

Preliminary investigation of fabrication composite structures by using shape memory alloys

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Abstract. The paper shows method of smart forming composite structures and fundamentals of propose fabrication technology. The presented method is based on innovative 3D printing technics with SMA (Shape Memory Alloy) fibres application. The SMA fibres layout cause an eccentric axial load after thermal activation. The result of this process is composite structures deflection in a predictable direction. The technology demonstrator sample was fabricated as well as numerical simulations were performed in aim of proof of concept. The identification process was developed to determine the layout of SMA fibres. The simulations were performed in MATLAB and ANSYS environment, where the genetic algorithm was used to identify geometrical parameters. The MAC (Modal Assurance Criterion) criterion was used to compare nodal solution with the predefined shape pattern. The simulation results shows possibilities of forming composite structures on the example of deflected beam.

1. Introduction

Shape memory alloys are a group of material, which are characterized by the ability to undergo a large deformation about 8% to 10% without permanent deformation effect [1-2]. If recovering to initial shape is self-contained that effect is called superelasticity or pseudoelasticity. If the above mentioned recovery is a result of heating to the specified temperature, the shape memory effect is observed then. These alloys are classified as smart materials and are frequently used to fabricate smart composite structures [3-8].

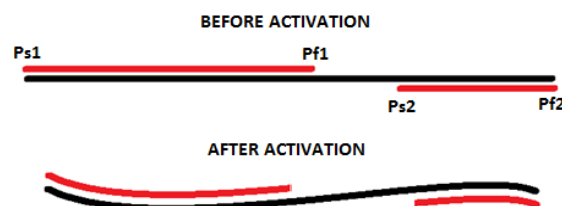


Figure 1. Example of SMA fibre fixing and expected beam shape after activation.

Proposed method of smart fabrication of composite structures is based on thermal actuation of SMA fibers. After activation SMA fibers are contracted and induce force which deforms structure in appropriate manner (Figure 1). Obtaining a predefined shape depends on many factors. The main assumption of this method is reducing costs and accelerating the manufacturing process of composite structures. In this aim SMA fibers layout was applied by using 3D printing method. The Figures 2 and 3 present example of 3D printed composite structure before and after activation.



Figure 2. Sample actuator made by 3D printing before activation.



Figure 3. Sample actuator made by 3D printing after activation.

2. Theoretical background

A simplified problem of composite structures deflection is a blending of simple beam. Description of the simple beam bending phenomena can be find for example in literature [9]. The main assumption which allow to analyze this task is an eccentric axial load that not act through the centroid of the beam cross section. An example is shown in Figure 4, where the cantilever beam $P_p - P_k$ is subjected to a tensile load P acting at distance D from the X axis.

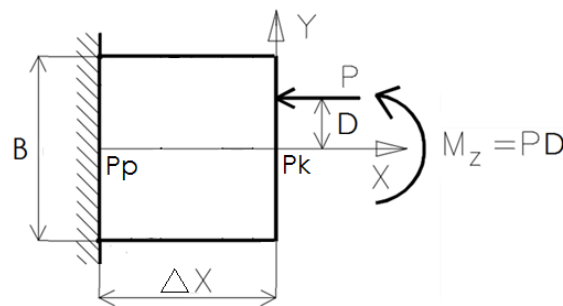


Figure 4. Simplified model of an eccentric load beam.

The eccentric force P is statically equivalent to an axial force P acting along the x axis and a bending moment M_b acting about the perpendicular axis.

$$M_b = P \times D \quad (1)$$

where:

- M_b – bending moment
- P – eccentric tensile force
- D – distance from the neutral axis

According to method of superposition the slope or deflection at any point on the beam is equal to the resultant of the slopes or deflections at that point caused by each of the load acting separately. The maximum deflection of the cantilever beam is equal:

$$\delta_{Pf} = \frac{M_b \cdot \Delta x^2}{2E \cdot I_z} \quad (2)$$

where:

- δ_{Pf} – beam deflection in the P_f point
- Δx – distance from point P_s to point P_f
- E – Young's modulus
- I_z – moment of inertia of plane area

3. Numerical simulation

The structure model has been simplified to a one-dimensional beam with a fixed defined cross-section. The beam was divided into 100 finite elements of the size of 1 mm each. The finite element type used in the analysis was BEAM188 and is suitable for analyzing slender and medium thick beam structures. This element is based on Timoshenko's beam theory, which includes shear effects.

One of the main simplifications in numerical simulations was the replacement of the SMA material model with a model which assuming adequate contraction to the SMA fiber according to the temperature. This dependency was made by applying negative thermal expansion coefficient of SMA fiber model.

The major aim of numerical simulation was identification of geometrical parameters of composite structure. These parameters are related with position of SMA fibers and their length. The developed identification process was based on genetic algorithms. The fitness function compared simulation results of particular iteration. The MAC (Modal Assurance Criterion) was used to relate degree of consistency between reference pattern shape and actual nodal solution [10].

$$MAC(sp, ns) = \frac{|\{\varphi_{sp}\}^T \{\varphi_{ns}\}|^2}{(\{\varphi_{sp}\}^T \{\varphi_{sp}\})(\{\varphi_{ns}\}^T \{\varphi_{ns}\})}, \quad (3)$$

where:

MAC – Modal Assurance Criterion

φ_{sp} – vector of shape pattern nodes

φ_{ns} – vector of actual nodal solution

The ANSYS solver was used to calculate parametric finite element model and transfer results in matrix form to a specify file. The MATLAB solver read results from the file and run genetic algorithm optimization process to identify composite structures geometrical parameters. The flowchart of this process is shown in Figure 5.

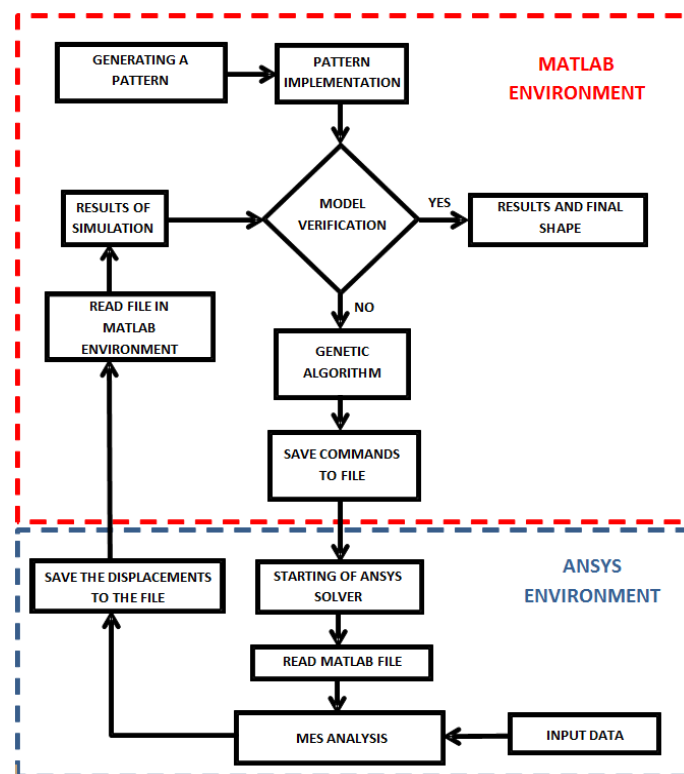


Figure 5. Flowchart of the identification process.

4. Result of simulations

The simulations were performed for three different pattern shapes. For each of them are presented fitness function values and shape changes dependent on iteration numbers.

The simulation for “sinus” pattern shape

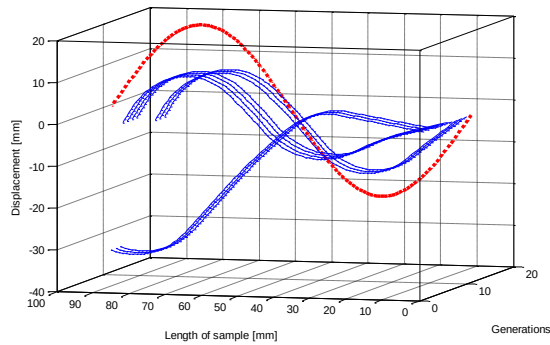


Figure 6. Shape changes depend on the iterations numbers.

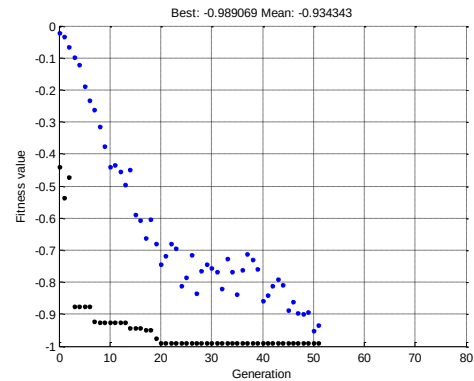


Figure 7. Average and maximum values of the fitness function for each generation.

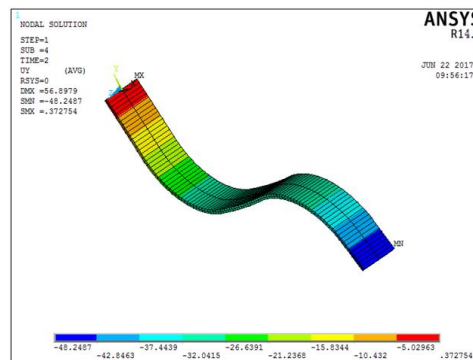


Figure 8. Node's displacements of final iteration.

The simulation for “U” pattern shape

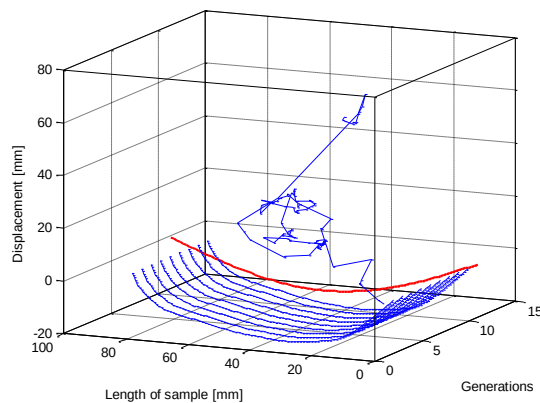


Figure 9. Shape changes depend on the iterations numbers.

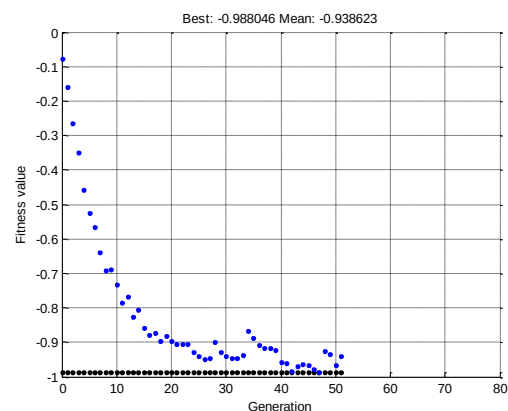


Figure 10. Average and maximum values of the fitness function for each generation.

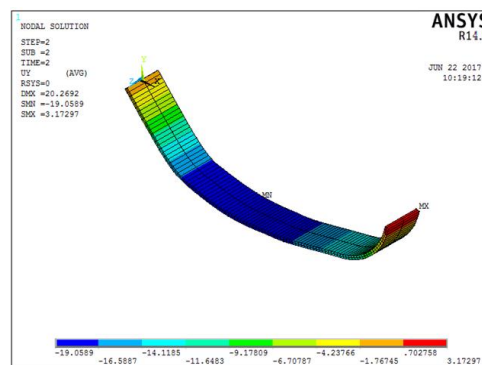


Figure 11. Node's displacements of final iteration.

The simulation for “trapezium” pattern shape

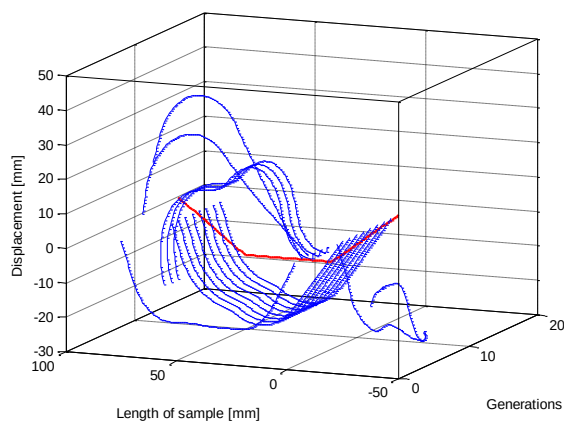


Figure 12. Shape changes depend on the iterations numbers.

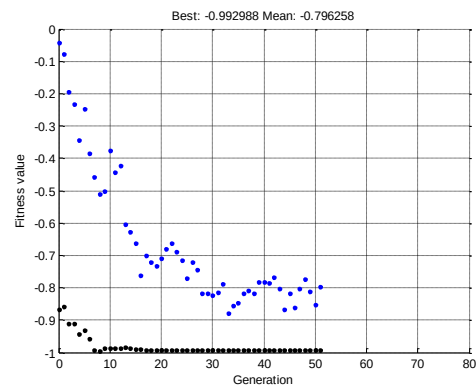


Figure 13. Average and maximum values of the fitness function for each generation.

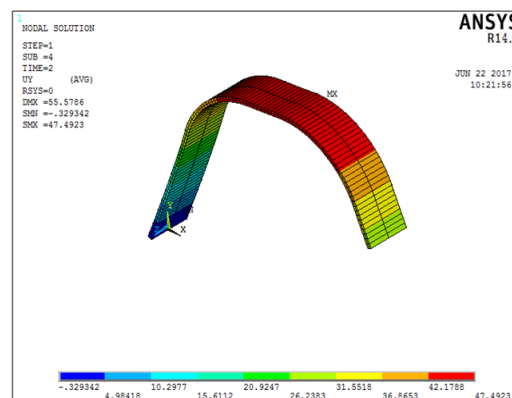


Figure 14. Node's displacements of final iteration.

The summary of simulation results is presented in Table 1. All simulations didn't exceeds 52 generation of genetic algorithm and had similar fitness function values.

Table 1. The summary of simulation results.

	Fitness Value	Number of generation	Point $Ps1$	Point $Pf1$	Point $Ps2$	Point $Ps2$
Shape pattern “sinus”	0,989	52	17	44	63	93
Shape pattern “U”	0,988	52	78	100	28	54
Shape pattern “trapezium”	0,993	52	33	56	66	90

5. Conclusions

The presented in this paper method of smart fabrication of composite structures requires further research works. There are several main aspects which could improve the proposed technology. One of them is obtaining more accurate shape from shape pattern by using more SMA fibers. This is related to increasing the number of variables in the identification process, which will affect the timing of the individual simulations. It is also important to check the possibility of forming spatial shapes using appropriately developed discrete models.

Another possibility for the development of research is to perform experimental research to verify the numerical models and to improve the production technology of such structures. It will be a great challenge to accurately positioning of SMA fibers relative to the neutral axis in the bending beam or shell. This parameter has significantly influence on degree of beam deflection. The solution to this problem can be a special 3D printer construction with double head – first for polymer matrix and second for SMA fiber application.

6. References

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Acknowledgments

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