Applications of Shape Memory Alloys

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Abstract

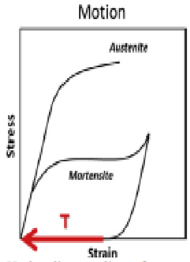
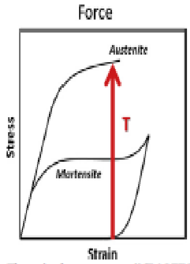
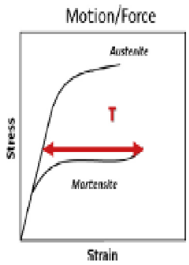
The paper focuses on the main applications of shape memory alloys. It can be divided into five main sections. The first section focuses on the general introduction of shape memory alloys and their applications. This section is followed by discussing biomedical applications. The robotic applications are discussed in the third section. The Automotive Applications are discussed in the fourth section. Finally, the fifth section reviews the aerospace applications.

KeyWords: Shape Memory Alloys, Biomedical Applications, Robotic Applications, Automotive Applications, Aerospace Applications.

1: Introduction

In 1932 smart alloy or shape memory alloy was first discovered by Arne Olander [1], while, Vernon was the first one described the term shape – memory in 1941 . However, the importance of shape memory alloys was not recognized until the shape memory effect was discovered by William Buehler and Frederick wang in 1962, when they described it in a nickel – titanium alloys (nitinol) [2]. Since then, shape memory alloys have been used for engineering and technical applications in numerous commercial fields; for examples, in automotive [3-5] , biomedical [6-9] , aerospace [10, 11], robotics [12-14], consumer products and industrial applications [15-17] and fashion [18]. In general, the SMAs applications can be divided into four groups depending on their key function of their unique properties, which are shape memory effect and superelasticity [15, 19, 20]. Table 1 Shows the types of shape memory applications [15]. This review focuses on applications of shape memory alloys particularly biomedical, robotic, automotive and aerospace applications.

Table 1 Shape memory applications categories [15]

Category	Description	Examples
Free recovery	The sole function of the memory element is to cause *motion* or *strain* on the applications Working principle: The memory element is stretched and then released (no load applied). It remains in stretched condition until heated above the transition temperature and shrink back to its original form, and subsequent cooling below the transition temperature does not cause any macroscopic shape change (e.g. OWSMA)	NiTi eyeglass frames (TiFlex™, TITANFlex®) and Simon IVC filter 
Constrained recovery	The memory element is prevented from changing shape and thereby generates a *stress* or *force* on the applications Working principle: The memory element is prevented from returning to its original form after being stretched and considerable force generated if heated above the transition temperature	Hydraulic couplings, fasteners and connectors: CryoFit™, Cryocon®, UniLok®, CryOlive®, CryoFlare®, CryoTact®, Permacouple®, Tinel Lock® and BetaFlex™ 
Actuator or work production (Force actuator, proportional control and two-way-effect with external reset force)	There is *motion* against a *stress* and thus work is being done by the memory element on the applications Most of applications fall in this category. Can be either OWSMA or TWSMA. Three types of actuators: Force actuator: The memory element exerts force over a considerable range of motion, and often for many cycles Proportional control: The memory element used only part of its selected portion of shape recovery to accurately position the mechanism, because the transformation occurs over a range of temperatures rather than at a single temperature Two-way-effect with external reset force: The memory element generates motion to overcome the opposing force, and thus do work. The memory element contracts upon heating to lift a load, and the load will stretch the heating element and reset the mechanism upon cooling (e.g. TWSMA)	Electrical actuators (VEASE™, SMArt Clamp™), thermal actuators (Memrysafe®, circuit breaker, window or louvre opener, valves), and heat engines 
Superelasticity	The applications are isothermal in nature and involve the storage of potential energy	Eyeglass frame, orthodontic archwire, Mammelok® breast hook, guidewires, anchors and underwire brassiere

2: Biomedical Applications

The materials used for vivo application which are touch with human tissue should have unique properties to meet this requirements, for example, these materials must have biological reliability – biological compatibility, free toxicity, perfect corrosion resistance, and accuracy of mechanical properties [21-23].

Since the discovery of shape memory effect in NiTi alloys in 1962, they proposed to use this shape memory alloy in biomedical applications [15, 19, 24]. Due to the unique properties of Ni-Ti shape memory alloy (SMA), shape memory effect (SME), shape effect (SE), and a very good corrosion resistance, Ni-Ti shape memory alloys are often used as prosthesis materials in the human body[25-27]. The application areas available with various size and shape, range from dental arch wire not directly in tough with blood flow in the human organism to stents used to stabilize damaged blood vessels as shown in figure 1 [15, 22-27].

Furthermore, shape memory alloys are used in medical devices in different areas such as orthopedics [22], neurology[22], cardiology and interventional radiology [21, 22]. In addition they are used in stents [21], endodontics [28], eyeglass frames [29], guide wires [30], aneurism treatments [31] and medical tweezers [32, 33], sutures [32, 33], anchors for attaching tendon to bone [32, 33], implants

[32, 33]. Figure 2 shows example of using shape memory alloy in catheter – based surgeries [34, 35]. NiTi shape memory alloy coiled spring can be used as a micro – muscle fiber as you can see in figure 3 [36, 37]. The researchers developed mechanical circulation using shape memory alloys fiber to assist patients with heart diseases as you can see in figure 4 [38].

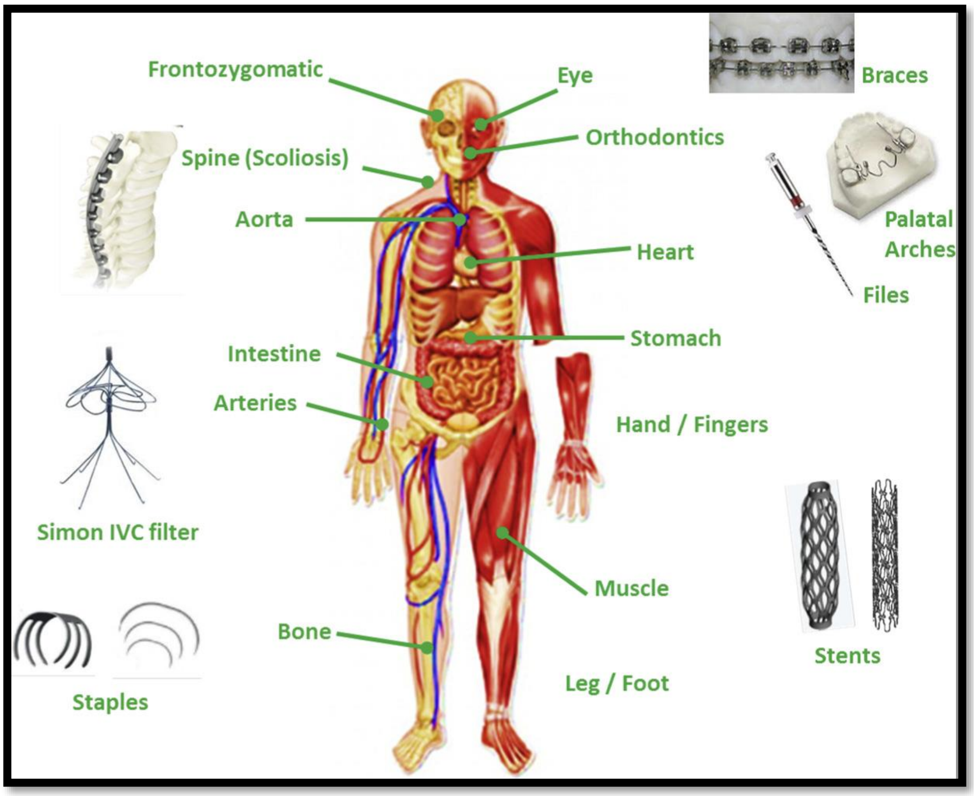


Figure 1 Potential and existing shape memory alloy applications in biomedical domain [15]

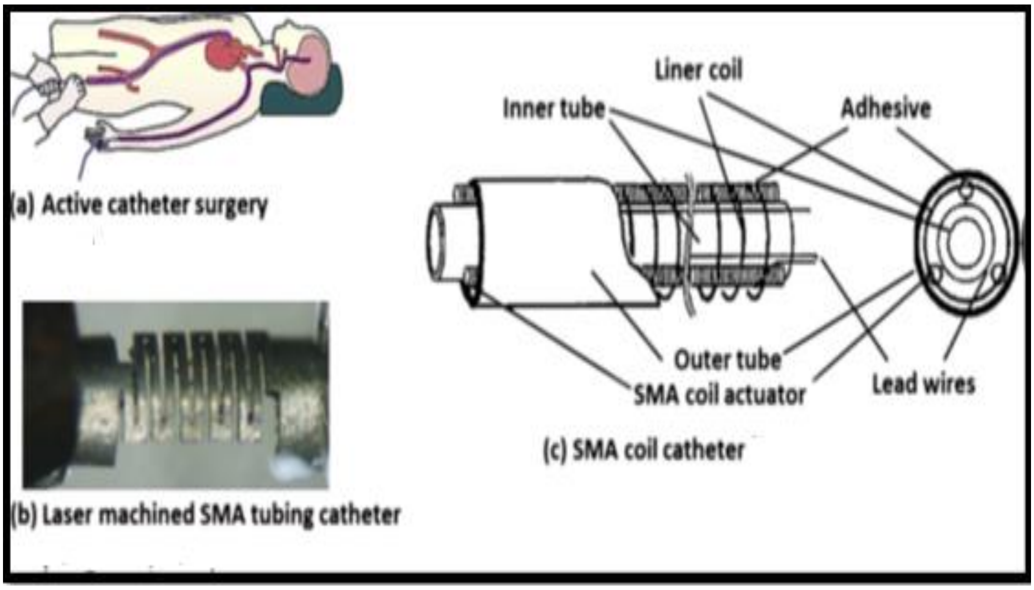


Figure 2 Shape memory alloy active catheter [34]

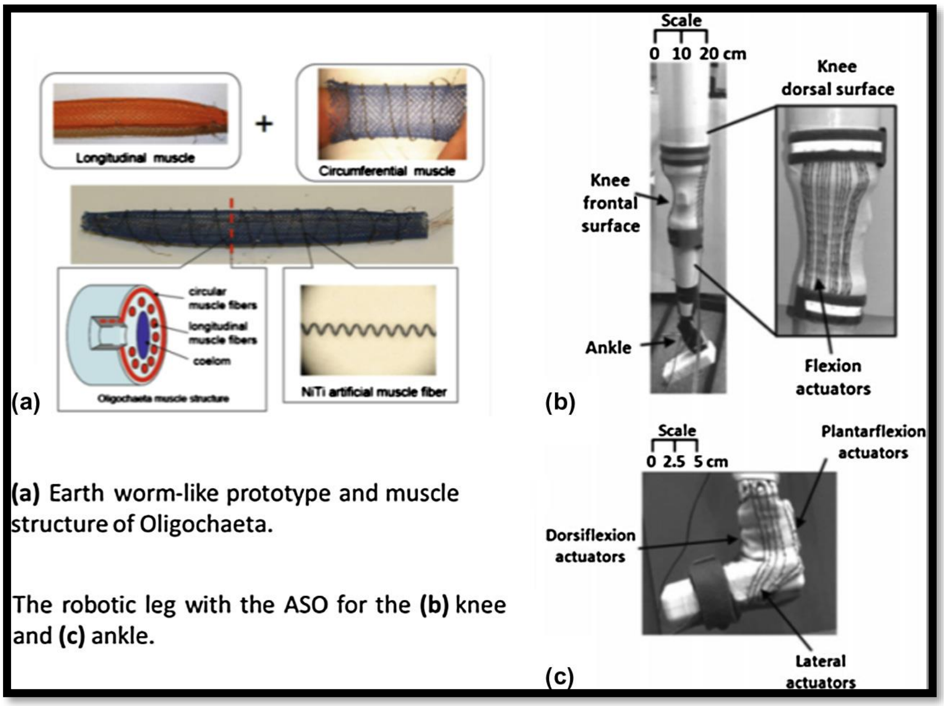


Figure 3 Muscle like NiTi shape memory alloy [37]

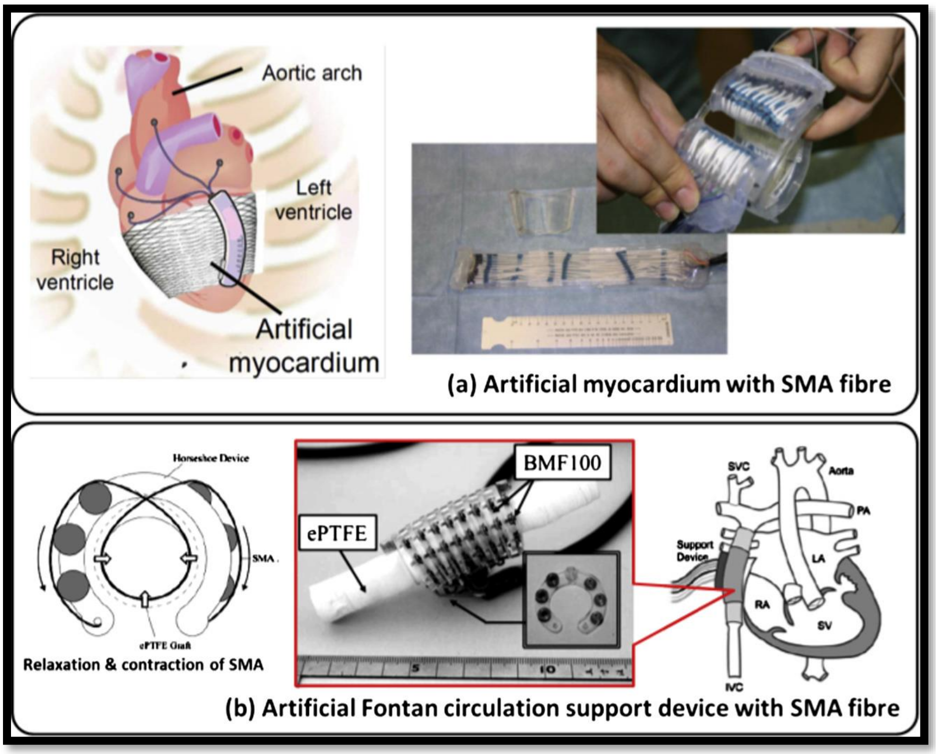


Figure 4 Artificial heart support device with shape memory fibre [38]

3: Robotic Applications

Shape memory alloys have been used in robotic application since 1980s [39-43]. However, the robots can be divided into several groups depending on their movement techniques and applications, for example jumper, crawler, fish, walker, flower, medical and biomimetic robotic hand [13, 14, 44]. Figure 5 shows the different kinds of shape memory alloys in the robotic applications [13, 14, 44]. Today, numerous works carried out on robotics have focused on biologically inspired and humanoid robots [14, 44]. These robots can be used to solve problems which are challenges for humans, for example can be used in underwater, space, air and land to provide pertinent information from these environments which is difficult to get by humans [13, 14, 44].

Recently, sever flying robots with shape memory alloys have been developed, for example Bat Robot [45] and BATMAV Robot [46, 47]. A dragonfly shown in figure 6 with a 44 cm length and a 63 cm wingspan was developed by Festo Group [48]. The dragonfly is known as BionicOpter see figure 6, the dragon equipped with four actuators shape memory alloys to control the movement dragonfly tail up and down and dragonfly head from side to side [48]. The dragonfly has thirteen degrees of freedom, can hover in maneuver in all direction and in mid – air [48].

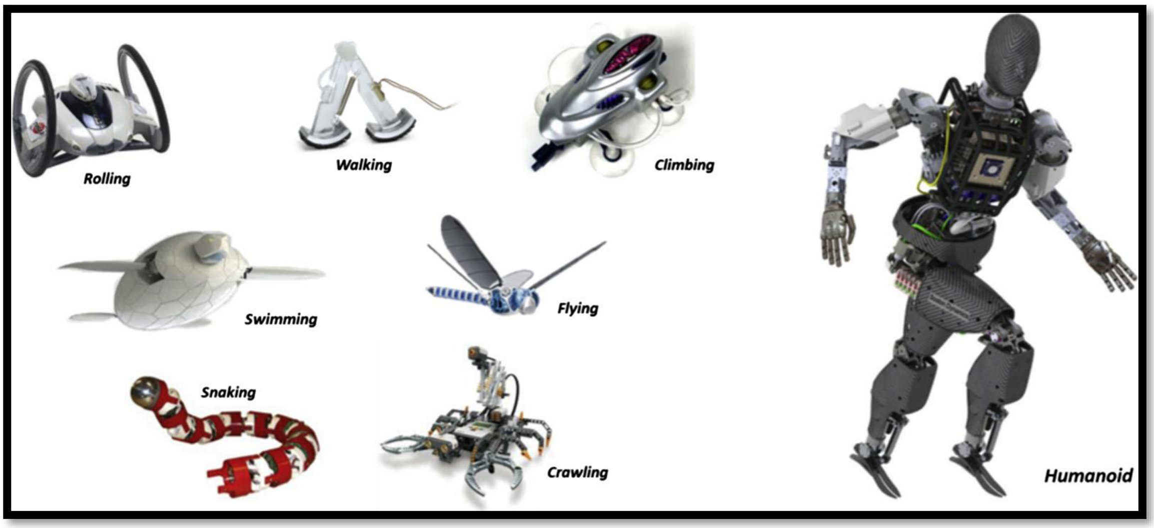


Figure 5 Potential and Existing shape memory alloys applications in robotic domain [14]

Figure 6 Festo BionicOpter - inspiration dragonfly flight [48]

4: Automotive Applications

Nowadays, the number of sensors and actuators are growing tremendously due to the request for reliable, convenient and good performance in modern vehicles [15]. Therefore, these offer a wide range for shape memory alloys to use in the automotive industry as shown in figure 7 [5, 49, 50].

There are numerous possibility applications for shape memory alloys in automotive industry which have been proposed, but very few of them have been used in practical applications due to the limited range of operating temperature compared with shape memory alloy transformation temperatures [15]. In addition, there are other limitations for example hysteresis width, stability and lifetime [5, 15, 49, 50].

However, shape memory alloys can be used in the mirror system in modern vehicles due to the versatility of shape memory alloy as shown in figure 8 [51]. Furthermore, figure 9 shows the emerging General Motors shape memory alloys applications [52-54]. Recently, several other shape memory alloy applications for automotive industry have been developed and they can be found in the literature [55-

58], for examples, tumble flaps actuator, micro – scanner system, pop – up bonnet and side mirror actuator as you can see in figure 10 [55-58].

It is well known that the stander transformation temperatures of NiTi shape memory alloy are at range temperatures – 40 ◦ C to approximately + 110 ◦ C [19]. In contrast, the stander operating temperature range for automotive application is between – 40 ◦ C to approximately +125 ◦ C as shown in figure 11 [4, 19, 59, 60]. Therefore, the majority of the practical applications of shape memory alloys are covered by NiTi shape memory alloy [19].

However, from the figure 11 and in order to act properly the shape memory alloys should exhibit a martensite transformation temperature above maximum operating temperatures as shown in the figure 11 the red dotted lines. Moreover, there are many kinds of high temperatures shape memory alloys, which are available as shown in the figure 11. But these alloys are of high cost for automotive industry [4, 19, 20, 59-61]. Although, the Cu-Al-Ni shape memory alloys exhibits martensitic transformation temperatures up to 200 ◦ C, these materials are unstable, brittle, exhibit low fatigue strength and cannot be used for multiple cyclic operations [4, 19, 20, 59-61].

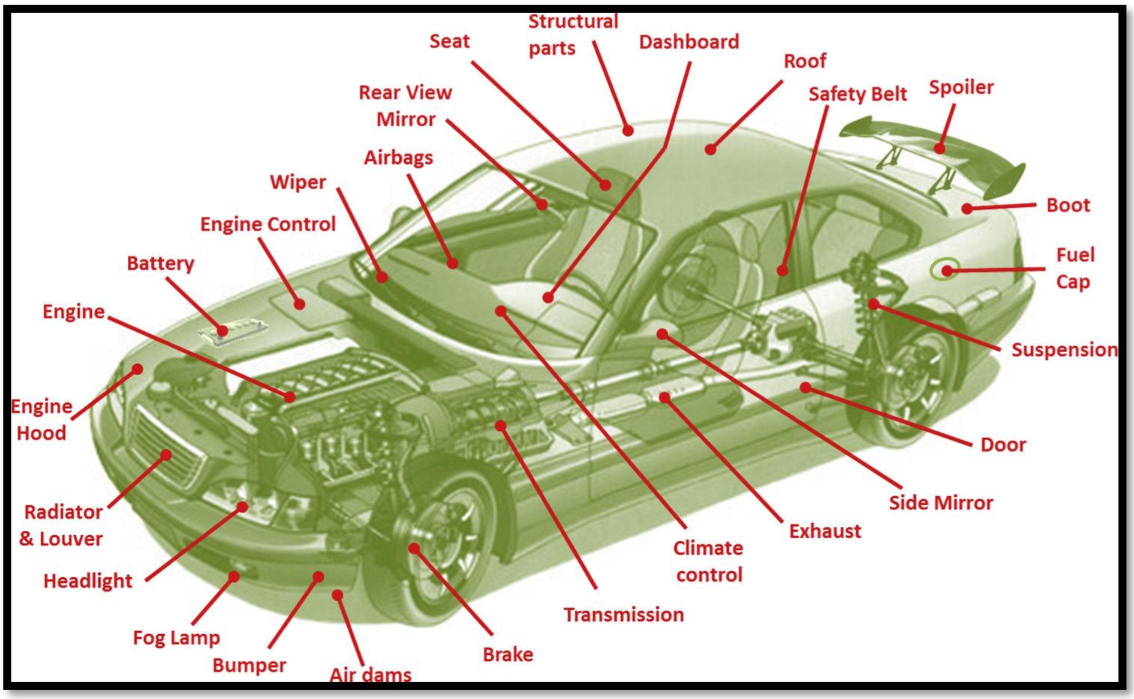


Figure7 Existing and potential shape memory applications in the automotive domain [50].

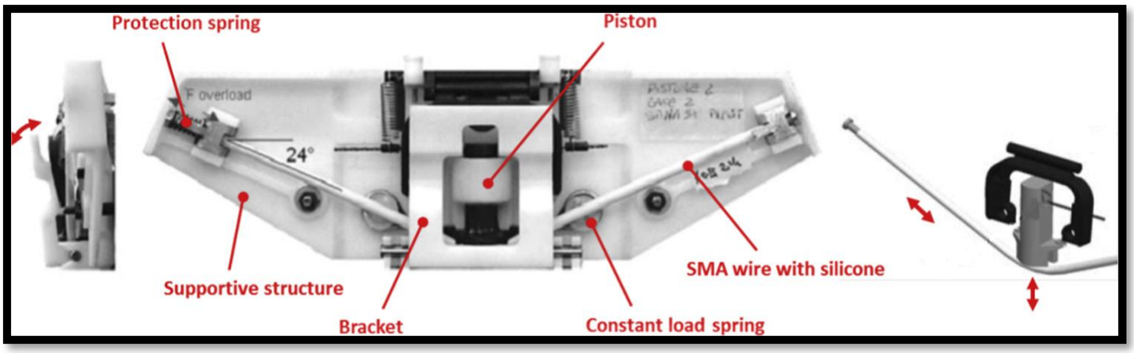


Figure 8 EAGLE mirror prototype [51]

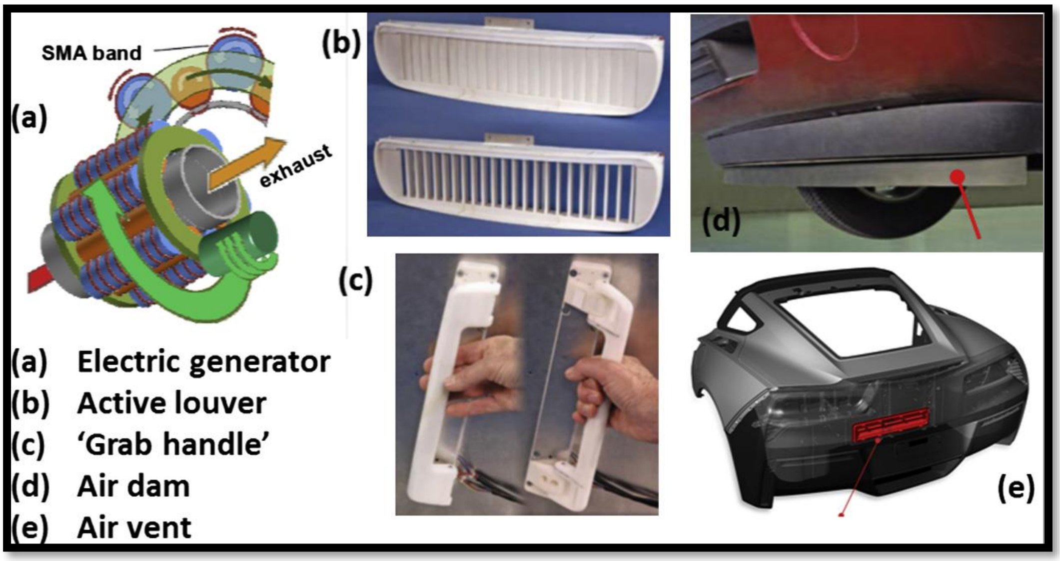


Figure9 Emerging General Motors shape memory alloy [54]

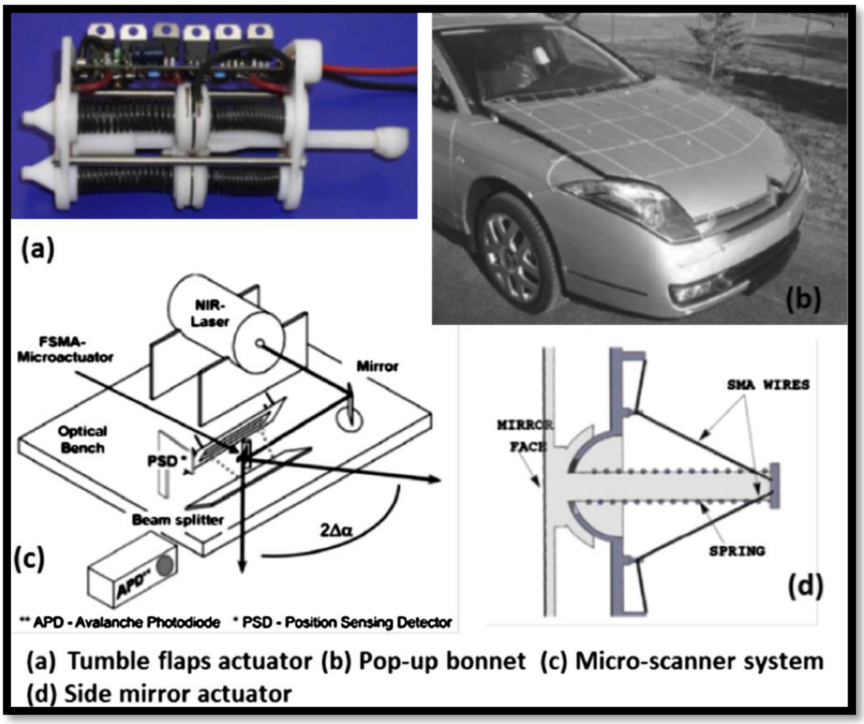


Figure10 Other shape memory alloys application in automotive domain [58]

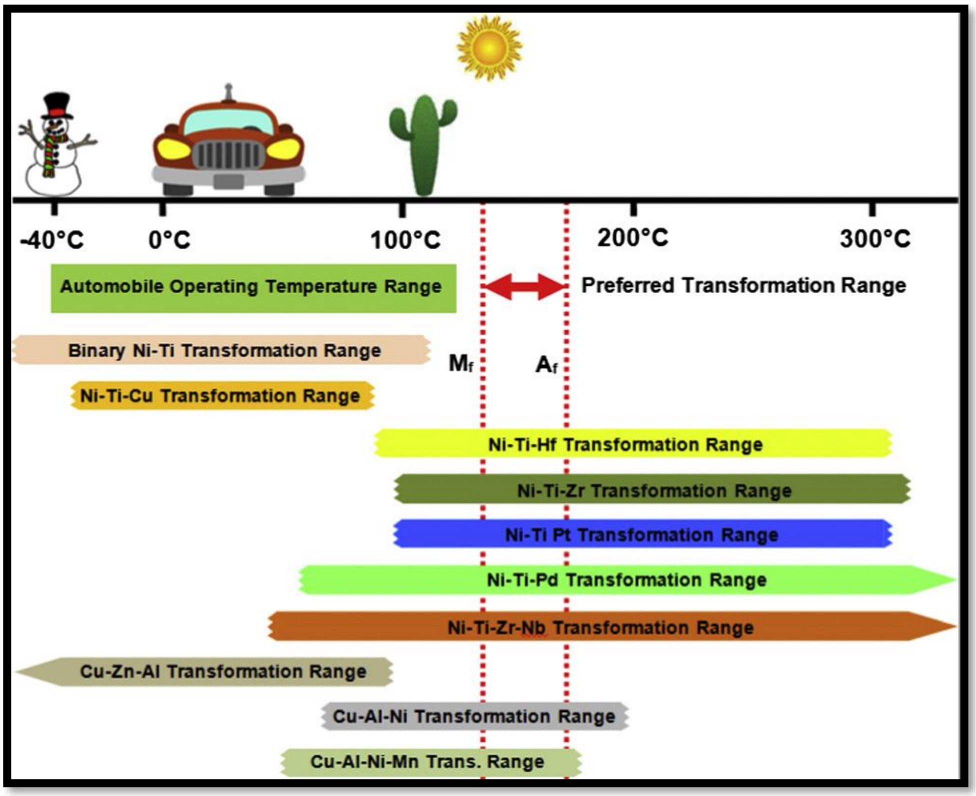


Figure11 Operating temperature range for automobiles applications and the transformation temperature for selected commercially available and developed shape memory alloys [60]

5: Aerospace Applications

SMAs have been used in aerospace since 1970s when used in hydraulic line coupling which is used in the F-14 fighter jets [62]. Since this time and due to the unique properties of SMAs many aerospace researchers have proposed to use this material for solving engineering issues in the aerospace manufacture[6, 11, 63-65].

In the 1990s, numerous works carried out on aerospace industry such as Advanced Research Projects Agency (DARPA) program for aircraft smart wings [66], the Smart Aircraft and Marine Propulsion System Demonstration (SAMPSON) program for jet engines[67] and another program can be seen in literatures [68-73]. The Boeing company has improved an active device based on SMA technology programs which is VGC, a variable geometry chevron on a 77-300 ER with GE90-115B jet engine, this device has the ability to minimize noise through take- off, figure 12 shows Boeing variable geometry chevron [71-73]. Then, after the VGC success, many companies such as Boeing, DARPA, NASA and other have been introduced more SMAs based on technology programs in order to use SMAs in aerospace industry [71-73].Figure 13 shows the possibility SMAs applications in the aerospace industry [10, 62].

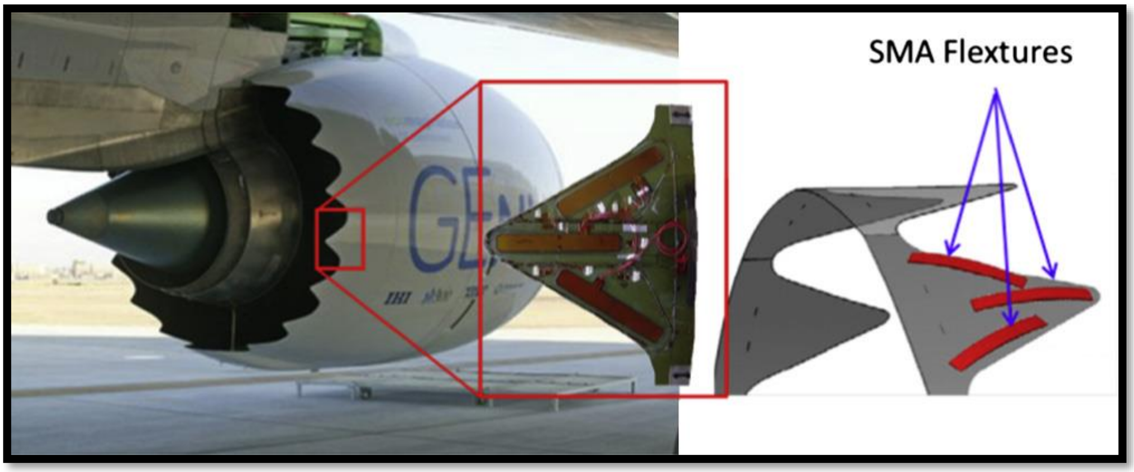


Figure12 Boeings variable geometry chevron (VGC) [71]

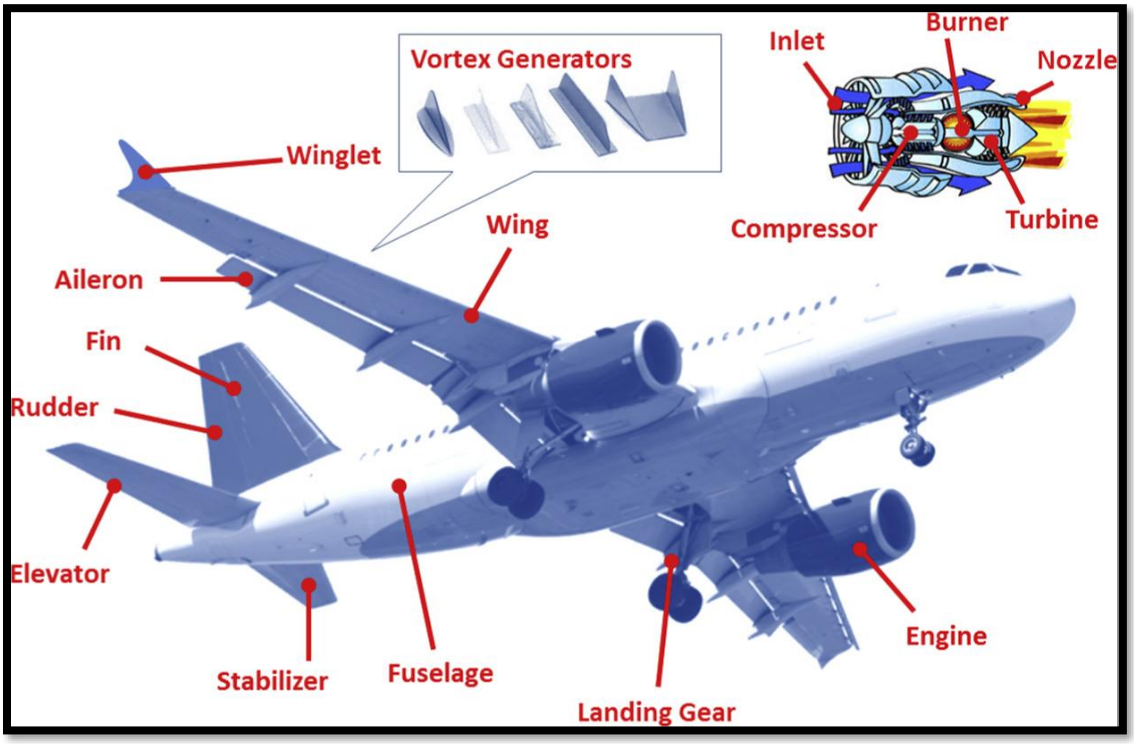


Figure13 Existing and potential shape memory alloys applications in the airspace domain [62]

6- Conclusions

1- This review has demonstrated that shape memory alloys can be successfully used in several applications particularly (biomedical, airspace, robots and automotive).

2- The applications of shape memory alloys can be divided according to their memory element such as shape memory effect and superelasticity. Shape memory effect can be used to generated force or motion or both. Superelasticity can be used to store energy.

3- The demand for shape memory alloys is increasing especially in the biomedical applications.

4- Several shape memories alloys have a good shape memory property to use at high temperatures, but they are relatively of high costs for automotive applications.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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مقالة مراجعة:

تطبيقات السبائك التي تتذكر شكلها

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الخلاصة:

البحث الحالي يركز على التطبيقات الرئيسية للسبائك التي تتذكر شكلها. حيث يقسم البحث الى خمسة أجزاء رئيسية. الجزء الاول يركز على مقدمة عامة عن السبائك التي تتذكر شكلها وتطبيقاتها. الجزء الثاني من البحث سيناقش التطبيقات الطبية للسبائك التي تتذكر شكلها. التطبيقات الخاصة بالريبورتات ستناقش في الجزء الثالث. التطبيقات الخاصة في المركبات ستناقش في الجزء الرابع. واخيرا الجزء الخامس سوف يراجع التطبيقات الفضائية للسبائك التي تتذكر شكلها.

الكلمات الدالة:– السبائك التي تتذكر شكلها، التطبيقات الطبية، التطبيقات الريبورتات، تطبيقات الحركية، تطبيقات الفضاء.