The turbine unit production cost: £283.55

Material Selection

Glass fibre reinforced composites (GFRCs), low carbon steel, carbon fibre reinforced composites (CFRCs), timber, and aluminium alloy are commonly utilised materials in manufacturing processes.

Table 1: Material Properties[Appendix]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Material** | **Density(kg/m3)** | **Young’s Modulus (GPa)** | **Yield Strength (MPa)** | **Fatigue**  **Strength at 107 cycles (MPa)** | **Cost (GBP/kg)** | **Disadvantage** |
| GRFC | 1.75x103– 1.97x103 | 21-21.8 | 207-304 | 41.3-91.1 | 25.3-27.9 | Costly |
| CRFC | 1.5x103-1.6x103 | 69-150 | 600-1000 | 150-300 | 28.6-31.8 | Costly |
| Low carbon steel | 7.8x103 | 200-220 | 255-355 | 203-278 | 0.52-0.55 | Heavy |
| Aluminium alloys | 2.64x103-2.81x103 | 69-75 | ~400 | 68.2-169 | 1.59-1.72 | Low processability, Metal fatigue |
| Timber | 470-625 | 8.7-15 | 36-62 | 19.2-42.8 | 1.29-2.01 | Prone to moisture |

Among these materials, fibre glass stands out due to its combination of high strength, lightweight, corrosion resistance, thermal insulation, and electrical non-conductivity. Its versatility in design and fabrication makes it particularly suitable for constructing the shell of wind turbine blades.

Environmental operating conditions, duty cycle and blade lifetime

From Granta EduPack, composites can perform well from -40°C to 200°C for GRFP composites and -70 to 200 °C for CFRP composites which means both composites can withstand large temperature variations. The fatigue strength for GFRP composite types at 107 cycles vary between 41.3 to 91.1 MPa and can withstand an elastic limit of about 300 MPa.

Compared to other materials such as aluminum alloy, at very low temperatures it can become brittle which can affect their mechanical properties, but they can still maintain some strength around –40 °C. The fatigue strength for aluminum alloy at 107 cycles is about 70 – 170 MPa and a maximum yield strength of about 400 MPa.

The lifetime of the wind turbine blades depends on: material used, maintenance practices, environmental condition. The blades are exposed to varying stresses and temperatures which can cause fatigue and degradation, with the average lifespan of the blades varying from 15-25 years with the use of appropriate materials which can withstand high stresses and have high fatigue resistance.

Manufacturing

The manufacturing process is split into material preparation such as cutting, resin infusion, demoulding and processes such as surface finishing and assembly.

* Material preparation: Fibre glass sheets will be cut, whilst the resin needed is pre-mixed

< 20 mins

* Resin infusion

1. Preparation of mould, vacuum bag preparation and resin feed: < 20 mins
2. Curing time ~ 1 hour at 120°C in a composite oven [1]
3. Demoulding + Trimming < 20 mins

* Surface treatment < 20 minutes
* Assembly < 1 hour
* Independently a blade should take around 3 hours to produce.
* 8 blades can be cured in one day using 1 mould set with the 8th one being left to cure overnight.

Blades manufactured a day is limited by the curing time it takes for one blade. Assuming 20 business days a month and an average working day being from 9 till 5, with breaks, giving around 7 hours of working time a day, producing 861 blades over a 6-month duration for 1 mould set. With 8 mould sets, 6720 blades can be made in under 6 months.

Surface finish [2]:

* Hydrophobic paint to stop ice forming on blades in cold conditions which would reduce efficiency and could lead to mechanical vibrations from ice loading.
* This will reduce maintenance costs over the lifespan of the turbine by up to 25%.
* Hydrophobic paint can also be applied to reduce the skin friction of the blades by reducing surface roughness. This will lead to a higher lift to drag ratio which will improve the overall performance of the turbine.
* £8 per blade with a 2mm layer thickness

Dimensional tolerance:

* This will depend on the materials and methods used in creating the molds for the blades.
* The standard tolerance of a 5 axis CNC machine is ± 0.005″ or 0.127 mm. This will lead to expected percentage errors of the order of 0.01% in the dimensions of the blade.

Expenses

Tools used in production includes moulds used for fibre glass, laser cutter for wood, bolts for fixtures. The vacuum infusion process is selected for the manufacturing of the wind turbines. By placing the glass fiber in the mould dry and apply vacuum, resin is drawn across the dry fibers through a flow media. Using a male mould for the upper half of the blade and a female mould for the lower half of the blade. A simple metal frame made by casting would be needed to apply pressure on the blade to ensure a tight fit. The support inside the blade is made of spruce by laser cutting.

The mold is made of polyurethane form and cut with a 5axis CNC cutter. A whole kit for vacuum tools is also needed (vacuum pump, resin catch pot, vacuum gauge, 1/4 turn value, tube clamp, silicone bag connector, vacuum hose, peel-ply). Labor work includes gluing the blade and the dovetail together and the painting work of the blade.

**Tooling cost:**

* Resin infusion kit ----- £145 [3]
* Casting for a steel frame ----- C40 carbon steel $2.3 per kg [4]
* Spruce strip ----- £4.35 each strip (12.5x12.5x915mm) [5]
* Polyurethane foam sheet ----- £22.8 1200x600x75mm [6]
* Two-part epoxy glue ----- £29.84 50ml [7]
* 5 axis CNC router ----- $75-120 per hour [8]
* Tooling cost for one foam mold: 46+22.8\*2+200= £291.6
* Tooling cost for one metal mold: 0.0225\*7850\*2.3= £406
* Metal mold is much more expensive than foam mold.

**Labor cost:**

Workers are paid £10/hour, given that around 21 workers are required, the total expenses per day are £1470 which gives less than £176,000 over the duration of 6 months for all 6000 blades.

**Composite Cost:**

Geometry of the Blade defined by chord and twist, tapered at root and tip for drag reduction.

Volume = 1.64 x10-4 m3

Surface Area = 1.62 m2 (Top = 0.85m2, Bottom = 0.77m2)

Fiberglass 8 layers at root and 2 layers at tip in linear distribution. Each Layer has skin thickness of approx. 0.5mm [10].

Total of 9.44m2 of fiberglass for each blade at a cost of £4.28 per m2 [11] totaling £40.38 per blade. For fiberglass composite a 2.5:1 ratio of resin to fibre is required [12]. Therefore 1.13 kg of resin required per blade, at a cost of £13.71 per kilo [13]. Total composite cost for all 6000 units £336,000.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Composite £** | **Tooling £** | **Labour £** | **Surface Finish £** | **Total £** |
| **1 Blade** | 56 | 1.12 | 29.40 | 8 | 94.52 |
| **6000 Blades** | 336,000 | 6,700 | 176,400 | 48,000 | 567,100 |

Recyclability

Resin infusion’s high temperature curing, and vacuum have a major environmental impact during production due to the energy consumption, while the remaining processes, predominantly manual labour like assembly have minimal environmental effects.

As wind turbine blades have a lifespan of around 20 years, it is important to consider the recyclability.

There are three main methods for recycling fibre glass [12]:

* Grinding: breaks the fibre glass into fine dust.
* Incineration: burns the fibre glass as a heat source.
* Pyrolysis: heats it to high temperatures to break it down.

Pyrolysis is the most useful method as it does the least damage to the glass fibres, transforming the fibre glass composites into useful biofuels. Incineration is not environmentally friendly given the low heat content of fibre glass creating a large amount of ash whilst grinding produces less useful products.

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Appendix

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Description automatically generatedA screenshot of a computer

Description automatically generated with medium confidenceA screenshot of a computer

Description automatically generated with low confidenceA screenshot of a computer

Description automatically generated with medium confidenceA screenshot of a computer

Description automatically generated with medium confidence