SIMULATION APPROACH FOR FRICTION STIR WELDED AA6351 ALUMINIUM ALLOY AT DIFFERENT LOAD INTERVALS

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Abstract

Friction Stir Welding (FSW) is an advanced solid-state joining process that has gained widespread adoption for welding aluminum alloys, particularly in applications where high joint strength, reliability, and precision are paramount. The aluminum alloy AA6351 is frequently used in industries such as aerospace, automotive, and marine due to its exceptional mechanical properties, including high tensile strength, good corrosion resistance, and excellent weld ability. However, the quality and performance of FSW joints are significantly influenced by process parameters, with load intervals defined by tool rotational speed, traverse speed, and different tools being among the most critical factors. This study presents a detailed exploration of the impact of varying load intervals on the FSW of AA6351 aluminum alloy, using a simulation-based approach to understand the underlying structural pattern of the weld.

Using structural analysis, the study simulates the FSW process under different load intervals, providing insights into the weight distribution, and resultant microstructural changes within the weld zone. The simulation results are used to predict the mechanical properties, including tensile strength and micro hardness, of the welded joints.

***Keywords**: ANSYS, Structural analysis, Load conditions*

1.0 Introduction:

In this chapter Designing and analyzing the structural performance of Friction Stir Welding (FSW) of AA6351 involves several key steps, including understanding the welding process, optimizing parameters, and performing structural analysis using methods like Finite Element Analysis (FEA). Here's a structured approach to designing and analyzing AA6351 FSW welding.

Designing and performing structural analysis of a heat-affected zone (HAZ) with silver nitrate ($AgNO_3$) using Friction Stir Welding (FSW) involves several steps, including the integration of nano particles, optimization of welding parameters, microstructural analysis, and computational simulations.

Silver nitrate can decompose to form silver nanoparticles during the welding process, potentially enhancing the mechanical and thermal properties of the welded joint.

2.0 STATIC STRUCTURAL ANANYSIS

Static Structural Analysis is a branch of structural analysis that deals with the study of the behavior of structures under static loads, which are loads that do not change over time. It involves the calculation of stresses, strains, and displacements in a structure

- Import the temperature distribution from the thermal analysis.
- Apply mechanical loads and boundary conditions.

- Analyze the residual stresses and deformations.

The FSW process parameters were optimized to maximize the tensile strength of the joint. The optimum levels of the rotational speed, transverse speed, were found to be 1000-2000 rpm, 150-180 mm/min respectively, for square cylindrical Tapered and Tapered

3.0 CASE-1

Static Structural Analysis
Cylindrical Tool
Loads: 150N,200N,250N

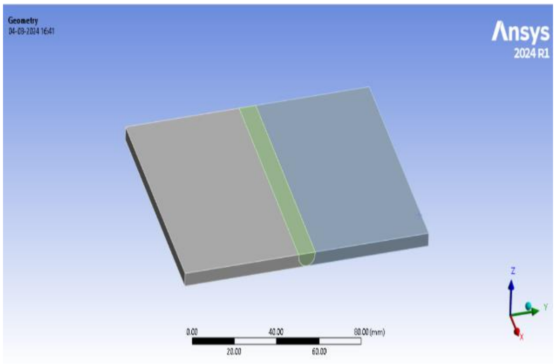


Figure 1 Imported model AA6351 aluminum alloy welded plate

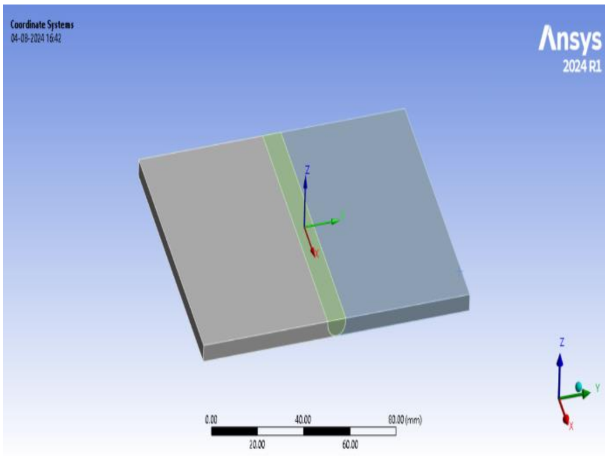


Figure 2 Coordinate System for AA6351 aluminum alloy welded plate

ANSYS has now deduced the component's elements. The next step is to specify how the modeled system should be segmented into discrete components.

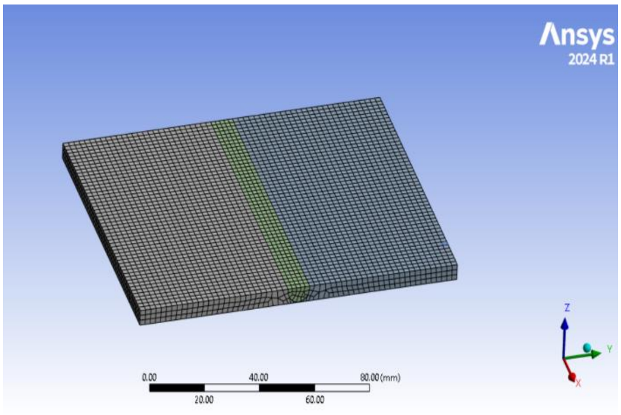
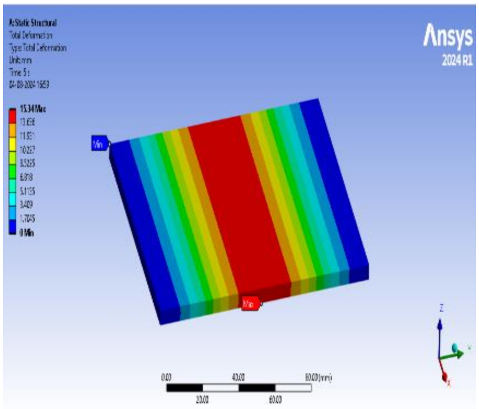
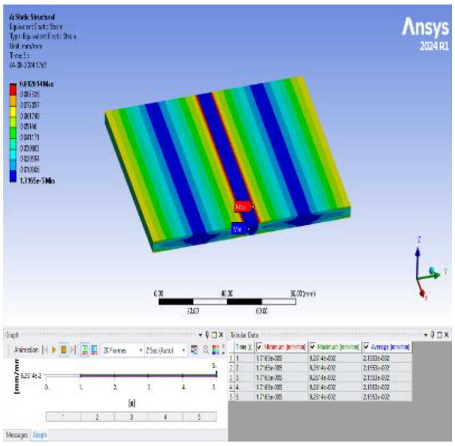


Figure 3 Meshed model AA6351 aluminum alloy welded plate

Tool	**Cylindrical**	**Tool**
No of Nodes	**51693**	**No of Nodes**
No of Elements	**9700**	**No of Elements**

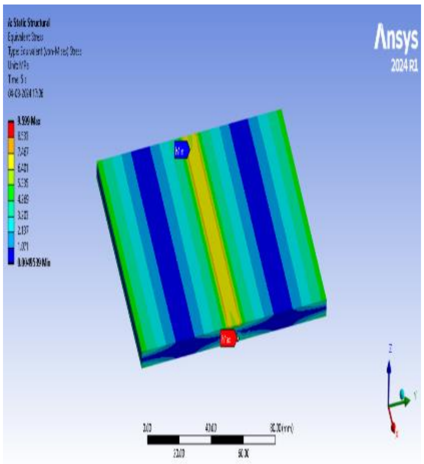
4.0 Cylindrical thread Tool Applied Load at 150 N:





Tabular Data

	Time [s]	Minimum [mm/mm]	Maximum [mm/mm]	Average [mm/mm]
1	1	1.7165e-005	9.2574e-002	2.1553e-002
2	2	1.7165e-005	9.2574e-002	2.1553e-002
3	3	1.7165e-005	9.2574e-002	2.1553e-002
4	4	1.7165e-005	9.2574e-002	2.1553e-002
5	5	1.7165e-005	9.2574e-002	2.1553e-002

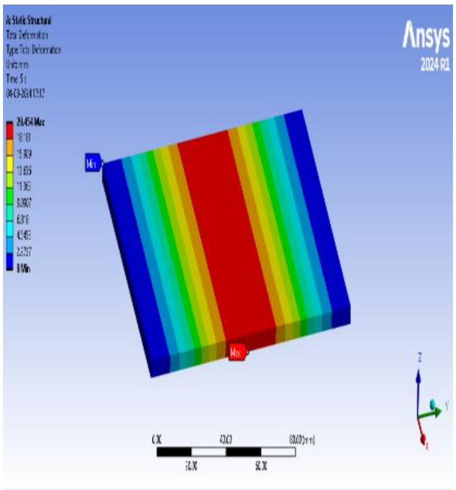


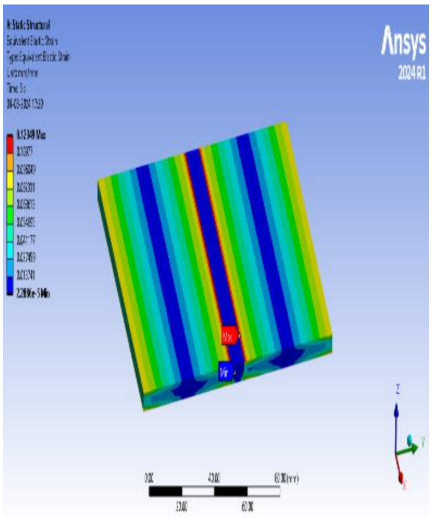
a) Total deformation

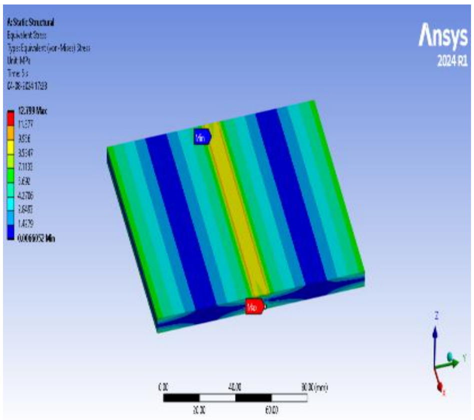
b) Equivalent elastic strain

c) Equivalent elastic stress

Figure 4 shows AA6351 welded plate at N: 1000rpm, S: 120 mm/min with cylindrical threaded tool at Load of 150N





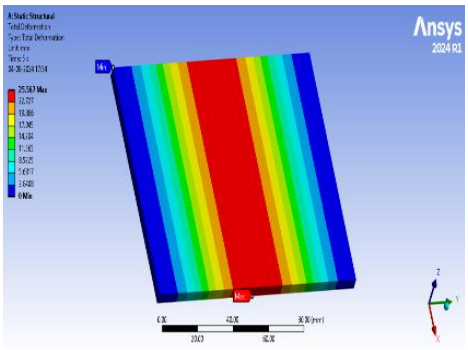


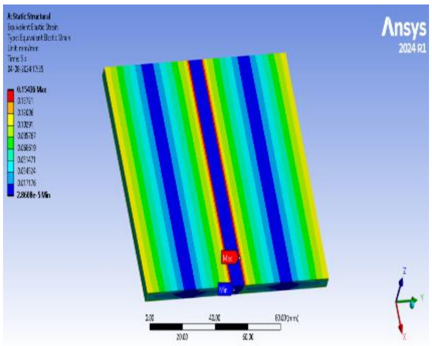
a) Total deformation

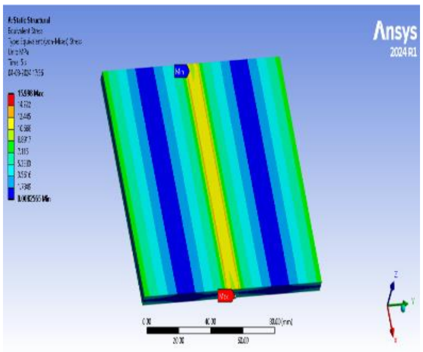
b) Equivalent elastic strain

c) Equivalent elastic stress

Figure 5 shows AA6351 welded plate at N: 1500rpm, S: 150 mm/min with cylindrical threaded tool at load of 200N







a) Total deformation

b) Equivalent elastic strain

c) Equivalent elastic stress

Figure 6 shows of AA6351 welded plate at N: 2000rpm, S: 180 mm/min with cylindrical threaded tool at load of 250N

4.0 CASE-2

Static Structural Analysis

Square Tool

Loads: 150N,200N,250N

Square Tool Applied Load at 150 N:

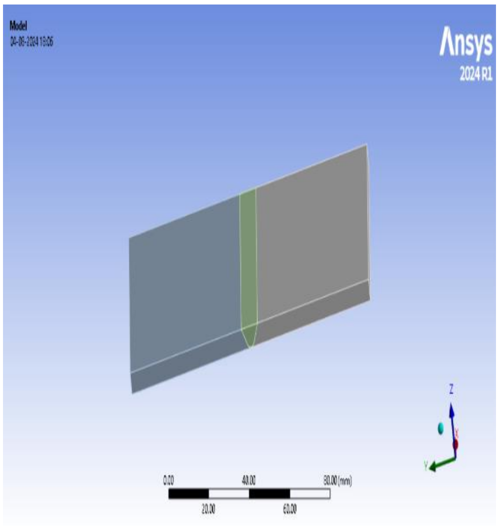


Figure 7 Imported model

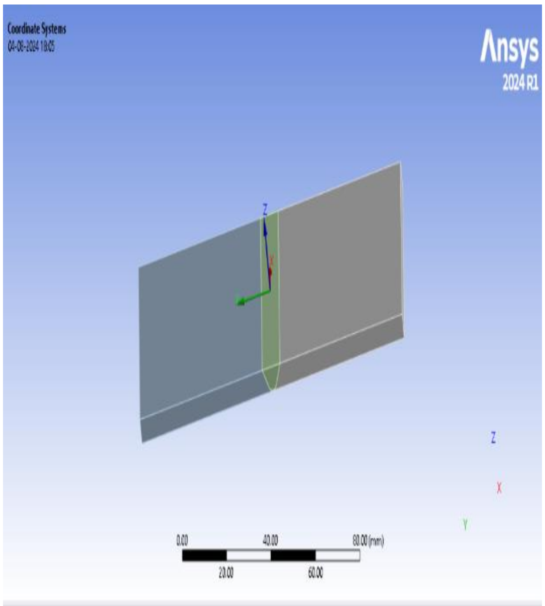


Figure 8 Coordinate System

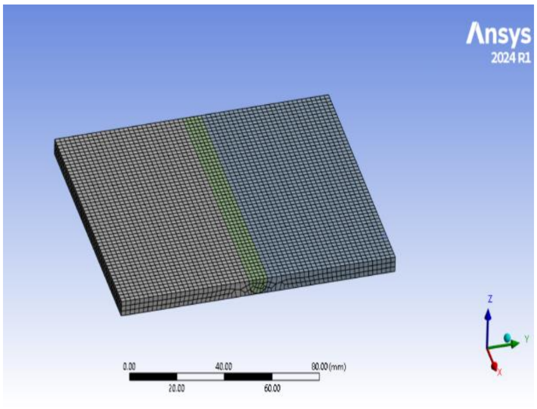
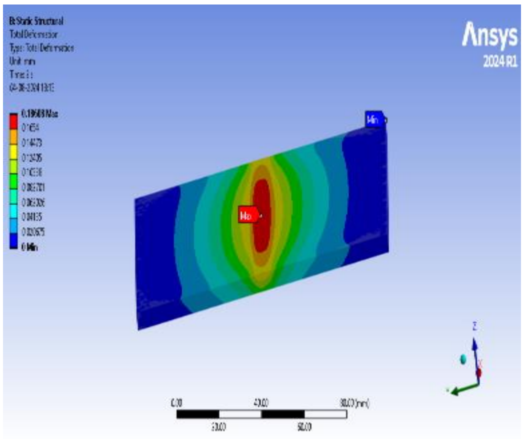
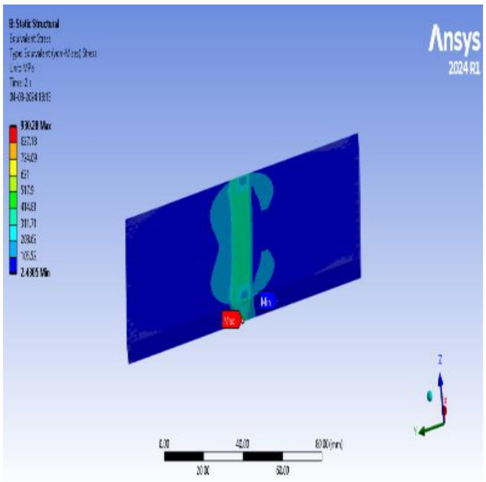
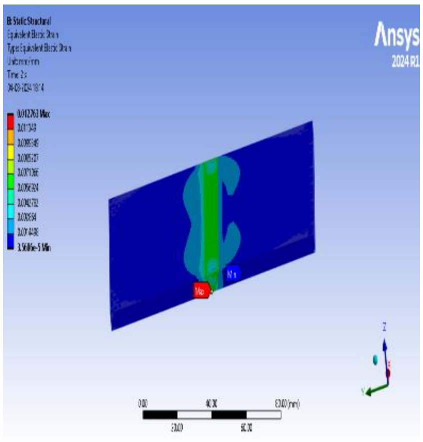


Figure 9 Meshed model

Tool	Cylindrical	Tool
No of Nodes	51693	No of Nodes
No of Elements	9700	No of Elements





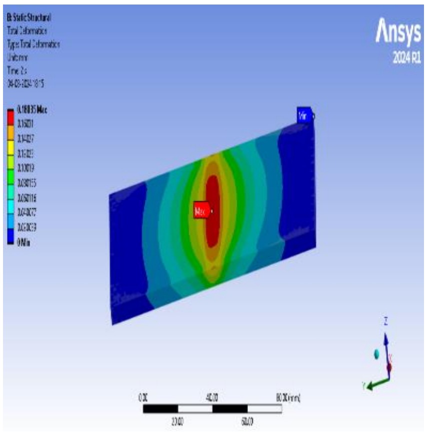


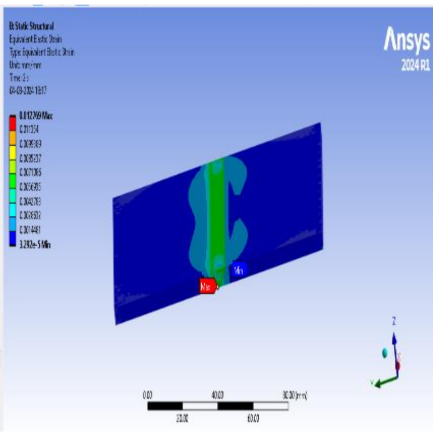
a) Total deformation

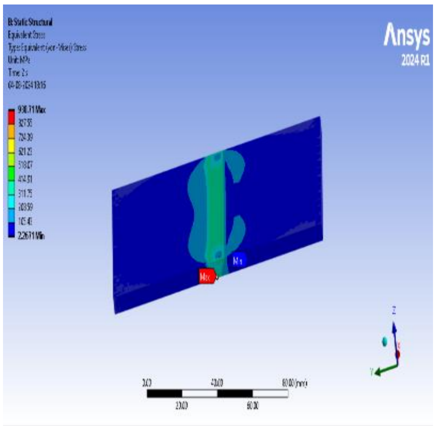
b) Equivalent elastic strain

c) Equivalent elastic stress

Figure 10 shows of AA6351 welded plate N: 1000rpm, S: 120 mm/min with Square tool Applied Load At 150 N





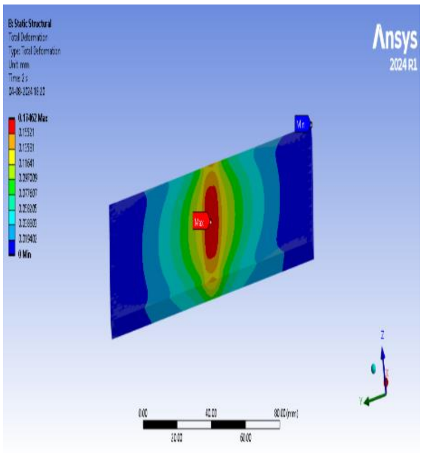


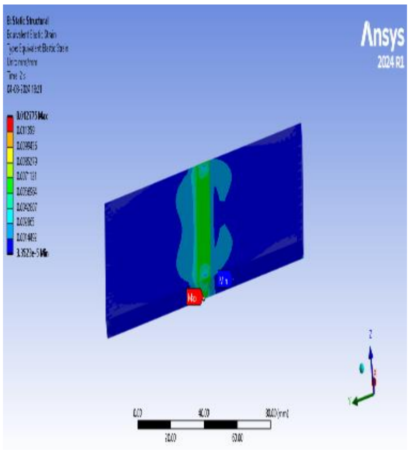
a) Total deformation

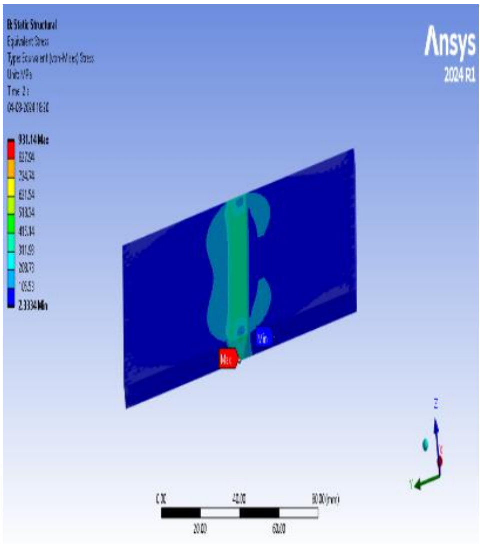
b) Equivalent elastic strain

c) Equivalent elastic stress

Figure 11 shows of AA6351 welded plate N: 1000rpm, S: 120 mm/min with Square tool Applied Load At 200 N







a) Total deformation

b) Equivalent elastic strain

c) Equivalent elastic stress

Figure 12 shows of AA6351 welded plate N: 1000rpm, S: 120 mm/min with Square Tool Applied Load At 250 N

5.0 CASE-3

Static Structural Analysis

Tapered Tool

Loads: 150N,200N,250N

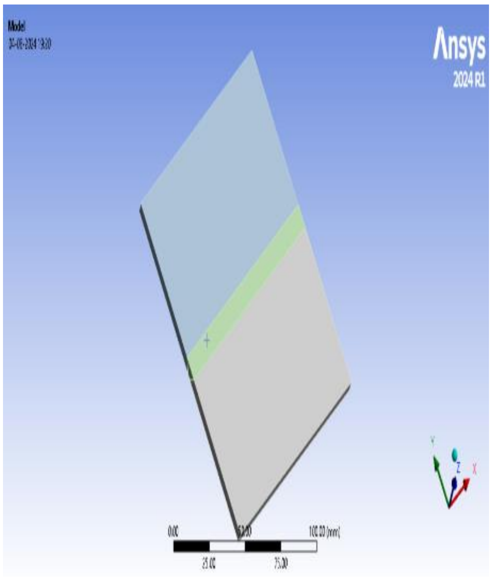
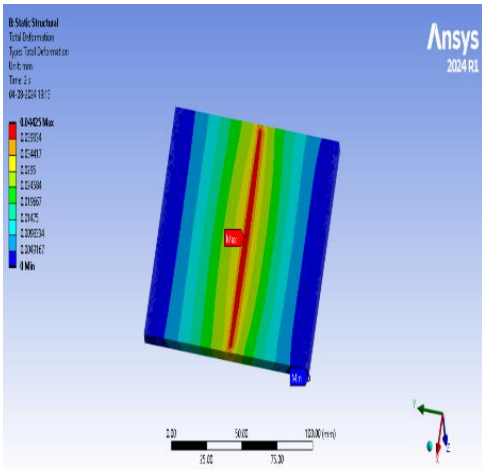
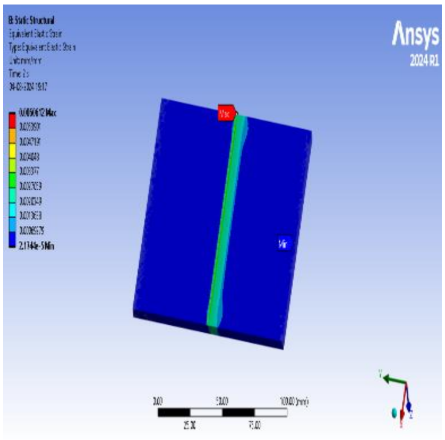
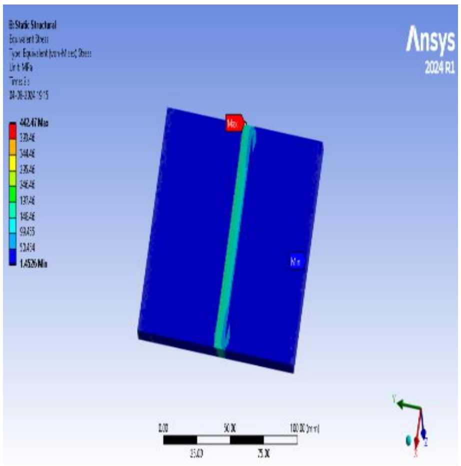


Figure 13 Imported model





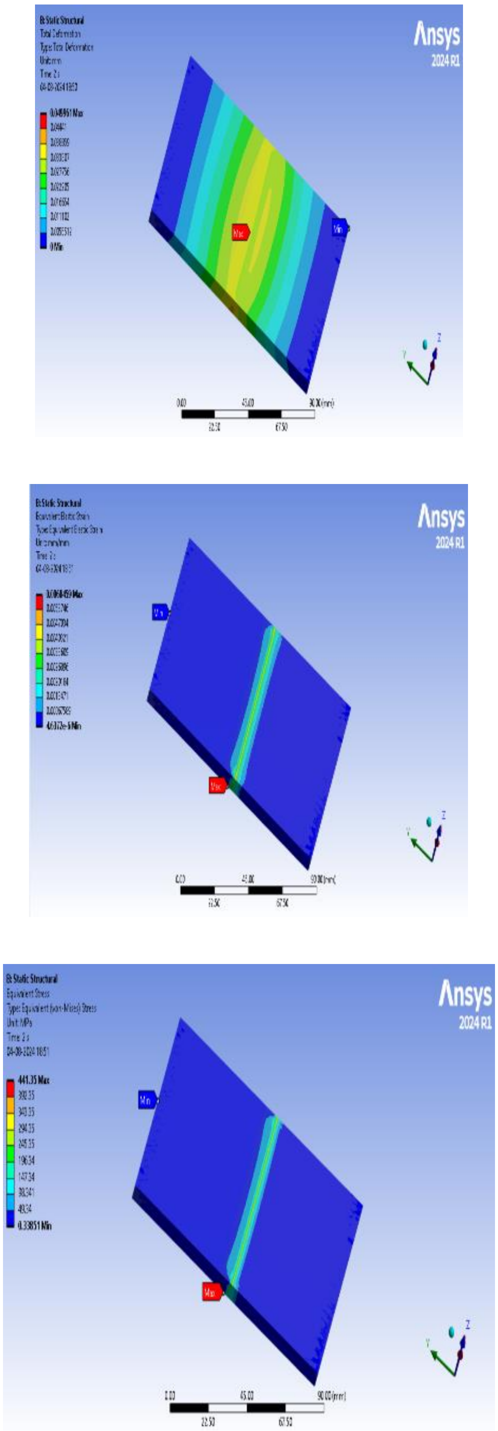


a) Total deformation

b) Equivalent elastic strain

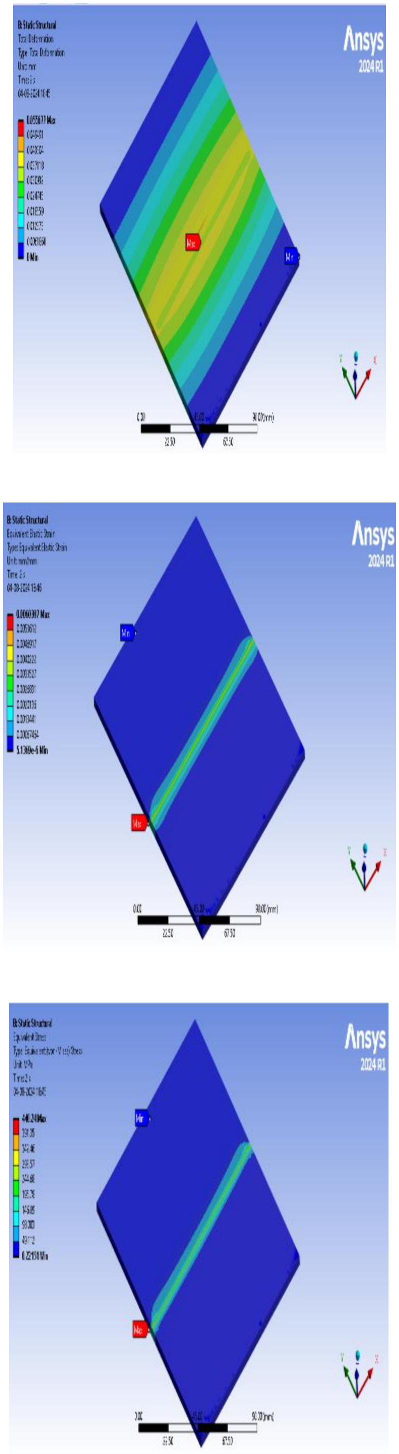
c) Equivalent elastic stress

Figures 14 shows AA6351 welded plate at N: 1000rpm, S: 120 mm/min with Tapered tool at load of 150N



a) Total deformation
b) Equivalent elastic strain
c) Equivalent elastic stress
Figures shows 15 AA6351 welded plate at N: 1000rpm, S: 120 mm/min with Tapered tool at load of 200N

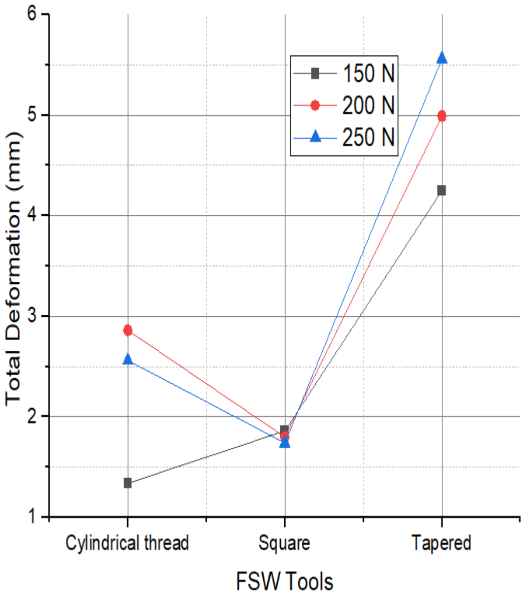
TAPERED TOOL APPLIED LOAD AT 250 N



a) Total deformation
b) Equivalent elastic strain
c) Equivalent elastic stress
Figures 16 shows AA6351 welded plate at N: 1000rpm, S: 120 mm/min with Tapered tool at load of 250N

Table 1Validation of Total Deformation (mm) at Different Tool and load Conditions

FSW Tools	150 N	200 N	250 N
Cylindrical thread	1.34	2.86	2.56
Square	1.86	1.80	1.74
Tapered	4.25	4.99	5.56

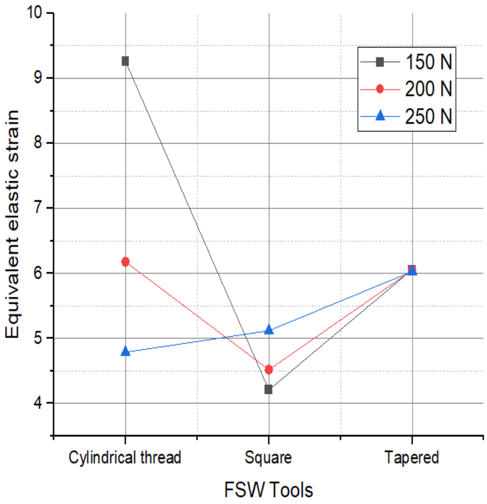


7.0 Graph Validation of Total Deformation (mm)

- Tapered tools show consistent minimal deformation across all loads, hinting at better stability under varying pressures.
- 150 N load results in the highest average deformation at 777.53 mm, indicating tools may endure more stress under this load.
- Cylindrical tools record the highest deformation at each load, suggesting potential concerns for structural integrity at higher pressures.
- Investigate material properties influencing deformation especially in cylindrical tools.
- Explore design optimizations for Tapered tools given their lower deformation.
- Perform additional tests to verify repetitive accuracy across other load conditions.

Table 2 Validation of Equivalent elastic strain at Different Tool and load Conditions

FSW Tools	150 N	200 N	250 N
Cylindrical thread	9.26	6.18	4.79
Square	4.21	4.52	5.12
Tapered	6.06	6.05	6.03



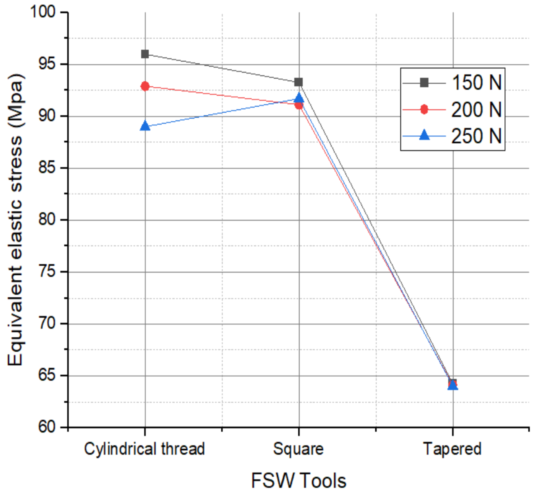
8.0 Graph Validation of Equivalent elastic strain

- At 150 N, the Cylindrical thread tool shows the highest equivalent elastic strain, peaking at 9.26, making it the least efficient at this load.
- The strain range for 150 N is notably larger (5.05) compared to 200 N and 250 N, indicating higher variability in performance or potential inconsistencies at this load.

- The Tapered tool maintains a relatively stable strain across all loads, indicating reliable performance regardless of load variation.
- Selecting the right tool for specific loading conditions is crucial. Cylindrical threads offer high flexibility at lower loads, whereas the Tapered tool guarantees consistency, making it a reliable choice for varied load applications.

Table 3 Validation of Equivalent elastic stress (Mpa) at Different Tool and load Conditions

FSW Tools	150 N	200 N	250 N
Cylindrical thread	95.99	92.91	89.01
Square	93.28	91.13	91.71
Tapered	64.24	64.13	64.02



9.0 Graph Validation of Equivalent elastic stress (Mpa)

- Load vs Stress Consistency: Higher loads reduce stress variability, as evidenced by decreasing standard deviations from 150 N to 250 N.
- Tool Consistency: The "Square" tool shows the highest consistency in stress across all load conditions, suggesting it is well-suited for varied applications.
- Performance Edges: Cylindrical thread tools yield the highest maximum stresses under all loads, indicating optimal performance under peak conditions.
- The cylindrical thread tools handle higher elastic stresses, while Tapered tools maintain more stable, low stress levels across all loads. Further exploration could optimize tool selection for specific load conditions.

10. Conclusion:

The research conducted on the simulation approach for friction stir welding (FSW) of AA6351 aluminum alloy at different load intervals has provided valuable insights into the complex interactions that govern the welding process and the resulting joint quality. By employing a structural analysis using ansys model, the study systematically examined the effects of varying load intervals—comprising tool rotational speed, traverse speed, and different tools for, mechanical properties, and microstructural evolution within the weld zone. The conclusions drawn from this study have significant implications for the optimization of FSW parameters, aiming to enhance the structural integrity and performance of welded joints in critical industrial applications.

In conclusion, this study has successfully demonstrated the critical importance of load intervals in the friction stir welding of

AA6351 aluminum alloy. The use of a simulation-based approach has provided a detailed understanding of how different load intervals influence the thermal, mechanical, and microstructural outcomes of the welds. The findings offer practical guidelines for optimizing FSW parameters to achieve superior joint quality, with significant implications for industrial applications. As industries continue to demand higher performance and reliability from welded components, the insights gained from this research will play a crucial role in advancing the state of welding technology and ensuring the continued success of FSW as a preferred joining method.

References:

1. *Msomi V, Mabuwa S (2020) Analysis of material positioning towards microstructure of the friction stir processed AA1050/ AA6082 similar joint. Advances in Industrial and Manufacturing Engineering 1:1–8. https://doi.org/10.1016/j.aime.2020. 100002*
2. *Murali Krishna P, Ramanaiah N, Prasada Rao K (2013) Optimization of process parameters for friction stir welding of similar aluminum alloys (AA2024 -T6 and AA6351-T6) by using Taguchi method. Int J IndEngComput 4(1):71–80.* https://doi.org/10.5267/j.ijiec.2012.11.002
3. *Thomas, et.al (1997) Friction Stir Welding for the Transportation Industries. Materials and Design, 18, 269 - 273.*
4. *W. J. Arbegast(2003) Modeling friction stir joining as a metal working process, pp 313. In: Z. Jin, A. Beaudoin, T.A. Bieler and B. Radhakrishnan (Eds.), Hot Deformation of Aluminum Alloys III, The Minerals, Metals and Materials Society, Warrendale, PA, USA, 2003.*
5. *Xu, et.al (2008) Temperature evolution, microstructure and mechanical properties of friction stir welded thick 2219- O aluminium alloy joints. Materials and Design, 30, 3460 - 3467.*
6. *Reghubabu et.al (2008) An experimental study of the effect of welding parameters on mechanical and microstructural properties of AA6082 - T6 friction stir welded butt joints. APN journal of engineering and applied science, 3 (5), 68 - 74.*
7. *R. Palanivel, et.al (2014) "Mechanical and metallurgical properties of dissimilar friction stir welded AA5083- H111 and AA6351-T6 aluminium alloys"*
8. *Ravikumar et.al (2014) "Effect of welding parameters on Macro and Microstructure of friction stir welded dissimilar aluminium butt joints between AA7075-T651 and AA6061- T651 alloys"*
9. *R.I. Rodriguez, et.al (2015) "Microstructure and mechanical properties of dissimilar friction stir Welding of 6061-to-7050 aluminium alloys." Materials & Design 83 (2015) 60–65*
10. *Raj Kumar.V et.al (2014)"Studies on effect of tool design and welding parameters on the friction stir welding of dissimilar aluminium alloys AA 5052 – AA 6061". MRS Singapore - ICMAT Symposia Proceedings Advanced Structural and Functional Materials for Protection*