International Journal of Pure and Applied Mathematics
Volume 118 No. 20 2018, 57-62
ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

Computation and investigation of an SMA engine using low heat recovery

M.R. Nagendra[1], M. Tamilselvan[2], C. Sadhasivam[3]*

[1,2]Student, Department of Mechanical Engineering, Saveetha School of Engineering, SIMATS, Chennai- 602105, TN, India

[3]Associate Professor, Department of Mechanical Engineering, Saveetha School of Engineering, SIMATS, Chennai- 602105, TN, India.

Email: [*1]nagendramakam555@gmail.com [2]tamilselvan277@gmail.com

Abstract— Shape memory alloys (SMA's) are popularly known as smart materials. SMA's When undergo through thermal cycles, mechanical work can be generated by recovering a memorized shape. As they have mechanical properties of this type and also due to their light weight and compactness they can be used in mechanical devices like actuating elements. Shape memory materials (SMM's), have unique property to 'remember' or regain their previous shape when undergone through certain stimulus like thermo magnetic or mechanical variations. As SMAs have many applications they have significant interest and attention from past few years and have broad range of commercial, medical, industrial applications, because of those unique properties; this development and research on SMA's has been supported by fundamental and applied research studies. As demand for energy saving technologies has increased, substantial interest in systems that recover waste heat also have increased. This interest resulted in rapid growth in the rate of publication of related technical articles. If the research on shape memory alloys goes on then there will be significant methods to save the natural resources.
Keywords—SMA, Compactness, thermomechanical.

1. INTRODUCTION

A shape-memory alloy has the property that "memorizes" its pre-defined shape and that when it undergoes deformation, returns to the remembered shape when it is heated. This material is very lightweight and alternative to mechanical devices and also solid-state alternative for conventional actuators known as pneumatic, hydraulic and systems based on motor. Shape-memory alloys also have many applications in automotive and robotic systems, biomedical and aerospace industries.

SMM's have two important types of shape-memory alloys namely copper-aluminum-nickel, and nickel-titanium (NiTi) alloys and SMAs properties can also be formed by alloying copper, gold, zinc and iron. Although copper-based and iron-based SMAs, like Cu-Zn-Al, Fe-Mn-Si, and Cu-Al-Ni, are cheaper and commercially available than nitinol, NiTi based SMAs are only preferred as their stability will be high in the practical usage and they also have superiority in their thermo-mechanic performances. SMA's another unique property is that they can be in different two phases, and six possible transformations with different three crystal structures.

NiTi alloys changes to martensite from austenite due to cooling; Mf is the temperature where the change to martensite from austrnite completes by cooling. similarly, while heating Af and AS are the temperatures where it transforms to austenite from martensite takes place. Shift in the characteristic transformation temperatures can occur due to continuous use of memory effect (this is known as functional fatigue, as it is related closely with a change of functional and micro structural properties of the material). The temperature at which further stress induction in SMAs cannot be done is called Md, at which the permanent deformation has occurred in the SMAs.

The transition to the austenite phase from the martensite phase depends only on stress and temperature but not on time, as in most phase changes are, no diffusion is involved. Accordingly, the name austenite structure is received from its steel alloys which is of similar structure. It is the process which is reversible and diffusion-less transition among these two phases which results in special properties. While martensite can be formed from austenite by rapidly cooling carbon-steel, this process is not reversible, so steel does not have shape-memory properties.

To obtain something from nothing is mostly desirable. Witness the endless fascination with perpetual motion machines. However, thermodynamics has such fanciful systems, probably squeezing out the best from what is going waste actually is the best thing. General motors have promised that it will produce a machine that would use the exhaust or waste heat energy that will come out from vehicles and machines. Maximum percentage of the fuel is burnt waste even by the most advanced internal combustion engines.

2. HISTORY OF SMA ALLOY

shape memory alloy was first discovered back in 1932, by a Swedish scientist Arne Olader when he first discovered that property in alloy named as gold-cadmium alloy. The material, can be physically deformed into any desired shape while cool, but it regains its memorized shape when it is heated. From then Several alloys have been discovered as SMA alloys. Some of them include MnCu, CuSn, TiNi, and InTi.

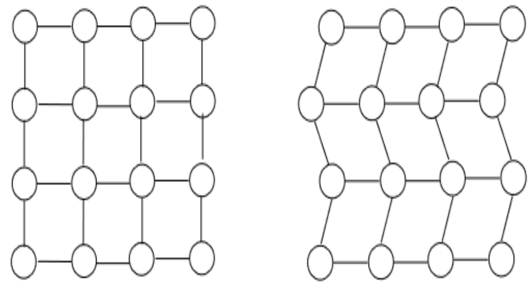
The alloys of TiNi, popularly called as Nitinol, and copper-based alloys which is the most commonly used, because they can regain substantial amount of strain, or the force generated while changing shape is significant. Flexinol is also a kind of shape memory alloy that gives competition to Nitinol in industry. Flexinol, similar to Nitinol, is also a shape memory wire. Flexinol has very good actuation property in the deformation line compared to NiTi and other SMA materials.

William Bueher, David Goldstein are the scientists who have developed Nitinol in 1962 at a laboratory known as Naval Ordinance. The name, "Nitinol," derived from the place and the names of elements in its composit; NIckel TItanium Naval Ordinance Laboratory. They even discovered that Nitinol, when struck, produces sound that changes with temperature. Later the study on SMA helped to discover the phase change of SMA and the phenomenon of SMA by jhonson A.D.

The first applications of the SMAs, in 1970s, was on heat engines. A heat engine means a device that converts heat energy into electrical or mechanical energy. The idea for this was developed from a existing rubber band model heat engine which was discovered long back before SMAs were discovered. With this discovery it is easy to convert the energy into other form just with typical water temperature, which is one of the best way for the application om utilizing energy from the sea.

Metallurgical Property of NiTi Alloy

Unlike to other metallic materials, SMAs can be deformed in large amount without any permanent deformation. Beside sustaining large amount of deformation, upon loading and temperature change they can also recover that strain. This characteristic can be seen/observed in SMAs due to their unique property known as phase transformation mechanism. Nitinol is one type of SMA, which will be as best example in explaining the unique and useful characteristic of SMAs.



(a): High temperature austenite cubic structure

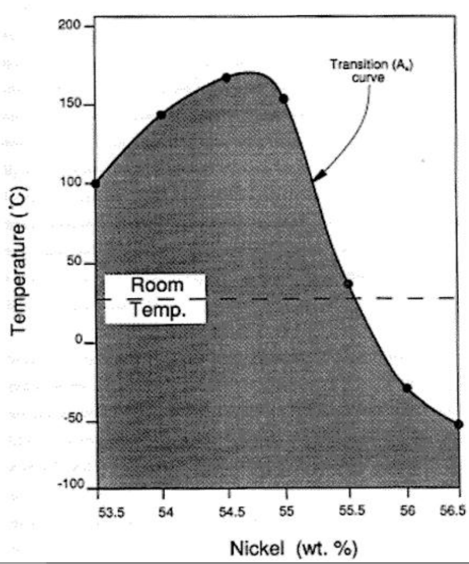
(b): Low temperature martensite (twinned) lattice structure

2.2 EFFECT OF STRESS COMPOSITION AND ANNEALING ON TRANSITION TEMPERATURE OF SMAS

For SMA alloys changing its composition is the basic way to change their transformation temperature. Figure gives a plot that explains about variation in temperature of austenite start regarding to the composition of Nickel. SMA's transition temperature can now be engineered within two degrees of the desired temperature.

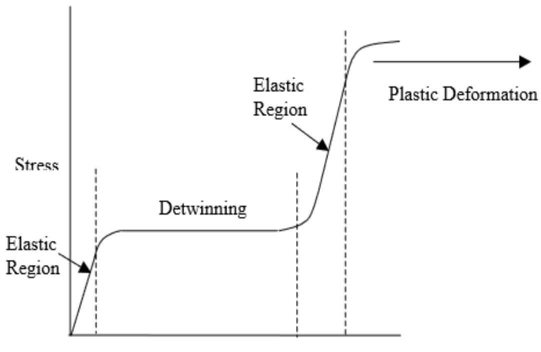
State of stress is the another main factor that affects transition temperature. The temperature of transition raises with stress (Duval, et. al.). As it occurs at higher temperature, if the stress point of SMA reaches where deformed martensite forms. This is because heat energy required is more in overcoming the stress which is increased.

Annealing, it is a process where the metal is heated to annealing temperature which is constrained in a given shape. An annealing process is used to make an SMA to remember its shape. SMAs annealing can be done between 450 and 800 oC. Besides annealing, drawing process and cold swaging cause residual stresses to occur locally within the material's microstructure. These stresses will significantly increase the start and finish transformation temperatures.



2.3 MECHANICAL BEHAVIOR OF Ni-Ti ALLOYS

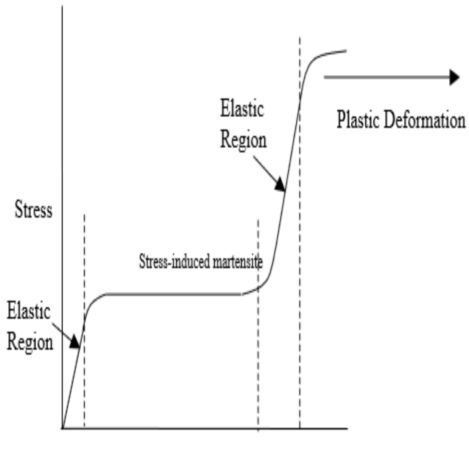
Although the shapes of the curves of a SMA in its martensite state and SMA is in its austenite phase are similar, the scale of the two figures are not the same.



stress and strain behavior of Martensite at temperatures below the finish temperature of martensite.

Martensite stress-strain behavior, it starts with an region known as elastic deformation. When applying a load within this region, the SMA is able to go back to its original length without any deformation when the load is removed. To strain the material into a stable elongated state, one has to strain it into the next stage, the curve in flat portion is indicated as 'detwinning.' Detwinning is the process in which twins are reoriented till they are in the one direction.

The material under go through the second stage of elastic deformation if detwinning is completed. In this and below this region, all the strain can be recovered, which is critical to the design of the heat engine. Any stress applied above this region gives result of plastic deformation in the material.



Stress and Strain Behavior of Austenite at temperatures above the finish temperature of austenite.

The characteristics of austenite stress-strain are shown in above graph. Similar to the martensite phase behavior, the plot starts out with an elastic region, in its austenite phase. At the end of the elastic limit, a martensite phase starts forming while we still have the high temperature environment. This region is what we refer to the "stress-induced martensite region."

3. PROBLEM STATEMENT

In automobile vehicles we use actuators which are running using the power/energy from the engine. This will reduce the efficiency of the vehicle. It will also increase the weight of the vehicle as it needs pulleys to connect with the engine. So we can replace them with SMA low heat recovery engine.

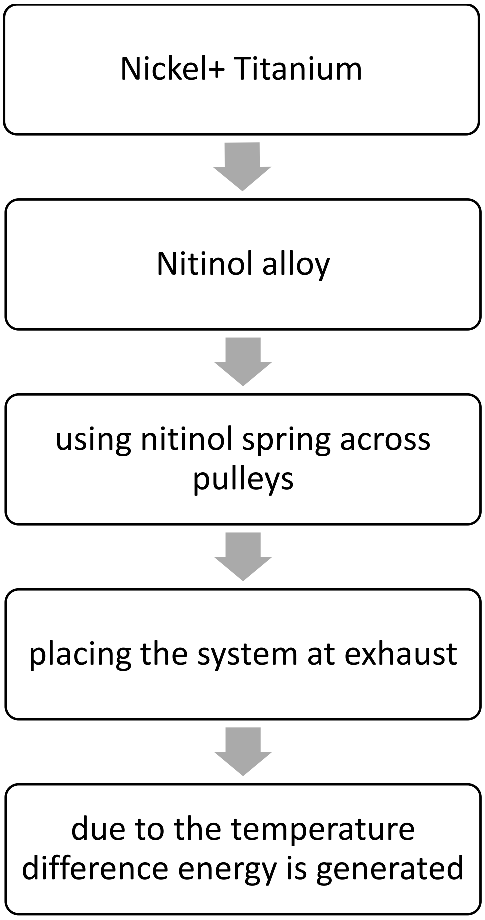
SMA engine has less weight compared to belt and pulley arrangement. So it helps to increase the efficiency of the vehicle. It also decreases the weight of the vehicle due to which fuel efficiency increases. This helps to save the usage of engine power.

3.1 METHODOLOGY

SMA materials have unique properties of remembering and regaining its structure. This property of material is used to extract mechanical energy directly from heat energy. This can be done by forming SMA material into form of wire and employing it across pulleys.

Now the wire at one end need to be in contact with any heat source. This helps the SMA to regain its shape, by which the pulley starts to rotate. This helps to get mechanical energy from heat energy.

This type of engines can be employed into automobile which helps to increase/raise the efficiency of the vehicle, by reducing the weight of the vehicle.



Methodology Flowchart

4. RESULTS AND DISCUSSION

Efficiency of nitinol heat engine can be calculated by

$$\textbf{Efficiency} = \frac{Thot - Tcold}{Thot}$$

The pulleys are placed in hot and cold water having the temperature of hot water is 85 C, and the temperature of cold water is 5 C

Hot water in kelvin 85+273=358k
Cold water in kelvin 5+273 =278k

So the efficiency is

$$\frac{358-278}{358} = 22.34\%$$

POWER OUTPUT:

voltage we get from the motor is 1.9V

$$\textbf{current} = 1.9 \times \frac{1}{1000}$$

$$= 1.9 \text{ mw}$$

5. CONCLUSION

SMA's, can currently designed as material which may be programmed for motion/actuation following to a pre-determined sequence, just like machines, however even with larger flexibility and intelligence which implies that the fabric will sense and so will react consequently, even at molecular level. SMAs/SMPs even have unrolled associate exciting field for a range of engineering applications, that isn't ancient/ standard conventional approach and sometimes problematic for traditional materials and approaches. as an example, we've seen SMP stents that don't seem to be solely degradable, however additionally with controlled drug unharness operate. The emergence of SMHs may open the door wider so SMMs become additional accessible to everybody. whereas the most trend at the present is to attain novel/unique functions/features, we should always bear in mind the wants so as to be relevant in our lifestyle and property for the long run. As the environment is to be taken care and it is most important thing to be concerned recycling of the products mostly electronics have been proposed. SMA's have proposed for recycling the electronics without any touching physically which have gained the interest of all electronic companies at times.

REFERENCES

[1] N.S. Lam, K.D. Schoenwald, D.W. Snyder, and D. S. Watson, Senior Design Report, University of Central Florida (2007).

[2] H. Funakubo, *Shape Memory Alloys*, Gordon and Breach Science Publishers, New York, 1987.

[3] L.M. Schetky, "Shape Memory Alloy Applications in Space Systems", in *Engineering Aspects of Shape-Memory Alloys,* edited by T. W. Duerig, K. N. Melton, D. Stöckel and C. M. Wayman, Butterworth-Heinemann, London, 1990, pp.170-178.

[4] K. Uchino, "Shape Memory Ceramics", in *Shape Memory Materials*, edited by K. Otsuka, and C. M. Wayman, Cambridge University Press, 1998, pp.184-202.

[5] R. Vaidyanathan, "Shape-Memory Alloys", in *Kirk-Othmer Encyclopedia of Chemical Technology*, Wiley InterScience, John Wiley and Sons Inc., New York, 2002 edition.

[6] W.J. Buehler and F.E. Wang, Ocean Eng. 1, (1967)105.

[7] V.B. Krishnan, Master Thesis, "Design, Fabrication and Testing of a Shape Memory Alloy based Cryogenic Thermal Conduction Switch", University of Central Florida (2004).

[8] S. Miyazaki and C.M. Wayman, Acta Metall., 36 (1988) 181.

[9] K. Gall, J. Tyber, V. Brice, C.P. Frick, H.J. Maier and N. Morgan, Journal of Biomedical Materials Research, 75A (2005) 810.

[10] K. Bhattacharya, Acta. Metal. Mater. 39 (1991) 2431.

[11] I. Ohkata and Y. Suzuki, "*The design of shape memory alloy actuators and their applications*", *Shape Memory Materials,* Cambridge University Press, Cambridge, UK, 1998.

[12] T.W. Duerig and A.R. Pelton, "*Ti-Ni Shape Memory Alloys*", Material Properties Handbook: Titanium Alloys, ASM International, 1994, pp.1035-1048.

[13] S. Miyazaki, Y. Jgo and K. Otsuka, Acta metal., 34 (1986) 2045.

[14] T. Saburi, Proceedings of ICOMAT 92, (1993) pp. 857-869.

[15] K.N. Melton, "*Ni-Ti Based Shape Memory Alloys*", in Engineering Aspects of Shape Memory Alloys, edited by T.W. Duerig, K.N. Melton, D. Stöckel

and C.M. Wayman, 1990, pp.21-35.
[16] J.H. Mulder, P.E. Thoma and J. Beyer, Z. Metalkunde, 84 (1993) 501.
[17] P.E. Thoma, M. Kao, S. Fariabi and D.N. Abyudom, Proceedings of ICOMAT' 92, (1993) pp.917-922.
[18] S.Prabhavathi, 2D.M.Chitra, "International Journal of Innovations in Scientific and Engineering Research (IJISER), Vol.2, No.1, pp.1-7, 2015.
[19] D.E. Hodgson, "Using Shape Memory Alloys", Shape Memory Applications, 1988.
[20] D. Stöckel, Actuator'92, 3rd International Conference on New Actuators, (1992) pp.79- 84.
[21] Y. Suzuki and H. Horikawa, Materials Research Society Symposium Proceedings, Vol. 246 (1991) pp.389-398.
[22] R.J. Salzbrenner, and M. Cohen, Acta Metall. 27 (1979) 739.
[23] C.R. Rathod, B.C. Clausen, M.A.M. Bourke, and R. Vaidyanathan, Appl. Phys. Lett. 88 (2006) 201919-3.
[24] J.L. Lemanski, V.B. Krishnan, R. Mahadevan Manjeri, W.U. Notardonato and R. Vaidyanathan, in: U. Balachandran (Ed.), Adv. in Cryo. Eng., 52 (2006) pp.3-10.
[25] V.N. Khachin, Y.I. Paskal, V. E. Gunter, A.A. Monasevich, and V.P. Sivokha, Phys. Met. Metallogr. (1978) 46.
[26] H.C. Ling, and R. Kaplov, Metall. Trans. A, 11 (1980) 77.
[27] M.B. Salamon, M.E. Meichle, and C.M. Wayman, Phys. Rev. B, 31 (1985) 7306.
[28] K. Otsuka, "*Introduction to the R-Phase Transition*", Engineering Aspects of Shape Memory Alloys, Butterworth-Heinemann, 1990, pp.36 - 45.
[29] H. Tamura, Y. Suzuki and T. Todoroki, Proceedings of ICOMAT-86, (1986) pp.736- 742.
[30] T. Saburi, Proceedings of the MRS International Meeting, 9 (1988) pp.77-92.
[31] S. Miyazaki, Y. Ohmi, K. Otsuka, and Y. Suzuki, J. De Phys. 43 12 (1982) C4-255.
[32] W.B. Cross, A.H. Kariotis, and F.J. Stimler, NASA CR-1433, September 1969.
[33] T. Saburi, T. Tatsumi, and S. Nenno, J. De Phys. 43 12 (1982) C4-26.
[34] M. Matsumoto and T. Honma, JIM International symposium (Kobe) (1976), pp.199-204
[35] C.M. Wayman, L. Cornelis, and K. Shimiz, Scripta Mater. 6 (1972) 115.