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Manufacture of a Wind Turbine Blade
Advanced Processes and Materials ACMA6000

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1 Abstract

This technical report focuses on the Manufacture of an 8MW Wind Turbine Blade designed for deployment off the North Sea coast. The project initially defines key blade requirements, including rotor diameter, blade taper, tip speed ratio (TSR) of 7-8, ultimately selecting the NACA 4712 airfoil design for its superior aerodynamic performance and higher power coefficient compared to other NACA profiles.

Research in this report explores the environmental factors such a blade would be subject to, such as extreme North Sea wind speeds (peaking at 35-40 m/s) and the challenges of marine corrosion, which significantly influence material selection. The report then explores different manufacturing routes, including metals, ceramics, and polymer composites. Ceramics are dismissed due to the prohibitive complexity and scalability issues of manufacturing blades nearly 100m in length, along with defect risks.

Casting metals faces similar defect challenges at scale. Polymer composites, specifically utilising vacuum infusion, are the most suitable method due to their high strength-to-weight ratio, fatigue resistance, and cost-effectiveness for large components, despite initial setup complexity.

The study also addresses COSHH regulations for manufacturing safety. A detailed Granta material assessment narrows down material choices based on critical factors like yield strength, density, and water absorption, resulting in a shortlist of epoxy aramid fibre composite, Mg EA55RS, and Mg ZC71. The report concludes with a costing analysis to determine the most financially viable option given the performance characteristics of the potential material options, settling with epoxy aramid fibre composite manufactured through a vacuum infusion method.

2 Introduction

This report aims to identify the key aspects of manufacturing a wind turbine blade, focusing on deploying it in a North Sea wind farm. This project will look at a typical 8MW wind turbine common to these applications. To this end, this report will explore the following aspects:

- What design aspects will the blade need to achieve to meet the objectives of minimising maintenance costs, enhancing energy output and choosing a reliable and repeatable manufacturing process.
- The environment in which the blade is to be deployed, and how this will affect the blade over its life span.
- The material choice for the blade with consideration to strength, longevity and efficiency.

By balancing these goals, this report hopes to define the best blade for the considered application.

3 Blade Requirement Overview

Wind turbines have several key dimensions which significantly influence efficiency; three main measurements to consider are rotor diameter, hub height (Stanley & Ning, 2019), tip speed ratio and the blade taper. Balancing these features ensures the design provides maximal efficiency of the wind turbine within its specific environment.

The rotor diameter directly affects the swept area of the turbine. Increasing the swept area is directly proportional to the power output of the wind turbine, as demonstrated by Equation 1 (excluding the power transfer coefficient of the wind turbine for clarity), Increasing the swept area increases the volume of air which can pass through the wind turbine's blade, corresponding to the amount of wind energy that can be harnessed. A larger rotor diameter increases the energy capture potential of the turbine, leading to higher efficiency rates. For commercial utility-scale wind turbines, typical rotor diameters range from 80 to 120 meters (Jonkman et al., 2009).

$$P = 1/2 \cdot \rho \cdot A \cdot v^3$$

Equation 1 Ideal equation of Power from a Wind Turbine

Moreover, the rotor diameter must consider TSR (tip speed ratio) values, which have a significant influence on overall efficiency. TSRs of 7 - 8 are generally considered optimal for aerodynamic performance in large turbines (Jiang et al., 2015). These values are based on an understanding of the relationship between TSR and the power transfer coefficient. As shown in equation B TSR (λ) is expressed as a function of rotor angular speed (Ω), rotor radius, the free-stream velocity of the air (v) (Chica & Rubio-Clemente, 2020).

$$\lambda = \Omega R / v$$

Equation 2 Tip Speed Ratio (TSR) (Chica & Rubio-Clemente, 2020)

A turbine's efficiency is significantly affected by its taper, the gradual reduction of the blade width from the root to the tip, as it influences both aerodynamic performance and structural integrity (Lololau et al., 2021). Introducing a taper increases resistance to bending moments, improving mechanical stability, and so extending the service life of the turbine by reducing stress along the blades (Krawczyk et al, 2013).

Traditional turbine blade designs employ linear tapers. These designs incorporated constant 'chord' lengths, which limited aerodynamic performance in changing operating conditions. Contemporary designs utilise advanced aerodynamic principles to optimise blade profiles by

incorporating non-linear tapers that help the aerodynamics of the blade perform in varying wind conditions and maximise energy extraction (Schubel & Crossley, 2014; Kasem, 2022).

Aerodynamic profiling of wind turbine blades is often achieved through the use of established airfoil designs. The NACA 4412 is a common airfoil design with favourable lift-to-drag ratio shown in Table 1 when compared to NACA 2412 or 4415; this is a common comparison metric in determining the efficiency of wind turbines (Taibaoui & Benmessaoud, 2024; Balbuena et al, 2025).

AOA	CL of NACA4412	CL of NACA 2412
0	0.412	0.0589
5	0.912	0.7429
10	1.26	1.1591
15	1.24	0.8412
20	0.908	0.435

Table 1 Lift-to-drag Coefficients of NACA 4412 & 2412 in increments of AOA (angle of attack in degrees) (Mohammad & Gok, 2024)

Although a common design, studies indicate that the NACA 4712 possesses a higher lift-to-drag ratio and power conversation constant compared to the NACA 4412, at moderate wind speeds. The NACA 4712 achieved a power coefficient of 0.49929 and produced at a wind speed of 7.66 m/s, while the NACA 4412 yielded a power coefficient of 0.395365 (Susilo et al, 2019) alongside a slightly better optimal lift coefficient of 1.696 (Trifiananto et al, 2022). Therefore the design of this wind turbine will focus on the NACA 4712 which a wind turbine profile suitable for applications requiring higher energy extraction.

4 Preliminary Literature Review

While maximising the power output of the turbine is crucial, it's also important to identify and understand environmental factors and design variables that are constrained. Material selections must take into account factors about the area where a wind turbine is to be placed in; these include:

- Wind Speeds (material loading & stress)
- Local Causes of Corrosion
- Expected Operating Lifespan
- Maintenance Access

The air speed is fixed at whatever environmental windspeed is applied to the turbine. Peak wind speeds in the North Sea have been documented to peak at highs of 35-40 m/s (about 126-144 km/h) during severe storms (Tambke et al., 2004); but typical wind speeds are near 10 m/s (Wróbel & Piskozub, 2016).

Corrosion in marine environments, particularly in the North Sea, poses unique challenges. The primary corrosion damage mechanisms applicable to wind turbine blades include the interaction of salt particles with the surface, which can lead to surface defects, including pitting, cracking, and general deterioration. Exposure to salt enhances surface roughness and promotes material fatigue due to the corrosive action of chloride ions present in seawater (Dong et al., 2013).

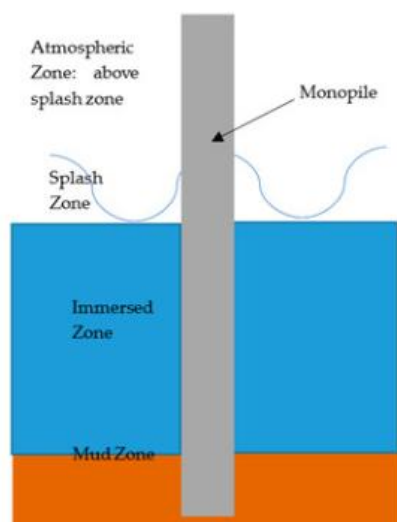


Figure 1 Different Corrosion Zones of a Turbine Monopile at sea (Mathiesen, et al., 2016)

5 Manufacturing Routes

5.1 Metals

Metals are less common in wind turbine blade applications, but are used when structural resilience is needed. Steel is utilised in specific structural applications due to its comparatively high yield stress and was used in early turbine applications; however, its considerable weight is a major drawback in terms of efficiently capturing wind energy (Mishnaevsky et al., 2017). Aluminium, on the other hand, is lauded for both a favourable strength-to-weight ratio and excellent corrosion resistance compared to ferrous alloys, making it viable for components that must withstand harsh environmental conditions (Ganesh et al., 2022). Corrosion resistance is crucial to the reduction of maintenance requirements in any engineering application, combined with its high weight and therefore poor energy-conversion performance, makes it an impractical choice.

Casting methods are commonly used for producing structures requiring complex shapes without a constant cross-section or other design features which might permit extrusion or other constant-cross-section manufacturing methods. Aerodynamic profiles are needed for optimal performance, but casting is expensive to set up, and inclusions and voids from the liquid metal cooling can weaken the alloy, as shown in Figure 2.



Figure 2 Voids in a cast Metal due to Cooling (Otarawanna, et al., 2009)

5.2 Ceramics

Ceramic materials in turbine blade construction are much rarer than metallic or polymer composites, but there are some cases where they are beneficial. A common method used for manufacturing ceramic cores for turbine blades is gelcasting with a ceramic slurry. This method facilitates the creation of complex structures that are essential for turbine blades with non-uniform cross-sections (Wu et al., 2009).

Gelcasting can be used for **integral core/shell fabrication** by combining **Stereolithography (SL) and gelcasting**. An SL resin prototype of the blade assembly, including complex internal cooling passages which wouldn't be possible with typical construction techniques, served as the mould for gelcasting. **Low-viscosity ceramic slurry** was poured into this resin mould, then **freeze-dried** to prevent shrinkage and cracks. The resin was pyrolysed, and the ceramic green body was **sintered at 1550°C** to form the integral mould (Wu et al., 2012).

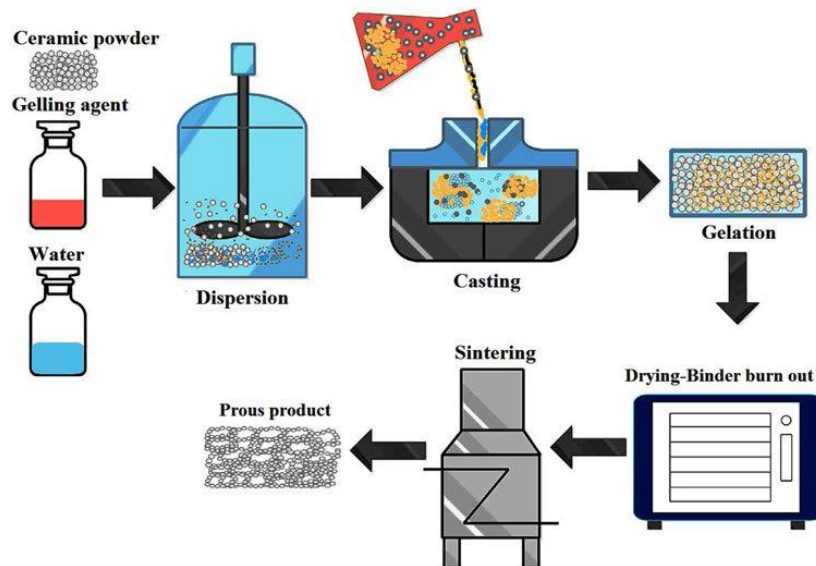


Figure 3 Gel-Casting Diagram (Azamiya, 2019)

Cost is a significant consideration in ceramic turbine blades. Traditional methods, while yielding high precision, often come with complex procedures, leading to higher expenses. Additive manufacturing shows promise in reducing costs by offering a method of reducing the development cycles of these parts (Song et al., 2024).

5.3 Polymer Composites

Two extremely common traditional polymer composite methods used to manufacture turbine blades are wet hand layup and vacuum infusion. Both methods leverage the inherent advantages of fibre-reinforced polymers, generally recognised for their high strength-to-weight ratios and exceptional fatigue resistance.

Wet Hand Layup process is one of the most cost-effective methods for low quantities and small-to-medium-sized parts where the high labour cost can be justified. It allows for a high degree of control over fiber orientation, controlling mechanical properties (Maskepatil et al., 2014). Common manufacturing challenges typically involve lower fibre volume fractions

(Galappaththi et al., 2012), along with a higher risk of air getting trapped in the matrix material, weakening the final material.

Vacuum Infusion offers greater consistency due to significantly higher fibre volume fractions, improving the mechanical properties of the composites produced (Dervilis et al., 2012).

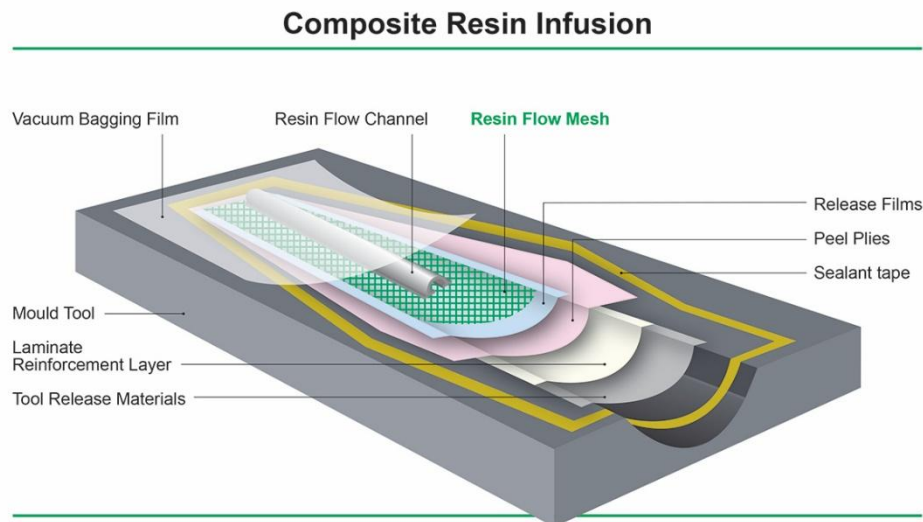


Figure 4 Vacuum Infusion Diagram (Nine Zero Tech, 2025)

This method also significantly reduces curing times and minimises the labour involved (Maguire et al., 2018), making the process much more cost-efficient for components manufactured at large scale or large quantities. However, the requirements for components to be held under vacuum, a typical setup of which is shown in Figure 4, naturally add setup costs and technical complexity.

Overall, vacuum infusion is the most suitable manufacturing method for the selected polymer composite material in this project. While it introduces some additional complexity, its advantages become particularly significant when considering the large size of the blade and the volume of components required for this location. The process's ability to reduce labour intensity—especially in the fabrication of major parts—plays a crucial role in lowering overall production costs, making it the most feasible and cost-effective option.

6 Blade Design

6.1 Blade Mathematical Definition

Using Equation 1 from the literature review, we can calculate the blade length (assumed to be the radius of the wind turbine's swept area). The calculation for the blade length of this 8MW turbine with a blade design of NACA 4712.

$$P = 1/2 \cdot \rho \cdot A \cdot v^3$$

$$\frac{2P}{\rho \cdot v^3} = A$$

$$\frac{2(8 \times 10^6)}{1.225 \times 10^3 \times 0.499} = A$$

$$A = 26,174.8 \text{ m}^2$$

$$A = \pi R^2$$

$$R = L = 91.28 \text{ m}$$

Equation 3 Calculation of Blade Length

The camber of a wind turbine gradually changes along the length of the blade, with the cross-section constantly changing. The entire profile for a given blade design can be expressed through the four NACA digits, representing the maximum camber, the distance of the maximum point, and the final digits representing the maximum thickness. Using these values, we can calculate the profile at any given point along the length of the wing for the required length of 91.28m.

Calculating every point is impossible, Figures 5&6 show 5 equidistant profiles for the upper and lower faces of the blade.

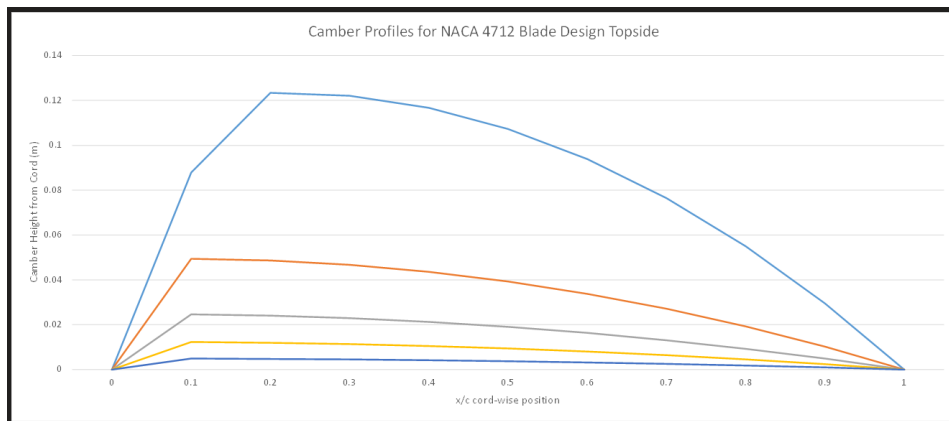


Figure 5 Graph of Turbine Blade upper profiles at 5 cross-sections

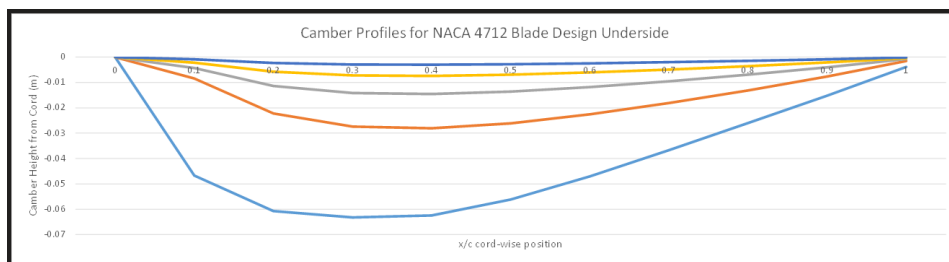


Figure 6 Graph of Turbine Blade lower profiles at 5 cross-sections

6.2 Manufacturability and scalability

The research previously undertaken addressing manufacturing methods highlighted some additional problems with ceramic components for this application. The process of using ceramics involves thoroughly mixing ceramic powder with a gelling agent, followed by casting and then curing the component with specialised equipment, as shown in Figure 3. The need to transfer the component between all these steps, and then placing an entire component within each successive machine, adds extreme complexity. Moving a blade of nearly 100m between each station, and sourcing machines large enough to perform each operation, makes this manufacturing route prohibitively complex.

For this reason, ceramics aren't a viable material for the construction of this wind turbine blade. In addition to the complexity and bespoke machinery required, curing such a large component through these types of processes cannot guarantee even drying and material properties, with cracks or fractures very likely to form (Hansen, 2020). If this were to happen, inspecting the entire length would be time-consuming and could still miss defects.

Similarly, casting metals can also suffer from similar defects due to the size of the components involved. As demonstrated in Figure 2, differing cooling rates and the inclusion of foreign materials will be exacerbated by the scale of the turbine blade. Yet, complex curing processes present in ceramic manufacturing methods aren't needed in metallic

castings, and so although more complex than a polymer layup method due to the temperatures required, metallic materials could still be beneficial.

6.3 COSHH as relevant to Manufacturing

Polymer composite lay-up and casting manufacturing methods involve substances likely to be classified as hazardous under CLP regulations, which COSHH regulates. Any manufacturing method implemented after this feasibility study for either material would need to comply with section 6 (Assessment of the Risk to Health), 7 (Prevention or Control of Exposure to Substances Hazardous to Health), 9 (Maintenance, Examination, and Testing of Control Measures) and 12 (Information, Instruction, and Training) under (UK Government, 2002).

To achieve this, the following would need to be accomplished under:

- Section 6 - Effective documentation of the known hazardous properties of resins and solvents referencing information from supplier data sheets; additionally, any exposure limits of dusts and fibres. The activities to be undertaken with potential for high exposure must also be recorded.
- Section 7 - Substitution needs to be first considered, and the potential for replacing hazardous substances or processes with less hazardous alternatives. Where this isn't possible, protective measures should be applied. The design of appropriate work processes, such as vacuum infusion, can reduce exposure compared to hand application. Controls like adequate ventilation systems to remove vapours and dust. Finally, PPE should be provided if adequate control cannot be achieved by other means.
- Section 9 - Any control measure must be properly maintained in good working order, and procedures must be enforced to ensure this. This might include examination and testing of respiratory protective equipment. Records of these examinations and tests must additionally be kept.
- Section 12 - Employees who are liable to be exposed to hazardous substances must receive suitable and sufficient information, instruction, and training. This includes details of the substances, risks, access to safety data sheets, etc.

(UK Government, 2002)

Additionally, for a process involving metallic casting, Regulation 4, Schedule 2 explicitly prohibits the use of certain substances for specific purposes, which could be relevant if

certain traditional casting materials were applied. Certain substances are prohibited as "material in connection with the making of metal castings" if they contain more than 3% by weight of silica compounds. Any materials chosen for the casting process, for the cast itself, must comply with this prohibition (UK Government, 2002).

7 Granta Material Assessment

In choosing a material, either a metal alloy or a polymer-fibre composite will be used, having now eliminated ceramics.

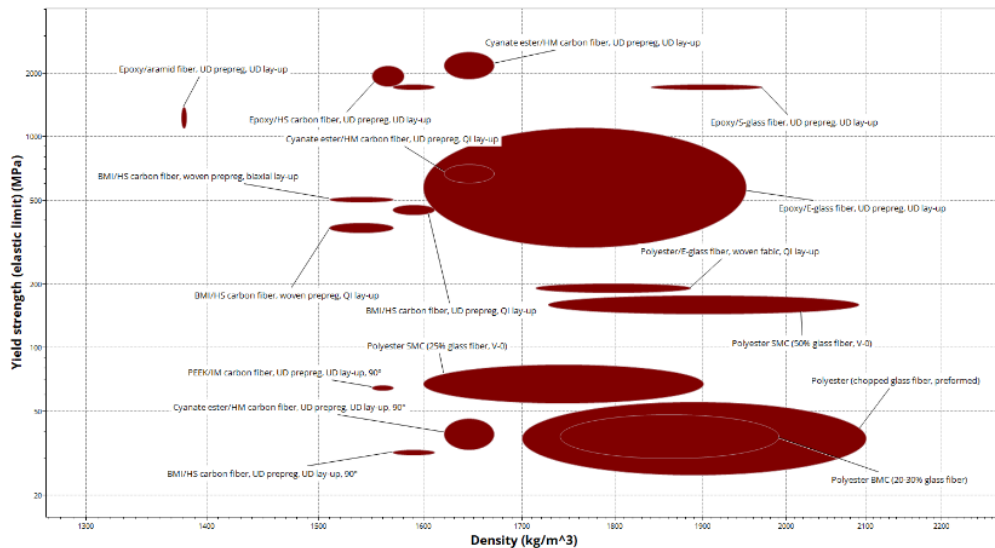


Figure 7 Graph from Granta of Composite Polymer Materials of Yield & Density

Figure 7 shows a wide spread of possible polymer composites on a density-yield strength graph from Granta. These two factors are key metrics for this project, with cost and material degradation being secondary concerns, as the mechanical properties are crucial for any such application. Additionally, excellent density or strength could allow the possible removal of material and components, saving on cost and repair complexity.

We can see from this graph that the materials, including BMI/HS and chopped fibres, have poor strengths compared to other composite materials, while not offering improved density.

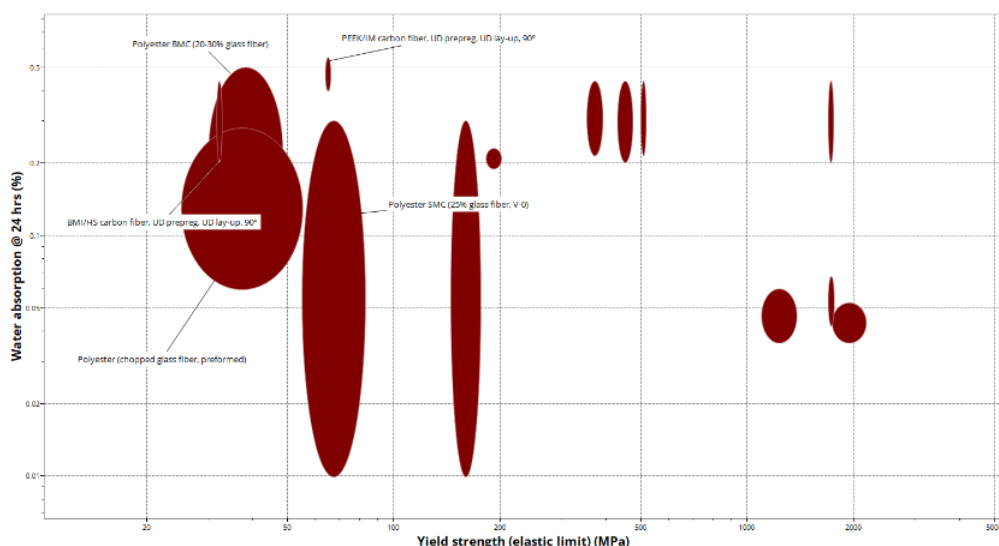


Figure 8 Graph from Granta of Composite Polymer Materials of Water Absorption by Yield Strength

The third crucial dimension to consider here is the water absorption of the material (Figure 8), which disrupts hydrogen bonds, increasing polymer chain mobility (Akil et al., 2014), reducing yield strength and the effectiveness of the fibre interface. Additionally, water-weight added to a material will inevitably increase the density, reducing power conversion efficiency over the product lifecycle.

All these factors increase maintenance costs associated with replacing defective or eroded parts, as well as possible preventive measures during manufacturing. In line with minimising the maintenance costs over the lifetime of this blade, materials with water absorption above 0.05% in 24 hours will be eliminated from consideration.

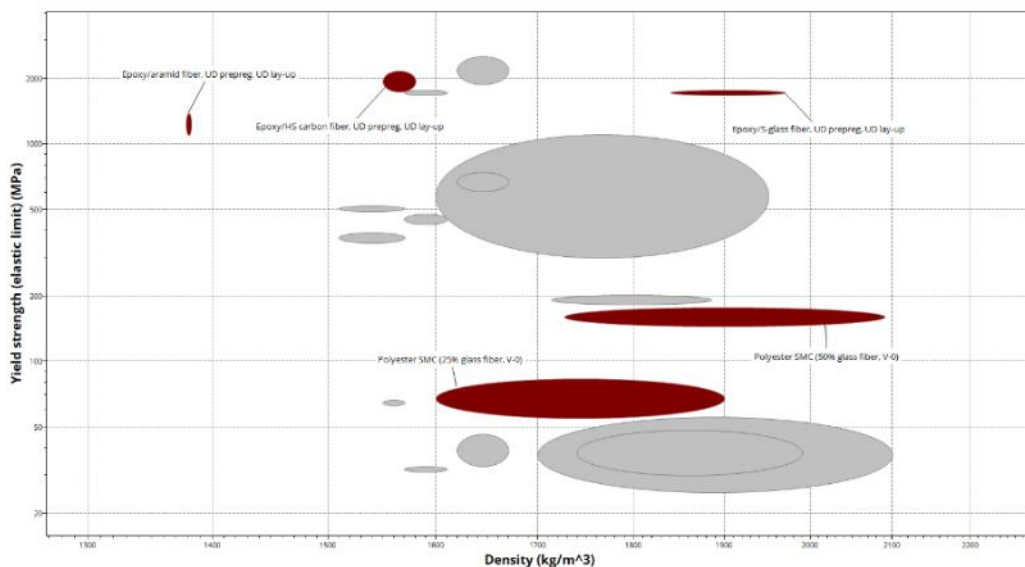


Figure 9 Polymer Composites after Water Absorption Filter

Figure 9 shows possible materials available at <0.05% absorption per day. The polyester composites can also be eliminated from consideration due to their low yield strengths. The remaining possible materials all have epoxy matrices, with glass fibre, carbon fibre and aramid fibre, respectively. As shown in Figure 9, all three of these materials have comparative densities and costs. Based on this, we can pick an epoxy aramid fibre material as the polymer composite shortlist option.

Metallic alloys have a wide variety of possibilities; however, most aren't suitable for weight-sensitive applications. Very few alloys match the weight efficiency of polymers while remaining competitive in yield strength. Graph D shows metallic compounds filtered down to those 2000kg/m³ in density, or those within 45% of the density of an epoxy aramid fibre composite.

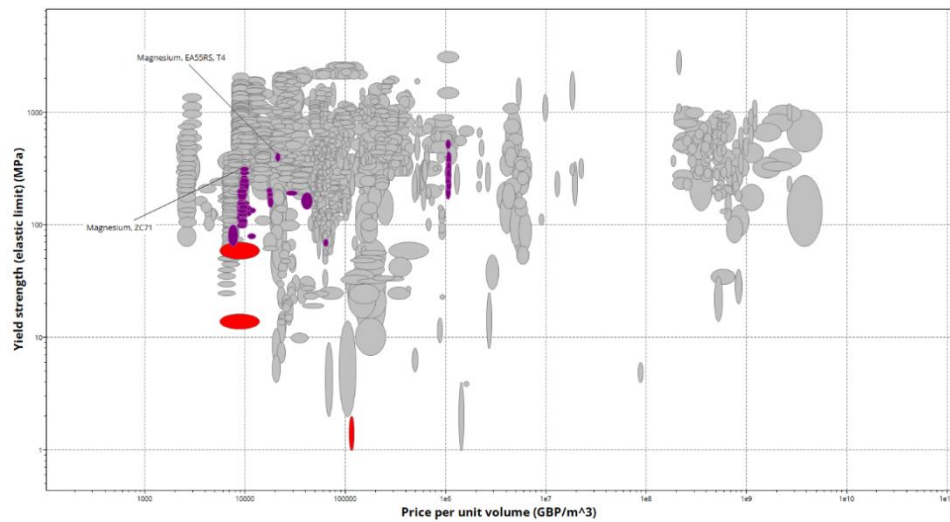


Figure 10 Price per Unit Volume vs Yield Strength for the remaining Metal Alloys

Yet, as shown in Figure 10, metallic alloys are extremely competitive in terms of cost-efficiency, with the closest metallic alternative being approximately five times cheaper than the shortlisted polymer composite. Additionally, it outcompetes any polymer material in many secondary aspects, such as recyclability and sustainability. Figure 10 highlights two metallic compounds equally competitive, where Mg EA55RS has a slightly better yield strength, and Mg ZC71 has a more competitive price. Both are approximately the same density at around 1900Kg/m³.

9 Costing

To choose a final material from the shortlist of Mg EA55RS, Mg ZC71 and epoxy resin 30% aramid fibre, we can compare the relative costs of each to manufacture based on the requirements of each. A typical skin thickness of 15mm (shown in Figure 12) throughout the blade has been assumed to calculate a component material volume of 0.155m^3 , using the CAD model pictured in Figure 11.

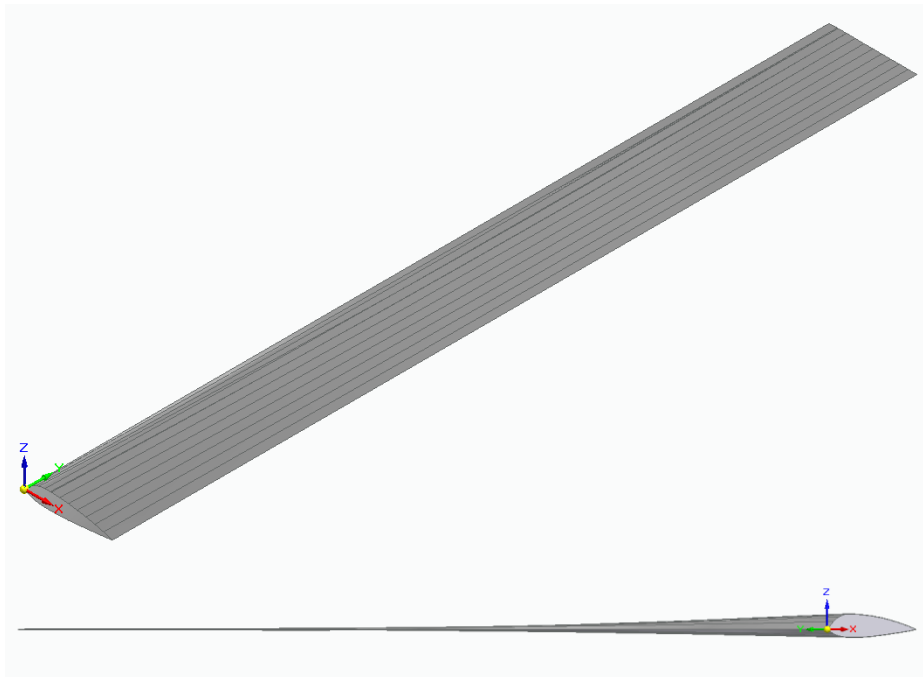


Figure 11 Isometric and Side View of Turbine Blade

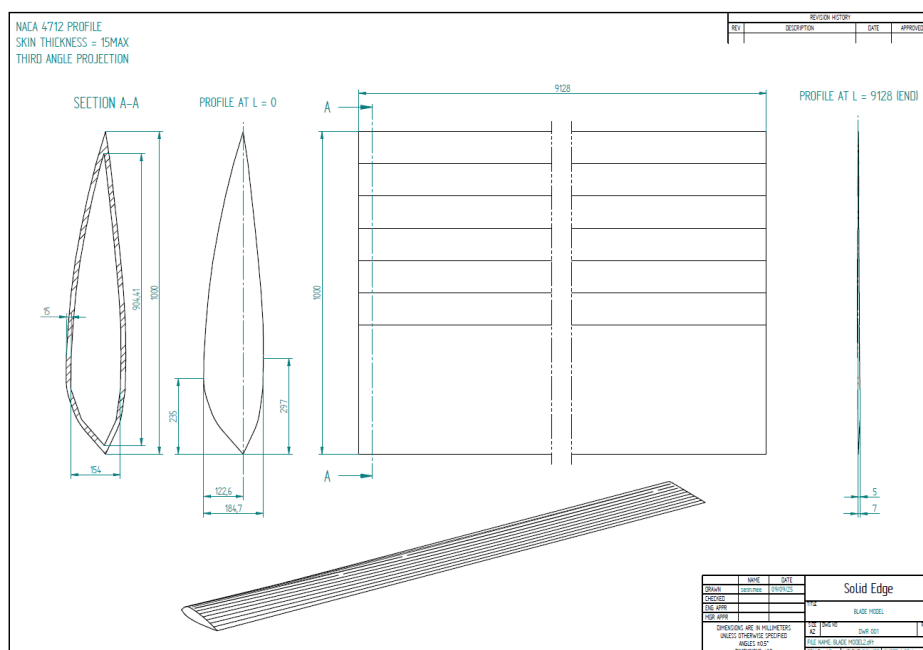


Figure 12 Engineering Drawing of Turbine Blade

Table 2 and Figure 13 show a comparative costing for the short list of materials, based on research around labour costs, the man-hours and complexity of each process. Additionally, the energy costs for the machinery required in each stage are based on the UK's energy price of £0.26 per kWh.

The costs for the magnesium alloys include the time required to pour the material (Impro, 2022), along with the energy used to melt the material for that period in a 50% efficient cast forge.

MATERIAL	Mg EA55RS	Mg ZC71	Polymer Composite	Silicon Carbide
Cost Per M ³	£ 50,000.00	£ 10,000.00	£ 60,000.00	£ 160,000.00
Cost	£ 7,750.000	£ 1,550.000	£ 9,300.000	£ 24,800.000
Technique	Cast Tooling	Cast Tooling	Layup	Cast Tooling
Labour Time (hr)	360	360	-	64
Labour Cost (£/hr)	£ 18.23	£ 18.23	£ -	£ 18.23
Cost	£ 6,562.80	£ 6,562.80	£ -	£ 1,166.72
Technique	Casting Pouring	Casting Pouring	-	Casting Pouring
Labour Time (hr)	56	56	-	32
Labour Cost (£/hr)	£ 18.23	£ 18.23	£ -	£ 18.23
Cost	£ 1,020.88	£ 1,020.88	£ -	£ 583.36
Technique	Cast Forge	Cast Forge	Vacumm Pump	Gel Cast Maching
Energy Cost	£ 2,038.40	£ 2,038.40	£ -	£ 3,521.00
Total Cost	£ 17,372.080	£ 11,172.080	£ 9,300.000	£ 30,071.080

Table 2 Material Shortlist Costs (Impro, 2022) (Glass Door, 2025) (Borui, 2024) (IMgA, 2025) (Bader, 2002)

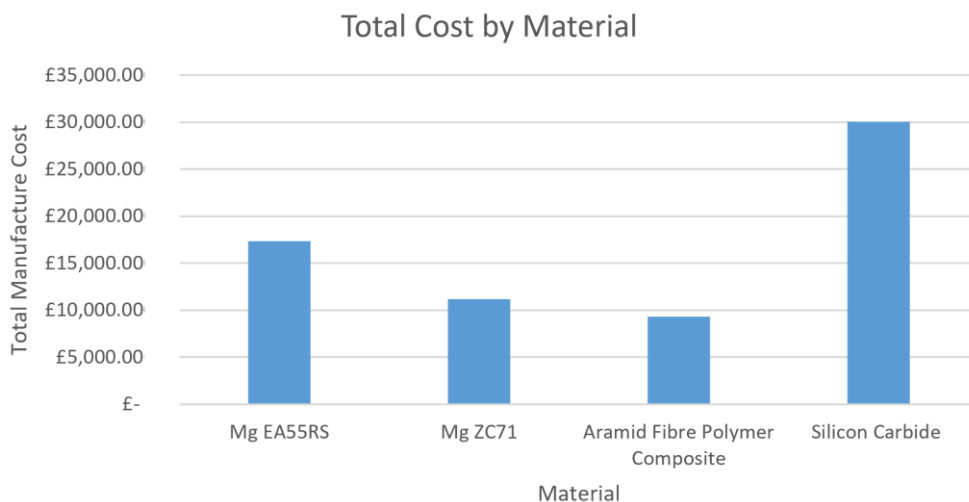


Figure 13 Graph of Material Costs

In consideration of the above information, the aramid fibre is the best overall choice of material. Due to the energy costs and the slow process of pouring such large metallic casts,

the fibre composite is cost-competitive despite the high material cost, especially as the labour and energy costs for this material type are excluded. Paired with excellent strength and process consistency, makes it an ideal material choice for large-scale turbine blades such as this.

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11 Appendix

Taking North Sea wind speeds into account, and adding a safety margin of 20%, a wind turbine would need to be able to operate in speeds from 0 to 48 m/s.

Using Equation 1, we can derive the theoretical force across each turbine blade F_b . Equation 4 includes the lift coefficient of a NACA 4712 design under ideal conditions of 1.696.

$$P = C_p \frac{1}{2} \rho A v^3$$

$$P/F = m s^{-1} = v$$

$$F = P/v = C_p \frac{1}{2} \rho A v^2$$

$$F = C_p \frac{1}{2} \rho A v^2$$

$$F_b = C_p \frac{1}{6} \rho A v^2 + WEIGHT$$

Equation 4 Force on the Turbine Blade

The blade must be able to withstand not only the force exerted onto it by the wind (Equation 4). Using both forces together, we can apply the bending of beams Equation 5; where the wind turbine blade can be approximated to be a uniform beam fixed at one end.

$$-1/2 \cdot W \cdot l^2 = EI \frac{d^2 y}{dx^2} \text{ (MOMENT EXERTED ON UDL)}$$

$$W = m \cdot g = -EI \frac{d^2 y}{dx^2} \cdot 1/2 \cdot l^2$$

Equation 5 Bending of Beams applied to a Turbine Blade

Using Equation 4, we can find the force on the blade to be equal $F(b)$ shown in Equation 6.

$$F_b = 1.696 \times \frac{1}{6} \times 1.225 \times (\pi \times 91.28^2) \times 48^2 + m \times 9.81$$

$$F_b = 1.696 \times \frac{1}{6} \times 1.225 \times (\pi \times 91.28^2) \times 48^2 + m \times 9.81$$

$$F_b = 20.9 \times 10^6 + 9.81m$$

Equation 6 Force on the Blade Expressed as Weight and Wind Force

From this, we can see that the mass of the blade is actually a comparatively small factor in the force being applied to the blade. As such, the mass primarily affects the energy conversion efficiency.

Re: Wind Turbine Manufacture

From Adrian Dennis <Adrian@marlec.co.uk>

Date Sat 30/08/2025 23:02

To Sean Mee (2218461) <2218461@student.uwtsd.ac.uk>

You don't often get email from adrian@marlec.co.uk. [Learn why this is important](#)

RHYBUDD: Deilliodd yr e-bost hwn o du allan i system E-bost Prifysgol Cymru Y Drindod Dewi Sant. Peidiwch ag ateb, na chlicio ar ddolenni nac agor atodiadau oni bai eich bod yn adnabod cyfeiriad e-bost yr anfonwr ac yn gwybod bod y cynnwys yn ddiogel.
WARNING: This email originated from outside University of Wales Trinity Saint David's Email System. Do not reply, click links or open attachments unless you recognise the sender's email address and know the content is safe.

Really sorry but we cannot help you as the information you have requested is commercially confidential.

Regards

Adrian

Sent from my iPad

On 30 Aug 2025, at 19:34, Sean Mee (2218461) <2218461@student.uwtsd.ac.uk> wrote:

Dear Sir/Madam,

I hope this message finds you well.

My name is Sean Mee, and I am currently undertaking a university project focused on evaluating the cost of manufacturing wind turbines using three distinct material categories: **Metals**, **Ceramics**, and **Polymer Composites**. As part of my methodology, I am gathering real-world pricing data to ensure the accuracy and relevance of my project.

Given Marlec's expertise in renewable energy technologies, I would be extremely grateful if you could assist me by providing indicative pricing or cost estimates with a basic understanding of how they are derived for turbine blades:

- Common metallic materials
- Relevant ceramic materials
- Polymer composite materials

If available, I would also appreciate any insights into material selection criteria or cost drivers that Marlec considers when designing and manufacturing wind turbines.

I fully understand that commercial pricing can vary based on volume, specifications, and market conditions, so even approximate figures or guidance would be incredibly helpful for academic purposes.

If you should require any further details about my project or university affiliation, please don't hesitate to reach out to me.

Thank you very much for your time.

Kindest Regards,
Sean Mee

University of Wales Trinity Saint David.

Figure 14 Email Communication with Turbine Manufacturer

Figure 14 is a selected response from a wind turbine manufacturer. Other manufacturers gave similar responses over phone calls to queries about methods of costing, as shown, and requests for sample costings to base my own costing on. As such, the costings presented in the main body of work are based on publicly available information, without direct information from industry.

Table 3 shows a complete costing, including labour and energy costs, based on research by Bader (2002), examining the time to apply layup composite materials to a single square metre of material and the energy requirements to run a vacuum pump.

MATERIAL	Mg EA55RS	Mg ZC71	Polymer Composite	Silicon Carbide
Cost Per M ³	£ 50,000.00	£ 10,000.00	£ 60,000.00	£ 160,000.00
Cost	£ 7,750.000	£ 1,550.000	£ 9,300.000	£ 24,800.000
Technique	Cast Tooling	Cast Tooling	Layup	Cast Tooling
Labour Time (hr)	360	360	148	64
Labour Cost (£/hr)	£ 18.23	£ 18.23	£ 18.23	£ 18.23
Cost	£ 6,562.80	£ 6,562.80	£ 2,698.04	£ 1,166.72
Technique	Casting Pouring	Casting Pouring	-	Casting Pouring
Labour Time (hr)	56	56	-	32
Labour Cost (£/hr)	£ 18.23	£ 18.23	-	£ 18.23
Cost	£ 1,020.88	£ 1,020.88	£ -	£ 583.36
Technique	Cast Forge	Cast Forge	Vacumm Pump	Gel Cast Maching
Energy Cost	£ 2,038.40	£ 2,038.40	£ 11.44	£ 3,521.00
Total Cost	£ 17,372.080	£ 11,172.080	£ 12,009.480	£ 30,071.080

Table 3 Costing Including Labour and Energy Costs of Composite Materials