To Analyze Joule Heating in Thermal Expansion with Copper Beryllium Alloy

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Abstract-Nowadays biomedical, industrial and electrical applications such as optical switches, thermostat and bimetallic strip systems which are parts of the actuation and sensing components are realized using thermal expansion fabricated using Micro Electro Mechanical Systems (MEMS) technology. This paper studies through comsol model, the joule heating properties of the actuation mechanism of comb shape thermal expansion with displacement produced in the device. The device is made up of copper Beryllium alloy i.e. UNS C17500. The device is more efficient when the UNS C17510 or UNS C26000 was introduced than UNS C17500 listed above to further increase the displacement.

Keywords*:* MEMS, RF MEMS, COMSOL, Bimetallic Strip, Joule Heating, Copper beryllium alloy, Thermostat

INTRODUCTION

MEMS has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining silicon-base microelectronics with micromachining technology. Its techniques and microsystem-based devices have the potential to dramatically affect of all of our lives and the way we live. [6] The rapid growth of MEMS technology has generated a host of diverse developments in many different fields like RF MEMS, optical MEMS, in biomedical science, in electrical, in mechanical.[7] In electrical there are Bimetallic strip system[2] which are used in air conditioner, electric iron, thermostat etc. Over the last two decades, optical fiber sensors have seen an increased acceptance as well as wide spread use in scientific research and in diversified engineering applications [3], [1]. The principle of bimetallic strip is based on the Thermal expansion[4].

DESIGNING

Thermal expansion is the type of actuator i.e.when we change temperature the material expands. The device is made up of copper beryllium alloy. The thermal balance consists of a balance of flux at study state. The heat flux is given conduction only. The heat source is a constant heat source of $1*10^8$ W/m^3. The air cooling at the boundaries is expressed using a constant heat transfer coefficient of 10 W/m^2 and an ambient temperature of 298 K. The expression for thermal expansion requires strain reference temperature for the copper beryllium alloy, which in this case is 293 K .[5] In this we use two sets of physics:

- A thermal balance with a heat source in the device, originating from Joule heating (ohmic heating). Air cooling is applied on the boundaries except at the position where the device is attached to a solid frame, where an insulation condition is set.
- A force balance for the structural analysis with a volume load caused by thermal expansions.The device is fixed at the positions where it is attached to a solid frame as shown in figure1.

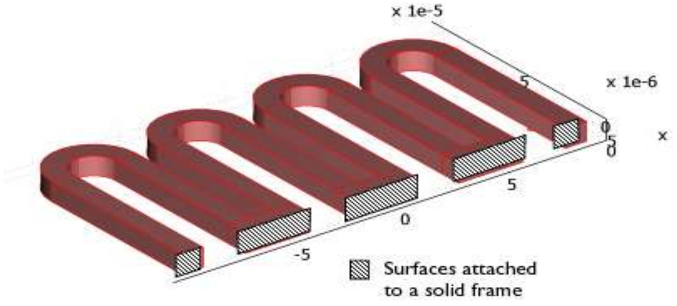


Figure1: Model Geometry of the Device

The displacement produced in the device is the function of temperature & heat source simultaneouly. In this paper we study the effect on displacement as temperature changes. As we change temperature displacement increases. The displacement is minimum at 273K(0^0C) and as we change temperature (either increases or decreases) displacement increases.

RESULT

(a) Themal Expansion with UNS C17500

When we use 298K as external temperature then the maximum displacement is $5*10^{-8}$. The figure 2 shows the temperature distribution in the device. The heat source increases the temperature to 323 K from an ambient temperature of 298 K. The temperature varies less than 1/100 of a degree in the device.

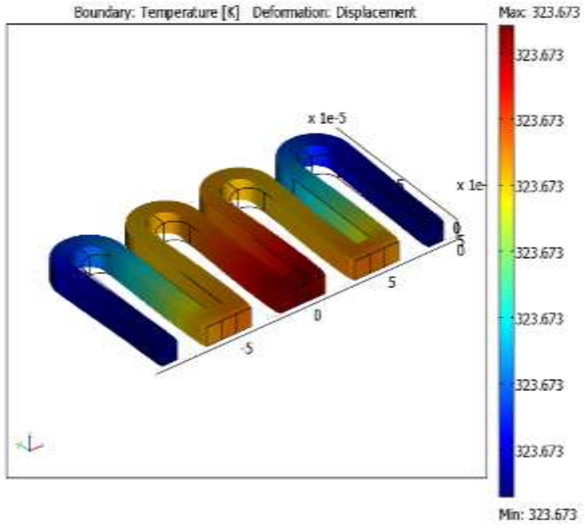


Figure2: Temperature distribution of the Device at 298K

The figure 3 shows the displacement of a curve that follows the top inner edges of the device from left to right.

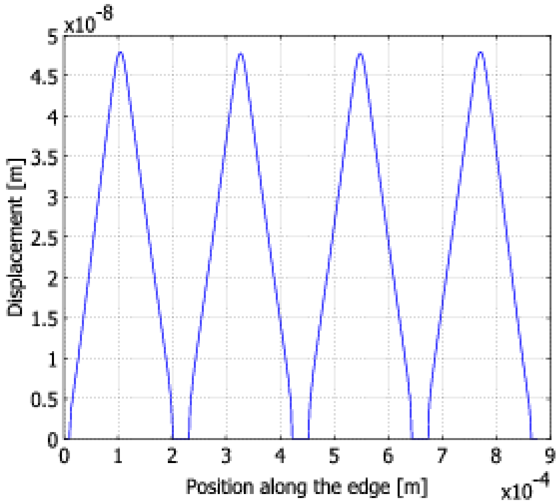


Figure 3: Displacement Vs Position graph

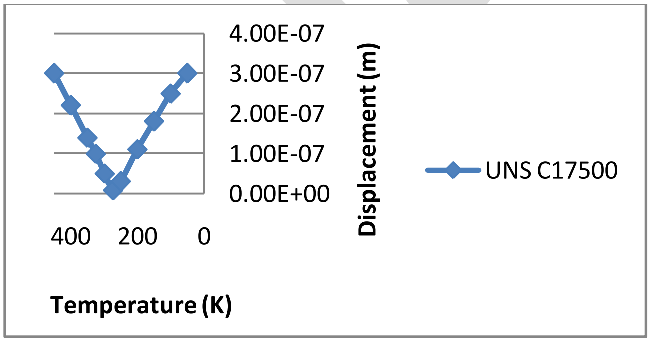
Temperature in Kelvin	Displacement (UNS C17500)
450	3.00E-07
400	2.20E-07
350	1.40E-07
325	1.00E-07
298	5.00E-08
273	9.00E-09
250	3.00E-08
200	1.10E-07
150	1.80E-07
100	2.50E-07
50	3.00E-07

The figure 3 shows the displacement produced between the top inner edges of the device Vs position along edges.

Table1: Displacement at different temperature

The above table shows the displacement produced in the device at different temperature range. The displacement is minimum at 273 K. when temperature is larger than 273K the displacement increases and also when temperature is less than 273K the displacement increases. There is same displacement value (3.00E-07) at two different temperature (450K & 50 K).

This is shown in next Figure.



. *Figure 4: Temperature Vs displacement graph*

The figure 4 shows the relation between temperature and displacement produced in the top inner edges of the device. The graph is V shape i.e. it shows 273K is reference temperature, at this temperature the displacement is minimum & displacement is increases on both side of the reference temperature.

(b) Themal Expansion with UNS C17510

When UNS C17510 is load into the device, it shows more displacement than the base material. In this case, the displacement increases to $1*10^{-8}$ at 273K (reference temperature). At 298K temperature, displacement is $5.5*10^{-8}$ with new material. Whereas with base material the displacement is $5*10^{-8}$ at same 298K temperture. This increase is due to the variation in chemical composition of the alloys.

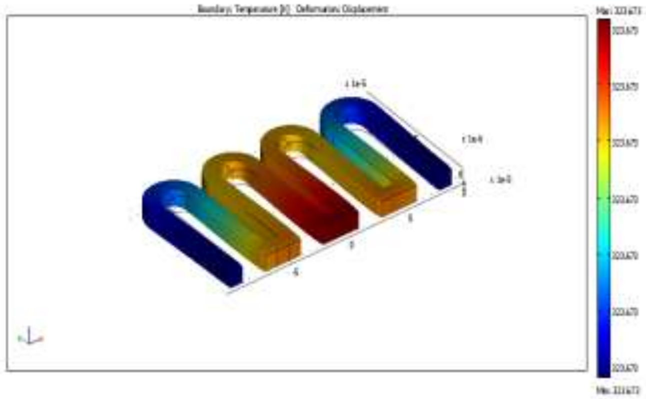


Figure 5: Temperature distribution of the Device with 298K

The figure 5 shows the displacement of a curve that follows the top inner edges of the device from left to right.

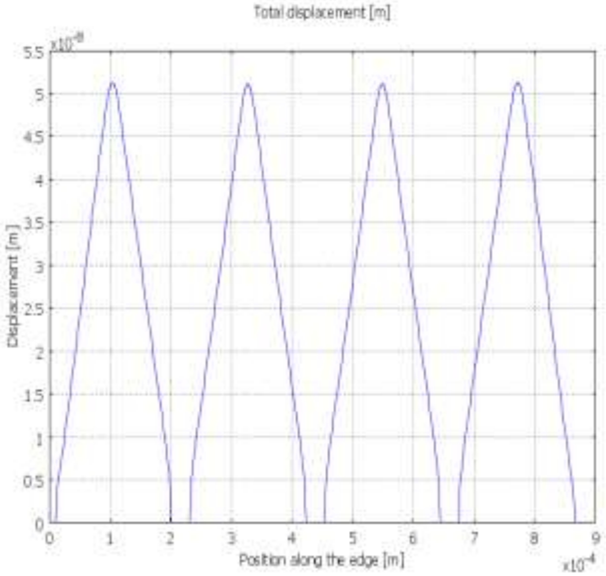


Figure 6 Displacement vs Position graph

The figure 6 shows the displacement produced between the top inner edges of the device Vs position along edges.

Table 2: Displacement at different temperature

Temperature in kelvin	Displacement (UNS C17510)
450	3.50E-07
400	2.50E-07
350	1.40E-07
325	1.00E-07
298	5.50E-08
273	1.00E-08
250	3.00E-08
200	1.20E-07
150	2.00E-07
100	3.00E-07
50	4.00E-07

The above table shows the displacement produced in the device at different temperature range. The displacement is minimum at 273 K. when temperature is larger than 273K the displacement increases and also when temperature is less than 273K the displacement increases. The displacement increases by a greater factor in this case i.e. the value of displacement is $3.5*10^{-7}$ at 450K when UNS C17510 used & it is $3*10^{-7}$ when base material is used.

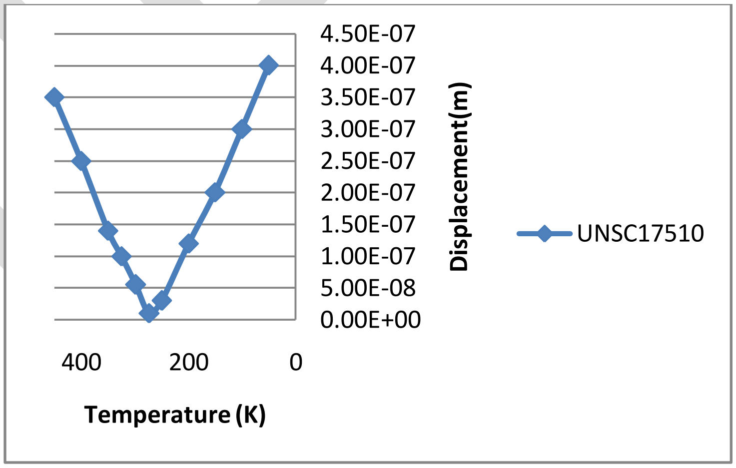


Figure 7: Temperature Vs displacement graph

The figure 7 shows the relation between temperature and displacement produced in the top inner edges of the device. The graph is V shape i.e. it shows 273K is reference temperature, at this temperature the displacement is minimum & displacement is increases on both side of the reference temperature.

(c) Themal Expansion with UNS C26000

When UNS C26000 is load into the device, it shows more displacement than two listed above.. In this case, the displacement increases to $1.2*10^{-8}$ at 273K (reference temperature). At 298K temperature, displacement is $7*10^{-8}$ with UNS C26000. Whereas with UNS C17510 the displacement is $5.5*10^{-8}$ & with base material the displacement is $5*10^{-8}$ at same 298K temperture. This increase is due to the variation in chemical composition of the alloys.

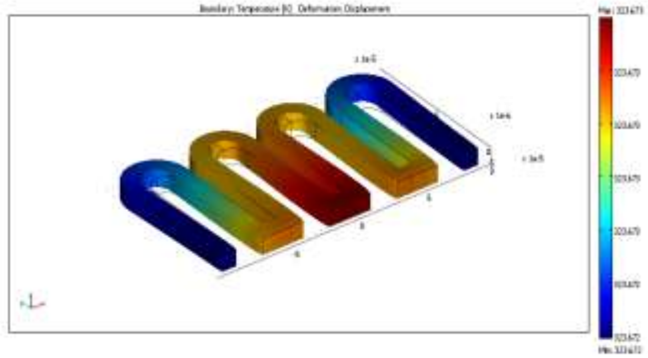


Figure 8: Temperature distribution of the Device with 298K

The figure 8 shows the displacement of a curve that follows the top inner edges of the device from left to right.

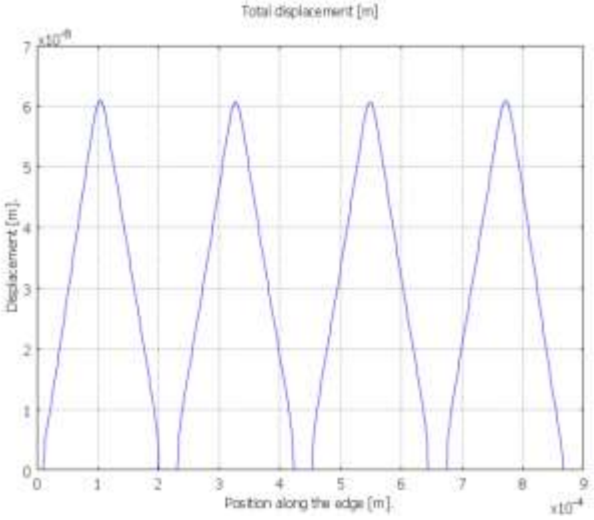


Figure 9: Displacement Vs Position graph

The above graph shows the displacement produced between the top inner edges of the device Vs position along edges.

Table 3: Displacement at different temperature

Temperature in kelvin	Displacement (UNS C26000)
450	4.00E-07
400	3.00E-07
350	1.80E-07
325	1.20E-07
298	7.00E-08
273	1.20E-08
250	3.50E-08
200	1.20E-07
150	2.00E-07
100	3.00E-07
50	3.50E-07

The above table shows the displacement produced in the device at different temperature range. The displacement is minimum at 273 K. when temperature is larger than 273K the displacement increases and also when temperature is less than 273K the displacement increases. The displacement increases by a greater factor in this case i.e the value of displacement is $4*10^{-7}$ at 450K when UNS C26000 used & the value of displacement is $3.5*10^{-7}$ when UNS C17510 used & it is $3*10^{-7}$ when base material is used.

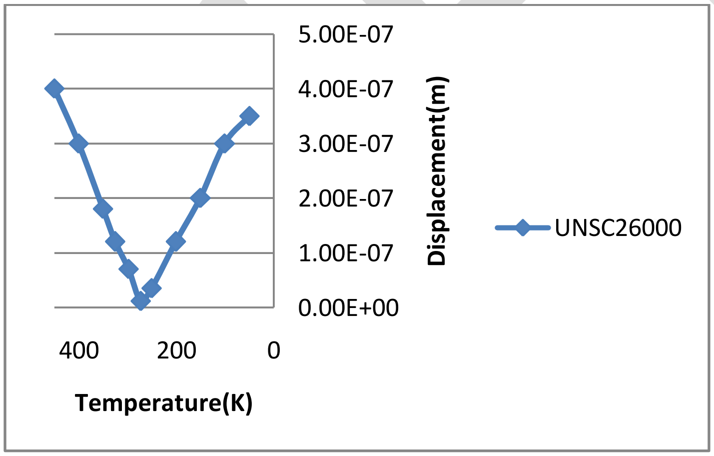


Figure 10: Temperature Vs displacement graph

The figure 10 shows the relation between temperature and displacement produced in the top inner edges of the device. The graph is V shape i.e. it shows 273K is reference temperature, at this temperature the displacement is minimum & displacement is increases on both side of the reference temperature.

(d) COMPARATIVE ANALYSIS

When we compare all the three material listed above then we noted that displacement is large in last case as shown in table.

Table 4: Displacement at different temperature

Temperature in kelvin	Displacement (UNS C17500)	Displacement (UNS C17510)	Displacement (UNS C26000)
450	3.00E-07	3.50E-07	4.00E-07
400	2.20E-07	2.50E-07	3.00E-07
350	1.40E-07	1.40E-07	1.80E-07
325	1.00E-07	1.00E-07	1.20E-07
298	5.00E-08	5.50E-08	7.00E-08
273	9.00E-09	1.00E-08	1.20E-08
250	3.00E-08	3.00E-08	3.50E-08
200	1.10E-07	1.20E-07	1.20E-07
150	1.80E-07	2.00E-07	2.00E-07
100	2.50E-07	3.00E-07	3.00E-07
50	3.00E-07	4.00E-07	3.50E-07

The above table shows that displacement produced in the top inner edges of the device at different temperature.

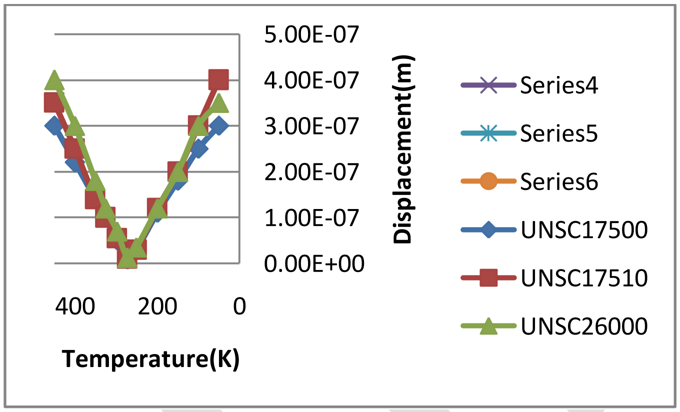


Figure 11: Temperature Vs displacement graph

The figure 11 shows that temperature Vs displacement variation of all the three material.

CONCLUSION

From result it is concluded that out of the three material used above UNS C26000 shows better result. Because in this case displacement is increases by greater factor. This is due to the variation in the chemical composition of the alloy.It is noted that in hot region UNS C26000 (triangle) is better & in this region result is increased by 33% when UNS C26000 is used & 16% when UNS C17510 is used. In cold region it is reverse result is increased by 16% when UNS C26000 is used &

33% when UNS C17510 is used. So it is concluded that in hot region UNS C26000 is better & in cold region UNS C17510 is better.

PROPOSED FUTURE WORK

In future we wish to redesign the thermal expansion from straight design into serpentine/zigzag shape. This would change the displacement in the top inner edges of the device. So we would redesign the device..

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