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A Comparative Finite Element Effort for Detection of the Effect of Epoxy and Rubber Interlayers on Temperature and Force Induced Stress Behavior in Metallic Laminate Composites

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Abstract – Recently, metallic laminate composites have been considered attractive for lots of industries like automotive, aviation, aerospace, construction, and defense owing to their high specific strength, impact resistance, and lightweight. In this paper, different from the previous literature efforts, temperature-induced deformation behaviors of polymer layer-added metallic laminates were analyzed via a finite element approach. As interlayer polymers, epoxy, and rubber were used separately between the metallic plates. The simulation results showed that as the ambient temperature increased from 20°C to 100°C fixed side of the model reflected higher stress levels. Also, when force levels went up total deformation escalated for both epoxy-added and rubber-added models. In addition, from the outcomes, it was obvious that polymeric interlayers had a blocking effect for excess stress concentrations on the whole design geometry and had the capacity to reduce the total weight compared to solely metallic combinations that are vulnerable to unwanted delamination.

Keywords – Interlayer, Epoxy, Rubber, Laminate Composite, Temperature-Induced Deformation

I. INTRODUCTION

Metal-polymer composites have various technical advantages and their usage in unlike sectors is rising sharply day by day [1]. Sandwich-structured metallic laminate composites can be seen as a sub-group of a general engineering composite family [2]. Particularly, metallic options have been preferred by different industrial areas such as automotive, aviation, aerospace, building, and construction [3]. By reason of their sufficient mechanical strength, specific strength, impact resistance, heat/aging treatment availability, lightweight, and high elongation capacity, metallic materials like Al, Mg, and Cu can be interpreted as a perfect option for critical component design [4, 5].

Due to their relatively low density (2.7 and 1.7 g/cm^3 for Al and Mg respectively) and relatively low melting temperature (approximately 660°C for both), Al and Mg alloys are significantly alluring for product development engineers and composite researchers. Specific to Mg-based alloys, AZ91 and AZ31 series can be accepted as the most popular versions compared to the others [6]. As a result of the performance increase triggered by the alloy combination of aluminum, zinc, and magnesium, these AZ91 and AZ31 series are usually selected for automotive, aerospace, and marine applications [7].

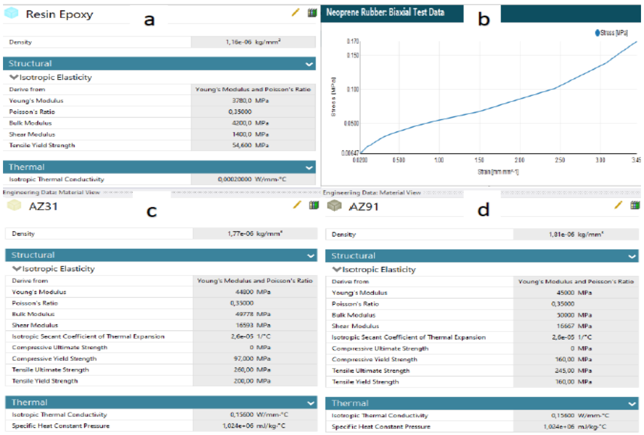
In actual working conditions, metal-based composite laminates are subjected to a set of unwanted difficulties. Corrosion, fatigue, impact loading, wear, and mechanical loadings are some of them [8-10]. Precisely because of that, differently combined sandwich structures gain importance in practice and can be seen as a good alternative to traditional metal components depending on the usage condition of the machine part. Thanks to the layer-based laminate design, core materials, and outer layer materials behave as if they are a united body, and this solidarity provides a reciprocal synergetic influence under real service conditions [11].

In this paper aiming to address the effect of the polymer interlayer addition on temperature-induced deformation behavior of sandwich structures, laminate composite structures consisting of AZ91 core material and AZ31 outer layer material were examined in point of bending properties. With this motivation, finite element-based approaches were tried, three different temperatures (20°C, 60°C, and 100°C) were chosen, and related models were set. Also, two different interlayer polymers (epoxy and rubber) were utilized to understand the effect of the design modifications. Finally, all of the finite element outcomes were assessed in terms of stress and displacement depending on the input parameters.

II. MATERIALS AND METHOD

Because of their low density and specific mechanical strength, AZ31 and AZ91 magnesium series were chosen in the metal sections of the laminates. As a core part AZ91 alloy was considered whereas AZ31 series plates were preferred as outer shield materials. This plan was used because AZ31 exhibits superior corrosion endurance, and this circumstance is an important advantage for oil, brine, water, and aggressive air environments.

As for the interlayers, owing to their elastic behaviors and flexible properties, epoxy and rubber materials were selected. In Figure 1, some major properties taken from the simulation software of these polymers can be seen. Besides, in Figure 2, a modelled composite laminate system can be found.



Resin Epoxy

Density	1,16e-06 kg/mm³

Structural

Isotropic Elasticity

Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	3780,0 MPa
Poisson's Ratio	0,35000
Bulk Modulus	4200,0 MPa
Shear Modulus	1400,0 MPa
Tensile Yield Strength	54,600 MPa

Thermal

Isotropic Thermal Conductivity	0,00020000 W/mm·°C

AZ31

Density	1,77e-06 kg/mm³

Structural

Isotropic Elasticity

Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	44800 MPa
Poisson's Ratio	0,35000
Bulk Modulus	49778 MPa
Shear Modulus	16593 MPa
Isotropic Secant Coefficient of Thermal Expansion	2,6e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	97,000 MPa
Tensile Ultimate Strength	260,00 MPa
Tensile Yield Strength	200,00 MPa

Thermal

Isotropic Thermal Conductivity	0,15600 W/mm·°C
Specific Heat Constant Pressure	1,024e+06 mJ/kg·°C

AZ91

Density	1,81e-06 kg/mm³

Structural

Isotropic Elasticity

Derive from	Young's Modulus and Poisson's Ratio
Young's Modulus	45000 MPa
Poisson's Ratio	0,35000
Bulk Modulus	50000 MPa
Shear Modulus	16667 MPa
Isotropic Secant Coefficient of Thermal Expansion	2,6e-05 1/°C
Compressive Ultimate Strength	0 MPa
Compressive Yield Strength	160,00 MPa
Tensile Ultimate Strength	245,00 MPa
Tensile Yield Strength	160,00 MPa

Thermal

Isotropic Thermal Conductivity	0,15600 W/mm·°C
Specific Heat Constant Pressure	1,024e+06 mJ/kg·°C

Fig. 1 Some properties of epoxy (a) AZ31(c) AZ91 (d) and stress/strain properties of rubber (b)

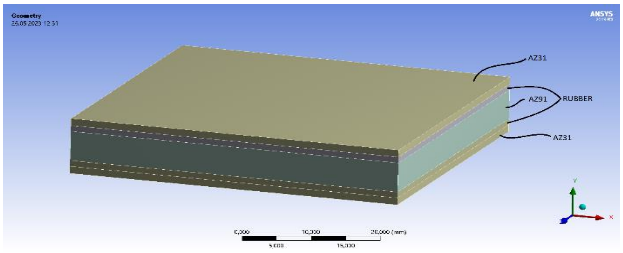


Fig. 2 Metal/polymer/metal/polymer/metal composite system

In the simulation study, ANSYS 2019 software was used, and all properties (Young modulus, shear modulus, Poison ratio, tensile strength, and compression strength) of the composite constituents were taken from the program library. To analyze the thermal effect, laminate composite models were fixed and heated from one side while the bending force was applied from the other free side. The surface area of the designed parts was 50×50 mm^2.

III. RESULTS

In Figure 3, epoxy layer added models that tested at 20°C with 25N force can be seen with their stress and displacement results. The highest stress reached almost 10 MPa at the fixed corner and stress distribution was controlled with the force.

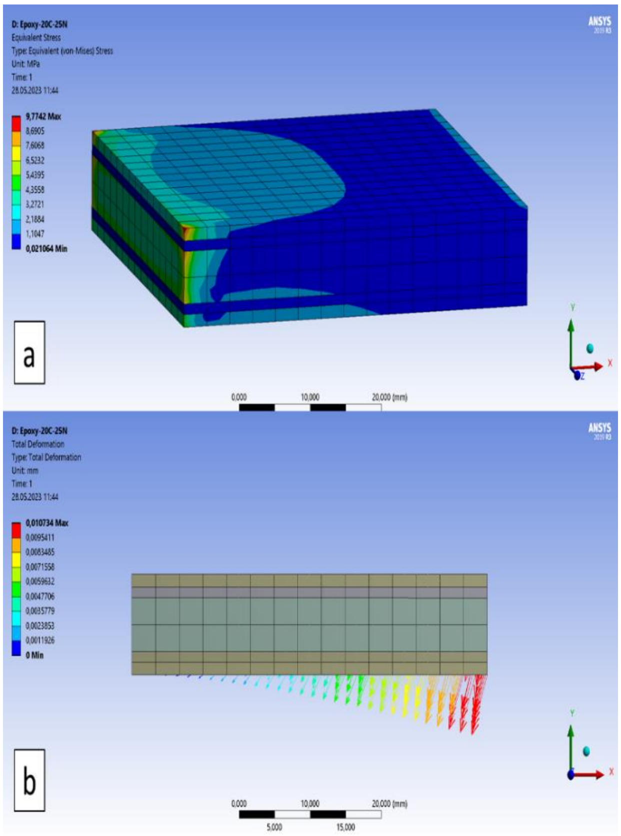


Fig. 3 Stress (a) and strain (b) simulations of epoxy added samples (20°C and 25 N)

Figure 4 shows the stress results noticed for 60°C with 25 N, 50N and 100N respectively. It was observed that as the temperature went up the calculated stress levels (up to 155 MPa) of epoxy added samples escalated at the fixed side.

Figure 5 depicts the displacements results for 60°C with 25 N, 50N and 100N respectively. It was also understood that thermal expansion effect was present in the sample elongation.

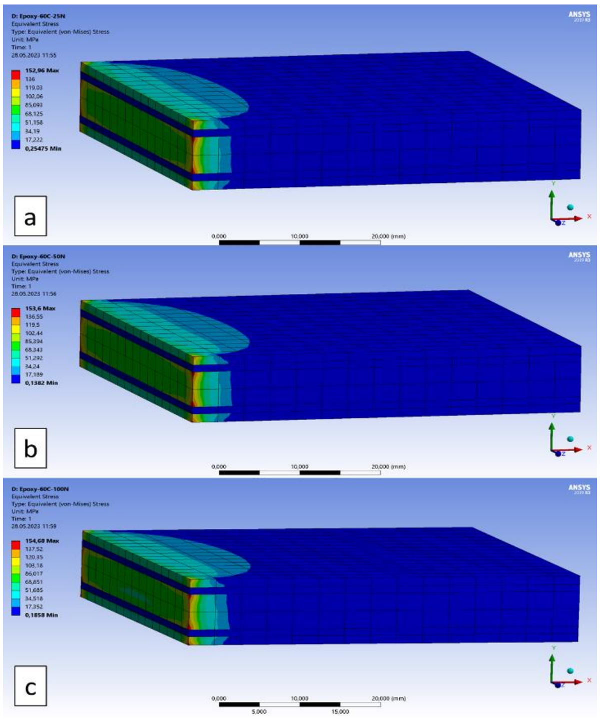


Fig. 4 Stress simulations at 60°C of epoxy added samples: 25 N (a), 50 N (b), and 100 N (c)

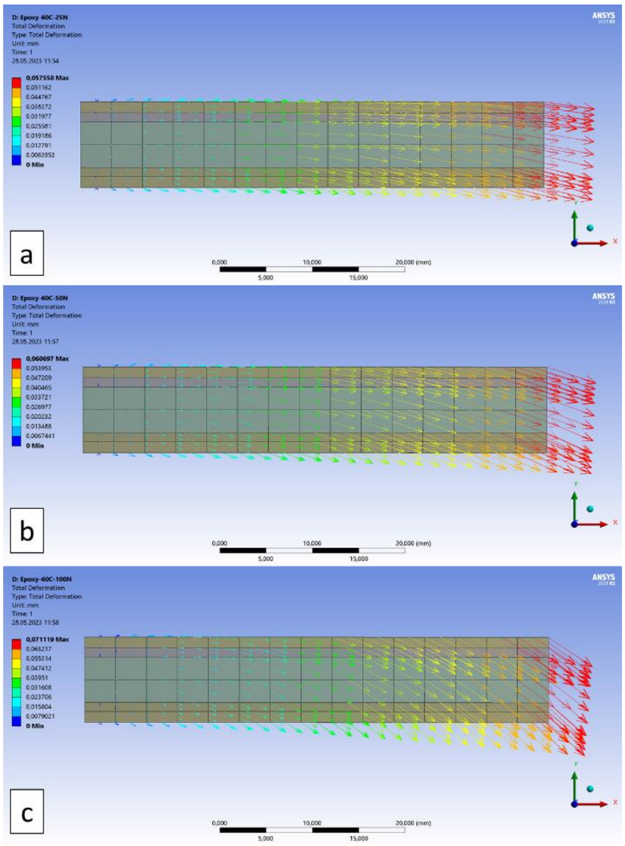


Fig. 5 Strain simulations at 60°C of epoxy added samples: 25 N (a), 50 N (b), and 100 N (c)

As the ambient temperature reaches up to 100°C, stress concentration levels also increase due to the combined impact of thermal expansion and deformation blocking capability of fixed joint. In Figure 6 and Figure 7, stress and displacement simulation are shared in detail. From these results, it should be noted that epoxy interlayers diminish the stress accumulation. The highest displacement of 0.12 mm belonged to the sample forced with 100 N.

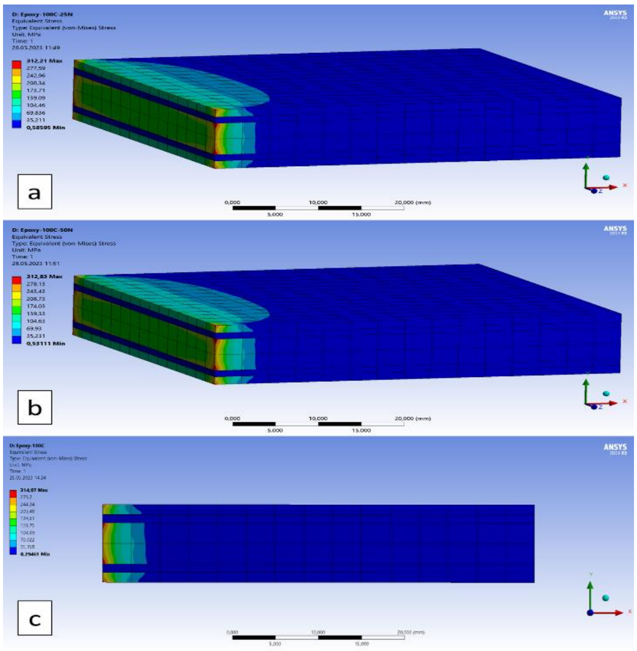


Fig. 6 Stress simulations at 100°C of epoxy added samples: 25 N (a), 50 N (b), and 100 N (c)

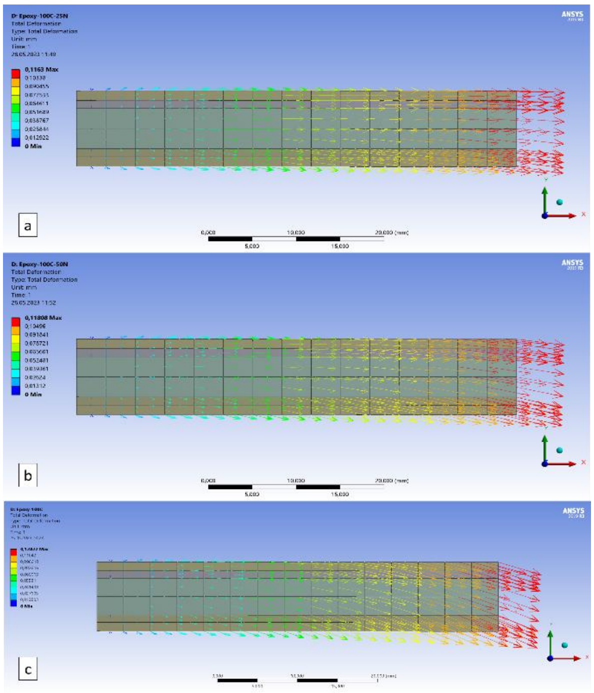


Fig. 7 Strain simulations at 100°C of epoxy added samples: 25 N (a), 50 N (b), and 100 N (c)

For rubber interlayer, similar trend that was obtained for the epoxy was ascertained and there was a positive effect for stress decrease in the whole rigid design body. Figure 8 illustrates the results for room temperature and the maximum stress utterly depended on the force instead of temperature.

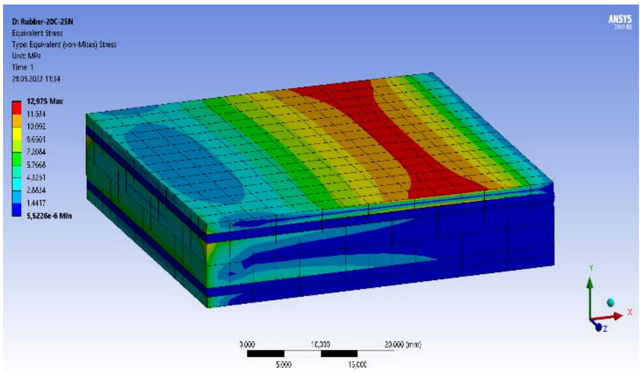


Fig. 8 Stress simulations of rubber added models (20°C and 25 N)

For 60°C, the case beheld at 20°C was different and the stress localization effect was present, particularly at the corner points of the fixed joint (up to 165 MPa). Figure 9 and Figure 10 demonstrate the stress and displacement results respectively for 60°C.

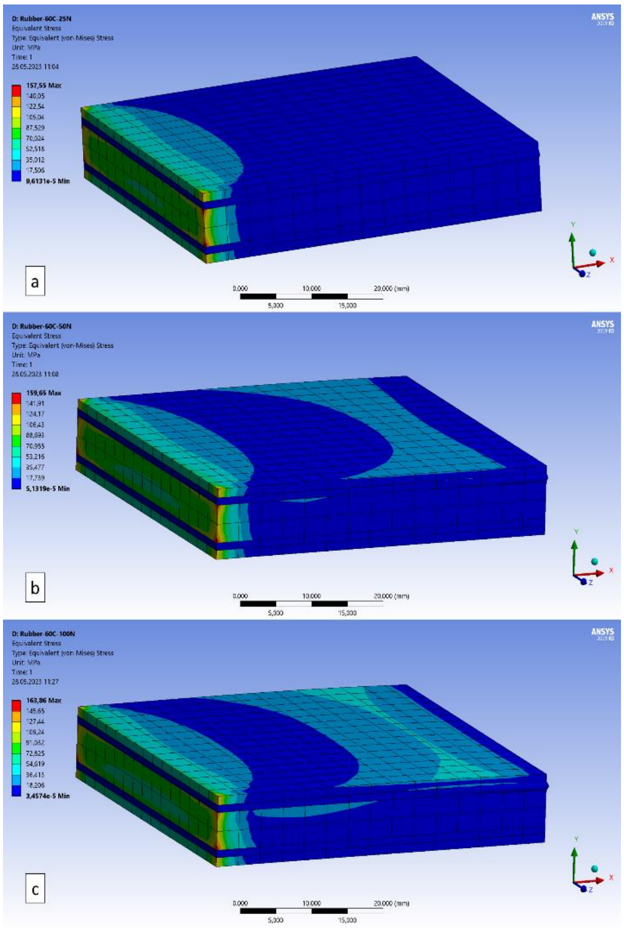


Fig. 9 Stress simulations at 60°C of rubber added samples: 25 N (a), 50 N (b), and 100 N (c)

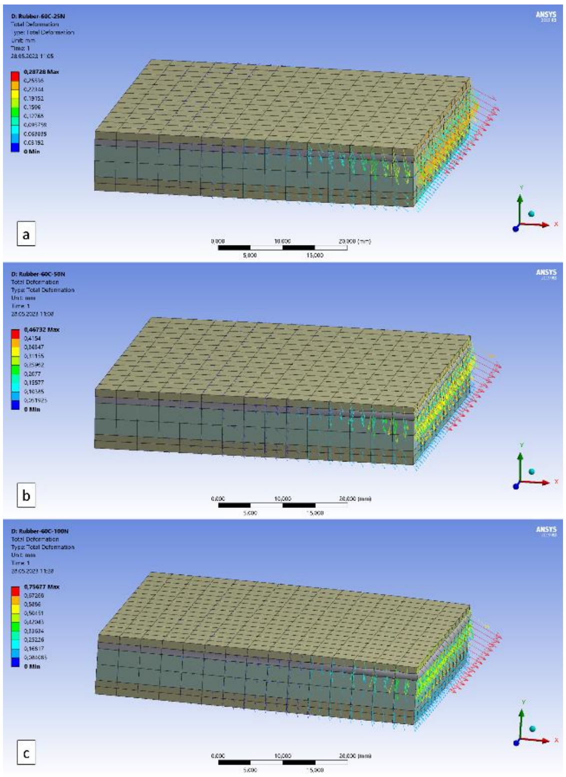


Fig. 10 Strain simulations at 60°C of rubber added samples: 25 N (a), 50 N (b), and 100 N (c)

At 100°C, because of the high thermal expansion of metal and polymeric sections, the fixed joint point was subjected to higher levels of stress and the peak value exceeded 327 MPa. On the other hand, as experienced for epoxy, rubber interlayers enhanced the flexibility of the laminate system and drop the stress concentration. Figure 11 and Figure 12 depict the stress and displacement simulations respectively for 100°C.

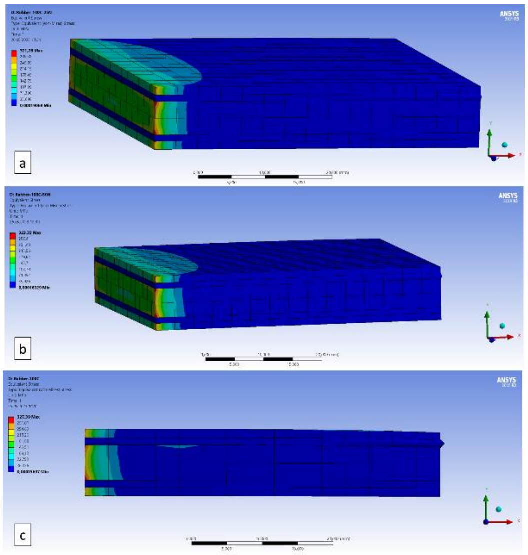


Fig. 11 Stress simulations at 100°C of rubber added samples: 25 N (a), 50 N (b), and 100 N (c)

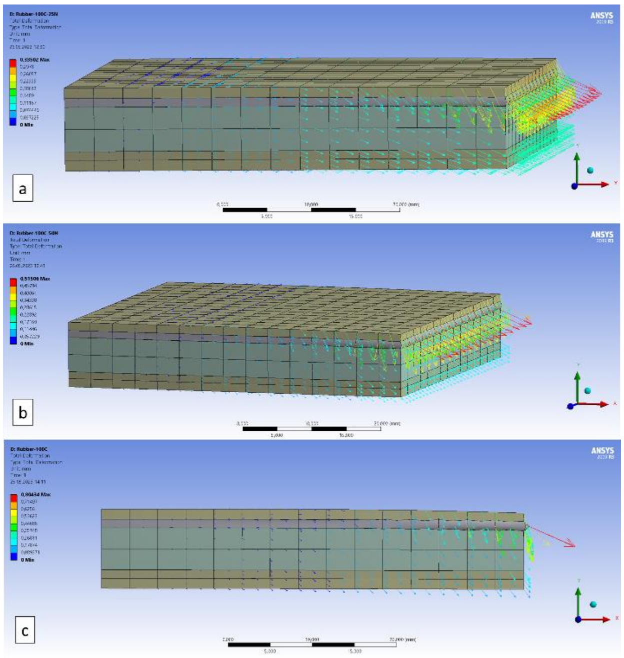


Fig. 12 Strain simulations at 100°C of rubber added samples: 25 N (a), 50 N (b), and 100 N (c)

IV. DISCUSSION

This paper indicates that epoxy and rubber interlayers have a big potential to reduce stress localization and stress rising in metallic laminate composites owing to their flexible structures. The impact of the temperature can be seen more comfortably with the stress values at the corner points of the fixed surface. Especially at low temperatures, test force was more dominant for stress concentration in the rigid body of the solid models regardless of the polymeric interlayer type. With the rising temperature, expansion mechanisms were also active on the laminate layer volumes and this fact caused displacement increase for both epoxy and rubber-added versions. At 100°C, rubber-added composites elongated more than epoxy-added models. This observation might stem from the synergetic effect of the thermal expansion difference of the polymers and applied force levels for bending.

V. CONCLUSION

Looking at the consequences of this finite element-based investigation, the followings can be stated.

- As the test force increase, total displacement rises, and local stress values go up for all models.

- Both epoxy and rubber provide better flexibility to the metallic laminate system owing to their own characteristics.
- The highest stress value was detected at the corner points of the fixed surface due to difficult thermal expansion of metallic layers.
- At lower temperatures, core AZ91 material is also subjected to higher stress values.
- There is no major difference between the epoxy and rubber interlayer in terms of thermomechanical behaviour, but epoxy-added composites have a little bit more displacements.

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