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STUDY OF THERMAL DEFORMATION ANALYSIS IN AL-STEEL AND CU-STEEL BIMETAL COMPOSITES BY ANSYS STATIC STRUCTURAL

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ABSTRACT

Bimetals are widely used in technology and industrial and fields due to bimetallic effect. In this work, the comparative analysis for thermal deformation between Aluminum-Steel and Copper-Steel bimetals is carried out by using ANSYS Static Structural. Both Aluminum-Steel and Copper-Steel are well-known bimetals and used in many fields of industry. When the temperature is increased, then the bimetals experience thermal bending due to difference in coefficient of thermal expansion between two materials. The bimetals used in this work comprise of two layers with same dimensions of 100×30 mm with thickness of 5mm. ANSYS is used to observe thermal deformation for a temperature range of 22-300 °C. Results shows linear trend between temperature and thermal deformation. At the temperature of 300 ℃, Aluminum-Steel bimetal deform to 0.62 mm while Cu-Steel bimetal shows a thermal deformation of 0.36 mm. The results concluded that Aluminum-Steel bimetals show more thermal deformation than Copper-Steel bimetal at all temperature.

Keywords: Bimetal, Composites, Thermal deformation, Aluminum Steel, Copper Steel.

Introduction:

Composite materials are getting popular day by day due to their dominant advantages over individual materials. They are used in vast range of fields from production of household materials to large scale industrial applications. As compared to individual materials, composite materials are electrical and thermal insulators and have high strength to weight ratio. Furthermore, they are corrosion resistant, non-magnetic, have long durability, require less maintenance and are transparent to radars. Due to these advantages, they are commonly used materials in aerospace, marine industry, electronics, consumer goods, transportation, construction and military applications [1, 2].

Bimetal is an important type of composite materials which has applications in various areas of technology. Bimetals are composed of two layers of same length but materials with different coefficients of thermal expansion. In bimetals, the layer with greater coefficient of thermal expansion is termed as active layer while the layer with smaller coefficient of thermal expansion is termed as passive layer. In bimetals, both active and passive layers are joined firmly and can't be detached from each other. Due to different coefficients of thermal expansion, when temperature of bimetals is raised, active and passive layers have different elongations. Due to this relative change in lengths, the active layer observes compression and passive layer observes tension. Due to these compression and tension in two layers of bimetals, it bends towards the passive layer causing thermal deformation [3].

The thermal bending in bimetals with respect to change in temperature is based on S. Timoshenko theory of bending in bimetal strip thermostats [4]. According to this theory, thermal bending of bimetals shows a direct trend with increase in temperature. Thermal bending is more when difference between coefficients of thermal expansion of layers is greater. While thickness of strip is in inverse relation to bending of bimetals.

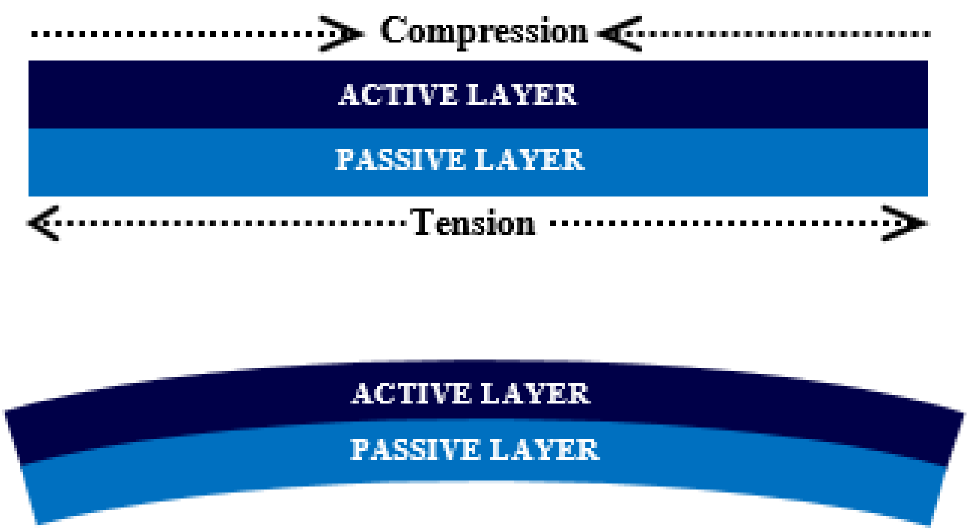

Fig. 1: Thermal bending in Bimetal

Due to this temperature response property, bimetals are widely used in technology and industrial and fields. They are commonly used in temperature indicators to measure temperature of airplane wings, refrigerators and other devices. They are also used in temperature controllers and controlling of functions by auxiliary heating of bimetals [5].

Due to such importance of bimetals, a lot of experiments and researches are conducted in field of bimetals and applications of thermal deformation in bimetals. In 1990, T. Y. Pan et al. developed an analytical model for the deformation in geometry of multi-layered stack assemblies against thermal loading. This model was based on S. Timonshenko's theory of bending in bimetal strip thermostat. The results of the analysis were correlate well with finite element analysis and experimental results [6]. In 2011, M. A. Ismail et al. reported the characteristics, design and implementation of a temperature sensor for solar panel using Fiber Bragg Grating (FBG) Bimetal.

This FBG bimetal temperature sensor has greatest sensitivity between 41 to 90 °C and is an excellent device for the real time measurement of solar panel temperature [7]. In 2012, A. V. Rao et al. using Finite Element Analysis to propose an empirical model to measure the deflection in bimetallic beam against thermal load. The results show that there is a linear relationship between thermal load and deflection in bimetallic beam [8]. In 2013, X. Y. Yang et al. improved the frequency stability of crystal oscillator by using the bimetal. This work performed both finite element simulation and real time experiment and results concluded that during temperature change, thermal stress of bimetal strip and crystal oscillator neutralize each other and reduced the frequency shift [9]. In 2019, P. Liu et al. used Gleeble-3800 thermomechanical simulator to perform compression test on BTW1-Q345R bimetal. This analysis was performed for a temperature range of 950-1200 °C. The results concluded that the thermal deformation should proceed for temperature of bimetal range from 1182 °C to 1200 °C [10]. In 2019, M. Fratita et al. used ANSYS to compare performance of steel pistons with steel-Aluminium bimetal pistons. This simulation results showed that as compare to steel pistons, bimetal pistons are not only less in weight but also have greater efficiency at cool start of the engine [11]. In 2020, D. Saha et al. developed a theory to predict negative coefficient of thermal expansion by using bimetal strip and universal antichiral metamaterial. This theory predicts coefficient of thermal expansion to be in range between 0.0006 and 0.0041 °C [12]. In 2020, Z. Zhang et al. suggested a new model for solar tracking in solar panels. This model used bimetallic thermal deformation property to steer the configuration of panel, so that cells receive maximum amount of solar radiations [13]. In 2020, Z. Li et al. used thermal bending of bimetals in automatic shading devices for rooms. In Beijing, this simulation results showed a reduction of 58% of indoor heat gain in summer [14]. In 2020, M. Kang et al. used bimetallic strip with PZT for harvesting of thermal energy. This work deals with both pryo- and piezo-electric effects simultaneously. The prototype used in this work produce an output of 4μW against a temperature difference of 15 K at frequency of 0.02 Hz [15]. In 2021, R. K. Jaya Kumar et al. used ANSYS to compare the electro-thermal deflection between Copper (Cu)-Steel and Aluminum (Al)-Steel bimetals due to passage of current from them. The initial temperature used in this simulation is 22 °C and the current ranges between 1-32 Amperes. Results of this simulation showed Al-Steel bimetal shows more deflection than Cu-Steel bimetal [16]. Many scientists worked on simulation techniques for different objectives of research [17-28].

Simulation

ANSYS is a very powerful and innovative software for multi-physics simulations. ANSYS is widely used in engineering field and industry for mechanical, thermal, fluid dynamics, electrical and electromagnetic simulations. In this work, thermal deformation of two well-known bimetal composites Al-Steel and Cu-Steel is compared by using ANSYS Static Structural. ANSYS Workbench design modeler is used to create geometry of bimetals. The created geometry consists of two joined rectangular strips with same dimensions of 100×30 mm and thickness of 5 mm.

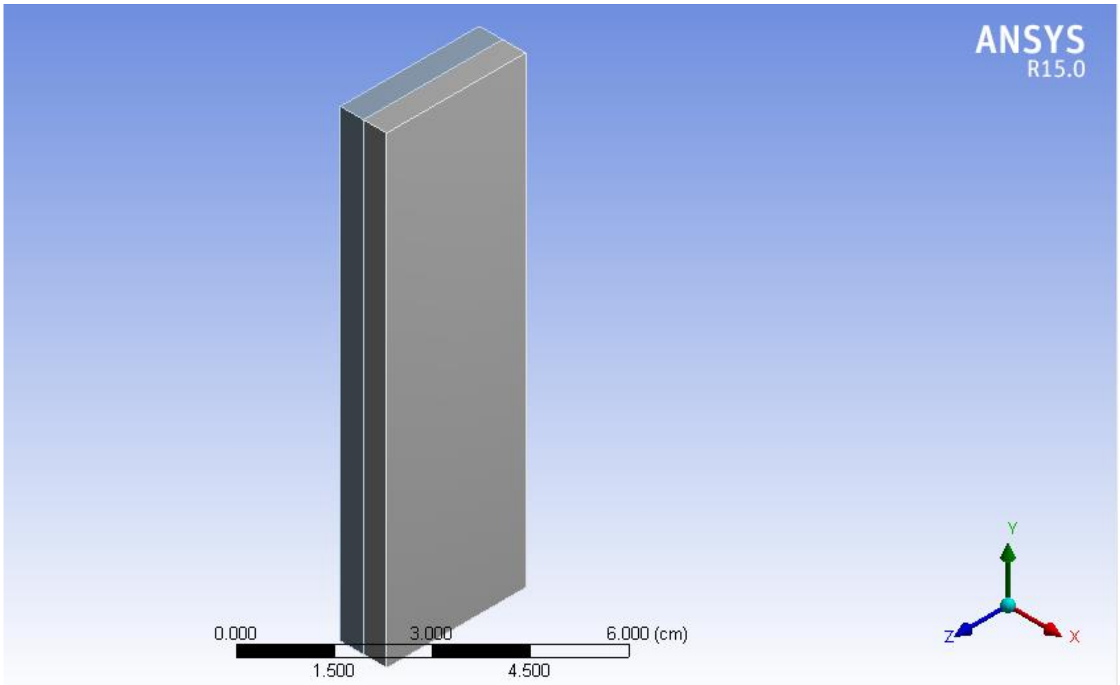

Fig. 2: Modeling of Bimetal

The initial temperature for both bimetals is 22 °C. For real time simulation, material properties are set by Engineering data source provided by ANSYS. The properties of the materials used in bimetals with dimensions are shown in the below table

Table I: Properties of materials of bimetals

Parameters	**Material**		
	Steel	**Aluminium**	**Copper**
Length (mm)	100	100	100
Width (mm)	30	30	30
Thickness (mm)	5	5	5
Initial Temperature (°C)	22	22	22
Density (kgm^{-1})	7850 [16]	2770 [29]	8300 [16]
Young Modulus (Pa)	2E+11 [16]	7.1E+10 [29]	1.1E+11 [16]
Poisson's Ratio	0.3 [16]	0.33 [29]	0.34 [16]
Bulk Modulus (Pa)	1.6667E+11 [16]	6.9608E+10 [29]	1.1458E+11 [16]
Shear Modulus (Pa)	7.6923E+10 [16]	2.6692E+10 [29]	4.1045E+10 [16]
Coefficient of Thermal expansion ($°C^{-1}$)	1.2E-05 [16]	2.3E-05 [30]	1.8E-05 [16]

For more accurate simulation, the geometry is finely meshed with size of elements set to be 1 mm. The meshed setting comprises of medium smoothing, fine relevance center and fine span angle center. The meshed geometry has comprised of 300000 elements and 142442 nodes in total.

The number of elements can be increased for more accurate results. But this finer meshing has a drawback of processing time in simulation. The thermal condition applied on both Al-Steel and Cu-Steel bimetal composites is ranged between 50 to 300 °C.

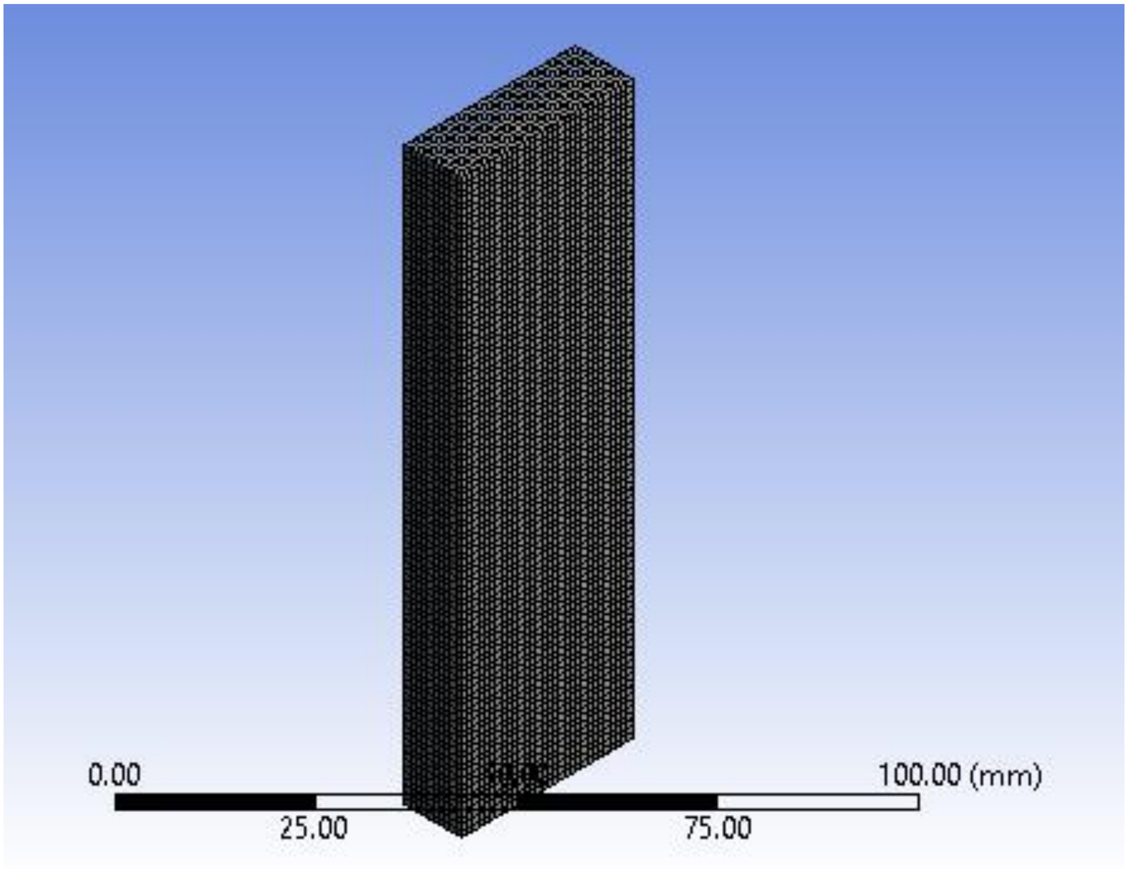

Fig. 3: Meshing of Bimetal

Results and Discussion

ANSYS Static Structural is used to compute the thermal deformation against increase in temperature. The initial temperature of bimetals is 22 °C with no deformation. When the temperature increase, both Al-Steel and Cu-Steel bimetals experienced deformation in shape. The results show that both bimetals experience maximum deformation at the center of strips. At the temperature of 300 °C, Al-Steel bimetal show maximum deformation of 0.62 mm and is located at the center of strip. While the bottom edge experience minimum deformation of 0.13 mm. For Cu-Steel bimetal, at 300 °C maximum deformation of 0.36 mm is observed at center of strip, while minimum deformation at bottom edge is 0.14 mm. This thermal deformation gradient correlate well with the assumptions of [6].

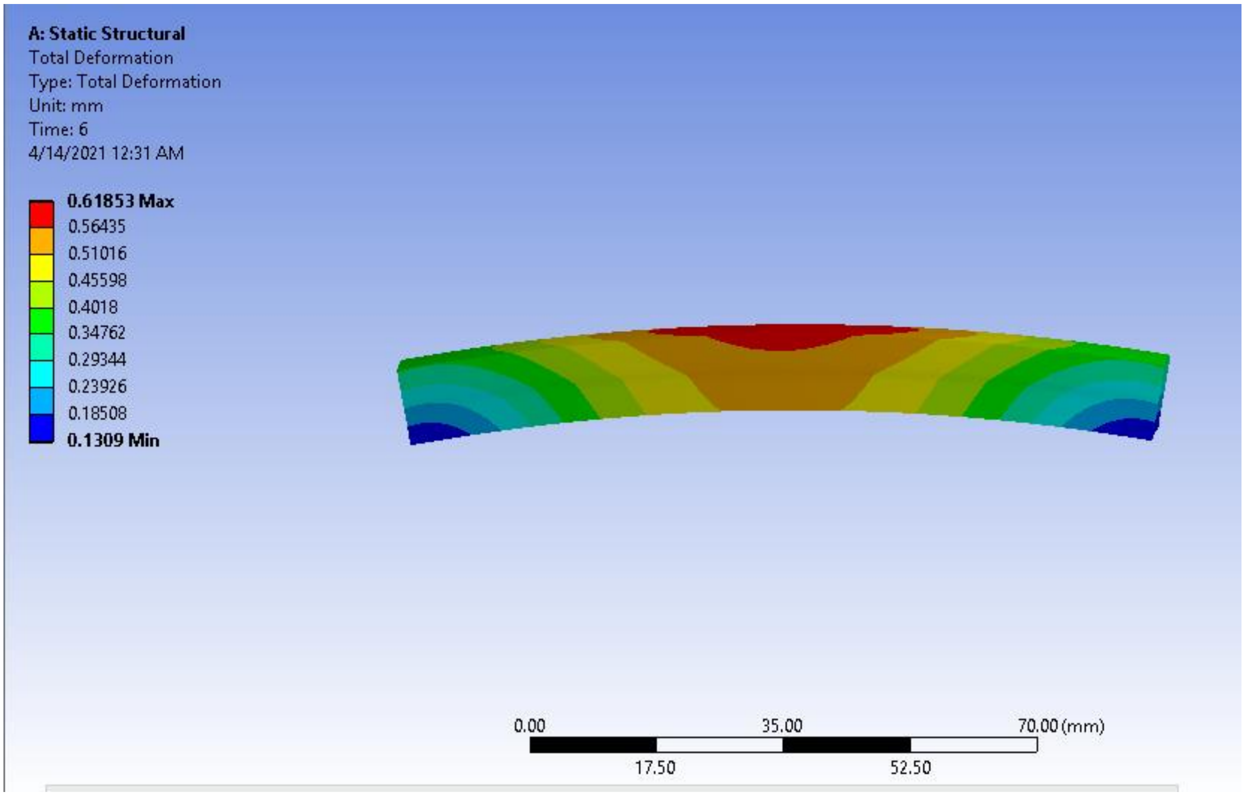

Fig. 4: Maximum thermal deformation at center of bimetal strip

In first simulation, thermal deformation in Al-Steel bimetal is observed against increase in temperature ranged 22-300 °C. When temperature increase bimetal observes thermal bending towards steel layer. Results show that thermal bending or deformation is in direct relation with increase in temperature. At maximum temperature of 300 °C, Al-Steel bimetal experience a thermal deformation of 0.62 mm at center and 0.13 mm at edge.

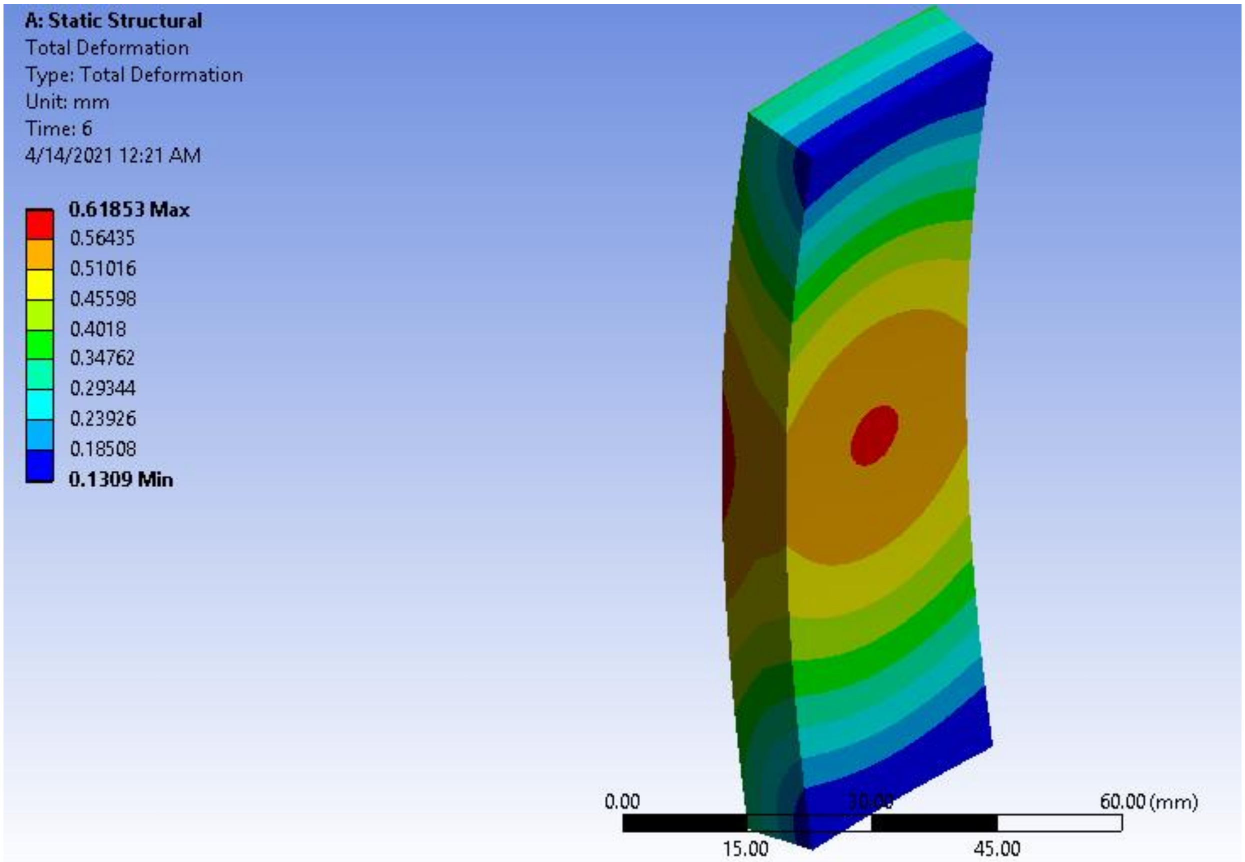

Fig. 5: Thermal Deformation in Al-Steel Bimetal

In second simulation, thermal deformation in Cu-Steel bimetal is observed against increase in temperature ranged 22-300 °C. When temperature increase bimetal observes thermal bending towards steel layer. Results show that thermal bending or deformation is in direct relation with increase in temperature. At maximum temperature of 300 °C, Cu-Steel bimetal experience a thermal deformation of 0.36 mm at center and 0.14 mm at edge.

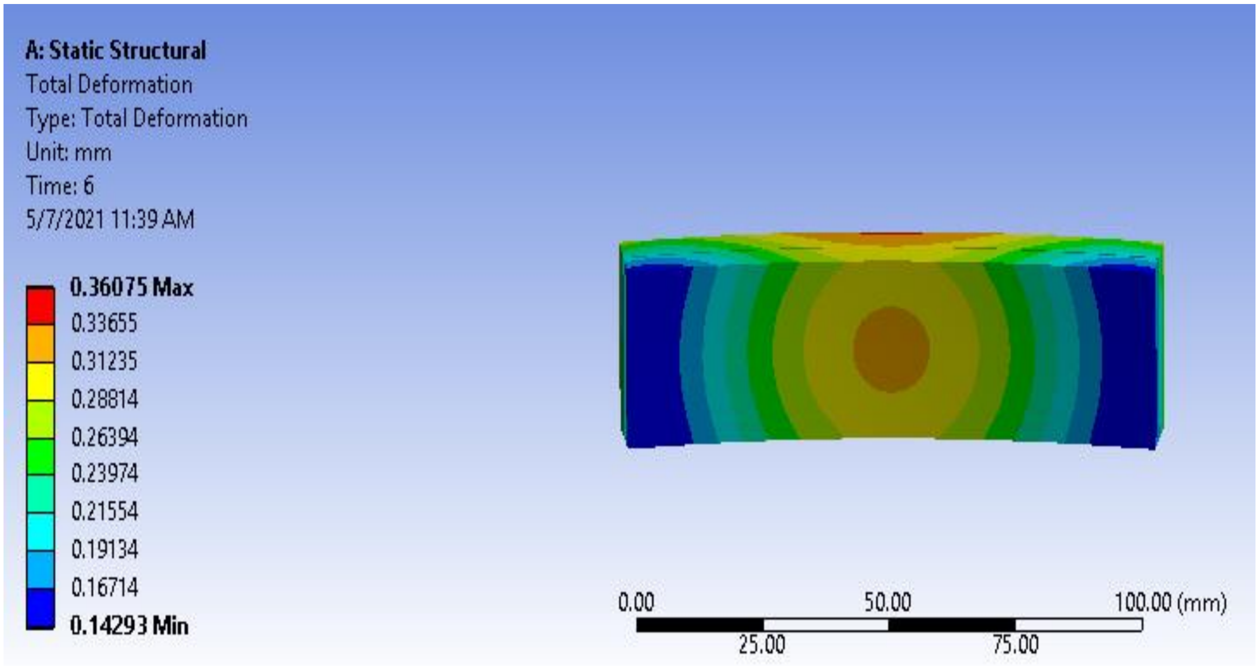

Fig. 6: Thermal Deformation in Cu-Steel bimetal

Table II: Thermal Deformation against variation of temperature

Temperature (°C)	Al-Steel (mm)	Cu-Steel (mm)	Difference (mm)
22	0	0	0
50	0.06	0.04	0.02
100	0.17	0.1	0.07
150	0.28	0.17	0.11
200	0.4	0.23	0.17
250	0.51	0.3	0.21
300	0.62	0.36	0.26

The results of this simulation show a linear trend between thermal deformation and temperature of bimetals. As the temperature increases, the difference between thermal deformation of both bimetals goes on increasing rapidly. The results of this simulation show same behavior thermal bending against temperature as for S. Timoshenko's theory of bending in bimetal strip thermostats [4].

When plotted a graph between thermal deformation y-axis against increase in temperature along x-axis, the curve of Al-Steel bimetal is above than that of Cu-Steel bimetal. Graph shows that Al-Steel is more deformed than Cu-Steel bimetal at all temperatures.

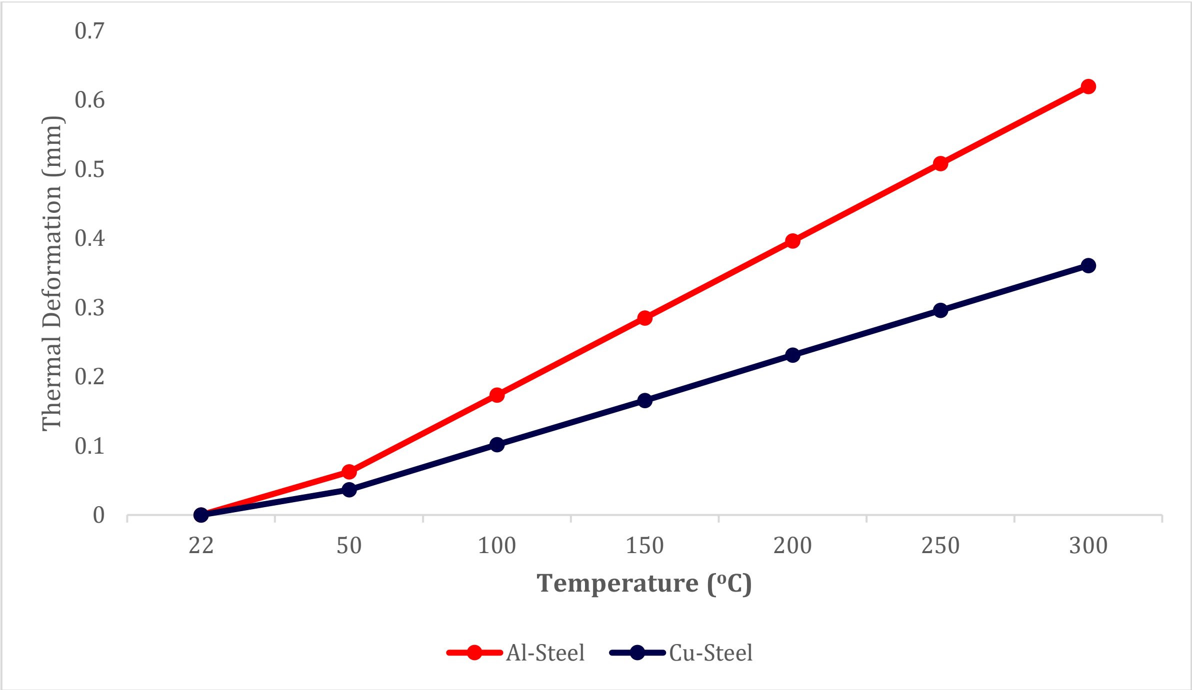

Fig. 7: Graph between Thermal deformation and Temperature for Bimetals

Conclusion

In this work, the comparative analysis for thermal deformation between Aluminum-Steel and Copper-Steel bimetals is carried out by using ANSYS Static Structural. Both Aluminum-Steel and Copper-Steel are well-known bimetals and used in many fields of industry. The bimetals used in this work comprise of two layers with same dimensions of 100×30 mm with thickness of 5mm. ANSYS is used to observe thermal deformation for a temperature range of 22-300 °C. Results shows linear trend between temperature and thermal deformation. At the temperature of 300 °C, Al-Steel experience thermal deformation of 0.36 mm at center and 0.14 mm at edge.to 0.62 mm while Cu-Steel bimetal experience thermal deformation of 0.36 mm at center and 0.14 mm at edge. The results concluded that Aluminum-Steel bimetals show more thermal deformation than Copper-Steel bimetal at all temperature.

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