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Fabrication and COP Calculation of Thermoelastic Cooling System

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ABSTRACT

Vapour pressure is the most encouraging innovation for meeting all the cooling and refrigeration needs around the entire world. It is a develop innovation yet its ecological effects remain a worldwide issue. VC's refrigerants, for example, hydrochloroflurocarbons (HCFC) and hydroflurocarbons (HFC) are a noteworthy wellspring of nursery discharges, and a dangerous atmospheric deviation potential (GWP) of these toxins is high 1000 times than CO2. So there is a critical need to build up an option high proficient cooling innovation that is moderate for the commercialization and environment inviting as well. Thermo-elastic cooling framework is among one of the option advances, and have exhibited promising execution potential on the material level. We exhibit that thermo-elastic cooling; a sort of cooling system which depends on the inert warmth of reversible marten-sitic change can have a coefficient of execution up-to 11, with a specifically measured ΔT up-to 17K. The execution of thermo-elastic cooling cycle utilizing Ni-Ti (Nitinol) composite was assessed based upon an adaptable model created in this study. It was found that the general framework COP was 1.53 for a standard case considering both driving engine and pump control utilizations, while COP ran from 5.2 to 7.7 when assessed with future enhancements. This new idea of separating cooling by pressing a strong state shape memory compound has pulled in individuals' consideration since it is an exceptional and new idea and does not depend upon fluorinated liquids. Thermo-elastic cooling framework has shown its potential for cooling in view of its better idle warmth than other focused advancements. The idea of thermo-elastic cooling framework is a feasible and ecological neighbourly cooling choice yet it is still in an early innovative work arrange. With the more research endeavours and upgrades to be carried out in future, this fresh out of the plastic new cooling innovation could be utilized as a part of our homes and workplaces.

Key words: Shape Memory Alloy, Thermo-elastic, Nitinol, Marten-site, Austenite

INTRODUCTION

Thermo-elastic cooling framework otherwise called Elastocaloric cooling framework is one of the most recent non vapour pressure innovation alternatives that pumps warm from a low temperature warm source to a high temperature sink, by using the Martensite-Austenite Phase change found fit as a fiddle memory amalgams (SMA).Thermo-elastic cooling framework utilizes a strong state material i.e.; a shape memory metal composite like a refrigerant and a strong to strong stage change to assimilate or discharge the dormant warmth. The exothermic stage change happens after focusing on the compound, which might be drafted by pressure, strain or by torsion. Cooling is accomplished amid the turnaround stage change handle when the anxiety is expelled. The elastocaloric cooling impact can be investigated by utilizing a wire made up of a shape memory compound. At the point when wire is focused on, it is really compelled to change its atomic arrangement to a martensite stage discharging inert warmth. This measure of warmth leaves a smouldering sensation to the skin. Upon stress evacuation, the wire changes back to its unique stage by engrossing comparable measure of warmth and give a frosty cool sensation to the touch [1].

SHAPE MEMORY ALLOY FOR REFRIGERATION

The shape-holding amalgam Nitinol (Nickel Titanium Naval Ordnance Laboratory), the 'compound with a memory remembrance, is reforming the assembling, designing, and medicine. William Buhler and his group named their new composite Nitinol (affirmed night-taking all things together) and it was not made deliberately. Really they were attempting to accomplish a warmth safe and erosion free combination. During the time spent making a destructive safe composite, they by shot, made a Shape Memory Alloy (SMA) made up of 55% nickel and 45% titanium as an unpleasant rate. This new material was moderately modest and much more secure than past SMA. The ‘Ni’ and ‘Ti’ are the nuclear images to speak to nickel and titanium. The ‘NOL’ speaks to the Naval Ordinance Laboratory since it was discoveredat that place [2]. In [3] Manosa et al studied the utilization of shape memory composite for mechanical refrigeration. The extensive temperature slope assessed for this impact, suggestthat there is a plausibility of utilizing this amalgam as a part of mechanical iceboxes. In [4] Ossmer et al utilized shape memory amalgam movies for elastocaloric cooling. The elastocaloric impact in Ni50.4Ti49.6 movies of 20 µm thickness is concentrated on by method for the ductile test and infrared thermography strategy., a most extreme temperature change of 16 K was watched for adiabatic conditions.

Tušek et al contemplated Elastocaloric impact of Ni-Ti wire for application in a cooling gadget. They provide details regarding the elastocaloric impact of a super versatile Ni-Ti wire to be utilized as a part of a cooling device.They examined the effect of the preparation temperature and coming about super flexible conduct on the adiabatic temperature changes. The most extreme measured adiabatic temperature angle amid the anxiety applying was 25K with a relating 21K change amid emptying. An exceptional concentration was put on the irreversibility's in the adiabatic temperature changes amongst emptying and stacking. At that point it was onlooker that there were two wellsprings of the temperature irreversibility's: the hysteresis and the transitory remaining strain created instantly subsequent to emptying separately [5]. Cui et al made a first working model of Thermoelastic cooling framework that comprises of a SMA plate which is been associated between two rotating actuators that could create usable space cooling by swaying the SMA core have tentatively exhibited SMA COPs of 2.7 for pressure (source temperature of 5°C and sink temperature of 47.5°C) and 3.05 for pressure (source temperature of 9°C and sink temperature of 29°C).

Studies suggest that nitinol has 17K adiabatic temperature span [6], whereas the Cu-Zn-Al and Cu-Al-Ni had 10K adiabatic temperature span. The nitinol also has much better mechanical superelastic performance than copper based alloys because copper based alloys are brittle and thus have poor fatigue performance. The major drawback of nitinol compared to copper based SMAs is the higher hysteresis [7], which may be reduced by adding small amount of copper Bechtold et al [8]. Physical properties and phase change parameters of some well-known shape memory alloys (SMA) are given in Table 1.

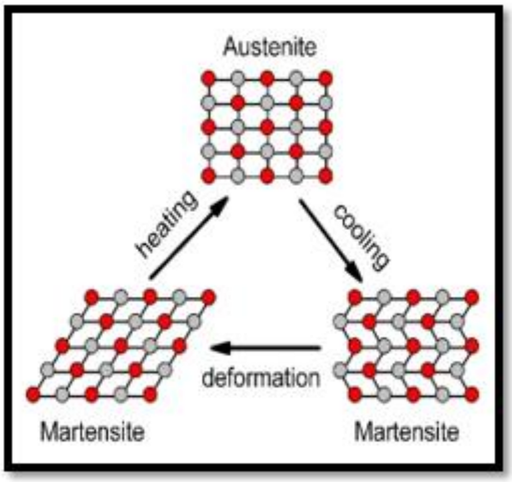

Fig.1 Phase Transformation of SMA

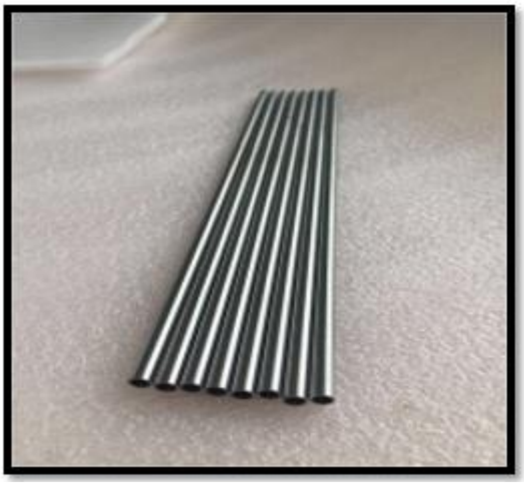

Fig.2 Shape memory alloy used in prototype

Table 1 - Physical Properties and Phase Change Parameters of Some Common Shape Memory Alloy SMA

Materials	Ni-Ti	Cu-Zn-Al	Cu-Al-Ni
Density[kg m^{-3}]	6400-6500 (6500)	7500-8000 (7900)	7100-7200 (7150)
Cp[J kg^{-1} K^{-1}]	470-620 (550)	390-400 (400)	373-480 (440)
Conductivity[W m^{-1} K^{-1}]	8.6-18 (18)	84-120 (120)	30-75 (75)
Δs[J kg^{-1} K^{-1}]	42	19-26 (20)	20-30 (20)
ΔT_{ad}[K]	22.9 (300 K)	15.0 (300 K)	13.6 (300 K)
Transformation temp [ºC]	-200-200	-200-150	-200-200
A[J kg^{-1}]	120	155	280
K[MPa]	1.72×10^4	3.10×10^4	4.90×10^3
Δ	0.02	0.025	0.029

Table 2 - Physical and Chemical Properties of Ni-Ti Tubes used in this Prototype

Physical Properties		**Chemical Composition (%)**	
Condition	Polished	Ni	55.9
Tensile strength [Mpa]	1685	Ti	Reminder
Yield strength [Mpa]	720	C	0.005
Elongation [%]	14.7	O	0.004
Af Temperature [ºC]	20±5	N	0.0008
Outer dia. [mm]	5	H	0.001
Inner dia. [mm]	4	Co	<0.005
Length [mm]	255	Cr	<0.005
Weight of each tube [g]	12.5	Nb	<0.01
No. of tubes	14	Fe	<0.01

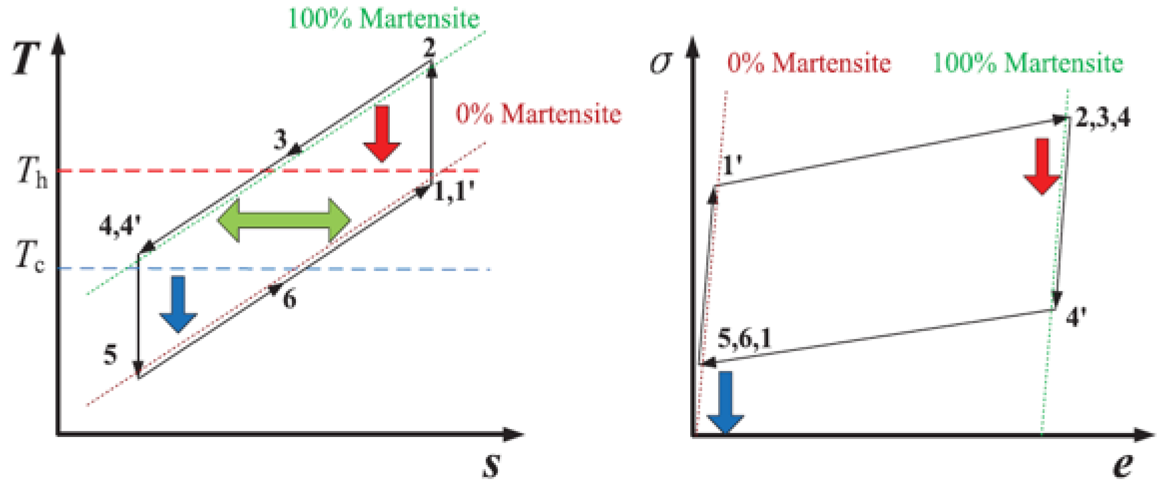

Fig. 3Reverse brayton cycle and its variation as a thermo-elastic cooling cycle

NITINOL USED IN THIS PROTOTYPE

One of the above combinations Ni-Ti called as NITINOL is utilized as a part of this venture as shape memory amalgam since it is more steady and less fragile than copper based compounds. Ni-Ti amalgams are requested intermetallic mixes in view of equal-atomic creation of, 50.9% Ni. Additionally, Because Ni-Ti composites have much higher quality, bigger recoverable strain, better erosion resistance and higher dependability figure than Cu. Despite the fact that the blend of nickel to titanium in Ni-Ti is about equivalent yet a little change in the proportion of mixes drastically affects the move temperature. For example, a 1% change in the proportion of combination differs the move temperature from [- 100C to +100C]. Physical and chemical properties of nitinol that is been used in this prototype are given below in Table -2.

The shape memory alloy is used in prototype is in the form of tube and is being polished to avoid corrosion and damages because the huge amount of stress being applied on this for the purpose of achieving cooling. The shape memory alloys tube which is being used in this project are shown in fig.2

THERMODYNAMIC CYCLE OF THERMOELASTIC COOLING SYSTEM

As indicated by thermodynamics, the cooling/warm pump cycle is a switch control cycle, since warmth is pumped from a low temperature warm locale (adapted space) to a high temperature warm sink (surrounding). For a perfect Thermo-elastic material worked under invert Carnot cycle, cooling, warming and power info can be appeared by the accompanying conditions [1].

$$q_c=T_c\Delta s$$
$$q_h=T_h\Delta s$$
$$W_{net} = q_c-q_h$$
$$W_{net} =-(T_h-T_c)\ \Delta s$$

Thermo-elastic cooling/warm pump cycle can likewise be accomplished by means of fundamental thermodynamic cycles: invert Brayton cycle which is appeared in Figure underneath.

Reverse Brayton Cycle

- It starts from state 1 which the material is under unstressed austenite phase, and then stress is loaded to the material causing it moves to state 1*and marten-sitic phase change starts.

- **(1* to 2)** The associated latent heat is then released adiabatically,causing the temperature to increase on the T-s diagram.
- Afterwards, the SMA temperature approaches the heat sink's temperature at Th, and the material is still in fully stressed at martensite phase.
- **(3 to 4)** at this stage before fully unstressed, the material can be cooled down further up-to 4 by exchanging sensible heat from one bed starting at state 3, to the other bed that has finished cooling to the conditioned space at state 6. This process of exchanging heat is called heat recovery process.
- For the perfect heat recovery process, the temperatures at state 4 and 6 must be same.
- **(4* to 5)** A reverse phase change process occurs during this and material gains its parent shape that is Austenite. This process is called unloading. Material remains unstressed during rest of the cycle.
- **(5 to 6)** At this stage cooling is provided to the conditioned space.
- **(6 to 1)** Reverse heat recovery process by exchanging heat to the other bed that undergoes process 3-4 at this stage.
- The heat rejected to sink should be equal to the summation of the heat absorbed from the conditioned space and the work needed to drive one cycle due to energy conservation of heat recovery process.

Stress-Strain Diagram

- The area underneath 1-1*-2 is the loading work, and the area underneath 4-4*-1 is the unloading work. For a properly designed system, the unloading work can be fully used to compensate part of the loading work. Therefore, the area surrounded by the cycle on δ-e (stress-strain) diagram is corresponding to the net power input with 100% work recovery design.

EXPERIMENTAL SETUP AND CALCULATIONS

Designing of bed containing SMA, prototype working and the calculation of cop for the prototype are illustrated in this section.

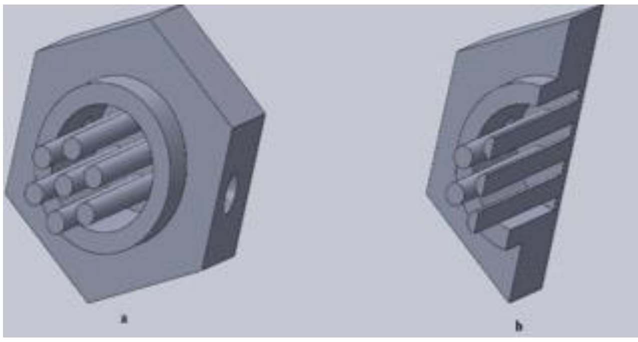

Fig. 4 loading Head design

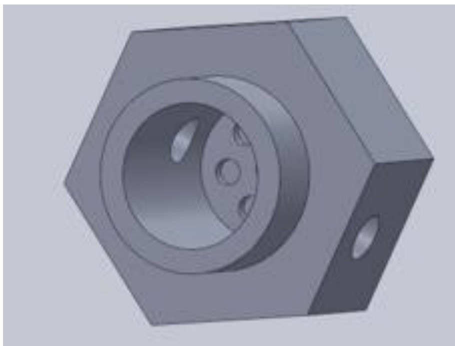

Fig. 5 Holding Head Design

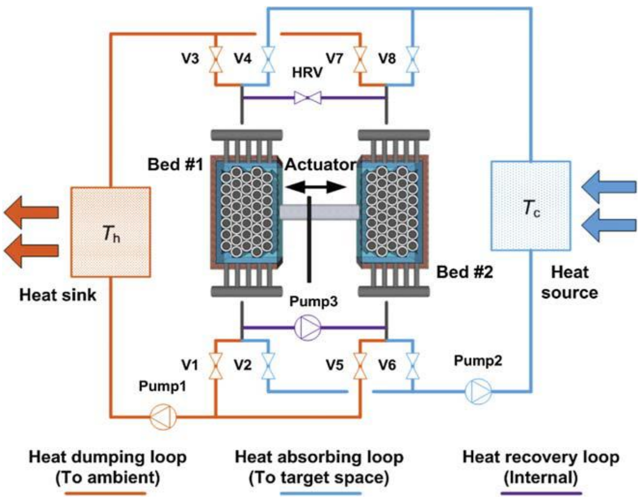

Fig. 6 Heat transfer fluid loop used for experimental setup

Design of Bed

The bed is used to hold the Nitinol tubes, and also allow the heat transfer fluid (water) to flow through it and exchanges the heat with Nitinol tubes by convection. The bed has three main parts

1. Tube holder 2. Loading head 3. Holding heads

EXPERIMENTAL SETUP

There are four basic components in the model: thermo-elastic material beds, heat source/sink, mechanical driver, and connecting pipes (three different colours for different loops). The flow diagram of Thermo-elastic cooling system is given below in figure 6.The two beds design enables heat recovery, work recovery of the mechanical driver and the continuous cooling/heating production. A linear mechanical actuator is used as a mechanical driving system to compress the tubes inside the two beds. When the bed one is producing cooling at the same time the other bed produces heating or it might be called unloading and loading respectively. During the loading process, the heat in the form of work recovery requires the unloading energy produced by the other bed to be applied in order to save the power consumption of the driving system. At the temperature change of bed temperature, the actuator and the HTF loops must operate and happen at same time in a certain order to guarantee proper cycle operation.

Working of Prototype

When the actuator moves towards the left (towards bed # 1) apply stress on the Nitinol tubes, these tubes release the latent heat of phase transformation (phase transformation from austenite to marten-site) the valve v7, v5 and pump 1 are operated and heat transfer fluid absorbs the heat from the tubes and dump it to the heat sink. At the same time bed # 2 is in unloading condition and Nitinol tubes are absorbing the latent heat of phase transformation (from martensite to austenite) the valve v2, v4 and pump 2 are operated and absorbs the heat from heat source. When actuator moves towards the left side (towards bed # 2) the valve v1, v3 and pump1 operated for bed # 2 and the valve v6, v8 and pump 2 are operated for bed # 1. The closing and opening of valve with respect to actuator movement are given in table -3.

Fig. 6 Prototype complete experimental setup and assembly with all components

Table -3– Opening and closing of valves and pumps with the movement of actuator

components	When actuator moves toward bed # 1	When actuator moves toward bed # 2
V1	O	X
V2	X	O
V3	O	X
V4	X	O
V5	X	O
V6	O	X
V7	X	O
V8	O	X
HRV	O	O
Pump 1	O	O
Pump 2	O	O
Pump3	O	O

Calculation of COP

COP = Output/Input = Cooling Effect/Work Done

COP is calculated by neglecting the atmospheric/nature input i.e., free circulation of air.

$$COP = \frac{coolingeffect}{workdone(pump) + workdone\ (actuator)}$$

The work done of pump is neglected in this case for calculating ideal COP

$$COP = \frac{\Delta T}{workdone(actuator) + 0}$$

$$COP = \frac{T2 - T1}{workdone\ (actuator)} \text{eq. (1)}$$

Work done by actuator is calculated as

Power = force × velocity

Work done = power × time= force × velocity × time= 1000 × 0.001 × 3= 3 N.m Joule

Work done = 3 N-m Joule

For Ideal Case COP = 3.34	For $\Delta T = 10\ K$
COP = 1.53	T2 = 34.7 °C, T1 = 30.1 °C
COP =1.06	T2 = 34.9 °C, T1 = 31.7 °C
COP = 0.90	T2 = 34.4 °C, T1 = 31.9 °C
COP = 0.81	T2 = 33.3 °C, T1 = 30.9 °C

This discusses how the system COP is determined by the operating and geometric parameters. The above calculations focus on an overview of how the COP is varying with change in temperature difference.

RESULTS

For checking the behaviour of change in temperature across two heat exchangers with respect to overall system COP, a graph has been plotted for the resulting values. It can be seen from the graph that the value of COP increases with the increase in the temperature difference across two heat exchangers. The trend can be viewed from the Fig. 8.

It can be seen from the Fig. 8 that higher the temperature difference, higher will be the COP and the thermo-elastic cooling system will be more and more efficient. There are following reasons for the drop of temperature difference.

- Thermal mass of the system
- Losses in pipes and fittings
- Hysterics loss during phase transformation
- Mechanical losses due to motor efficiency (frictional losses)

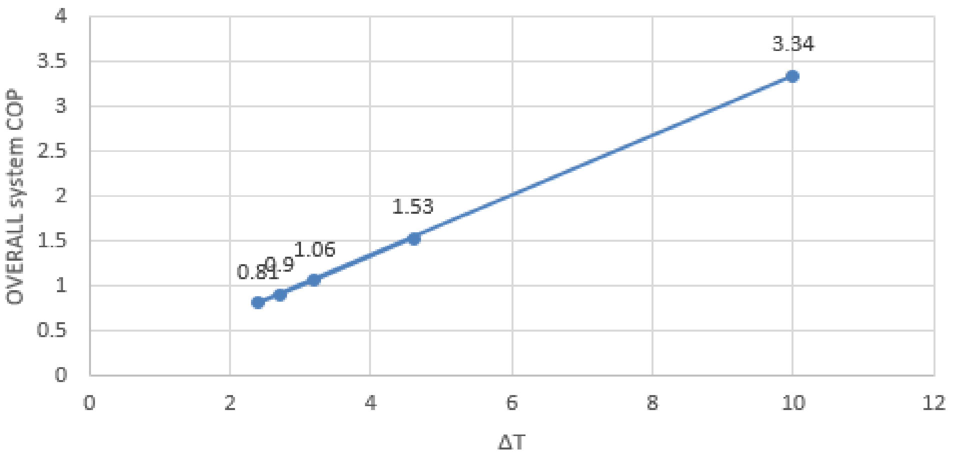

Fig.8 System COP

CONCLUSIONS

The primary inspiration for the present work was to build up a straightforward Thermo-elastic cooling framework that is totally functional. This paper provides details regarding the outline and improvement of a basic, ecological benevolent and vitality productive for space cooling application. From the outcomes, the execution of Thermo-elastic cooling framework relies on the SMA and actuator movement. The bed ought to have inside covering of warmth safe material like TEFLON to maintain a strategic distance from warmth misfortunes. The outcomes introduced in are the initially itemized temperature estimation in the warmth exchanger i.e. bay and outlet temperature with thermocouple. The genuine execution was tried in the wake of joining the warmth exchangers on both sides i.e. warm source and warmth sink. The outcomes have shown that the Thermo-elastic cooling framework separated warmth from the frosty end warm exchanger and conveyed warmth to the hot end warm exchanger. The comparing COP is roughly 1.53. Another value of Thermo-elastic cooling framework is that it can give cooling and warming all the while, that is, cooling from the one end and warming from the flip side. This new option cooling alternative is promising however difficult as well, and requires more research push to exhibit its potential in genuine model and improvement its execution.

REFERENCES

[1] S Qian, J Ling, Y Hwang, R Radermacher and I Takeuchi, Thermodynamic Cycle Analysis and Numerical Modeling of Thermoelastic Cooling Systems, *International Journal of Refrigeration*, **2015**, 56, 65-80.

[2] Y Sato, N Yoshida, Y Tanabe, H Fujita and N Ooiwa, Characteristics of a New Power Generation System with Application of a Shape Memory Alloy Engine, *Transactions of the Institute of* Electrical *Engineers of* Japan., **2008**,165, 8-15.

[3] Erell Bonnot, Ricardo Romero, Llu´ıs Ma˜nosa, Eduard Vives and Antoni Planes, The Use of Shape-Memory Alloy for Mechanical Refrigeration, *Functional Materials Letters*, **2009**, 2 (2), 73–78.

[4] T Saburi and S Nenno, The Shape Memory Effect and Related Phenomena, *Solid Phase Transfer,* **1981**, 545, 1455–1479.

[5] H Sehitoglu, R Hamilton, D Canadinc, XY Zhang, K Gall, I Karaman, Y Chumlyakov and HJ Maier, Detwinning in Ni-Ti alloys, *Metallurgical and Materials Transactions A*, **2003**, 508 5–13.

[6] S Miyazaki, T Imai, Y Igo and K Otsuka, Effect of Cyclic Deformation on the Pseudo Elasticity Characteristics of Ti-Ni alloys, *Metallurgical and Materials Transactions A*, **1986**, 17(1), 115–120.

[7] T Saburi, Ti-Ni Shape Memory Alloys, In: K Otsuka and C Wayman, *Shape Memory Materials*, Cambridge University Press, Cambridge, UK, **1998**, 75-79.

[8] C Picornell, J Pons and E Cesari, Stresses temperature Relationship in Compression Mode in CueAleNi Shape Memory Alloys, *Materials Transactions*, **2004**, 45, 1679-1683.