Numerical Simulation and Experimental Verification of Laser Welding of Nylon 6

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Introduction

- Nylon-6 and polymer resin –PBT account for over 90% plastics applications in automotive electronics
- The applications of Nylon-6 are also seen in the industry components where toughness, lubricity and wear are important
- Laser welding is one of the acceptable joining process for the plastic parts that are sensitive and involve complex geometry
- Laser welding of thermoplastics has a number of advantages over conventional welding processes
- The integrity of these joints depends upon the mechanical and metallurgical characteristics
- Numerical simulations have the capability to simulate the welding process without physical experimentation by evaluating weld-bead geometry and internal stress

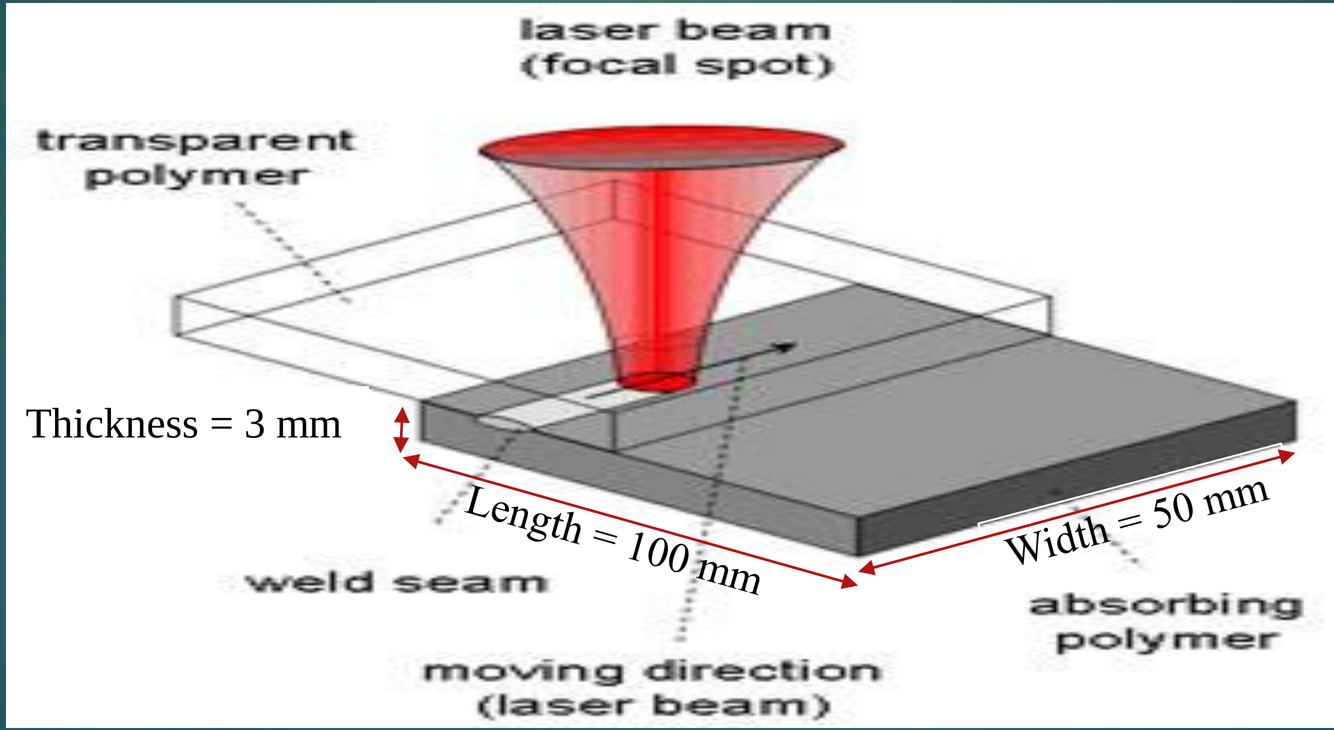
Literature Survey

Author	Year	Key Findings
Yuewei et al.	2018	❖ Laser transmission welding of PET and Ti6Al4V had been modeled and validated. ❖ A 3D transient numerical model considering the melting and fluid flow had developed and found a good agreement between weld bead geometry prediction and experimental data.
Derakhshan et al.	2018	❖ Residual stress and distortion in laser welding of thin structural steel had been experimentally and numerically predicted by using three dimensional thermo-metallurgical-mechanical finite element method. Simulation and experimental result of residual stress and weld cross-sectional shape were found to match.
Ai et al.	2017	❖ This paper focused on understanding the formation mechanism of whole weld-bead by proposing a 3-dimensional model considering the heat transfer, key hole geometry, surface tension and recoil pressure. ❖ The simulated results of weld penetration, depth and reinforcement had a good agreement with the experimental values.
Wang et al.	2013	❖ An intelligent method comprises of FEM, RSM and GA was proposed for simulation and optimization of laser transmission welding of PET and titanium. ❖ FEM model was developed to simulate the temperature field of the welding.

Objectives

- Estimation of weld-bead geometry, i.e., penetration depth and weld width
- XRD phase analysis of the fusion zone
- Estimation of thermally induced residual stress after laser welding
- Estimation of accuracy of numerical model by comparing its results with experimental data

Experimental Setup



Laser power (P), scanning velocity (V) and frequency (F) are assorted in the intervals of 7 W to 9 W, 0.15 mm/s to 0.25 mm/s, and 4 KHz to 6 KHz, respectively. The beam diameter used for welding experiment was kept constant at 0.05 mm.

Temperature (T) dependent physical properties, viz., density (ρ), thermal conductivity (k), specific heat (C_p), Young's modulus (E), coefficient of thermal expansion (α) and Poisson's ratio (μ) were used in thermal modeling.

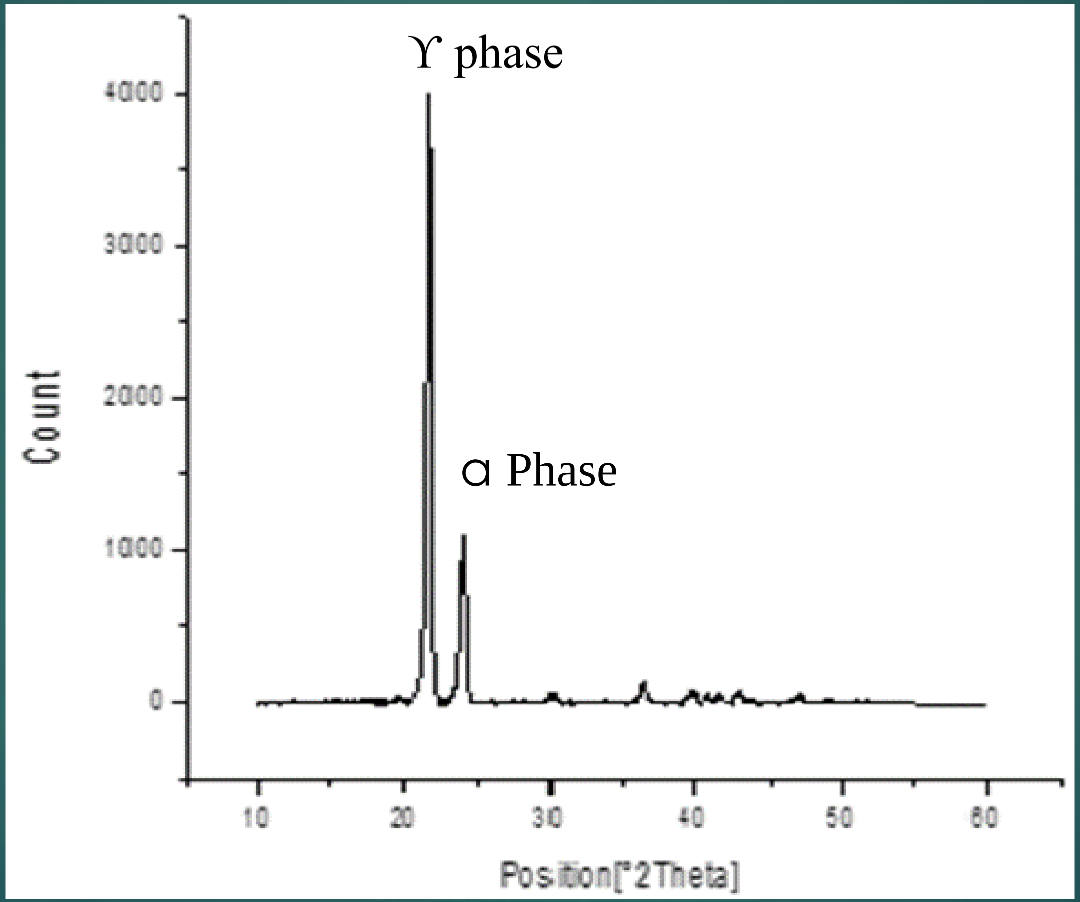
When the input parameters considered for the experiment were 7 W, 0.20 mm/s and 5 KHz, it resulted into line energy of 35 J/mm and aspect ratio of 1.75. However, when the parameters were varied to 9 W, 0.15 mm/s and 4 KHz, there was an increment in line energy and aspect ratio. Line energy of the second condition was 60 J/mm and aspect ratio improved by 0.11.

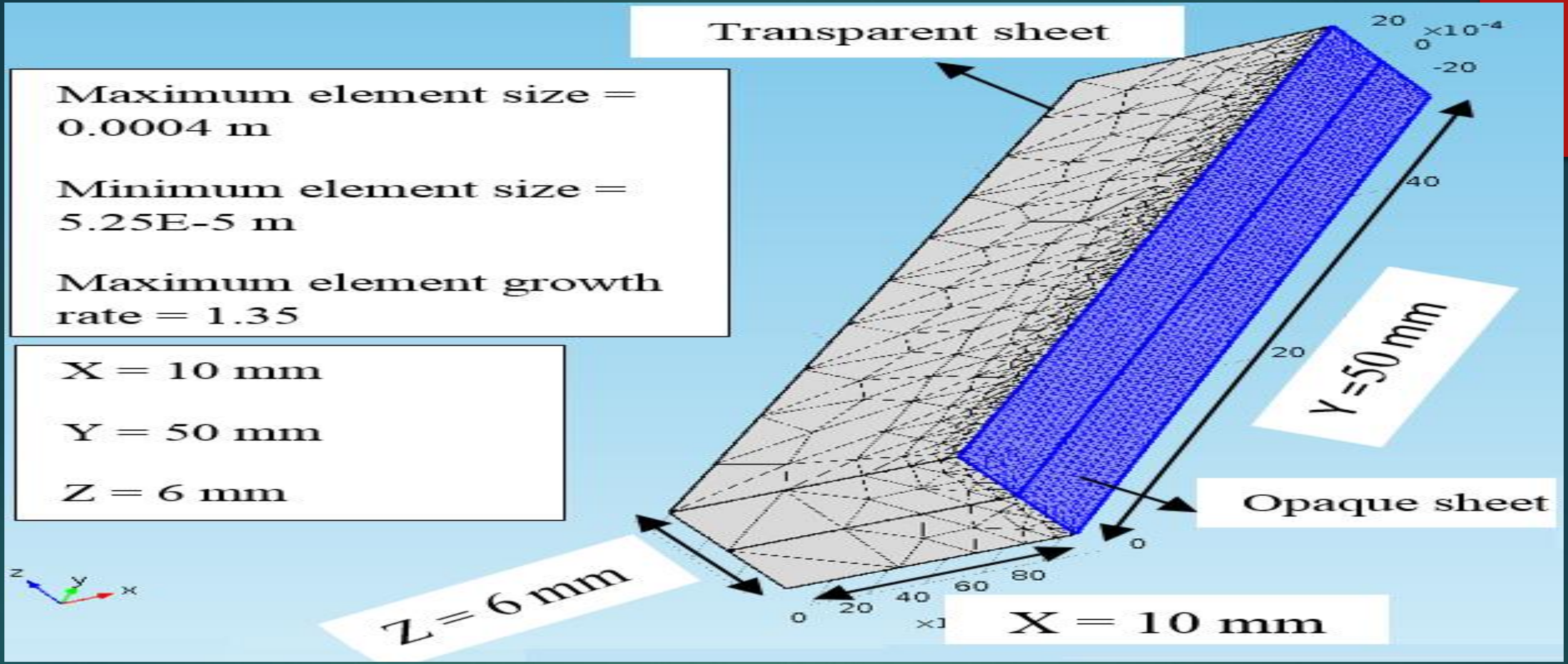
Nylon 6 are mainly composed of these two phases. The α phase shows the anti-parallel chains, whereas in ϒ phase, the parallel chains are evitable. The peak for ϒ phase is found to occur at 2θ = 21.72 and α phase is present at 2θ = 24.1047.

The thermal stresses along the transverse direction of the scanning direction of the laser source were measured and compared to the stresses quantified by numerical analysis

Induced thermal stresses showed an increasing trend with an increase of line energy from 35 J/mm to 60 J/mm.

XRD phase analysis of the fusion zone





Discretized region of the overlapped portion

The present work deals with TTLW of Nylon 6. The three welding parameters that were used to weld Nylon 6 sheet in lap joints configuration using diode laser and then, simulated by COMSOL Multiphysics are Laser power (P), scanning velocity (V) and frequency (F). Each welded joint constitutes of one transparent sheet and one opaque sheet each. Dimensions of each sample are 50 mm x 50 mm x 3 mm.

Governing Equations:

The heat equation for the simulation includes convective terms to quantify temperature over the whole geometry, as given below

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathrm{u} \nabla T = \nabla (k \nabla T) + q_v,$$

where ρ is the density, C_p is the specific heat, u is the velocity field, k is the thermal conductivity, T is the temperature and q_v is the volumetric heat generated by laser.

$$q = h(T_s - To) + \sigma\varepsilon(T_s{}^4 - T_o{}^4),$$

where q is total heat loss by convection and radiation, T_s is the surface temperature and T_o is the ambient temperature. Convective heat transfer coefficient is denoted by h. Material emissivity and Stefan Boltzmann constant are denoted by ε and σ, respectively.

The thermal stresses induced are governed by the equations

$$\varepsilon = \frac{1}{2}[(\nabla u)^T + \nabla u],$$

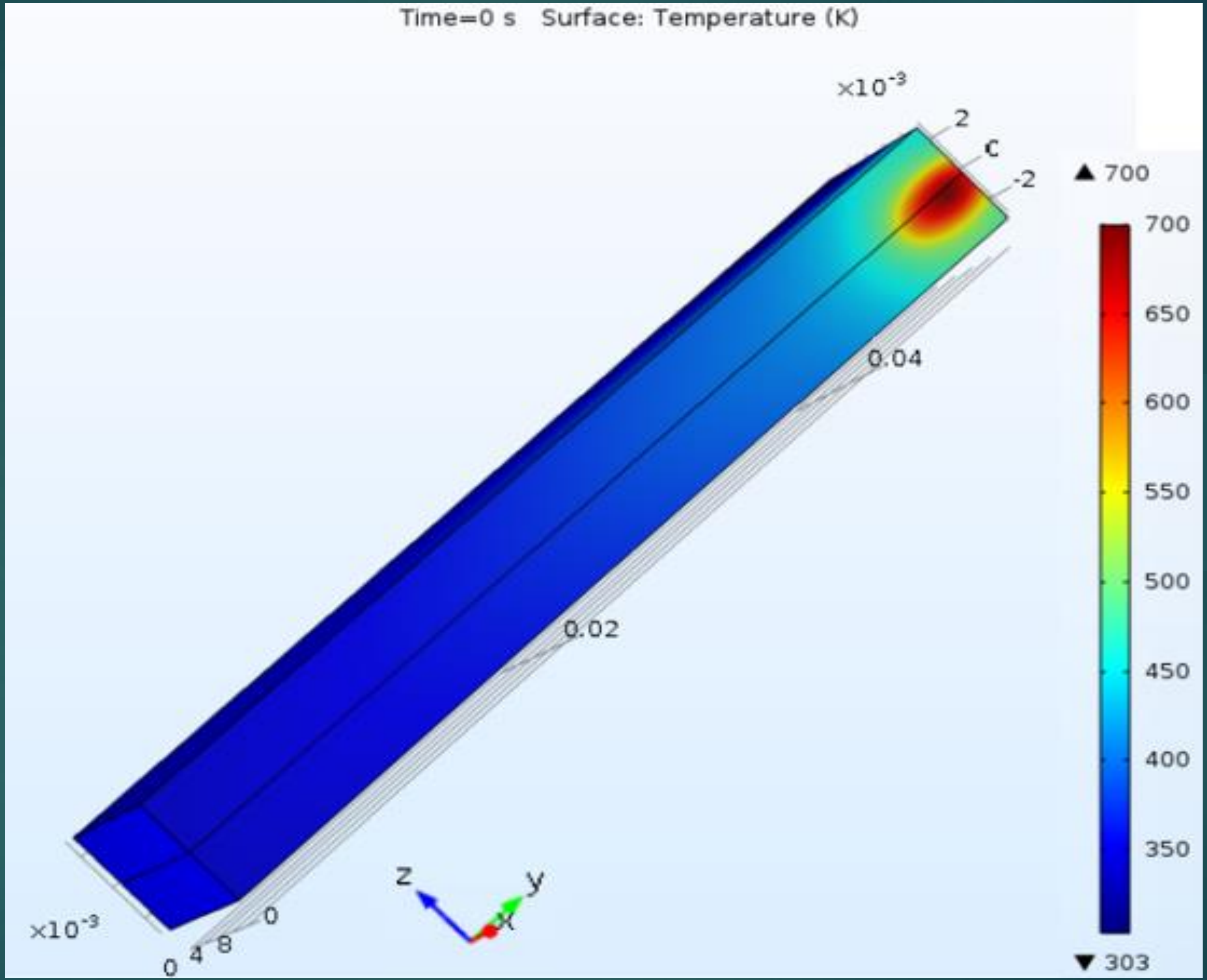
where ε is the symmetric strain tensor.

Stress tensor is related to the elastic strain tensor ϵ_{EL} by the Hooke's law:

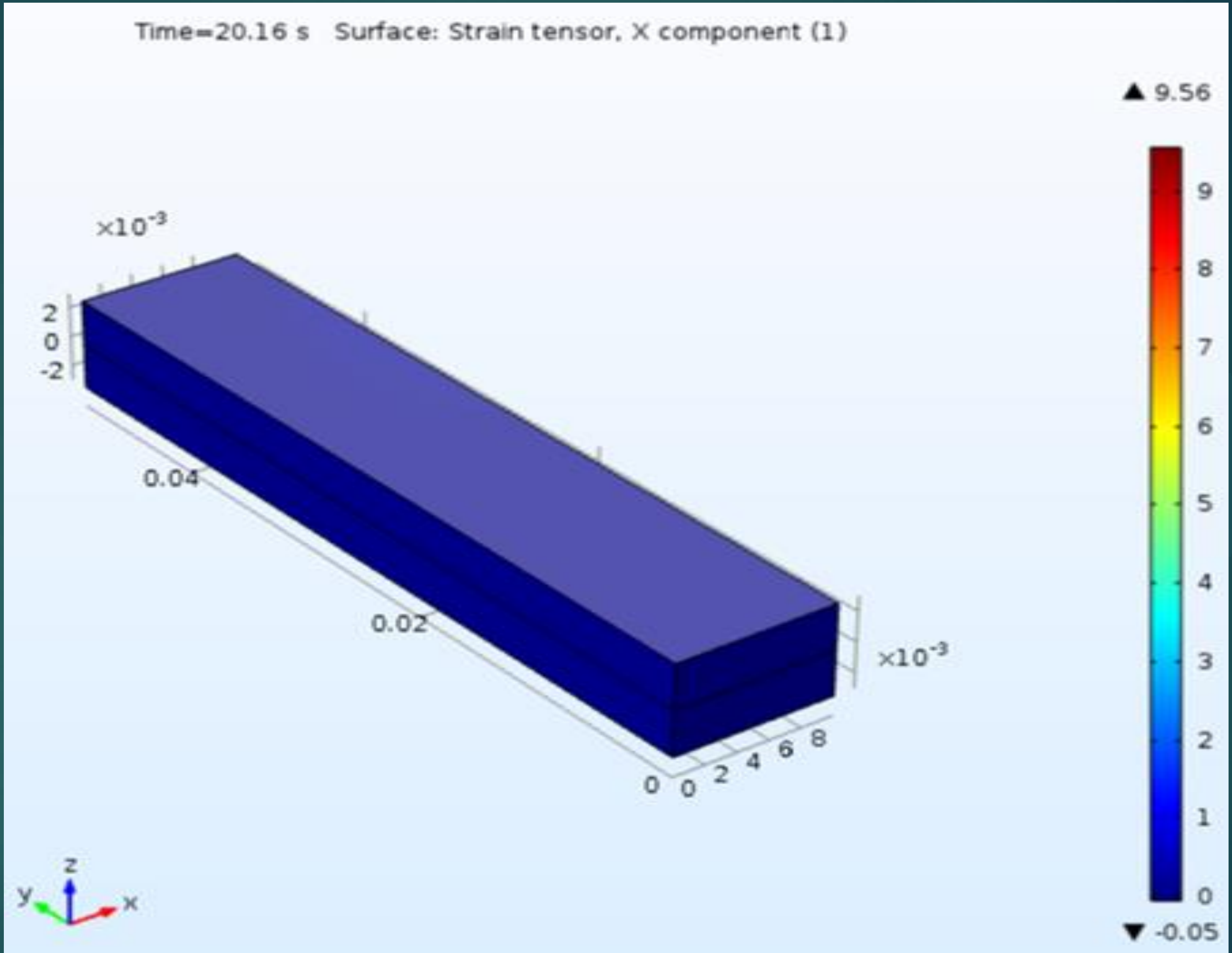
$$\epsilon_{EL} = \varepsilon - \varepsilon_{th}$$

$$\varepsilon_{th} = \propto (T - T_{ref})$$

where ∝ is the coefficient of thermal expansion. T_{ref} is the ambient temperature and T is the working temperature



Temperature distribution at the interface of the two sheets



Stress variation at the interface of the two sheets

Comparison between experimental and simulated results for different combination of input parameters

Sl. no	P (W)	V (mm/s)	F (kHz)	Expt. PD (mm)	Simulated PD (mm)
1	7	0.20	5	2.954	3.451
2	8	0.15	5	3.287	3.860
3	9	0.15	4	3.615	4.252
Sl. no	P (W)	V (mm/s)	F (kHz)	Expt. WW (mm)	Simulated WW (mm)
1	7	0.20	5	1.682	1.961
2	8	0.15	5	1.774	2.059
3	9	0.15	4	1.941	2.283
Sl. no	P (W)	V (mm/s)	F (kHz)	Expt. Stress (MPa)	Simulated Stress (MPa)
1	7	0.20	5	9.268	10.66
2	8	0.15	5	10.481	11.54
3	9	0.15	4	11.029	11.88

Conclusions

- Heat transfer in solid and thermal stress were used to model the whole process by numerical analysis to quantify the dimensions of weld-bead and thermal stresses induced after welding.

- The results of experimental work and numerical analysis were found to differ by 15%. This shows that there is a good agreement between the experimental data and simulated results.

- Considering the accuracy in the simulation, the perspective work can be used to model conduction and keyhole modes of laser welding for different metals and non-metals.

- Numerical analysis helps in reducing the number of experiments and thus, helps in reducing the wastage of resources.

References

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Thanks