

Fabrication and Mechanical Behaviour of Composite Material Embedded With SMA Wire

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ABSTRACT: One of the major topics in the development of smart adaptive composite is the material design. Fabrication of shape memory alloy hybrid composite (SMAHC) laminate for different types of testing is the key point in this paper. We have fabricated the SMAHC laminate by using unidirectional E-glass fibre and NiTi wire having $300\mu\text{m}$ diameter. The hardware required for the fabrication of SMAHC laminate is described in this study. The structural response of the host material can be improved by embedding the SMA wire. So we have investigated the mechanical behaviour of the SMAHC specimens by using ASTM standards for tensile and compressive test. The GFRP consists of epoxy resin as the matrix that houses and holds in position the glass-fibres, the combination offering the improved properties as listed above, over the conventional materials.

KEYWORDS: Shape memory Alloy (SMA), Resin Film Infusion (RFI), Glass Fibre.

I. INTRODUCTION

Human being have been aware of composite materials since several hundred years and applied innovation to improve the quality of life. A COMPOSITE MATERIAL [1] is a macroscopic combination of two or more distinct materials, having a recognizable interface between them. Practically [2] composite material consists of two phases one is reinforcement phase and another is matrix. One of the best examples of composite material is concrete. Concrete is a mix of aggregate (small stones or gravel), cement and sand. Now-a-days [2] polymer matrix composites (PMCs) have emerged as a class of material capable of advanced structural, aerospace engineering and marine engineering applications. Because of qualities such as versatility, low cost and light weight, polymers are increasingly used in many industries to substitute some conventional materials and alloys.

Mainly we were fabricated hybrid composite by using glass fibre reinforced plastic (GFRP) by embedding shape memory alloy (SMA). The material which we have selected for the fabrication is unidirectional E-glass fibre. Because the E-glass is the most common reinforcement material used in civil structures and basically it is produced from lime-aluminaborosilicate which can be easily obtained from abundance of raw materials like sand. We cannot use only fibers because they cannot transmit loads from one to another and to form composite material it can be embedded in a matrix material, the matrix serves to bind the fibers together and it transfer loads to the fibers.

The most commonly used matrix material for composite is epoxy resin. Epoxy [3] resins have relatively low molecular weight pre-polymers capable of being processed under a variety of conditions. Two important advantages of these resins are over unsaturated polyester resins are: first, they can be partially cured and stored in that state, and second they exhibit low shrinkage during cure.

Basically we have focused on the investigation of mechanical properties such as tensile and compressive strength of the shape memory alloy hybrid composite (SMAHC). Since the concept of SMA hybrid composites was first proposed in 1988 by Rogers et al. [4], these composites have attracted enormous attention in terms of improving creep and fatigue properties, strength and damping capacity, as well as to control the shape or vibration response property. Among these materials, the SMA/Glass-Fiber Reinforced Plastic (GFRP) hybrid composite - in which the embedded SMA is used to

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improve structural damping, thereby saving weight and stiffness, is especially important due to the wide potential or effective technological application of GFRP in all, real-life engineering environments

Shape Memory alloy

Shape memory alloys (SMAs) [5] belong to a class of shape memory materials (SMMs), which have the ability to 'memorise' or retain their previous form when subjected to certain stimulus such as thermomechanical or magnetic variations. Application of SMA achieved many fields such as industries including automotive, aerospace, robotics and biomedical. Currently, SMA actuators have been successfully applied in low frequency vibration and actuation applications. Recently [5], many researchers have taken an experimental approach to enhance the attributes of SMAs, by improving the material compositions (quantifying the SMA phase transition temperature) to achieve a wider operating temperature range, and better material stability, as well as to improve the material response and stroke with better mechanical design (or approach), controller systems and fabrication processes. Shape memory alloy carries important properties such as, superelasticity (SE), shape memory effect (SME) and damping capacity. All [6] these properties are dependent on the reversible phase transformation between austenite and martensite which is induced by either stress or temperature.

II. LITERATURE SURVEY

JanS chrooten et al. (2002) they have examined selection and characterisation of the material constituents, development of manufacturing processes for the production of composites with pre-strained SMA-wires. By examining above parameters they brought the knowledge on SMA composite which is reliable for manufacturing and design, and the emergence of new industrial applications [7]. Fathollah et al. (2011) they have investigated the parameters like mechanical behaviour of the constituents i.e. host composite and the temperature loading effects as well as the fabrication process. Finally they have concluded that embedment of SMA wire increased the stiffness and strength of reinforced composite plate. Travis Turner (2002) described the method and hardware required for fabricating a SMAHC laminate with bi-directional SMA reinforcement by using the material glass-epoxy unidirectional prepreg tape and NiTiNol ribbon. By using the fixture (i.e. hardware developed) they have fabricated the tensile test specimens according to ASTM D3039-95. Finally they got the significant results as compared with conventional composite material [8]. Mi sun Rim et al. () firstly they have investigated tensile test for SMA wire to improve the impact resistance. Further they have carried out the low velocity impact test with and without embedment of SMA wire. Also they have tested the impact test for different stacking sequence such as $[90^0/0^0]$, $[-45^0/+45^0]$ as well as embedment of SMA wire at different layers. By conducting these experiments they observed that, embedding SMA wires at lower position near the back face of plates can improve the impact resistance more effectively compared to other positions [8].

III. FABRICATION PROCESS

There are two processes for manufacturing the large composite materials these are,

- 1) Vacuum Assisted Resin Transfer Moulding (VARTM)
- 2) Resin Film Infusion (RFI)

Vacuum Assisted Resin Transfer Moulding (VARTM):

The [10] VARTM is a closed mold process which carries important benefits such as high quality, repeatability and clean handling of the resin transfer molding (RTM) process with the advantages of flexibility and scalability of open-mold hand layup processing. VARTM mostly developed for the production of complex composite parts with lower cost and improved quality. Also widely used for energy infrastructure building, aerospace, marine and defence industries. Below figure shows the detailed manufacturing process of VARTM process.

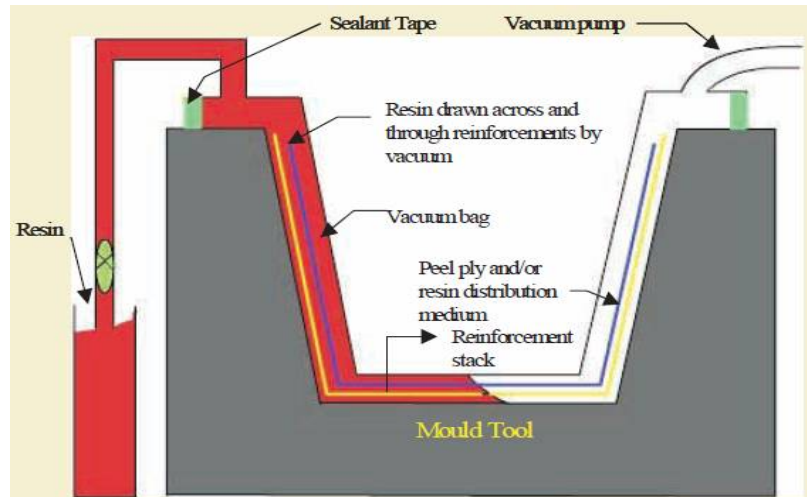


Fig 1 Schematic diagram of VARTM process [12]

Resin Film Infusion (RFI)

There are variety of manufacturing methods have been developed for aerospace industry to meet the requirement in the reduction of manufacturing cost of the material. For that purpose an important method could meet the above criteria i.e. liquid molding. Resin [11] Film Infusion (RFI) is one of the liquid moulding techniques which is shown in below fig. that has become attractive to composite manufacturers which has the potential to reduce the tooling cost. RFI[12] molding is one of the promising fibre-reinforced plastic composite fabrication techniques developed for structural applications in aerospace, automotive, and military applications as a replacement for expensive autoclave prepregs technology. Resin Film Infusion technique [12], proprietary to R&DE(E), is equivalent to the popular patented technique HEXPLY/SPRINT developed by HEXCEL Composites, UK. R&DE (E) has developed the RFI process including resin formulation, film casting, sandwiching, and composite fabrication.

In this experimentation we have used the RFI process because this technique is cost effective for fabrication of complex- shaped composite parts and to overcome the problem encountered in other fabrication process.

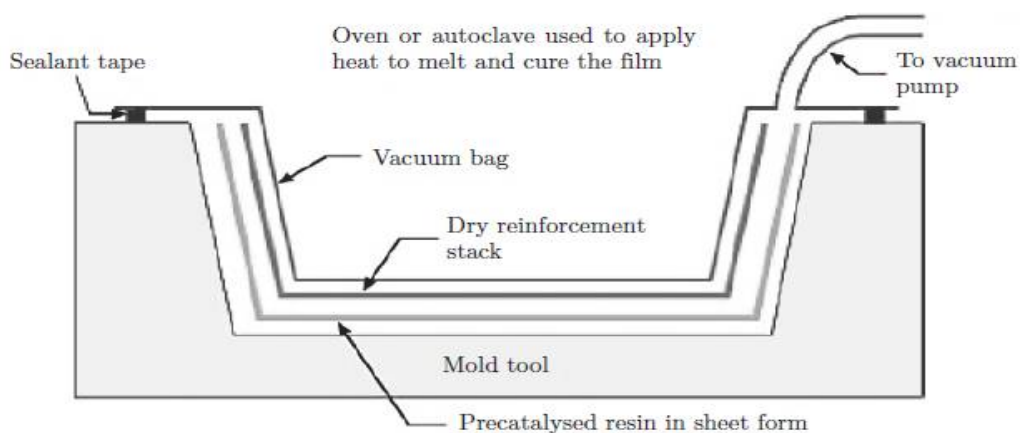


Fig 2 Schematic diagram of RFI process [13]

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IV. RESULTS AND DISCUSSIONS

COMPRESSION TEST:

Preparation for compression testing

According to ASTM D3410/D3410M the specimens were fabricated and tested:

For compression testing 6 plies of glass fibers are used. The SMA wire is embedded after 3 plies i.e. in the center of the composite laminate. The laminate is fabricated by using RFI process. Below figure shows the fabricated specimens for compression testing and the fixture of 10 Ton servohydraulic testing machine.

The following are taken into consideration for compression testing.

- Width = 10 mm
- Gage length = 10-25 mm
- Overall length = 140-155 mm
- Tab length = 65 mm
- Tab thickness = 1.5 mm



Testing Specimens



Fixture for testing

- 1) Stick the end taps onto the laminate providing the space (12.7mm) in between the laminate.
- 2) Place laminate into the hydraulic press for one day at 20bar pressure.
- 3) After that put the laminate into the oven for post curing at 40°C for 4hr and 80°C for 1hr.
- 4) Cut the laminate into the cutting machine having the size 143x12.7mm.
- 5) Polish the specimen on silicon carbide grinding paper.

Compressive stress can be calculated by the following formula,

$$F^{cu} = P^{max}/A$$

$$\sigma_i^c = P_i/A$$

Where;

- F^{cu} = compressive strength, MPa [psi],
- P^{max} = maximum force before failure, N [lbf],
- P_i = force at ith data point, N [lbf],
- A = cross-sectional area at test section, mm² [in.²], and
- σ_i^c = compressive stress as the ith data point, MPa [psi].

Resin Requirement

- No. of glass fiber used = 6
- Weight of 6 plies of glass fiber = 91 gm

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Resin required = total wt of fiber X 25/75
= 91 X 25/75
= 30.33 gm

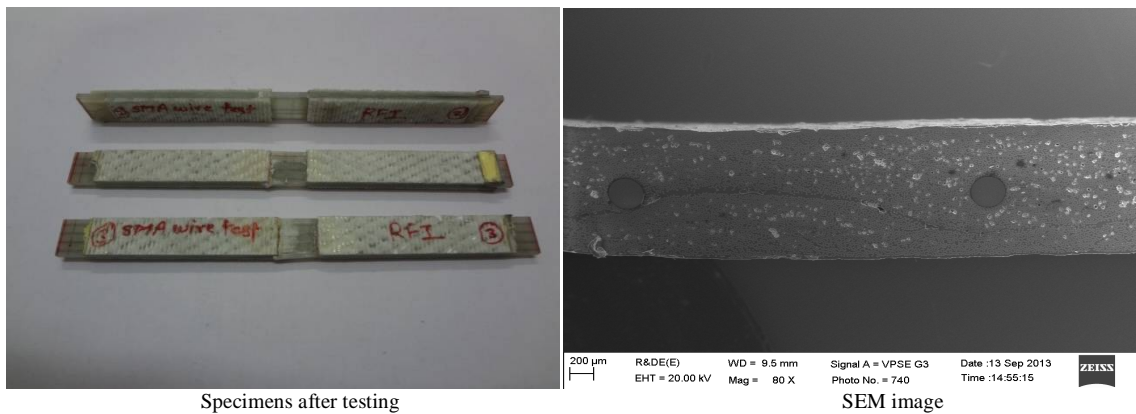


Fig.3 Overall view of compression testing

The above figure shows the tested specimens. Most of the specimen's breaks near the center of the specimens and remaining specimens break inside the tab which is not the favourable for the testing. Also we have taken the SEM image of the laminate to identify the uniformity and alignment of the wire.

The compression testing was done on 10 Ton servohydraulic machine and the results obtained are summarized below:

Table 1: Compression results for steel wire embedded composite

SAMPLE NO.	WIDTH (mm)	THICKNESS (mm)	No. Of Wires	LOAD (N)	STRESS (MPa)
1	12.72	2.16	4	21174	770.65
2	12.68	2.30	4	22373	767.14
3	12.60	2.16	4	20983	770.98
4	12.64	2.16	4	21437	785.16
5	12.66	2.14	4	21415	790.44
6	12.74	2.20	4	20473	730.44
7	12.72	2.32	4	21829	739.70

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TABLE 2: COMPRESSION RESULTS FOR SMAHC

SAMPLE NO.	WIDTH (mm)	THICKNESS (mm)	No. Of Wires	LOAD (N)	STRESS (MPa)
1	12.75	2.06	4	21704	826.34
2	12.65	2.34	4	20768	701.59
3	12.65	2.22	5	22007	783.64
4	12.70	2.28	5	18259	630.57
5	12.65	2.19	4	22691	819.06
6	12.65	2.32	4	20543	699.97
7	12.55	2.13	3	24289	908.62

TENSILE TEST

According to ASTM D 3039/D 3039M the specimens were fabricated and tested: For tensile testing 3 plies of glass fibers are required. The below schematic diagram shows the SMA wire is embedded after the first ply from the bottom to get the better strength.

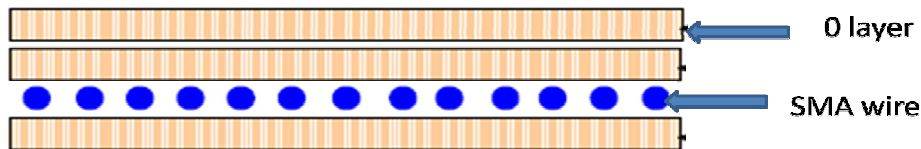


Fig 4 Schematic diagram of tensile specimen

Tensile Specimen Geometry Recommendations

- Width = 15 mm
- Overall length = 250 mm
- Thickness = 1 mm
- Tab length = 56 mm
- Tab thickness = 1.5 mm

Resin requirement

$$\begin{aligned}
 \text{Weight of 3 plies of glass fiber} &= 86.5 \text{ gm} \\
 \text{Resin required} &= \text{total wt of fiber} * 25/75 \\
 &= 86.5 * 25/75 \\
 &= 28.83 \text{ gm}
 \end{aligned}$$

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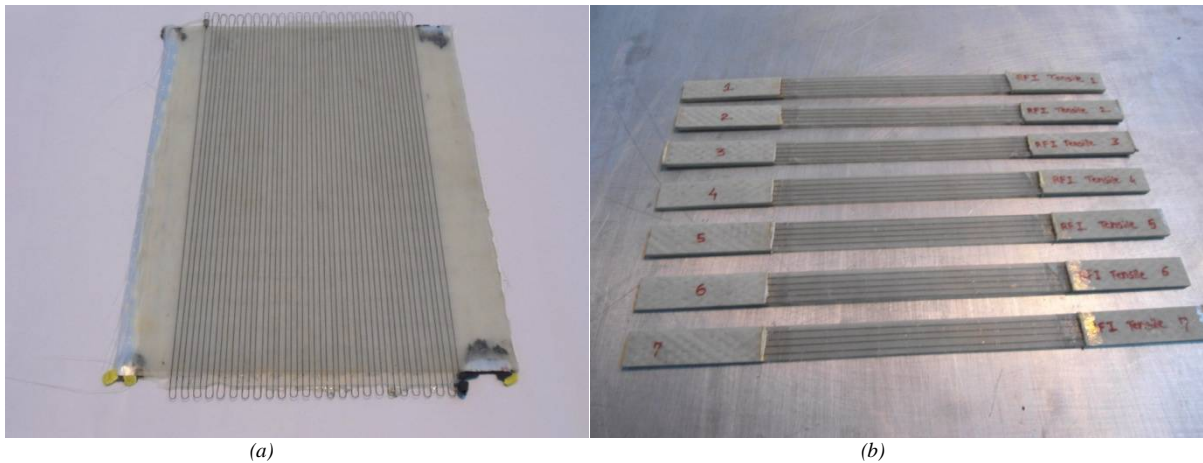


Fig 4 Tensile laminate (a), testing specimens (b)

Above figure shows the fabricated tensile laminate and the tensile specimens which are produced by using the ASTM D 3039 standard. For better results and uniformity in the results we have selected the specimens which are having five wires in each of the specimen.

Table 3: Tensile Test results of SMAHC

SAMPLE NO.	WIDTH (mm)	THICKNESS (mm)	No. Of Wires	LOAD (N)	STRESS (MPa)
1	14.35	1.00	5	17497	1219.30
2	15.00	0.97	5	19415	1334.36
3	14.60	1.00	5	15911	1089.79
4	14.45	1.00	5	19295	1335.29
5	15.30	1.00	5	19069	1246.33
6	15.00	1.00	5	17941	1996.06
7	15.00	0.98	4	18221	1239.52

V. CONCLUSION

The basic objective of this research project was to fabricate and characterize the shape memory alloy hybrid composite (SMAHC) by using resin film infusion (RFI) process. For embedment of SMA wires in the GFRP a fixture was designed and fabricated. By using this fixture SMAHC laminates were successfully produced. These laminates were tested for mechanical properties like compression and tensile. The tabulated values for compressive and tensile

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testing shows greater increase in their stress as compared with conventional composite material. Also by conducting this research work it is concluded that, SMA wires have large failure strain and stress with superelasticity.

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