STM JOURNALS

Journal of
Materials & Metallurgical Engineering

https://journals.stmjournals.com/jomme

ISSN: 2231-3818 (Online)
ISSN: 2321-4236 (Print)
Volume 15, Issue 3, 2025
September–December
DOI (Journal): 10.37591/JoMME

Review JoMME

Short Review: The Expanding Role of Shape Memory Alloys in Technology and Medicine

Sonam Patel[1,*], Tushal Kyada[1]

Abstract

Shape Memory Alloys (SMAs) are a unique class of smart materials that can recover their original shape when exposed to specific stimuli, such as temperature or magnetic fields. This exceptional property, attributed to the martensitic phase transformation, has garnered significant interest in various industries. SMAs exhibit remarkable characteristics such as pseudoelasticity, high corrosion resistance, excellent biocompatibility, and superior fatigue strength, making them ideal for applications in biomedical, aerospace, automotive, and civil engineering fields. Among these, Ni-Ti (Nitinol) and Cu-based SMAs are widely utilized due to their superior mechanical and functional properties. This review provides an overview of the historical development of SMAs and their diverse applications, with a particular focus on medical, industrial, automotive, aerospace, and civil engineering sectors. The growing commercial adoption of SMAs highlights their expanding role in modern technology, paving the way for future advancements in smart materials.

Keywords: Shape Memory Alloys; Medical Application; Industrial Application; Automobile Application; Aerospace Application

INTRODUCTION

Currently, smart materials are a rapidly growing field in various industries, attracting significant interest. Among these, shape memory materials stand out as one of the most promising areas of research. Shape memory alloys (SMAs) are metallic alloys with the unique ability to regain their original shape when heated to a specific temperature, known as the critical transformation temperature. This behavior is primarily attributed to martensitic phase transformation. In this process, the parent austenite phase, which has a body-centered cubic structure, undergoes a diffusionless transformation into an orthorhombic or monoclinic martensite phase. This phenomenon, known as the shape memory effect (SME), is illustrated in Figure 1 [1–3].

In the early 1930s, Olander found the 1st shape memory alloys and its effect in Au-Cd alloys. He found that this alloy could be plastically distorted during cooling and recovered to their original shape upon heating [2]. At the initial stage SMAs actuator were used in greenhouse window to conveyed temperature – dependent ventilation. As time goes the use of SMAs has increases extremely in 1990s [4]. Super elastic SMAs are used in plastic – covered cell phone antennas. It would be able to recover its own shape even after distortion or twisting. Versatile properties of shape memory alloys make it extremely beneficial for medical field [5].

Many alloys show the shape memory effect but commercially those alloys are used that recover more strain or produce recovering force. Among many SMAs, commercially Nickel-Titanium (Nitinol) and Copper-Aluminium and Iron based alloys are widely used in various fields [2, 6, 7].

***Author for Correspondence**
Sonam Patel
E-mail: smp22789@gmail.com

[1]Lecturer, Metallurgy Department, Dr. S. & S. S. Ghandhy College of Engineering & Tech., Surat, Gujarat, India

Received Date: April 02, 2025
Accepted Date: April 18, 2025
Published Date: July 25, 2025

Citation: Sonam Patel, Tushal Kyada. The Expanding Role of Shape Memory Alloys in Technology and Medicine. Journal of Materials & Metallurgical Engineering. 2025; 15(3): 35–44p.

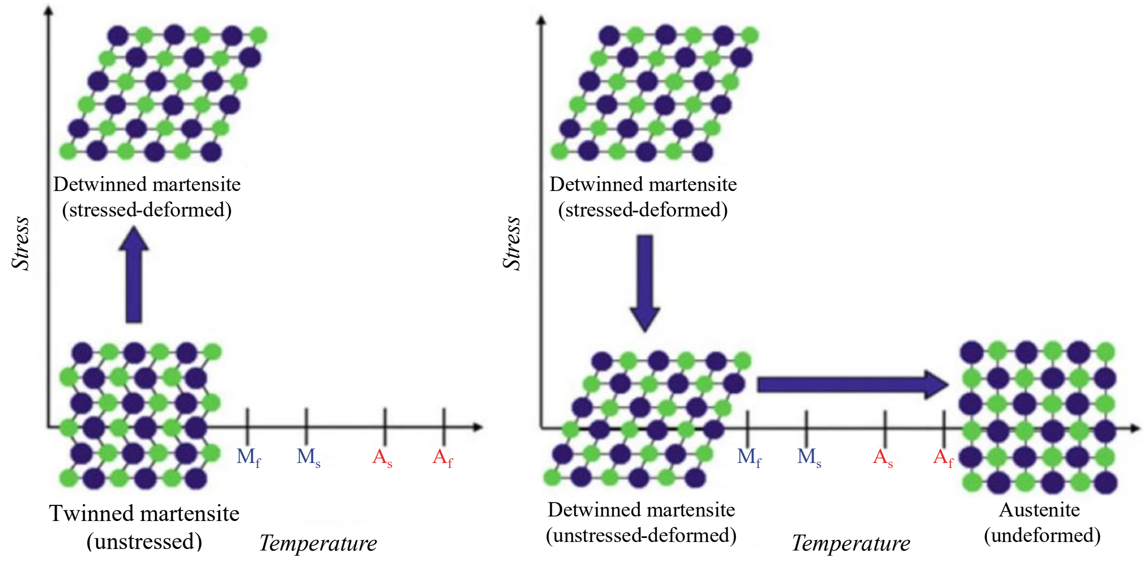

Figure 1. 2D diagram of shape memory effect [2].

Because of excellent biological compatibility, super elasticity and high corrosion resistance, Ni-Ti based alloys are mainly used in biomedical applications such as blood-clot filter, orthodontic wires, actuated implantable drug delivery system and inter-vertebral disc connector [8, 9].

NiTi, NiTi-based, and Cu-based alloys exhibit shape memory effects at temperatures ranging from room temperature (in the case of pseudoelasticity) to around 400 K for conventional SMAs, and up to approximately 600 K for high-temperature variants like NiTiHf. Their applications span multiple industries, including healthcare (e.g., stents, grafts, orthopedic staples, orthodontic archwires, and eyeglass frames), aerospace and defense (e.g., couplers in F-14 aircraft), safety systems (e.g., seismic vibration dampers and automatic fire sprinklers), and robotics (e.g., actuators) [10].

In recent years, shape memory alloys (SMAs) have attracted significant interest and found extensive applications across various commercial sectors. This review aims to explore and present the diverse applications of SMAs in fields such as medicine, industry, civil structures, automotive, and aerospace, based on existing literature.

APPLICATIONS OF SHAPE MEMORY ALLOYS IN DIFFERENT FIELDS

Medical Field

The development of shape memory alloys (SMAs) has significantly transformed the biomedical field, leading to advancements in medical technology. This progress began in 1963 with the discovery of Nitinol, a nickel-titanium alloy recognized for its shape memory and superelastic properties. In 1971, SMAs found their first dental application with the introduction of shape memory braces, enhancing orthodontic treatments. By 1977, the Simon Vena Cava filter was developed, utilizing SMA properties for effective blood clot prevention. The first Nitinol stent, introduced in 1983, revolutionized vascular treatments by providing self-expanding support for blood vessels. Further innovations followed, including the laparoscopic retractor in 1995 and the abdominal wall lift in 2000, both improving minimally invasive surgical techniques. The introduction of an endoscopic bleeding control device in 2007 enhanced hemostasis, while thin-film microtubes and stents in 2008 paved the way for advanced medical implants [11, 12].

Due to their unique properties, SMAs have found widespread use in various medical applications. Although, Nickel-titanium alloys more expensive than stainless steel, SMAs offer superior performance in medical applications. Their versatility extends across fields such as neurology, radiology, cardiology,

Journal of Materials & Metallurgical Engineering
Volume 15, Issue 3
ISSN: 2231-3818 (Online), ISSN: 2321-4236 (Print)

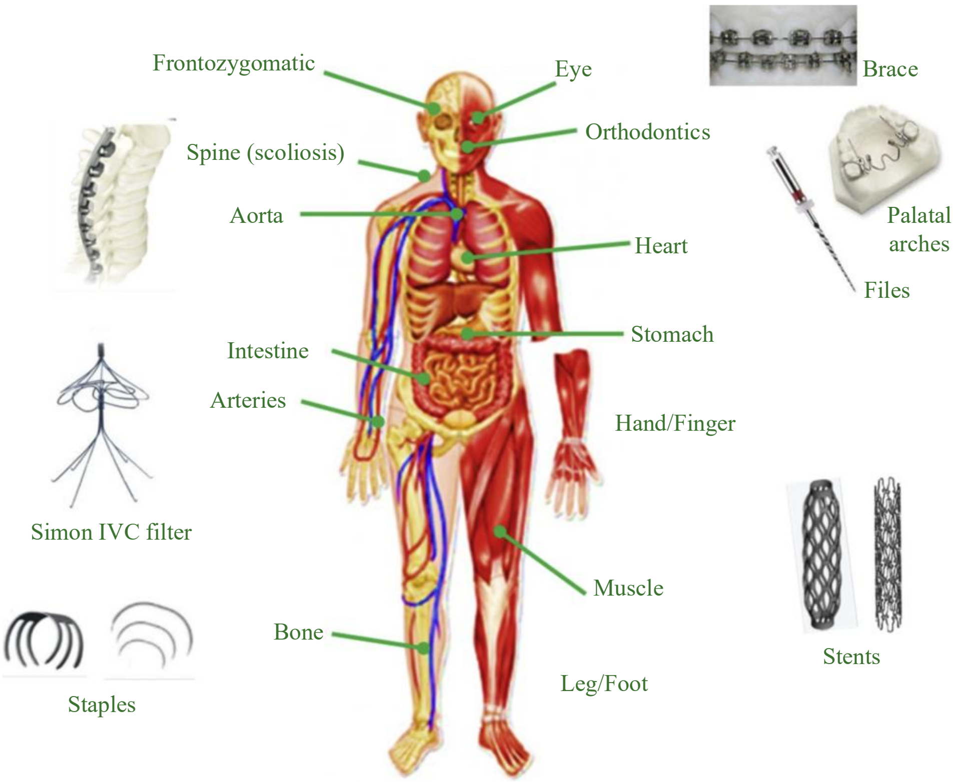

Figure 2. Application of SMAs in medical field [9].

Table 1. Medical and biomedical applications of materials in various fields [9]

Field	Applications
Orthodontic	Braces/brackets, Palatal arches
Biomedical/Surgical instruments	Catheters, Snares, Scopes (Ureteroscopy, Endoscopy, Laparoscopy), Files, Suture
Orthopaedic	Head, Spine, Bone, Muscles, Hands/Fingers, Legs
Miscellaneous	Cardiology (Heart), Hepatology (Liver, Gallbladder, Biliary Tree, Pancreas), Otorhinolaryngology (Ear, Nose, Throat), Gastroenterology (Gullet, Stomach, Intestine)
Vascular	Aorta, Arteries, Vena Cava Filter, Ventricular Septal Defect (VSD), Vessels, Valves
Other medical fields	Urology (Kidneys, Adrenal Glands, Ureters, Urinary Bladder, Urethra, Male Reproductive Organs), Plastic, Reconstructive & Aesthetic Surgery, Ophthalmology (Eye)

and orthopedics. Additionally, they are used in endodontics, stents, eyeglass frames, medical tweezers, sutures, anchors, and guide wires, making them indispensable in modern healthcare. Figure 2 illustrates the various biomedical applications of SMAs [9, 13].

Table 1 shows the various applications of Shape Memory Alloys (SMAs) across multiple medical fields. These include orthodontics, surgical instruments, orthopaedics, cardiology, gastroenterology, and vascular treatments.

Cardiovascular Applications

1st cardiovascular gadget was created with SMAs was known as Simon filter [14]. This Simon filter channel addresses another age of gadgets which are utilized for the vein stoppage to prevent pulmonary embolism. This gadget is made with shape memory alloy wire and with a waterproof fil of polyurethane. Concerning the instance of Simon filter, the medical procedure is to put this device exploits the SME,

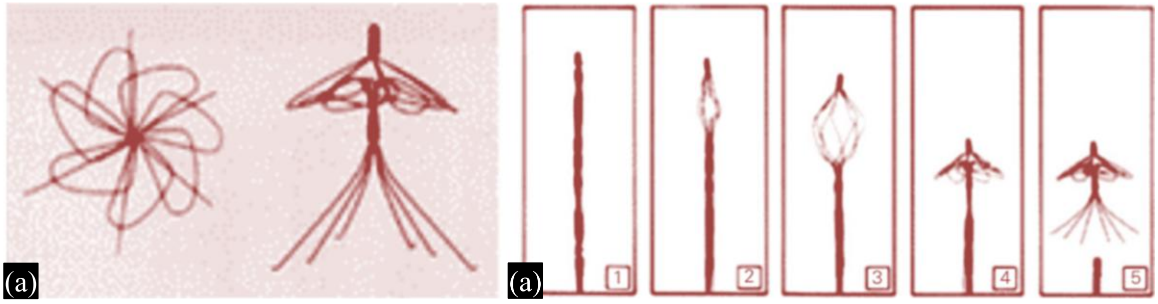

Figure 3. Simon filter. (a) in recovery form (martensitic state), (b) In release form [5, 6].

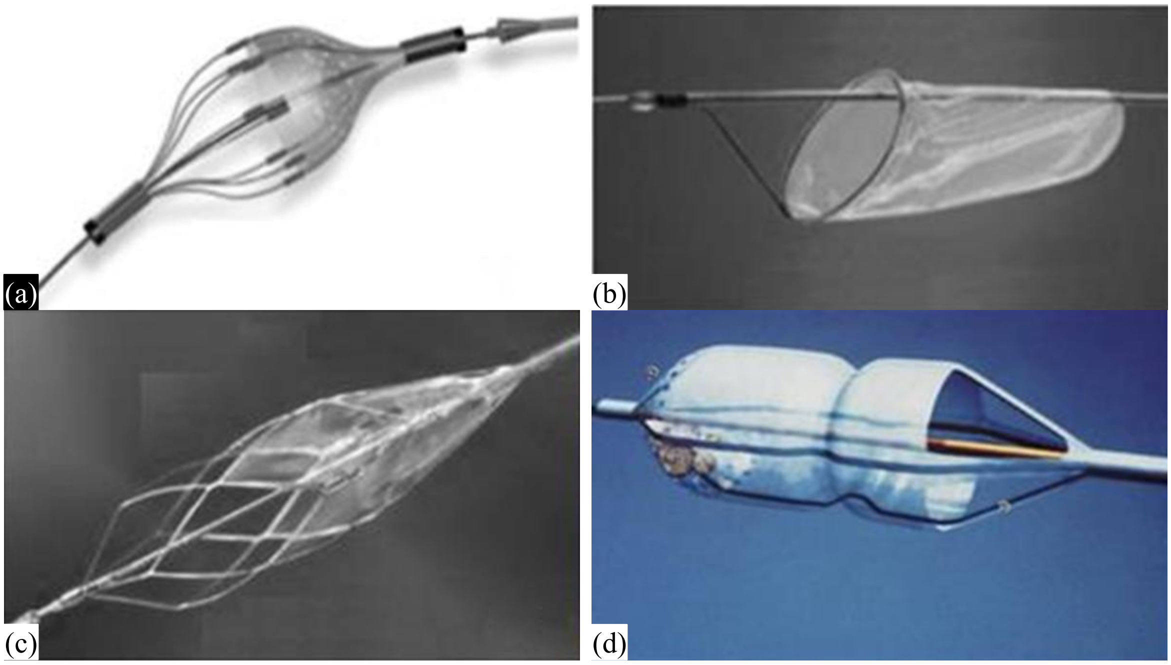

Figure 4. (a) Angio guard RX (fits vessels sized from 3.0 mm to 7.5 mm in diameter), (b) filter wire EZ (fits vessels sized up to 5.5 mm), and (c) AccuNet filter (fits vessels sized from 3.25 mm to 7.0 mm in diameter) (d) Neuroshield filter (fits vessels sized from 3.5 mm to 7.5 mm in diameter) [17, 18]

it is in effect substantially less intrusive than the traditional [15]. The goal of this gadget is to filter the clots which are travelling inside the blood stream. The Simon filter traps these coagulations that in time are disintegrated by the blood stream. The addition of the filter inside the human body is finished by exploiting the SME [5]. Shape changes of Simon filter is shown in Figure 3.

The Accunet embolic protection system, developed by Guidant Corporation in 2003, is a Nitinol-based embolic filter with a fusiform design. Its Nitinol wire forms a basket structure, supporting a polyurethane (PU) filter mesh with a 120 µm pore size. The filter adapts well to complex vessel structures, ensuring effective embolic protection. Similarly, MedNova Ltd. designed the Neuroshield carotid embolic protection system, later advanced by Abbott Vascular Devices. It features a Nitinol basket with four expandable struts and a porous membrane mesh (140 µm pore size). The expandable struts create radial force, securing the filter to vessel walls. Studies confirm its effectiveness in preventing major embolic strokes [16].

Orthodontic Applications

Another industrial application is the utilization of very versatile and thermal shape recovery alloys in orthodontic field. For many years, stainless steel arch wires were used as corrective measure to aligned

Figure 5. (a) Arc wire and (b) palatal expanders of Nitinol [11, 19].

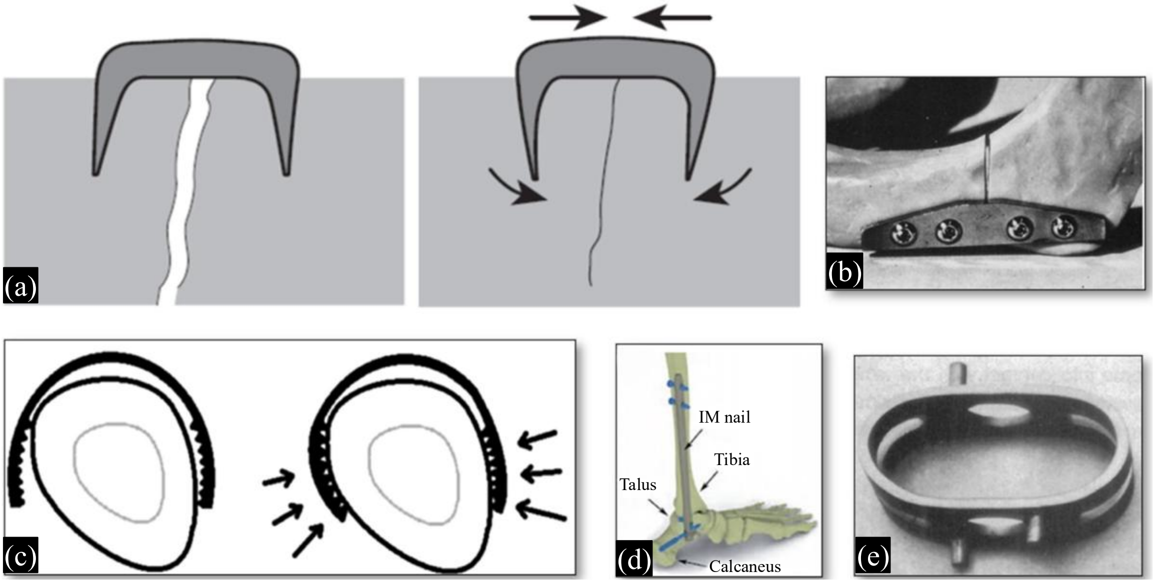

Figure 6. Orthopaedic applications of SMAs (a) staple, (b) plate (c) embracing fixator (d) intramedullary nail (e) vertebrae spacer [19]

skewed teeth. Due to the less stretch and ductile qualities of these kinds of wires, extensive load is to be applied to teeth and it cause too much discomfort. At the point when the teeth are to be yield the right force applied to it, yet the stainless-steel wire is to be re-tensioned. In the starting phase of dental treatment visits to the dentist is might be essential to re-tension the wire in each 3 to 4 weeks. As time passed, stainless steel wire was replaced by SMAs. Recently, Ni-Ti based SMAs are used in orthodontic to make arch wires and palatal expanders. (Figure 5) The most important feature of this arc wire is to apply the same forces on teeth during repositioning. Compare to classic alloys, SMAs can deliver proper consistent spring back forces due to the steady oral cavity temperature [1, 15, 19].

SMAs are used in large number of orthopedic parts. To get effective joint among two separate bone parts, important features are steady fixation and correct compression among the two parts. Therefore, broken bones are repaired by using fixation device to provide strength and keep proper alignment during curing. Ni-Ti based SMAs are widely used to make staple, plates, embracing fixator, intramedullary nail, spinal vertebrae spacer, correcting rod and Intervertebral fusion devices (porous). Figure 6 shows the various orthopaedic applications of SMAs [15, 19, 20].

Applications in Surgical Devices

In recent years, medical science is mainly focusing on less intrusive surgeries to reduce pain and infection risk, faster recovery and decrease post operational complications [15]. To fulfil this requirement alloy used for surgical devices should be more stretchable and flexible. Super elastic SMAs satisfy all the demands and used in many surgical procedures such as Endoscopic surgery, single-incision

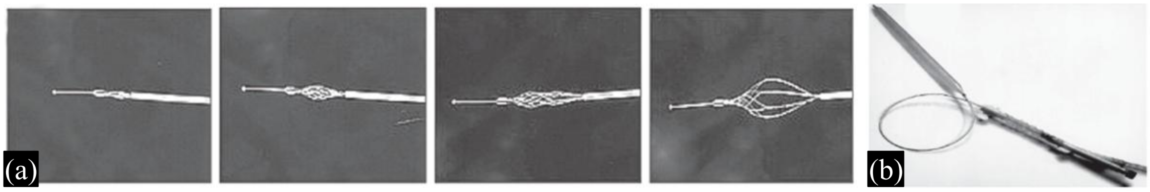

Figure 7. (a) sequence of retrieval basket, (b) intra-aortic balloon [19, 20].

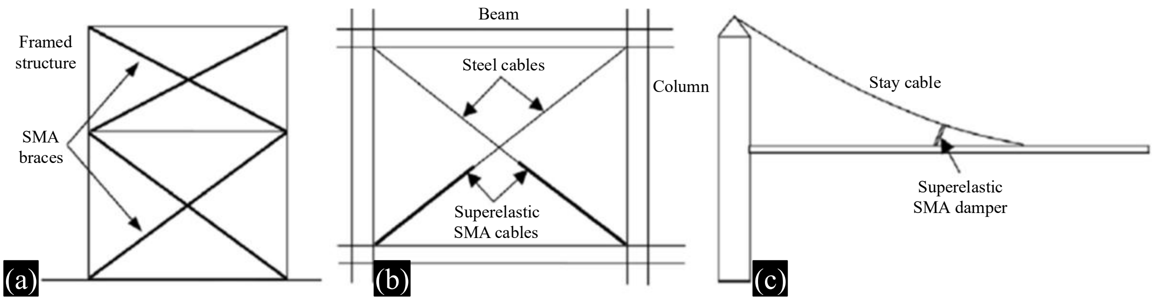

Figure 8. Schematic of the SMA (a) braces for a 2 story steel frame (b) frame structure (c) super elastic damper for a stay-cable bridge [23]

laparoscopic surgery etc. They are used in various tools and devices like curved spatula, radiofrequency interstitial tissue ablation device, retrieval basket, pipes, coil actuators, guidewires, self-expandable stents and clips. Figure 7 represent the images of shape memory basket and intra-aortic balloon pump. Shape memory nitinol retrieval backet is used to remove stones from kidneys, bile duct and bladder and intra-aortic balloon is used to unclog blood vessels throughout angioplasty [6, 19, 21].

Industrial Applications

Raychem Corporation's introduced a use of SMA in tubing and pipe coupling. That Ni-Ti based SMAs couplings are used to connect hydraulic lines of aircraft. Similarly, Ni-Ti SMAs fixtures have been widely used for plumbing of ships and submarines. Raychem were also introduced a copper based SMAs to use as a coupling, fasteners, retainer, and clamp [22].

Civil Structures

Utilizing SMAs for passive design control depends on the shape memory alloys damping property, which represents its capacity to dissipate vibration energy of designs subject to dynamic loading. Commonly used super elastic Ni-Ti shape memory alloy wires shows energy dissipation. In civil structures, SMAs are used in isolation devices and energy dissipation devices such as SMAs wire for re-centering devices for building, bars for highway bridges, multi-story shear frame, dampers for cable bridges etc. [23]. Figure 8 shows the various applications of SMAs in civil structures.

The importance of shape memory alloys (SMAs) in concrete structures lies in their ability to enhance ductility, making them ideal for earthquake-resistant construction. SMA fibers improve tensile and flexural strength while contributing to self-healing properties, increasing the durability of concrete. Additionally, SMA-hybrid composites (SMAHC) offer a lightweight yet strong alternative to traditional reinforcement materials. Their unique shape memory and superelastic properties provide significant advantages in structural resilience, ensuring long-term performance and safety [24].

Automotive Field

The demand for sensors and actuators in the automotive sector is steadily increasing to enhance vehicle safety, performance, and comfort. This growing need presents an opportunity for shape memory alloy (SMA) actuators to replace traditional electromagnetic actuators. In response, many automotive manufacturers have started incorporating SMAs into their designs. The first commercial use of an SMA actuator in the automotive industry was introduced in 1989 when Mercedes-Benz integrated a thermally

Journal of Materials & Metallurgical Engineering
Volume 15, Issue 3
ISSN: 2231-3818 (Online), ISSN: 2321-4236 (Print)

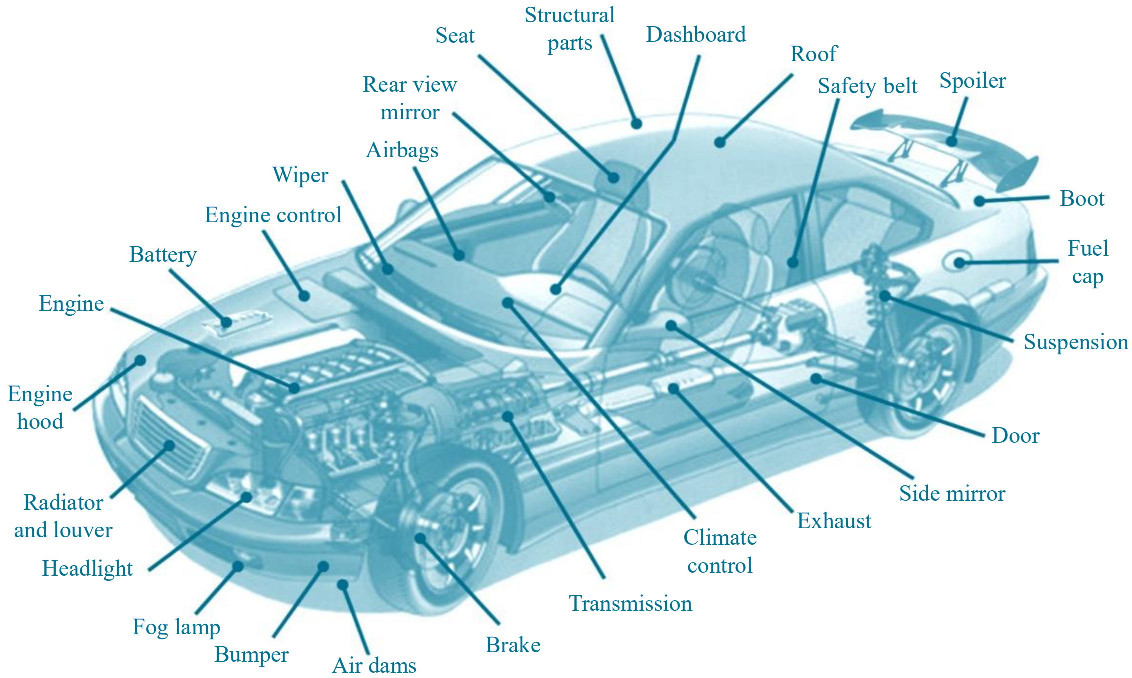

Figure 9. Existing and potential uses of SMAs in automobile field [9]

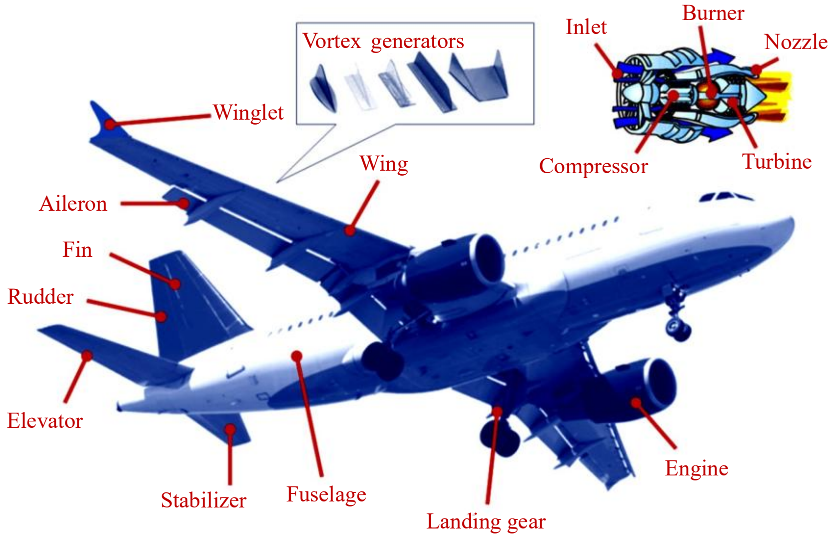

Figure 10. Existing and potential uses of SMAs in aerospace field [9]

responsive pressure control valve into its automatic transmission system, improving gear shifting. In 2014, the Chevrolet Corvette became the first vehicle to feature SMA actuators, replacing bulkier motorized components. These actuators controlled the hatch vent, facilitating air release from the trunk and making it easier to close. The existing shape memory alloys applications are shown in Figure 9 [9, 25].

Aerospace Applications

In the 1970s, SMAs were used in coupling for hydraulic lines of F-14 fighter jets. Due to SMAs unique properties, more interest was developed in this area. SMAs are used in actuators, wings, manipulators, structural connectors, pathfinder applications. Current and potential uses of SMAs in aerospace field are shown in Figure 10. Table 2 shows a wide range of applications of Shape Memory Alloys (SMAs) across various fields, including micro-actuators, orthodontics, robotics, medical devices, and even aerospace, demonstrating the versatility and potential of SMAs in diverse technologies [9].

Table 2. Applications of SMAs.

Micro-actuators	Robot actuators	Scoliosis correction
Orthodontic archwires	Rock splitting root canal drills	Solar actuators
Penile implant pipe couplings	Satellite antenna deployment	Spectacle frame
Pipe couplings	Steam valves	Vibration dampers
Aircraft flap/slat adjusters	Stents	ZIF connectors
Anti-scald devices	Switch vibration damper	Aids for disabled
Arterial clips	Contraceptive devices	Fibre-optic coupling
Braille print punch	Electrical circuit breakers	Filter struts
Catheter guide wires	Keyhole instruments	Fir dampers
Fire sprinklers	Graft stents	Kettle switches
Gas discharge	Intraocular lens mount	

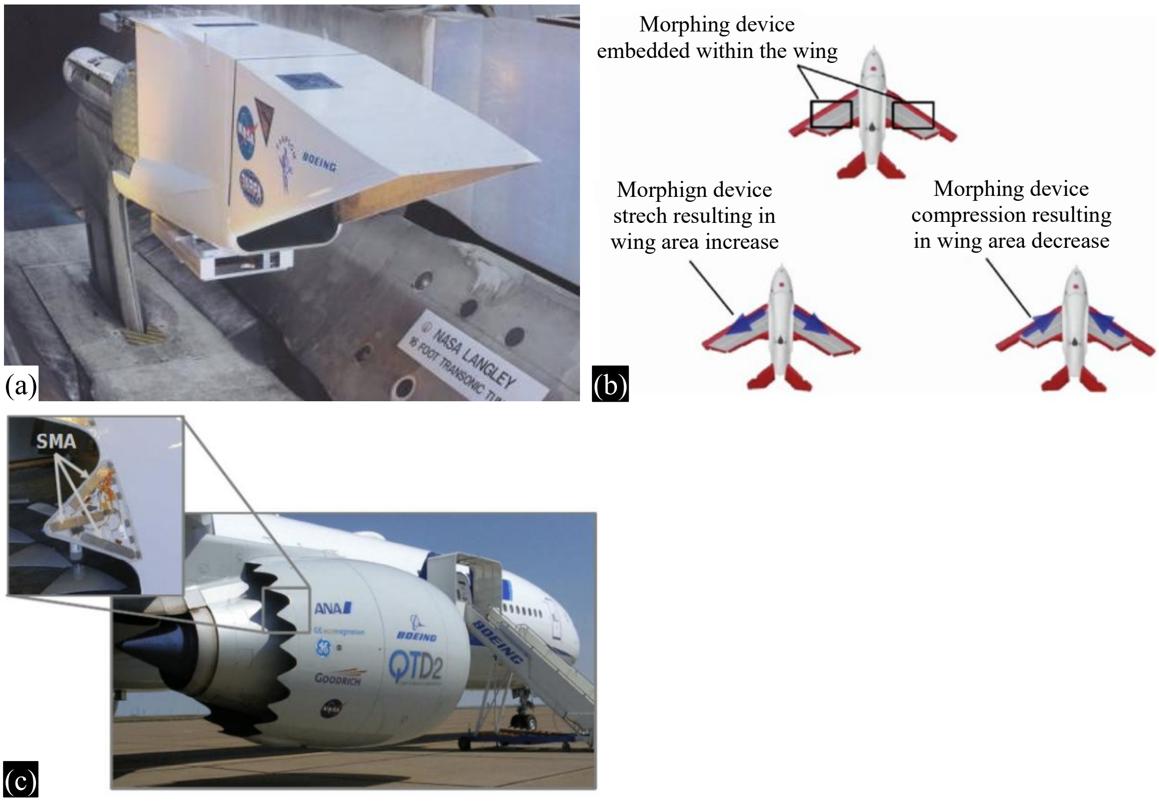

Figure 11. (a) The SAMPSON F-15 inlet tested in the facility at Langley (NASA) (b) Various morphing devices employed on the wing airplanes can change, stretching or compressing, the aerodynamic profile (c) Variable geometry chevron activated by SMA in the full-scale test [26, 27]

Shape memory alloys (SMAs) are being explored for aerospace applications, including adaptive inlets and noise reduction systems. The F-15 inlet system, tested at NASA Langley, utilized SMA-actuated components to modify airflow. However, slow cooling and retraction time remained challenges. Additionally, Boeing investigated SMA-based Variable Geometry Chevrons (VGC) to reduce jet noise at takeoff. These adaptive nozzles improved efficiency by minimizing drag during cruising. Experimental results demonstrated effective actuation and noise reduction, though further development is needed for operational deployment [26].

Figure 11 shows the SAMPSON F-15 inlet tested at NASA Langley, various morphing devices on aircraft wings that adjust aerodynamic profiles, and a full-scale test of an SMA-activated Variable Geometry Chevron [26, 27].

CONCLUSIONS

The unique properties of Shape Memory Alloys (SMAs), including shape recovery, superelasticity, and biocompatibility, have made them indispensable in various fields. From medical implants and surgical tools to aerospace actuators and automotive components, SMAs have demonstrated significant potential in enhancing functionality and efficiency. Their increasing use in civil structures for vibration damping and earthquake-resistant designs further expands their application scope. Despite their higher cost compared to conventional materials, continuous advancements in alloy design and manufacturing processes are expected to improve their affordability and expand their commercial use. Future research will likely focus on developing high-temperature SMAs, improving fatigue resistance, and optimizing their integration into emerging smart technologies. SMAs continue to revolutionize multiple industries, and their potential applications are bound to grow with ongoing innovation and material advancements.

REFERENCES

1. Lendlein A, Kelch S. Shape-memory polymers. Angew Chem Int Ed Engl. 2002;41(12):2034–57.
2. Wanhill RJH, Ashok B. Aerospace materials and material technologies. In: Aerospace Materials Volume 1. 2016. p. 467–81.
3. Mohammed SH, Shahatha SH. In: AIP Conference Proceedings. American Institute of Physics Inc.; 2023.
4. Sabahi N, Chen W, Wang C-H, Kruzic JJ, Li X. Mechanical performance of additively manufactured metallic lattice structures. JOM. 2020;72:1229–53.
5. Xue D, Xue D, Yuan R, Zhou Y, Balachandran PV, Ding X, Sun J, Lookman T. Accelerated search for materials with targeted properties by adaptive design. Acta Mater. 2017;125:532–41.
6. Machado LG, Savi MA. Medical applications of shape memory alloys. Braz J Med Biol Res. 2003;36(6):683–91.
7. Hodgson DE, Wu MH, Biermann RJ. Shape memory alloys. 1990.
8. Dasgupta R. Shape memory alloys: microstructure, properties and applications. J Mater Res. 2014;29:1681–98.
9. Jani JM, Leary M, Subic A, Gibson MA. A review of shape memory alloy research, applications and opportunities. Mater Des. 2014;56:1078–113.
10. Nespoli A, Ninarello D, Fanciulli C. Recent developments in shape memory alloys. Metals (Basel). 2023;13(1).
11. Petrini L, Migliavacca F. Biomedical applications of shape memory alloys. J Metall. 2011;2011:501483.
12. Balasubramanian M, Srimath R, Vignesh L, Rajesh S. In: Journal of Physics: Conference Series. IOP Publishing Ltd; 2021.
13. Fernandes DJ, Peres RV, Mendes AM, Elias CN. Nickel-titanium alloys in dentistry. Int Sch Res Not. 2011;2011:132408.
14. Ryhänen J. Biocompatibility evaluation of nickel-titanium shape memory metal alloy [PhD thesis]. University of Oulu; 1999.
15. Duerig T, Pelton A, Stöckel D. An overview of nitinol medical applications. Mater Sci Eng A. 1999;273–275:149–60.
16. Yang C, Abanteriba S, Becker A. Developments in applications of shape memory alloys. AIP Adv. 2020;10.
17. Ohki T, Roubin GS, Veith FJ, Iyer SS, Brady E. A comparison of stents for peripheral arterial disease. J Vasc Surg. 1999;30(6):1034–44.
18. Saw J. Coronary artery anomalies: current perspectives. Can J Cardiol. 2014;30(1):22–34.
19. Auricchio F, Boatti E, Conti M, Marconi S. Modeling of shape memory alloys. In: Shape Memory Alloy Engineering. Elsevier; 2021. p. 627–58.
20. Machado LG, Savi MA. Medical applications of shape memory alloys. n.d.
21. Lagoudas DC, Rediniotis OK, Khan MM. Shape memory alloys: modeling and applications. In: Scattering Theory in Biomedical Engineering Modeling and Applications. 2000. p. 195–207.
22. Wayman CM. Shape memory phenomena. J Met. 1990;6:149–56.

23. Song G, Ma N, Li H-N. Applications of shape memory alloys in civil structures. Eng Struct. 2006;28(9):1266–74.
24. Qian H, Umar M, Ayaz Khan MN, Shi Y, Manan A, Raza A, Li F, Li Z, Chen G. Emerging trends in smart materials for structural health monitoring. Mater Today Commun. 2024;40:109738.
25. Khalifa E, Khichadiya J, Rao VJ. A review on shape memory alloys. Int Res J Eng Technol. 2021.
26. Costanza G, Tata ME. Shape memory alloys in aerospace applications. Materials (Basel). 2020;13(4).
27. Yuchen C, Xing S, Jiefeng L, Jinjin C. Review of shape memory alloy applications in aerospace. Chin J Aeronaut. 2019;32(5):1040–50.

