

# A Review on Shape Memory Alloy (SMA) Hybrid Composite

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**ABSTRACT:** Composite materials are manufactured from two or more materials to take benefit of desirable characteristics of the components.. Hybrid composites are more advanced composites as compared to conventional FRP composites. Hybrid composite contains higher modulus which provides stiffness and load bearing qualities. That's why, new technologies have been developed enabling more original and more advanced applications for hybrid composite materials. For this purpose new methods are developed to integrate the shape memory material (SMM) into the composite material. Nickel-Titanium (NiTi) is considered the SMA with the most engineering significance owing to its ductility at low temperature, high degree of shape recovery capability, large pseudoelastic hysteresis, corrosion, fatigue resistance, biomedical compatibility, and relatively high electrical resistance. The demand of composite material is continuously growing, so further research is still being carried out to expand this field.

**KEYWORDS:** Hybrid composite, Shape Memory Alloy (SMA), shape memory effect.

## I. INTRODUCTION

Composite materials are very well known from the ancient days. So we know the historical examples e.g. the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians and laminated metals in forging swords. In the 20th century [9] modern composites were used in the 1930s when glass fibers reinforced resins. From glass composites aircrafts and boats were built out, commonly called as fibre glass. Also [9] in 1970s, application of composites has widely increased due to development of new fibers such as carbon, boron, aramids and new composite systems with matrices made of metals and ceramics.

Composite material is a form of two or more combined constituents that are combined at a macroscopic level and are not dissolved in each other. One [9] constituent is called the *reinforcing phase* and the one in which it is embedded is called the *matrix*. In these days many sport science and aerospace industries are going to use the composite materials. In aircraft panels it requires the vibrational control for to reduce the resonance effects and these capabilities exists in these materials. It means the increase demands on the performances of materials with multiple characteristic used in engineering applications as well as the necessity of lightweight constructions in various applications can be fulfilled by development of so-called adaptive, multifunctional and intelligent materials. Mainly we are focusing on the study of glass fibres because 95% of the fibers used in reinforced plastics are glass fibers, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced. Glass fibre having low density, resistance to chemicals, insulation capacity are other bonus characteristics however, it remains break-resistant at higher stress-levels in shorter time frames. Glass fibers are available in the form of mates, tapes, cloth, continuous and chopped filaments, roving and yarns.

### Types of glass fibers

- E-glass with a calcium aluminoborosilicate composition and a maximum alkali content of 2% are used as a general-purpose fiber when strength and high electrical resistivity are required.
- S-glass has a magnesium aluminosilicate composition and hence is found in applications where high tensile strength and high thermal stability is required.
- C-glass has a soda-lime borosilicate composition and is used due to its chemical stability in corrosive environments.

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- d) R glass – enhanced mechanical properties.
- e) C glass - resists corrosion in an acid environment.
- f) D glass – good dielectric properties.

Mainly the hybrid composite having high damping capacity, stiffness, superelastic behavior, may be varied in response to external or internal stimuli. In this research we discussed on composite material embedded with shape memory alloy (SMA) which forms the hybrid composite. Aerospace, automotive, and medical industries gaining the interest in shape memory alloys (SMAs) due to their unique characteristics, which include the shape memory effect, pseudoelasticity, and improved material behavior upon heating.

Smart material is a type of materials that has inherent intelligence to react toward external stimuli such as heat, electrical field and electromagnetic field. This reaction will produce the desired functions such as changing the shape and modifying structural behaviour of a structure. Smart materials that react by inducing an amount of strain can be classified into several types: piezoelectric material, shape memory alloys (SMA), magnetostrictive materials, electrorheological fluids, electro-optic materials, electro acoustic materials and electromagnetic materials. Mainly the smart materials are,

**Piezoelectric materials** are materials that produce a voltage when stress is applied. Since this effect also applies in the reverse manner, a voltage across the sample will produce stress within the sample.

**Shape-memory alloys** and shape-memory polymers are materials in which large deformation can be induced and recovered through temperature changes or stress changes (pseudoelasticity). The large deformation results due to martensitic phase change.

**Magnetostrictive** materials exhibit change in shape under the influence of magnetic field and also exhibit change in their magnetization under the influence of mechanical stress.

The other types of shape memory alloys as they are, Piezo-ceramics (PZTs), Piezo-polymers (PVDFs), Electrostrictive ceramics (PMNs), Polymer gels.

## SHAPE MEMORY ALLOY

SMAs [10] are a group of metallic alloys that can return to their original form (shape or size) when subjected to a memorisation process between two transformation phases, which is temperature or magnetic field dependent. This transformation phenomenon is known as the shape memory effect (SME). The use of SMA can be divided into several sections based on the application domain, such as automotive, aerospace, robotics and biomedical as well in other areas. Shape memory alloys have important properties such as, One-way shape memory effect (OWSME): The one-way SMA (OWSMA) retains a deformed state after the removal of an external force, and then recovers to its original shape upon heating. Two-way shape memory effect (TWSME) or reversible SME: In addition to the one-way effect, a two-way SMA (TWSMA) can remember its shape at both high and low temperatures. Another important property is pseudoelasticity, when a SMA is heated, it begins to transform from martensite into the austenite phase. The [10] austenite-start-temperature ( $A_s$ ) is the temperature where this transformation starts and the austenite-finish-temperature ( $A_f$ ) is the temperature where this transformation is complete. Once a SMA is heated beyond  $A_s$  it begins to contract and transform into the austenite structure i.e. to recover into its original form. This transformation is possible even under high applied loads, and therefore, results in high actuation energy densities

## II. LITERATURE REVIEW

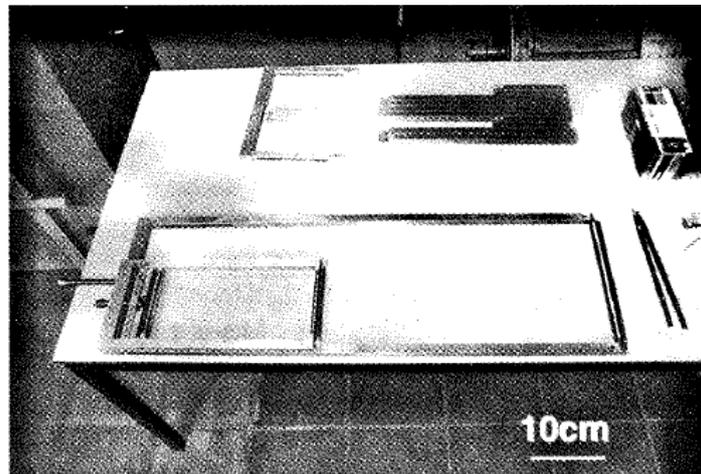
[1] **JanSchrooten et al.** They presented their work in the following major steps, selection and characterization of the material constituents, development of manufacturing processes for the production of composites with pre-strained SMA wires, analysis and modeling of the action of the SMA wires in the composite, the contribution of the SMA-resin interface, analysis and modeling of the functional, thermo mechanical, impact and durability properties of SMA composites and the development of a simple, large-scale, aerodynamic model. They have used SMA wire diameter would be 150 $\mu$ m. The LTM 217 resin produced by the Advanced Composites Group was selected and studied by means of IR spectroscopy Laser Raman Spectroscopy (LRS), Dynamic Mechanical Analysis (DMA) and Differential Scanning Calorimetry (DSC). Rheometry tests were also performed to study the curing kinetics and to establish the optimum curing conditions for the epoxy resin and the composite.

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Production of hybrid composite: They have used a special frame to produce SMA composites with pre-strained SMA wires carrying pre-strained SMA wires at different volume fractions, size, spacing, etc. were designed and manufactured which is shown in Fig. 1. The frames enabled SMA wires to be wound around comb-like pins, 500  $\mu\text{m}$  apart, situated at both ends of the frame. One of these combs could be moved in order to pre-strain and then hold the wires at the required pre-strain value during curing. The maximum number of wires possible was 2 wires/mm, but two frames could be superimposed to provide 2 layers of wires in the final product. The laminated assembly, which combines the Kevlar prepregs and the pre-strained SMA wires, was cured in an autoclave. The frame prevented the strain recovery of the pre-strained SMA wires during heating. After curing the frame was removed. They have prepared samples ( $125 \times 125 \text{mm}^2$ ) consisted of SMA wires embedded in a glass fibre epoxy matrix, covering a width of 16mm. A stafil G-EPI- 140/142 glass fibre epoxy prepreg from hexcel composite was used.



**Fig.1** Comparison between the frames used for the production of the standard SMA composites (small frame) and for the production of the scaled model (big frame) [1].

[2] **D. Bolas, et al.** they have investigated the ability of single SMA wires to act as internal stress generators in fibrous polymer composite systems. The stress fields recorded both at the specimen level and internally in the reinforcing fibers by means of Raman microscopy measurements have confirmed that SMA wires can serve as effective stress-actuators. They have obtained the maximum value of stress in the fibers at a distance of approximately one wire radius was 227 MPa. They have examined the functionality of epoxy resin/aramid fiber/ NiTiCu wires systems have taken place within the framework. They concluded that, the as-received SMA wire is capable of generating constant stresses up to approximately 350 MPa, while the generated stress from the prestrained NiTiCu(12%) wire remains constant at almost 450 MPa. The fluctuation width of generated stress values of approximately 50 MPa was due to the sensitivity of the 2.5 kN load cell that was used at its 10% dynamic range. Finally they have concluded that the assumption of the initial prestrain induced during manufacturing is sufficient for stress generation under constrained conditions. The NiTiCu(12%) single wire, examined for comparison, also exhibits a similar “behavior” but it was found to be less efficient than the NiTiCu(6%) wire.

[3] **Travis L. Turner, et al.** They have carried out the fabrication and characterization work for better understand the mechanics of the material system, address fabrication issues cited in the literature, and provide specimens for experimental validation of a recently developed thermomechanical model for SMAHC structures. Also they described processes and hardware developed for fabrication of the SMAHC specimens. For the fabrication of hybrid composite they were used a glass-epoxy matrix material system and a Nitinol alloy in ribbon form was selected because of favourable electrical resistance, availability and shape memory capabilities. The fabrication process contains following steps, prestrain (elongate) the SMA actuators, lay-up the composite laminate, cure the laminate while restraining the actuators, and machine beam specimens from the consolidated SMAHC laminate. For the fabrication the apparatus was

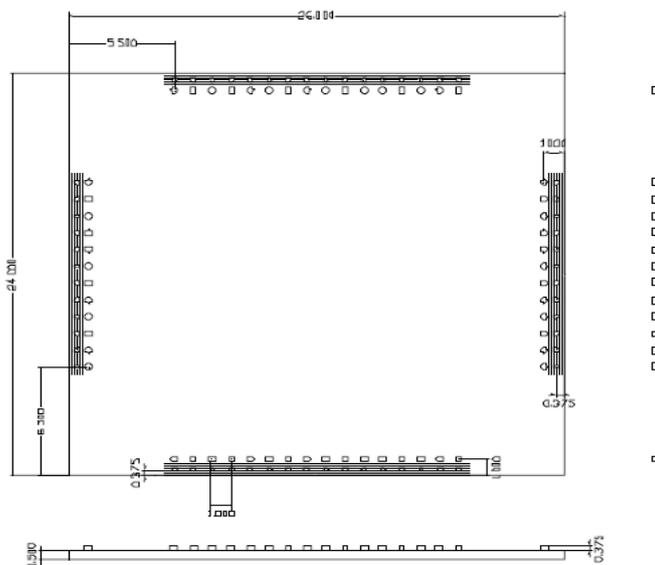
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designed to provide a flat surface ( $\pm 0.005$  inches) and mechanical grips to restrain the SMA during an autoclave cure procedure.

Two laminates were fabricated from the glass-epoxy material system to provide specimens for thermomechanical testing; a unidirectional lay-up  $(0)_{20}$  and an angle-ply lay-up  $(45)_4$ . Tab material was post-cured to the laminates and the resulting structures were machined into uni-axial tensile specimens with dimensions of  $0.2286 \times 0.0254$  m (9x1 inches) (gage length of 0.1524 m, 6 inches). The tensile specimens were instrumented with a "T-strain gage" at the mid-span and tested on a servo-hydraulic test machine. The unidirectional specimens were tested according to ASTM D3039-95a for estimates of the Young's moduli and Poisson's ratios; E1, E2. The angle-ply specimens were tested according to ASTM D3518-94 for estimates of the shear modulus G12. They have concluded that the glass-epoxy matrix properties showed significant thermal nonlinearity. The following properties were estimated from the experimental data; E1, E2,  $\nu_{12}$ , G12,  $\alpha_1$ , and  $\alpha_2$ . The constrained recovery stress behaviour of the Nitinol ribbon was measured as a function of temperature, thermal cycle, and prestrain level (2%, 3%, and 4%). Modulus values were estimated from the stress-strain behaviour of the specimens used in the recovery stress tests. The schematic diagram of the laminate lay-up and cure tooling apparatus is as shown in below.



**Fig.2** Mechanical drawing of the laminate lay-up and cure

tooling apparatus (all dimensions in inches)[3].

**[4] Fathollah Taheri-Behrooz et al.** In this paper they introduced the design process of a SMA wire-reinforced hybrid composite (SMAHC) plate. They discussed the influence of various parameters on the overall behavior of the SMAHC plate. These parameters include: the mechanical behavior of the constituents (i.e. the host composite and SMA), the SMA volume fraction, the temperature dependent loading effects and the fabrication process. For the experimentation they were used NITI wire having diameter 0.381mm. For that, they were fabricated a series of SMAHC plates and tested under monotonic loading condition. The main objective of this paper is that the verification of the assumption that the shape memory alloys are considered as structural reinforcement for those applications wherein heating would be a source of material degradation. For that tests were conducted on the wires at different temperatures and under different pre-strains. Recovery stress of 4% pre strained of SMA wires were measured experimentally at elevated temperatures and used as input data to estimate the stress-strain response of the SMAHC plates. They observed that the embedment of SMA wires could improve the overall structural response of the host material in terms of stiffness and strength at elevated temperatures.

Also they described the manufacturing process for pre-straining the SMA wires and sandwiching them between two composite laminates. The SMA wires were pre-strained using an in-house designed rigid steel frame with movable

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rods as shown in on the adjustable and fixed rods, threads with appropriate pitch size were machined to produce the maximum SMA volume fraction after winding the SMA wires around them. Moreover, due to constant pitch size in the rods, an equal distance between any two wires could be attained. This ensured that the wires would be homogenously distributed within SMAHC plates. The movable horizontal rods could be adjusted by the two nuts mounted on each of the side rods to create the desired pre-strain. In order to adjust the value of the wire pre-strain precisely, a digital deflectometer was used to measure the deflection in the side rods. After winding the SMA wires around the horizontal rods, the wires were stretched by the adjustable frame to a certain level. Then the tension on the wires was released, and the wires were sandwiched between glass/epoxy composite prepregs to produce the SMAHC plates. At this stage, the entire assembly was vacuum bagged to approximately 2500 Hg vacuum. The assembly was subjected to the oven cure cycle recommended by the vendor (heating rate of 2 °C/min, ramped to 135 °C, held for 120 min at that temperature and cooled down to room temperature) and the resulting consolidated plate produced within the manufacturing frame is shown in Fig. below

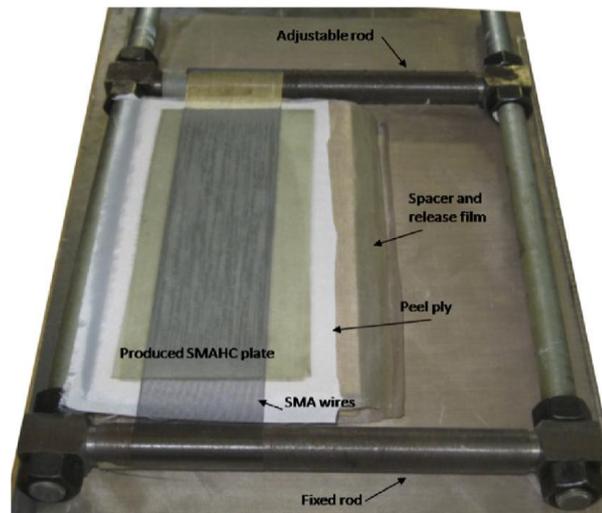


Fig.3 The rigid adjustable frame and SMAHC plate after curing [4].

From experimentally it has been shown that SMA wires in martensite phase under monotonic tensile loading experience large deformation (typically as high as 7%) and recover to their original shape when heated up to temperatures more than their activation temperature. It is observed that the SMAHC behavior under the ambient temperature, the removal of the mechanical load at any stage would leave some residual strain in the SMA wires and matrix and under elevated temperatures, SMA wires were elongated before embedding them into the host material, a compressive strain will be developed within the host material, which in return will enhance the load capacity of the SMAHC plate when subjected to a tensile load.

Scanning electron microscopy (SEM) was conducted on the SMAHC specimens in order to evaluate: (a) quality of the bond between the SMA wires and host material; and (b) whether the SMA wires were uniformly distributed within the host composite. For this it is observed that SEM observations exhibited uniform distribution of SMA wires inside the host material and verified existence of appropriate bonding qualitatively in SMA composite interface.

[5] **Alok Hegde et al.** They have used Diglycidyl Ether of BisphenolA(DGEBA) / TriEthylene Tetra Amine(TETA) as the epoxy matrix and unidirectional glass fabric is used to reinforce with the polymer matrix by hand layup and vacuum bagging process. The specimens prepared from GFRP for various testing Tensile Strength, Tensile Modulus, Specific Tensile Strength and Specific Tensile Modulus. They carried out experimental procedure as per ASTM D3039 standards. For making the laminates they used unidirectional fabric of E-glass with density 220 gsm along with the vacuum hand lay – up technique. For 0° they obtained 325.67MPa tensile strength, 10.07GPa tensile modulus, 5.55 MPa-m<sup>3</sup>/k Specific Tensile Strength, 0.171 GPa-m<sup>3</sup>/kg Specific Tensile Modulus. For 45° laminate 48.55MPa tensile strength, 2.53GPa tensile modulus, 0.827 MPa-m<sup>3</sup>/k Specific Tensile Strength, 0.0431 GPa-m<sup>3</sup>/kg Specific Tensile

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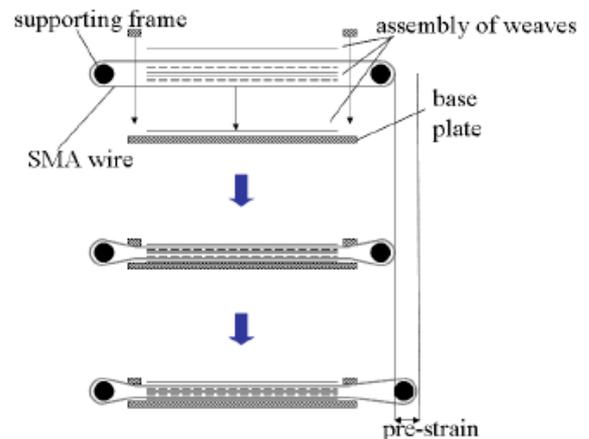
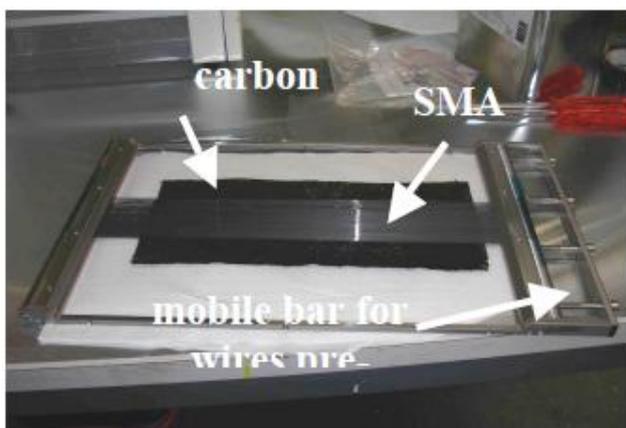
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Modulus. For 90° laminate 30.10MPa tensile strength, 1.93GPa tensile modulus, 0.512 MPa-m<sup>3</sup>/k Specific Tensile Strength, 0.0329 GPa-m<sup>3</sup>/kg Specific Tensile Modulus.



**Fig.4** Manufacture of Glass fibre laminate using Vacuum hand lay – up technique [5].

[6] **Véronique Michaud et al.** they have used carbon fibre reinforced plastic (CFRP) composite by embedding NiTi alloy wires for increases their damping by using infusion process. Basically they carried out the experiment with two types of NiTi wires, having the same diameter of 203 μm, were considered, one superelastic at room temperature, the other one martensitic. The impact on the cure progress and the internal stress build-up during cure and post-cure of composite was evaluated using optical fibre Bragg gratings (FBG) sensors. For manufacturing purpose a metallic frame was designed that guaranteed the wire positioning and superelastic wires pre-straining. From free vibration tests they have verified the effectiveness of the embedment of the SMA wires by vacuum infusion process.



**Fig.5** Metallic frame for SMA wires positioning and procedure for pre-strain [6].

[7] **Gang zhou et al.** The developed fabrication process allowed both quasi-isotropic E-glass/epoxy and carbon/epoxy hosts to be eccentrically embedded with 10 parallel prestrained wires with a purpose-made alignment device and cured successfully in an autoclave. Smart composite beams of three different lengths were made for each type of host. They have prepared nitinol wires for prestraining, each piece of nitinol wires was first suspended under a constant load at the side of a 6-m tower before embedment and was trained by cycling it through transformation temperatures via resistive heating for a total of 25 times.

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They have designed an alignment frame which is shown below to ensure that during composite cure the prestrained wires were kept not only longitudinally straight with the desired wire to wire spacing but were also at the desired through-the-thickness location. It consisted of an aluminium base plate; a pair of through-the-thickness positioning blocks; a pair of wire tension tightening blocks; and two arrays of wire fixers (one array metal ferrules and one array of nuts). Each through-the-thickness positioning block had the same number of orifices as the nitinol wires and the diameter of each orifice was fractionally greater than the wire diameter so that the wires were threaded through easily without being damaged.

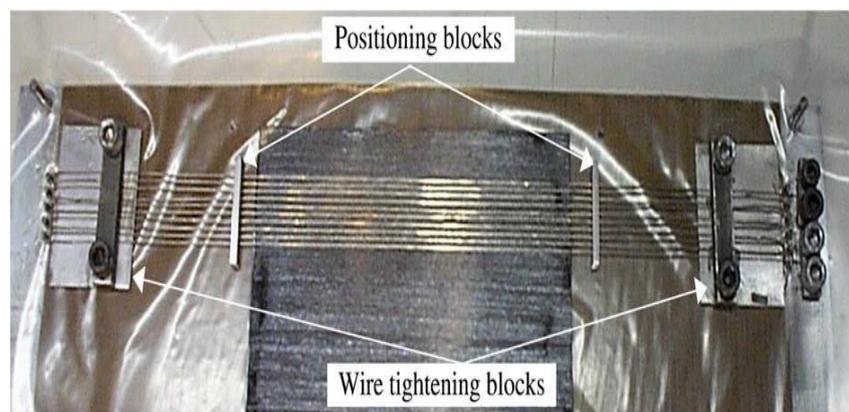


Fig.6 SMA wire alignment device for manufacturing adaptive composite beams [7].

[8] **Mi sun Rim et al.** In this paper they have investigated tensile test and low-velocity impact tests of SMAHC plates and conventional composite plates without SMAs at the critical energy level. Conventional composite plates without embedded SMA wires were fabricated with graphite/epoxy prepreg CU-125NS (Hankuk Carbon Co.) and SMAHC plates were fabricated by embedding SMA wires (SE508) into conventional composite plates. For impact test firstly the stacking sequence of conventional composite plates was  $[90^0/0^0]_{3S}$ . To fabricate SMAHC plates, SMA wires were aligned along the centre of the plate, covering a width of 20mm, with a volume fraction of 2.24%. To prevent delamination SMA wires were aligned along the fiber direction and embedded in the center layer of the conventional composite plate between  $0^0$  plies. In the second case, the stacking sequence of the conventional composite plates was  $[45^0/-45^0/90^0/0^0]_S$  and the volume fraction of SMAHC plates was 7.57%. They have used a weight-drop-type universal impact testing machine and a hemispherical steel impactor with a diameter of 15.35mm and a mass of 2.38 kg was dropped to make an impact into the center of the plate type specimen. In the first case at incident impact energy is 20 J and they observed that the composite material was totally fractured however, the SMA wires in the composite plate were not fractured and sustained the impact load after the fracture of the composite materials. In the second case, specimens fractured at the critical impact energy of 7 J. However, they found that the contact force of SMAHC plates after fracture was greater, reduced energy was greater, deflection was smaller and recovered deflection was greater than those of conventional composite plates.

They have also tested the low-velocity impact tests for different position of embedded SMA wires to improve the impact resistance more effectively by changing the position. The results showed that embedding SMA wires at a lower position near the back face of plates can improve the impact resistance more effectively compared to other positions.

### III. CONCLUSION

The main aim of this study is to compare different types of fabrication processes using the special alignment device to produce the hybrid composite using shape memory alloy (SMA). So SMA composite could be produced successfully. The design and manufacturing process of active composite based on SMA wire is now reality which is currently used in the many industrial applications. It is observed that by embedding the SMA wire into the composite tensile strength,

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fracture toughness, impact resistance etc can be improved also the deflection was less and the recovery stress was greater compared to the without SMA embedded into the composite material.

Most of the researchers have designed the fabrication fixture for the  $0^0$  and  $90^0$  ply of the glass fibre. From this study there should be an improvement in the alignment device (i.e. fabrication fixture) so we can embed the SMA wire in angular direction like  $(+45^0/-45^0)$ . It is concluded that we can easily embed the SMA wire into the glass fibre instead of the carbon, graphite material.

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