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Prediction of Spring-back Deformation for CFRP Reflectors Manufactured using Various Processes

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Abstract
The Carbon Fiber Reinforcement Polymer (CFRP) is widely used in space application, automobile industries, aerospace and sports equipments because of good specific properties over conventional metals and alloys. Many composite manufacturing processes are accustomed nowadays depending on product size, shape and processing time. The hot air oven and Vacuum Assisted Resin Transfer Moulding (VARTM) are the low cost with high dimensional stability manufacturing method. In this research paper, CFRP reflectors have been manufactured using oven curing as well as VARTM process to predict spring-back deformation. The dimensions of the inner surface of the manufactured reflectors have been measured using 3D scanning techniques at different location. The deviation between theoretical CAD model and reflector dimensions at each location gives spring-back deformation for the manufactured CFRP reflectors. The laminate thickness and layup orientation have been considered as a processing parameters in reflector manufacturing. The comparison of spring-back deformation for manufactured reflectors with various process parameters using oven curing and VARTM manufacturing techniques have been carried out. The percentage difference in spring-back deformation is found within acceptable limit. The spring-back deformation decreases as laminate thickness increases.

Keywords: Hot air oven curing; Reflector; Spring-back deformation; VARTM.

Introduction
A composite material is made by combining two or more materials to give a unique combination of properties. It is widely used in aerospace industries, space applications, automobiles and sport industries due to its high strength to weight ratio [1]. Hot air oven process is used as alternative process of autoclave. A prepreg is a pre-impregnated fibre and available as uni-directional, bi-directional and twill fabric tape [2]. Hot air oven curing process is widely used for making complex shaped composite components because of low capital and processing cost. But, due to low dimensional accuracy, VARTM process is the alternative manufacturing method. The variation between cured laminated composite part dimensions and theoretical dimension is usually referred as spring-back deformation or warpage depending on shape of components.
Many researchers worked on prediction of the spring-back deformation and warpage for the composite products. Darrow and Smith [3] considered three process parameters – thicknesses cure shrinkage, mould expansion and fiber volume fraction gradients which effects on spring-back deformation. Fernlund and Poursartip [4] demonstrated the effect of the tool surface condition and cure cycle on spring-back deformation. Kaushik et al. [5] studied the effect of different parameters – pressure, degree of cure and ramp rate on coefficient of friction in autoclave process. Kappel et al. [6] measured effect of essential parameters such as part thickness, layup, part radius and scattering of occurring distortion during autoclave manufacturing process. Correia et

al. [7] developed analytical formulation of governing equation for incompressible flow and this model successively used to measure the effect of process parameters such as inlet and outlet pressure, fibre architecture and lay-up orientation. Govignon et al. [8] performed experimentation on thickness variation during compaction to replicate reinforcement behaviour while pre-filling, filling, and post filling stage. Hammami et al. [9] studied the effects of the processing variables in vacuum infusion moulding process by developing 1-D model. The compaction test was conducted with the maximum compaction pressure not exceeding 1 bar. It was found that for low compaction pressures (≤1 bar), the number of layers did not have significant influence on the compaction behaviour of the preform. Arulappan et al. [10] performed experiments on CFRP material with flat plate, L-shaped plate and flat plate with central circular hole. The pressure was varied for a different shape. The flow of resin depends on flow medium. For large structure, High Permeability Medium (HPM) was selected for getting high flow rate and reduce filing time. Song et al. [11] developed experimental model for incorporating resin flow through the preform and relaxation of the preform because resin pressure and part thickness variation were parameters in VARTM which play a vital role in manufacturing component.

In this research paper, Hot-air oven and VARTM manufacturing process have been used to predict dimensional accuracy of CFRP reflectors. The stainless steel AISI 430 material has been selected for fabrication of parabolic mould. The thickness of the laminate and layup orientation have been considered as process parameters. The Hinpreg A45 CFRP prepreg is used in hot air oven process whereas carbon fiber dry fabric along with epoxy resin 520 and D-type hardener are used in VARTM process. The parabolic shape reflectors have been cured using hot air oven process and VARTM process. The dimensions at inner surface of manufactured CFRP reflectors have been measured using 3D scanning techniques at different 200 locations. The deviation between theoretical CAD model and reflector dimensions at each location gives dimensional inaccuracy or spring-back deformation for the manufactured CFRP reflectors. The comparison of spring-back deformation of cured reflectors manufactured using hot air oven and VARTM manufacturing techniques have been carried out.

Experimental Preparation

The stainless steel AISI 430 grade has been identified as mould material with 300 X 300 X 70 mm size. The 3D model of the parabolic mould has been prepared using solid modelling software. The dimension of parabolic profile at one side is 240 mm circumferential diameter with 50 mm depth. The stainless steel mould block has been machined using NC code in 5–axis vertical milling center with very high surface finish as shown in Figure 1.

Figure 1: Manufactured stainless steel mould

Reflectors manufacturing using hot air oven process

The Hinpreg A45 unidirectional prepreg tape has been selected for hot air oven experimental process. Layers of prepreg are cut into the round shape of 300 mm diameter depending upon required number of laminates and thickness. The consolidation materials like release agent, peel ply, breather cloth, vacuum bagging etc. have been used in hot air oven process. In hot air oven process, initially release agent has been applied on the parabolic mould surface. The arrangement of prepreg layers with proper orientation is shown in Figure 2. Peel ply permits free passage of volatiles and excess matrix while curing. Breather fabric provides the means to apply the vacuum and assists removal of air and volatiles from the whole assembly. Sealant tape and vacuum bag are used for sealing the entire assembly. The entire setup has been vacuum bagged using vacuum film, vacuum valve and hose pipe as shown in Figure 3.

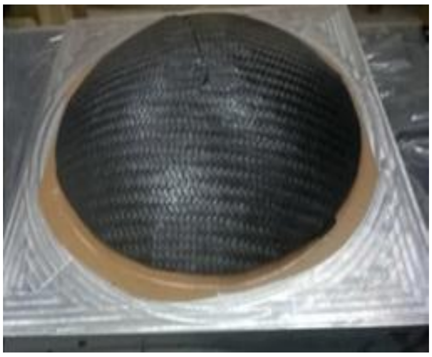

Figure 2: Layers of CFRP prepreg on steel mould

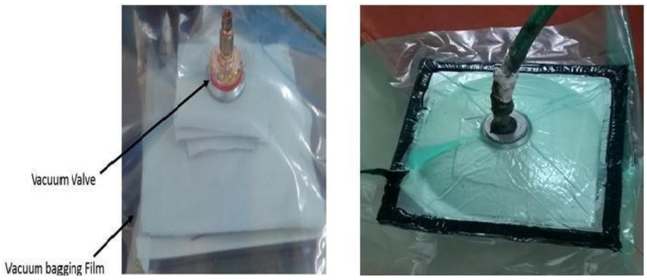

Figure 3: Vacuum bagging and air suction process

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Reflectors manufacturing using VARTM process

The parabolic shape reflectors are also manufactured using VARTM process. The dry carbon fabric has been selected as a reinforcement and epoxy resin and hardener as a matrix material in VARTM experimental process. The vacuum pump, infusion mesh, purported plastic, catch pot, etc. have been used for VARTM process. The layer of release agent is applied on the paraboloid surface of mould for ease of demoulding. The four layer of carbon fiber have been arranged on the mould surface in proper sequence as shown in Figure 4. Similarly, peel ply, purported plastic and infusion mesh are placed on fiber layers simultaneously and whole assembly is sealed using sealant tape and vacuum bag. The PVC hose pipe is attached at resin inlet and other side for obtaining vacuum pressure. The resin is sucked in the system because of vacuum pressure as shown in Figure 5.

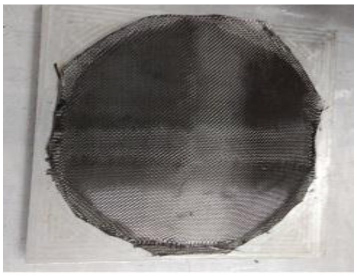

Figure 4: Layers of carbon fibers

Figure 5: Resin inlet and vacuum hose

Curing of CFRP reflectors

In hot air oven process, the entire setup – mould, composite prepreg along with consolidation materials is kept in oven machine for curing purpose. The mould along with consolidate material have been cured for twenty four hours at atmospheric temperature in VARTM process. The entire assembly is taken out from oven machine after curing process and consolidation materials are detached from assembly at room temperature. The demoulding process for VARTM process is also done in similar fashion. The final cured reflectors for hot air oven and VARTM processes are shown in Figure 6 and Figure 7 respectively.

Figure 6: Cured reflector manufactured using hot air oven process

Figure 7: Cured reflector manufactured using VARTM process

Dimensional Measurement using 3D Scanning

The inner surface of reflectors are selected for dimension measurement and 200 number of coordinate points are identified on this surface. These points are obtained projecting circles of diameter 50, 100, 150, and 240 mm on parabolic surface of reflector. Measurement of specified points is performed to ensure the accuracy of the parabolic reflector using 3D scanner. This scanned model of composite reflector is superimposed with theoretical CAD model for the same to achieve deviation on each prescribed coordinate points. The deviation at each coordinate points is given using contour plot as shown in Figure 8. The root mean square of all 200 deviation is referred as spring-back deformation for that reflector. The theoretical X, Y and Z coordinates and scanned X, Y and Z coordinates are given in Table 1 for hot air oven curing process whereas Table 2 for VARTM curing process.

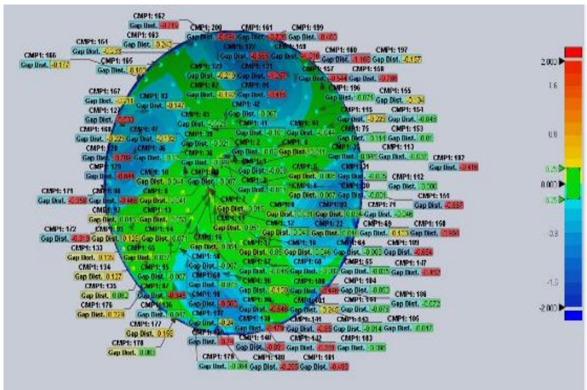

Figure 8: Deviation contour plot for composite reflector

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
. . . 200	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 spring-back deformation for the reflector manufactured using hot air manufacturing process is 0.58 mm whereas for the reflector manufactured using VARTM process is 0.35 mm. This value has been obtained for the same configuration reflector in each case. The percentage deviations in spring back deformation has been reduced up to 40% in case of VARTM compared to hot air oven curing process. The different antenna reflectors have been manufactured with different laminate thickness and lay-up orientations. The 4, 8 and 12 number of layers and unidirectional, cross and quasi-isotropic layup orientations have been considered. The deviation i.e. dimensional inaccuracy is observed and root mean square value is compared from VARTM and hot air oven curing process for each case.

Conclusion

The CFRP antenna reflectors have been manufactured using hot air oven and VARTM manufacturing process with stainless steel AISI 430 mould. Hinpreg A45 unidirectional prepreg tape is used in hot air oven and bi-axial dry fabric with epoxy 520 resin along with hardener D have been used in VARTM process. The dimension at inner surface of CFRP manufactured reflectors have been measured using 3D scanning techniques at 200 different locations. The comparison of spring-back deformation of cured reflectors manufactured using hot air oven manufacturing techniques and VARTM process have been carried out. The percentage deviations in spring back deformation has been reduced up to 40% in case of VARTM compared to hot air oven curing process. The effect of laminate thickness and layup orientation have been considered as a process parameters. As laminate thickness increases, the spring back deformation decreases. The quasi-isotropic layup orientation have minimum spring back deformation.

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