

University of Wales Trinity Saint David

School of Engineering



Mechanical and Manufacturing Engineering

Manufacture of Wind Turbine Blade

Sheunesu Ziki

2205423

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Table of Contents

1	Introduction	5
2	Literature review.....	6
2.1	Aerodynamic profiles and design parameters	6
2.2	Material properties	7
2.3	Environmental conditions	8
3	Design specifications	8
3.1	Blade geometry and parameters.....	8
3.2	Chord length distribution	9
4	Material selection	10
4.1	Weighted decision matrix	10
4.2	Selection justification	11
5	Exploration of manufacturing methods.....	11
5.1	Metal manufacturing methods.....	11
5.1.1	Casting.....	11
5.1.2	Extrusion.....	12
5.2	Ceramic manufacturing methods	13
5.3	Polymer composite manufacturing methods	13
5.3.1	Resin transfer moulding (RTM).....	13
5.3.2	Vacuum infusion.....	14
5.4	Comparative analysis.....	15
6	Cost evaluation	15
6.1	Raw material costs.....	15
6.2	Blade material cost estimation	16
6.3	Manufacturing costs.....	17
6.4	Cost performance trade offs.....	17
7	Mechanical properties analysis	18

7.1	Aerodynamic force calculations	18
7.2	Root bending and torsional moments	19
7.3	Comparison with material strength.....	20
8	Comparative analysis.....	21
9	Blade drawing	22
10	Conclusions and recommendations.....	22
11	References	23

Figure 1:	Shows wind turbine components and loads.	5
Figure 2:	Shows NACA4412 airfoil geometry.	6
Figure 3:	Shows chord length distribution and linear taper from root to tip.....	9
Figure 4:	Shows the sand casting process.....	12
Figure 5:	shows the extrusion process.	12
Figure 6:	Shows the sintering process.	13
Figure 7:	Shows resin transfer moulding process.	14
Figure 8:	Shows the vacuum infusion process.	14
Figure 9:	Shows composite blade components	16
Figure 10:	Shows CAD model.	22

Table 1:	Comparison of mechanical properties.	7
Table 2:	Shows the blade design parameters.....	8
Table 3:	Shows the blade geometry specifications.	9
Table 4:	Shows the weightings used for each criterion.....	10
Table 5:	Shows the weighted decision matrix scores.	10
Table 6:	Shows a comparison of manufacturing methods.	15
Table 7:	Shows raw material costs from market costs.....	16
Table 8:	Shows a cost-performance comparison.....	18
Table 9:	Shows the calculated lift and drag forces for the blade sections.....	19
Table 10:	Shows a comparison between bending stress and material strength.	20
Table 11:	Shows manufacturing defects, impacts and mitigation.....	21

Abstract

The rapid growth in the global wind energy sector has created a demand for efficient and durable wind turbine blades. The design and manufacturing method that is used for creating turbine blades is important as it affects the wind turbines capture efficiency, structural reliability and long term operational costs. This report looks at some suitable materials and manufacturing methods for the development of a large scale wind turbine blade.

This study assesses materials such as metals, ceramics and polymer composites. The best material was chosen using a weighted decision matrix that uses a criteria comprising of specific strength, fatigue performance, cost, corrosion resistance, environmental factors and manufacturing feasibility. The NACA 4412 airfoil profile was used to determine blade geometry and chord length distribution along the 50.97m blade span using some aerodynamic calculations. The blade geometry was modelled in SolidWorks to visualise its aerodynamic shape and to give a foundation for its manufacture.

Manufacturing processes such as extrusion, casting, sintering, resin transfer moulding (RTM) and vacuum infusion were investigated to see which method is best in terms of production costs, scalability, complexity and potential defects. The results showed that polymer composites have a significant advantage compared to metals and ceramics due to having a higher strength to weight ratio and a better fatigue resistance.

The cost analysis demonstrated that even though polymer composites have a higher raw material cost, their low weight and higher structural strength provide lower lifecycle costs. The study concluded that glass fibre reinforced polymer (GFRP) that is made using vacuum infusion offered the best solution for manufacturing wind turbine blades. This is due to its balance between mechanical performance, cost efficiency, manufacturing scalability and long term durability. These results match those seen in current industrial cases where GFRP blades make up 90% of the industry's wind turbine blades.

1 Introduction

With global trends shifting towards renewable energy, wind turbines have become a valuable tool in power generation as they now produce over 1000GW of power globally. With turbines becoming larger and more powerful, the design and manufacturing of their blades have posed as a major engineering challenge.

The blades play a vital role in converting the kinetic energy from the wind into mechanical rotation which is then converted to electrical energy using the generator located in the hub. The aerodynamic performance, structural reliability and weight of the blades influence the overall systems efficiency in capturing and converting power. The blades are required to be lightweight, durable and able to withstand loading conditions during the wind turbines lifespan ((Johnson et al., 2023).

A client approached Company X with a project to develop next generation blades that are lightweight to reduce structural loads, durable to withstand environmental conditions and efficient to increase the power coefficient (C_p) closer to the Betz limit of 0.593 (59.3%) (Hansen, 2015).

The main aim of this report is to evaluate suitable materials and manufacturing methods for the wind turbine blade. The evaluation includes aerodynamic parameters, material property comparisons, evaluation of suitable manufacturing methods and an analysis of the costs involved. The evaluation helps with identifying the ideal material and manufacturing process for the production of the wind turbine blade.

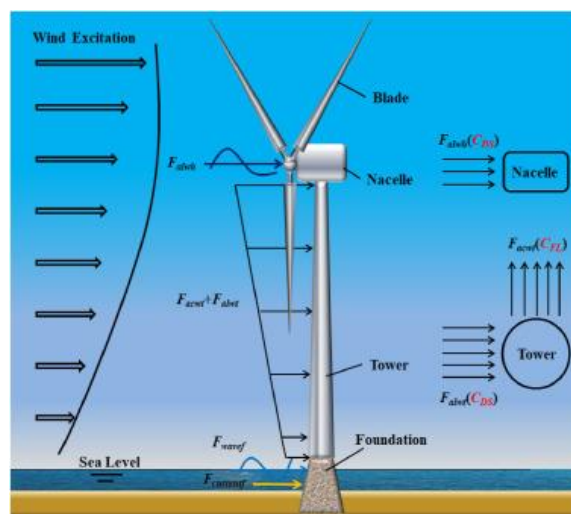


Figure 1: Shows wind turbine components and loads.

2 Literature review

2.1 Aerodynamic profiles and design parameters

The NACA 4412 is a profile with a good camber and is popular in horizontal axis wind turbine applications (Abbott & Von Doenhoff, 2012). The 4412 means a 4% maximum camber located at 40% of the chord position with a 12% maximum thickness. This geometry allows for a good lift to drag ratio (C_l/C_d) which exceed 100 at angles of attack that are between 6-10 degrees ((Fauzan Adziimaa et al., 2025).

Optimal blade dimensions come from the relationship between rotor radius, tip speed ratio (TSR) and wind speed. Modern turbines operate at TSR values that are between 6 and 8 which adjust the aerodynamic efficiency against structural loading (Burton et al., 2021). The power coefficient (C_p) is the fraction of available wind power extracted by the rotor. Practical designs can achieve C_p values of 0.4-0.48 which is approximately 75-80% of the theoretical Betz limit (Hansen, 2015).

Blade geometry uses a linear or nonlinear taper from root to tip to reduce the chord length and improve the angle of attack along the blade span. For this study, calculations considered chord lengths that vary from 0.4m at the blade root to 0.04m at the tip. The twist distribution on the blade should satisfy the increasing tangential velocity towards the blade tip, which maintains the optimal angles of attack across all the radial sections ((Manwell et al., 2002).

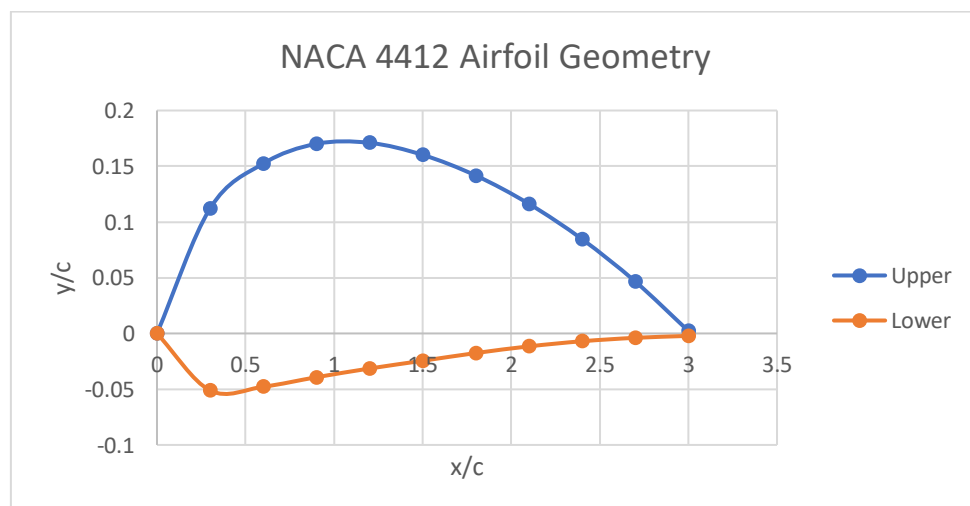


Figure 2: Shows NACA4412 airfoil geometry.

High lift to drag ratios (C_l/C_d) indicate an efficient airfoil. The NACA 4412 can achieve a maximum C_l/C_d of 120 at 8 degrees which ensures efficient energy

extraction while reducing drag. Blades go through around 10^8 to 10^9 loading cycles over an operation of 20-25 years, which justifies the importance of using materials with a good fatigue resistance ((Fauzan Adziimaa et al., 2025).

2.2 Material properties

The main properties of the materials considered in this study are shown in Table 1 below. The table mainly covers the material density, tensile strength, elastic modulus, specific strength advantages and disadvantages.

Table 1: Comparison of mechanical properties.

Material	Density (Kg/m ³)	Tensile strength (MPa)	Elastic modulus (GPa)	Specific strength (MPa/(g/cm ³))	Advantages	Disadvantages
Aluminium 6061-T6	2700	310	69	115	Good machinability, corrosion resistance, recyclable	Lower fatigue resistance, heavy compared to composites
Mild steel	7850	400	200	51	High strength, established manufacturing methods, low cost	High density leading to heavy blades and high structural loads
Silicon carbide	3100	350	410	113	Excellent hardness, thermal stability, corrosion resistance	Brittle, poor fracture toughness. Manufacturing difficulty for large parts
Glass fibre reinforced polymer (GFRP)	1900	700	40	368	High strength to weight ratio, good fatigue resistance, corrosion resistant	Difficult to recycle, potential moisture absorption
Carbon fibre reinforced polymer (CFRP)	1550	1800	135	1161	Very high stiffness and strength, very lightweight	High raw material costs and complex manufacturing

From the table above we see that composite materials have significantly higher specific strength than ceramics and metals, which makes them more suitable for blade manufacturing due to their strength and lightweight.

2.3 Environmental conditions

Wind turbine blades experience demanding environmental conditions throughout their operational duration. The conditions that they face vary from wind speed, temperature changes, UV radiation, moisture ingress and solid particle erosion (Mishnaevsky Jr et al., 2017). Wind turbines at offshore sites face harsher environmental conditions such as salt corrosion from the sea water due to salt being quite corrosive. They also face higher lightning exposure due to their height, isolation and the electrical properties in marine environments. This shows how important it is for the blades material to be able to withstand harsh environmental conditions while staying structurally strong (Lopez & Kolios, 2024).

3 Design specifications

3.1 Blade geometry and parameters

The design parameters used in this study are shown in Table 2 below which are taken from the performed aerodynamic calculations.

Table 2: Shows the blade design parameters.

Parameter	Value
Blade length (R)	50.97m
r/R	0.4
Lift coefficient (Cl)	1.2
Tip speed ratio	6
Number of blades	3
Chord length	1.744m
Airfoil profile	NACA 4412
Wind speed	12m/s
Air density	1.225kg/m ³

3.2 Chord length distribution

Aerodynamic calculations were done in excel to find the chord length taper as shown in Table 3 below.

Table 3: Shows the blade geometry specifications.

r/R	Radius (m)	Chord length (m)	Thickness ratio (t)
0.4	20.388	0.04	0.12
0.5	25.485	0.0388	0.12
0.6	30.582	0.0356	0.12
0.7	35.679	0.03	0.12
0.8	40.776	0.0222	0.12
0.9	45.873	0.0122	0.12
1.0	50.970	0	0.12

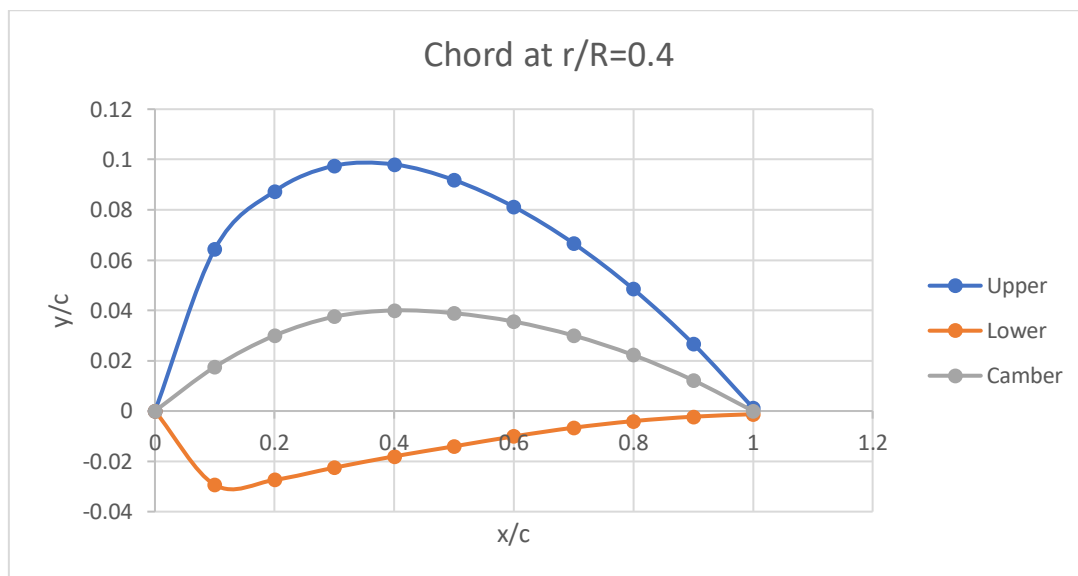


Figure 3: Shows chord length distribution and linear taper from root to tip.

From Table 3 the radius was calculated using $r = \frac{r}{R} \times R$. The table also shows a constant thickness distribution of 12% which is a well-known characteristic of the NACA 4412 airfoil where the maximum thickness is located at 30% of the chord position as shown in Figure 3. This allows for the blade to have enough structural strength while maintaining its aerodynamic performance.

4 Material selection

4.1 Weighted decision matrix

A weighted decision matrix was used to compare aluminium alloy, steel, ceramics and polymer composites against a set criterion that is important for wind turbine blade performance. Weights were applied to show the importance of each set criteria to the blades performance and operational duration as shown in Table 4 below.

Table 4: Shows the weightings used for each criterion.

Criterion	Weighting
Strength to weigh ratio	0.25
Fatigue resistance	0.20
Cost	0.20
Corrosion resistance	0.15
Manufacturing scalability	0.10
Recyclability	0.10
Total	1.00

Each material was scored using a scale from 1 to 5 for each criterion, with 1 = poor and 5 = excellent. The weighted scores were calculated and added up as seen in Table 5 below. The number in brackets represents the assigned weighted value.

Table 5: Shows the weighted decision matrix scores.

Material	Strength to weight ratio	Fatigue	Cost	Corrosion	Scalability	Recyclability	Total score
Aluminium alloy	2 (0.50)	3 (0.60)	4 (0.80)	2 (0.30)	5 (0.50)	5 (0.50)	3.20
Steel	1 (0.25)	4 (0.80)	4 (0.80)	2 (0.30)	5 (0.50)	5 (0.50)	3.15
Ceramics (SiC), (ZrO ₂)	2 (0.50)	1 (0.20)	1 (0.20)	5 (0.75)	1 (0.10)	2 (0.20)	1.95
GFRP	5 (1.25)	5 (1)	4 (0.80)	5 (0.75)	4 (0.40)	2 (0.20)	4.40
CFRP	5 (1.25)	5 (1)	2 (0.40)	5 (0.75)	3 (0.30)	2 (0.20)	3.90

4.2 Selection justification

The weighted decision matrix shown in Table 5 shows glass fibre reinforced polymer (GFRP) as the best material to use for the production of the wind turbine blade due to its total score of 4.40, thus making it the recommended material. This matches industrial practice where (GFRP) is widely used due to its higher strength to weight ratio, excellent fatigue performance, low costs, durability and manufacturing scalability.

Carbon fibre reinforced polymer (CFRP) came in second place with a score of 3.90 due to having good mechanical properties but is limited due to its high raw material costs of roughly £30/kg where GFRP has a raw material cost of £2/kg (Bortolotti et al., 2019). The metallic materials scored poorly due to their strength to weight ratios even though they scored high in the cost and recyclability criterion. Ceramics were found to be unsuitable for wind turbine blades due to their brittleness, manufacturing difficulty and scalability limitations.

5 Exploration of manufacturing methods

The selected manufacturing method for producing the blades plays a vital role as it determines the structural quality, production costs and scalability. Many manufacturing methods were evaluated for the materials considered in this report. Each method was evaluated based on its manufacturing feasibility, potential defects, production efficiency and suitability for wind turbine blades.

5.1 Metal manufacturing methods

5.1.1 Casting

Casting involves the pouring of molten metal into a mould that is shaped with the blade's geometry as shown in Figure 4. After the metal solidifies the blade is removed from the mould and goes through finishing processes like heat treatment and machining. Aluminium alloys are used in casting due to their low melting temperature of around 660°C (Beeley, 2001).

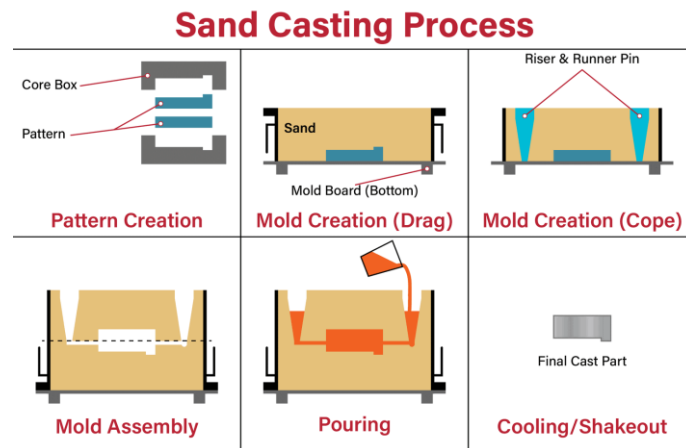


Figure 4: Shows the sand casting process.

Although casting allows for complex shapes to be produced it has several limitations when it comes to turbine blade production. Components made from casting are prone to defects such as voids and porosity which reduces the structural strength. Metallic blades are heavier than composite blades, which increases their gravitational loads reducing their efficiency. Due to this casting is said to be unsuitable for wind turbine blade production (Campbell, 2011).

5.1.2 Extrusion

Extrusion is where heated metal is forced through a shaped die to produce components with a constant cross section as seen in Figure 5. This method provides a good surface finish and has good mechanical properties. This makes it suitable for structural components such as support structures (Saha, 2000).

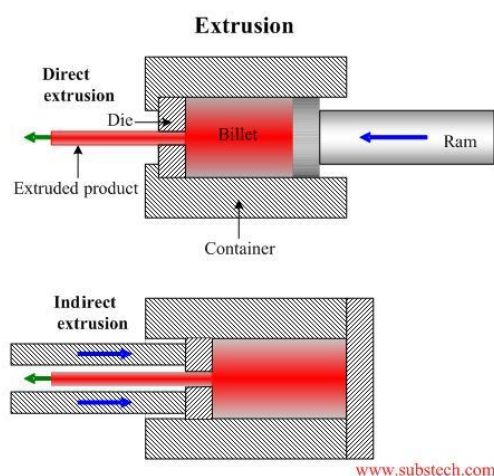


Figure 5: shows the extrusion process.

Extrusion is seen as an unsuitable method for manufacturing wind turbine blades. This is due to the constant cross section that extrusion produces whereas turbine blades need a varying chord length making extrusion limited to internal parts in the turbine rather than the blades.

5.2 Ceramic manufacturing methods

Ceramic materials are produced using methods such as sintering. Sintering involves ceramic powders being compacted into a green body and being heated to around 1600 °C to form a structurally dense solid as shown in Figure 6 below.

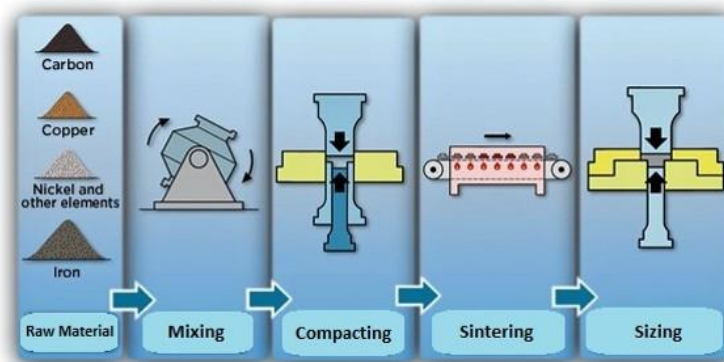


Figure 6: Shows the sintering process.

While ceramics have excellent hardness and corrosion resistance, their brittleness makes them unsuitable for load bearing structures such as wind turbine blades. Ceramics have a low fracture toughness and are sensitive to failure under any tensile load. The manufacturing process for ceramics is difficult, expensive and energy intensive thus making ceramics more suitable for protective coatings rather than blade structures (Rahaman, 2017).

5.3 Polymer composite manufacturing methods

5.3.1 Resin transfer moulding (RTM)

Resin transfer moulding is a closed mould composite manufacturing method where dry fibre reinforcements are placed into a mould and pressurised resin is injected as shown in Figure 7. The injected resin saturates the fibres before curing to form a solid composite component.

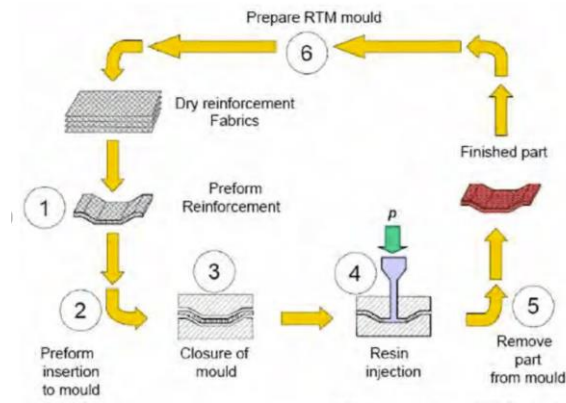


Figure 7: Shows resin transfer moulding process.

RTM has an excellent surface finish and has high fibre volume fractions meaning it makes components with consistent mechanical properties. The tooling costs incurred by RTM are very high making this method expensive for large components such as wind turbine blades (Rudd et al., 1997).

5.3.2 Vacuum infusion

For manufacturing wind turbine blades vacuum infusion is the most used method in industry. This process involves dry fibre fabrics being placed into a mould and covered with a vacuum bag (Gajjar et al., 2020). Resin is then pulled into the fibre layers using vacuum pressure to ensure the fibres are completely saturated as shown in Figure 8.

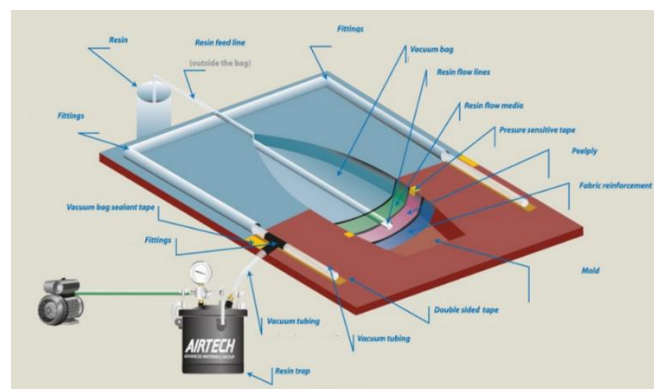


Figure 8: Shows the vacuum infusion process.

Vacuum infusion has many advantages such as low tooling costs, good fibre volume fractions and the ability to manufacture large components. Vacuum infusion also reduces the amount of resin wasted and allows for better control of void formation during the curing process. Due to its scalability and cost effectiveness vacuum infusion has become the most suitable manufacturing method for composite blades.

5.4 Comparative analysis

The different manufacturing methods discussed above can be compared using production time, tooling costs, part quality and scalability. Table 6 below outlines the main characteristics of the evaluated manufacturing methods in this report.

Table 6: Shows a comparison of manufacturing methods.

Process	Production time	Tooling costs	Part quality	Scalability
Metal casting	4-8 hours	Medium	Poor – fair	Medium
Metal extrusion	Minutes per meter	High	Good	High but for simple shapes
Ceramic sintering	24-72 hours	Medium	Good	Poor
Resin transfer moulding (RTM)	2-6 hours	High	Excellent	Medium – high
Vacuum infusion	8-24 hours	Low - medium	Very good	Excellent

From the comparison above it is seen that vacuum infusion is the best manufacturing process for wind turbine blades. This is due to its balance between part quality, cost effectiveness and scalability. Therefore, vacuum infusion is the recommended method for manufacturing the blades.

6 Cost evaluation

6.1 Raw material costs

Raw material prices vary between metals, ceramics and composite materials. These costs have an impact on the overall manufacturing costs especially for large structures such as turbine blades where a lot of material is required. Table 6 shows the market prices and densities for the materials considered in this report. The prices are based on 2024-2026 market values (Shikkerimath).

Table 7: Shows raw material costs from market costs.

Material	Density (kg/m ³)	Cost per kg (£)	Cost per m ³ (£)
Aluminium 6061	2700	£2.50	£6750
Mild steel	7850	£0.80	£6280
Silicon carbide	3100	£25	£77500
Zirconia	5700	£35	£199500
Glass fibre		£1.87	
Carbon fibre		£30	
Epoxy resin	1150	£3.63	£4175
Polyester resin	1100	£2.80	£3080
PVC core material	80	£8	£640

6.2 Blade material cost estimation

To estimate the approximate material cost for a wind turbine blade, a simplified calculation was done for a blade length of around 50m. Composite blades are made up of many components such as outer skin laminates, spar caps, internal core materials and resin as seen in Figure 9.

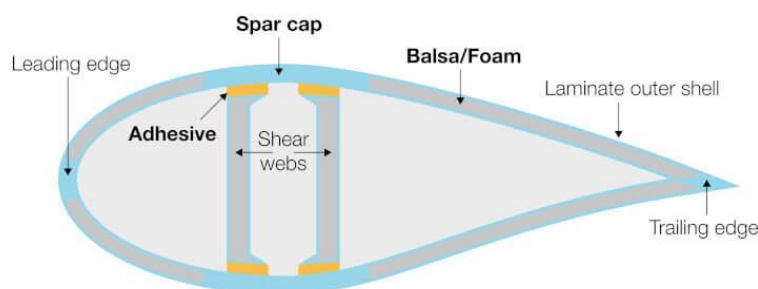


Figure 9: Shows composite blade components

A glass fibre reinforced polymer blade manufactured using vacuum infusion has the following material requirements which are used to find their estimated cost by multiplying their mass and price per kilogram:

- Skin laminations: 3500kg of glass fabric at £3/kg =£10500
- Spar caps: 1200kg glass fibre at £1.87/kg = £2244
- Core materials: 350kg PVC foam at £8/kg = £2800
- Resin: 2800kg epoxy resin at £3.63/kg =£10164
- Adhesives, gel coat and consumables = £3500

The total estimated cost for producing one blade is roughly £29208 which equates to about £585 per meter of the blade length(World Renewable Energy Network, 1991).

6.3 Manufacturing costs

Composite manufacturing methods such as vacuum infusion require 120 – 180 labour hours from skilled technicians per blade at a cost of £25 - £35 per hour. The skilled technicians are responsible for the fibre layup, vacuum bagging, and resin infusion process. This shows that labour costs take up a big chunk of the overall manufacturing costs of producing a wind turbine blade.

The blades total weight also affects its transportation and installation costs. This is due to the need of hiring heavy haulage transportation and a crane to assist in the installation of the blades. Composite blade weighs around 2500kg whereas aluminium blades weigh more than 8000kg. heavier blades need larger transportation and stronger towers which increases the overall manufacturing costs (Bawah et al., 2011).

Lighter blades improve the aerodynamic efficiency and allow for the turbines to operate at higher tip speeds. This can increase the annual energy production of the wind turbine by 2 – 5 % which increases long term revenue from electricity generation (Bawah et al., 2011).

6.4 Cost performance trade offs

Table 8 below shows that glass fibre reinforced polymer blades that are made using vacuum infusion have the best balance between cost, structural performance and long operational efficiency. Although aluminium has lower material costs, GFRP's lower weight and better fatigue resistance results in overall lower lifespan costs (Bawah et al., 2011).

Table 8: Shows a cost-performance comparison.

Material and manufacturing method	Material costs (£)	Blade weight (kg)	20 year lifespan cost	Performance
GFRP using vacuum infusion	£29208	2500	£65000	Very good
CFRP using vacuum infusion	£48512	2000	£70000	Very good
Aluminium using casting	£23250	8500	£95000	poor
Ceramics using Sintering	£200000	6000	£350000	Unsuitable

7 Mechanical properties analysis

This chapter looks at the structural performance of the designed wind turbine blade by linking the aerodynamic loads on each spanwise section to the bending and torsional stresses at the blade root. The analysis calculates the lift and drag forces, determines root bending and torsional stresses and compares the resulting stresses against the strengths of the materials.

7.1 Aerodynamic force calculations

The rotor runs at a tip speed ratio of $\lambda = 6$, a wind speed of $V = 12m/s$ and a blade radius of $R = 50.97m$. The angular velocity is calculated using $\omega = \frac{\lambda V}{R} = \frac{6 \times 12}{50.97} = 1.41 rad/s$. At each radial position r the tangential velocity is $V_t = \omega r$ where the relative wind speed at the section is calculated using $V_{rel} = \sqrt{V^2 + V_t^2}$ which is a combination of the axial wind and rotational element.

The lift and drag per unit are evaluated using the following aerodynamic equations:

- Lift $= L' = \frac{1}{2} \rho V_{rel}^2 c C_L$
- Drag $= D' = \frac{1}{2} \rho V_{rel}^2 c C_D$

Where $\rho = 1.225 \text{ kg/m}^3$ is the air density, c is the local chord length, $C_L = 1.2$ is the design lift coefficient and $C_D = 0.012$ is the drag coefficient for the NACA 4412 airfoil at its operational angle of attack. For this report the blade is bisected into spanwise sections of width $\Delta r = 0.1R = 5.097 \text{ m}$. This means that the total lift and drag on each section is $L = L' \times \Delta r$ and $D = D' \times \Delta r$.

Using the geometry and parameters from chapter 3 the forces were calculated as seen in table 9.

Table 9: Shows the calculated lift and drag forces for the blade sections.

r/R	Radius (m)	Chord (m)	V _{rel} (m/s)	Lift per unit (N/m)	Drag per unit (N/m)	Section lift (N)	Section drag (N)
0.4	20.388	0.4	31.2	286.2	2.86	1458.7	14.6
0.5	25.485	0.388	37.9	410.7	4.11	2093.1	20.9
0.6	30.582	0.356	44.8	526	5.26	2681	26.8
0.7	35.679	0.3	51.8	591.9	5.92	3016.7	30.2
0.8	40.776	0.222	58.8	564.9	5.65	2879.1	28.8
0.9	45.873	0.122	65.9	389.4	3.89	1985	19.9
1.0	50.97	0.04	73	156.6	1.57	798.4	8

The calculations show that the lift increases from the inner area and peaks at $r/R=0.7$. The lift then decreases as the chord tapers towards the blade tip. This matches the aerodynamic literature on tapered blades.

7.2 Root bending and torsional moments

The root bending moment is calculated by adding the moments of the section lift forces around the blade root using $M = \sum_i L_i r_i$. Using the root bending equation, M is $\approx 5.22 \times 10^5 \text{ Nm}$. The torsional moment from drag was calculated using $T = \sum D_i r_i$ making $T \approx 5.22 \times 10^3 \text{ Nm}$. To calculate the stress at the root, the root section was simplified as a rectangular section of width $b = 0.40 \text{ m}$ and thickness $h = 0.04 \text{ m}$. The

second moment of area is: $I = \frac{bh^3}{12} = \frac{0.4 \times 0.04^3}{12} = 1.26 \times 10^{-3} \text{ m}^4$. The

maximum bending stress is therefore: $\sigma = \frac{My}{I} = \frac{(5.22 \times 10^5)(0.20)}{1.26 \times 10^{-3}} = 82.9 \text{ MPa}$. The

torsional shear stress for a simplified rectangular section was calculated using:

$\tau_{max} \approx \frac{1.5 \times (5.22 \times 10^3)}{0.4 \times 0.4^2} \approx 122 \text{ MPa}$. This shows that bending stress is the biggest loading, while torsional shear is much smaller.

7.3 Comparison with material strength

Table 10 compares the calculated bending stress with the tensile strengths for the materials and their allowable stresses using a safety factor of 2.

Table 10: Shows a comparison between bending stress and material strength.

Material	Tensile strength (MPa)	Stress with SF=2(MPa)	Applied bending stress (MPa)	Evaluation
Aluminium 6061	310	155	82.9	Adequate for bending, but is heavy and prone to fatigue
E-glass with epoxy laminate	700	350	82.9	Adequate and weight efficient
Carbon with epoxy laminate	1800	900	82.9	Very adequate and has the best weight efficiency
Glass spar reinforcement	1200	600	82.9	Adequate with big safety margin

These results should be seen as estimates due to the root being simplified as a simple rectangular section. This analysis shows that composite blades need reinforced root sections and internal structures rather than a simple shell. This supports the material selection where polymer composites won due to their higher strength and durability.

8 Comparative analysis

Table 11: Shows manufacturing defects, impacts and mitigation.

Process	Typical defects	Impact on performance	Mitigation strategies
Casting	Porosity, shrinkage cavities	Stress concentration, reduced strength by 20-40%	Controlled solidification, vacuum casting
Extrusion	Surface defects, dimensional changes	Surface finish, fatigue initiation areas	Die maintenance, heat control
Sintering	Cracking, density gradients	Brittle failure, property changes	Improved heating profiles, green body quality
RTM	Dry spots, voids (1-5%)	Delamination, reduced strength by 5-15%	Flow simulation, many injection ports
Vacuum infusion	Voids (<2%), resin rich areas	Minor strength impact by <5%, weight increase	Degassed resin, good vacuum pressure

The selected material and manufacturing method is compared to metal, ceramic and CFRP to validate mechanical performance, productivity, defects and environmental factors. GFRP has a high strength to weight ratio, good stiffness and good fatigue resistance allowing for a light blade with an acceptable safety factors under load. Aluminium and steel meet the strength requirements but are three times heavier which increases the tower weight, fatigue loading and transportation costs. Ceramics have good stiffness and corrosion resistance but are too brittle for the forces. CFRP has the best stiffness and lowest weight but has higher material costs (Amenabar et al., 2011).

Looking at productivity and scalability, vacuum infusion and RTM both have good fibre volume fractions and finish quality. However vacuum infusion uses cheaper

tooling and is better for manufacturing blades over 50 meters. Casting and extrusion are fast manufacturing methods but are difficult when it comes to producing large twisted hollow blades without additional welding and machining. Sintering and additive manufacturing are too slow and are limited by size (Amenabar et al., 2011).

Defect risks are very low for vacuum infusion where a void content below 2% is achievable. Defects such as dry spots, porosity and resin rich areas can be mitigated through vacuum control and quality control inspections. Metal casting is prone to shrinkage porosity and inclusions, while ceramic parts are prone to cracking and density gradients. Vacuum infusion reduces styrene emissions compared with open moulding. Metals have good recyclability characteristics but have a higher embodied energy per kg than GFRP.

9 Blade drawing

The final CAD drawing shows the 50.97m blade span with a linear chord taper, NACA 4412 cross section and a spanwise sections at $r/R = 0.2, 0.4, 0.6, 0.8$ and 1.0 . Main dimensions such as root and tip chord, maximum thickness locations and twist angles are shown.

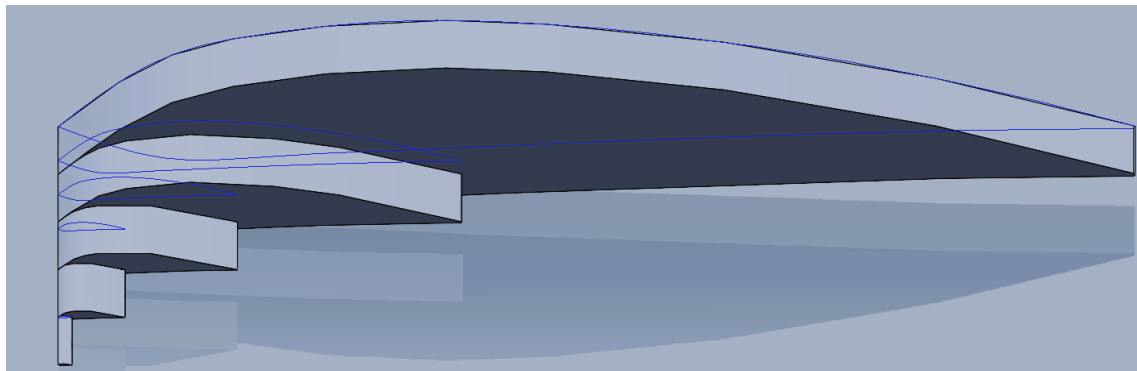


Figure 10: Shows the CAD model.

10 Conclusions and recommendations

This report shows that GFRP blades made using vacuum infusion give the best balance between performance, cost and manufacturability. The aerodynamic analysis of the NACA 4412 and the chord distributions achieved the targeted C_p value of 0.4 while the structural calculations at the root confirmed acceptable stresses. The comparison with aluminium, steel and ceramics showed that the

selected GFRP has a lower weight, better fatigue resistance and lower lifespan costs over a 20 year period.

It is recommended that Company X should use GFRP for their blades and should use tools such as finite element analysis, fatigue analysis and manufacturing trials to find room for refinements. Further work should look at better recycling methods and better resin systems to improve the sustainability of composite blades.

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