Thermo-mechanical simulation of the effect of tool welding speed on butt-joint friction stir welding (FSW) of AA6061

Simulação termo-mecânica do efeito da velocidade de soldadura da ferramenta durante a soldadura por fricção (FSW) de AA6061

Simulación termomecánica del efecto de la velocidad de soldadura de la herramienta durante la soldadura por fricción (FSW) a tope de AA6061

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ABSTRACT
FSW is a welding method that joins pieces of material by rotating a non-consumable pin at high speeds (RPM) while moving it along the weld joint. The combination of this rotation and movement generates heat through friction between the tool and the sheets, facilitating the welding process without the requirement for filler metal. Developed by the British Welding Institute (TWI) in 1991, FSW is celebrated for producing strong, reliable welds and is extensively used in industries such as automotive and aerospace. In these sectors,

aluminum alloys are essential due to their unique set of properties, making them highly suitable for FSW applications. In FSW, welding speed refers to the linear velocity at which the tool progresses along the joint line during the welding process. This parameter plays a pivotal role in controlling heat generation, material flow, and ultimately, the quality of the weld. The quantity of heat introduced to the plates directly influences the final weld quality, as well as the residual stresses and deformation observed in the workpieces. This research examines how different welding speeds affect temperature distribution, the width of the heat-affected zone, and the Von Mises stress distribution in welded aluminum alloy 6061 sheets. The aim of this study is to gain a comprehensive understanding of how these factors interact, with the ultimate goal of contributing to the optimization of FSW parameters and improving weld quality. The analysis was performed using finite element method and ALTAIR software, providing valuable insight into the effects of welding speed variations.

Keywords: friction stir welding, welding speed, temperature distribution, heat affected zone, von-mises stress, thermo-mechanical simulation, finite element method.

RESUMO

O FSW é um método de soldadura que une peças de material através da rotação de um pino não consumível a altas velocidades (RPM) enquanto o move ao longo da junta de soldadura. A combinação desta rotação e movimento gera calor através da fricção entre a ferramenta e as chapas, facilitando o processo de soldadura sem a necessidade de metal de enchimento. Desenvolvido pelo Instituto Britânico de Soldadura (TWI) em 1991, o FSW é famoso por produzir soldaduras fortes e fiáveis e é amplamente utilizado em indústrias como a automóvel e a aeroespacial. Nestes sectores, as ligas de alumínio são essenciais devido ao seu conjunto único de propriedades, tornando-as altamente adequadas para aplicações FSW. Em FSW, a velocidade de soldadura refere-se à velocidade linear a que a ferramenta progride ao longo da linha de junta durante o processo de soldadura. Este parâmetro desempenha um papel fundamental no controlo da geração de calor, do fluxo de material e, em última análise, da qualidade da soldadura. A quantidade de calor introduzida nas chapas influencia diretamente a qualidade final da soldadura, bem como as tensões residuais e a deformação observadas nas peças. Esta investigação examina a forma como diferentes velocidades de soldadura afectam a distribuição da temperatura, a largura da zona afetada pelo calor e a distribuição das tensões de Von Mises em chapas soldadas de liga de alumínio 6061. O objetivo deste estudo é obter uma compreensão abrangente da forma como estes factores interagem, com o objetivo final de contribuir para a otimização dos parâmetros FSW e melhorar a qualidade da soldadura. A análise foi realizada utilizando o método dos elementos finitos e o software ALTAIR, fornecendo informações valiosas sobre os efeitos das variações da velocidade de soldadura.

Palavras-chave: soldadura por fricção, velocidade de soldadura, distribuição de temperatura, zona afetada pelo calor, tensão de von-mises, simulação termo-mecânica, método dos elementos finitos.

RESUMEN

FSW es un método de soldadura que une piezas de material mediante la rotación de un perno no consumible a altas velocidades (RPM) mientras se mueve a lo largo de la junta de soldadura. La combinación de esta rotación y movimiento genera calor a través de la fricción entre la herramienta y las chapas, facilitando el proceso de soldadura sin necesidad de metal de aportación. Desarrollada por el Instituto Británico de Soldadura (TWI) en 1991, la FSW es famosa por producir soldaduras fuertes y fiables, y se utiliza mucho en industrias como la automovilística y la aeroespacial. En estos sectores, las aleaciones de aluminio son esenciales debido a su conjunto único de propiedades, que las hacen muy adecuadas para las aplicaciones FSW. En FSW, la velocidad de soldadura se refiere a la velocidad lineal a la que la herramienta avanza a lo largo de la línea de unión durante el proceso de soldadura. Este parámetro desempeña un papel fundamental en el control de la generación de calor, el flujo de material y, en última instancia, la calidad de la soldadura. La cantidad de calor introducido en las chapas influye directamente en la calidad final de la soldadura, así como en las tensiones residuales y la deformación observadas en las piezas. Esta investigación examina cómo afectan las diferentes velocidades de soldadura a la distribución de la temperatura, la anchura de la zona afectada por el calor y la distribución de tensiones de Von Mises en chapas soldadas de aleación de aluminio 6061. El objetivo de este estudio es obtener una comprensión exhaustiva de cómo interactúan estos factores, con el fin último de contribuir a la optimización de los parámetros de FSW y mejorar la calidad de la soldadura. El análisis se realizó utilizando el método de los elementos finitos y el software ALTAIR, proporcionando una valiosa visión de los efectos de las variaciones en la velocidad de soldadura.

Palabras clave: soldadura por fricción, velocidad de soldadura, distribución de temperatura, zona afectada por el calor, tensión de von-mises, simulación termomecánica, método de los elementos finitos.

1 INTRODUCTION

FSW is a contemporary industrial technique designed to join metals that are typically challenging to weld. This method was first introduced by the Welding Institute (TWI, Cambridge) in 1991 (Thomas et al., 1991). The heat necessary for this process is produced by the friction between the tool and the sheets, which is subsequently transferred to both the material being welded and the tool itself. The amount of heat introduced into the plates is crucial in defining the weld quality, the extent of residual stresses, and the degree of deformation in the workpieces. Similarly, the heat transferred to the tool affects its durability and its capacity to effectively carry out the welding process. (Chao et al., 2003).

The first part of our study focuses on the analytical development of the heat equation, including the modeling of the welding thermal source. Additionally, we addressed the material being studied and conducted 3D modeling of the tool's geometry and the welded plates. In the second part, we present and interpret the results of all 2D and 3D thermo-mechanical simulations applied to 6061 plates, with particular attention to the temperature distribution, the width of the heat-affected zone (HAZ), and the Von Mises stress distribution.

This study allows to understand the impact of the speed of welding on temperature distribution, heat-affected zone width, and Von-Mises stress distribution through a thermo-mechanical simulation of the welded aluminum alloy 6061 sheets.

The study by Wenmin Ou et al. explores the welding of aluminum alloy 6061 and stainless steel 304, utilizing Friction Stir Welding (FSW) as the main technique. By developing aCFDmodel integrated with the welding tool, significant improvements were observed in minimizing temperature gradients and achieving a more uniform temperature field in the aluminum-steel joint. Furthermore, the research demonstrated the potential for reducing the thickness of intermetallic compounds (IMCs) at the aluminum-steel interface by adjusting the traverse speeds(Wenmin Ou et al., 2023).

The work of I. Uchegbulam et al. Focuses on statistical modeling and optimization of FSW process parameters for 6061-T651 Aluminum alloy. The statistical optimization resulted in an optimum Ultimate Tensile Strength (UTS) of 166.32 MPa for the welded AA6061-T651 joints. The developed model was shown to be suitable for predicting and optimizing UTS, with a strong correlation between experimental and predicted results (I. Uchegbulam et al., 2023).

Jingqing Zhang et al created a 3D model to replicate the FSW process of 6061-T6 Al, considering the conditions of contact between the tool and the work piece. The heat generation was calculated, and found that the heat was generated primarily in the area near the shoulder, with a high temperature at the top of the weld and decreasing with thickness. They observed a flow of material around the tool, with material in front of the tool sweeping to the receding side and depositing behind the tool. The simulation findings exhibited a high level of concordance with the experimental observations (Jingqing Zhang et al., 2014).

In their research, Zhihao Chen et al examined the effect of repair weld dimensions on residual stress redistribution in AA6082-T6 aluminum alloy joints. Using a combination of blind hole drilling and stress linearization in BS7910, the study looked at the redistribution of residual stress across different repair weld dimensions. The findings highlighted optimal repair welding principles, suggesting a repair length of 15t, depth of 0.25t, and width of t for butt joints, adhering to the principle of "SNL" (shallow, narrow, and long) (Zhihao Chen et al, 2022).

In research done by Noureddine Zina et al. A numerical simulation was used to examine the impact ofFSWparameters on the maximum temperature, residual stresses, and Von Mises stress of AA6061-T6. A thermomechanical model integrated into the ANSYS APDL tool developed by Zhu and Chao was used for the study. Analyzed were two distinct welding situations, which differed in factors such as feed rate and rotating speed. The modeling findings demonstrate that the maximum temperature at the welded joints escalates with an elevated rotation speed, whereas an augmentation in welding speed results in larger residual stress. Nevertheless, the model suggests that the residual stresses remain below 54% of the elastic limit (Noureddine Zina et al., 2019).

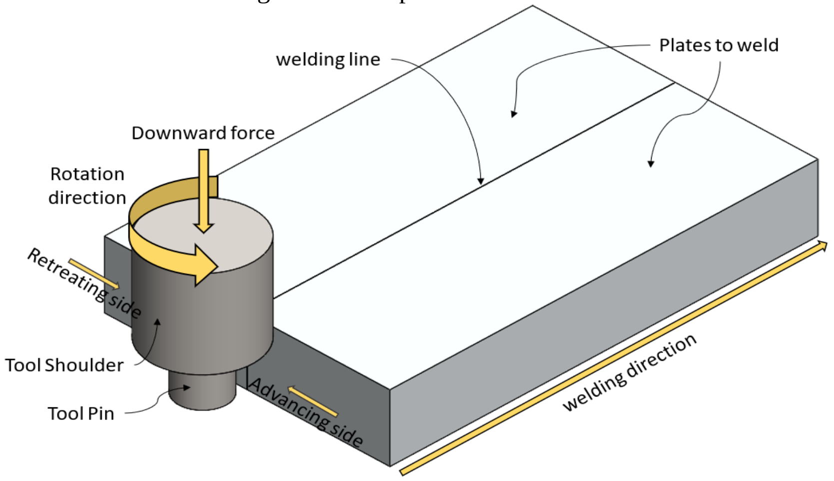
Mohamadreza Nourani et al presents a method for optimizingFSW process parameters specifically tailored for AA6061. The approach aims to effectively minimize both the distance to theHAZand the peak temperature. Utilizing the Taguchi optimization method, the research delves into identifying the most influential parameters. The analysis conducted via ANOVA highlights rotational speed as the most significant parameter in the FSW process. Conclusively, the method proves successful in reducing both HAZ distance and peak temperature. Optimal process parameters are identified and further validated through confirmation runs, confirming the effectiveness of the proposed approach in improving FSW results for 6061 aluminum alloy (Mohamadreza Nourani et al., 2011).

2 GENERALITIES

2.1 DEFINITION

FSW is a solid welding process, that means no metal is melted during the process, this technology also creates plasticized areas of the material, but in a different way. The first step is to push the non-consumable rotary tool into the material to be welded, then place the center pin or probe, followed by the shoulder, against the two parts to be connected. As the tool rotates, the material it contacts heats and plasticizes. (Sasikumar Ayyanar et al., 2021). In other the material from the front of the tool is forced back around this plasticizing ring as the tool moves along the bond line, removing the interface., figure (1).

Figure 1. FSW process schematic.



Source: Prepared by the authors

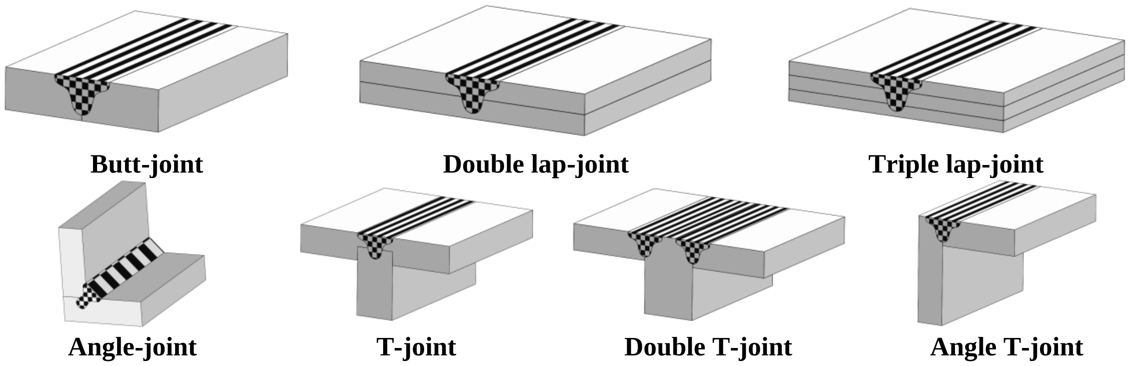
Friction Stir Welding (FSW) can be performed using several configurations depending on the type of joint required. Here are the main FSW configurations (Figure (2)).

Butt joint: The most common joint used in FSW. Two materials are placed edge to edge and the tool moves along the joint line to weld them together. This type is commonly used in the sheet metal, aerospace and automotive industries.

Lap-Joint: One piece of material is placed over another, and the tool moves along the overlapping area, welding them together.**This type is commonly used w**here sheet metal parts overlap, such as car panels or aircraft structures.

T-Joint: One piece of material is positioned perpendicularly (90 degrees) to another, forming a "T" shape. The tool moves along the interface where the two pieces meet.This type is commonly used wherecomponents need to be joined at right angles.

Figure 2. FSW joint types.



Source: Padmanaban, R et al., 2014

Angle T-Joint: The edges of two sheets are joined together at a right angle. This type of joint is typically used when fabricating boxes or containers.This type is commonly usedin enclosure manufacturing or for components that form an angle.

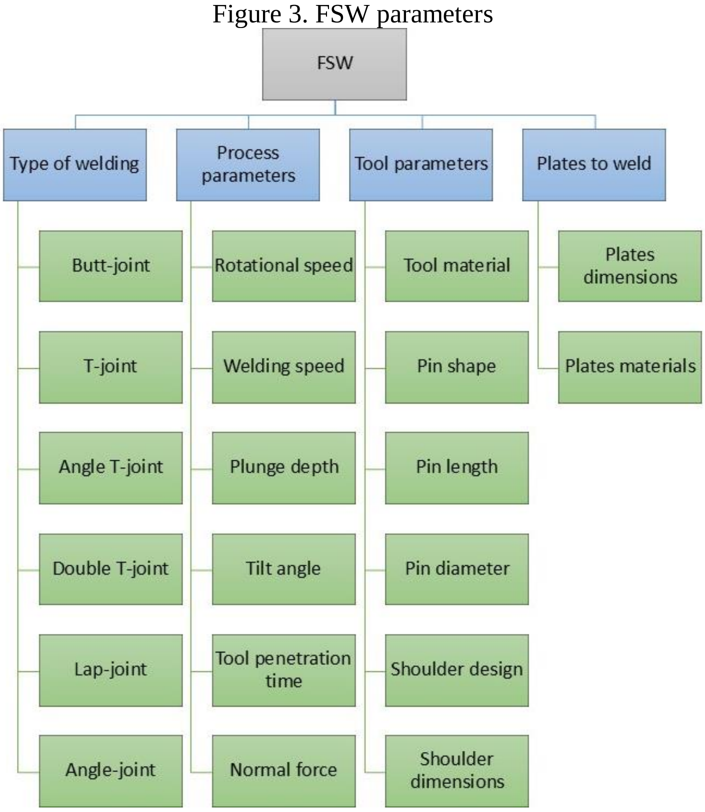
Double Lap-Joint: Involves two overlapping pieces of material, with another material placed on top. The tool moves through the layers to create a strong weld.Used in scenarios requiring extra strength or stiffness, such as in thick plates or aerospace components.

Each type of joint is chosen based on the mechanical requirements of the structure, the material properties, and the design constraints of the product.

2.2 FSW PARAMETERS

FSW effectiveness is influenced by various parameters (figure 3), which can be grouped into four main categories: type of welding, process parameters, tool parameters, and plate characteristics. The type of welding refers to different joint configurations, including butt-joint, T-welding, lap-joint, and angle welding, each affecting the approach and execution of the process. Process parameters like speed of rotation, feed speed,tilt angle, depth of plunge, and normal force control how the tool interacts with the material and directly impact the quality of the weld. Tool parameters, such as tool material, pin geometry, pin length, and shoulder design, are crucial for generating the necessary heat and managing thematerial flow during welding. Lastly, the plate to weld includes the plate's dimensions and material, which determine the welding conditions required for a successful bond. Together, these parameters must be optimized to ensure strong, defect-free welds in FSW.

Figure 3. FSW parameters



Source: Padmanaban, R et al., 2014

Figures 4 and 5 show the welding tool, the sheets being welded, the direction of rotation, and the direction of movement. During the process, the tool turns at high speed, which we call the rotational speed, and moves along the weld line, which we call the welding speed.

Figure 4. FSW welding tool

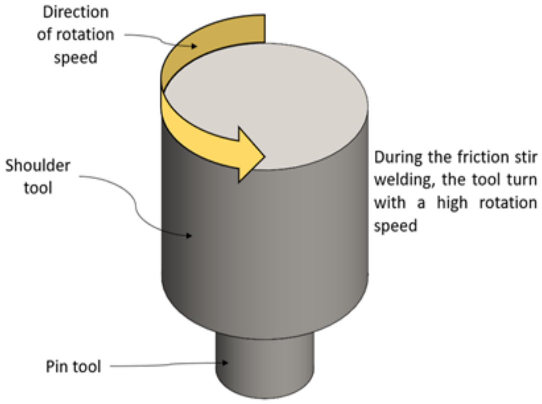


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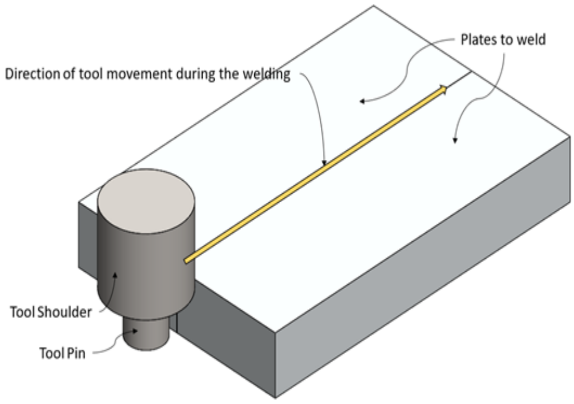
Figure 5. Direction of tool movement



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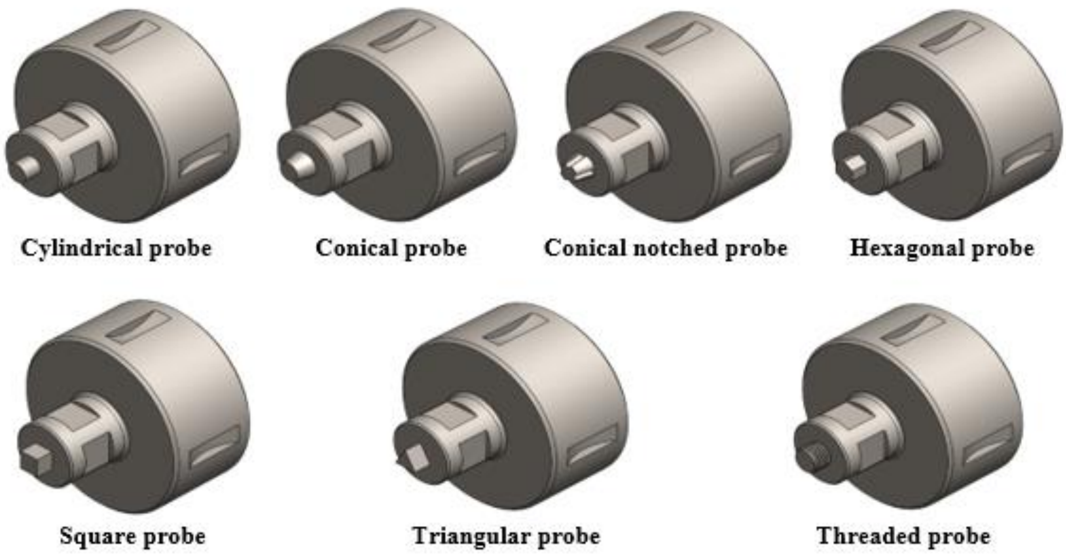
In FSW process, the geometry of the tool probe is vital in influencing the quality and characteristics of the weld. Various probe shapes are utilized (Figure 6), each offering distinct advantages :

Cylindrical Pin: Characterized by a straight, uniform diameter, the cylindrical pin provides consistent stirring action throughout the weld. This geometry is widely used for materials that need uniform heat distribution, making it suitable for various applications.

Conical Pin: With its simple tapered design, the conical pin allows for efficient material flow and effective heat generation. This shape is particularly advantageous for welding thicker materials, as it can enlarge the heat-affected zone and improve bonding between layers.

Figure 6. Probe shapes in FSW



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Conical Notched Pin: This design features a tapered shape with a notch that enhances stirring action and facilitates better material flow. The conical notch reduces the force required during welding while improving joint strength and minimizing defects.

Hexagonal Pin: The hexagonal pin incorporates edges that enhance mixing and material flow during welding. This shape can lead to better mechanical properties by refining the microstructure and reducing weld defects.

Square Pin: Like the hexagonal pin, the square pin has flat edges that aid in effective material stirring. This geometry is especially useful for achieving strong bonds and improved fatigue resistance in welds.

Triangular Pin: The triangular pin shape has distinct edges that improve stirring action and material flow. This geometry is effective for producing welds with superior mechanical properties by promoting a finer microstructure.

Threaded Pin: The threaded pin features helical grooves that increase material flow. This design enhances mixing and can produce a more homogeneous weld by facilitating better material engagement and heat generation.

Each probe shape affects welding behavior and outcomes differently, enabling engineers to choose the most suitable geometry for specific materials and applications in FSW.

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3 THEORETICAL AND NUMERICAL STUDY

3.1 MATHEMATICAL MODEL

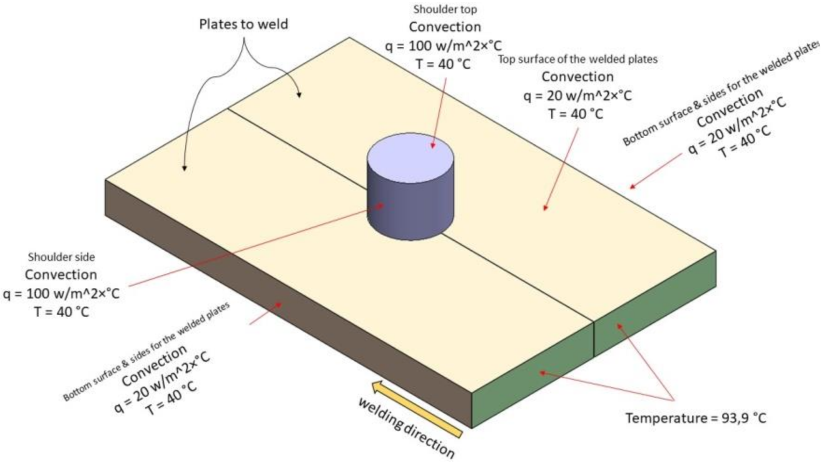
The heat transferred in the part to be welded is given by the following equation :

$$Q = \rho C_p V_T . \nabla T + \nabla . (-k \nabla T) \quad (1)$$

Where Q is the heat source [W / m^2], $\rho$is material density [Kg / m^3], C_p is the thermal capacity [j kg^{-1} k^{-1}], $V_T$is the welding speed [mm/s], k is the thermal conductivity [w m^{-1} k^{-1})], and T is temperature [k].

The boundary condition used and the heat transfer in the pin and in the shoulder are shown in the following figures 7:

Figure 7. Boundary conditions.



Source: Prepared by the authors

The heat flow at the interface between the side surface of the pawn and the plates is given by the following expression:

$$q_{pin}(T) = \begin{cases} \frac{\mu}{\sqrt{3(1+\mu^2)}} r_p \omega \bar{Y}(T) & : T < T_{melt} \\ 0 : T > T_{melt} \end{cases} \quad (2)$$

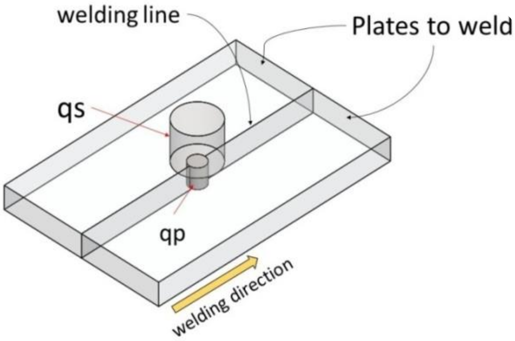
Where μ is the coefficient of friction, r_p is the tool pin diameter [mm], ω is the rotational speed [RPM], Y is the average shear stress of the material [MPa] and T is the temperature [k].

The heat flux between the tool shoulder and the welded sheet interface is:

$$q_{shoulder}(r,T) = \begin{cases} \left(\mu \frac{F_n}{A_s}\right)\omega . R_i \ ; \ T < T_{melt} \\ 0 \qquad\qquad ; \ T \geq T_{melt} \end{cases} \quad (3)$$

Where μ is the coefficient of friction, R_i is the distance between the axis of

Figure 8. Pin and shoulder heat flux



Source: Prepared by the authors

rotation of the tool and a point at the interface below the shoulder[mm], ω is the rotational speed [RPM],T is the temperature [k], A_s The friction surface of the shoulder [mm^2] and $F_n$the vertical force applied [N].

A heat flux imposes on the tool/material contact surfaces:

$$k\frac{\partial T}{\partial n} = \quad (4)$$

At the tool/environment interface, convection takes the form of an exchange flow described by the following equation:

$$k\frac{\partial T}{\partial n} = h(T - T_i) \quad (5)$$

Where h is the total heat exchange coefficient. Heat exchange by convection is considered in the force regime at the tool/material interface.

An initial condition is given by: $T(t = 0) = T_i = 93.9\ °C$

3.2 MATERIAL AND GEOMETRY USED

AA6061 is a popular aluminum alloy from the 6000 series, mainly alloyed with magnesium and silicon. It is known for its excellent resistance in corrosion, strong weldability, and high strength-to-weight ratio, making it ideal for a broad range of applications.AA6061 is commonly used in structural components, automotive parts, marine applications, and aerospace components due to its versatility and ease of machining.

The following tables 1 and 2, show the chemical compositions and the solidus and liquidus temperature of the aluminum alloys 6061, (G. Madhusudhan Reddy et al., 2006) and (Brahami et al., 2018).

Figure 9 illustrates the flow stress as a function of strain rate for five different temperatures situated between the Liquidus and Solidus temperatures.

Table 1. 6061 alloys chemical composition

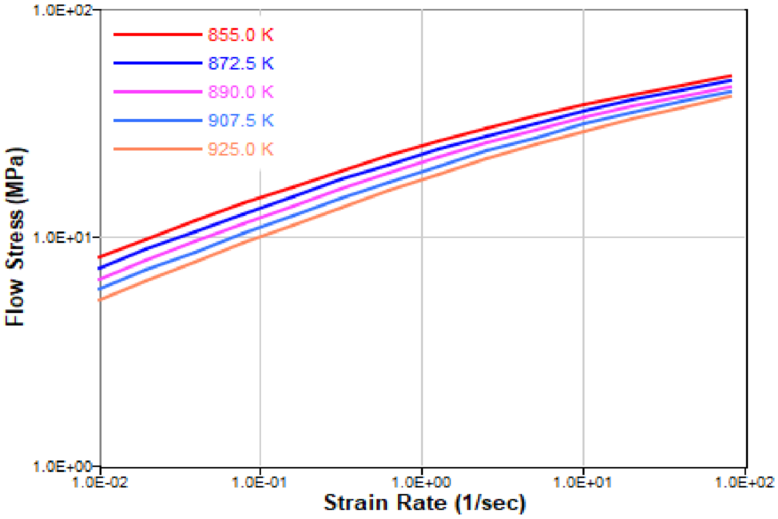
Material	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Al
6061	0.8-1.2	0.4-0.8	0.7	0.15-0.4	0.25	0.15	0.15	0.04-0.35	Rest

Source: G. Madhusudhan Reddy et al., 2006, Brahami et al., 2018.

Table 2. Solidus and Liquidus temperature for AA 6061

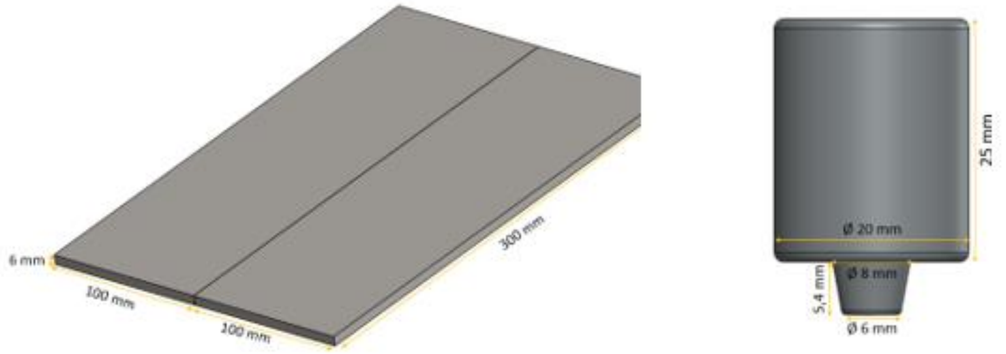
Solidus Temperature (K)	855
Liquidus Temperature (K)	925

Figure 9. Flow stress depending on strain rate for the five different temperatures between the Liquidus temperature and the Solidus temperature



The geometry and dimensions of the welded plates and the welding tool in our study are illustrated in Figure 10, those 3D parts have been modeled by SolidWorks software, the unite ofmeasurements are mm.

Figure 10. Geometry and dimensions of plates to weld and welding tool (The unit of measurement is mm.)



Source: Prepared by the authors

4 RESULTS AND DISCUSSIONS

In this simulation, we examined theeffect of feed speeds on the temperature distribution, HAZ width, and Von Mises stress distribution in welded plates. The welding process includes several parameters with precise settings. The tool's welding speed varies between 2 and 5 mm/s, while its rotational speed is fixed at 900 RPM. Both thedepth of the plunge and the angle of the tiltare maintained at 0 mm and 0°, respectively. The pin of the tool features a conical geometry, with an upper diameter of 8 mm, a lower diameter of 6 mm, and a height of 5.4 mm. The tool's shoulder has a diameter of 20 mm, a height of 25 mm, and a plate-shaped design. The material being welded is a 6061-aluminum alloy plate, measuring 100×300×6 mm, and the tool used is made of H13 steel.

4.1 WELDING SPEED EFFECT ON THE TEMPERATURE DISTRIBUTION

Table 3 show the temperature distribution on the upper surface for different welding speed, the iso values and the isometric view for the temperature distribution on the welded plates. Depending on the operating conditions, the temperature gradient in front of the tool can be very high as the plate is cooled by exchange with the external environment.These simulations confirm the results developed by Chiumenti. (Chiumenti M et al., 2013).

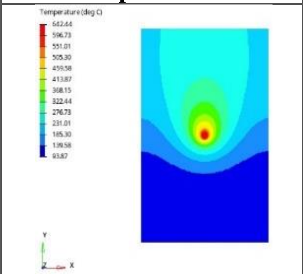
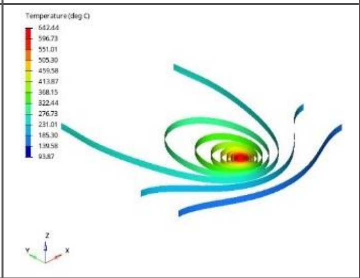
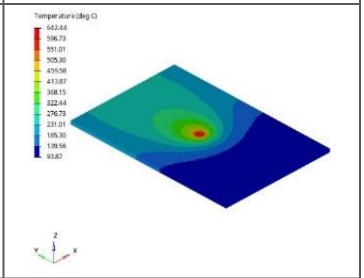
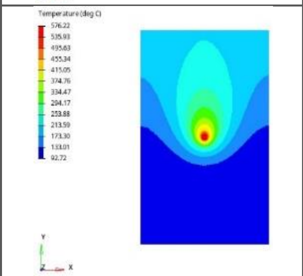
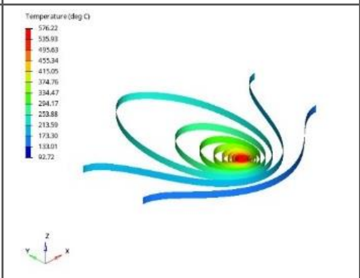
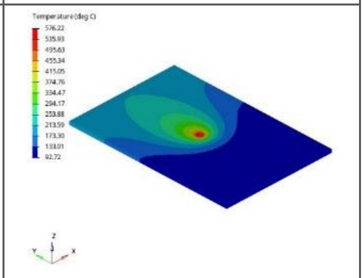
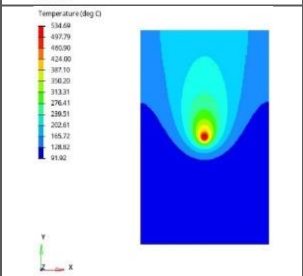
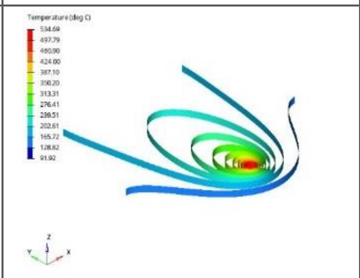
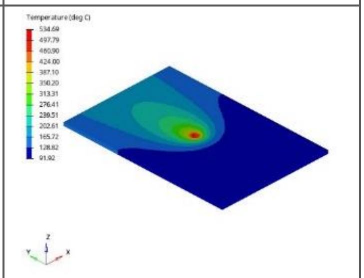
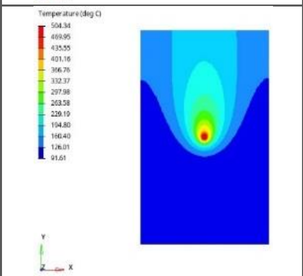
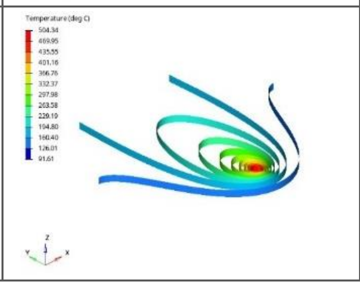
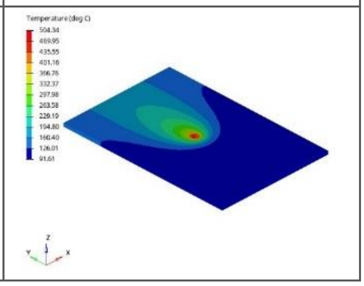
The maximum temperature values as a function of different speeds are illustrated in Figure 11. Note how the peak temperatures stabilise at smaller speeds, limited by the melting temperature.

Figure 12 shows the lines from which the results were taken, figures 13, 14, 15 and 16 show the temperature variationfor various welding speedsalong the center line, the straight line perpendicular to the weld line, the advanced and the retreating sides, respectively, of the upper surface of the welded sheet metal. Depending on the conditions applied, increasing the speed of welding will decrease the maximum temperature.

Figure 17 and 18 shows the section which the HAZ width have been measured and the different zones as TMAZ, HAZ and the BM these zones are defined by different temperature values.

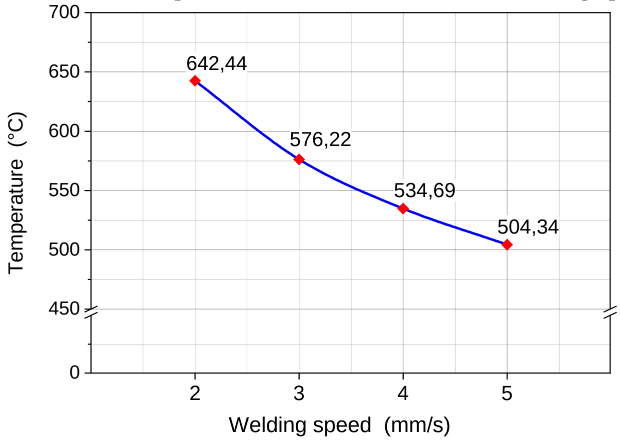
Table 4 presents the HAZ width for various welding speeds. Based on the applied conditions, an increase in feed speed results in a wider HAZ.

Table 3. Temperature distribution for different welding speed

Welding speed (mm/s)	Temperature distribution on the top surface of the welded plates	ISO value for temperature distribution	Isometric view for the temperature distribution
2			
3			
4			
5			

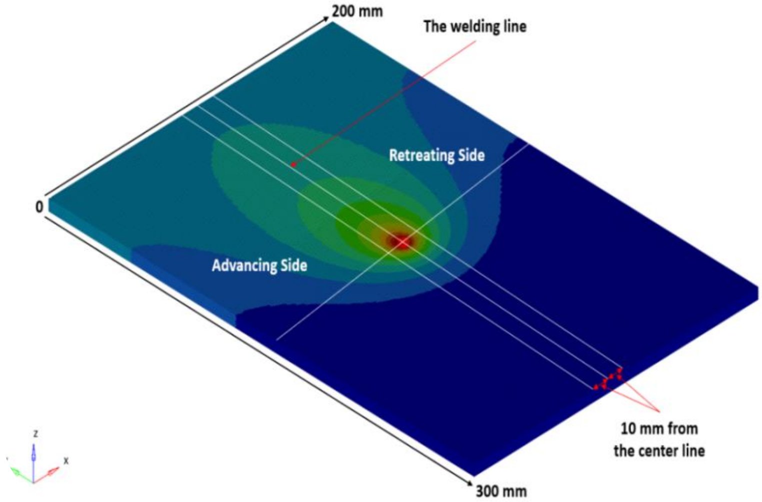
Source: Prepared by the authors

Figure 11. Peak temperature variation for different welding speed



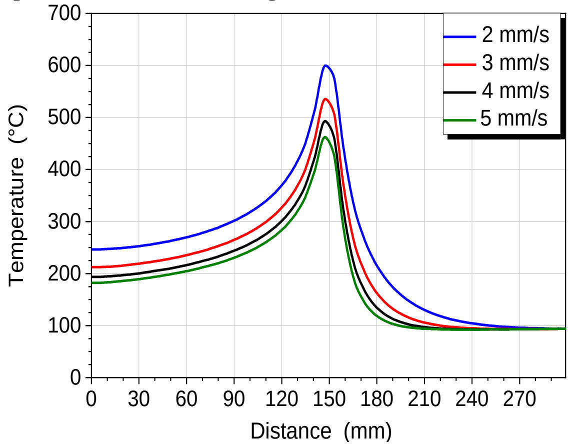
Source: Prepared by the authors

Figure 12. Lines from which the results were taken



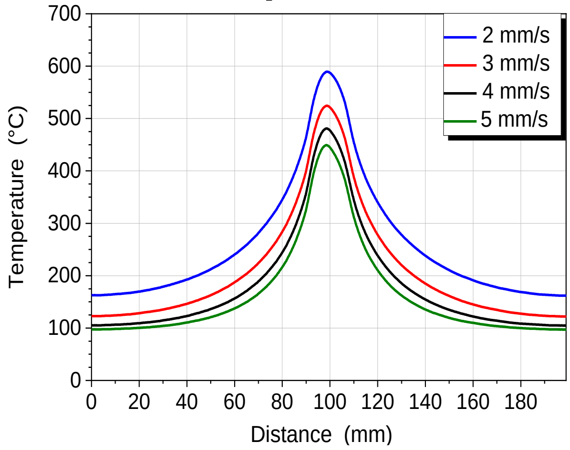
Source: Prepared by the authors

Figure 13. Temperature variations along a center line for different welding speeds



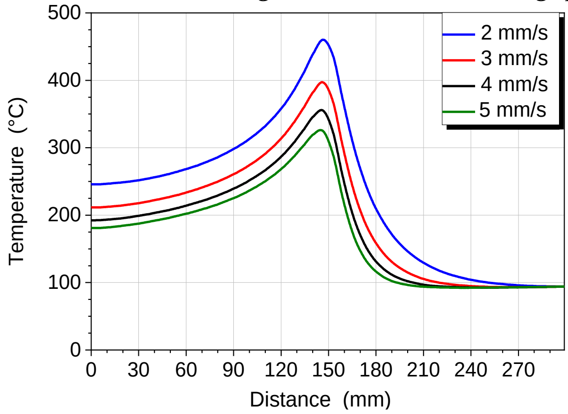
Source: Prepared by the authors

Figure 14. Temperature variations along a straight line perpendicular to the weld line for different welding speed



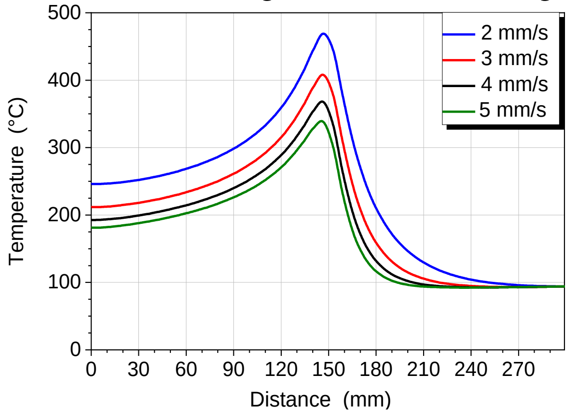
Source: Prepared by the authors

Figure 15. Temperature variations along a straight line parallel to the weld line with distance of 10mm from the center line in the retreating side for different welding speeds



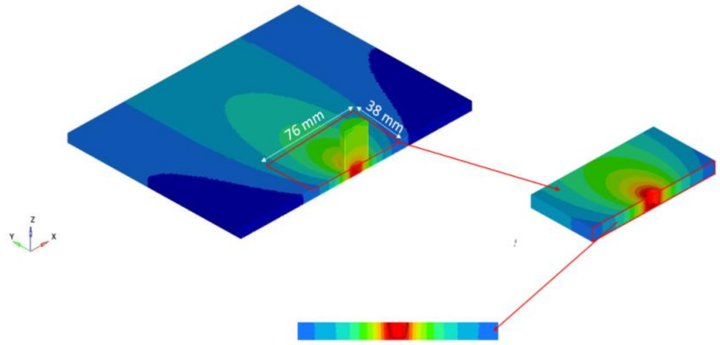
Source: Prepared by the authors

Figure 16. Temperature variations along a straight line parallel to the weld line with distance of 10mm from the center line in the advancing side for different welding speeds



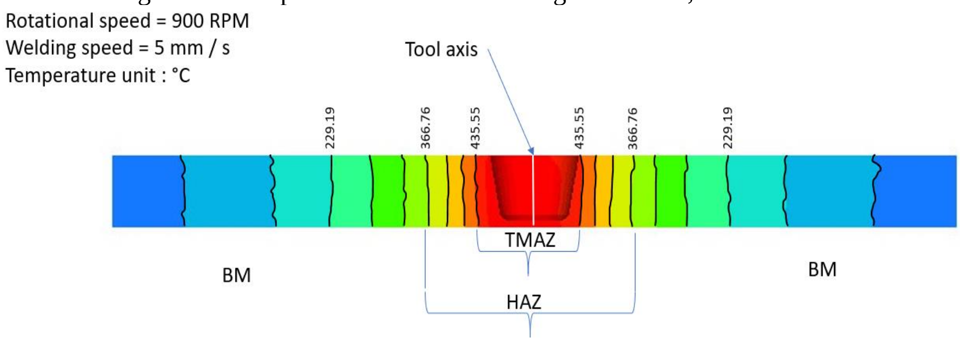
Source: Prepared by the authors

Figure 17– Section from which the HAZ widths have been measured



Source: Prepared by the authors

Figure 18–Temperature variation showing the TMAZ, HAZ and BM



Source: Prepared by the authors

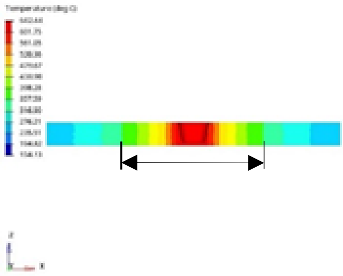
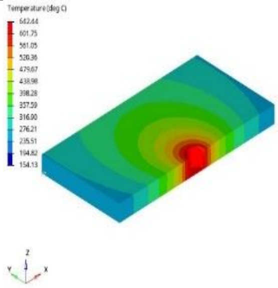
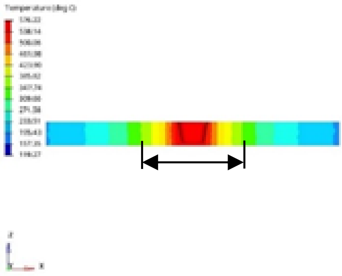
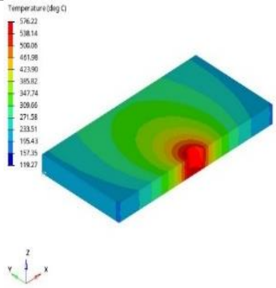
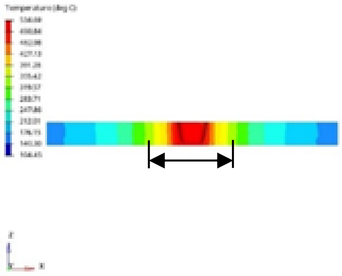
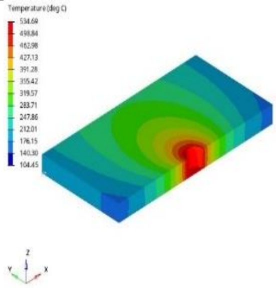
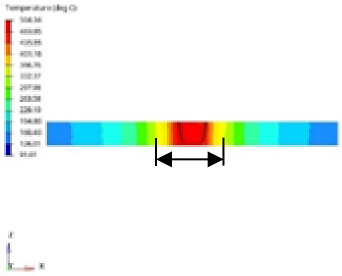
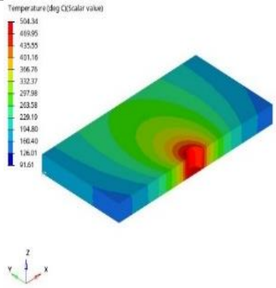
Figure 19 displays the values of the HAZ width and their variation for different welding speeds. According to these results, it is clear that the width of the heat-affected zone (HAZ) decreases with decreasing the speed of welding. The HAZ reaches its maximum width at 2mm/s speed of welding, that has a direct impact into the quality of the welding bead, the optimum width must be equal to the tool shoulder diameter.

4.2 WELDING SPEED EFFECT ON THE VON-MISES STRESS

Table 5 below show the Von-Mises stress distribution in the upper surface of the welded plates, also the isometric view for different welding speed.

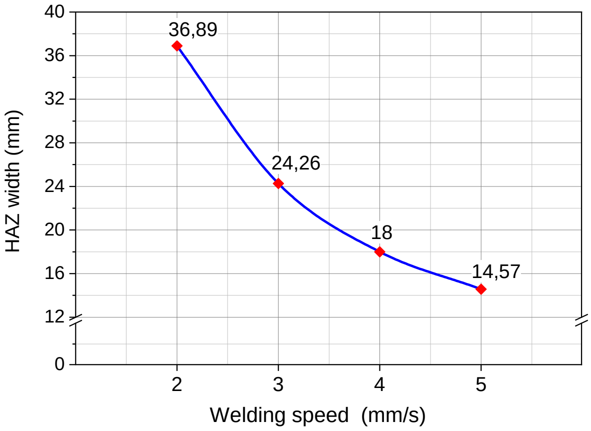
Figure 20 shows how different welding speeds of tool impact the internal stresses along the welding line. Slower speeds (2 mm/s) result in more gradual stress accumulation, whereas faster speeds (5 mm/s) reach the peak stress faster but also lead to fluctuations after the peak.

Table 4. HAZ width for different welding speed

Welding speed (mm/s)	HAZ width	ISO value for temperature distribution section
2		
3		
4		
5		

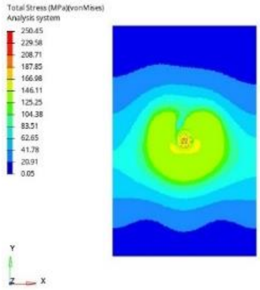
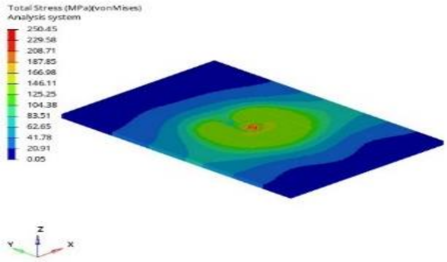
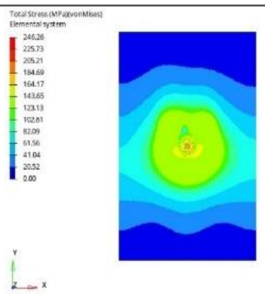
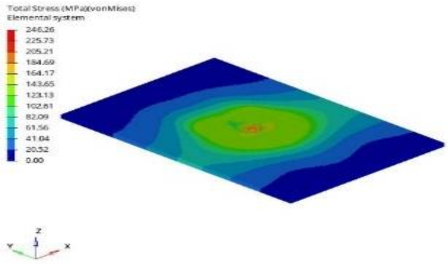
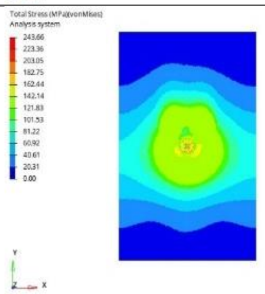
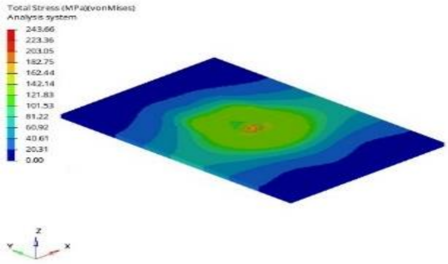
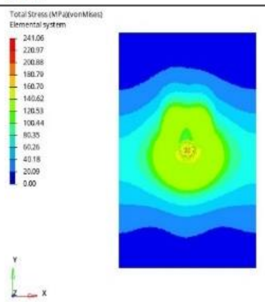
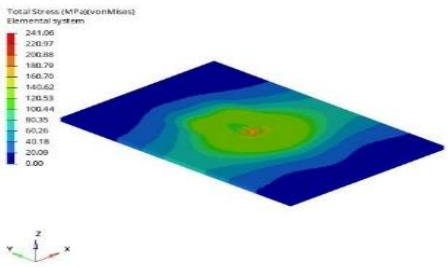
Source: Prepared by the authors

Figure 19. HAZ width values for different rotational speed



Source: Prepared by the authors

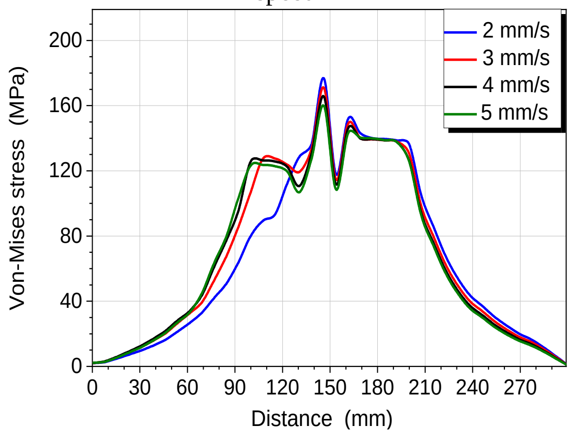
Table 5. Von-Mises stress distribution for different welding speed

Welding speed (mm/s)	Von-Mises stress distribution on the upper surface of the welded plates	Isometric view of Von-Mises stress distribution
2		
3		
4		
5		

Source: Prepared by the authors

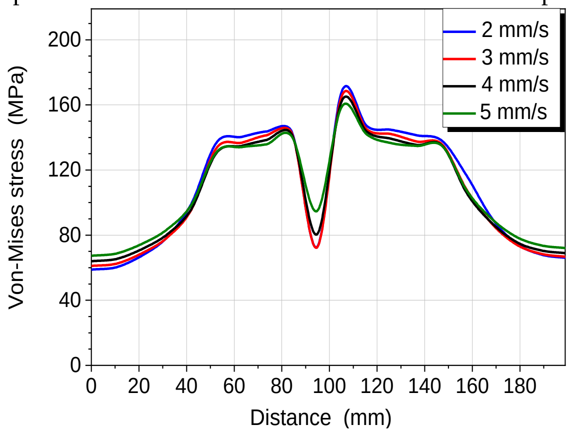
Figure 21 shows the Von Mises stressvariation along the line perpendicular to the welding line and passing from the center, this graph demonstrates that, regardless of welding speed, the material undergoes significant stress changes at specific points along the weld seam. The sharp dip in stress may be a critical point related to the welding tool's interaction with the material, possibly indicating a change in temperature, force, or material flow dynamics. The consistent peak stress across speeds suggests that the material's yield strength is reached, with higher speeds introducing more variability in the stress profile.

Figure 20. Von-Mises stress variations along a straight line located in the weld line for the different welding speed



Source: Prepared by the authors

Figure 21. Von-Mises stress variations along a straight-line pass from the center of the welding tool and perpendicular to the weld line for the different feed speed



Source: Prepared by the authors

5 CONCLUSION

Our work has enhanced our understanding of how welding speeds affect temperature and Von-Mises stress distributions. Here are some key findings from our thermo-mechanical simulations during butt-joint friction stir welding (FSW):

1- The FSW process induces significant plastic deformations and temperature rises, leading to changes in the material's microstructure that affect its properties. Therefore, it’s essential to analyze the alterations in mechanical and thermal properties to optimize welding parameters and enhance weld strength.

2- Reducing the welding speed increases both the maximum temperature and the HAZ width.

3- The width of the HAZ directly impacts the quality of the weld bead, making it vital to identify the optimal welding speed for achieving the desired HAZ width.

4- Although variations in welding speed have little effect on the overall area of the Von-

Mises stress distribution, decreasing the welding speed does result in a higher maximum value of total Von-Mises stress.

5- Understanding this stress behavior is crucial for optimizing the welding process to avoid material defects or failures.

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THOMAS, W. M.; NICHOLAS, E. D.; NEEDHAM, J. C.; MURCH, M. G.; TEMPLE-SMITH, P.; DAWES, C. J. Friction stir butt welding. **International patent application No PCT/GB92/02203) and GB patent application No 9125978.8**; 1991.

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