5.1 Introduction to SWT Blades Manufacturing:

Small size wind turbine blades can be manufactured by using various techniques. Hand lay-up technique [27] is employed to produce the blades in the present work. In hand lay-up method, the successive layers reinforcement web / mat are positioned on the mould by hand. Resin is used to coat / impregnate the reinforcement. It is then followed by curing the resin to fix the shape permanently. External aid can be used for completing the curing process or it can be done at room temperature. The technique in which resin saturated reinforcement are placed in the mould is called “wet lay-up”.

The time for manufacturing is much lower and it is cost effective when the blades are produced in one batch. The moulds offer repeatability with very good quality in producing the blades.

5.2 Overview of the Production Process:

- Original blade is produced and is used as a reference to make copies
- From the original, a female mould is taken; this mould is in two-halves. The mould can be used for a number of times to produce the blade.
- A number of layers of glass fiber mat with resin are used for separating the two blade halves.
- When dry, the blade halves are trimmed neatly and the edges are tapered so that the two halves attaches together properly.
- Inserting more number of fiber glass layers at the root increases the strength at the root. More compressive strength, which is essential in assembling the blade hub can be obtained when more number of layers are added at the root section of the blade.
- Pre-defined shaped UV hard foam is added in between the two halves of the blade to improve the stiffness in the blade. Tapered rectangular UV foam is placed as a bridging element which was kept in parallel to the blade halves.
- The second part of the blade is stuck to the first half and fixed in to the mould by clamping firmly. Clamping should be done to ensure the correct shape.
- Expanding foam is used for fill the gaps present in the blades. The blade is further processed to obtain smooth finish.
- The blades are painted to obtain surface quality with good appearance.

5.3 Basic Design:

Two different blade profiles are selected and manufacturing of them is carried out using hand lay-up technique. The two profiles are R21 and R22. The basic drawings of R21 and R22 are shown in Fig: 5.1 & 5.2. The blade
shapes are to be modified based on the selected profile where the structure can be lightly loaded and it should produce a better power output.

**Fig: 5.1 SWT Blade – R21 Basic Drawing**

**Fig: 5.2 SWT Blade – R22 Basic Drawing**

**Fig: 5.3 Exploded View of Blade Construction [36]**
5.4 Materials Required:

Reinforced materials form the biggest and most important group of composite materials. The purpose of reinforcing is always to improve the strength properties. Reinforcement may involve the use of dispersed phase or strong fibre, thread or rod. The materials required for the fabrication of wind turbine blades should have high strength, good stiffness and high fatigue life. Fibre reinforced materials offer the solution. Stronger and higher modulus filler, in the form of thin fibres of one material, is strongly bonded to the matrix of another. The matrix material provides ductility and toughness and supports and binds the fibres together and transmits the loads to the fibres. The fibres carried most of the load. The toughness of the composite material increases, because extra energy will be needed to break or pull out a fibre. Also when any crack appears on the surface of a fibre, only that fibre will fail and the crack will not propagate catastrophically as in bulk material. Failure is often gradual, and repairs may be possible [29 - 35].

Due to the above mentioned desirable properties of the matrix materials, the commonly used matrix materials are metals and polymers, such as Al, Cu, Ni, etc., and commercial polymers.

Fibre-reinforced materials can be made quite an isotropic through directional control of the strong fibres in the relatively weak matrix. It is possible to produce parts where strength control is
developed in different directions. If the part is loaded parallel to the fibres, the matrix material yields plastically under equal strain, the stress within the fibres will be much greater than in the matrix. Even if the fibre breaks, the softness of the matrix hinders the propagation of the crack. The fibre directions are tailored to the direction of the loading.

The blades are manufactured by using a composite material, fibre glass. It is a composition of glass fibres having high tensile and compressive strengths. Resin offers good rigidity. The following chemicals and other materials are used in blades fabrication.

5.5 Chemicals Required:

5.5.1 Resin:

Different types of resin, with different properties are available but the following two resins are used in blades fabrication.

5.5.1.1 Resin Type 'R10-03':

R10-03 is a rigid orthophthalic (FRP) polyester resin. It is widely used for producing the wind turbine blades and is relatively inexpensive. This resin is used to produce the blades in both R21 and R22 variations.
5.5.1.2 Resin Type 'Polymer 31-441':

Polymer 31-441 is also called as Gel Coat Polyester Resin. It is completely isophthalic with Neopentyl Glycol (NPG). This is chemical resistant with high hard wearing. It is used on the outer layers of the blade.

5.5.2 Hardener:

Hardener is used in curing process, is added to the resin for solidification. The quantity of hardener and accelerator can control the time taken for setting the resin. It must be worked quickly into fibre glass as the resin solidifies quickly as the hardener is added.

5.5.3 Styrene Monomer:

Viscosity of the resin can be reduced by mixing resin with styrene Monomer. It is easier and workable to paint on the fibre glass layer.

5.5.4 Cobalt:

Hardening process can be speeded up by adding cobalt to the resin. Setting time can be controlled easily by cobalt addition to the resin.

5.5.5 Toner:

Toner is used to add color to the outer layers of the resin. Approximately 5 to 10 percent (of weight) should be added to the
mixture of resin. Toner has got no structural properties but adding a greater amount of toner may inhibit the solidification process.

5.5.6 Lowilite:

Material degradation by sunlight can be prevented by using Lowilite, is a UV stabilizer available in powder form.

5.5.7 Dura wax:

Dura wax is a release agent and is applied to the mould before each layup in order to confirm that the produced item will not stick to the surface of the mould. A non stick thin film may be added to the moulds and thus part sticking can be avoided. Wax release agent is used to take out the complex curved shape parts from the mould.

5.6 Fibre Glass:

5.6.1 CSM (Chopped Strand Glass Fibre Mat):

Random orientation of fibers in CSM exhibit same strength in every direction. It offers a great ease and cheapest. A 300 GSM is used for moulds and a thin 100 GSM for joining the sides and to safe guard the leading edge.
5.6.2 WC (Woven Cloth Glass Fiber):

WC consists of woven strands having high strength in the direction of the weave and it is harder to work with. The cut weave can be unraveled when it is used in a dry state.

5.6.3 Thinners:

Thinners are used to remove the excess resin and for cleaning any spills, painting brushes, tools and containers.

5.6.4 Fibre Core Root:

A small amount of fibre strands are required to form core to the blade root. Core root is developed by using a number of layers of glass fibres to obtain the required thickness.
5.6.5 **Car Body Filler:**

Before the final blade is obtained, it is essential to fill the small gaps. A two-part car body filler is a resin added with hardener and catalyst used to fill the gaps. MEK peroxide is a catalyst. The two items are mixed in a ratio of 1 to 3 percent hardener to the resin.

5.6.6 **Expanding Foam:**

Air gaps within the blade are filled up by a low density two-part expanding polyurethane foam. The foam is primarily with two liquids and they must be mixed in a ratio of 1:1. The foam will expand to 25 times to its initial volume. The rigidity and the strength of the blade can be significantly improved.

5.6.7 **Blade Half Manufacture:**

The backward half and the windward half are the two blade halves are developed according to the basic design of the small wind turbine blade. The present process shows the process how these two blade halves are produced. Fiber glass mat is used as a primary material. Totally eight layers of fiber glass are used in fabrication. To get more strength in the direction of forces acting on the blade, woven cloth is used. The resin should not be allowed to set when these two blade halves are being produced. This may cause the de-lamination of the two dry layers. So the fabrication process should be done with careful preparation with hands on material so that the process goes in a smooth and effective manner.
5.6.8 Fabrication Procedure:

5.6.8.1 Initial Preparations:

➢ Preparation of Gel Coat:

Gel coat is a combination of resin, aerosol powder and pigment. For R21 profile blades produced by using polyester as resin, the quantity of gel coat mixture is equal to 90 grams. If the resin employed is epoxy resin then the quantity of gel coat mixture is 75 grams. For R22 profile blades produced by using polyester resins the quantity of gel coat mixture is equal to 115 grams. In case of epoxy resin the quantity is equal to 85 grams for R22 profile blade.

➢ Preparation of Powder Matt:

Powder matt is a mixture of pieces of ± fibers with resin and hardener. For R21 polyester blades the quantity of powder matt is equal to 125 grams. For R21 epoxy blades the quantity of powder matt is 270 grams. For increasing the ratio of powder matt content 75 grams additional quantity of powder matt is used. For R22 profile polyester blades the quantity of powder matt is equal to 150 grams. For R22 epoxy blades the quantity of powder matt is 280 grams. For increasing the ratio of powder matt content 100 grams additional quantity of powder matt is used.
Resin:

For R21 profile blades, the resin used is polyester then the quantity of polyester resin is 250 grams. If epoxy is used as resin then its quantity is 210 grams. For R22 profile blades, the resin used is polyester then the quantity of polyester resin is 250 grams. If epoxy is used as resin then its quantity is 230 grams.

Fibre Glass

The woven cloth (WC - 200gsm) fibre glass is trimmed to the required shape prior to layup. Total 8 layers are essential at the stronger part of the blade i.e., blades root. 4 layers are required from root to tip of the blade. ±45 Glass fibre matt and CDB matt are cut according to the required geometry and shape. The glass fibre layers which are ready for placing on the mould are shown in the Fig: 5.20. The glass fibre layer should not be twisted or folded and is to be carried with care as shown in Fig: 5.21 because if the twisting occurs then the fibre core alignment will be disturbed and leads to improper alignment between the fibre strands.

5.6.8.2 Blade Fabrication Procedure:

- Initially, on the open side of the mould, the gel coat is applied uniformly as shown in Fig: 5.22 and wait until the surface becomes dry.
Apply the powder matt uniformly over the surface, once the gel coat is applied on the open mould half. The powder matt application is as shown in the Fig: 5.24.

Fill the moulds with glass fibre layers as shown in Fig: 5.23 and apply resin in between the successive layers of the resin. The resin coating on the open mould half is as shown in the Fig: 5.22. Once the first layer is placed, the resin is applied uniformly on the first layer and the second layer is placed. Similarly the procedure is followed for 4 layers to obtain the blades wind-ward surface.

The root section of the blade should have more number of small rectangular glass fiber pieces and the same is shown in Fig: 5.14. The root must be strong because the bending moment due to wind force, the effect from gyroscopic forces will be high at this section.

The setting time required is 8 hour, after setting the blade half is removed and grinded to accurate size and surface finish.

5.6.8.3 Mould:

According to Aerodynamic theory the airfoil shapes are developed. To acquire the basic profile shape of the blade, the airfoil shape is to be obtained through out the length of the blade. To obtain this more number of stations across the blade length are developed and airfoil shape is acquired. The basic airfoil shapes for R21 and R22 are as
shown in the Fig: 5.18 and 5.19 respectively. The two mould halves are cleaned every time and the excess resin also should be cleaned. ‘Dura wax’ is applied over the surface with soft cloth. All surfaces which are exposed to resin must be coated with the Dura wax. Excess quantity is buff dried with a clean cloth. The process is repeated at least for six times. The two halves of R21 and R22 profile blade moulds are shown in the Fig: 5.16 & 5.17 respectively.

5.6.8.4 Blade Joining:

Once the second half is produced by the lay-up procedure, the first half i.e., wind ward side of the blade is joined accurately so that the two pieces get good alignment. Additional resin and fibre glass are used for joining purpose. The two halves are set-up by closing the two mould plates which is as shown in the Fig: 5.27 and clamped tightly using 12 C-clamps. Curing is followed at room temperature for 15 hours, which is shown in the Fig: 5.28. To reduce the type of curing additional heat supply system can be employed.

5.6.8.5 Blade Trimming:

A circular cutting saw is used to remove the excess material from the blade surface. Mini-cutter or a jigsaw could be also used for excess material removal. A separating line at the edge of the blade should show a smooth section between the mould and the excess overlap.
While removing the excess material the final blade part must be taken care. The blade trimming process is shown in Fig: 5.25.

5.6.8.6 Blade Finishing:

The blade finishing should ensure quality and aesthetic appearance. This involves the closing the gaps which appear on the blade edges [42]. Adding a thin ‘veil’ of fiber glass at the blade leading edge, removing any imperfections and then painting. Car body filler is used for filling the gaps. After filling, leave for sometimes to obtain the dry state. Surface smoothness must be ensured. CSM fiber glass narrow strip is added to the leading edge. Two layers must be applied so that they can hold the two blade halves together; it can protect the leading edge also. Further the gaps are filled up the car body filler. Once the dry state is obtained the blade may be further sanded. Dust particles must be removed and the blades are painted for protection and aesthetic appearance. Finally drilling the holes at the root section of the blade is done. Before hoisting the blades on to the turbine, the turbine system must be ensured for correct balancing. After the fabrication the weight of all the blades is measured and is mentioned in the Table 5.1. The Fig: 5.30 show the blades fabricated by using R21 profile for three material variations such as GFRP + Polyester, GFRP + Polyester SW and GFRP + Epoxy SW. The Fig: 5.31 show the blades fabricated by using R22 profile for three material variations such as
GFRP + Polyester, GFRP + Polyester SW and GFRP + Epoxy SW respectively.

<table>
<thead>
<tr>
<th>Material</th>
<th>Blade Profile</th>
<th>Blade-1 (kg)</th>
<th>Blade-2 (kg)</th>
<th>Blade-3 (kg)</th>
<th>Blade-4 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Glass Polyester Resin</td>
<td>R-21</td>
<td>2.35</td>
<td>2.36</td>
<td>2.38</td>
<td>2.12</td>
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<tr>
<td>Fiber Glass Polyester + Sandwich</td>
<td>R-21</td>
<td>1.96</td>
<td>1.94</td>
<td>1.91</td>
<td>1.88</td>
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<tr>
<td>Fiber Glass Epoxy Resin + Sandwich</td>
<td>R-21</td>
<td>1.44</td>
<td>1.37</td>
<td>1.41</td>
<td>1.34</td>
</tr>
<tr>
<td>Fiber Glass Polyester Resin</td>
<td>R-22</td>
<td>2.53</td>
<td>2.51</td>
<td>2.41</td>
<td>2.42</td>
</tr>
<tr>
<td>Fiber Glass Polyester + Sandwich</td>
<td>R-22</td>
<td>1.99</td>
<td>1.92</td>
<td>1.98</td>
<td>2.01</td>
</tr>
<tr>
<td>Fiber Glass Epoxy Resin + Sandwich</td>
<td>R-22</td>
<td>1.47</td>
<td>1.45</td>
<td>1.44</td>
<td>1.47</td>
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<td>Fig: 5.16</td>
<td>Two Mould Halves of R-21 Profile</td>
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<td>Fig: 5.17</td>
<td>Two Mould Halves of R-22 Profile</td>
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<td>Fig: 5.18</td>
<td>Air Foil Acquisition for R-21 Profile</td>
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<td>Fig: 5.19</td>
<td>Air Foil Acquisition for R-22 Profile</td>
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<td>Fig: 5.20</td>
<td>Fibre Layer Cutting</td>
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<td>Fig: 5.21</td>
<td>Handling the Glass Fibre Layer</td>
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<td>Fig: 5.22</td>
<td>Open Mould Half with Resin Coating</td>
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<td>Fig: 5.23</td>
<td>Alignment of Glass Fibre Layer</td>
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<td>Fig: 5.24 Applying Powder Matt</td>
<td>Fig: 5.25 Blade Trimming</td>
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<td>Fig: 5.26 Fixing the UV Hard Foam Sandwich</td>
<td>Fig: 5.27 Joining Two Halves by Closing the Mould Plates</td>
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<td>Fig: 5.28 Curing (Set-up) by Using C-Clamps</td>
<td>Fig: 5.29 Measuring the Distance from Reference Point to Blade Tip</td>
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<td>Fig: 5.30 R21 - Profile Blades in Various Material Compositions</td>
<td>Fig: 5.31 R22 - Profile Blades in Various Material Compositions</td>
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5.6.9 Sandwich Material:

In the present research work SWT Blades are fabricated in R21 and R22 Blade profiles by varying resin materials. For the first variety polyester resin is used but for the second variety apart from using polyester as resin, a sandwich material (UV Hard Foam) is used as a central beam element. For the final variety of the blades UV hard form is used but epoxy resin employed. The alignment of UV Hard Foam in the fabrication of SWT Blade is as shown in the Fig: 5.26. The Sandwich consists two high strength skins separated by a core material as shown in the Fig: 5.36 [32]. The bending stresses are absorbed by this high strength skin thus giving a hard wearing surface of the structure [45]. The light core material is shown in Fig: 5.38, it absorbs the shear stresses which are generated by various
loads and distributes over a large area. When compared to Aluminum, steel and monolithic composite laminates, the sandwich can reduce weight with a sufficient increase of stiffness and more strength. By increasing the core thickness the high strength and improved stiffness properties are obtained without specific weight penalty. The different layers of sandwich material include skin, Bondline and UV Core and these layers representation is shown in Fig: 5.37. The monolithic Laminate structure of the sandwich is shown in the Fig: 5.35. Because of higher stiffness, the supporting structure to be reduced thus it can enable further reductions in weight. It is possible to incorporate compound curves and also the outer skins can be aligned accurately to the load paths. Sandwich materials offer structural integrity and performance can be improved. The sandwich materials posses high strength-to-weight ratio and it can be used in various ways - longer range, greater payload capacity, high speeds and thus can give economic and better operating. Sandwich composites posses dynamic strength, excellent insulation and low water absorption. Sandwich composites require less maintenance and repairs can be done without the compromise in structural integrity. Cost Effective Components can be readily manufactured using low cost tooling. In addition a wide variety of processes can be used including hand and spray laminating, vacuum consolidation, press molding and resin infusion. Sandwich composite
as a subcomponent represents the blade structure can influence the blade manufacture method [34].
5.6.10 Balancing the Turbine Rotor:  
Unwanted vibrations will be developed if the wind rotor is not properly balanced. If the balancing is not done properly the rotor fails after working for a few hours. Tip failures occur because of improper balancing of the rotor. It also affects power output. Weight balancing should be done once the fabricated blades are assembled to the hub. In weight balancing process each blade should have same tip weight. The distance between tips must be equal for each pair as shown in Fig: 5.40. The line between the tips must pass through the center of the rotor exactly. When the blades are hoisted on to the generator the tips must pass through the same space when they rotate. After complete assembly it must be verified for dynamic balancing. Apart from the wind force, various other forces like Thrust Force, Gyroscopic Forces and Centrifugal Forces also act on the turbine blade. Various forces acting on the turbine blade are shown in the Fig: 5.39. Fig: 5.41 shows the blade details from root to tip of the blade like the number of stations at which the chord width is to be maintained, local radius of the blade and center of the rotor. These details are to be developed for SWT blades which are essential in defining the airfoil shapes at each station.

5.6.11 Mounting the Rotor Blades:  
The three blades of the rotor are securely bolted to a hub which aligns with Permanent Magnet Generator. The rotor hub is shown in
the Fig: 5.32 and it is an aluminum alloy based disc, to which the blades are assembled and hoisted on to the turbine system.