



A BRIEF REVIEW OF CHARACTERISTICS AND APPLICATIONS OF SHAPE MEMORY ALLOYS IN ENGINEERING AND RELATED FIELDS

Wasiu Ayinde Issa^{1,2*}, Huseyin Camur¹ and Mahmut Savas¹

¹Department of Mechanical Engineering, Near East University, Nicosia, Cyprus

²Department of Mechanical Engineering, Kwara State University, Malete, Nigeria

*Corresponding Author

ABSTRACT

Shape Memory Alloys shortened as SMA's are examples of smart materials. They sense and respond to changes in environmental conditions or stimuli, such as chemical, electrical, mechanical among others. This review, discusses the concept of SMA's, including their engineering effects and innovations in SMA's research. Similarly, the uses and applications of SMA's in engineering and related fields such aerospace, biomedical, chemical, civil, electrical, and mechanical engineering are reviewed briefly including the merits and demerits of using SMA's.

Keywords: Applications, Demerits, Engineering, Merits, Shape Memory Alloys, Smart Materials.

Cite this Article: Wasiu Ayinde Issa, Huseyin Camur and Mahmut Savas, A Brief Review of Characteristics and Applications of Shape Memory Alloys in Engineering and Related Fields, *International Journal of Mechanical Engineering and Technology (IJMET)*, 12(9), 2021, pp. 34-43.

<https://iaeme.com/Home/issue/IJMET?Volume=12&Issue=9>

1. INTRODUCTION

Shape Memory Alloys shortened as SMA's belong to a group of engineering materials referred to as smart materials [1]. These are materials that exhibit the ability to adjust themselves with respect to changing load conditions [2,3]. SMA's are materials with intelligent behaviour of changing their shape with respect to varying external conditions. The deformed shape can attain its initial state due to some external stimulus, such as mechanical, electrical, chemical, thermal and electro-magnetic [4-8]. Nitinol and copper base alloys [9], are two common examples of shape memory alloys. SMA's have wide applications in many areas of engineering [10-12] with respect to their unique properties [13]. Among these includes applications such as automotive, aerospace, oil and gas, biomedical and robotics [14]. This brief review aims at discussing some of the trends in SMA usage in engineering and biomedical engineering with respect to the merits and demerits of using the smart materials.

2. BASIS OF SHAPE MEMORY EFFECT

The SMA deformation usually occurs at a relatively low temperature but the material remembers (shape memory) upon heating [9]. This occurs as a result of a diffusionless martensitic phase transformation that accompanies the reversion back to the original size/shape [9].

The two mostly used behaviors of the materials are the shape memory effect, SME and super elasticity, SE also known as pseudo elasticity. The initial shape can be recovered through heating of the shape memory effect and unloading of the pseudoelasticity, respectively. The reversible martensitic transformation is induced by stress for superelasticity and temperature for shape memory effect [4,15,16].

Polymer materials also can exhibit shape memory behavior and are known as shape memory polymers, SMP's. SMA's and SMP's are two major shape memory materials being widely studied [17-19].

3. ENGINEERING APPLICATION

The benefits of crystallographic phase change of Shape Memory Alloys have been explored over the years in various areas including aerospace, civil, mechanical among others [20].

3.1. Aerospace Engineering

SMA's usage in aerospace will improve the efficiency of the aircraft through reduction in weight and operational cost [21]. Since the application of shape memory technology in the aerospace industry on F-14 hydraulic tubing coupling in the early '70s till the present time, much researches utilizing shape memory effects has increased [20, 22].

The deformation of the SMA's can help to lower the aerodynamic load with respect to the required condition [23]. Also, there is lack of structural rigidity by the lifting components of the aircraft [21]. SMA is useful in morphing aircraft. A shape memory alloy can be used to morph the flap of airplane [24]. Bashir et al. compared a morph flap with a conventional mechanical flap and observed that the morphed flap is better than conventional flap in terms of lift/drag ratio. Thus replacing a conventional mechanical flap with a morph flap can help to achieve a more efficient flight level [25]. The Smart and Aircraft and Marine Propulsion (SAMPSON) system demonstration project [26, 27], among others, are aimed at identifying novel material with shape compliant structures for aircraft [25].

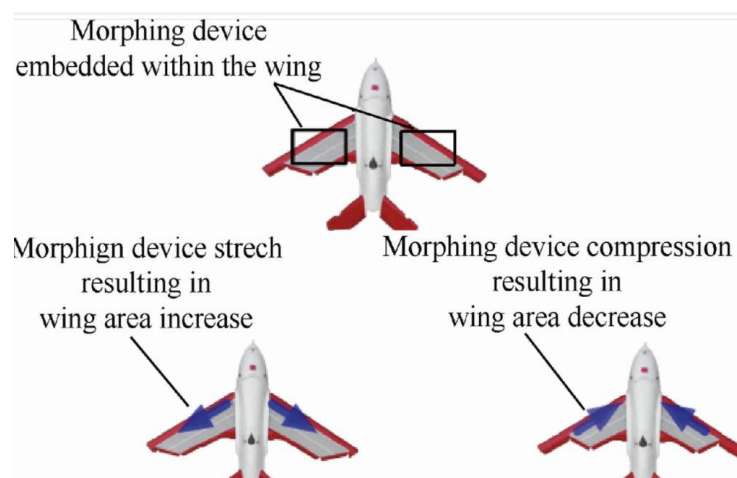


Figure 1 Morphing devices application on aircraft [28].

A mesh washer utilizing a pseudoelastic property of shape memory alloy proposed by Kwon et al. [29] is useful in reducing some of the problems associated with the launch of an aircraft [25]. SMA's application in a spacecraft is concerned with solving problems associated with the launch of a spacecraft or its operation [25, 30].

3.2. Biomedical Engineering

SMA's application in biomedical engineering covers the circulatory system (Vascular Field), dentistry (Orthodontic Field and implantology), Brain treatment (Neurosurgical Field), Bone fracture treatment (Orthopaedic Field), among others [4, 31, 33].

Li et al. added copper as alloying element in a Ti-Ni SMA to produce a ternary alloy of Ti-Ni-Cu which can help to prevent bacterial infections on medical implants [32]. SMA usage in orthodontics helps to provide a homogeneous distribution of constant force as compared to stainless steel braces [31]. Bone plates based on the shape memory effect implanted between two broken bones aid quick recovery of mobility as compared to the conventional surgical approaches [31].



Figure 2 Orthopedic staple [33, 34].

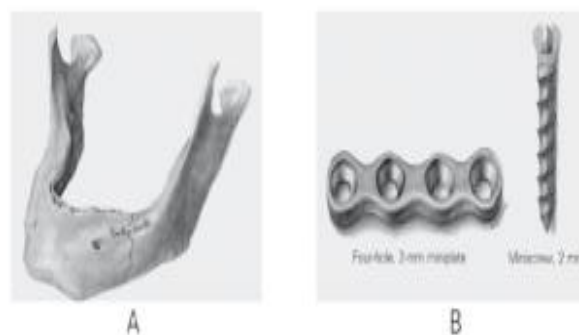


Figure 3 SMA bone plates: (A) plates in use, (B) Plate and screw details [33, 35].

3.3. Chemical Engineering

Liu et al. showed the usage of iron based SMA pipe couplings successfully in chemical plants, oil field and underground water to prevent corrosion and leakage [36]. This may help to reduce the problem of oil spillage in the petroleum industry.

3.4. Civil Engineering

Shape Memory Alloys have been used in engineering structures. Wen-Shao and Yoshikazu observed that the SMA's developed by an EU-funded Istech project [37] comprising SMA wires of nickel–titanium can be used to prevent building collapse or extensive deformation of slender buildings, depending on how the SMA is attached to the building [38].



Figure 4 SMA device developed in the Istech project [37, 38].

SMA is also useful in seismic regions when installed in buildings [39]. Buildings and bridges fail in regions prone to earth quake due to extensive lateral displacement leading to damages [39]. Thus, installing SMA's as reinforcement material in such structures in seismic regions, would help to regain much deformation [40].

Another SMA used in civil engineering includes shear frame structures with a multi degrees of freedom, SMA's bars used for highway bridges, re-centering wire made of SMA's for civil structures, among others [41-43].

3.5. Electrical and Computer Engineering

SMA's have found applications in electronics, power, telecommunication, and computer. Jose Macques et al. developed and tested a rotary motor that was driven by Ni-Ti SMA mini springs and observed that the system produces higher torque to motor weight ratio, and energy density index, when compared with other similar motors [44]. SMA's can also be used as micromanipulator, which was developed using SMA wire as driving material and the substrate being a spring steel [45].

Other applications encompasses the development work of a microcomputer code lock to improve lock reliability and security, which was actuated by a SMA spring [46]; in Fuze-Safety System [47]; in mobile communication system as in telephone antenna utilizing the super elasticity principle [21,48 ,49].



Figure 5 Telecommunication phone antenna based on superelastic behaviour [49]. (Courtesy of Fujitsu Corp.)

3.6. Mechanical Engineering

Nitinol SMA's are widely used in automobile. Modern cars use SMA actuators which are useful in providing drivers comfort and improving drivers' safety [21]. SMA's can be utilized in heat engines [21]. Engine mechanical power can be generated from a SMA made of Ni-Ti [50]. This can be achieved through the expansion of the Ni-Ti SMA wire wound over the engine and depending on whether hot or cold air is passing through the SMA based on the shape memory effect [50, 51].

Jaronie et al. reported the possible applications of SMA's in a car with respect to their areas of functionality [52].

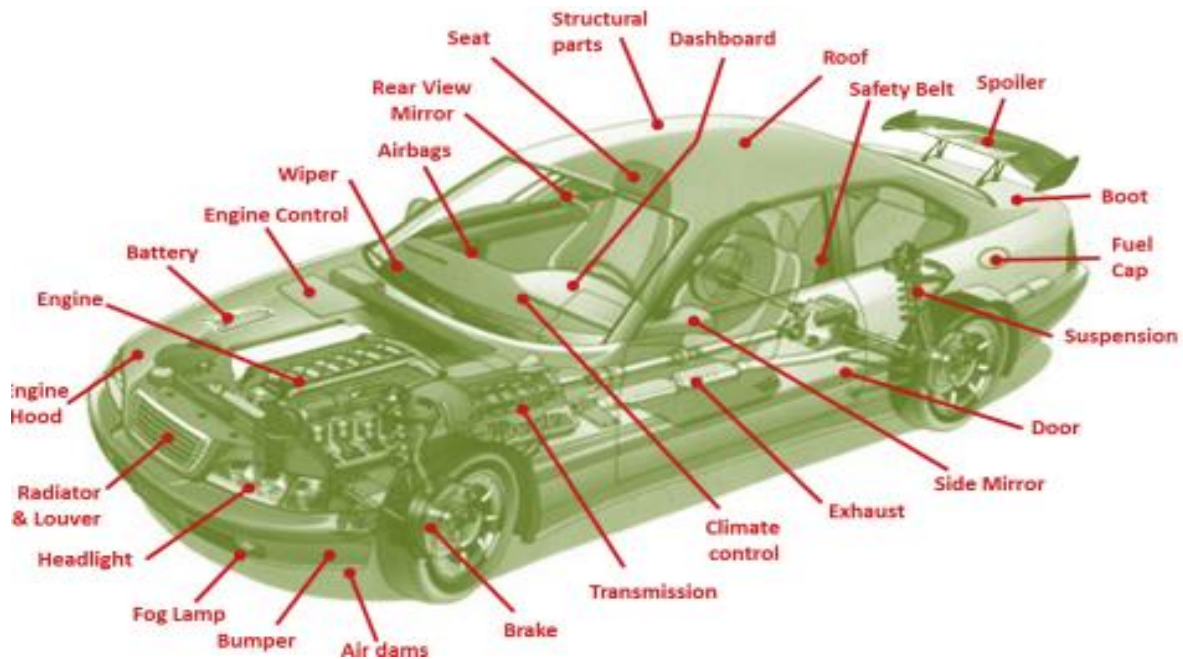


Figure 6 Possible applications of SMA in an automobile [52-55].

Other uses can be seen in naval operations and commercial water ways [21, 56]; in internal electric resistance feedback as actuators [21, 57]; for soft actuating materials in robotic gripper application [21, 58]; to mention but few.

In addition, SMAs find application in household devices [21]. For instance, it can be used in rice cooker as excess steam is expelled out through the opening of the pressure control valve of the rice cooker by the spring of the shape memory alloy [59].

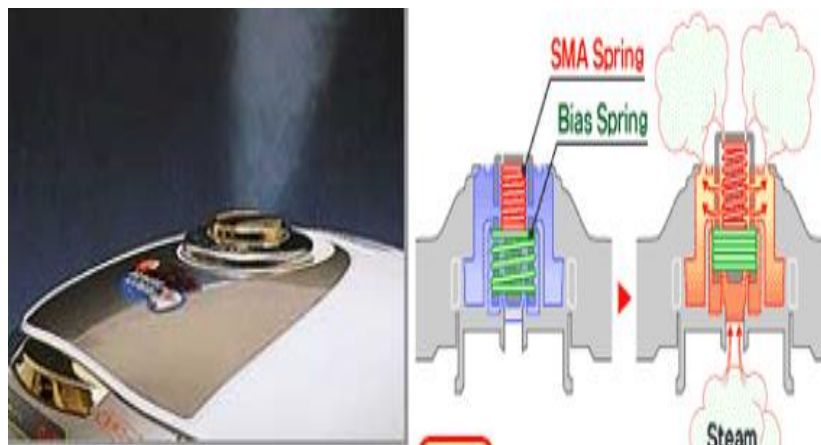


Figure 7 SMA used in rice cooker [59].

SMA's application in air conditioner helps in moving the flap of the air conditioner [21]. SMA spring changes the direction of the louver to upward when cooling and downward when heating in an air conditioning system [59].

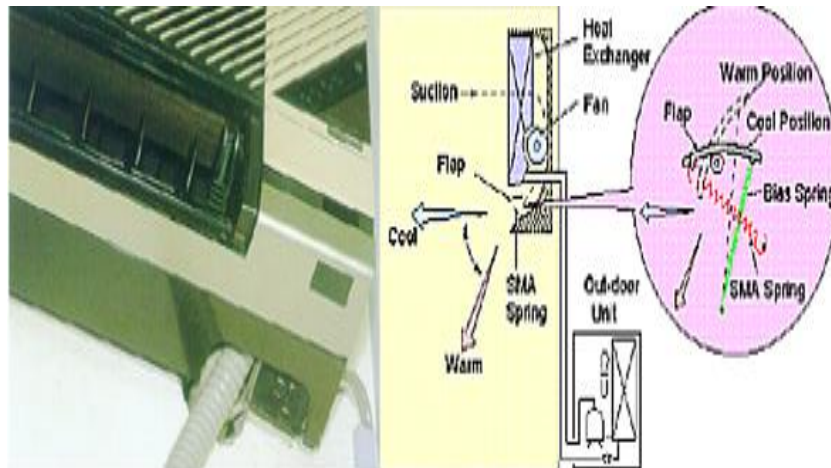


Figure 8 SMA used in Air Conditioner [59].

SMA is also useful in coffee maker [21]. Boiled hot water is being poured over the coffee beans by the spring of the SMA [59].

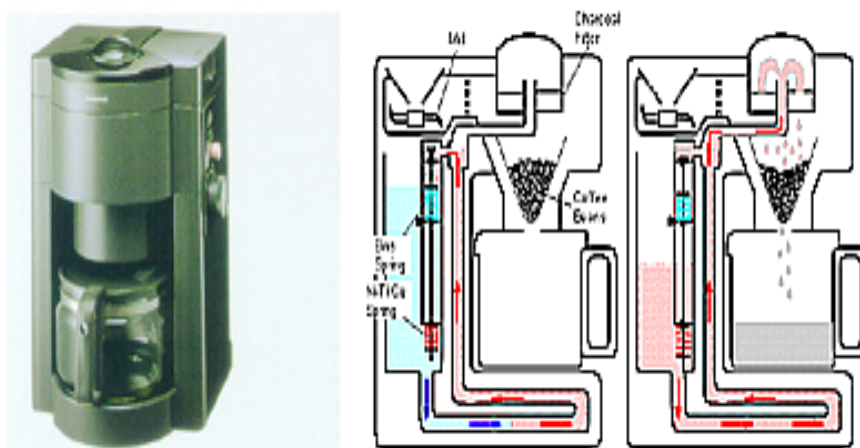


Figure 9 SMA used in coffee maker [59].

4. CONCLUSION

This brief review is concluded by discussing some of the merits and demerits of using SMA's.

4.1. Merits of SMA's

- SMA's have capabilities of providing sufficient actuation stress through a wide strain range.
- A SMA single component can be enough in terms of providing actuation as compared to a hydraulic or an electromechanical actuator with an advantage of weight reduction.
- SMA's aid in the production of very flexible actuation components as they can actuate in three dimensions [30].

4.2. Demerits of SMA's

- Fatigue of SMA's remain a challenge due to repeated load cycles.
- SMA's have low actuation efficiencies which pose a challenge when a SMA is used on spacecraft with limited power [30].

REFERENCES

- [1] S. Zareie, A. M. Shahria, R. J. Seethlaer, and A. Zabihollah, Effect of shape memory alloy-magnetorheological fluid-based structural control system on the marine structure using nonlinear time-history analysis, *Journal of Applied Ocean Research* 91, 2019, 101836.
- [2] J. M. Jani, M. Leary, A. Subic, and M. A. Gibson, A review of shape memory alloy research, applications and opportunities, *Materials and Design* 56, 2014, 1078–1113.
- [3] S. Zareie, M. S. Alam, R. J. Seethaler, and A. Zabihollah, A novel shape memory alloy-based element for structural stability control in offshore structures under cyclic loading, *Journal of Ships Offshore Structures* 2019, 1–8.
- [4] L. Petrini, and F. Migliavacca, Biomedical applications of shape memory alloys, *J. Metall.* 2011, 1–14.
- [5] J. W. Cho, J. W. Kim, and Y. C. Jung, Electroactive shape-memory polyurethane composites incorporating carbon nanotubes, *Macromol Rapid Commun* 26, 2005, 412–416.
- [6] A. Lendlein, A. M. Schmidt, and M. Schroeter, Shape-memory polymer networks from oligo (ϵ -caprolactone) dimethacrylates, *Journal of Polymer Science Part A: Polymer Chemistry* 43 2005, 1369–1381.
- [7] F. Ji, Y. Zhu, and J. Hu, Smart polymer fibers with shape memory effect, *Journal of Smart Materials and Structures* 15, 2006, 1547.
- [8] A. Lendlein, H. Jiang, and O. Junger, Light-induced shape-memory polymers, *Nature* 434, 2005, 879–882.
- [9] W. D. Callister, and D. G. Rethwisch, *Materials Science and Engineering An Introduction*, (John Wiley & Sons, Inc. 2010) 379-383.
- [10] H. Aryan, and M. Ghassemieh, Mitigation of vertical and horizontal seismic excitations on bridges utilizing shape memory alloy system, *Adv. Mater. Res.* 831, 2014, 90–4.
- [11] S. Zareie, and A. Zabihollah, Semi-active SMA-MRF structural stability element for seismic control in marine structures, *Journal of Applied Ocean Resources* 100, 2020.
- [12] S. Yan, Z. F. Xiao, M. Y. Lin, and J. Niu, Numerical analysis of dynamic behavior of prestressed shape memory alloy concrete beam-column joints, *conference series: materials science and engineering* 348, 2018, 12013.
- [13] C. Cisse, W. Zaki, and T. B. Zineb, A review of modeling techniques for advanced effects in shape memory alloy behavior, *Smart Materials and Structures* 25 (10), 2016, 103001.
- [14] S. Barbarino, F. Saavedra, E. I. Ajaj, R. M. Dayyani, and I. Friswell, A review on shape memory alloys with applications to morphing aircraft, *Smart Materials and Structures* 23(6), 2014, 063001.
- [15] J. Ma, I. Karaman, and R. D. Noebe, High temperature shape memory alloys, *International Materials Reviews* 55 (5), 2010, 257–315.
- [16] K. Tsuchiya, Mechanisms and properties of shape memory effect and superelasticity in alloys and other materials, A practical guide, In: *Shape Memory and Superelastic Alloys*, (Woodhead Publishing 2011) 3–14.

A Brief Review of Characteristics and Applications of Shape Memory Alloys in Engineering and Related Fields

- [17] E. Hornbogen, Comparison of shape memory metals and polymers, *Advanced Engineering Materials* 8 (1-2), 2006, 101–106.
- [18] I. S. Gunes, and S. C. Jana, Shape memory polymers and their nanocomposites: A review of science and technology of new multifunctional materials, *Journal of Nanoscience and Nanotechnology* 8 (4), 2006, 1616–1637.
- [19] F. El Feninat, G. Laroche, M. Fiset, and D. Mantonovo, Shape memory materials for biomedical applications, *Advanced Engineering Materials* 4(3), 2002, 91-104.
- [20] K. R. Melton, General applications of shape memory alloys and smart materials, In *Shape memory materials*, Otsuka, K. Wayman, C. M., Eds., (Cambridge University Press, Cambridge 1999) 220–239.
- [21] S. K. Saurabh, K. N. Chethan, G. K. Laxmikant, P. Anand, and N. H. Padmaraj, Innovations and recent trends in Shape Memory Alloy: a review, *International Journal of Engineering and Technology* 7(4), 2018, 2172-2177.
- [22] D. J. Hartl, and D. C. Lagoudas, Aerospace applications of shape memory alloys. *Journal of Aerospace Engineering* 221, 2007, 535-552.
- [23] S. Barbarino, E. I. Saavedra Flores, R. M. Ajaj, I. Dayyani, I. and M. I. Friswell, A review on SMA's with applications to morphing aircraft, *Smart Mater. Struct.* 2004, 23, 63001.
- [24] M. Bashir, P. Rajendram, C. Sharma, and D. Smrutiranjana, Investigation of smart material actuators & aerodynamic optimization of morphing wing, *Materials Today* 5(10), 2018, 21069–21075.
- [25] C. Girolamo, and E. T. Maria, Shape Memory Alloys for Aerospace, Recent Developments, and New Applications: A Short Review, *Materials* 13(8), 2020, 1856.
- [26] E. Garcia, Smart structures and actuators: Past, present, and future, *Proc. of the SPIE Smart Structures and Materials*, San Diego, CA, USA. 2002, 1–12.
- [27] B. Sanders, R. Crowe, and E. Garcia, Defence advanced research projects agency—Smart materials and structures demonstration program overview, *Journal of Intelligent Materials Systems Structures* 15(4), 2004, 227–233.
- [28] Y. Chen, X. Shen, J. Li, and J. Chen, Nonlinear hysteresis identification and compensation based on the discrete Preisach model of an aircraft morphing wing device manipulated by an SMA actuator, *Chinese Journal of Aeronautics* 32(4), 2019, 1040–1050.
- [29] S. C. Kwon, S. H. Jeon, and H. U. Oh, Performance evaluation of spaceborne cryocooler micro-vibration isolation system employing pseudoelastic SMA mesh washer, *Cryogenics* 67, 2015 19–27.
- [30] D. J. Hartl, and D. C. Lagoudas, Aerospace applications of shape memory alloys. *Journal of Aerospace Engineering* 221, 2007, 535-552.
- [31] D. Mantovani, Shape memory alloys: Properties and biomedical applications, *JOM* 52, 2000, 36–44.
- [32] H. Li, K. Qiu, F. Zhou, L. Li, and Y. F. Zheng, Design and development of novel antibacterial Ti-Ni-Cu shape memory alloys for biomedical application, *Sci Rep* 6, 2016, 37475.
- [33] T. Daniela, D. N. Tarniță, N. Bîzdoacă, I. Mîndrilă, And V. Mirela, Properties and medical applications of shape memory alloys, *Romanian Journal of Morphology and Embryology* 50(1), 2009, 15–21.
- [34] GROUP LÉPINE, Available Online: www.groupe-lepine.com/php/fr/index.php (accessed on 19th Sept. 2021).

- [35] Sma/Mems Research Group, Available Online: http://www.cs.ualberta.ca/database/MEMS/sma_mems/sma.html (accessed on 19th Sept. 2021).
- [36] D. Z. Liu, W. X. Liu, and F. Y. Gong, Engineering Application of Fe-Based Shape Memory Alloy on Connecting Pipe Line, *Journal de Physique IV* 5, 1995, 1241-1246.
- [37] M. Indirli, and M. G. Castellano, Shape-memory alloy devices for the structural improvement of masonry heritage structures, *Inter Journal of Architectural Heritage* 2, 2008, 93–119.
- [38] C. Wen-Shao, and A. Yoshikazu, Use of shape-memory alloys in construction: a critical review, *Proc. of the ICE - Civil Engineering*, University of Bath, United Kingdom 169 (2), 2016, 87-95.
- [39] K. Sarth, and V. Zunubia, A Review on: Applications of Shape Memory Alloy in Construction, *IJAERD* 2017, 83-86.
- [40] K. Yachuan, and O. Jinping, Self-repairing performance of concrete beams strengthened using superelastic SMA wires in combination with adhesives released from hollow fibers, *Smart Material Structure* 2008, 025020.
- [41] O. Corbi, Shape memory alloys and their application in structural oscillations attenuation, *Simulation Modeling Practice and Theory* 11, 2003, 387–402.
- [42] K. Wilde, P. Gardoni, and Y. Fujino, Base isolation system with shape memory alloy device for elevated highway bridges. *Engineering Structures* 2, 2000, 222–9.
- [43] M. Dolce, D. Cardone, and R. Marnetto, SMA re-centering devices for seismic isolation of civil structures, *Proc. of SPIE*, Newport Beach, CA, USA, 4330, 2001, 238–49.
- [44] B. S. José Marques, F. C. Maxsuel, E. Angelo, S. Cícero da Rocha, and R. A. Andreas, A compact rotary motor actuated by shape memory alloy mini springs, *Journal of Intelligent Material systems and structures* 31(15), 2020, 1808-1820.
- [45] D. Liu, Micro-manipulator Driven by Shape Memory Alloy Wire, Beijing University of Industry, Available Online: https://en.cnki.com.cn/Article_en/CJFDTotl-ZJYC200109009.htm (Accessed on 16th Sept. 2021).
- [46] Y. Zhang, S. Zhang, and J. Yang, Design of a Microcomputer Code Lock Actuated by Shape Memory Alloy, University of Science and Technology of China, Available Online: https://en.cnki.com.cn/Article_en/CJFDTotl-ZDHY200703001.htm (Accessed on 16th Sept. 2021).
- [47] HAN Zhi-li, LIU Jiang-nan, LI Gao-hong, The Application of Shape Memory Alloys in Fuze-Safety System, Xi'an Institute of Technology China. Available Online: https://en.cnki.com.cn/Article_en/CJFDTotl-XDYX200505001.htm (Accessed on 16th Sept. 2021).
- [48] K. Otsuka, and C. M. Wayman, editor. *Shape memory materials*, (Cambridge University Press 1998) 284.
- [49] K. Otsuka, R. Xiaobing, Recent developments in the research of shape memory alloys, *Intermetallics* 7, 1999, 511–528.
- [50] S. Vollach, R. Caciularu, and D. Shilo, Equilibrium stress during the response of SMA's to an abrupt heat pulse, *Scripta Materialia* 141, 2017, 50–53.
- [51] C. B. Churchill, A. Arbor, and A. L. Browne, SMA, *SIS*2011-2016, 1–6.
- [52] M. J. Jaronie, L. Martin, S. Aleksandar, and A. G. Mark, A review of shape memory alloy research, applications and opportunities, *Materials and Design* 56, 2014, 1078-1113.

A Brief Review of Characteristics and Applications of Shape Memory Alloys in Engineering and Related Fields

- [53] R. W. Johnson, J. L. Evans, P. Jacobsen, J. R. Thompson, and M. Christopher, The changing automotive environment: high-temperature electronics, *IEEE Trans Electron Pack Manuf* 27(3), 2004, 164–176.
- [54] D. Stoeckel, Shape memory actuators for automotive applications, *Materials and Design* 11(6), 1990, 302–307.
- [55] F. Butera, Shape memory actuators for automotive applications, *Adv Mater Processes* 2008, 166:37.
- [56] A. J. Angilella, F. S. Gandhi, and T. F. Miller, Design and testing of a SMA buoyancy engine for unmanned underwater vehicles, *Smart Materials and Structures* 24, 2015, 115018.
- [57] N. Ma, G. Song, and H. Lee, Position control of SMA actuators with internal electrical, *Smart Materials and Structures* 13, 2004, 777.
- [58] W. Wang, H. Rodrigue, H. Kim, M. Han, and S. Ahn, Soft composite hinge actuator and application to compliant robotic gripper. *Composites* 98, 2016, 397–405.
- [59] Furukawa Techno materials, Available Online: <https://www.furukawa-ftm.com/english/nt-e/appli/kaden.htm> (accessed on 19th Sept. 2021).