Composite Materials Inspired by Nature

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Abstract

Nature provides us with interesting models for structures with a wide range of use. Construction of composite materials is based on nature. We refer to composite materials based on auxetic materials and shape memory alloys.

Fish, for example, is an interesting source of inspiration for architecturing smart composite properties. Fish exemplifies the use of flexible materials to generate force during the movement, and the structure and form suggests the use of fins deformation to generate propulsion.

Keywords: *composite materials, auxetic materials.*
ACM/AMS Classification: 68U99

1. Introduction

The fish represents a source of inspiration for architecturing new composite materials with smart properties. The humans are studying the interesting properties of fish in order to adapt and apply them in engineering materials. We refer to the bilaminar fish bone structure that allows muscle active control of the curvature and respectively, to the role of flexibility for the propelling body. The following paper presents an analogy between intelligent systems and biological systems in the belief that intelligent systems can be thought as biological systems adapt their functionality in a smart way.

2. Composite Materials

An interesting analogy between smart materials systems and biological systems has been developed by Jain and Sirkis (1994): *The technologic purpose of intelligent structures is to reproduce biological functions. These functions describe the nervous system made by a network of sensors to monitor the condition of the structure, the motor system to ensure an appropriate (optimum) response, the immune system's ability to provide healing and neural system to ensure learning and decision to act.*

Actuators and sensors characteristics were explained thus by the same authors: *The sensors have the feedback ability to transmit thermal, electrical* *and magnetic signals to the motor system, needed in the activity to response to change thermomechanical characteristics of the structure.*

The fish is an elegant solution to the macroscale water movement problem. The fish strikes through the diversity of body shapes, fin position and their size (Lauder et al. 2011). Shaped structure of the fin rays is complex, having different material properties. The average value of the modulus of elasticity is 1.34 GPa, but may be varied between 0.24 and 3.7 GPa for the different structures of the rays. Distal region is less rigid and elastic modules vary between 0.11 and 0.67 GPa. These data are similar to those of human tendons (modulus of elasticity of about 0.5 GPa). The propulsion analysis using flexible sheets allows the investigation of the effect of change in bending stiffness variations in swimming speed. The fusiform shape and structure of fish scales on the body and the mucus which covers their body helps them swim.

Lateral lines consisting of sensorial papillae have a role in the perception of water currents. The body is supported by fish skeleton that is dressed of muscles - muscles of the head, trunk muscles and fin muscles, helping them to move. Pectoral and abdominal fins in pairs and serve to helm, the dorsal, anal and tail are unpaired and serve to maintain balance.

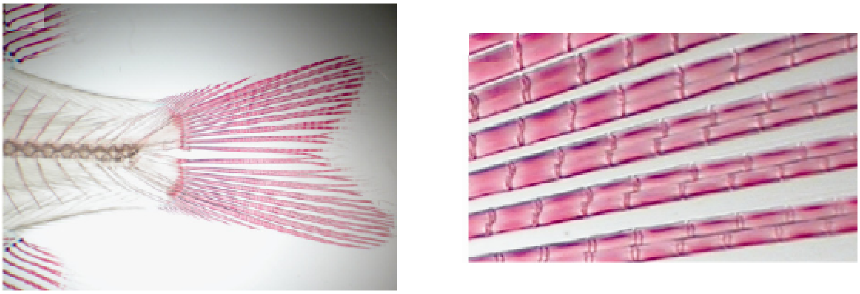


Fig. 1. (left) Caudal fin of a Lepomis fish; (right) Every fin ray is composed of joined bone segments and between rays we can see a thin membrane (Lauder et al. 2011).

In some species the pectoral fins are thin as filaments and long, in other species the caudal fin can be large compared to the rest of the body, as a veil of different types, and in other species have been developed an oversize dorsal and anal fins. The main role in fish moving is the tail. The tail hits the water pushing the body forward. The caudal fin of a Lepomis fish is shown in Fig. 1 (Lauder et al. 2011).

Fig.2 is a diagram of the caudal fin fish in side view and a rear view of across the two blades. The razal blade consists of two half moon curved segments coating type. In the figure we can see the razal blade in section and the two half moon curved segments composed of fine bones connected by fiber. Fish locomotion has been studied from mathematical point of view by a number of researchers. Biometric robot fish models have been developed, powered by actuators composed of different composites. Shape memory alloys can be adapted to substitute muscles. The properties of these alloys provide a large potential in architecturing ambulatory controllers.

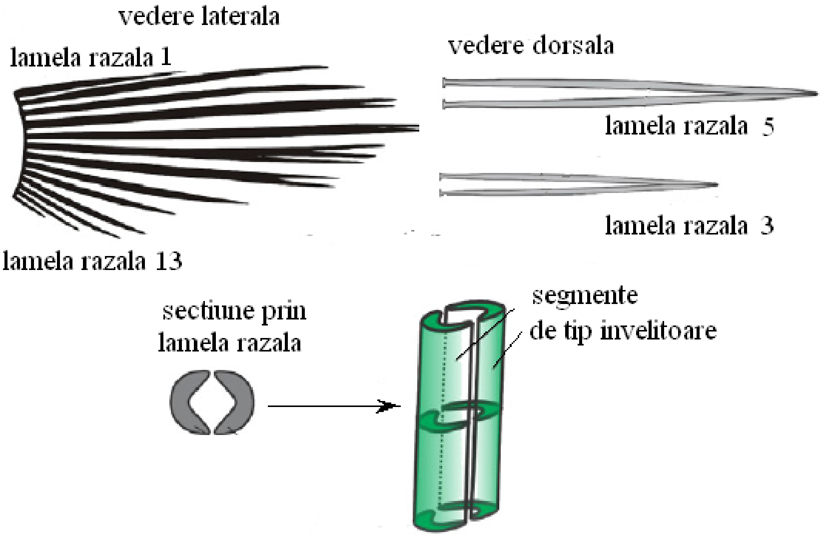


Fig. 2. Radius blades of the fin fish.

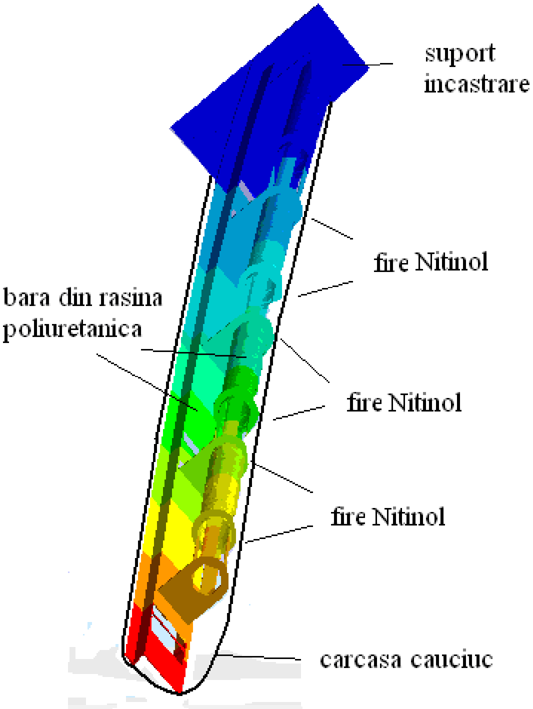


Fig. 3 Razal blade structure.

Using an outpatients controller for ripple made from a flexible element to model the razal blade (prof. P.P.Delsanto, PhD.A.Gliozzi, PhD. V.Chiroiu and PhD.M.Poienariu) we evaluated the ability of nitinol wires to control axial undulations. The NiTi wires have a diameter of about 50m and can generate tensional load up to 30 grams. The arrangement of wires is activated by a mechanism of generating wave motion by sequentially generated flexions. This way you can get specific wave-like movements for slow or fast swimming. In the curling system, flex type signals are sequentially sent to the NiTi wires.

Fig. 3 shows the schematic structure of the radial blade. It is composed of a polyurethane resin bar that supports an arrangement of the 6 nitinol wires disposed as a circle. The bar and the wires can be inserted into a rubber housing.

The geometry and material parameters are shown in Tables 1 and 2. Indices s and f refer to the words "start" and "finish" for temperature, and "0" was designated for "stress-free".

Table 1. Material parameters and the geometry of polyurethanic resin bar.

Parameter	Symbol	Value	Unit
length	L	30	mm
width	l	5	mm
thickness	d	0,5	mm
density	ρ	30	Kg/m^3
Lam$\acute{e}$ elastic moduls	λ μ	50,01 28,21	GPa GPa
linear coefficient of thermal expansion	α	$1,2 \times 10^{-5}$	$l/^\circ$ C

Table 2. Material parameters for NiTi wires (after Ditman, White i Bergman 1991).

Parameter	Symbol	Value	Unit
wire diameter	d_{NiTi}	0,05	mm
wire length	l_{NiTi}	15,7	mm
loop diameter	d_b	5	mm
density	ρ_a	$6,45 \times 10^3$	Kg/m^3
Lam$\acute{e}$ elastic moduls	λ^A; λ^M μ^A; μ^M	28,26; 6,3 18,85; 4,19	GPa GPa
linear coefficient of thermal expansion	α^A; α^M	$12,5 \times 10^{-6}$	$l/^\circ$ C
thermal conductivity	k^A k^M	18 8,5	W/m° C
slope voltage - temperature	C^A C^M	13,5 13,5	$MPa/^\circ$ C
transformation temperature	A_{0s}; A_{0f} M_{0s}; M_{0f}	57; 35 21; -12	$^\circ$ C GPa
thermal capacity	C_v	$5,44 \times 10^6$	$Jm^{-3}\,^\circ$ C
electrical resistivity	ρ_e	$0,5 \times 10^6$	Ωm

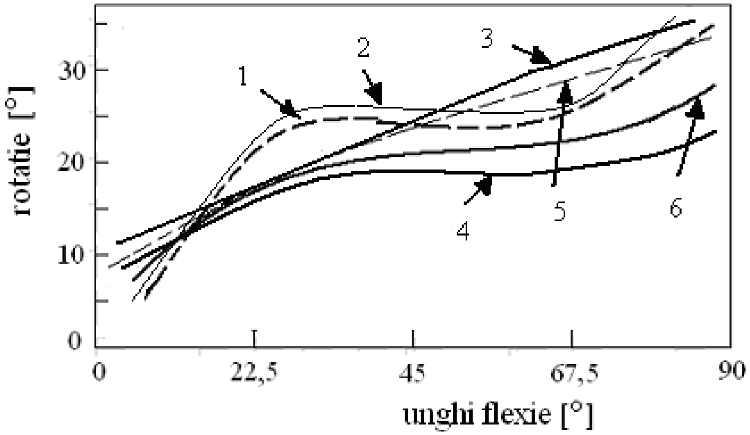
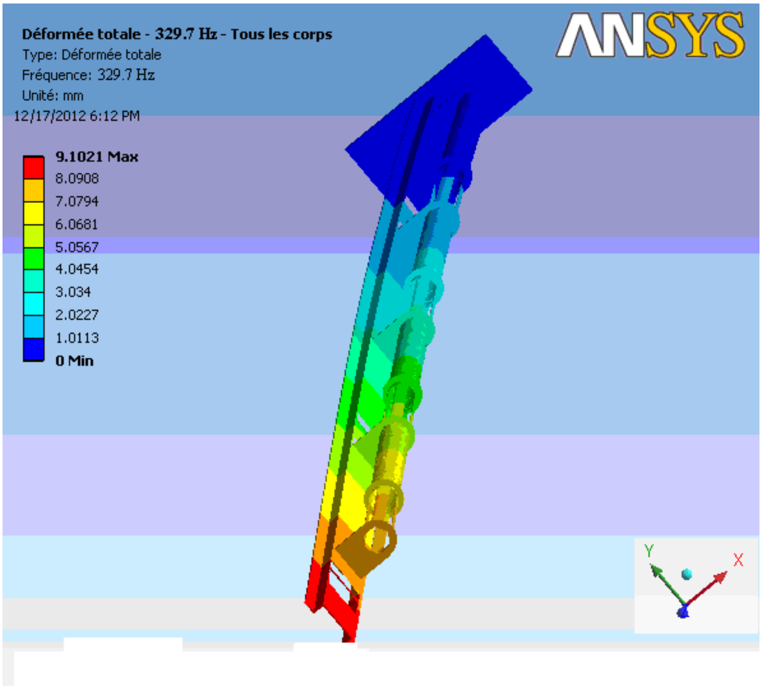


Fig. 4 A sequence consisting of 6 turns depending on the angle of flexion.

Table 3. First own frequencies.

Vibration mode	Frequency [Hz] FEM	Frequency [Hz] Experimental
1	329,7	333
2	2066,2	2187
3	5785,5	6003
4	11337,2	11434
5	18741,3	18229
6	27996,2	–
7	54902,3	–



Déformée totale - 329.7 Hz - Tous les corps
Type: Déformée totale
Fréquence: 329.7 Hz
Unité: mm
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Fig. 5 Radius blade deformation for the first own frequency 329,7 Hz.

A modal analysis was performed with the determination of their frequencies and deformations, both theoretically and experimentally. Structural modeling of the radius blade model was performed using finite elements so that it can be used a FEM type commercial program.

Modal analysis was conducted for the requested flex generated sequentially structure and were determined values and own vectors in the case of a quick swim. The request method it is shown in Fig.4. Flexion is expressed by a rotation [°] depending on the angle of flexion [°]. A sequence consists of 6 turns usually applied after the 1-2-3-4-5-6 rule (one rotation every 10 seconds). If the rule changes and rotation applies the opposite way, ie 6-5-4-3-2-1, then note the sequence bar above. Maximum speed of advance is 0.2 m / s.

Table 3 shows their frequencies for the first seven modes of vibration caused by both FEM and the experimental. There is a maximum difference between the theoretical and experimental values of up to 7%. We put these differences on the ANSYS program which can not take into consideration the actual nonlinearities which the shape memory material introduces the structure. Vibration modes corresponding to the first own frequency are shown in Fig. 5-11.

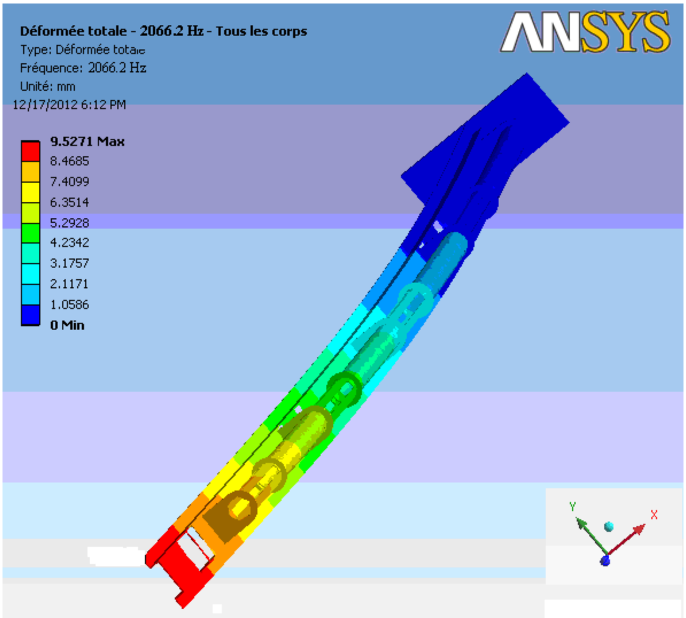

Fig. 6 Radius blade deformation for the second own frequency 2066,2 Hz.

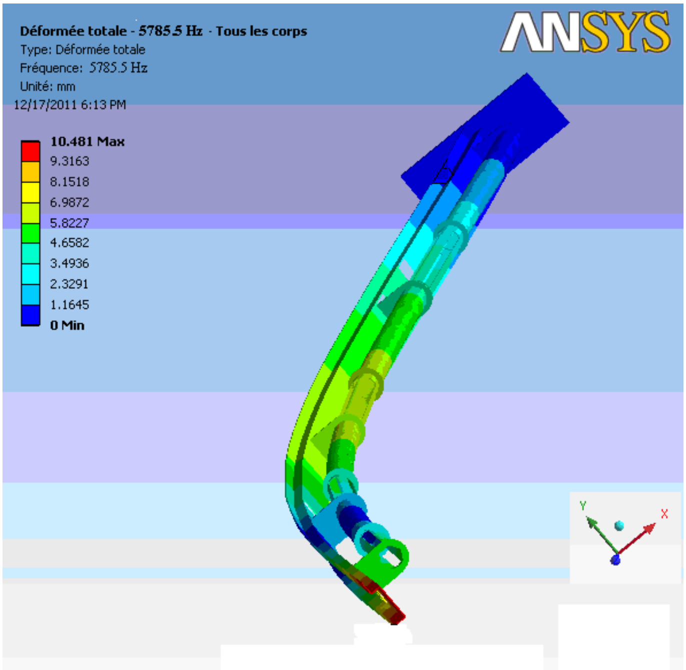

Fig. 7 Radius blade deformation for frequency 5785,5 Hz.

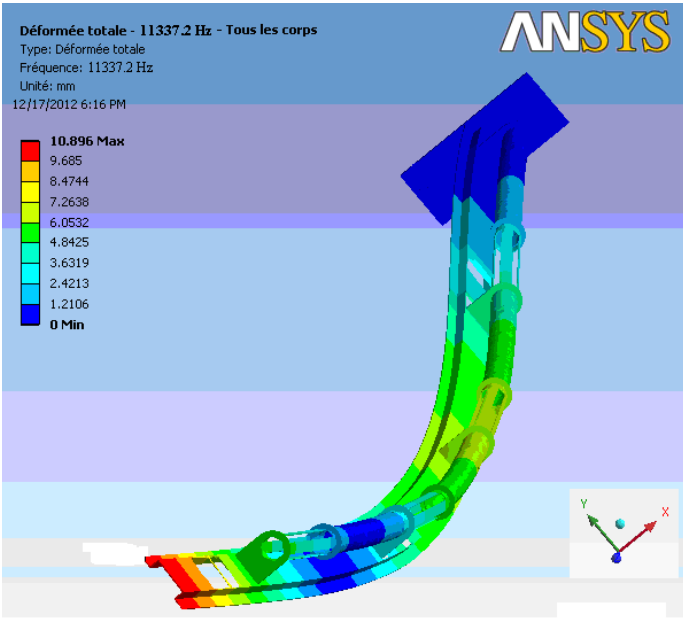

Fig. 8 Radius blade deformation for the frequency 11337,2 Hz.

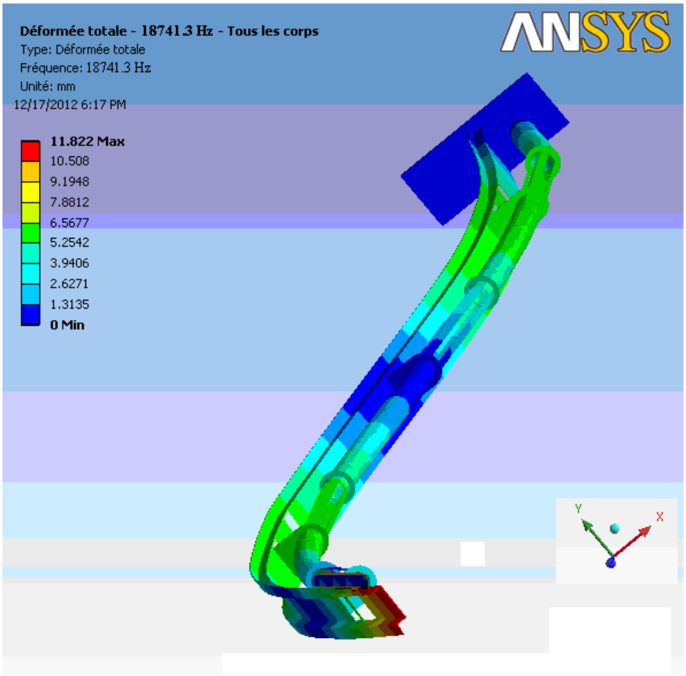

Fig. 9 Radius blade deformation for the frequency 18741,3 Hz.

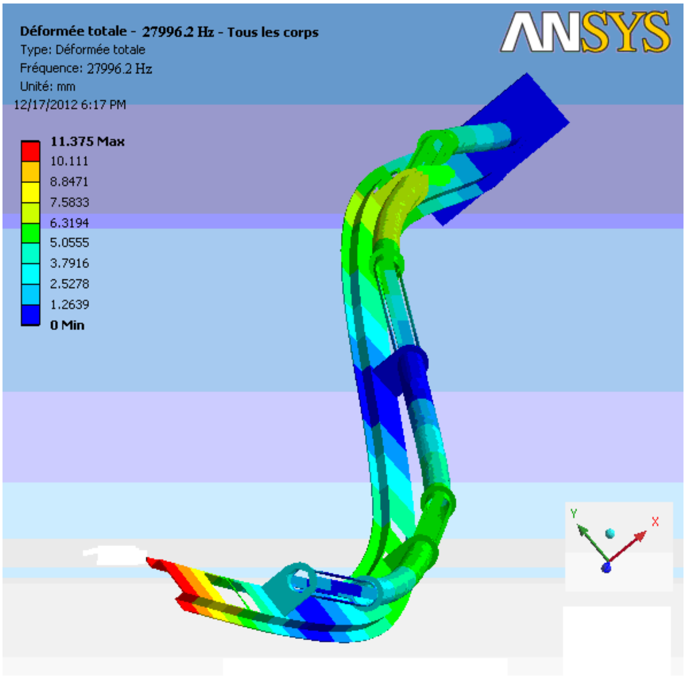

Fig. 10 Radius blade deformation for the frequency 27996,2 Hz.

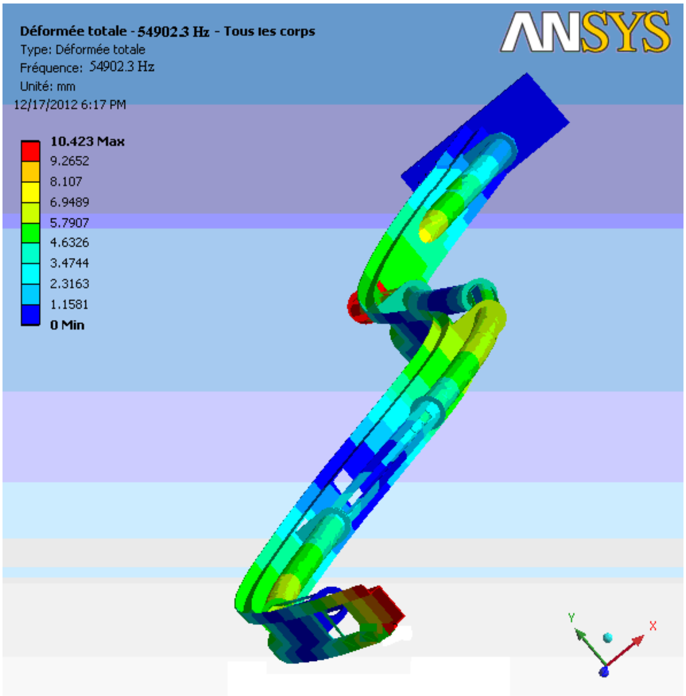

Fig. 11 Radius blade deformation for the frequency 54902,3 Hz.

Radius blade deformations emphasize the undulatory movements of the structure by activating arrangement NiTi wires by generating sequential flexion mechanism.

It is known that razal blades vary considerably from the point of view of the curvature. In our study we considered a slide in the middle of the tail. The middle tail blades have a curvature about 0.3 mm for a displacement of 0.2 mm, but the heads of the blades can travel around 5-13 mm. Also, a force applied to the blade 30mN may cause curvature of 0.1 mm to 0.4 mm, and displacements of maximum 9 mm to 12 mm.

The Maximum displacements corresponding to their own frequencies obtained by FEM are shown in Table 4. The values of these movements are consistent with the results obtained Lauder et al. (2011), for a Lepomis fish.

Table 4. First own frequencies.

Vibration mode	Maximum displacements [mm] using FEM
1	9,1021
2	9,5271
3	10,481
4	10,896
5	11,892
6	11,375
7	10,423

3. Conclusions

Construction of composite materials is based on nature, which provides interesting models for structures with a wide range of use. We refer to smart composite materials based on auxetic materials and shape memory alloys. Fish are an interesting source of inspiration for us architecturing smart composite properties.

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