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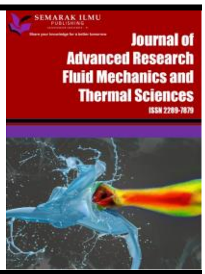

Investigation of the Effect of Heat Transfer during Friction Stir Welding (FSW) of AZ80A Mg Alloy Plates using a Pin Tool by Conducting Finite Elements Analysis

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ABSTRACT

Friction stir welding (FSW) is an innovative solid-state welding process that has attracted substantial attention due to its potential for combining problematic materials such magnesium alloys, such as AZ80A. In order to better understand the impact of heat transport during FSW of AZ80A magnesium alloy plates using a pin tool, this study used finite element analysis (FEA). The welding process's thermal features, such as temperature distribution, thermal stresses, and material flow patterns, are the major focus of this analysis. The first step of the study is to conduct a comprehensive literature evaluation to lay a firm groundwork and pinpoint knowledge gaps. The thermal conductivity, specific heat, density, and mechanical characteristics of AZ80A magnesium alloy are measured and recorded as part of the material characterisation process. To ensure an exact simulation of real-world welding circumstances, a comprehensive 3D model of the welding setup is built, including the AZ80A magnesium alloy plates and the pin tool. In order to accurately record temperature variations, a tiny mesh is used, particularly in the welding zone. By include boundary conditions that mimic the real-world welding characteristics, such as the rotation of the pin tool and the clamping or fixturing of the plates, finite element analysis is used to model the FSW procedure. To simulate the heat input produced by FSW, a heat source or heat production model is used.

1. Introduction

Magnesium alloys, and low-density magnesium alloys in particular (such as AZ80A), are used in a wide variety of applications within the automotive and aerospace industries as a result of their high strength (specific strength), rigidity, attractive damping capacity, and consistent dimensions both prior to and after machining [1]. This is due to the fact that low-density magnesium alloys have a higher specific strength than their higher density counterparts [2]. The extensive use of magnesium alloys can be attributed, in large part, to the fact that they have desirable damping properties in

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addition to their high specific strength and stiffness. Casting techniques are used to create the overwhelming majority of the components that go into making Mg alloys, while other methods, such as plastic forming operations, are employed to get the remaining components [3]. Casting processes are used to manufacture the vast majority of the components that go into making Mg alloys. As more and more uses are found for magnesium alloys, it is becoming more important than ever to have a method of connecting that is not only long-lasting but also highly effective [4]. Magnesium alloys provide a severe task when seeking to establish an efficient joining process. This is because magnesium alloys are prone to early cracking, porosity, and high stresses (residual). Because of this, it is vital to perform research into the quality of the welds in order to increase the utility of Mg alloy welds [5,6]. When it comes to linking certain magnesium alloys, FSW is an extremely useful technique [7]. The AZ80A, the AZ31B, the AM60, and the AM20 are just a few of the numerous that may be discovered in this spot [8,9]. Almagsoosi *et al.,* [10] carried out research that investigated the ways in which a wide number of factors had an effect on the strength, hardness, and impact energy of manufactured AZ31B welded joints. An orthogonal L9 array was utilized as the foundation for the data collection in each iteration of the experiment, and an analysis of the effectiveness of the various joining technique settings was carried out. The results of the experiments and the analysis of variance (ANOVA) [11] indicate that the factors of the welding process that are of the utmost significance are the rotation speed of the FSW tool, the traverse of the tool, and the tool that is being used [12].

It was possible for Geng *et al.,* [13] to employ FSW to successfully weld together pieces of AZ31Mg alloy that were three millimeters in thickness. This was achieved in spite of the fact that the rotation and welding speeds required to be extremely slow in order to get the desired results. There is a potential that the manufactured joints will have a considerable number of twins and dislocations in addition to grains that are quite exact [14,15]. This is in addition to the fact that there is a possibility that the grains will be highly accurate. The development of twin structures on a microscopic scale results in a significant reduction in the prominence of the conspicuous textures that are observed in generated weldments [16]. The ductility of the finished product does not suffer at all throughout the production process, but the joint strength noticeably improves. In light of these findings, friction stir welding (FSW) is an alternate method that may be utilized for successfully joining AZ31B Mg alloy plates [17,18]. This strategy, which enhances the joint's microstructure as well as its mechanical characteristics, does not have the least adverse effect on the joint's ductility and, as a consequence, the joint's mechanical qualities are enhanced. Zhao *et al.,* [19] produced joints out of two distinct types of magnesium alloy (i.e., AZ31 and AZ91) in order to explore the effect that a variety of factors have on the beginning of the hot cracking process. They did this by constructing joints out of AZ31 and AZ91 respectively [20]. It was revealed that joints with a certain distribution of phase grain architectures were generated in the middle of the stir zone when the tool was spun at 1400 revolutions per minute and the traverse rate was set to 25 millimeters per minute [21,22]. The setting for the traverse rate was 25 millimeters per minute. It was discovered that these joints were created in a way that led to the formation of the zone. In addition, the core of the nugget contains a sizeable number of aluminum particles that have been dissolved. On the flat plates of the Mg alloy with a low fraction of Al (i.e. AZ31), the interaction surface of the thermally mechanically altered zone and the nugget region is readily apparent to the naked eye [23]. The AZ31 presents this surface for observation. The results of this study suggest that friction stir welding (FSW) is able to successfully remove high-temperature-induced cracks that appear during the joining of magnesium alloys [24-25].

According to Khaliq *et al.,* [26], it takes a large commitment of time, effort, and financial resources in order to determine the best settings for FSW and how each of its element’s effects joint health on an individual basis. This is something that has to be done before finding the optimal settings for FSW.

In addition to that, a significant quantity of time is essential. The researchers had a feeling that if they employed Taguchi methods, they would be able to cut down on the number of tests that were necessary and focus in on statistically dominating components [27]. Experiments were run to study the effects that the technique's two criteria, namely the speed of the spinning tool and the rate of motion, have on the creation of microstructures as well as the grain hardness in the stir zone. The speed of the spinning tool and the rate of motion are the criteria in question [28,29]. A 32-factorial design was employed as the analytical framework for conducting the analysis of the findings from the experiments that were carried out with three varied rotational and translational speeds. In this specific study, we explored the influence of these two characteristics both separately and in conjunction with one another [30]. Specifically, we looked at how each of these parameters affects the other. By using a cylindrical tool with a pin shape that is tapered, Heidarzadeh *et al.,* [31] constructed a statistical model to assess the quantity of heat that is produced during FSW. This model allows them to determine how much heat is produced. The purpose of this exercise was to ascertain the total quantity of heat that was generated. It was found that the graphs and results of the newly formed model were compatible with each other when compared to those of earlier models made by Çam [32]. This was noticed when the graphs and findings of the newly established model were compared to those of the previous models.

Within the scope of this work, an investigation into the influence of heat transfer utilizing a pin tool during friction stir welding (FSW) of AZ80A Mg alloy plates has been carried out in accordance with an application of finite element analysis.

2. Methodology

2.1 General characteristics of AZ80A ALLOY

It is crucial to learn about the qualities of a substance before trying to comprehend its behavior. A Young's Modulus of 45 GPa is indicative of stiffness, and is only one of several characteristics that aid in engineering design and analysis. A density of 7.860 kg/m^3 and a Poisson's ratio of 0.27, which together regulate how much space can be compressed or expanded. Table 1 shows that this material has a specific heat of 990 J/kg K and a thermal expansion coefficient of 26 m/m°C, both of which quantify the material's ability to store and transport heat. Predicting deformation under load, monitoring temperature responses, and guiding material selection for structures and components all rely on them for optimal performance and dependability across a wide variety of applications as shown in Table 1.

Table 1
Mechanical and thermal properties of AZ80A ALLOY

Young's modulus (Gpa)	Passion ratio	Density g/cm³	Thermal Conductivity W/m-K	Thermal expansion coefficient µm/m°C
45	0.35	1.80	77	26

2.2 Primary Boundary Condition

The spot on the plate that is directly in the center was chosen for the welding procedure. It is situated 200 millimeters (mm) away from the end of the plate. In the Ansys program, the movement of heat was modeled with a thermal transient in conjunction with a static structure.

2.3 Geometry and Mesh

It was possible, with the assistance of AutoCAD, to carry out the hollow plate shape shown in the figure and to carry out a statistical analysis of the data. The beginning and end of the level area are delineated by a split that develops in the center. ANSYS, Inc., the Company ANSYS, Inc. In order to complete the meshing strategy that was used to this specific issue, mesh generation was utilized. During the process of creating the mesh for the model, the total number of the model's particles is reduced from an infinite number to a range that is easier to handle. The precision of the simulations is ensured by the use of a very fine mesh that is built on top of a rigid grid. This paves the way for the manufacturing of the mesh. In order to get the output that was required for a fine mesh, it was necessary to carefully regulate the size of the curve using a coarse mesh and the size of the element using face meshing. The manufacture of the exceedingly thin mesh that was necessary was made possible as a result of this. There are now a total of 45303 binary nodes spread over all of the wedge's zones. This is an increase from the previous figure. These vertices were produced by the wedge in their present positions. Figure 1 is a two-dimensional representation of an example of the building of such a mesh.

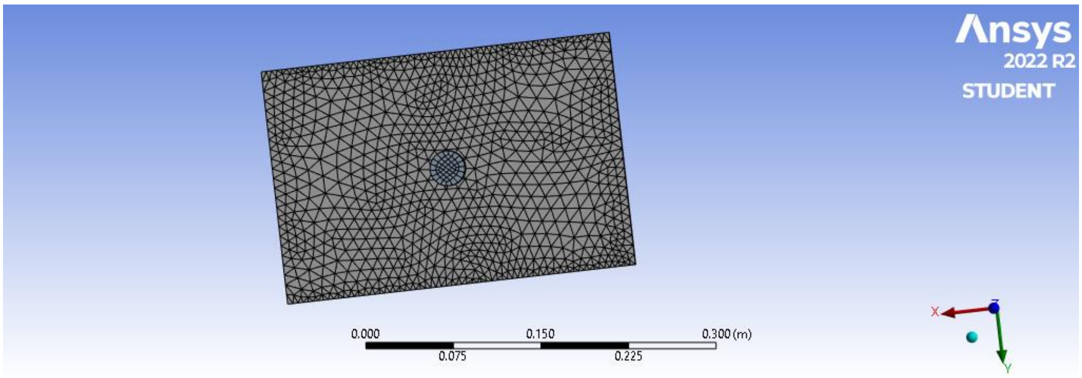

Fig. 1. Meshed model

2.4 Grid Independent Study

During the testing phase, a variety of grid numbers and resolutions are applied in order to assess how well a numerical or computational model operates and how accurate its outputs are. The goal of this phase is to evaluate the model. Within the context of these simulations, the mesh that was used to discretize the problem domain has the potential to have a significant impact on the results. One of the goals of a test that is not dependent on the grid is to determine whether or not the response that is obtained from a simulation continues to be consistent and converges to a reliable result regardless of the changes that are made to the grid. Figure 2 presents the results of an investigation into the currently-simulated procedure that did not make use of a grid. The method was carried out while maintaining a steady heat flow throughout. There are a total of 27653 atoms, and the temperature is now at 200 degrees Celsius. After a total of 27993 components have been counted, the temperature is determined to be 250 degrees Celsius. There is no longer any variation in the von miss stress once the atomic number 28003 has been reached. As a consequence of this, as seen in Figure 2, the element count of the mesh will not change from 28003, and computations will be carried out using this particular element count.

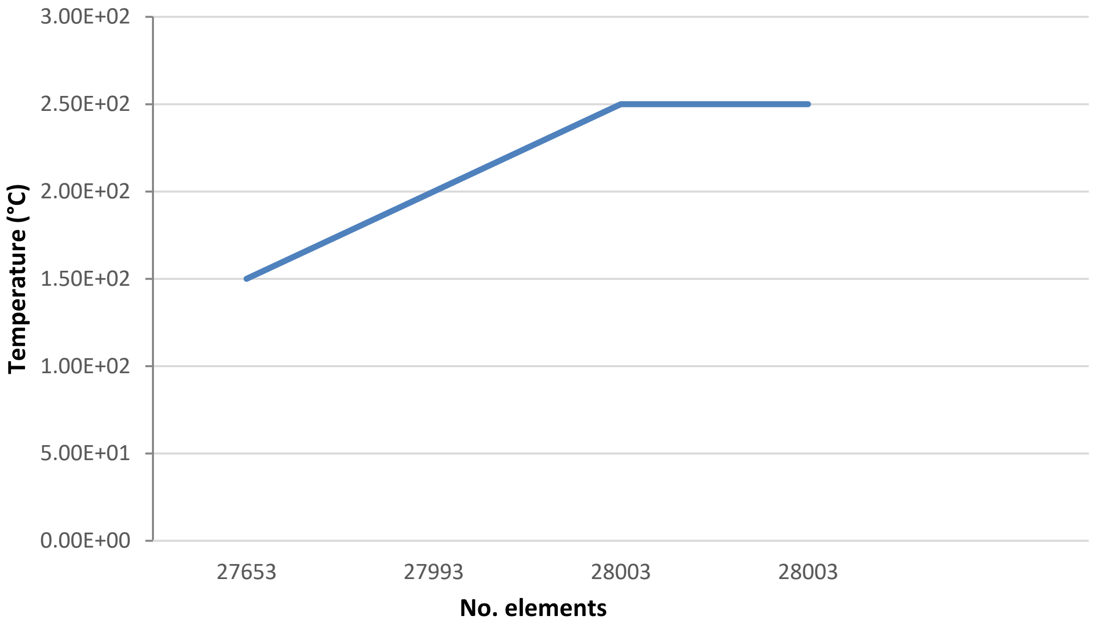

Fig. 2. Grid independent study

3. Results and Discussion

3.1 Heat Transfer Efficiency

The thermal behavior of an AZ80A alloy plate during welding is depicted by the figure 3, which denotes accurate temperature values at various positions along the length of the plate. The length of the plate is 400 mm, and the welding process generates a maximum temperature of 507 °C at the welding junction, which is located 200 mm away from one end of the plate. The distance between the welding junction and the other end of the plate is. When moving away from the weld site and toward the plate's edge, one will notice that the temperature is dropping at an increasingly rapid rate. At a distance of 195 mm from the welding spot, the temperature was reported as being 500 °C, however at the perimeter of the plate, the temperature was only 20 °C.

The use of principles related to heat conduction in material systems can shed light on the observed temperature distribution and help explain it. During the welding process, tremendous heat is used, which results in a temperature difference between various parts of the plate. The rapid dissipation of heat may be inferred from the observation that the temperature dropped to 500 degrees Celsius within a distance of 5 millimeters from the welding area (more specifically, at a distance of 195 millimeters). The fact that the temperature dropped from 1200 degrees Celsius at a distance of 195 millimeters to 20 degrees Celsius at the plate's edge is evidence that heat was effectively dissipated over the whole length of the plate.

Under these specific environmental circumstances, the AZ80A ALLOY material's thermal properties have the potential to have an effect on the way it behaves. Because of the relatively high thermal conductivity of the material, it is possible to achieve efficient heat transmission, which, in turn, causes the temperature to decrease as the heat travels down the plate. In addition, the ability of AZ80A MG ALLOY to absorb energy, as well as the pace at which it heats or cools, is substantially impacted by the material's thermal capacity.

The results of the simulation that were generated by ANSYS provide important new insights into the transient thermal dynamics of the plate both during and after the welding technique. The information that has been presented is of the highest significance when it comes to analyzing the potential structural repercussions that may emerge as a result of an uneven distribution of temperature. These potential consequences include thermal stress and expansion effects. In addition to this, it makes it possible to predict how the material will react when subjected to high temperatures, which enables engineers to design plates and structures that are able to withstand the effects of fluctuating temperatures.

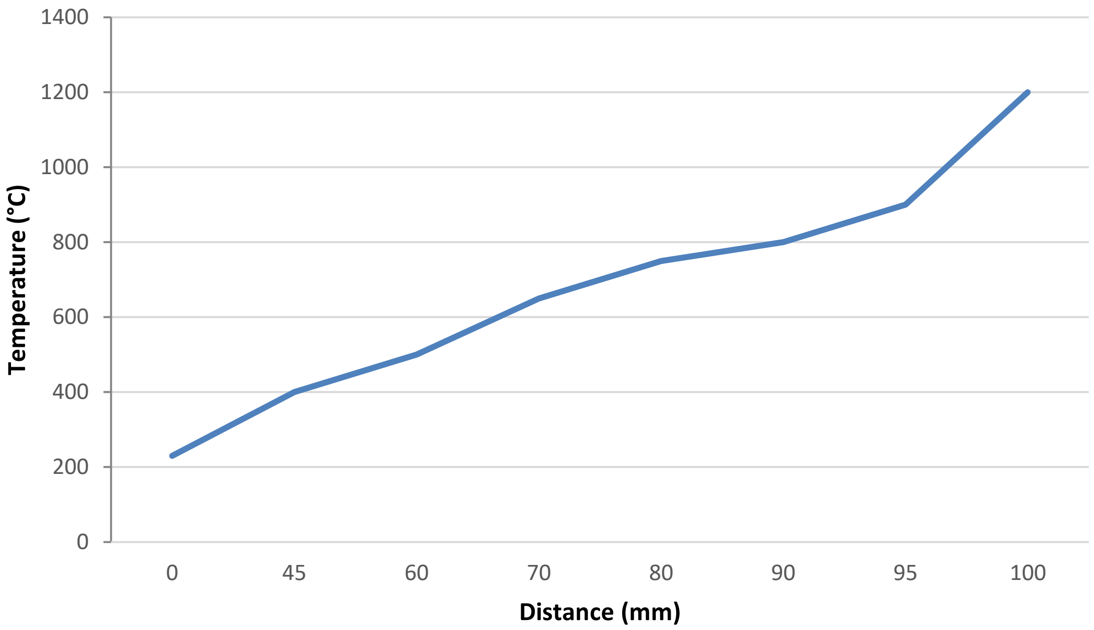

Fig. 3. Heat distribution along the plate

It is essential, from a purely practical viewpoint, to take into consideration the thermal impacts that take place during the welding process and to design structures that are capable of withstanding the temperature gradients that are associated with it. In addition, the numerical findings that have been verified offer more evidence that the simulation model is accurate. These findings can serve as a basis for drawing well-informed conclusions on the choice of materials, welding techniques, and the overall structural soundness of the structure. Figure 4 shows a visual representation of how the weld traveled from the spot where it was conducted to the main body of the plate. This process is depicted graphically in the figure. According to the statistical information, the temperature reaches a maximum of 507 degrees Celsius in the welding region, although the maximum temperature in the heat-affected zone (HAZ) is only 150 degrees Celsius. The temperature of the remaining regions of the body is consistent with what is considered normal, which is 20 degrees Celsius.

3.2 Impact Total Heat Flux Due to Temperature on FSW

The impact of heat flux as a result of the welding process is depicted in Figure 5. The central point is highlighted in red to signify the maximum concentration of heat at that specific location, and the figure shows how this influence manifests itself. After then, the thermal energy moves on to the subsequent zone, where it has a progressively less significant effect. The immediate surrounding area is what's known as the Heat-Affected Zone (HAZ), and it gets its name from the acronym. Utilizing a variety of different methodologies, both static structural and thermal transient, that are a part of the Ansys software proved helpful in the computational examination of this occurrence.

The use of this approach makes it possible to conduct an in-depth analysis of the structural response and dynamic thermal behavior that result from the welding operation. Figure 4's visual representation offers a substantial new viewpoint on the spatial arrangement of thermal effects, which may help engineers make decisions on the use of materials, design considerations, and the long-term stability of the structure as a whole.

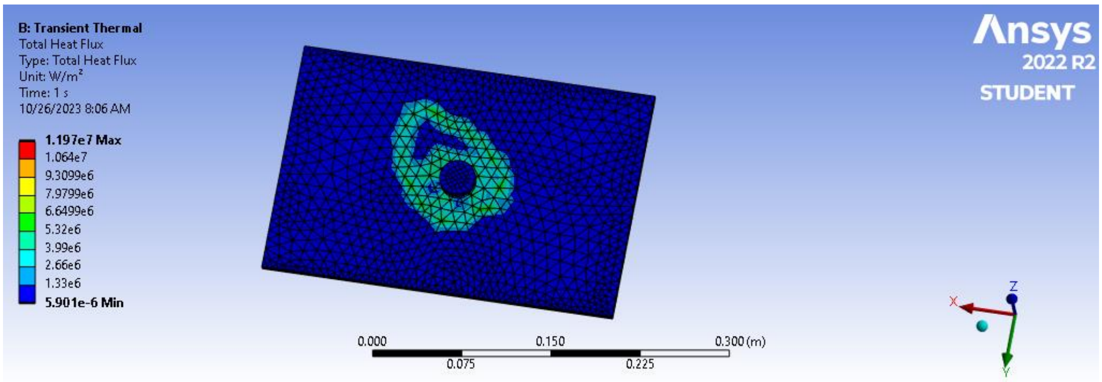

Fig. 4. Illustration of numerical results of total heat flux

The computational examination into the overall heat flux has produced satisfactory findings so far. It has been determined that the overall heat flow has reached its maximum, which is 1.197 W.m-2. At a temperature of 1200 degrees Celsius, this value is at its highest point. In comparison, the minimum value for the total heat flow is e-6 W.m-2, and it drops to a minimum of 6e-6 W.m-2 when the temperature is 35 degrees Celsius. These detailed results reveal the complicated spatial and thermal dynamics, demonstrating the influence of both temperature and direction on the dispersion of heat in the environment. As demonstrated in Figure 6, these insights help to the optimization of material performance, structural design, and heat management methods used in welding applications.

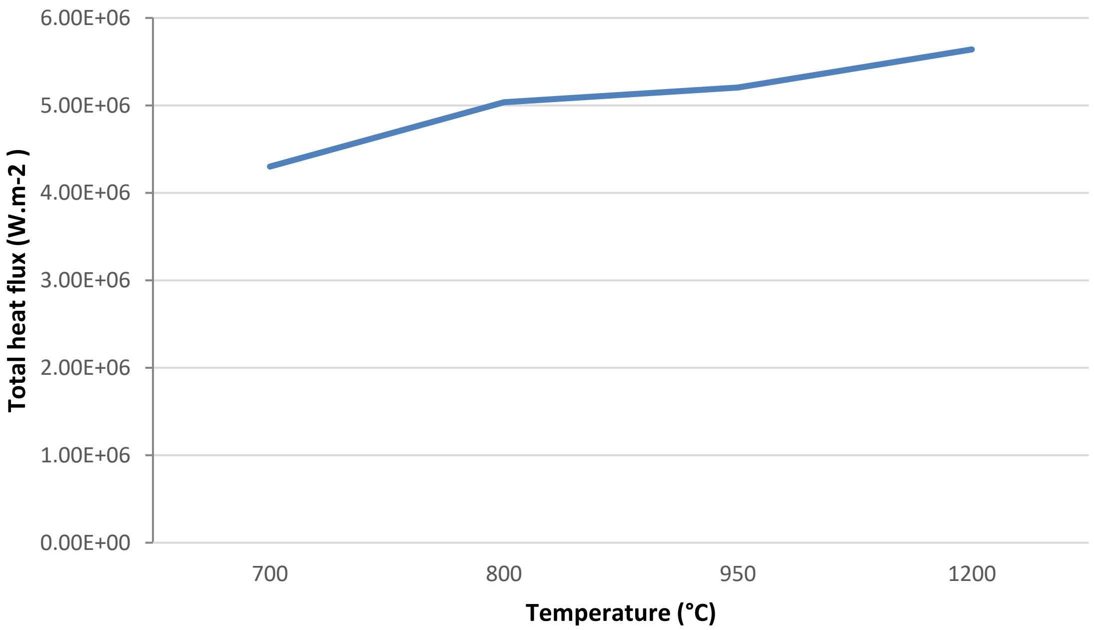

Fig. 5. Computational analysis of total heat flux

3.3 Stresses Due to FSW

The heating process is responsible for the presence of residual stress, as demonstrated by the numerical data. The visual representation of how the temperature of the weld affects the tension on the body is shown in Figure 6. The maximum intensity sress is equal to 27.3 e6 Pa. It is abundantly obvious that the most residual tension took place at the plate's edge. The evaluation of stress distribution using the stress intensity criterion in combination with the temperature that is being applied leads to the discovery of insightful new information. The stress intensity achieves its greatest value of 7.6e6 Pa at the region of the welding, which is also where the temperature reaches its highest point of 1200 degrees Celsius. The heat effects that are created during the welding process are responsible for the substantial degree of stress that was encountered. Temperature and stress are shown to have an inverse relationship, which provides evidence that there is a connection between these two factors.

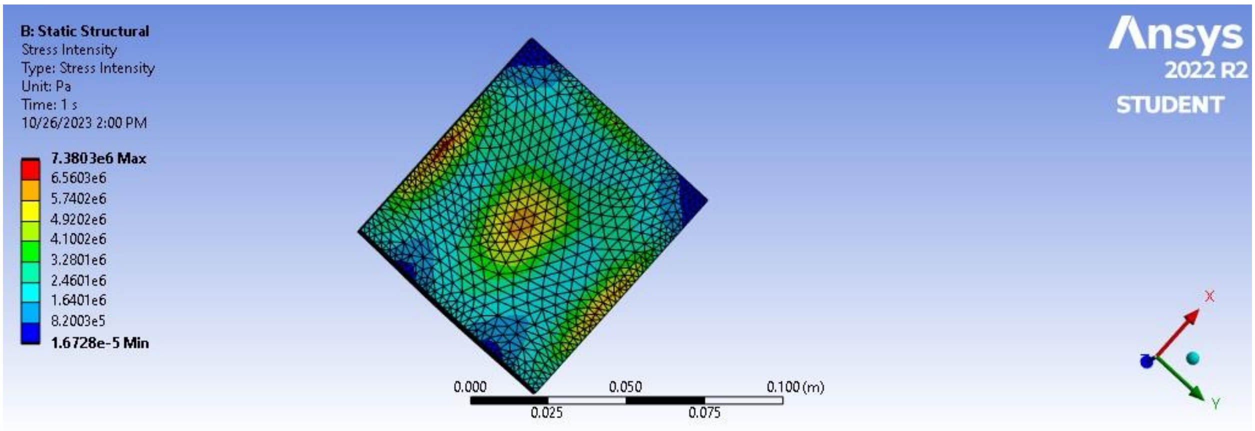

Fig. 6. Computational illustration of stress intensity

The response of the material to the different thermal conditions may be thought of as the root cause of the observed relationship between stress and temperature. The welding process causes localized heating in the plate, which leads to thermal expansion and non-uniform deformation. This occurs because the plate is being deformed in an uneven manner. Because of this, areas that are subjected to higher temperatures tend to develop stress concentrations as a direct result of this phenomenon. The stress intensity is a measure that quantifies the combined effects of tensile and shear stresses; as a result, it pinpoints portions of the material that have the potential to fail or that are of interest to researchers. As an instance, when the temperature approaches 750 degrees Celsius, the tension drops to 1.01e6 pascals as seen in Figure 7.

It is possible that the dissipation of thermal effects is the cause of the observed decrease in stress levels that occurs in response to a falling temperature. A decrease in thermal expansion and contraction can be brought on by lower temperatures, which can then lead to a lessening in the amount of stress concentrations. The link between stress and temperature draws attention to the relevance of evaluating the structural integrity of welded components. This draws attention to the necessity of taking into consideration both the thermal and mechanical elements of the situation.

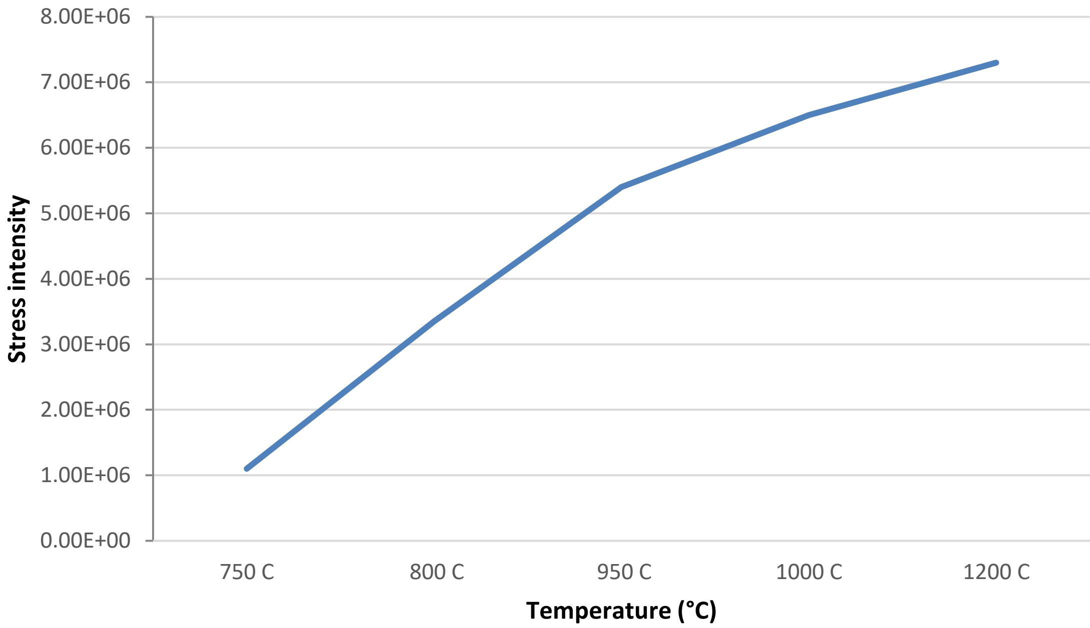

Fig. 7. Numerical results of von Mises stresses

4. Conclusion

In conclusion, Friction stir welding (FSW) is a sophisticated solid-state welding technology that has gained a lot of attention due to its potential for combining difficult materials such magnesium alloys like AZ80A. In this study, finite element analysis (FEA) is used to examine the impact of heat transmission during friction stir welding (FSW) of AZ80A magnesium alloy plates utilising a pin tool. The major concern is with the study of welding's thermal features, such as temperature distribution, thermal stresses, and material flow patterns. The first step of the study is to conduct a comprehensive literature evaluation to lay a firm groundwork and pinpoint knowledge gaps. Thermal conductivity, specific heat, density, and mechanical characteristics, among others, are collected through material characterization of AZ80A magnesium alloy for the FEA model. The welding process is simulated by creating a precise 3D model of the setup, complete with the AZ80A magnesium alloy plates and the pin tool. Particularly in the welding area, where temperature variations need to be captured, a tiny mesh is used. In order to replicate the FSW procedure, finite element analysis is used, using boundary conditions that mimic the real welding characteristics, such as the rotation of the pin tool and the clamping or fixturing of the plates. The heat intake during FSW is modelled using a heat source or heat generation model.

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