Implementation of Optimized Manufacturing Process of Gyrocopter Rotor Blade from Composite Materials

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Abstract—Rotating wing aircraft rely on a rotating wing to provide lift. Gyrocopter rotor bladesmay bemadeof bamboo, fabric, wood, metalorcomposites. The strength of composite structures depends on the number of layers, the orientation of fibers, the nature of fibers and the method of manufacturing process. Manufacturing of composite structures needs optimized approach to obtain expected performance and to save manufacturing time and cost.

This paper is an attempt to formulate an optimized process of composite gyrocopter rotor manufacturing, made ofcomposite skins, foam core and longitudinal spars. Though there are many manufacturing possibilities, indicating the easiest and affordable processes are the objective of this paper. The proposed optimized manufacturing process starts from mold preparation by tracing 2D drawing of the airfoil section on plywood, cutting the section, stacking and aligning number of sections linearly, joining those sections and splitting into half parts of the mold, finishing the surface of the mold and ready for part manufacture, layup required number of layers and accomplish skin manufacturing by vacuum assisted methods. Preparing requirednumber of ribs, assembling ribs and spars and finally joining the two split parts end up by surface finish and painting.

The rotor blades manufactured by this way has better aerodynamic, better quality and has no signof delamination.

Key words- **Composite, Rotor Blades, Mold Preparation, Vacuum Assisted Manufacturing Processes**

I. INTRODUCTION

Gyrocopter is a type of rotorcraft which uses an unpowered rotor in autorotation to develop lift, and an enginepowered propeller, similar to that of a fixed wing aircraft, to provide thrust. It has comparable performance to both fixed wing aircraft and helicopter**.** Rotor blade is one of the most essential and critical parts of gyrocopter. Gyrocopter rotor blades have smaller chord and larger span than those used on helicopters[1]. Because the rotor on gyrocopter must be in autorotation it needs not only enough area to produce lift but rotor has to have enough energy to rotate as well. Gyrocopter rotor blades have been made from bamboo and fabric, wood, metals and composites. Those materials have been used on many different types of rotor systems and with different manufacturing methods.

In the previous times wood were an appropriate material for rotor blade constructions, though it has certain undesirable characteristics such as variable grain structure and varying moisture absorption characteristics[2]. Now-a-days aluminum and high grade steels are used to manufacture rotor blades, but manufacture process needs special machineries and this is the reason for less possibility to homemade aluminum and high grade steel rotor blades.

II. COMPOSITE GYROCOPTER ROTOR BLADES

Composite rotor blades with fiberglass skins and foam or Nomexhoneycomb core offered something that had not been available before: a non-catastrophic failure mode. Whereas the older metallic blades would crack around a nick or damages, sometimes failing suddenly, these newer blades would give plenty of warning if they develop problems [2]. With fiber glass skin, each cross fabric resists crack growth like trying to rip the fabric of a shirt. What results is a non-catastrophic failures mode which gives visible indications of the damage or warns the pilot with gradually increasing vertical vibration. Complex shapes were now possible since blade shapes could be molded and cured in custom mold. Composite rotor blades have infinite operating life and infinite storage life. Composite blades can be replaced blade by blade, whereas metallic blades are replaced set by set [3].

III. ROTOR SPECIFICATION

Geometry and structural analysis datafor single seat hand-start-ablegyrocopter, where taken from previous research work of the author [4].

A. Rotor Blade Geometry (Single Blade)

- Rotor airfoil profile – NACA 8H12
- Blade pitch – 2^o
- Blade chord – 200 mm
- Maximum blade thickness – 24 mm
- Blade span length – 3.5 m
- Blade weight – 7 kg

B. Rotor Blade Structural Property (Single Blade)

- Type of fiber – woven [0,90]s Carbon-Kevlar hybrid
- Fiber thickness – 0.3 mm
- Number of layers – 9
- Number of ribs – 26
- Ribs material – Polyester Foam
- Spar diameter – 8 mm
- Spar material –Structural Steel
- Hard core at the root – T2024 Aluminum
- Hard core at blade to strap plate attachment holes – Bronze bushing

IV. STRUCTURAL COMPONENTS OF THE ROTOR BLADE

A. *Blade Skin*

This is the outer shell of the blade which supports aerodynamic pressure distribution from which the lifting capability of the blade is derived. These aerodynamic forces are transmitted in turn to the ribs by the skin. Blade skins made up of metallic, wooden or fiberglass skins. Woven type Carbon-Kevlar hybrid fiber was used for this research work.

B. *Spar*

Blade spars can be manufactured from fibers, metals or wooden structures. The primary function of spar here is not only to withstand longitudinal load but also to increase rotational energy of free spinning blade. The spar can also doa duty to share main load of the gyrocopter along longitudinal direction.Steel rod spar is used to satisfy both load carrying capacity and energy storing requirement.

C. *Ribs*

The blade ribs are prepared in the shape of airfoil by offsetting from outer profile and used to carry transverse load acting on the blade. The ribs provide the necessary aerodynamics shape which is required for generation of lift by the gyrocopter. Ribs have also a duty to keep structural stiffness and used to transfer loads from blade skin to spar elements.Polyester foam, Nomexhoneycomband wood materials are used for ribs structure. In this research workpolyester foam was employed for ribs material.

V. MATERIAL AND METHODOLOGY

A. Raw Materials and Equipment

The raw materials and equipment required for mold preparation and part manufacturing mentioned below.

For Mold Preparation	*For Part Manufacturing*
I. Raw Materials	*I. Raw Materials*
Plywood 10 mm thick	Carbon-Kevlar fiber
Nail 2mm diameter	Araldite
Steel Sheet 0.3 mm thick	Perforated nylon
Chopped strand matt	Filler
Polyester resin	Breather fabric
Stucco	Stucco
Wax	Vacuum nylon
Filler	Hardener
II. Equipment	Epoxy resin

Hand grinder	Vacuum sealant
Marking tools	*II. Equipment*
	Vacuum pump
	Hand grinder
	Fiber cutter
	T-joint and Spiral tube

B. Methodology

Optimized manufacturing process takes into consideration Carbon-Kevlar hybrid/epoxy woven fabric composite made by hand layup vacuum assisted techniques/HLVAT/.

Hand layup manufacturing process has the advantage of low cost and versatility, but involving substantial time consumption, has less uniformity and can be delaminates easily. Design simplicity, needs cheap mould material and cost effectiveness are some of the advantages of vacuum bagging. After stacking required number of layers using hand layup process followed by vacuum bagging techniques, sufficient curing time can be employed.

Vacuum bagging uses atmospheric pressure as a clamp to hold laminate plies together. The laminates were sealed within an airtight envelope. The envelope may be an airtight mold on one side and an airtight bag on the other. When the bag was sealed to the mold, pressure on the outside and inside of this envelope was equal to atmospheric pressure. While the vacuums pumpworking outside pressure becomes higher than inside pressure.The pressure difference between the inside and outside of the envelope determines the amount of clamping force on the laminate [5].

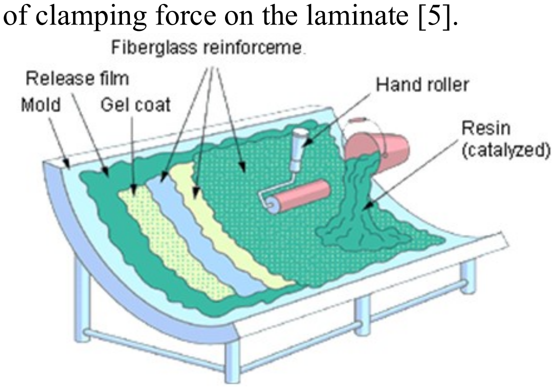


Fig.1. Hand layup process [6]

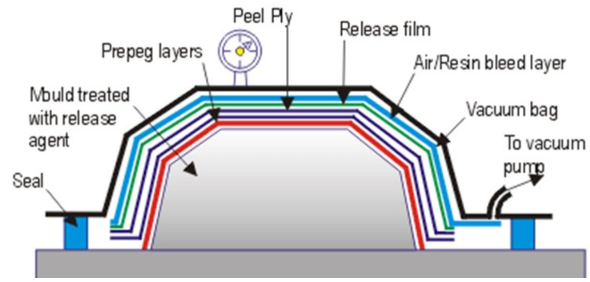


Fig.2. Vacuum bagging process [6]

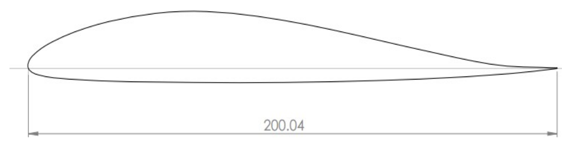
VI. DETAILED MANUFACTURING STEPS

The whole manufacturing steps describe for one blade.

The following steps should be followed to desire an optimum gyrocopter rotor blade. Mostly hand tools were usedfor mold preparation.

Part I*Mold Preparation*

Step1Preparing 2D drawing of airfoils, printing paper and cutting its shape.



Step 2Tracing thecutout sectionand cutting the plywood using jig saw.

To cutout the section from plywood needs relevant skill to get the required shape and to maximize blade efficiency. Blade efficiency highly depends on this step.

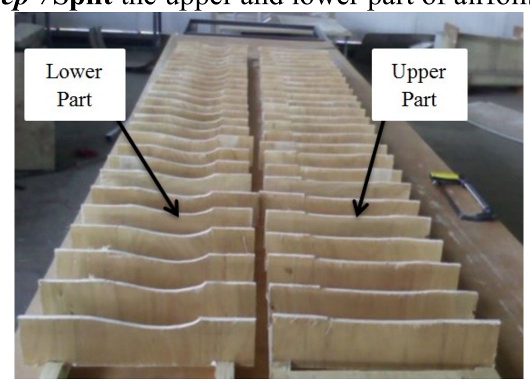
Step 3Preparing 26 airfoils sections on 40cm x 20cm size plywood

Step 4Stacking all the airfoils on the prepared frames at equal interval of 135 mm

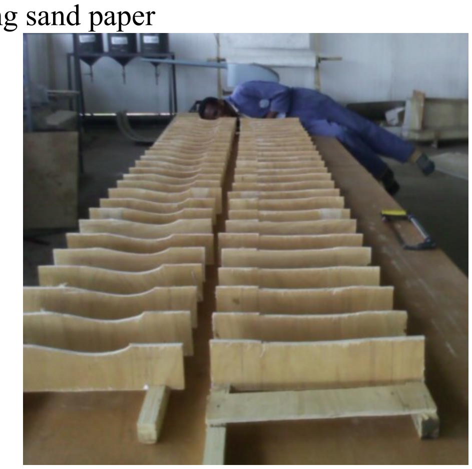
Step 5Aligning all airfoils

Step 6Fixing aligned airfoil sectionsusing wood frame

Step 7**Split** the upper and lower part of airfoils



Step 8Smoothing the surface of split molds using sand paper



Step 9Covering the surface of airfoil using flexible thin sheet and fix it using nails

Step 10Reinforcing the sheet at the bottom side usingsufficient number of chopped strands matt layers

Step 11Remove the cover sheet and smooth the surface using stucco

Step 12Smoothing the surface using zero grade sandpaper, use wax and preparing the mold for part

Part II*Part Manufacturing*

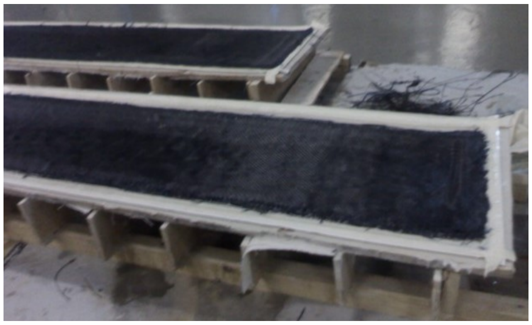
Part manufacturing made by hand layup process followed by vacuum bagging techniques. When layer layup process starts additional number of labors is required in order to prevent rapid epoxy curing. After nine number of layers stickup for the lower part of single blade by hand layup process, vacuum bagging process is followed.

Step13Preparing all the materials and tools for composite material manufacture process (vacuum pump, perforated nylon, breather fabric, vacuum sealant, scotch, peel ply, spiral tube, vacuum tap, epoxy resin, hybrid, fiber cutter, epoxy brush)

Step 14Binding the part size using vacuum sealant and scotch)

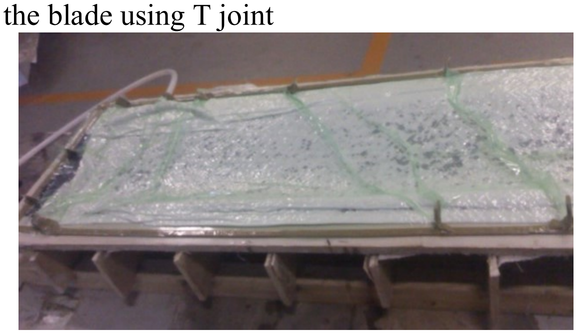
Step 15Starting tomanufacture the first layer

Step 16Layup up to the required thickness

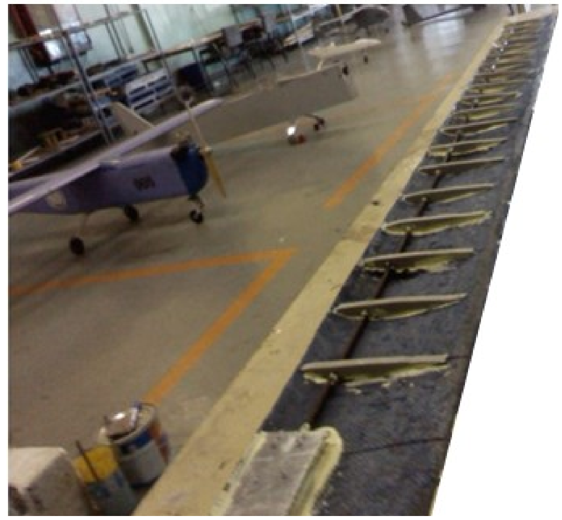


Step 17Covering the part to avoid exposure to atmosphere airs and to suck excess air and resin inside the part

Step 18Plugging vacuum pumps at both ends of the blade using T joint



Step 19preparingrequired number ofpolyester foam ribs, aluminum hard coreand steel rod longitudinal spar



Step 20Attaching the two halves using araldite, filer, and polyester resin

Step 21 Painting the partsusing aviation grade paint and finalizing the surface finish for good aerodynamic task

VII. CONCLUSION

The rotor blade manufactured through this approach has sufficient structural strength, good aerodynamic shape and adequate weight for autorotation. Even if blade performance can be increased by employing high-tech manufacturing technology, this approach has acceptable performance for home-made manufacturing systems.

Once the first mold prepared for the first blade, it can be used for mass production by slightly smoothing the surface finish after previous part relived. Part manufacturing takes considerably little time compared to mold preparation.

VIII. RECOMMENDATION

It is recommended to cut the fiber step-by-step starting by wider outer fiber to narrow inner fiber in order to make almost zero trailing edge thickness. If all layers have equal width, it is difficult to have smooth surface finish by grinding process, due to less machining property of Kevlar fiber. It is also recommended to take a good care when cutting the airfoil section on plywood.

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