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Spring-back Deformation Prediction for CFRP Reflectors Manufactured Using Various Processes

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Abstract

Because of its superior particular characteristics to traditional metals and alloys, carbon fibre reinforced polymer (CFRP) is widely utilised in space applications, automobile sectors, aircraft, and sports equipment. Many composite manufacturing techniques are now standard, depending on the size, shape, and processing time of the result. The hot air oven and Vacuum Assisted Resin Transfer Moulding (VARTM) are low-cost production methods with good dimensional stability. CFRP reflectors were produced utilising oven curing and the VARTM method to estimate spring-back deformation in this study. The inner surface dimensions of produced reflectors were measured using 3D scanning methods at various locations. The spring-back deformation of produced CFRP reflectors is caused by the difference between the theoretical CAD model and reflector dimensions at each point. In the manufacture of reflectors, the laminate thickness and layup orientation have been studied as processing factors. The spring-back deformation of produced reflectors has been compared with various process parameters utilising oven curing and VARTM production methods. The difference in spring-back deformation % is determined to be within acceptable limits. As the laminate thickness rises, the spring-back deformation reduces.

Keyword: *CAD model, VARTM production, CFRP reflectors, Spring-back deformation*

INTRODUCTION

A composite material is created by fusing two or more materials together to provide a unique set of characteristics. Because of its excellent strength-to-weight ratio, it is widely utilised in the aerospace, space, car, and sporting goods sectors [1]. As an alternative to the autoclave, the hot air oven method is employed. Prepreg is a pre-impregnated fibre that comes in unidirectional, bi-directional, and twill fabric tapes [2]. Because of its cheap capital and processing costs, the hot air oven curing technique is frequently utilised for producing complicated shaped composite components. The VARTM process, however, is an alternate production method due to its low dimensional precision. Depending on the geometry of the component, the difference between the cured laminated composite part dimensions and the theoretical dimension is referred to as spring-back deformation or warpage.

For composite goods, several studies concentrated on predicting spring-back deformation and warpage. Darrow and Smith [3] looked at three process factors that affect spring-back deformation: thicknesses, cure shrinkage, mould expansion, and fibre volume fraction gradients. The impact of tool surface quality and cure cycle on spring-back deformation was proven by Fernlund and Poursartip [4]. In the autoclave process, Kaushik et al. [5] investigated the influence of several factors such as pressure, degree of cure, and ramp rate on coefficient of friction. During the autoclave production process, Kappel et al. [6] evaluated the influence of critical factors such as part thickness, layup, part radius, and dispersion of occuring deformation. Correia et al. [7] devised an analytical version of the incompressible flow governing equation, which was then utilised to quantify the influence of process factors including input and outlet pressure, fibre architecture, and lay-up orientation. Govignon et al. [8] tested thickness variation during compaction in order to recreate reinforcing behaviour throughout the pre-filling, filling, and post-filling stages. Hammami et al. [9] used a 1-D model to investigate the impact of processing factors in the vacuum infusion moulding process. The highest compaction pressure used in the compaction test was not more than 1 bar. The number of layers did not have a significant impact on the compaction behaviour of the preform at low compaction pressures (less than 1 bar). Arulappan et al. [10] used a flat plate, an L-shaped plate, and a flat plate with a centre circular hole to test CFRP material.

For each form, the pressure was changed. The flow of resin is affected by the flow medium. High Permeability Medium (HPM) was chosen for the big structure to achieve a high flow rate and decrease filing time. Because resin pressure and part thickness fluctuation are factors in VARTM that play a critical role in manufacturing component, Song et al. [11] established an experimental model for integrating resin flow through the preform and preform relaxation.

The hot-air oven and the VARTM manufacturing process were utilised in this study to estimate the dimensional accuracy of CFRP reflectors. For the construction of the parabolic mould, stainless steel AISI 430 was chosen. The thickness of the laminate and the orientation of the layup were taken into account as process factors. In the hot air oven method, Hinpreg A45 CFRP prepreg is utilised, but in the VARTM process, carbon fibre dry fabric, epoxy resin 520, and D-type hardener are employed. The hot air oven and VARTM processes were used to cure the parabolic form reflectors. 3D scanning methods were used to measure the inner surface dimensions of produced CFRP reflectors at 200 distinct places. Dimensional inaccuracy or spring-back deformation in produced CFRP reflectors is caused by the difference between the theoretical CAD model and reflector dimensions at each point. The spring-back deformation of cured reflectors made using hot air oven and VARTM production methods was compared.

Experimental Preparation

The stainless steel AISI 430 grade was chosen as the mould material, with dimensions of 300 X 300 X 70 mm. Solid modelling software was used to create a 3D model of the parabolic mould. The parabolic profile has a circumferential diameter of 240 mm and a depth of 50 mm on one side. As illustrated in Figure 1, the stainless steel mould block was machined using NC code in a 5-axis vertical milling centre with a very high surface quality.

Figure 1: Manufactured stainless steel mould

Reflectors manufacturing using hot air oven process

For the hot air oven experiment, the Hinpreg A45 unidirectional prepreg tape was chosen. Depending on the number of laminates and thickness necessary, layers of prepreg are cut into a circular form with a diameter of 300 mm. In the hot air oven process, consolidation materials such as release agent, peel ply, breather cloth, vacuum bagging, and so on were utilised. Initially, a release agent was applied to the parabolic mould surface in the hot air oven process. Figure 2 depicts the placement of prepreg layers with appropriate orientation. While curing, the peel ply allows volatiles and surplus matrix to flow freely. Breathable fabric allows for suction to be applied and aids in the evacuation of air and volatiles from the entire assembly. The entire assembly is sealed using sealant tape and a vacuum bag. As illustrated in Figure 3, the complete system was vacuum bagged using vacuum film, a vacuum valve, and a hose pipe.

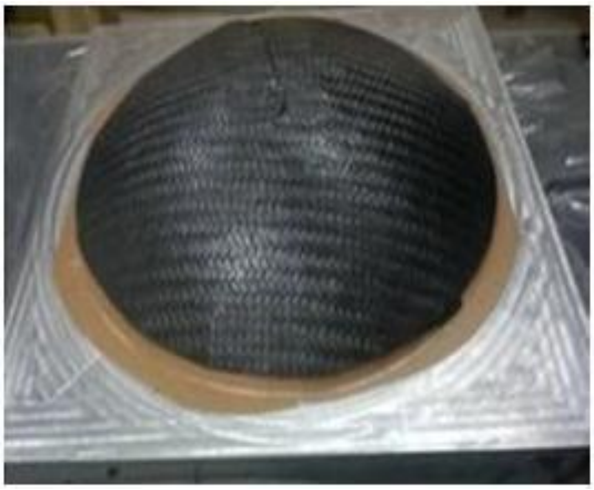

Figure 2: Layers of CFRP prepreg on steel mould

Figure 3: Vacuum bagging and air suction process

Reflectors manufacturing using VARTM process

The VARTM technique is also used to make parabolic shape reflectors. In the VARTM experimental method, dry carbon fibre was used as a reinforcement and epoxy resin and hardener as a matrix material. For the VARTM process, vacuum pumps, infusion mesh, purported plastic, catch pots, and other items were employed. For ease of demoulding, a coating of release agent is placed to the paraboloid surface of the mould. Figure 4 shows how the four layers of carbon fibre were laid down on the mould surface in the right order. Peel ply, claimed plastic, and infusion mesh are also put on fibre layers at the same time, and the entire assembly is sealed with sealant tape and a vacuum bag. For vacuum pressure, a PVC hose pipe is linked to the resin inlet and the opposite side. As illustrated in Figure 5, the resin is sucked into the system by vacuum pressure.

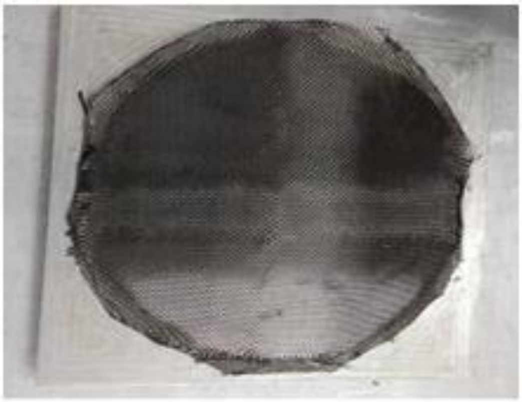

Figure 4: Layers of carbon fibers

Figure 5: Resin inlet and vacuum hose

Curing of CFRP reflectors

The complete setup - mould, composite prepreg, and consolidation ingredients – is retained in the hot air oven machine for curing purposes. In the VARTM method, the mould and consolidation material were cured for twenty-four hours at ambient temperature. After the curing process, the complete assembly is removed from the oven machine, and the consolidation materials are separated from the assembly at room temperature. Demoulding for the VARTM process is likewise done in a similar manner. Figures 6 and 7 show the final cured reflectors for the hot air oven and VARTM processes, respectively.

Figure 6: Cured reflector manufactured using hot air oven process

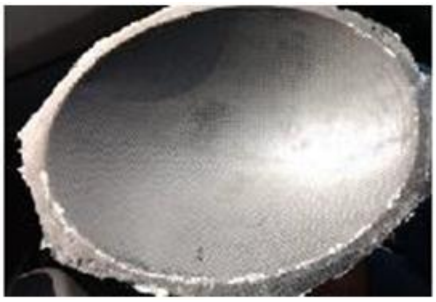

Figure 7: Cured reflector manufactured using VARTM process

Dimensional Measurement using 3D Scanning

For dimension measurement, the inner surface of reflectors is chosen, and 200 coordinate points are determined on this surface. These spots were achieved by projecting circles with diameters of 50, 100, 150, and 240 mm on the reflector's parabolic surface. Using a 3D scanner, measurements of certain locations are taken to verify the parabolic reflector's precision. To accomplish variation on each required coordinate point, this scanned model of composite reflector is overlaid with a theoretical CAD model for the same. Figure 8 shows a contour plot that shows the divergence at each coordinate point. Spring-back deformation for that reflector is defined as the root mean square of all 200 deviations. Table 1 shows the theoretical X, Y, and Z coordinates as well as the scanned X, Y, and Z coordinates for the hot air oven curing process, whereas Table 2 shows the VARTM curing process.

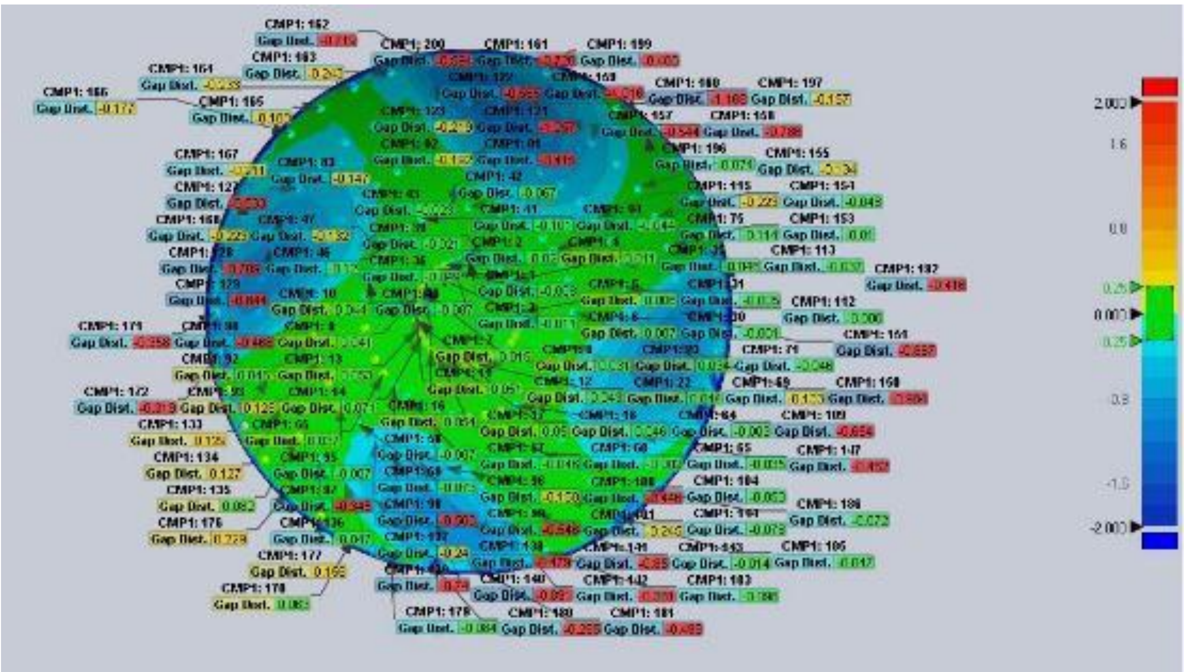

Figure 8: Deviation contour plot for composite reflector

Table 1: Deviation of each coordinate points in hot air oven curing process

Sr. No.	Predefined coordinate points in mm			Scanned coordinate points in mm			Deviation in mm
	X	Y	Z	X	Y	Z	
1	0	-2.003	25	0	-2.057	24.992	0.054589
2	-3.911	-2.003	24.692	-3.913	-2.008	24.691	0.005477
3	-7.725	-2.003	23.776	-7.728	-1.978	23.81	0.042308
4	-11.35	-2.003	22.275	-11.355	-1.957	22.284	0.047138
5	-14.694	-2.003	20.225	-14.71	-1.949	20.235	0.057201
6	-17.677	-2.003	17.677	-17.687	-1.953	17.687	0.051962
. . . 20	18.772	-46.083	118.521	18.722	-46.433	118.251	0.44486
Min.	-120	-46.084	-120	-120.32	-47.072	-119.68	0.004
Max.	120	0	120	120.54	0.004	119.832	1.234
RMS							**0.58**

Table 2: Deviation of each coordinate points in VARTM curing process

Sr. No.	Predefined coordinate points in mm			Scanned coordinate points in mm			Deviation in mm
	X	Y	Z	X	Y	Z	
1	0	-2.003	25	0	-1.995	25.001	-0.008
2	-3.911	-2.003	24.692	-3.911	-1.983	24.695	-0.02
3	-7.725	-2.003	23.776	-7.726	-1.992	23.778	-0.011
4	-11.35	-2.003	22.275	-11.349	-2.014	22.273	0.011
5	-14.694	-2.003	20.225	-14.694	-2.009	20.224	0.006
6	-17.677	-2.003	17.677	-17.677	-2.01	17.677	0.007
. . . 200	18.772	-46.083	118.521	18.831	-45.612	118.877	-0.594
Min.	-119.999	-46.084	-119.997	-120.217	-46.265	-120.3	-1.168
Max.	119.999	0	119.997	120.258	0.023	120.441	0.229
RMS							**0.35**

The reflector created using the hot air manufacturing method has a spring-back deformation of 0.58 mm, whereas the reflector manufactured using the VARTM process has a spring-back deformation of 0.35 mm. In each example, this value was achieved for the identical configuration reflector. When compared to the hot air oven curing method, the percentage variations in spring back deformation have been reduced by up to 40% in the case of VARTM. Different laminate thicknesses and lay-up orientations were used to make the various antenna reflectors. The number of layers, as well as unidirectional, transverse, and quasi-isotropic layup orientations, were taken into account. For each example, the deviation, or dimensional inaccuracy, is measured and the root mean square value from the VARTM and hot air oven curing processes is compared.

CONCLUSION

The CFRP antenna reflectors were made in a hot air oven utilising the VARTM production method and a stainless steel AISI 430 mould. In the VARTM method, Hinpreg A45 unidirectional prepreg tape was utilised in the hot air oven, and bi-axial dry fabric with epoxy 520 resin and hardener D was employed. At 200 separate sites, the inner surface size of CFRP produced reflectors was measured using 3D scanning methods. The spring-back deformation of cured reflectors made using hot air oven manufacturing techniques was compared to the VARTM process. When compared to the hot air oven curing method, the percentage variations in spring back deformation have been reduced by up to 40% in the case of VARTM. As a process parameter, the influence of laminate thickness and layup orientation has been examined. The spring back deformation reduces as the laminate thickness rises. Spring back deformation is minimal in the quasi-isotropic layup orientation.

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