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Review Article

SMART MATERIALS AS MODERN ENGINEERING SUBSTANCES

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ABSTRACT
The article presents the type and use of intelligent materials in aviation and medicine. Their basic features and properties have been discussed. Moreover, the authors quote examples of different uses of intelligent materials, both the existing ones and those in design and development stages. Their use is claimed to be increasing the efficiency and reliability of processes and equipment as well as facilitates the development of new mechanisms.

Keywords*:* smart materials, piezo-ceramics, shape memory alloys, aviation, medicine.

INTRODUCTION

The development of civilization is inseparably concerned with the use of materials, hence the names of époques such as The Stone Age, The Bronze Age and the Iron Age. The advancement of science is related to the advancement in construction materials. Researchers keep developing new materials. In 1980's a group of materials called intelligent materials appeared [1]. Certain types of them had been known and used before, yet the discovery of their of specific features generated new interest in them. 1990's and the beginning of the new millennium brought a lot of interest and turbulent advancement in their research. Different names of such materials can be encountered in literature: intelligent materials, smart materials, adaptive materials, or even multifunctional materials.

Presently, so called smart solutions are more and more broadly used. Usually, it is state-of-art electronic or mechatronic systems based on the so called artificial intelligence that are be hidden behind this term. Smart materials are less often associated with intelligent solutions [1, 2].

In spite of rapid development of such materials, no single universal definition of intelligent materials has been developed. Intelligent material is most frequently defined as the material which is capable of reacting to external stimuli by making significant changes in their properties in order to provide a desired and efficient reply to the stimulus [1] (Fig. 1). With the use of mechatronical terminology – intelligent material is the one that should play the role of the sensor, processor and initiating device – an updater that translates the obtained effect. At the same time, the properties should have the features of feed back and feed forward system. It is vital to obtain the effect in real time or in approximate to real time [1]. Figure 1 presents a general idea of smart materials. In these materials such external factors as temperature, humidity, exerted pressure, electric or magnetic field change one or more physical properties of the material. Depending on the type of material and the stimulus, the following properties may change: shape, size, internal structure,

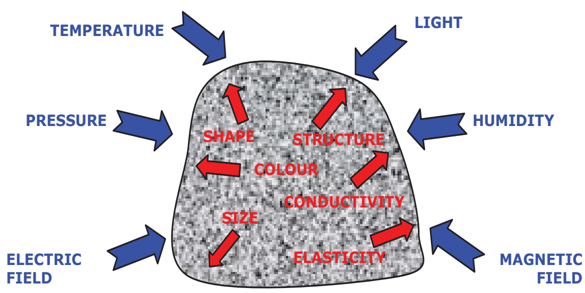

Fig. 1. The general rule of action intelligent materials

colour, electric, magnetic and thermal conductivity as well as resilience [1, 2] (Fig. 2).

Smart type materials are increasingly frequently used as propelling systems, steering elements and sensors. These elements are used to change the properties of dynamic constructions, adapt the shape to the needs and to collect information about the construction.

The branches of technology where such materials are used include medicine, aviation, sport and robotics. The article describes a few uses of smart materials for different applications in medicine and aviation.

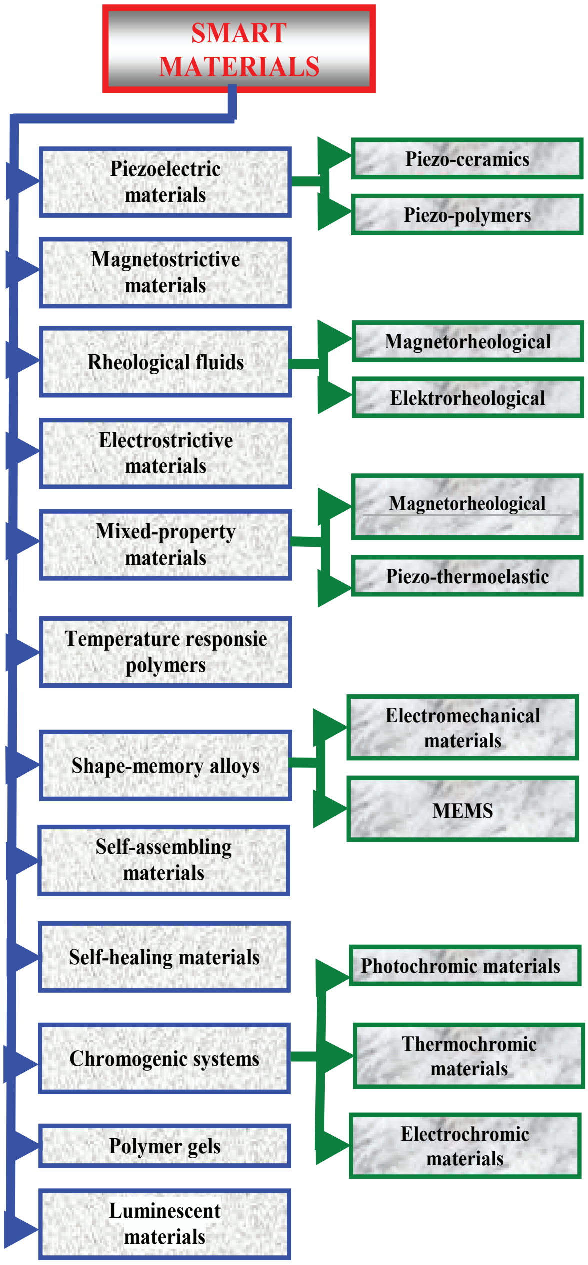

Fig. 2. Types of smart materials

SMART MATERIALS IN AVIATION

Limiting vibration in the tailplane

Modern planes, especially military constructions, reach large speeds and operate in high load factor conditions. In case of some constructions disturbed air stream flowing off the wing edges hits the tailplane causing dangerous vibrations (Fig. 3). The vibrations cause abrupt tailplane construction stability decrease, limit the time allowed in the air and increase failure rate.

Fig. 3. The plane with the "twin" tail

The system for deadening tailplane construction vibrations was ordered by US Air Force and developed by ACX company, in cooperation with Canadian and Australian government agencies [4].

The basic element that deadens vibrations are piezoelectric, formable performing elements. Other elements of the system include acceleration and deformation sensors that provide information for a digital signal processor (DSP).

The driver prepares signals, sent to executing elements in real time via high voltage amplifier that closes the driver circuit. The scheme of the system is presented in Fig. 4. The set belongs to the groups of active vibration reduction.

Piezoelectric performing elements located in the tailplane were designed and ordered for this purpose. The construction, its distribution, isolation of electric connections allow safe use of the system in military purposes, where normal way of providing high voltage required by uncovered piezoceramic materials is hazardous. The technology allows even placing the elements beneath the plane sheathing, dipped in the fuel. Another requirement that every plane element must meet is their weight and size. In

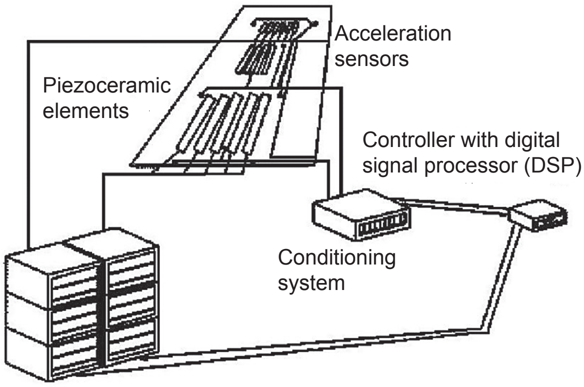

Fig. 4. Vibration Reduction Scheme of the tail of the aircraft

case of actuators, the limiting factor was weight of 10 kg for the tailplane.

With the use of Finite Element Method numerical optimisation of the actuators' thickness and distribution, in order to maximise primary controllability (bending) and secondary (turning) form of tailplane vibration. The conducted tests showed that these forms in experimental constructions are induced at 15 Hz and 45 Hz by the disturbance of air stream running off the wings. As a result of research, piezoelectric plates were located in one of three layers, 0.05 mm thick in the places of actuators on both sides of each tailplane.

The system of sensor acceleration and deformation was designed in such a way that ensures providing information to the feedback system. The data from sensors is used to compute the reply sent to the actuators.

The feedback control system with a double input and output was implemented with a digital computer operating in real time and sending the control impulses at the frequency of 5000 times per second.

Piezoelectric system of vibration damping was tested in two phases. The first stage concerned gathering data in the open (uncontrolled) system of feedback, when the signals from sensors were not sent to the actuators, but were collected for further analysis.

The analysis of signals allowed developing the rules and algorithms which should be followed in the closed system in order to minimise vibrations. The second phase concerned data implementation and testing it during flights. The tests proved over 50% reduction of strains in the core of tail structure.

Active plane manoeuvrability

To large extent plane manoeuvrability depends on the movement of the rear part of wing flaps. It is important that they are reliable and effective. In most planes they are hydraulically driven. The system uses centrally located hydraulic pumps. In order to maintain the flops' correct operations it is necessary that the collective hydraulic line connects each set of flaps. This complex system of pumps and lines is quite difficult and expensive to maintain. What is more its weight is quite significant. Different solutions that allow substituting hydraulic systems were examined. Ono of the possibilities was to use rods with shape-memory alloys (Fig. 5).

The wing flaps' construction is presented in Figure 6. The scheme of the system using rods made of smart materials are presented in Figure 7. The system with smart materials is much smaller and more efficient.

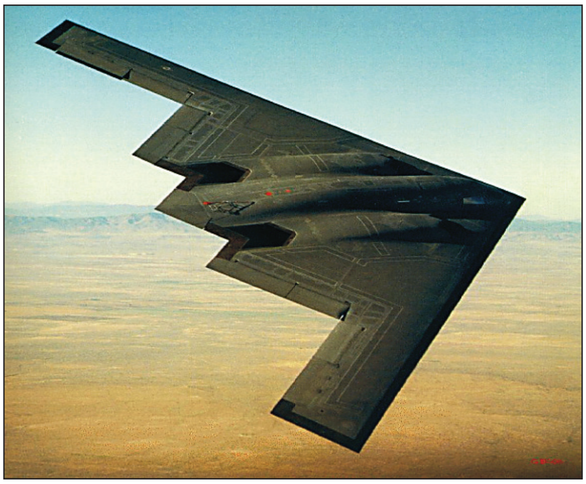

Fig. 5. The aircraft in which the wires used shape memory material

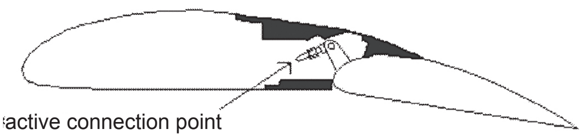

Fig. 6. Schematic of the wing flaps [7]

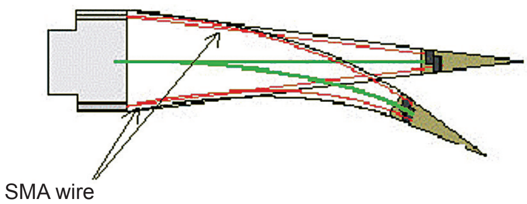

Fig. 7. Schematic of layout of wires comprising a shape memory material [7]

The rods were placed in the upper and lower part of the wing. When the flap falls down, the lower rod is heated, whereas when the flap is raise the upper part rod is heated (Fig. 7) [8].

The rod was shortened under the influence of the electric fields provided by the electric installation eliminates vast hydraulic pipe lines. Without hydraulic system the costs and time of reparations are significantly higher.

Plane constructed with smart materials

In NASA research centre in Virginia, USA scientists construct revolutionary planes with smart materials, which can adapt during the flight (Fig. 8). The planes built in the framework of Morphing project were designed as safe and quick aircrafts which, alike birds, can adapt their shapes to the conditions [5]. NASA is planning to build an unmanned combat aerial vehicle. It is planned to construct an aircraft reaching the speed of 0.5-0.9 mach with wingspan of c.a. 40 feet. The project anticipates the possibility to change the wing geometry index by 200%, the change of wing surface by 50% and the change of wing rotation by 50% and wing angle by 20 degrees. The weight of wing should not exceed the weight of a conventionally built element (Fig. 8) [7].

Additional requirements that the design is to meet is the possibility to modify air inlets into engines, in order to obtain an optimum air stream flow for various speeds and decrease the size of fuel containers after emptying them. Smart materials would also be used to construct "virtual rudders". They could „appear" when needed and „disappear" when they are no longer useful (Fig. 9). NASA mainly relies on piezoelectric materials and shape memory materials. Further plans concern the design of transportation and passenger aircrafts that can fly at the speed significantly exceeding the speed of sound. With smart materials scientists attempt to limit the so called sonic boom.

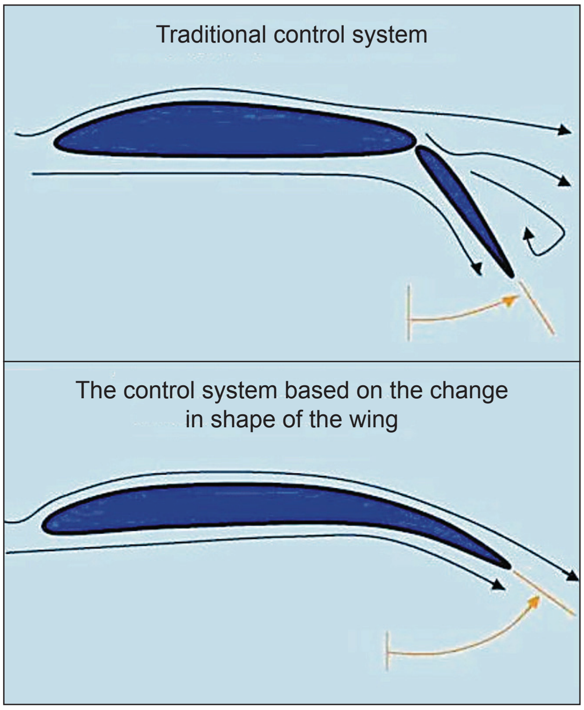

Fig. 8. Comparison of traditional wing and wing made of smart materials

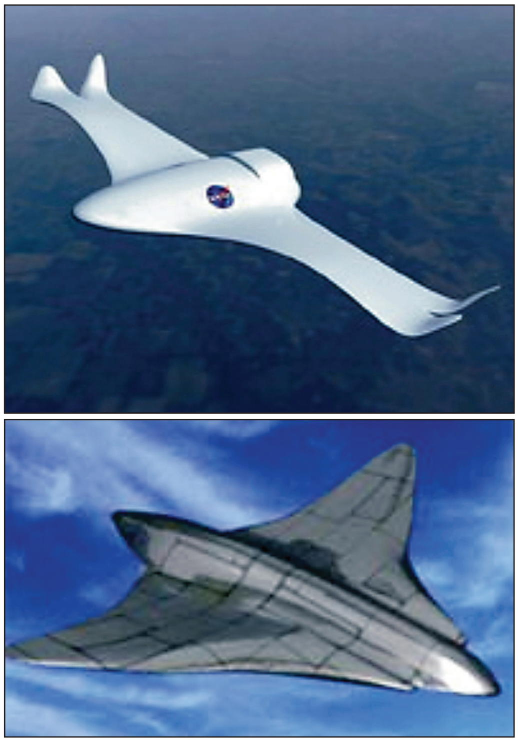

Fig. 9. Models of unmanned aircraft built by NASA with intelligent materials [5]

SMART MATERIALS IN MEDICINE

Staple for osteosynthesis

Staples for osteosynthesis with shape memory are used wherever osteosynthesis is conducted with Blount staples made of traditional implant metals. The advantage in Blount staples made of shape memory alloys over traditional materials concerns the possibility to obtain close and strong connection of the broken bones. This allows quick and controlled treatment. One example is the operation of axial correction of legs (X or O curve) that requires cutting off a wedge in the knee joint (Fig. 10). The use of two, three staples, which are heated with electric current, guarantees stable osteosynthesis [1, 3].

Another example of using the staples is the operation of foot in case of immobilised crurotalar joint (Fig. 11). The use of staples made of shape memory alloys ensures good clamp of resection surfaces. Following the resection and foot correction the staple, alike the traditional one, is adjusted to the bone and heated with two electrodes, until strong connection is obtained. In order t to stabilise the joint 2–3 staples are used.

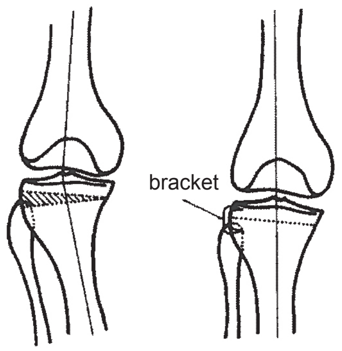

Fig. 10. The use of staples for osteosynthesis after knee surgery

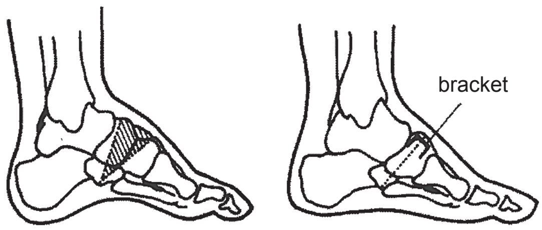

Fig. 11. The use of staples for osteosynthesis for ankle surgery

For clinical purposes staples with transformation temperatures ranging from 42 to 46 °C are used. Prior to delivering to clinics the staples are the subjected to deformations and heating in order to test their behaviour. The staples are delivered in special plastic bags and sterilised with γ radiation.

It is significant to know the strains in broken bones. For this purpose a special device was designed to measure the strength exerted by staples' arms during heating. Due to the construction of the device which does not allow shape changes, strains were induces with the increase of temperature. At 60 °C the strength of 1160 N is induced. Further heating up to 100 °C raises the strength to 2500 N. During the operation the staple is heated up to 55 °C. Its slow cooling down to body temperature causes the decrease of strength. At 37 °C both staples exert the power of 880 N, therefore, single staple exerts the power of 440 N. The value refers to a staples sized 3.5×4.5 mm = 15.75 mm^2. For larger staples with the cross section of 17.5 mm^2 analogical values of strain were obtained.

Staples for curing broken ribs

Another example of the use of shape memory metals in surgery, which makes the operation significantly easier, is the staples made of perforated metal sheets for treating broken ribs (Fig. 12). In subsequent pictures the state after tempering (*a*), deforming (*b*) is presented. In such a state the staple is placed onto a broken rib and heated (*c*). As a consequence, the staple return to the original shape and connects broken elements of the rib (*d*). One advantage of such an operation is not only simplifying the operation but also limiting the springiness of the connection.

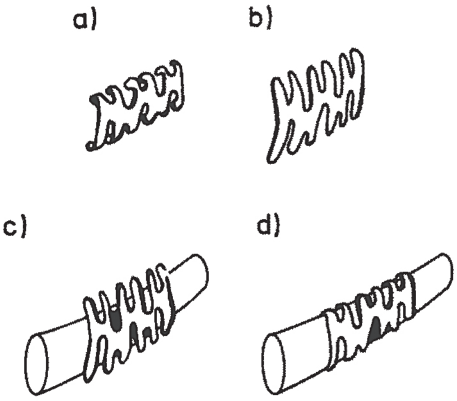

Fig. 12. The use of staples for the treatment of fractures of the ribs [1, 3]

Osteosynthesis plates

In extreme situations of broken bones osteosynthesis plates area used. The plates are attached to both sides of the broken bone with screws. This hastens the fracture treatment [1, 4] and balances the distribution of compressive strains onto the connection surface. In order to obtain even distribution of compressing strains plates with oblique holes or pitches for screws with ball-shaped heads. Osteosynthesis plates made of shape memory alloys have an advantage of tightening large cracks in fractures, what cannot be done with conventional plates. The plate in initial state is lengthened by stretching and attaching to the fracture. While being heated, it shrinks and eliminated the crack sized up to 5 mm. At the moment when both elements connect, the operator cuts of the heat inflow and the position is maintained. In case heat inflow is not cut off, harmful concentration of strains in the fracture from the side of the plate is observed.

Intramedullary rod

In order to treat closed spiral fractures, e.g. in thigh the rods are forced into the medullary cavity. A rod of larger diameter than the cylindrical hole is placed into the bone what stabilises the fracture. Along with numerous advantages, there is one disadvantage. It takes a lot of strength to force the rod into the bone. Removing the rods generates further problems, including leaving the rod as a permanent implant. Such inconveniences disappear when a tube made of NiTi alloy is used instead of the implant. The tube increases its diameter as a result of heating, and decreases when cooled down below the temperature of human body. The rule of using such a tube is presented in Figure 13. 10 mm tube (6), made of metal sheet, narrows down to 8.5 mm (1) and is placed into the hole in the broken bone (1). As a result, it increases its size up to 9.5 mm, what tightens the broken bone (5). After the end of treatment, the place is cooled down in with distilled water or physiological liquid to the temperature below M_s and tube shrinkage down to 9 mm (4). Finally, the tube can be removed without using strength [1, 3].

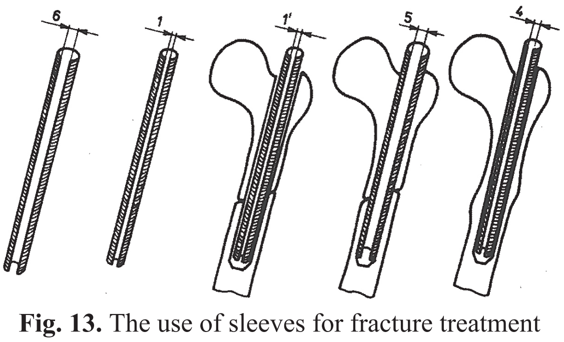

Fig. 13. The use of sleeves for fracture treatment

Blood clot filter

The purpose of this filter, which is implanted into vena cava, is to catch blood clots, caused by various injuries, which can migrate to heart. Filter of different shapes are made of NiTi wire sized 0.5 mm in diameter and 200 mm long. Tempered in icy water, the shaped filter is straightened (deformed) and inserted into the vessel with the use of a catheter. At body temperature a reverse process takes place and the wire return to its original shape – a filter-mesh sized 2 mm. This allows efficient capture of harardous clots. Scientists' experience with tests on dogs is encouraging enough to run clinical tests.

Dental braces

Dental braces are made of NiTi alloys. They are attached to teeth in order to correct the dental displacements (Fig. 14). Such material is replacing stainless steel wires that had been used before. NiTi wires in martensic state are flattened (30% deformation) as a result of their rolling. In this state of pseudo-resiliency the wires are characterised by high resilience.

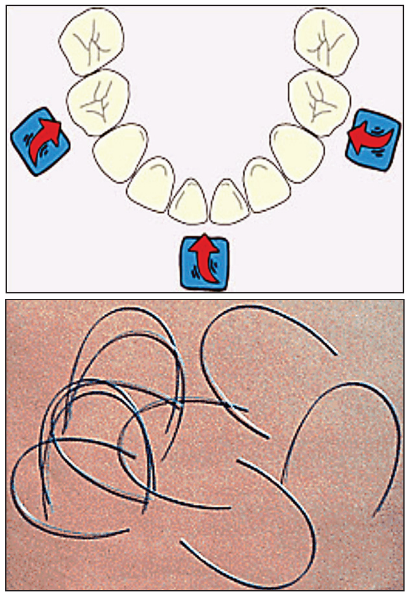

Fig. 14. The use of nitinol as orthodontic wire

Deformed by 90° they return to the original shape, unlike stainless steel wires, which remain curved at 55°. One important advantage of nickel titanium wire, in comparison to steel wires, is the value of Young's module that is 6 times lower, thus for the same bend significantly lower strengths are employed (Fig. 15). From clinical point of view, this means that nickel titanium wire exerts lower and more stable strength on the bite than it is in case of steel.

The use of NiTi wire in orthodontics (Fig. 16) has the following advantages:

- requires smaller bend curve,
- limits the time of operation,
- limits the time of treatment,
- limits tiresomeness for patients,
- lower number of visits at orthdent's,
- higher comfort for patients, due to lower values of extorted strengths onto the teeth.

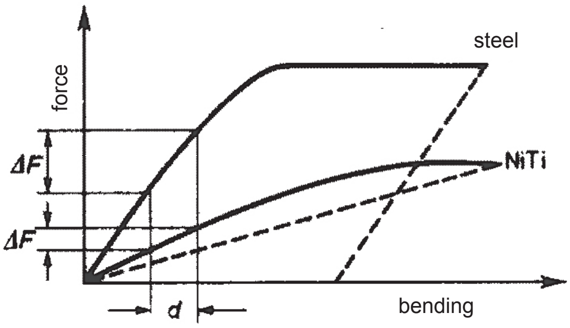

Fig. 15. Deformation forces for wires from NiTi and of austenitic stainless steel [1, 3]

Fig. 16. Dental braces of nitinol

CONCLUSIONS

Increasingly high competition and higher expectations from consumers limit the use of classical construction materials. Broader use of modern, smart materials is expected. Their use improves efficiency and reliability of devices and allows designing new equipment that had been impossible to construct before. The use of these materials is more and more evident in such industries as aviation and medicine.

With their property of dimming mechanical vibrations, smart materials are used to construct rudder or carrying surfaces, but also to produce elements subjected to variable loads in medicine. Due to their simplicity of use and low cost they should also be used in other branches of industry.

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