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# Transformation of Conventional Mechanical Elements to Smart by Adding Sensors and Actuators to Composite Materials

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**Abstract** Adding sensors and actuators to machine elements will make them more active and useful. The idea is elaborated by combination adding these elements to machine elements manufactured of composite materials as well. With this, the properties of composites are supported by the traits of sensing, monitoring as well as actuating. In this study the evidences supporting this idea was presented and generalized to include all machine elements in order to be smart. For more confidence a mathematical model of the most popular engineering elements namely beam is implemented without implanted wires compared with a second one that implanted with two rows of SMA wires, Nitinol. The two models are solved and analyzed with the finite element method; Ansys package software. The results, deflections, stresses, showed how the beam isn't degraded when implanted with wires and still retains its strength. The advantages of this idea are focused mainly on the quality enhancement as well as pre warning failure.

**Keywords:**. Smart structure, machine elements, composite materials, Ansys.

## 1 Introduction

The smart structure can be defined as a system or material which has built in or intrinsic sensor(s), actuator(s) and control mechanism(s) whereby it is capable of sensing a stimulus, responding to it in a predetermined manner and extent, in a short appropriate time, and reverting to its original state as soon as the stimulus is removed [1]. A composite material is two or more materials are combined in a macroscopic scale to form a useful third material [2]. The third material usually exhibits highest qualities of their constituents and some that neither constituents possess. Consequently, the two concepts, smartness and composite materials traits may be combined to build high efficient machine elements along with reducing of high cost of predictive and periodic maintenance in addition to new design concepts because of abundant information and real time monitoring.

The very idea of adding sensors and actuators to composites is not new, rather it is used indeed especially in the field of airspace engineering for safety working. The shape and vibration control applications in large space structures, noise reduction in military and civil aircrafts, and even in health monitoring are most known applications [3].

The bonded composite patches are used to repair or reinforce defective metallic in structures. The smart patches concept consists of a bonded composite repair with the ability to monitor its own health [4], hence making a continuous safety with timely decision and monitoring before structure failure. In shape adaptive structure, various optimized aerodynamic shapes are provided according to flight conditions replacing conventional surface shapes [5]. The determinations incorporate the development of a SMA torque tube to achieve twist within the wing and to actuate the trailing edge, the SMA tendons are used.

To overcome the commercialization limitation of tidal turbine blades manufacturing, Tomas Flangon etal. describe a manufacturing process for tidal blade implanted with a system of sensors within the blade

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construction in order to manufacture high quality cost-effective smart blades that capture data from sensors embedded within the blade and monitor strain and damage during operation [6].

Conventional materials, Cast Iron and welded steel are used in manufacturing moving parts of MT are suggested to be replaced by a new class of materials [7]. This new class including composite materials, CFRP layered materials with UHM (Ultra High Module) carbon fibers in epoxy resin is one of them, outcomming to strong mass reduction of the mobile parts of the milling machines along with increasing their stiffness and damping in addition to chatter stability of machine.

Supeni E.E. etal [8] suggested embedding SMA (Nitinol NiTi) in the wind turbine in order to prevent deboning and rapid aging during multicycle actuations. They fabricated a graded GFRP beam with hand layup. The test experimentally carried out and the load is applied with hot and cold wire (with and without current applied to SMA wire). They found that the SMA embedded in composites alleviated the deflection. This shows that there is a hope to solve one of the unresolved problems in wind turbine blades that is deformation of the plate. Choi etal [9] solved how buckling control reached the post buckling of the beam with the reactive moment. The study is performed experimentally on a laminated composite beam with SMA embedded eccentrically.

Nuballah Abd Hamid, Muhammad Hussain, Azmi Ibrahim, et al. [10] applied a SMA, nickel titanium alloy, as a replacement for steel rebar in reinforcement beam. The alloy has the super elasticity behavior. They used Ansys workbench 15 to analyze the beam at different loading conditions and they found that the beam with Nickel titanium alloys was superior to the conventional one at residual displacements and crack formation the beam.

Applications namely in medical fields as well, smartness is added like dental arch wires, microsurgical tools, micro grippers, guiding wires for catheters, implants.

Of these applications, the idea is making the traits of composite materials to be supported by the possibilities of implementing sensors and actuators during fabrication machine elements. Hence they have both sensing and actuating capabilities as well as being strength and reliable.

The aim of this study is to prove that the machine elements should be smart replacing the conventional elements and made of composites by listing evidences supporting this idea. A mathematical model- beam-made of composite was embedded with wires of SMA (Nitinol NiTi) is analyzed with the aid of Ansys package software 15 to guarantee that the implants have no side effects.

## 2 Smart Machine Elements made of Composites

Do composite materials support smart structures? Before answering, let's take a look at some material requirements for smart structures.

1. The requirements of Mechanical properties such as yield strength, fatigue, etc.
2. Behavioral C/S including damage, tolerance, heat transfer.
3. Economical side; raw materials availability and procedure costs.
4. Technological aspects; manufacturing, forming and welding abilities, thermal processing.
5. Environmental aspects, pollution, toxicity.
6. Recycling and reuse capabilities.
7. Actuating and sensing functions concern to composites and adaptation to the solicitations.

Of these points composite materials match most of these conditions. By adding the functions of sensing and actuating to composites, the latter is going to be used for reinforcement as well as for sensing and actuating purposes combined with sophisticated data acquisition and monitoring apparatus.

The outcomes of that is revealed in the following benefits:

1. Safety enhancement, the structure is taken out of service when required.
2. Economic benefits associated with decreasing design margins.

## 3 Analysis and Motivation

In order to assure that adding sensors and actuators to structures is not have bad effects, a common mechanical element, beam, is chosen for analysis. A composite beam of 32 mm wide and 300 mm long was considered with 9 Nitinol wires to be embedded side by side spacing of 6 mm and in two rows Fig. 1. The beam material of T300/934 composite (Carbon Epoxy Laminate) is considered with mechanical properties as following [11]:

$E_x = 141.6\ GPa$
$E_x = 141.6\ GPa$
$E_y = 10.7\ GPa$

$E_z = 10.7\ GPa$
$G_{xy} = 3.88\ GPa$
$G_{xz} = 3.88\ GPa$
$G_{yz} = 3.58\ GPa$
$\upsilon_{xy} = 0.268$
$\upsilon_{xz} = 0.268$
$\upsilon_{yz} = 0.495$

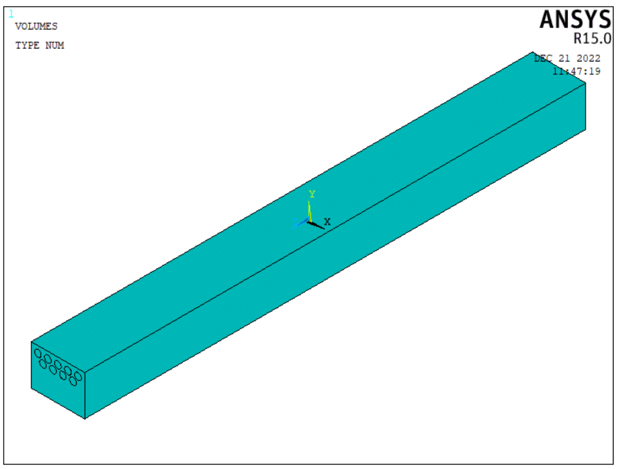


**Fig. 1** Beam model and wires locations

The wire used is (Nitinol) of Nickel content 55.3 %, d = 4 mm, no. = 9 wires, pre strain = 5.5 %, and the location of SMA wire is in the upper half thickness of the beam. The properties of SMA wire are:

$C_1 = h = 500\ MPa$ (hardening parameters)
$C_2 = T_o = 253.15\ k^o$(reference temperature)
$C_3 = R = 45\ MPa$ (elastic limit)
$C_4 = \beta = 7.5\ MPa.k^{-1}$(temperature scaling parameter)
$C_5 = \overline{\epsilon}_L\ (\mu = 0.33)$ (maximum transformation strain
$C_6 = E_m = 70(10)^3 MPa$ (martensitic module)
$C_7 = m =\ 0$ (load dependency parameter)
And $E = 47\ GPa\ ,\ \upsilon = 0.33$ [12]
And The modulus is 47 GPa [13].

The selected wire diameter is 4.00 mm. The wire location is in two rows as 5 plies over and 4 plies under to make eccentricity in the embedment.

SMA namely NiTi (Nitinol) alloy is chosen for many reasons as it is suitable and widely used for engineering applications. It can produce a large force even it had limited dimensions and weight. In addition to that the following advantages were reported:

1. Low cost.
2. Small danger (health point of view)
3. Ease in manufacturing and machining method.
4. It has greater recovery capacity - excellent corrosion resistance.
5. Compatibility with a cure temperature of the present host composite [11].

## 4 Results and Discussions

For achieving numerical results supporting the goals of this work, Ansys package software 15 is used. At the beginning, the beam in question is modelled and analyzed without Nitinol wires and then with nine wires to make a comparison between the two cases.

The beams are fixed at the root and loaded at the tip with the same load value for all models. Figures 2 to 8 shows the results obtained after executing the program.

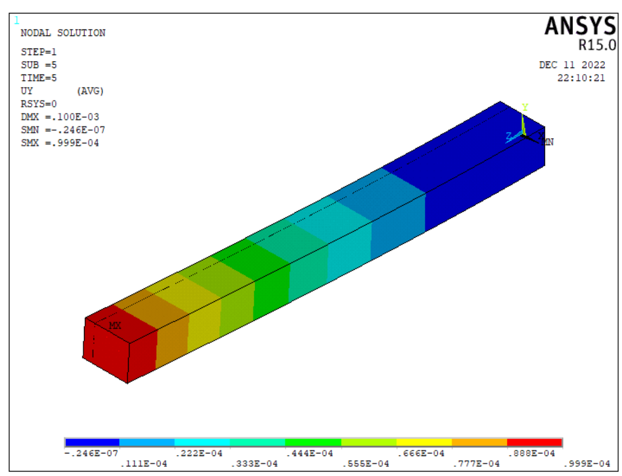


**Fig. 2** Transverse deflection in the beam without SMA wires

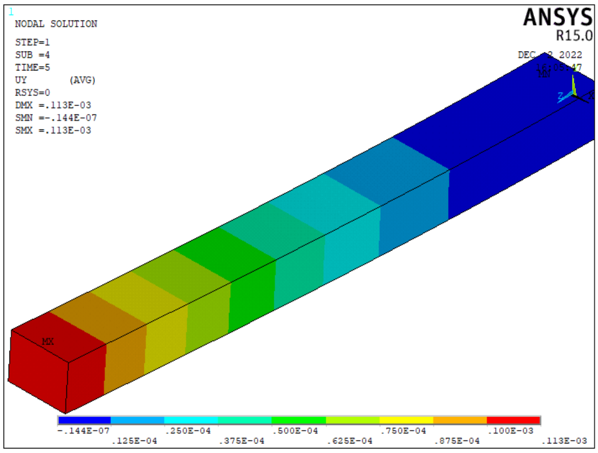


**Fig. 3** Transverse deflection in the beam with SMA implanted wires

Fig.2 shows a contour plot of transvers deflections induced in a solid beam without implanted wires while Fig.3 explains how the deflection will be in the same beam but with implanted SMA wires to present a clear comparison between the two cases. Both are at the same loading and the same conditions. Not only about un effectiveness, rather there is an enhancement on the strength of the beam after implanting the wires as the deflection in y direction (maximums) are reduced from $0.113\times10^{-3}$ to $0.100\times10^{-3}$

This is verified clearly with Fig. 4 shows the transverse deflection of the beam without and with wires along the beam (i.e. along the centerline of the neutral plane) measured at the 4 mm depth from upper surface (where the first raw of wires supposed to be implanted after then).

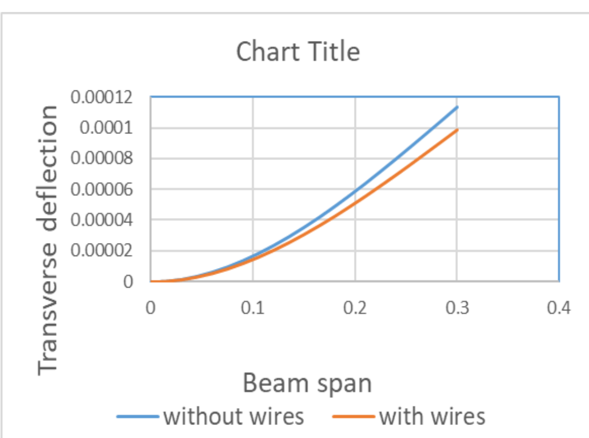


**Fig. 4** Transverse deflection along the beam with and without SMA implanted wires

The deflections measured is obviously still greater than that of the same beam of implanted wires. Focusing on these two graphs, the curves presents as if the implanting wires making the beam stiffer than that of without wires.

Concerning the stresses, Fig. 5 and Fig. 6, the stress distribution in both beams without and with wires implanted are almost identical. The stresses are concentrated at the tip of the beams namely at the place where the point load are applied. The wires implanted have no effect the distribution of stresses.

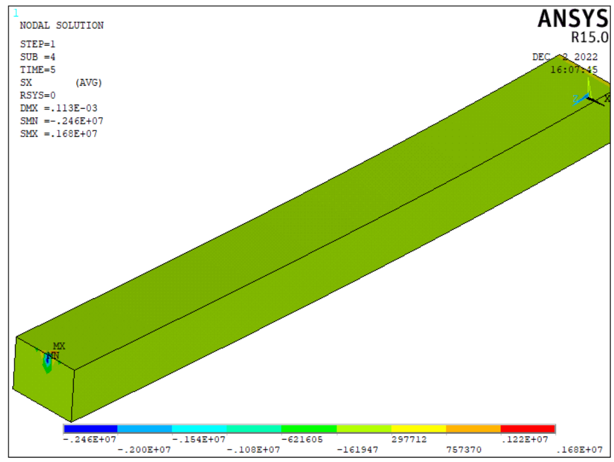


**Fig. 5** Contour plots of axial stress in the beam without wires.

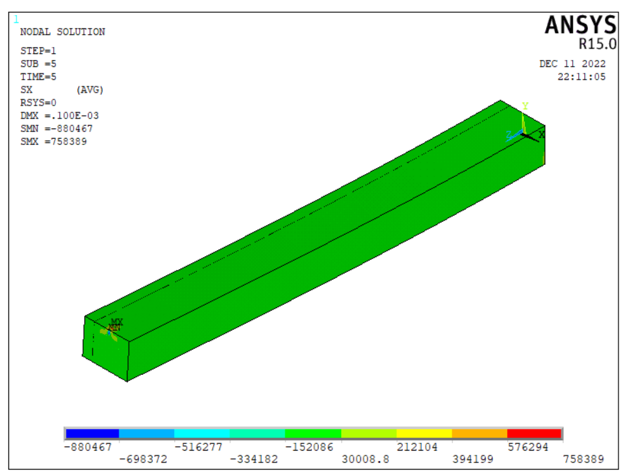


**Fig. 6** Contour plots of axial stress in the beam with implanted SMA wires.

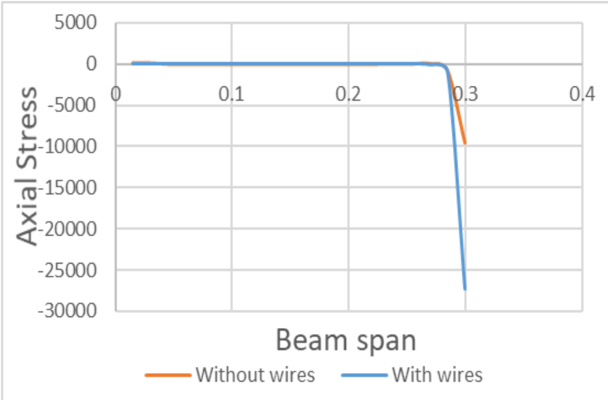


**Fig. 7** Axial stress along the beam with and without SMA implanted wires

Fig. 7 proves that most clearly, axial stress along the beam is clearly the same as for the beam with wires as for that without wires except at the tip of the beam where the stresses obviously rise in the case when wires are planted in the beam.

Even for VonMises stress as in the Fig. 8, Although there are increasing in the stresses values at the root of beam in the case of planted wires, however, the effect is still moderate. In addition, the stresses at the tip are somehow analogy and become decrease somehow than of beam with no wires implanted.

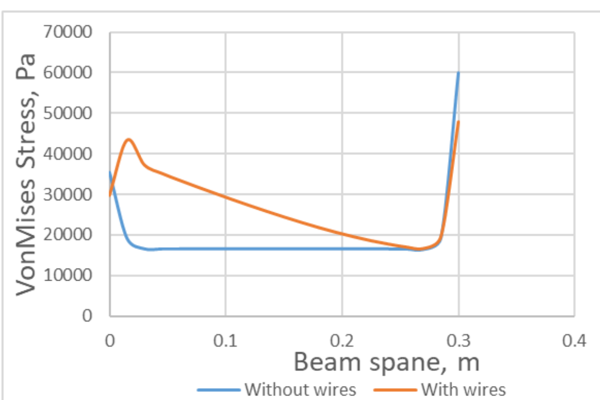


**Fig. 8** VonMises stress along the beam with and without wires

## 5 Conclusions

In order to achieve a smart effective mechanical element, sensors and/or actuators should be embedded within these elements during manufacturing process. These elements themselves should be made of composite materials. The process could be done without any degrading the strength of the elements. If so, the benefits are: quality enhancement, advance failure warning, reduced insight maintenance and design enhancement.

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