# Thermal Analysis of Laser Powder Bed Fusion using Finite Element Modeling

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## MOTIVATION

- A finite element model to understand the relationship between process parameters, temperature history, and thermally induced residual stresses in the laser powder bed fusion process.
- A modeling strategy to predict temperature distribution and melting pool size which serves as a beginning step towards a full residual stress analysis.[3]
- Understand how high residual stress is created to reduce cracking, fatigue-failure, distortion and the need for support structures.

## METHODOLOGY

The LPBF process was modeled using Abaqus with a user defined Fortran subroutine to simulate the laser with a moving heat flux. The thermal analysis was done with stainless steel 316L.

$$q(x,y) = \frac{\alpha_R P}{\pi r_0^2} exp\left\{-\frac{r^2}{r_0^2}\right\}$$

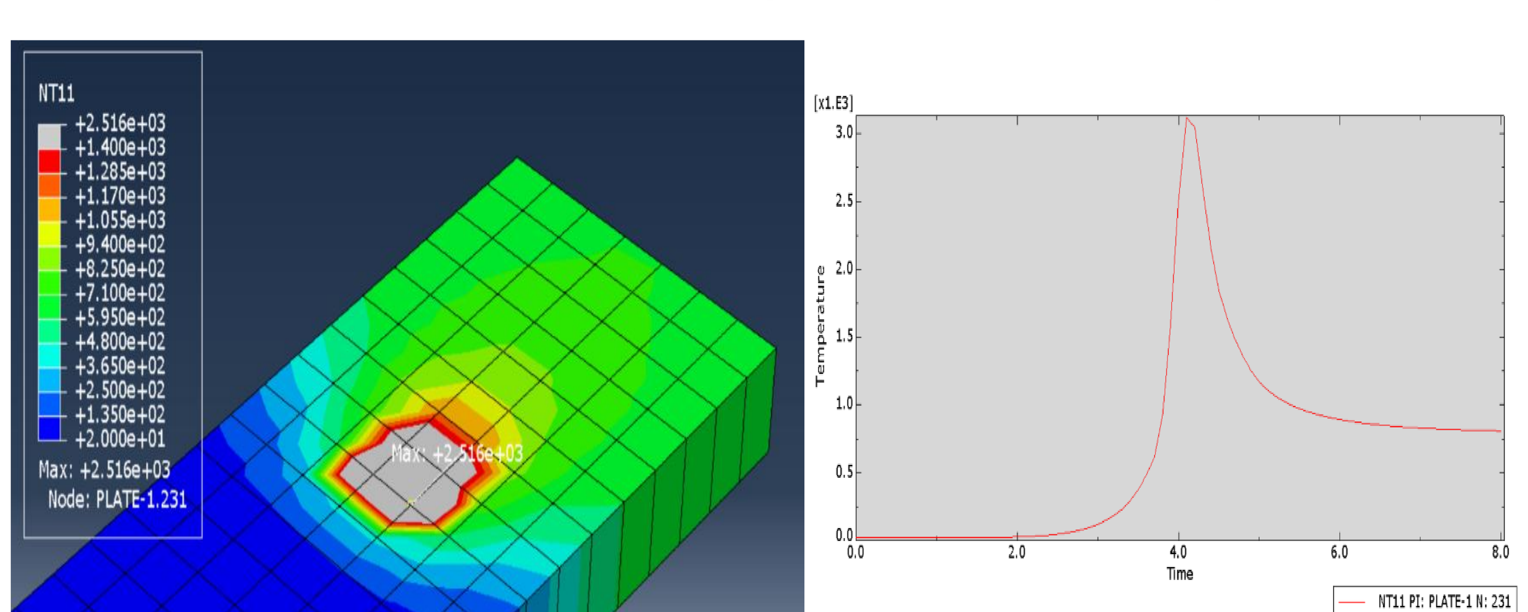
| Table 1: Process parameters used to define heat source | |
|---|---|
| **Laser Power (W)** | 2000 |
| **Scan Speed (mm/s)** | 10.4 |
| **Radius of Laser Beam (mm)** | 2 |
| **Absorption Efficiency (%)** | 40 |

**Table 2:Test cases varying in laser power and scan speed**

| Case | Laser Power (W) | Scan Speed (mm/s) | Melt Pool Size (mm) | Max Temperature (K) |
|---|---|---|---|---|
| 1 | 800 | 10.4 | N/A | 1305 |
| 2 | 1000 | 10.4 | 2.5 x 6.3 x 1.1 | 1624 |
| 3 | 2000 | 10.4 | 10.2 x 9.5 x 4.3 | 3181 |
| 4 | 3000 | 10.4 | 20.4 x 14.5 x 7.3 | 4696 |
| 5 | 2000 | 15.0 | 9.9 x 9.8 x 3.3 | 2461 |
| 6 | 2000 | 7.5 | 12.5 x 11.2 x 4.7 | 2795 |
| 7 | 2000 | 5.0 | 22.5 x 16.9 x 7.3 | 4527 |

## RESULTS

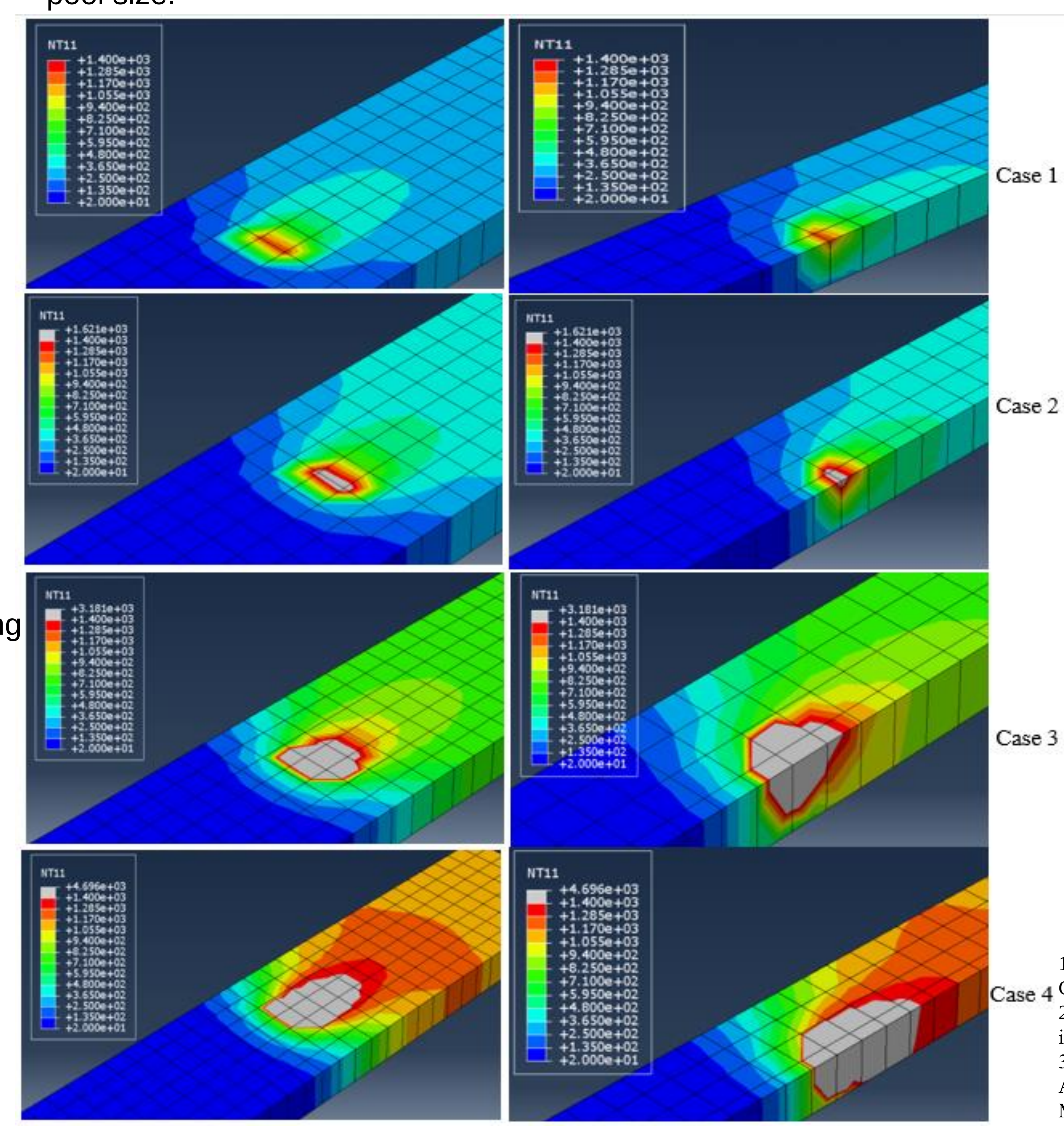
- Laser increases the temperature of the powder exceeding its melting point, turning the powder into liquid and creating a melt pool
- Laser passes, the temperature returns below its melting point. It cools and hardens to form a segment of the first layer.



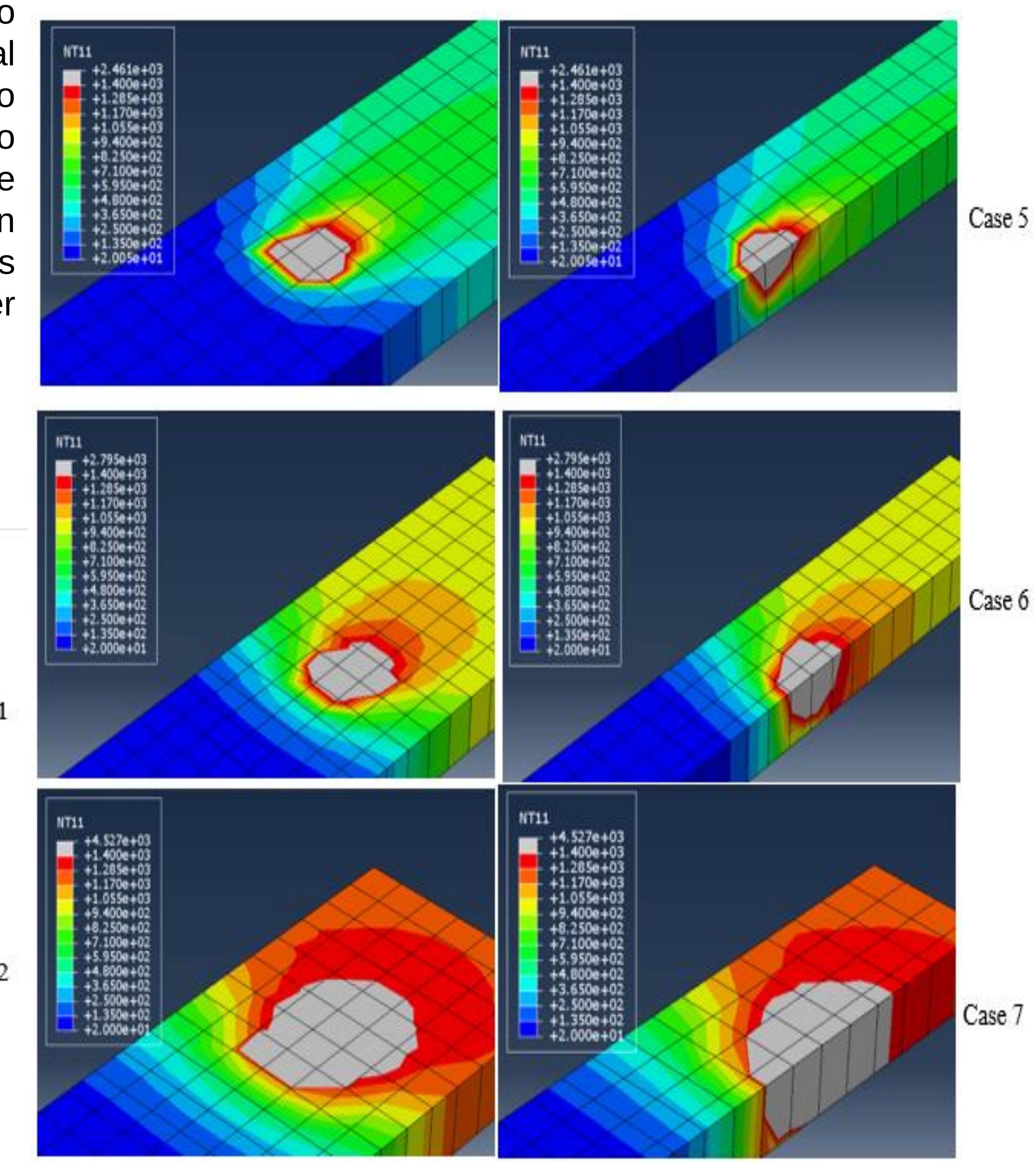

## ABSTRACT

Additive manufacturing has quickly found widespread applications in various industries, because it allows for manufacturing of complex geometries, weight reduction, material waste minimization, and improved component quality. This has especially gained attention in the aerospace industry due to its ability to repair complex and expensive parts instead of replacing them.[1] While there are many benefits that come with using additive manufacturing, there are also many challenges. One of the challenges is understanding the thermal residual stress generated during the formation of the part.[2] The aim of this work is to model the laser powder bed fusion process to provide an effective way to understand the relationship between process parameters and temperature history. This process was modeled in Abaqus with a user defined Fortran subroutine to simulate the laser with a moving heat flux. It is found that there is an increase in max temperature and melt pool size with increasing laser power or decreasing scan speed.

- As laser power increases, there is an increase in maximum temperature recorded in the system as well as an increase in melt pool size.




- As scan speed increases, there is a decrease in maximum temperature recorded in the system as well as an decrease in melt pool size. This is attributed to quick movement of the laser that causes a decrease in the exposure of powder reducing its energy absorption.




## CONCLUSIONS AND FUTURE WORK

- Laser power and scan speed directly effect melt pool size and max temperature
- The shape of the melt pool resembles a teardrop with lengthening trailing edge that grows in a direction opposite to that of the direction of the laser
- To further investigate the LPBF process, a full thermal residual stress analysis should be completed.[5]

## REFERENCES

1. Gouge, M., Michaleris, P., (2018) "An Introduction to Additive Manufacturing Process and Their Modeling Challenges: Laser Powder Bed Fusion Systems" in Thermo-Mechanical Modeling of Additive Manufacturing
2. Parry L., Ashcroft I., Bracket D., Wildman R. D., Kolacinski R. (2014) "Investigation of Residual Stresses in Selective Laser Melting", In Key Engineering Materials Vol. 627, pp. 129-132
3..Li, Q., Gnanasekaran B., Fu Y., Liu G.R., "Prediction of Thermal Residual Stress and Microstructure of Additive Manufacturing Processes of Direct Laser Metal Deposition via a Coupled Finite Element and Multiphase Field Framework"