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Fabrication and Simulation of Shape Memory Alloys by Using ANSYS

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Abstract
Shape Memory Alloys are highly advanced materials which have the capability to restore themselves with change in pressure, temperature etc. and have the ability to regain its shape after severe deformation.
The present project aims at fabrication of CU-AL-NI shape memory alloy using conventional casting method and the fabricated work piece is analysed used EDAX (Energy dispersive X-ray analysis) for the estimation of percentage of composition formed during fabrication. Based on the EDAX values composite material is formed and performed Simulation using ANSYS Software and evaluate material properties under Impact test and Compression Test, Considering results from the ANSYS simulation and standard relations for mechanical properties of materials determine the mechanical properties (Youngs Modulus, Bulk Modulus, Modulus of Rigidity) of fabricated shape memory and these properties are compared with the standard properties of CU-AL-NI Shape Memory Alloy

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I. INTRODUCTION

Ashape-memoryalloyisanalloythatcanbedistortedwhencoldyet repay to its pre-deformed ("remembered") shape when heated. It mayalsobecalledmemorymetal,memoryalloy,smartmetal,smart alloy, or muscle wire. Parts made of shape-memory alloys can be lightweight, solid-state alternatives to conventionalactuatorssimilarly hydraulic, pneumatic, and motor-based systems. They can also be used to make hermetic joints in metal tubing.

Shape memory alloys (SMAs) are an intense class of working materials with a capacity to recover its actual shape at high temperatures. There is a broad range of alloys which reveal the shape memory effect, but only those alloys are commercially enchanting which show a fundamental amount of strain retrieval and cause significant force due to shape change. Among the Cu- based shape memory alloys, Cu-Al-Ni alloys have a high up thermal stability than Cu-Zn-Al alloys. Therefore, Cu-Al-Ni alloys are being developed for high temperature applications due to their potential to be used as sensors and actuators at temperatures around 200°C. On the other hand, Cu-Zn-Al alloys have highest working temperatures of 120°C, but they show better ductility as compared to Cu-Al-Ni alloys for low temperature applications. Shape Memory Effect (SME) is shown by alloys exhibiting crystallographically reversible thermo-elastic martensitic transformation. At a higher temperature, the same alloys have another unique property called as super- elasticity. Super elasticity is caused due to large non-linear recoverable strain (up to 18%) upon loading and unloading, in which a specimen once deformed by application of force regain its original shape automatically without any application of heat. The Ni-Ti, ferrous alloys and Cu-based alloys are considered as practical materials for applications among many shape memory alloys. Ni-Ti alloys, an equi-atomic compound of Ni and Ti, are the most widely used shape memory alloys. They show magnificent shape memory strain up to 8% and are thermally stable. However, the reactivity of Ti limits their processing in air and hence all melting operations are to be carried out in vacuum. In current decades, Cu-based shape memory alloys have appeared as a potential material for variety of applications, such as high doused material, sensors and actuators. Cu-Al-Ni shape memory alloys have gained special attention due to their high thermal stability among the other Cu-based shape memory alloys. The presence of SME, thermo-elastic martensitic transformation and crystallography in the Cu-Al-Ni alloy was established by Otsuka. Some ferrous alloys also show SME under fixed conditions. Fe-Mn-Si alloys are the most important iron-based shape memory alloy. However, they can recover shape memory strain less than 4%.

Shape memory alloy is an alloy. SMA is one of the type of smart materials, Shape Memory Alloys are materials that "remember" their initial shape. If distorted, they recover their original shape upon heating. They can extract huge stresses without undergoing permanent deformation They can be found into several shapes like bars, wires, plates and rings thus serving various functions.

II. METHODOLOGY

Scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample. The electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image. In the most common SEM mode, secondary electrons emitted by atoms excited by the electron beam are detected using a secondary electron detector (Everhart-Thorley detector). The number of secondary electrons that can be detected, and thus the signal intensity, depends, among other things, on specimen topography. Some SEMs can achieve resolutions better than 1 nanometer.

Specimens are observed in high vacuum in a conventional SEM, or in low vacuum or wet conditions in a variable pressure or environmental SEM, and at a wide range of cryogenic or elevated temperatures with specialized instruments.

SEM samples have to be small enough to fit on the specimen stage, and may need special preparation to increase their electrical conductivity and to stabilize them, so that they can withstand the high vacuum conditions and the high energy beam of electrons. Samples are generally mounted rigidly on a specimen holder or stub using a conductive adhesive. SEM is used extensively for defect analysis of semiconductor wafers, and manufacturers make instruments that can examine any part of a 300 mm semiconductor wafer. Many instruments have chambers that can tilt an object of that size to 45° and provide continuous 360° rotation.The scanning electron microscope (SEM), in which a beam of electrons is scanned over the surface of a solid object, is used to build up an image of the details of the surface structure.

Energy-Dispersive X-Ray SpectroscopyEach of our SEMs are equipped with energy-dispersive X-ray (EDX, also referred to as EDS) spectroscopy facilities. When exposed to the electron beam, an atom emits characteristic X-rays unique to its atomic number; this allows a sample's elemental composition to be analyzed, whether at a single point or over a large region, including line scanning and elemental mapping. Semi-quantitative analysis can also be performed to assess the chemical composition of a sample. TWI also has capabilities for wavelength- dispersive X-ray (WDX) analysis to detect light elements, such as oxygen, nitrogen etc. Combined with conventional SEM analysis, EDX can give a fuller insight into the local composition of a sample.

Why SEM analysis?

Performing a visual analysis of a surface using scanning electron microscopy contributes to the identification of contaminates or unknown particles, the cause of failure and interactions between materials.

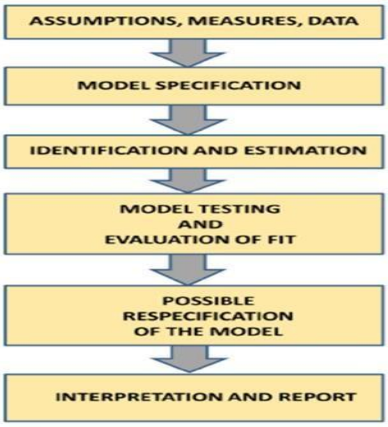
In addition to surface evaluation, SEM analysis is utilized for particle characterization, such as wear debris generated during mechanical wear testing. The high magnification, high-resolution imaging of our SEM analysis supports the determination of the number, size, and morphology of small particles, allowing clients to understand the wear properties of their material.

Combining SEM & EDAX Analysis

Energy dispersive x-ray spectroscopy, also referred to as EDX, EDS or EDAX, provides additional understanding of the surface material during the SEM analysis process. EDX analysis is used to acquire the elemental composition of a sample and allows for a more quantitative result than that provided by only SEM analysis. The combination of SEM and EDX analysis offers chemical composition and elemental investigation – providing a comprehensive metallurgical evaluation.

Benefits of Combining SEM & EDAX

- To identify the elements involved in the specific specimen.
- In case of making composites it can be able to see what are the contents of each material present.
- It is use to determine the homogeneity and its elemental distribution in the synthesize structure.

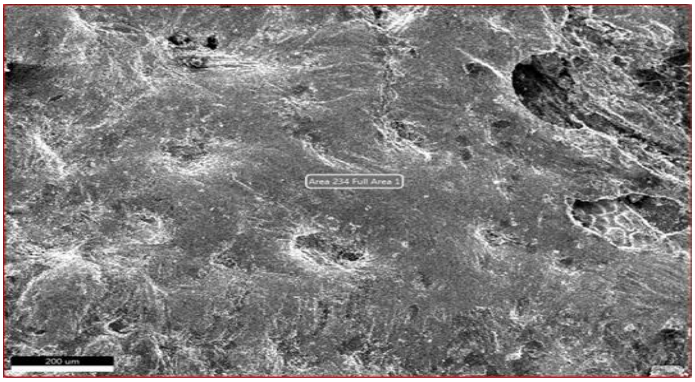


Testing and Analysis of the Fabricated Shape Memory Alloy

This project is concentrated on forming the composite material involving Copper (75%)-Aluminum-(14.5%)-Nickel (5%) with additional 2% weight of chromium which is used as refinement and proposed composite will enhance a special property named as Shape Memory Effect, Hence it is named as Shape Memory Alloy.

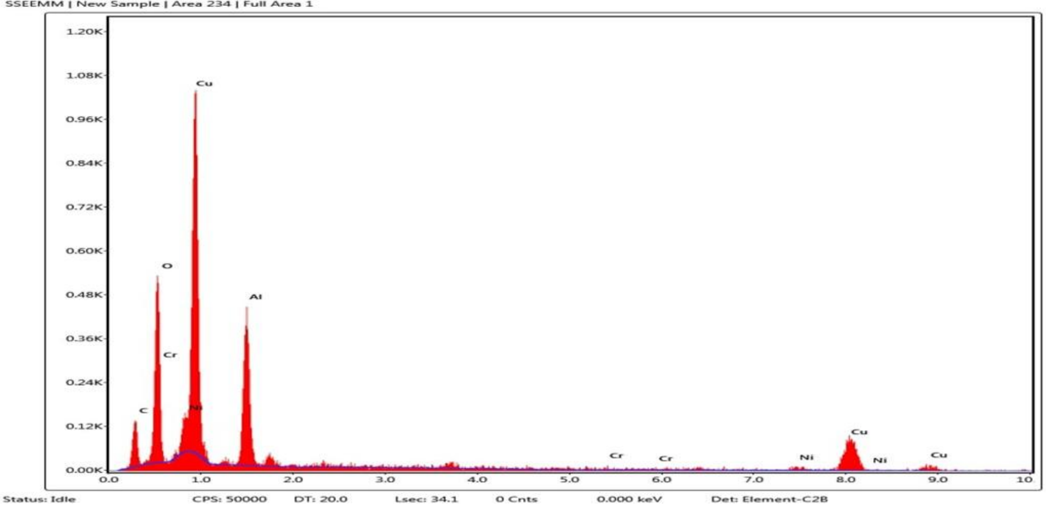
The fabrication of the sample is done by following Conventional Casting Method and specimens are prepared as per the standards of SEM Analysis, the evaluation of results are as follows.

Scanned image of SEM
Area 234mm



Specimen Area consider for analysis = 234 mm

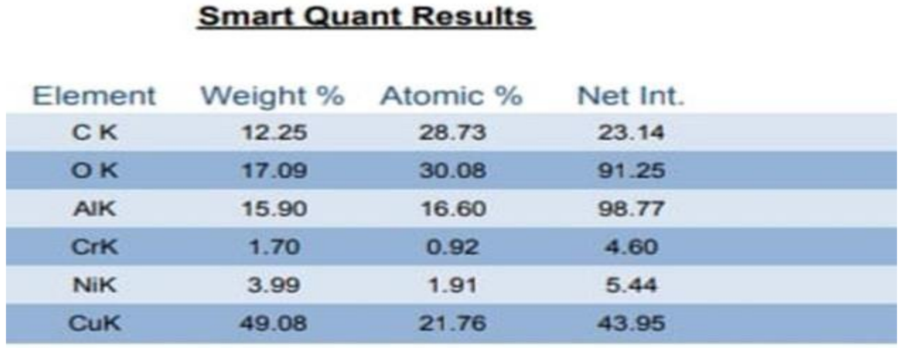
Interpretation of data using EDAX



` Count of samples

Energy dispersive x-ray spectroscopy, also referred to as EDX, EDS or EDAX, provides additional understanding of the surface material during the SEM analysis process and used to plot the spectrum as above, from this graph it is witnessed the materials involved in the composition of the fabricated material and the exact weighted percentage of all the composites will be expressed in the table below.

Table for EDAX Composition of materials

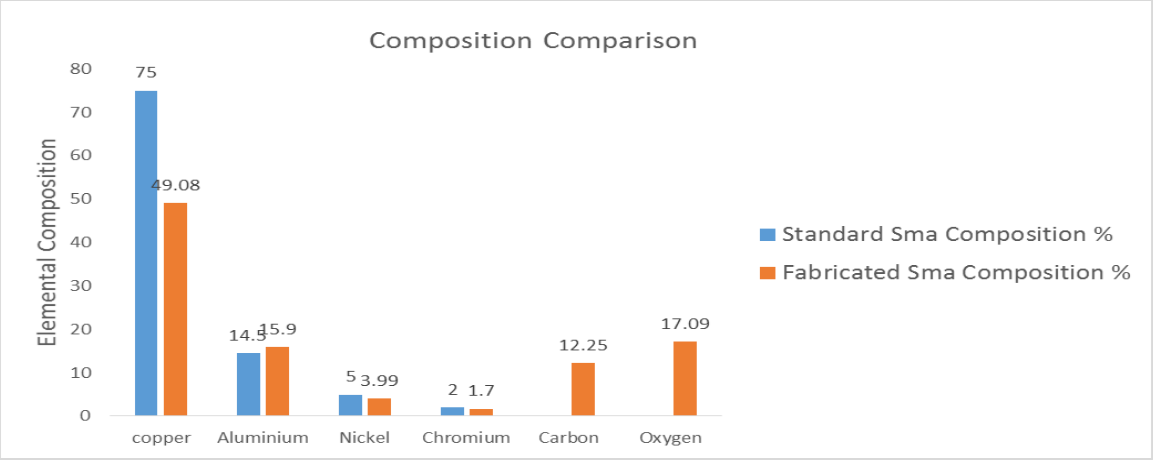


Smart Quant Results

Element	Weight %	Atomic %	Net Int.
C K	12.25	28.73	23.14
O K	17.09	30.08	91.25
AlK	15.90	16.60	98.77
CrK	1.70	0.92	4.60
NiK	3.99	1.91	5.44
CuK	49.08	21.76	43.95

In order to confirm the formation of (CU-AL-NI) shape memory alloy EDAX analysis was performed, During the EDAX measurement area 234mm was focused and the formed the spectrum of the interpretation the graph given the values are measured in the atomic and weight % are listed in above table.

Comparison of Standard composition of Shape Memory Alloy with the Fabricated specimen is mentioned in the below graph.



From the above graph it is estimated that all required materials are present in the fabricated specimen and due to atmospheric conditions oxides of oxygen and carbon is involved in the structure apart from this no other impurities are added to the structure on basis of all these experimental analysis and results it can be ensured that material fabricated in this project has required characteristics of CU-AL-NI ShapeMemoryAlloy.

Analysis of Shape Memory Using ANSYS software

ANSYS is a general-purpose, finite-element modeling package for numerically solving a wide variety of mechanical problems. These problems include static/dynamic, structural analysis, heat transfer, and fluid problems, as well as acoustic and electromagnetic problems. Ansys is analyzing software for mechanical product design and civil structure designs, it is widely used for developing analyzing solutions in the industry.

What is the function of ANSYS?

Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analyzing the strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes.

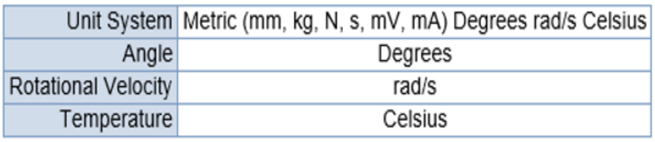
Procedure for solving problem using ANSYS

Once you have determined the important features of the problem you want to solve, follow the basic procedural steps shown below.

1. Define the modeling goals.
2. Create the model geometry and mesh.
3. Set up the solver and physical models.
4. Compute and monitor the solution.
5. Examine and save the results.

- Material Data
    - cu-al-ni (49.8% - 15.9% - 3.99%)

Units

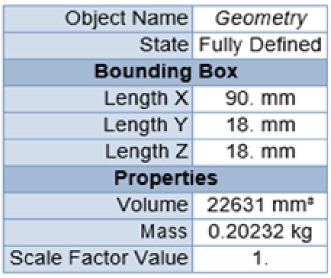


Unit System	Metric (mm, kg, N, s, mV, mA) Degrees rad/s Celsius
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Celsius

Model (A4)

Geometry

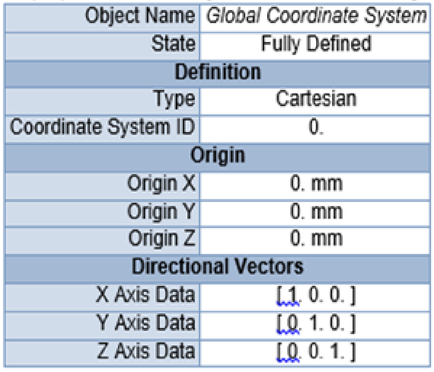
Model (A4) > Geometry



Object Name	*Geometry*
State	Fully Defined
Bounding Box	
Length X	90. mm
Length Y	18. mm
Length Z	18. mm
Properties	
Volume	22631 mm^3
Mass	0.20232 kg
Scale Factor Value	1.

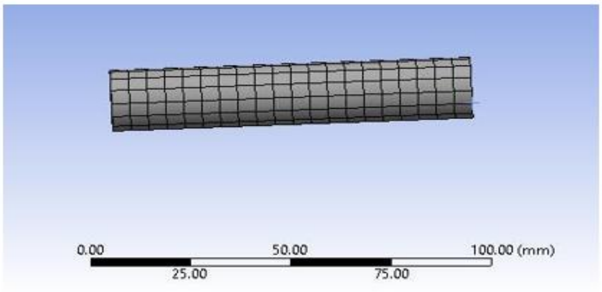
Coordinate Systems

Model (A4) > Coordinate Systems > Coordinate System

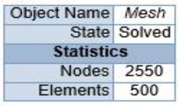


Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. mm
Origin Y	0. mm
Origin Z	0. mm
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh



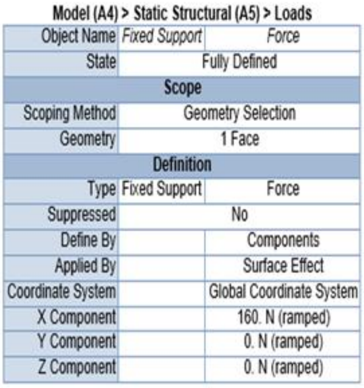
Model (A4) > Mesh



Object Name	*Mesh*
State	Solved
Statistics	
Nodes	2550
Elements	500

Compressive test

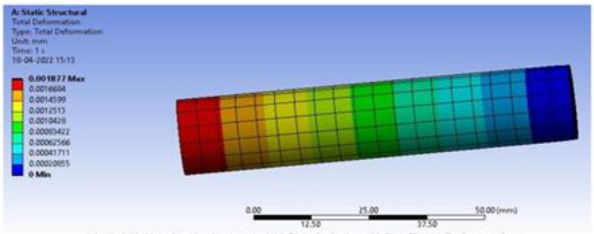
Static Structural (A5)



Model (A4) > Static Structural (A5) > Loads

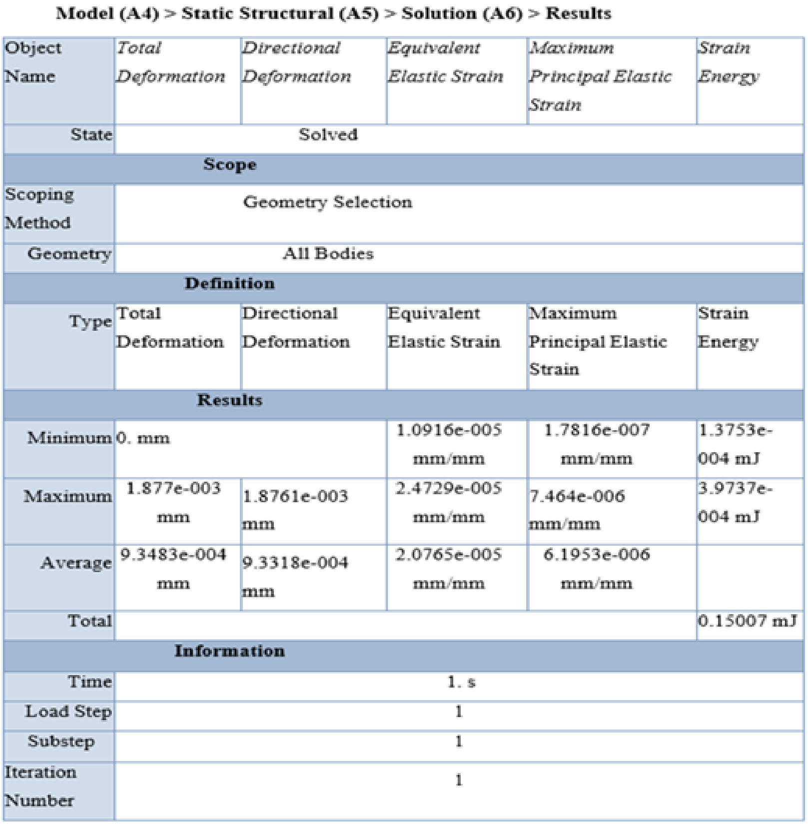
Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	1 Face	
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Applied By		Surface Effect
Coordinate System		Global Coordinate System
X Component		160. N (ramped)
Y Component		0. N (ramped)
Z Component		0. N (ramped)

Solution



Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	0.	1.877e-003	9.3483e-004

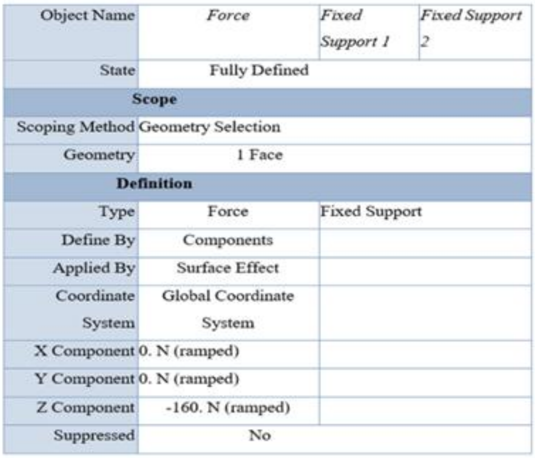


Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Directional Deformation*	*Equivalent Elastic Strain*	*Maximum Principal Elastic Strain*	*Strain Energy*
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Total Deformation	Directional Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Strain Energy
Results					
Minimum	0. mm		1.0916e-005 mm/mm	1.7816e-007 mm/mm	1.3753e-004 mJ
Maximum	1.877e-003 mm	1.8761e-003 mm	2.4729e-005 mm/mm	7.464e-006 mm/mm	3.9737e-004 mJ
Average	9.3483e-004 mm	9.3318e-004 mm	2.0765e-005 mm/mm	6.1953e-006 mm/mm	
Total					0.15007 mJ
Information					
Time	1. s				
Load Step	1				
Substep	1				
Iteration Number	1				

IMPACT TEST

Model (A4) > Static Structural > Loads



Object Name	*Force*	*Fixed Support 1*	*Fixed Support 2*
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Geometry	1 Face		
Definition			
Type	Force	Fixed Support	
Define By	Components		
Applied By	Surface Effect		
Coordinate System	Global Coordinate System		
X Component	0. N (ramped)		
Y Component	0. N (ramped)		
Z Component	-160. N (ramped)		
Suppressed	No		

Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

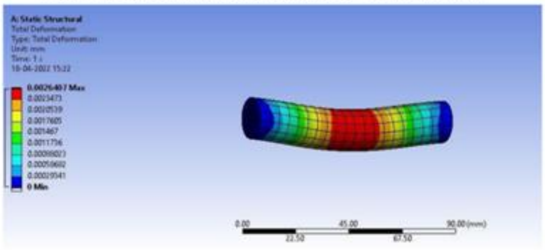
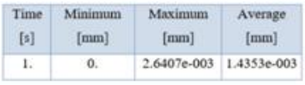


Figure 4.3 Total Deformation

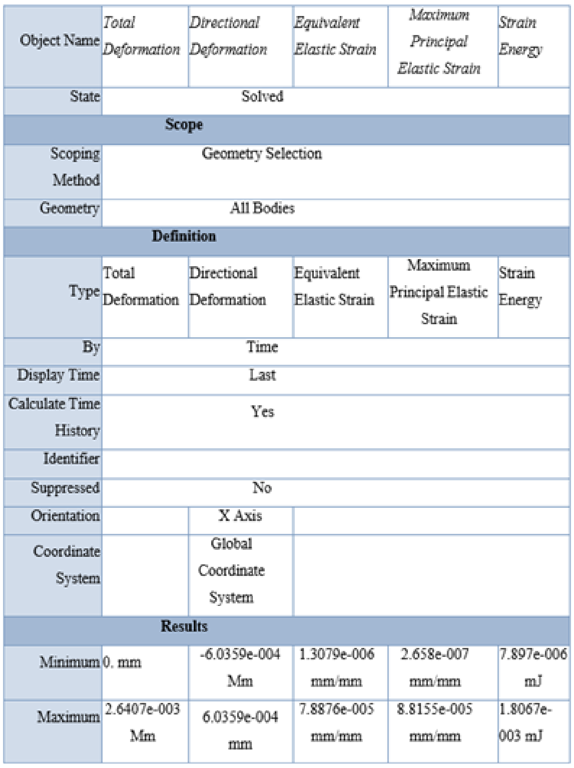
Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Table 4.8 Solution

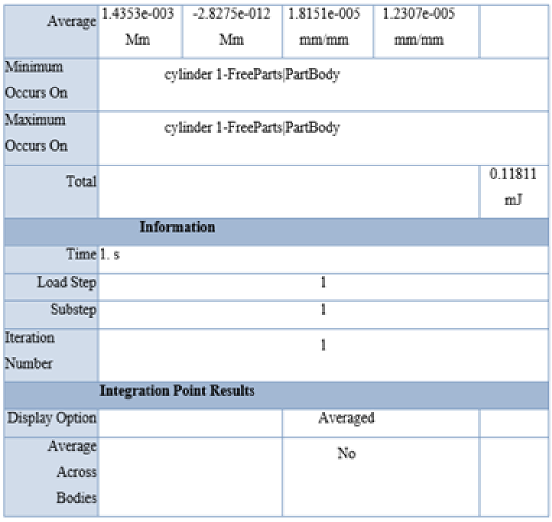


Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	0.	2.6407e-003	1.4353e-003

Model (A4) > Static Structural (A5) > Solution (A6) > Results



Object Name	*Total Deformation*	*Directional Deformation*	*Equivalent Elastic Strain*	*Maximum Principal Elastic Strain*	*Strain Energy*
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Total Deformation	Directional Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Strain Energy
By	Time				
Display Time	Last				
Calculate Time History	Yes				
Identifier					
Suppressed	No				
Orientation		X Axis			
Coordinate System		Global Coordinate System			
Results					
Minimum	0. mm	-6.0359e-004 Mm	1.3079e-006 mm/mm	2.658e-007 mm/mm	7.897e-006 mJ
Maximum	2.6407e-003 Mm	6.0359e-004 mm	7.8876e-005 mm/mm	8.8155e-005 mm/mm	1.8067e-003 mJ



Average	1.4353e-003 Mm	-2.8275e-012 Mm	1.8151e-005 mm/mm	1.2307e-005 mm/mm	
Minimum Occurs On	cylinder 1-FreeParts|PartBody				
Maximum Occurs On	cylinder 1-FreeParts|PartBody				
Total					0.11811 mJ
Information					
Time	1. s				
Load Step	1				
Substep	1				
Iteration Number	1				
Integration Point Results					
Display Option			Averaged		
Average Across Bodies			No		

Estimation Of Mechanical Properties From Ansys Simulation

Fabricated Alloy with Composition Cu-al-ni (49.8% - 15.9% - 3.99%) is done simulation using Ansys software and estimated solution, by using Ansys Average solution and standard formulas few mechanical properties of fabricated shape memory alloy is calculated and the calculations are as follows

Standard Relations used are

☐.$\boldsymbol{strainenergy(\mu\epsilon)=\frac{\sigma^2 v}{2E}}$

☐.Youngs Modulus(E)= 2G(1+$\boldsymbol{\mu}$)   Here G= Modulusof rigidity

☐.YoungsModulus(E)=3K(1-2μ)   K= Bulk Modulus

FromtheANSYSsimulationwehave gotthefollowingdatai.

VolumeV=22631mm^3=22631*$10^{-9}$$m^3$

ii. Totaldeformation=9.348*10^{-4}mm

iii. Equivalentstatestrain(E)= 2.0765*10^{-5}

iv.

Strainenergy()=0.15007*10^{-3}J

Poisionsratio of copper() =0.34

Weknow that

$Youngsmodulus(E)=\frac{\sigma}{g}=\frac{\sigma}{2.0765*10^{-5}}$

σ=2.0765*10^{-5}E ➡ Equation 1

➡ $strainenergy(\mu\epsilon)=\frac{\sigma^2 v}{2E}$=0.15007*$10^{-3}$

$$\frac{(2.0765\times10^{-5}E)^2\times22631\times10^{-9}}{2E}=0.15007*10^{-3}$$

$$\frac{(2.0765\times10^{-5}E)^2}{2E}=\frac{0.15007\times10^{-3}}{22631\times10^{-9}}=6.6311$$

$$(215.592\times10^{-12})E=6.6311$$

$$E=\frac{6.6311}{(215.592\times10^{-12})}=30757547409.005$$

$$E=30757547409.005\times10^{-9}$$

$$\boxed{E = 30.75\ GPa}$$

Here from Equation 1 we have

$$\sigma = 2.0765*10^{-5} \times E$$

$$\sigma = 2.0765 \times 10^{-5} \times 30.75 \times 10^{9}$$

$$\sigma = 638523.75 \text{ Pascals}$$

$$\boxed{\sigma = 638.52 \text{ Kpa}}$$

We know that

$$E = 2G\,(1+\mu) \quad \text{Here 'G' is Modulus of rigidity}$$

$$E = 2G\,(1+\mu) = 30.75*10^{9} = 2G^{(1+0.34)}$$

$$\boxed{G = 11.48 \text{ Gpa}}$$

We know that

$$E = 3K\,(1-2\mu) \Rightarrow k = \text{Bulk Modulus}$$

$$\Rightarrow 30.75 \times 10^{9} = 3K\,(1-2*0.34)$$

$$\boxed{K = 32.04 \text{ Gpa}}$$

RESULTS

i. Fabrication of CU-AL-NI shape memory alloy using conventional casting method is done successfully.

ii. Analysis of fabricated shape memory is done using EDAX and SEM and attained proportion composition of Cu-al-ni (49.8% - 15.9% - 3.99%).

iii. Simulation of fabricated alloy is done using ANSYS software and the result of software is used for further investigation of mechanical properties of shape memory alloy.

iv. Using Ansys solution and Standard relations few mechanical properties is determined that are as follows

  a. Youngs Modulus (E) = 30.75 Gpa. (Standard = 16.5 Gpa to 40.2 Gpa)
  b. Modulus of Rigidity (G) = 11.48 Gpa.
  c. Bulk Modulus (K) = 32.04 Gpa.

By detailed investigation of calculated mechanical properties are matching with the standard properties of Cu-Al-Ni shape memory alloy materials and hence the fabrication done in this project is achieved properties of shape memory alloy.

CONCLUSIONS

- The fabricated Cu-Al-Ni shape memory alloy has achieved the acceptable level of Composition of shape memory alloy.
- Simulation of the Material is done and estimated the mechanical properties of material which is matching standard values.
- The many uses and applications of shape memory alloys ensure a bright future.
- Research is currently carried out at many robotic departments and materials science departments for latest advancements.
- Today, the most promising technologies for efficiency and improved reliability include the use of shape memory alloy material and structure. Smart materials have all the possible potentials to fulfill maximum requirements of the changing trend which ultimately resulted in use of smart material in almost all the sectors of Engineering and medical field.

FUTURE SCOPE

The alloy also can be machined through electric discharge machining which comes under conventional machining process that coverts the work piece into required dimensions of wire and that can be applied for the above applications.

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