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On the fabrication of carbon fabric reinforced epoxy composite shell without joints and wrinkling

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Abstract. This article describes a simple and cost effective fabrication procedure by using hand lay-up technique that is employed for the manufacturing of thin-walled axi-symmetric composite shell structures with carbon, glass and hybrid woven fabric composite materials. The hand lay-up technique is very commonly used in aerospace and marine industries for making the complicated shell structures. A generic fabrication procedure is presented in this paper aimed at manufacture of plain Carbon Fabric Reinforced Plastic (CFRP) and Glass Fabric Reinforced Plastic (GFRP) shells using hand lay-up process. This paper delivers a technical breakthrough in fabrication of composite shell structures without any joints and wrinkling. The manufacture of stiffened CFRP shells, laminated CFRP shells and hybrid (carbon / glass / epoxy) composite shells which are valued by the aerospace industry for their high strength-to-weight ratio under axial loading have also been addressed in this paper. A fabrication process document which describes the major processing steps of the composite shell manufacturing process has been presented in this paper. A study of microstructure of the glass fabric/epoxy composite, carbon fabric/epoxy composite and hybrid carbon/glass/fabric epoxy composites using Scanning Electron Microscope (SEM) has been also carried out in this paper.

Keywords: composite structure; CFRP; GFRP; thin-walled shell; hybrid; hand lay-up; SEM

1. Introduction

Structures composed of light weight composite materials especially Polymer Matrix Composites (PMC) (Tarpani 2006, Immarigeon and Holt 1995) which excel over their metallic counterparts have been applied in aerospace (Matsui 1995, Velmurugan 2009) and automotive industries to a greater extent, because of the weight savings of the principal structural components as well as dimensional stability. Fabric reinforced or Textile composites (Naik and Ganesh 1992) play an important role in aerospace application and as well in automotive application (ASM International 1990) like automobile exterior body cover (Poorzeinolabedin Golzar 2011) due to their low processing cost and high process ability typically in lay-up manufacturing of composite structures.

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The aerospace industry predominantly uses carbon fabric composites impregnated with epoxy matrix system due to their high performance characteristics at elevated temperatures (Mazumdar 2010, Hancox 1988). The rocket motor cases, space platforms, supporting structures, antenna and solar panels have been constructed using carbon fabrics (Mitra 2000, Nair 2011). Thin-walled composite shells are widely used in commercial aircrafts for making components like radome, rudders, centre fuselage, rear fuselage, nacelle, air conditioning ducts, outboard and inboard aircraft flaps, aileron, engine nose cone and rotor blades which require precisely controlled mechanical properties. Thin-walled composite shells are widely used as a structural member for the protection of expensive electronic packages in case of launch vehicle applications. Stiffeners (Jones 1999, Buragohain and Velmurugan 2011, Lalmoni and Rachel 2007) are structural members that can be integrated into a shell structure for increasing the rigidity of the shell. Composite shells structures (Lalmoni and Rachel 2007) stiffened with internal longitudinal stiffeners (Jones 1999) are finding increasing applications in launch vehicles, satellite structures, aircraft wings, fuselage structures, civil structures because of its high energy absorbing capabilities. Noor et al. (2000) studied the concept of Advanced Grid Stiffened Structure using affordable composite materials along with the structures technology for the future aerospace systems. The present study concerns with the manufacture of composite shells with combined geometry of frustum of conical shell (Topal 2013) and a shallow spherical shell at the top, fabricated with carbon and glass fabric composite material.

The scope of the present work is to study the feasibility of making composite shells using hand lay-up method without any wrinkling and joints. The study prescribed in this paper would be useful for making thin-walled axi-symmetric composite shells without any joints and wrinkling. The principal objective of the present study carried out deals with the following two stages of work:

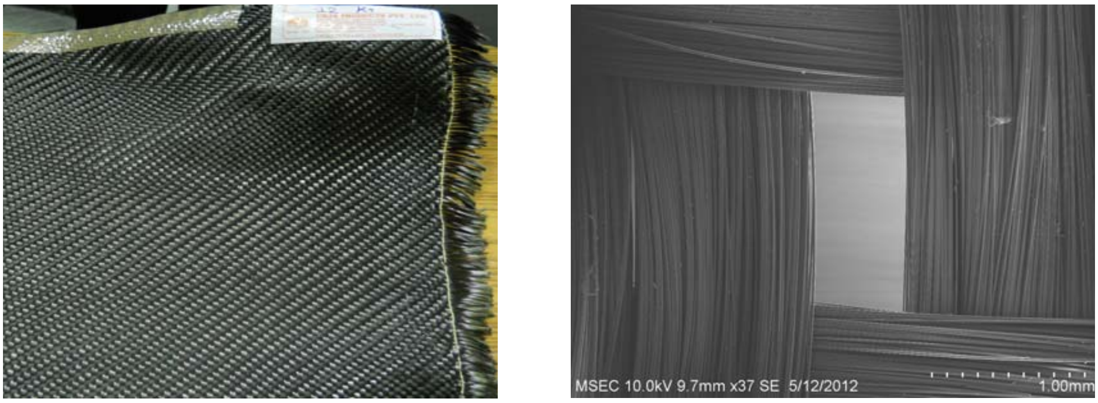
- In the first stage of the paper, the fabrication procedure for the manufacture of plain thin-walled Carbon Fabric Reinforced Plastic (CFRP) shells without any wrinkling and joints using the hand lay-up technique has been presented.
- The second stage of this paper deals with the manufacture of plain thin-walled Glass Fabric Reinforced Plastic (GFRP) shells, stiffened CFRP shells, laminated CFRP shells and hybrid (carbon/glass/epoxy) shells using the hand lay-up procedure. A microscopic investigation of test samples of GFRP, CFRP and Hybrid composite structures have also been attempted in this work.

2. Materials

2.1 Composite material

The materials used for the present study were based upon bidirectional carbon fabric and glass fabric with epoxy resin system (Kingsley 1958, Sundqvist *et al*. 1977) which is a strong, resilient, heat-resistant thermosetting plastic.

The epoxy resins along with hardener were supplied by Huntsman Advanced Materials, Switzerland (Huntsman Advanced Materials 2012). The carbon and glass fabric were supplied by Urja Products (Pvt.) Ltd. (2011). The physical properties of materials carbon fabric and epoxy resin materials employed in the present study are presented in Table 1. Fig. 1(a) shows the photographic image of a typical carbon fabric and Fig. 1(b) shows the SEM image of carbon fabric which is used for the fabrication of plain and stiffened shell structures. The warp and weft



(a) Photographic view (b) SEM photograph

Fig. 1 Carbon fabric

Table 1 Properties of carbon & glass fabric, epoxy resin

Description	Carbon fabric	Glass fabric	Description	Matrix
Weave type	Plain	Plain	Type	ARALDITE® AW106 Epoxy
Count (along warp & weft)	3 k	3 k		
Fabric width, mm	1000	1000	Curing temperature	200C - 1800C
Thickness, mm	0.25	0.27	Density, kg/m^3	1.06 ×103
Weightper sq.meter,g/m^2	640	380	Hardener	HV 953 U
Tensile strength,kg for an area of 25.4 × 101.6 mm	225/Warp, 230/Weft	115/Warp, 92/Weft	Tensile strength, MPa	33
Filament diameter, μm	6.96	11		

Fig. 2 Shell model using SOLIDWORKS®

directions of the carbon fabric are clearly represented in the SEM photograph (Fig. 1(b)).

2.2 Specimen geometry

In this paper, the specimen configuration (h_c = 95; h_s = 45; d_b =147; d_t = 90; α = 22^0; t = 3; All dimensions are given in mm) shown in Fig. 2 has been considered as a structural module, which is an axi-symmetric structure consists of thin-walled conical shell with nearly a thin-walled hemispherical shell on the top. The geometry of the shell specimen has been modelled by using SOLIDWORKS® software package to enable the fabrication of wooden mandrel which is required for the CFRP and GFRP shell fabrication work.

3. Fabrication procedures

3.1 Hand lay-up technique

The hand lay-up process (Mazumdar 2010) was the predominant fabrication method for making composite parts which are widely used in aerospace and marine industries for making the composite prototype parts. Among the various fabrication techniques hand lay-up is the simplest one for making carbon and glass fiber PMCs. In fact the hand lay-up process (Balasubramanian and Alagusundaramoorthy 2011) is the most elementary of composite manufacturing processes that offer number of benefits such as low tooling cost, no restrictions on the size and shape of the product and lowest investment. Fig. 3 represents the schematic diagram of the hand lay-up process for the fabrication of plain CFRP thin-walled shells. Plain weave fabrics are most popular in hand lay-up applications due to their speedy wet-out and easiness in processing.

The four basic steps involved in the manufacturing processes of plain CFRP thin-walled shells for the present study are: Impregnation, lay-up, Consolidation, Solidification. In the first step, every carbon fabric layer is impregnated with epoxy resin system in proper proportion so as to ensure that the epoxy resins flows entirely around all the fibers. The purpose of the second step

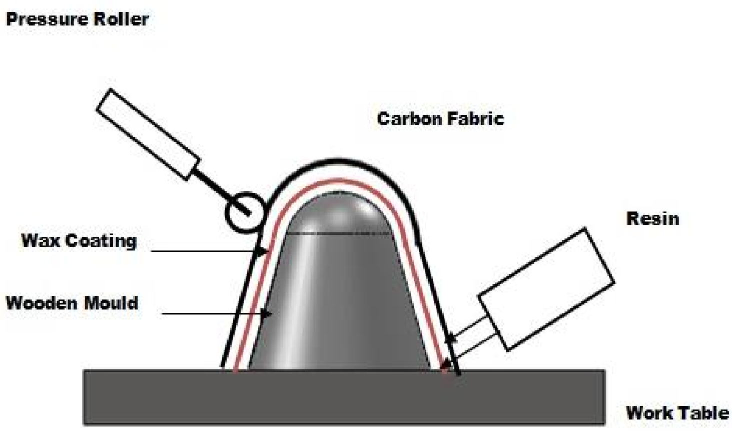


Fig. 3 Schematic illustration-hand layup process

is to accomplish the desired fabric architecture as dictated by the mandrel design. In this step the desired thicknesses of the composite shell is built up by placing various layers of fabric and epoxy resin mixture. During the consolidation process a uniform pressure is applied with the aid of a pressure roller ensuring that all the entrapped air is removed between the fabric layers. In consolidation process the applied pressure is shared by both resin system and fabric structure. Solidification is the final step in the composite manufacturing processes wherein the fabric specimen is cured in room temperature curing for certain time periods which depends on the resin formulation.

3.2 Fabrication process document

The basic steps involved in the manufacturing process of thin-walled CFRP plain shell by hand lay-up process (Murphy 1998) are summarized as follows.

3.2.1 Preparation of mandrel

The wooden mandrel surface has been cleaned thoroughly and coated with a thin film of wax (wax material) and polished to give a smooth surface as shown in Fig. 4(a), so as to get easy ejection of CFRP composite shell from the mandrel & to get smooth inner surface. Alternatively Nylon or polyester film may also be used if the mould is not coated with permanent release coating.

3.2.2 Preparation of carbon fabric mat

Initially, the required carbon fabric mat (size: $500\,\mathrm{mm} \times 500\,\mathrm{mm}$) has been snipped from the carbon fabric roll as shown in Fig. 4(b) was exposed to direct sunlight for some hours in order to eliminate the moisture content present in the carbon fabric.

3.2.3 Preparations of resin mix

The epoxy resin mix has been prepared from the weight of the required carbon fabric material (in grams).The measured weight is rounded to the nearest multiple of ten. The same amount of resin is being used for the lay-up process. The resin and hardener ratio is taken as $100:27$ for obtaining better strength. The proportions of the composite materials taken for the fabrication of CFRP shell with single layer are shown in Table 2. While mixing the resin with hardener the necessary precautions (Kingsley 1958, Huntsman Advanced Materials 2012) were taken into account with reference to the safety data sheet.

3.2.4 Preparation of CFRP shell by impregnating with epoxy resin system

The resin mixture was fed over the surface of the wooden mandrel as shown in Figure 4c. Then the carbon fabric has been laid over the resin spread (Fig. 4(d)). Pressure is gently applied by hands from the apex of the wooden mandrel (spherical part) to the bottom edge of the mandrel (conical part) tangential to the work table surface (Fig. 4(e)) until the carbon fabric material is adequately constricted against the wooden mandrel. Then uniform pressure is applied with the aid of a pressure roller for impregnating the carbon fabric with the epoxy resin so as to form a wrinkle free surface of uniform wall thickness. Resin mix is applied over the carbon fabric for attaining good axial strength and surface finish (Fig. 4(f)). Then the specimen is kept at 3-5 hrs for curing at room temperature as shown in Figs. 4(g) and (h).

Fig. 4 CFRP shell-fabrication steps

Table 2 Composite material proportion

Sl. No	Description	Quantity
1.	Weight of the carbon fabric mat used for fabrication	156 g
2.	Weight of the Epoxy Resin	160 g
3.	Resin to hardener ratio	100 : 27
4.	Hardener Weight	42.12 g
5.	Curing Time	3-5 hrs at RT

3.2.5 Trimming the CFRP shell

Even though uniform pressure is applied at the time of fabrication process, wrinkles usually occurs at the bottom edges of the conical part of the post cured CFRP shells whereas the spherical part of the CFRP shells are free from wrinkles due to excellent forming of carbon fabric over the spherical portion of the wooden mandrel. The wrinkles formed in the bottom edges of the post cured CFRP shells will be removed by trimming processes (Fig. 4(l)) by applying pattern allowances (Fig. 4(k)) for the wooden mandrel. The shells are trimmed further to the actual

(a) Photographic view

(b) SEM photograph

Fig. 5 Scanning electron microscope with ion sputter

configuration by machining in the centre lathe (Figs. 4(i) and (j)).

3.3 SEM analysis

In the present study, a SU-1510 model Scanning Electron Microscope (Hitachi 2009) of beam energy range 300 eV to 30 keV with a magnification range of × 5 to × 300, 000 was used to observe the microstructure (Sato 1985, Razvan and Bakis 1990, Manjunatha *et al.* 2010) of the carbon fabric / epoxy composites, glass fabric/epoxy composites and hybrid composite test specimens. The sample preparation equipment, Ion Sputter E-1010 (Hitachi) has been used for the preparation of the composite samples. In order to obtain SEM observations of non-conductive specimens like composite test samples with good resolution of the microstructures, thin layer of gold could be coated on the carbon fabric/epoxy, glass fabric/epoxy composites and hybrid composite test specimens by the ion sputter unit for electric conduction. Gold coating is also necessary for avoiding specimen charging and to acquire an enriched high quality SEM image.

4. Results and discussions

The experimental study prescribed in this work includes the development of CFRP shell specimens with single layer, CFRP shell specimens with double layer, GFRP shell specimens with single layer, Stiffened CFRP shells and Hybrid shells using the hand lay-up process without any joints. After finishing the wall thickness and weight of all the shells (Tables 3, 4 and 5) were recorded. In each shell the wall thickness was measured by a digital Vernier Caliper (ABSOLUTE Digimatic, Mitutoyo Japan) at ten different locations in the frustum of the conical shell of the same specimen and a mean value is obtained.

4.1 Fabrication of Plain CFRP shells

The plain CFRP shell specimens with single layer (Fig. 6, Table 3) were fabricated using the

Fig. 6 CFRP shell

Table 3 CFRP shell configuration

Sample No.	#1	#2	#3	#4	#5	#6	#7	#8
Wall thickness, mm	3.14	2.66	2.60	2.78	3.36	2.88	2.58	2.82
Weight of the shell, gm	170	140	137	144	188	145	146	159

hand lay-up process without any joints. These CFRP thin-walled shells are used as space capsules in launch vehicle and re-entry vehicle applications which accommodate expensive electronic packages.

4.2 Fabrication of plain GFRP shells

The GFRP shell specimens with single layer (Fig. 7, Table 4) were also fabricated using the same manufacturing procedures without any joints. Such GFRP thin-walled shells are used in the construction of aircraft radome model which encloses the valuable instruments.

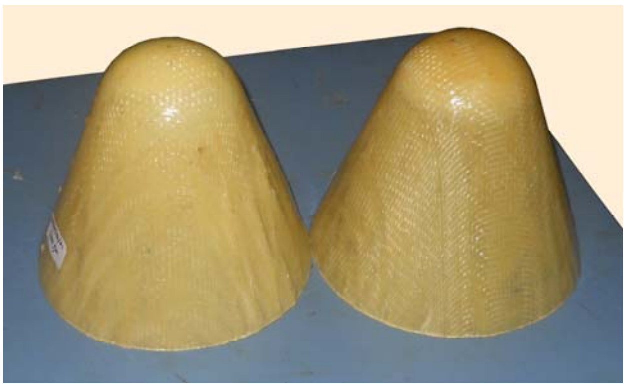


Fig. 7 GFRP shell

Table 4 GFRP shell configuration

Sample No.	Wall thickness, mm	Weight of the shell, gm
#1	2.18	154
#2	2.21	157
#3	2.24	148
#4	2.20	158
#5	2.22	145

4.3 Fabrication of laminted / stiffened / hybrid shells

The CFRP shell specimens with double layer (Fig. 8(a)) were fabricated by impregnating woven carbon fabric with epoxy resins and hardener mixture over the wooden mandrel using hand lay-up technique consecutively for the two layers. This multiple layered CFRP shells would be used for the laminate applications in aerospace structures for designing a product with more mechanical characteristics than the single-layer counterpart. The CFRP stiffeners were fabricated separately using hand lay-up technique and finished to the actual size using machining operations. Alternatively, using pultrusion process or roll forming process the stiffeners can also be fabricated.

The axial stringer type CFRP stiffeners of length 92.8 mm, wide 25 mm and thick 3.6 mm were internally bonded into the skin of the CFRP shell as shown in Fig. 8(b) using the hand lay-up process using epoxy resin. Bonding stiffeners into the skins of a composite structure with epoxy resins is certainly a very feasible and natural method. For better bonding sufficient pressure is applied on the stiffeners which are integrated into the interior walls of the CFRP shell. This internally stiffened CFRP shells would be useful for the enhancement of energy absorption in case of aerospace and launch vehicle structure applications. Stiffeners are usually placed on the inner walls in case of aircraft, submarine, missile fuselage structures so as to maintain an aerodynamically clean exterior. Fig. 8(c) shows the hybridization of carbon fabric with glass fabric in epoxy resin system in order to form a hybrid shell (inner layer-glass fabric; outer layer-carbon fabric) for enhancing the fatigue strength of the shell structure. The measurement of laminated CFRP shells, Stiffened CFRP shells and hybrid shells are shown in Table 5.

(a) CFRP Shell (2layer) (b) Stiffened CFRP shell (c) Hybrid shell

Fig. 8 Laminted / stiffened / hybrid shells

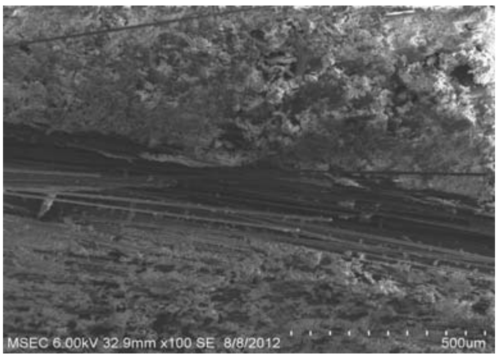
Table 5 Laminted/stiffened/hybrid shells configuration

Laminated CFRP shell			Stiffened CFRP shell			Hybrid shell		
Sample No.	Wall thickness, mm	Weight of the shell, gm	Sample No.	Wall thickness, mm	Weight of the shell, gm	Sample No.	Wall thickness, mm	Weight of the shell, gm
#1	4.48	324	#1	2.59	224	#1	3.36	231
#2	4.31	333	#2	2.96	201	#2	3.62	239
#3	5.38	305	#3	2.88	221	#3	3.50	247
#4	5.84	304	#4	2.99	226	#4	3.39	222
#5	4.46	363	#5	3.02	237	#5	3.43	239

4.4 SEM analysis results

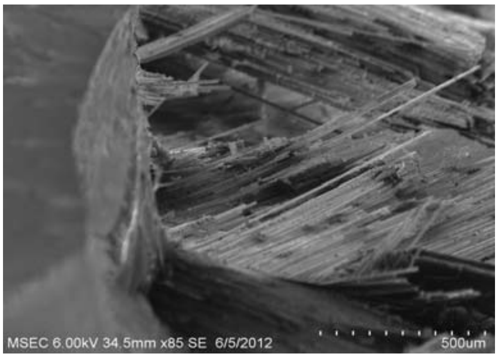
Scanning electron microscope (SEM) examinations were conducted in this study for observing the microstructure of carbon, glass and hybrid (carbon with glass) fabric in epoxy matrix system.

Fig. 9(a) shows the SEM image with a magnification of ×100 at 32.9 mm wide and a scale of 500 μm for carbon fabric / epoxy composite with single layer wherein the longitudinal lines indicate the uniform distribution of fibers in warp directions. Fig. 9(b) shows the microstructure (magnification of ×85 at 34.5 mm wide; Scale: 500 μm) for carbon fabric/epoxy composite with double layer which indicates the principal directions of fabric warp and weft directions for the adjacent layers. The SEM image with a magnification of ×130 at 34.9 mm wide and a scale of 400 μm for glass fabric/epoxy composite with single layer is presented in Fig. 9(c). Fig. 9(d) indicates the microstructure (magnification of ×230 at 30.3 mm wide; Scale: 200 μm) of hybridization of carbon fabric with glass fabric composites. It was deliberately studied from SEM perspectives that, the microstructure of composite laminates reinforced with woven fabrics is significantly different from that of the uni-directional counterparts.

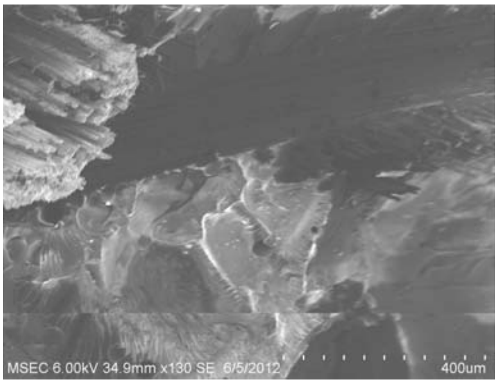


(a) CFRP-single layer

Fig. 9 SEM Photographs of composite structures



(b) CFRP-double layer



(c) GFRP-single layer

(d) Hybrid carbon / glass composite

Fig. 9 Continued

5. Conclusions

A simple fabrication procedure which requires little capital investment and expertise by using hand lay-up method for the fabrication of CFRP thin-walled shell structures at room temperature curing were presented in this paper. Based upon the manufacturing procedure of plain CFRP thin-walled shells, experiments have been conducted for the manufacture of shell structures, viz.

plain GFRP shell, stiffened CFRP shell, laminated CFRP shells and hybrid carbon/glass/fabric epoxy composite shells configurations. This study has also shown that the CFRP, GFRP and hybrid shell structures were fabricated using epoxy resin system by hand laying up technique without any joints and wrinkling. The microstructure of the glass fabric/epoxy composite, carbon fabric/epoxy composite and hybrid carbon/glass/fabric epoxy composite test specimens were examined using SEM. The manufacturing procedure described in this paper would be useful in the aerospace and marine industries for making prototype composite parts.

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NOMENCLATURE AND UNITS

r	Bottom diameter of the cone, mm
d_t	Top diameter of the cone, mm
h_c	height of cone, mm
h_s	height of hemisphere, mm
t	Thickness of the shell, mm
α	Semi cone angle
PMC	Polymer Matrix Composites
CFRP	Carbon Fabric Reinforced Plastic
GFRP	Glass Fabric Reinforced Plastic
SEM	Scanning Electron Microscope

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