Library Progress International *Print version ISSN 0970 1052*
Vol.44 No.3, Jul-Dec 2024: P. 23410-23415. *Online version ISSN 2320 317X*

Original Article *Available online at www.bpasjournals.com*

Fabrication and Flexural Performance of Self-Healing Composites with Micro-Vascular Channels

Vishwaretha K R[1*], Ajith Kumar[2], Augustin Dsouza[3], Amar G S[4], Prashant[5] Y Shriraj Rao[5]

[1,2,4,5,6]Department of Aeronautical Engineering, Mangalore Institute of Technology and Engineering, Moodabidri, Dakshina Kannada, Karnataka, India-574225
[3]Shree Devi Institute of Technology and Engineering, Mangalore, Dakshina Kannada , Karnataka, India-574142

***Corresponding Author:** Vishwaretha K R
k.vishu1994@gmail.com

How to cite this article: Vishwaretha K R, (2024). Fabrication and Flexural Performance of Self-Healing Composites with Micro-Vascular Channels. Library Progress International, 44(3), 23410-23415.

Abstract
Composite materials play an important role in weight reduction, making them suitable for structural applications including aircraft components. To account for efficiency losses caused by impact, existing damage models often incorporate large safety margins, which can result in overweight and less effective structures. Implementing self-healing capabilities is another way to reduce sensitivity to impact damage. This work focuses on the developing of self-healing composite materials and demonstrating how strength is recovered when resin-filled hollow fibres are dispersed at specific intervals within the composite. The primary goal is to minimise loss of mechanical properties while maximising efficiency of healing events. In this research, the specimens of composite material were created both with and without micro-vascular channels. The specimens with micro-vascular channels were filled with a resin and hardener mixture. Both types of specimens were then subjected to a flexural test to assess the loss in strength. The results showed a 6.7% and 14.3% loss in flexural strength of the self-healing composite materials compared to a control specimen. Due to this minimal loss, these materials hold potential for a wide application. In aerospace, they could be used in fuselage and aerostructures, engine blades, corrosion protection coatings, smart paints, and impact-resistant space structures.

Keywords: Self-Healing Composites, Micro-Vascular Channels, Vacuum Assisted Resin Transfer Molding, Flexural Test, Structural Integrity, Aerospace Applications.

Introduction

Composite materials are composed of two or more materials with remarkably different chemical and physical properties. When blended, these materials produce a substance with unique characteristics that differ from those of individual constituents. The resulting composite may offer advantages such as improved performance, reduced weight, or lower cost compared to traditional materials. Because of their high strength-to-weight ratio, fibre-reinforced composites (FRCs) are used across various applications, including in space technology. However, a significant limitation of FRCs is the formation of micro cracks under load. This issue not only shortens the material's lifespan but also increases potential risks with its use in engineering components.

Self-healing materials have the remarkable ability to repair damages themselves autonomously without external intervention. These self-healing materials can restore their functionality fully or partially when damaged by ballistic, thermal, mechanical, or other types of stress. When a material is damaged during operation, its self-healing ability helps extend the product's lifespan and enhances its durability, thereby improving both economic and human safety aspects. Therefore, self-healing properties should be a key consideration when selecting materials for applications where repair is not feasible, as these materials are designed to perform effectively even under such conditions.

Self-healing systems utilize autonomous or induced repair mechanisms to prolong the life of materials. A self-healing E-glass fibre/epoxy composite, incorporating micro-vascular channels was developed by removing solid reforms. The specimen was created by hand layup. The healing agent demonstrated a recovery of flexural strength by 46%, surpassing predictions (Babolhavaeji et al., 2017). The development of self-healing materials for wind turbine blades was explored, focusing on a bio-mimetic design approach that heals damage as it occurs in composite materials. Several low-cost and straightforward techniques for creating vascular channels were tested. Experiments with borosilicate tubes indicated no significant loss in tensile strength when hollow tubes were incorporated. The findings highlighted the importance of developing a more efficient network of fibreless reinforced polymer composites to deliver selfhealing agents (Matt et al., 2016). The embedment of adhesive-filled hollow glass fibres (HGF) as a method of combating micro-crack development in fibre-reinforced polymer (FRP) structures was investigated. The formation of a simple 2D network of concave channels within glass fiber-reinforced polymer structure was discussed. The results demonstrated a good recovery of stiffness and mechanical properties, depending on the type of healing agent used (Fifo et al., 2014). The strategy for developing self-healing materials based on embedded vascular networks of micro channels, that transport reactive fluids to damage areas was also explored. The analysis included active pumping methods for pressurized delivery of a two-part healing system. Various pumping strategies were investigated to improve the mixing and polymerization of healing agents at the damage zone. The results demonstrated significant improvements in healing cycles and overall efficiency compared to prior passive schemes that relied solely on capillary forces for healing agent delivery, as well as a significant reduction in the volume of vascular system required (Hamilton et al., 2012). The analysis focused on the development of advanced FRPs to improve the performance of engineering structures through their superior specific strength and stiffness. One of the research explored automatic selfhealing in carbon fibre-reinforced polymers, demonstrating significant strength recovery. This was achieved by incorporating a resin-filled hollow glass fiber system at specific interfaces within the laminate, which optimized the healing process while minimizing any impact on mechanical properties. The findings indicated that embedded resin-filled HGF enabled CFRP laminates to self-heal after low velocity impact damage, partially restoring their compressive strength. This approach also highlighted the potential of integrating self-healing functions without affecting the host laminate's performance (Williams et al., 2009).

From the above literatures, it is evident that there has been limited research on the development of self-healing materials using micro-vascular channels. Therefore, the main objective of the proposed work is to develop such materials with maximum strength recovery.

2. Materials and Methods

2.1 Materials Details

The basic raw materials used to prepare the composite are peel ply fabric, E-glass fibre, epoxy resin LY556 and hardener HY951. These materials are procured from CF Composites, Delhi. HY951 is a hardener that cures at room temperature. **Table 1** presents the physical properties of glass fibre, while **Table 2** indicates the properties of epoxy and hardener. **Figure 1** shows a photograph of glass fibre, while **Figure 2** displays epoxy resin and hardener used in this work.

Table 1: Physical Properties of Glass Fibre.

Physical Properties	**Values**
Density (g/cm^3)	2.6
Tensile strength (MPa)	2000
Young's modulus (Gpa)	80
Poisson's ratio	0.23
Orientation	Bi-directional (0°/90°)

Table 2: Properties of Epoxy and Hardener.

Properties	**LY556/ Epoxy Resin**	**Hardener HY951/ TETA**
Viscosity at 25°C	9000-12000 mPa	500-1000 mPa
Density at 25°C	1.13-1.16 g/cm^3	0.90-0.95 g/cm^3
Flash point	>150°C	129°C

Figure 1: E-Glass Fibre.

Figure 2: Epoxy Resin and Hardener.

2.2 Fabrication Process

Vacuum assisted resin transfer molding (VARTM) process is used to create the fibreglass composite samples. In this method, a vacuum pump is used to create a vacuum within the mould. The resin-hardener combination is introduced into the mould via an inlet, where glass fibre sheets have been laid down. The mixture percolates through the glass fibre layers and cures, forming a stiff specimen. The resin-hardener mixture used in this study was made up of commercially available epoxy resin and medium cure hardener.

In this work, glass fibre was cut to match the mold size of 200 mm×200 mm. To achieve the required laminate thickness, 12 layers of fibres were used. Resin and hardener were mixed in the ratio of 100:10 and stirred thoroughly for about 10 minutes. Shape memory alloy (SMA) wires were used to create the channels. The primary goal was to establish a network of hollow channels throughout composite to deliver a healing agent. The SMA wires were located in the middle of the matrix as a layer. The wires were spaced equidistantly (approximately 6 mm apart) to form a central thin coating in the composite (positioned above the sixth layer of glass fibres from the bottom). Before the VARTM process, the wires were coated with a releasing agent to facilitate their removal after curing. Then the mold was allowed to cure for approximately 24 hours. Four types of specimens were created with varying thickness, specifically 2 with the passage and 2 without the passage.

Figure 3 illustrates the various stages process of composite fabrication, including layer stacking, resin transfer and mixture flow, post curing and cutting of the laminate.

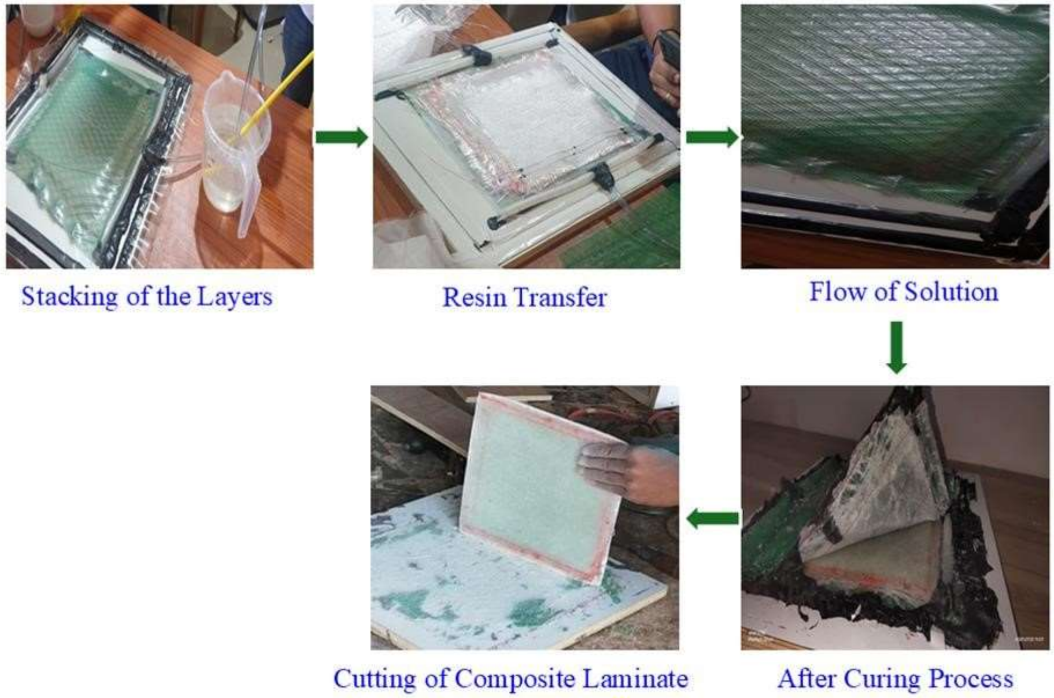

Figure 3: Different Stages Involved In Fabrication.

2.3 Flexural Test Details

The flexural test specimen was prepared by machining the fabricated laminate. Test was conducted as per ASTM D790 standard. According to the standard, the specimen dimensions were 120 mm×10 mm. Testing was performed using a Universal Testing Machine at crosshead speed of 0.01 mm/mm/min. The span was set at 100 mm, resulting in a support span-to-depth ratio of 16:1. **Figures 4** and **5** display photographs of the samples, illustrating both the variants with channels and those without respectively.

Figure 4: Samples with Passage.

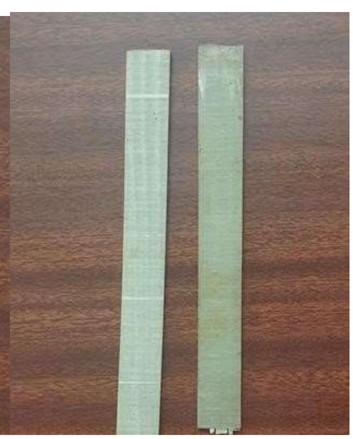

Figure 5: Samples without Passage.

3 Results and Discussion

3.1 Flexural Properties

The flexural modulus was determined using the slope of flexural stress versus stress lines obtained from the test results. The specimens were also tested until failure to determine their ultimate flexural strength. **Table 3** provides a summary of flexural test results. The flexural strength of composites with channels was comparable to that of a traditional composite without channels. The results indicate that the formation of channels has no significant effect on flexural strength.

Table 3: Flexural test result for the specimens.

Contents	Specimen (Without Channels)		Specimen (With Channels)	
	1	2	3	4
Thickness (mm)	4.03	4.49	4.1	4.47
Maximum Load (N)	750	941	665	870
Flexural Strength (MPa)	511.50	517.03	438.20	482.30
Max Strain	0.03	0.0413	0.035	0.035
Flexural Modulus (MPa)	18.97	13.82	15.08	15.573

The specimens without channels exhibited flexural strengths of 511.5 MPa and 517.03 MPa. The specimens with channels showed values of 438.2 MPa and 482.30 MPa respectively. A comparison of these specimens was made by finding the percentage loss in flexural strength. A reduction of 14.32% in flexural strength was observed when comparing specimen 1 with 3. Similarly, a 6.72% reduction was noted when comparing specimen 2 with 4. The bar chart in **Figure 6** compares the flexural strength of four specimens: two with micro-vascular channels and two without. The average flexural strength is slightly higher for specimens without channels. However, the variation in the data suggests that the presence of micro-vascular channels does not have a significant impact on the flexural strength of these specimens. **Figure 7** illustrates four rectangular specimens subjected to flexural testing. The specimens bend under the applied load, resulting in visible cracks on the outer layer.

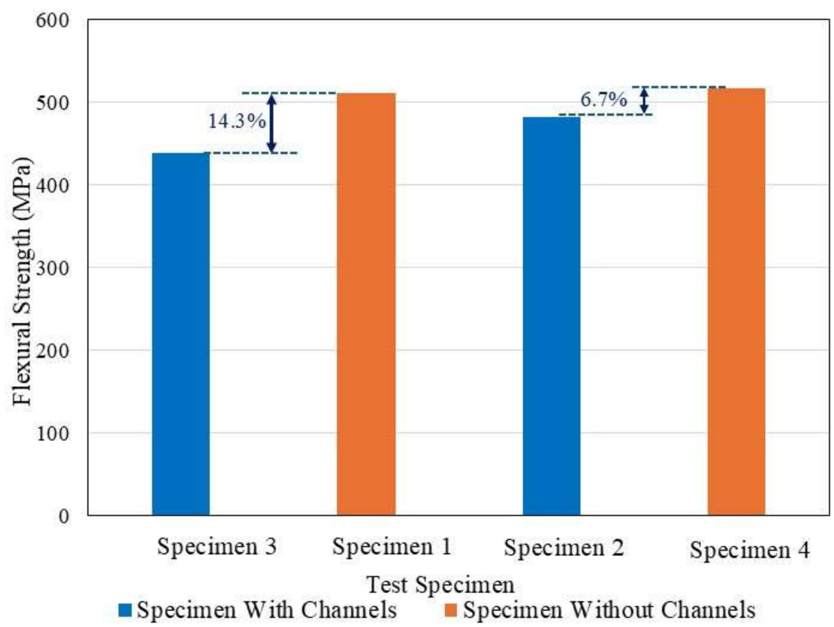

Figure 6: Comparison of Flexural Strength.

Figure 7: Photograph of Samples after Testing.

4. Conclusions

In this study, flexural strength of composites with and without channels was estimated and compared. The results revealed recovery strengths ranging from 85.67 to 93.30%, indicating that composites with channels through which a healing agent can pass are effective in mitigating micro-cracks. These materials show promise as alternatives for applications in the aerospace and automobile industries, including the fabrication of fuselage and aircraft structures, engine blades, combustion chambers, and anticorrosion coatings. To gain a deeper understanding, future research might include microscopic examination to identify potential defects and assess material variations in the composites.

Acknowledgments

The authors express their sincere gratitude to Dautya Aerospace Pvt. Ltd., Bangalore, for providing access to their research facilities. Authors also wish to acknowledge Mr. Rajesh Chouta, Chairman of Mangalore Institute of Technology & Engineering, Moodabidri, for providing infrastructure facilities and encouraging research activities.

Declaration of conflicting interests

The authors declare no conflict of interest.

References

Babolhavaeji, M., Eslami Farsani, R., & Khosravi, H. (2017). Micro-vascular channel based self-healing fibrous composites under transverse loading. *Modares Mechanical Engineering*, 17(5), 63-68.

Matt, A. K., Strong, S. P., & Amano, R. S. (2016). Development of self-healing materials for use in wind turbine blades. In *54th AIAA Aerospace Sciences Meeting* (p. 0992).

Fifo, O., Ryan, K., & Basu, B. (2014). Glass fibre polyester composite with in vivo vascular channel for use in self-healing. *Smart Materials and Structures*, 23(9), 095017.

Hamilton, A. R., Sottos, N. R., & White, S. R. (2012). Pressurized vascular systems for self-healing materials. *Journal of The Royal Society Interface*, 9(70), 1020-1028.

Williams, G. J., Bond, I. P., & Trask, R. S. (2009). Compression after impact assessment of self-healing CFRP. Composites Part A: *Applied Science and Manufacturing*, 40(9), 1399-1406.