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A Study of Functionality of Mold for Bladder Assisted Composite Manufacturing (BACM)

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Bladder-Assisted Composite Manufacturing (BACM), Molding, Hollow components, Efficiency.

Abstract

Composite manufacturing faces challenges in producing complex, hollow components with good mechanical performance. Current methods like injection/compression moulding are cost-effective but often have poorer mechanical performance. Continuous fibre reinforced materials are used in high-strength areas like defense and aerospace. The BACM mould offers a unique method for shaping composite structures, allowing precise control over pressure and forces during curing. This study aims to provide insights on the BACM mold's capabilities and applications, paving the way for advanced manufacturing and composite materials. It was shown that the BACM method reduced the energy needed to create a composite component by more than 50% resulted in the production of a hollow structure. The found of this study show that BACM can greatly improve the mechanical properties of hollow composite components when compared to previous approaches, but it has disadvantages in terms of cost.

1. Introduction

The composite manufacturing sector faces challenges in producing complex, hollow components with good mechanical performance. Current methods like injection/compression molding are cost-effective but often have poorer mechanical performance. Continuous fiber-reinforced materials are used in high-strength areas like defense and aerospace. The BACM mold offers a unique method for shaping composite structures, controlling pressure and forces during curing. This study aims to provide insights on the BACM mold's capabilities, limits, and applications, paving the way for advanced manufacturing and composite materials.

Bladder Assisted Composite production (BACM) relies on process parameters for efficiency and quality. Mold fabrication is crucial for achieving accuracy and a smooth finish. However, existing information lacks a comprehensive understanding of the link between BACM process parameters and mold manufacturing, particularly in terms of accuracy and surface polish. This study aims to evaluate the impact of BACM process parameters on mold fabrication precision and surface polish, potentially leading to improved composite manufacturing methods.

2. Methodology

Bladder Assisted Composite Manufacturing (BACM) uses a mold as a crucial component in shaping and consolidating multilayer composite materials. The mold, typically made from silicone or rubber, ensures equal pressure distribution and proper consolidation of composite layers. BACM's ability to create lightweight, high-strength materials with improved structural integrity is a notable example of its performance. The mold in BACM meets strict performance standards in industries like sports equipment, automotive, and aviation, demonstrating better strength-to-weight ratios. Overall, the mold demonstrates the effectiveness, accuracy, and revolutionary potential of BACM.

2.1. Typical Types of Molds

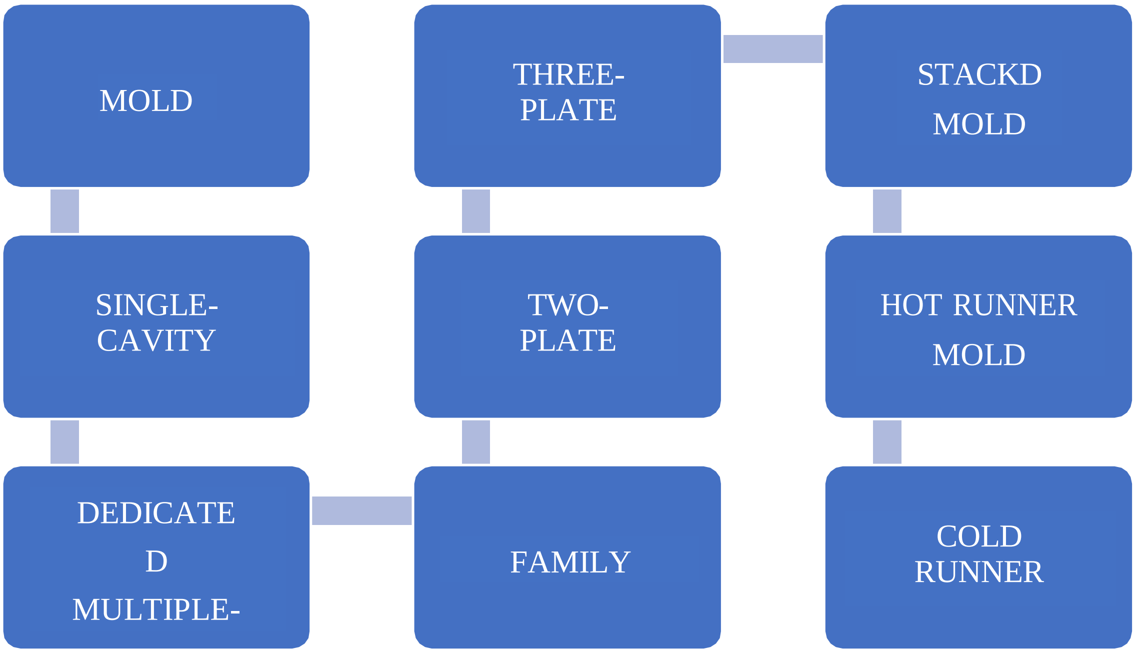

Figure 2.1: Type of mold (Shenzen,2022).

2.2 Parting Line

A parting line is a crucial part of injection moulded products, separating the two halves of a Mold. It runs the entire perimeter of the part, separating bad and positive draughts. In complex parts, the location of this line varies. Despite using a single parting line, sharp edges on section separating lines reduce the cost of Mold design, development, maintenance, and component production. Injection moulded parts often have multiple separating planes for complete separation.

2.3 Prepreg

Prepreg is a pre-impregnated fabric used in bladder-assisted composite manufacturing, where fibre-reinforced material is pre-impregnated with a resin system. This process involves several steps, including mold preparation, handling, cutting, layer placement, compression, bladder assistance, curing, demoulding, cooling, part removal, and post-processing. Prepreg layup offers benefits such as quality control, strength and performance, and reduced waste. It ensures a consistent resin-to-fibre ratio, producing high-quality, uniform composite parts. Prepreg materials also provide excellent mechanical properties, including high strength-to-weight ratios. This method aligns with the need for high-performance composite parts in bladder-assisted manufacturing, ensuring durability and reliability. By incorporating prepreg layup into Mold projects, high-quality composite parts can be produced, meeting the specific requirements of bladder-assisted manufacturing processes, ensuring precision, strength, and consistency.

2.4 Lay-up

The lay-up process in carbon fiber manufacturing involves layering sheets of carbon fiber fabric, impregnated with a resin matrix, and cured to form a solid, high-strength composite structure. The process begins with mold preparation, where a mold is designed to the specific shape of the final component. The fabric is selected based on the desired properties of the final composite, such as unidirectional, woven, or multiaxial fabrics. Carbon fiber sheets are placed onto the mold in a specific sequence and orientation, with the orientation of the fibers in each layer significantly influencing the mechanical properties of the final composite. Resin is applied to each layer manually or through pre-impregnated fibers, and each layer is consolidated to remove air bubbles and ensure proper adhesion between layers. The resin is then cured at room temperature, heat curing, or autoclave processing. The composite part is removed from the mold, and finishing may require trimming, sanding, or additional finishing processes.

2.5 Material That use For Mold

Table 2.1 : Steel Grade

Grade	Description
4130 alloy steel	This high-strength steel is used primarily forcavity and core retainer plates, support plates, and clamping plates and is supplied at26 to 35 Rc
6145 alloy steel	The primary use of this type of steel is for sprue bushings and it is supplied at 42 to 48 Rc
420 stainless steel	Used in applications requiring exceptional chemical resistance (such as molding PVC resins), this steel is usually supplied in an annealed condition (15 to 25 Rc) but can be hardened to 55 to 60 Rc. Its primary use isas steel for cores and cavities
Aluminium AA5000	AA 5000 series (aluminum magnesium alloy) The main models of the AA 5000 series (aluminum magnesium alloy) are 5052, 5005, 5083, and 5A05. These models contain a high amount of magnesium, which is between 3% and 5%, so they are also called magnesium- aluminum alloys.They not only have high elongation And tensile strength, and the density is very low, and has a good degree of fatigue resistance, but it can not be strengthened by heat treatment, it is a kind of alloy aluminum plate widely used in the industry.

In this experiment, the AA5000 series was chosen due to its magnesium content, which is made up of dislocation structures created by cold rolling and non-heat-treatable alloys reinforced by elements in solid solution. Alloy 5083 has better formability, weldability, and chemical environment resistance than other non-heat-treatable alloys.

2.6 Quality Control and Inspection

Quality control measures are crucial after CNC machining to ensure accuracy and conformance to specifications. Inspections focus on dimensional correctness, surface quality, and essential features, with calibrated measuring tools for tight tolerances. Non-destructive testing examines the mold's structural integrity and surface qualities. Comprehensive documentation records inspection results and remedial actions, promoting traceability. These post-CNC quality control techniques help meet industry requirements, refine machining settings, and increase production efficiency. After quality inspection, the mold is ready for composite manufacture, with surface finish checks, geometry, and essential elements ensuring consistency with the original design. Material integrity inspections ensure longevity and dependability, and non-destructive testing identifies potential subsurface concerns. Proper documentation creates a verifiable record of inspections and remedial actions.

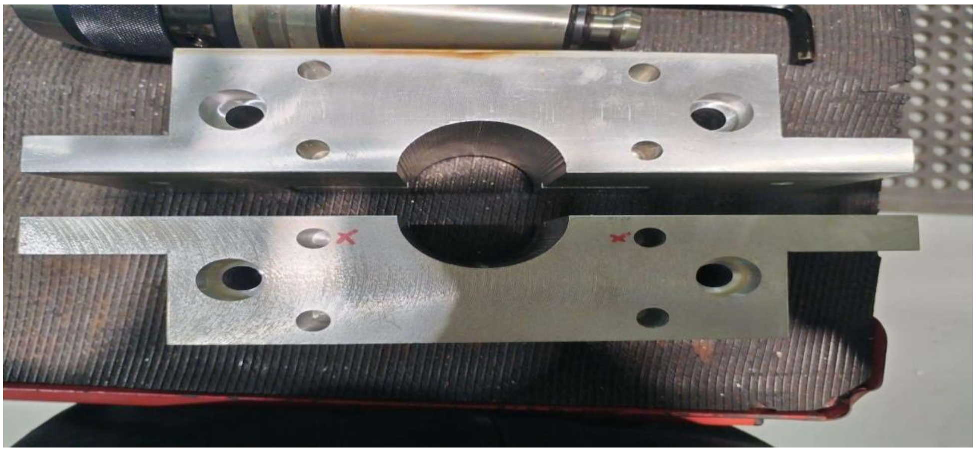

Figure 3.1: Correction of the Screw Hold Based on Sketching.

2.7 Method to Produce Mold

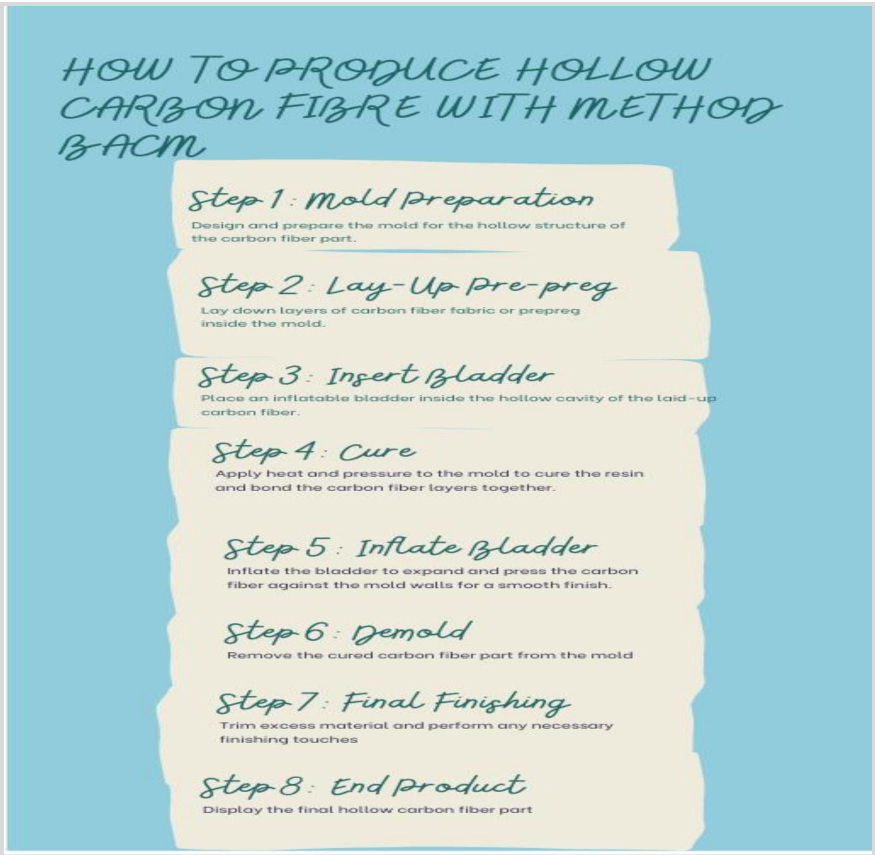

Figure 3.3 : Infographic how to produce hollow carbon fibre with method BACM.

3.5 Socket Head

Figure 3.4 : Socket Head.

Socket cap screws are ideal for mould assembly due to their sturdy joints and resistance to corrosion. These high-tensile alloy steel fasteners are used in demanding technical applications like mould manufacturing, automotive, aerospace, and precision machinery. They offer a balance of strength, space efficiency, and precision, making them suitable for bladder-assisted composite production moulds. Their compact head design ensures minimal protrusion and a clean appearance.

2.8 Design process

A practical holder size ensures a snug fit, stability, and easy handling. It should be lightweight, ergonomic, and maximize space utilization. It should accept various sizes, prioritize safety, and be suitable for its intended purpose. The chosen size simplifies organizing, supporting, and securing items.

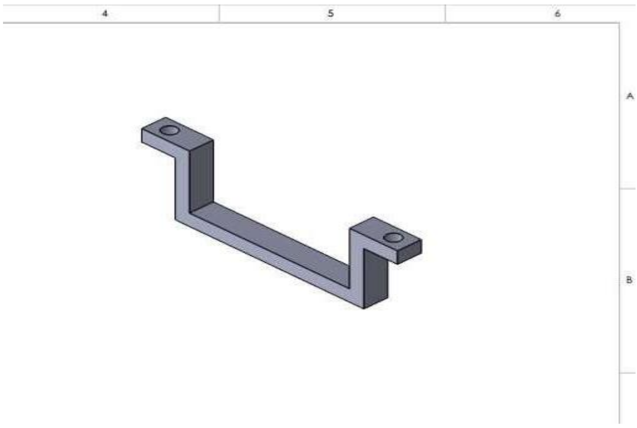

Figure3. 5 : Design of the holder

2.9 Material Preparation

The aluminum holder is a practical and efficient solution for various uses due to its combination of strength and lightweight characteristics. Its ergonomic proportions prioritize user comfort and minimize fatigue. The holder's size minimizes material waste, supports space utilization, and accommodates items of different sizes. Its machining capabilities maximize manufacturability, ensuring accurate fabrication and economical manufacturing. The aluminum holder is a testament to sensible design ideas.

2.10 Conceptual Design

The aluminum holder's creative and user-centric conceptual design considers both form and function. The holder's ergonomic and elegant form aspect guarantees a pleasant handling for the user. Its design emphasizes a compromise between minimal weight and structural strength, making the most of aluminum's sturdy yet lightweight properties. The holder offers adaptability for safely retaining products of different shapes and sizes thanks to its adjustable sections and sturdy grips. Adding chamfered edges not only makes the piece seem better but also makes it easier to operate. The concept design prioritizes user safety, lowering the possibility of handling-related injuries with rounded edges and smooth surfaces. Manufacturability is carefully considered, and the design uses aluminum machining technologies to achieve precision and economy. The aluminium holder's overall conceptual design is to slickly combine functionality, visual attractiveness, and user comfort, producing a dependable and adaptable solution for safely keeping things in various situations.

2.11 Tap Method For Thread adjustment

The tapping method is a machining process that creates threads for screws, bolts, or other threaded fasteners, ensuring symmetrical and aligned threads for smooth assembly and secure fastening. It involves drilling a pilot hole, selecting the appropriate tap, applying cutting fluid, turning clockwise, cleaning chips, and completing the thread through holes or blind holes. It offers precision, versatility, and efficiency, but requires correct tap size, lubrication, and regular inspection.

Figure3. 6 : Tapping Process

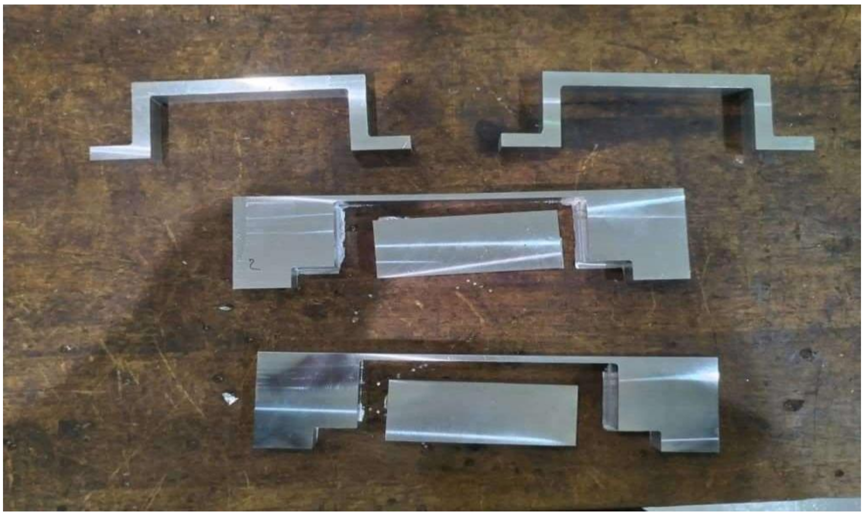

Figure3. 7 : Cut the block using Mazak Nexus VCN 410A Milling Machine

Figure3. 8 : Surface Finish

2.12 Presssure Test

Pressure test conducted to identify the capability of the bladder to sustain the pressure due to its strength. There were a test for data analysis which are pressure capability to be functionality of molding that has been produce.

Figure 3.9 : Pressure test on below 1 bar

3. Results and Discussion

Carbon fibre is a lightweight, robust organic polymer-based material made from polyacrylonitrile (PAN) and petroleum pitch or rayon. It is used in building, sports equipment, and aircraft due to its low thermal expansion, chemical resistance, and high tensile strength. PAN fibres undergo several procedures to ensure molecular alignment, facilitating the subsequent synthesis of carbon fibre. The result compare from previous research journal.

3.1 Previous research On Carbon fiber

Table 4.1 The Production Of Hollow Carbon Fibre from a special PAN Precursor.

JOURNAL	AIMS	RESULTS
The Production Of Hollow Carbon Fibre From A Special PAN Precursor	To develop a technique for producing large diameter hollow carbon fibers from a PAN precursor to improve compressive strength and damage tolerance	▯ Hollow carbon fibers showed structural similarities to high-strength carbon fibers, with comparable modulus but lower UTS due to structural flaws. ▯ Preliminary compression tests indicated higher strain to first failure, suggesting better compressive properties.

Table 4.2 Comparison of disorder ratio measured (using laser Raman spectroscopy) for Hollow Carbon Fibre.

Fibre type	Diameter	Ultimate	Standard	Modulus in	Standard

	µm	Tensile Strength GPa	deviation GPa	Tension GPa	deviation GPa
Preliminary hollow carbon	34.78 ± 2.7	0.38	0.09	106.52	16.67
Present hollow carbon	38.4 ± 2.4	0.52	0.2	249.4	120.5

The developed hollow carbon fibers demonstrate promising mechanical properties, particularly in terms of compressive strength. Future research will focus on improving structural consistency and tensile strength, with potential applications in smart materials and medical devices.

Table 4.3 Properties of Composite Cylinders Fabricated by Bladder Assisted Composite Manufacturing.

JOURNAL	AIMS	RESULTS
Properties of Composite Cylinders Fabricated by Bladder Assisted Composite Manufacturing	To investigate the properties of composite cylinders fabricated using the Bladder Assisted Composite Manufacturing (BACM) method, with a focus on fiber volume fraction and void content.	Fiber volume fractions increased with processing pressure up to a certain point before reducing in BACM parts. The presence of voids affects the density of the composite, and the BACM process can produce components with low void content at high fiber fractions

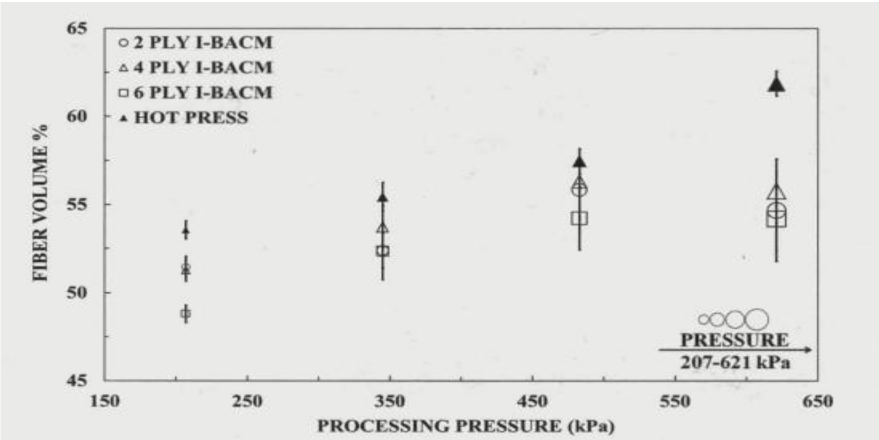

Figure 4.1 : Effect of processing pressure on fiber volume fraction.

4.2.3 Third Journal

Table 4.4: 3D Printed Hollow Off-Axis Profiles Based on Carbon Fiber-Reinforced Polymers Mechanical Testing and Finite Element Method Analysis.

JOURNAL	AIMS	RESULTS
3D Printed Hollow Off-Axis Profiles Based on Carbon Fiber-Reinforced Polymers: Mechanical Testing and Finite Element Method Analysis	To design, manufacture, and test an off-axis composite profile of circular cross-section using continuous carbon fibers and the fused deposition modeling (FDM) method	Experimental and FEM analysis showed that the critical force at which the composite profile failed was close, differing by only 7%. Failure of 3D printed composite parts was primarily due to material failure rather than loss of stability. The composite profiles produced were geometrically accurate, production-repeatable, and highly resistant to compressive deformations.

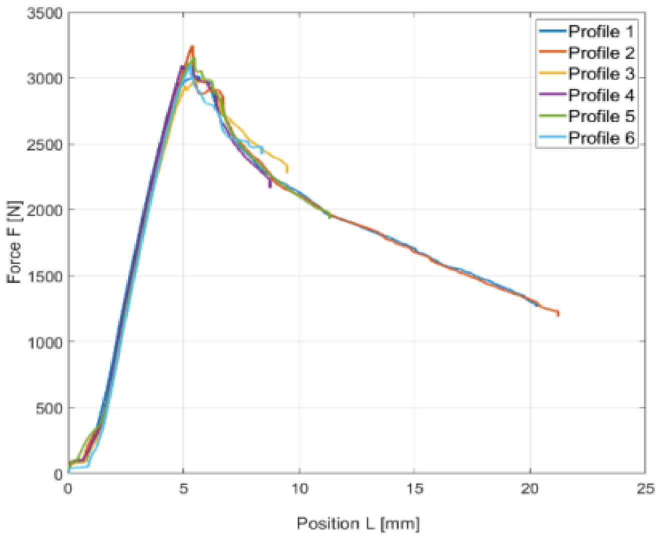

Figure 4.2 : A line graph of the dependence of the maximum force on the deformation shift.

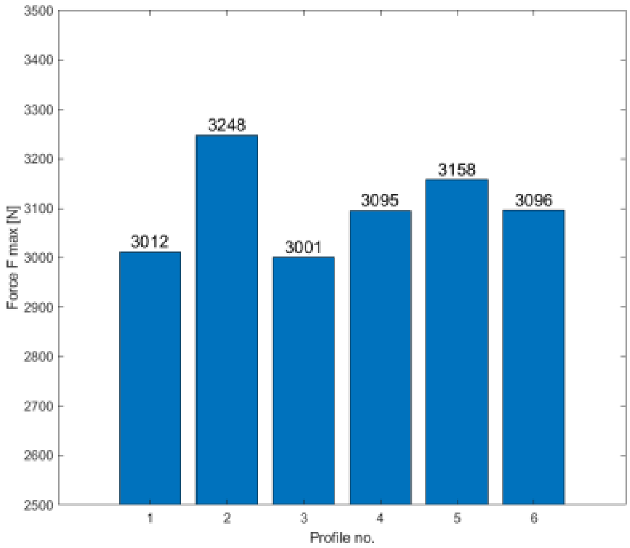

Figure 4.3 : A bar graph of the achieved maximum forces for individual profiles.

The result of the buckling test was a stress–strain diagram of the material, which is a curve of the dependence of the load force on the profile displacement. The data were plotted in MATLAB R2019b. Two types of graphs were used for graphical evaluation in Figure 4.2 . A line graph showing the dependence of load force on the displacement (compression) of the test profile. The second bar graph (Figure 4.3) shows the values of maximum failure. strength for each profile. As the hollow sections do not have the shape of a straight bar, they have been subjected to both buckling and bending forces. During testing, the profiles were subjected to compressive forces, but graphs are plotted in absolute values. The study successfully demonstrated that the mechanical properties of 3D printed composite laminates could be predicted based on theoretical models. Future work will explore the fatigue failure of off-axis printed CFRP composites.

The project aims to construct a mould for bladder assisted composite manufacturing (BACM), a crucial step in producing high-performance composite products. The project uses carbon fibre as the composite material and aims to increase cost-effectiveness, productivity, and product quality by optimizing the BACM process's performance. The results could also aid in creating more eco-friendly composite manufacturing techniques.

Three journals discuss advancements in composite materials, each offering unique insights and areas of focus. The first journal, "3D Printed Hollow Off-Axis Profiles Based on Carbon Fiber-Reinforced Polymers: Mechanical Testing and Finite Element Method Analysis," presents a comprehensive approach to designing, manufacturing, and testing an off-axis composite profile using continuous carbon fibers and the fused deposition modeling (FDM) method. The second journal, "Properties of Composite Cylinders Fabricated by Bladder Assisted Composite Manufacturing," addresses critical aspects of fiber volume fraction and void content, resulting in high-performance components. The third journal, "The Production of Hollow Carbon Fiber from a Special PAN Precursor," presents an innovation aimed at addressing limitations in the compressive strength of conventional carbon fibers.

The development of computational models could significantly advance composite materials, predicting static and dynamic properties, such as fatigue and failure modes. Further research into the effects of processing conditions on fiber volume fraction, void content, and structural integrity is crucial. Hollow carbon fibers represent a significant material innovation, with future research focusing on overcoming structural flaws and inhomogeneities and exploring potential applications in aerospace, automotive, and medical devices.

4. Conclusion

The project successfully addressed major obstacles in fabricating a bladder assisted composite manufacturing (BACM) mould by focusing on precision and surface finish. The main problems were the installation of a gripper to handle high pressures, sharp edges, and gaps in the mould plates. The study is important because it helps understand the intricate relationships between mould production and BACM process parameters, allowing for optimization of the BACM process and increased product quality, productivity, and cost-effectiveness.

The three journals highlight significant advancements in composite material manufacturing and performance. The study on off-axis composite profiles using FDM validated the use of 3D printing techniques for high-quality composite structures. BACM proved effective in producing components with high fiber fractions and low void content, crucial for applications requiring high material integrity. The development of hollow carbon fibers from a PAN precursor showed promising improvements in compressive strength, although structural inconsistencies need further refinement.

To fully leverage these advancements, future research should focus on enhancing computational modeling techniques to predict dynamic behaviors accurately, optimizing manufacturing parameters for both FDM and BACM processes, addressing structural flaws in hollow carbon fibers, and exploring their interdisciplinary applications in aerospace, automotive, and medical devices. Interdisciplinary collaborations should be encouraged to maximize the potential of these innovative materials and processes.

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