, Nirma University, Ahmedabad – 382 481, India

E-mail : *dbshah@nirmauni.ac.in; tushar.gajjar79@gmail.com

Abstract. The carbon fiber reinforced polymer (CFRP) is one of the modern composite material which is widely used in space applications, automobile industries and many more because of its high specific properties over conventional metals and alloys. Various manufacturing processes are available for preparation of CFRP components. Hand layup process is a versatile process for manufacturing a composite material because of its simplicity and cost-effectiveness. In this research paper, L-shape components from CFRP have been manufactured using the hand layup process. The mixture of different epoxy resin systems along with proper hardener is applied to dry carbon fabric to prepare composite parts using hand layup process. The spring-in deformation has been measured for CFRP L-shaped components fabricated from four and eight layer laminates with different epoxy resin systems. The spring-in deformation is minimum for eight layer components made using Hinpoxy VB resin system.

Keywords. CFRP, hand-layup process, spring-in deformation, epoxy resin system

1. Introduction

The composite material is the combination of two or more materials which produce a new material with desired mechanical properties. It is widely used nowadays in space applications, automobile industries etc. because of its high specific properties over conventional metals and alloys [1]. Spring-back deformation is a very important parameter for the composite product and it depends on material properties. Tavakol et al. [2] worked on various parameters for manufacturing of carbon fiber epoxy composite parts like cure shrinkage, thermal strains, tool-part interface, cure kinetics and concluded that coefficient of thermal expansion (CTE) between the tool and part has more effect on the process-induced residual stresses as well as distortion in the parts causing spring-in or spring-back deformation.

Many researchers worked to find spring-back deformation with changing different properties. Fornlund et al. [3] performed different experimentation and test for detecting effects of design and process parameters on the spring-in of composite laminates with a symmetric layup. Spring-in occurs due to differential thermal bending between fibers and matrix as well as the growth of mechanical properties of laminates during the process and it varies with changing the resin properties. Johnston et al. [4] observed that spring-back deformation occurs at the surrounding angle of a corner section. It occurs during stress transformation is uniform through the thickness. Typically for CFRP material, the angle variation for 90° corner section is in order of 1° to 3°. Similarly, spring-forward was primarily happened because of a mixture of anisotropic material performance and the geometry of the corner section. Shah et al. [5] manufactured parabolic shaped antenna reflectors using autoclave process and found the spring-back deformation. The spring-back deformation measured with changing different parameters like mould material, prepreg lay-up sequence, laminate thickness and curing cycle and
found optimum spring-back deformation of the antenna reflector. Fiorina et al. [6] presented an engineering method for prediction of spring-back deformation for aircraft thick composite structure. Bellini et al. [7] performed a numerical and experimental model for spring-in analysis. Thermo-chemical and thermo-mechanical phenomena happened during the curing process. The numerical model was used for calculating the spring-in angle for different laminate in order to evaluate the influence of the thickness, corner radius and lay-up sequence on the laminate deformation. Ding [8] performed a three-dimensional thermo-viscoelastic analysis of process-induced residual stress in composite laminates. Hahn and Pagano [9] studied on solidification and curing of resin matrix which effect on elastic modulus of resin. The stress varies with temperature change. Total strain temperature relation developed which used to determine curing stresses of the epoxy composite laminate. Fernlund et al. [10] simplified the prediction of spring-in using 2D process analysis and 3D structured analysis. The code was developed for measuring spring-in for T-45 rib and aircraft part.

In this research paper, L-shape CFRP components have been manufactured using hand layup process. Aluminium block of 6351 grade has been selected as a mould material. Aluminium block has been machined using the vertical milling machine. The L-shape CFRP components have been fabricated with different type of the resin systems and different laminate thickness. HINPOXY C, HINPOXY VB, ARL 135 and ARL 136 have been selected as resin material and the bi-axial dry fabric has been considered as reinforcement. Four and eight layers of L-shape CFRP components have been manufactured. The spring-in angle has been measured for mould material and L-shape CFRP fabricated components using universal bevel protector. The effect of different epoxy resin systems, as well as laminate thickness, have been studied.

2. Experimentation

2.1. Material Selection

The aluminium block 6351 grade material has been selected as the mould materials based on easy availability and cost-effectiveness. The coefficient of thermal expansion of the aluminium block is 21.6 µm/m-K whereas thermal conductivity is 175 W/m-K. The bi-axial carbon fiber having the areal weight of 200 g/m², the tensile strength of 4000 MPa, tensile modulus of 230 GPa has been selected for the experiment. Four different epoxy resin and corresponding hardener systems have been used in the experiment. The technical specifications like viscosity, density, gel time and curing cycle for each epoxy resin systems are given in table 1. The mixing ratio of resin and hardener systems for Hinpoxy C, Hinpoxy VB, ARL 135 and ARL 136 are 100:30, 100:35, 100:32 and 100:90 respectively [11-14]. The other consolidate materials like release film, gloves, brush, clamp used in hand layup process. The release film has been used for a flexible demoulding process for easy removal of the manufactured part from the mould.

| Epoxy systems | Viscosity (mPa) @ 25°C | Density (gm/cm³) @ 25°C | Gel Time (Min.) @ 25°C | Cure Time (Hrs.) @ 25°C |
|---------------|------------------------|--------------------------|------------------------|------------------------|
| Hinpoxy C(Resin) | 9000 to 12000 | 1.15 to 1.20 | 120 | 24 |
| Hinpoxy C (Hardener) | < 50 | 0.94 to 0.95 | | |
| Hinpoxy VB (Resin) | 22000 to 30000 | 1.20 to 1.25 | 150 | 24 |
| Hinpoxy VB (Hardener) | < 50 | 0.94 to 0.95 | | |
| ARL 135 (Resin) | 1000 to 1500 | 1.1 to 1.2 | 150 | 24 + 8(@ 70°C) |
| AH 334 (Hardener) | 50 to 150 | 0.98 to 1.04 | | |
| ARL 136 (Resin) | 2500 to 4500 | 1.14 to 1.17 | 150 | 1(@ 100°C) + 6 (@ 160°C) |
| AH 126 (Hardener) | 100 to 300 | 1.1 to 1.2 | | |

2
2.2. Experimental procedure

The line diagram of the entire experimental set-up for the hand layup process is shown in figure 1. The rectangular aluminium block grade 6351, size 80 mm X 80 mm X 200 mm has been taken for a mould material and has been machined to 70 mm X 70 mm X 200 mm using the vertical milling machining.

![Figure 1. Line diagram for the hand layup process.](image1)

The flat mill tool has been used for making a flat surface cut. The finish cut has been taken as 0.2 mm for getting a smooth surface finish. The sharp corner of the mould edge has removed by applying 4 mm corner radius. The machined aluminium mould has shown in figure 2. The corner angle of aluminium mould has been measured with universal bevel protector and found 90°.

![Figure 2. Mould after applying corner radius](image2)

The release film tape has been mounted on the mould surface for easy demoulding of manufactured components. The single layer of resin and hardener mixture has been applied over the mould surface. The dry carbon fabric has been kept on resin and hardener mixture. The uniform pressure has been applied on dry carbon fabric using a roller to remove extra resin and air gaps between layers. The entire process sequence of resin-hardener mixture and dry fabric layer has been repeated for a number of times as per required thickness of composite components. The entire process has been described in figure 3.
The four and eight layers of L-shape CFRP components have been manufactured using hand layup process. The Hinpoxy C, Hinpoxy VB, ARL 135 and ARL 136 as epoxy resin and Hinpoxy C, Hinpoxy VB, AH 334 and AH 126 as hardener systems have been selected for the manufacturing of L-shape CFRP components. The curing conditions are different for each resin and hardener mixture system. The Hinpoxy C and Hinpoxy VB systems have been cured at atmospheric temperature without any external pressure or loading condition for 24 hours. The ARL 135 system has been cured at atmospheric temperature for 2 hours and then cured at 70 °C for 8 hours. The ARL 136 system has been cured at 100 °C temperature for 1 hour and then cured at 160 °C for 6 hours. The dead weight clamps have been used for supporting as additional weight on the samples to minimize the chances of warpage during its curing time. The curing conditions for different epoxy resin systems have been shown in figure 4.

The cured L-shape CFRP components have been demoulded after completing curing cycle as shown in figure 5. The multiple L-shape CFRP components have been fabricated using different epoxy resin systems for four and eight layers laminate.
3. Measurement of spring-in deformation

The spring-in deformation has been measured for each fabricated L-shape CFRP components prepared using different epoxy resin systems and four and eight layer laminate thickness. The spring-in deformation depends on various parameters like glass transition temperature, the heat of reaction, the degree of cure etc. The exterior angle has been measured using universal bevel protector for each manufactured samples. The least count value of the universal bevel protector is 5°. The spring-in angle measurement process using universal bevel protector has been shown in figure 6.

The average measured spring-in angle for each sample are shown in table 2. The result shows that the spring-in angle is different for the different components fabricated using different epoxy resin systems and four and eight layer laminate thickness. The spring-in angle decreases with increasing number of the layer so the spring-in angle is less for components made using eight layers as compared to components made using four layers. The highest spring-in angle measured in components fabricated using Hinpoxy C resin systems. The lowest spring-in angle measured in components fabricated using Hinpoxy VB resin systems.
Table 2. Measured exterior angle for L-shaped components

| Epoxy System | 4 Layer | 8 Layer |
|--------------|---------|---------|
| Hinpoxy C    | 85.67°  | 88.16°  |
| Hinpoxy VB   | 89.083° | 89.25°  |
| ARL-135      | 87.42°  | 88.58°  |
| ARL-136      | 88.10°  | 88.83°  |

The spring-in angle for different epoxy resin systems has been shown in figure 7. The results show that Hinpoxy C has a maximum spring-in angle while Hinpoxy VB has a minimum spring-in angle. The spring-in angle depends on the curing process and curing time. The angle variation for ARL-135 and ARL-136 epoxy has nearly 1° with the increasing number of layers from 4 layers to 8 layers while Hinpoxy VB has 0.15° variation.

Figure 7. Spring-in angle for different epoxy resin systems

4. Conclusion
The experimental investigation for spring-in deformation has been carried out for L-shape CFRP components. The aluminium block 6351 grade has been selected as the mould material. The metallic mould has been machined using the vertical milling machine to obtain a smooth surface finish. The L-shape CFRP components have been manufactured using hand layup process. The different epoxy resin along with corresponding hardener systems and four and eight layers laminate thickness have been considered as process parameters to study spring-in deformation. The proper consolidation materials have been identified for manufacturing of components in hand layup process. The average spring-in angle has been measured for each fabricated L-shape components using the universal bevel protector. The spring-in angle decreases with increasing number of the layer so the spring-in angle is less for components made using eight layers as compared to components made using four layers. The results show that Hinpoxy C has a maximum spring-in angle while Hinpoxy VB has a minimum spring-in angle.

References

[1] Mazumdar S K, Composites Manufacturing Materials, Product, and Process Engineering, CRC Press.

[2] Tavakol B, 2013, Prediction of residual stresses and distortion in carbon fiber epoxy composite parts due to curing process using finite element analysis, Journal of Applied
Polymer Science, 128, 2, 941-950.

[3] Albert C and Fernlund G, 2002, Spring-in and warpage of angled composite laminates, Composites Science and Technology, 62, 14, 1895-1912.

[4] Johnston A, An integrated model of the development of process-induced deformation in autoclave processing of composite structures, 1997, University of British Columbia.

[5] Shah D B, Patel K M, Patel A I, Pariyal V, Joshi S J, 2018, Experimental investigation on spring-back deformation during autoclave curing of parabolic antenna reflectors, Composites Part A: Applied Science and Manufacturing, 115, 134-146.

[6] Fiorina M, Seman A, Castanié B, Ali K M, Schwob C, Mezeix L, 2017, Spring-in prediction for carbon/epoxy aerospace composite structure, Composite Structures, 168, 739-745.

[7] Bellini C, Sorrentino L, Polini W, Corrado A, 2017, Spring-in analysis of CFRP thin laminates: numerical and experimental results. Composite Structures, 173, 17-24.

[8] Ding A, Li S, Wang J, Zu L, 2015, A three-dimensional thermo-viscoelastic analysis of process-induced residual stress in composite laminates, Composite Structures, 129, 60-69.

[9] Hahn H T and Pagano N J, 1975, Curing stresses in composite laminates, Journal of composite material.

[10] Fernlund G, Osooly A, Poursartip A, Vaziri R, Courdji R, Nelson K, Griffith J, 2003, Finite element based prediction of process-induced deformation of autoclaved composite structures using 2D process analysis and 3D structural analysis. Composite Structures, 62, 2, 223-234.

[11] TechnicalDatasheet- Tentative specifications of Hinpoxy C Resin/ Hinpoxy C Hardener: 1-2.

[12] TechnicalDatasheet- Tentative specifications of Hinpoxy VB Resin/ Hinpoxy VB Hardener: 1-2.

[13] TechnicalDatasheet- Tentative specifications of ARL 135 Resin/ AH 334 Hardener: 1-2.

[14] TechnicalDatasheet- Tentative specifications of ARL 136 Resin/ AH 126 Hardener: 1-2.