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A Study on Different Friction-Stir Processing Parameters effect on LM-25 Aluminum Alloy

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Abstract

This research studies the effect of friction stir processing (FSP) on the mechanical properties of LM-25 aluminum alloy. The research is conducted by trying different processing parameters (spindle speed and feed rate) settings to observe the effect of such parameters on the alloy. A tensile test and a Vickers hardness test are carried out to analyze the result of the FSP on the mechanical properties of the alloy. The results show a notable improvement in the mechanical properties and show a relation between the processing parameters and the mechanical properties of the alloy. Improvement in strength, toughness, and hardness of the alloy is linked directly to the parameters of the friction stir processing of the alloy.

Keywords
Friction Stir Processing, Metallurgy, Tensile Strength, Hardness, LM-25 aluminum alloy.

1. Introduction
Aluminum alloys are nonferrous metals that have a large spectrum of applications and are heavily utilized in multiple industries. Aluminum is considered a sustainable material since its recycling process does not affect its quality nor its quantity and saves about 95% of the energy required to produce it from ore (Black et al. 2017). Noting that aluminum and its alloys are the second in global expenditure and quantity after steel and are used in most industries like automotive, aerospace, construction and electrical applications etc. (Latif et al. 2022).

The joining of different alloys and metals brings a combination of higher properties of both metals to the product. However, the joining process by fusion or welding can be difficult due to the difference in physical and chemical properties of the metals (Jadidi et al. 2022). Friction stir welding (FSW) created joints with better mechanical properties than the parent material (Yogesh et al. 2022), which lead researchers to study the ability to improve the metal's properties using Friction Stir Processing (FSP). FSW is a process that plastically deforms two objects by generating heat between the tool and the work piece (Choy et al. 2022).

The technique reviewed in this paper is friction stir processing. FSP is a process derived from friction stir welding used to modify the microstructure of the material (Sharma et al. 2020). FSP can be used to process material and change its mechanical or physical properties. In this study, tensile specimens were cut according to ASTM – E8 standards from the aluminum alloys (LM25) plates that were processed under different processing parameters.

1.1 Objectives
The objectives of this paper are:
- Apply Friction Stir Processing to achieve an improvement in mechanical properties
- Test different processing parameters effect on material properties

2. Literature Review
Applications of FSP
Friction stir processing concentrates on altering the mechanical and microstructure of the material by giving it superior characteristics. This created a need in various industries to improve the structures of components and products. Papantoniou et al (2020) presented an innovative approach to use FSP to integrate foaming and stabilizing agents into metal foam precursors. Chumaevskii et al (2020) have combined an additive manufacturing technique and FSP to create hardened surfaces. They used wire-feed electron beam additive manufacturing and followed it with friction stir processing to achieve a hardened surface layer. In addition to that, they were able to reach superior mechanical properties in the processed region.

Processing Parameters
Rajakumar et al (2021) discussed in their research how the dimensions of the FSP tool and processing parameters affected the formation of the FSP zone and the strength of AA 7075-T_6 alloy. They have achieved various conclusions about the effect of the rotational speed of the tool, welding speed, axial force, tool shoulder diameter, pin diameter, and tool hardness. Based on the parameters mentioned the welded/processed region had the following criteria: defects (pinhole, kissing bond, wormholes, etc.) or defect-free, and linked the type and location of the fracture to these parameters as well. Their final conclusion on FSW for AA 7075-T_6 aluminum alloy is that to achieve high strength properties the material should be processed with tool parameters having a shoulder of 15 mm, a pin diameter of 5 mm, and tool hardness of 45 HRc. In addition, the processing parameters of welding speed of 60 mm/min, tool rotational speed of 1400 rpm, and an axial force of 8 kN. The high tensile strength was linked to a defect-free fine-grained microstructure of the weld nugget.

Material Properties and Applications
The characteristics of the aluminum alloy studied in this paper is LM-25 (Al–Si7.5Mg); it has high wear resistance, low coefficient of thermal expansion, strength at raised temperatures, and good bearing and corrosion resistance. LM-25 is widely consumed in the automotive industry in the building of cylinder heads and engine blocks (Jojith et al. 2018). The ultimate tensile strength of low-pressure casted LM-25 is 248 MPa, with 2% elongation and hardness of 85 BHN (Srinivasan et al. 2005). It is worth noting that the LM-25 used in that research had a different chemical composition than the alloy used in this paper.

The literature shows how FSP can be used in altering the mechanical properties of alloys. Furthermore, the process of welding using friction-stir have been proved to give the welded region superior mechanical properties to the parent material. This initiated this study to examine the effect of friction stir processing on the aluminum alloys and identify means of application.

3. Methodology
A conventional vertical milling machine; Kearney & Trecker 307-S12, was used to carry out the friction stir process of the aluminum plates. This machine operates with a spindle speed range from 25 to 2000 rpm and a feed rate ranging from 5 to 640 mm/min. Minton et al. (2006), have verified previously that conventional milling machines are capable of carrying out friction stir welds. The Aluminum alloy was cut into rectangular plates as seen in Figure 1 with features and dimensions that would let us cut specimens to conduct a tensile test after its been processed.

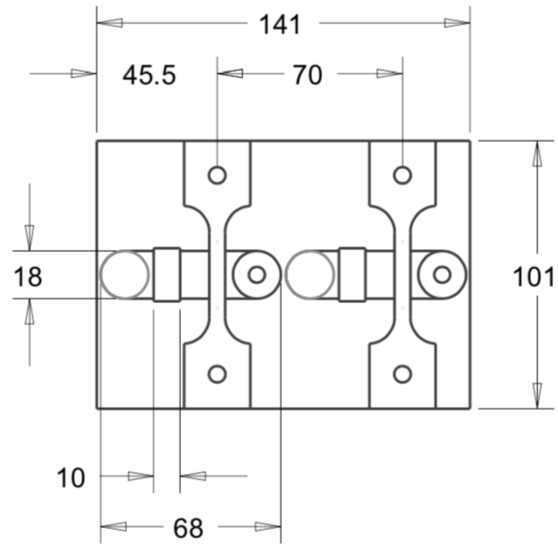

Figure 1. Aluminum Plate with sketches of the tensile specimens and friction stir processed regions (All units in mm)

These rectangular plates were then placed on a fixture and friction-stir processed with different sets of parameters and investigated later on. The parameters studied were the Feed Rate and spindle speed. The spindle speeds and feed rates were classified into two settings high and low as shown in Table 1. Then different aluminum plates were processed under a different set of parameters. For each set of parameters, three specimens (P#) were taken into consideration as observed in Table 2.

Table 1. Processing parameters

	High	**Low**
Spindle Speed (rpm)	1660	774
Feed Rate (mm/min)	92	25

Table 2. Processing sets

Parameter set	**Spindle Speed (rpm)**	**Feed Rate (mm/min)**
P1, P2, P3	774	92
P4, P5, P6	1660	25
P7, P8, P9	1660	92
P10, P11, P12	774	25

Tools used in friction stir welding can have a major effect on the quality of the processed regions. The pin profile and shoulder size and profile should be defined and noted. The dimension of the tool used in this study was a blank tool

(Figure 2 and Figure 3); no features on the pin nor the shoulder, it had a pin diameter of 6 mm and a length of 4 mm. The tool shoulder had a diameter of 16 mm and a 5° concave.

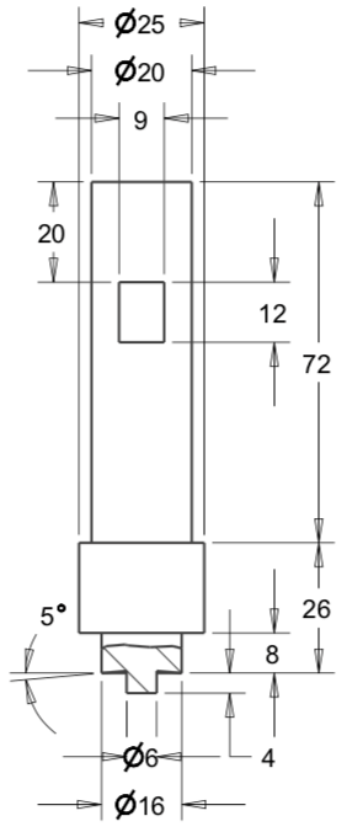

Figure 2. FSP Tool designed and used (All units in mm)

Figure 3. One of the processed plates with two sets of parameters.

After the plates were processed, tensile specimens were cut out from these plates with the processed region in the middle of these specimens as shown in Figure 1. The dimensions of the specimens conformed with ASTM E8/E8M Standard Test Methods for testing of metallic materials 2016. After the tensile specimens have been cut and prepared, a tensile test is conducted, and the results of these tensile tests are presented in the next section of this paper. A rectangular part is also cut from these plates for hardness testing. These plates can be seen in Figure 7 under the microscope to observe the microstructure of the weld nugget, and for conducting the hardness test. A hardness test was conducted along the horizontal and vertical axis of the cross section of the weld. For this test the weld center is located and then the indentations are done with ± 1 mm offset from the center in each direction. All the data is collected and presented in the next section.

4. Results and Discussion

4.1 Numerical Results

During friction stir process, the processed region does not reach the melting temperature indicating that cold working is being done. The nugget undergoes localized plastic deformation, which is defined as strain hardening, which can cause the material to be stronger (Black et al. 2017). Tensile tests were carried out for the entire specimens obtained from the experiment and the results were plotted in Figure 4 and Figure 5.

By comparing the results of the processed specimens with the results of an unprocessed specimen, we can reach the following deductions:

- A significant change in the mechanical properties; tensile strength and toughness, can be observed.
- Specimens P10, P11, and P12 experienced a notable increase in their tensile strength with values between 82 MPa and 95 MPa, whereas the unprocessed specimen had a tensile strength equal to 65 MPa.
- An increase in Material toughness is perceived, with the area under the curve increasing due to an increase in tensile strength and strain.

In addition to the tensile tests, a Vickers hardness test was conducted to observe the change of hardness of the processed and unprocessed areas. Figure 6 shows a graph of the hardness values from the processed areas on the specimen. The hardness of specimens P4 to P9 range from 60 to 68 Hv5, whilst having the hardness of the unprocessed region equal to 55 Hv5. Furthermore, a hardness test was done on the cross-section of the weld nugget to see how the hardness values varied. In Figures 7, 8, and 9 we can notice the hardness values on the advancing side are larger than the values on the retreating side of the center of the weld nugget.

4.2 Graphical Results

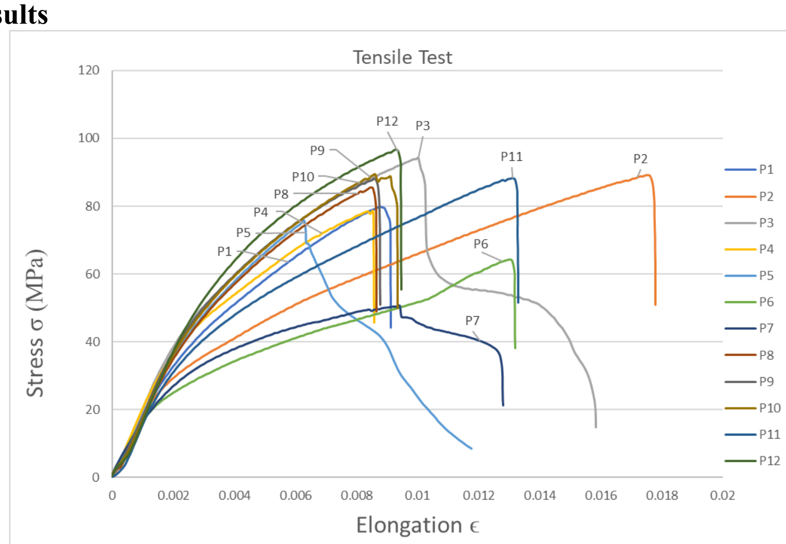

Figure 4. Graph showing the stress/strain curve for all the processed specimens, the tensile strength ranges between 70 and 90 MPa

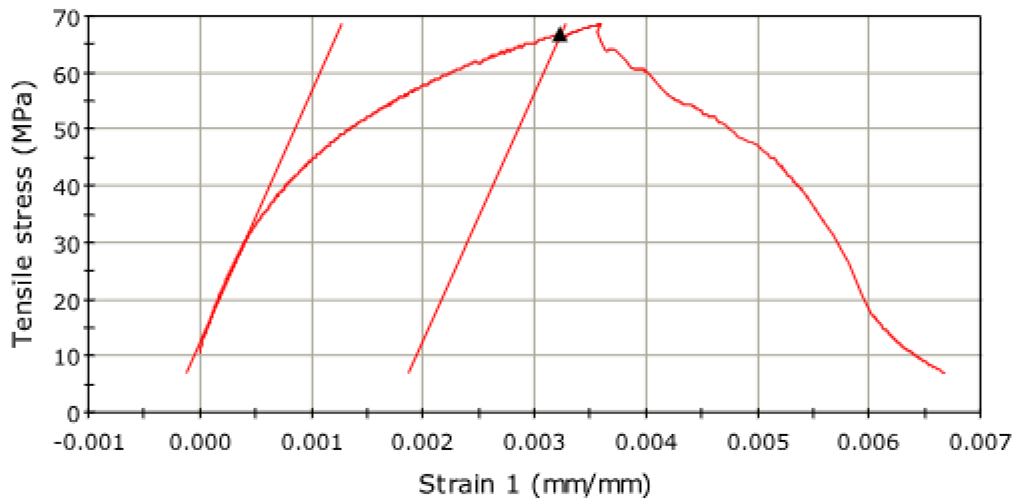

Figure 5. Stress/Strain graph of the unprocessed specimens, showing a tensile strength of 65 MPa

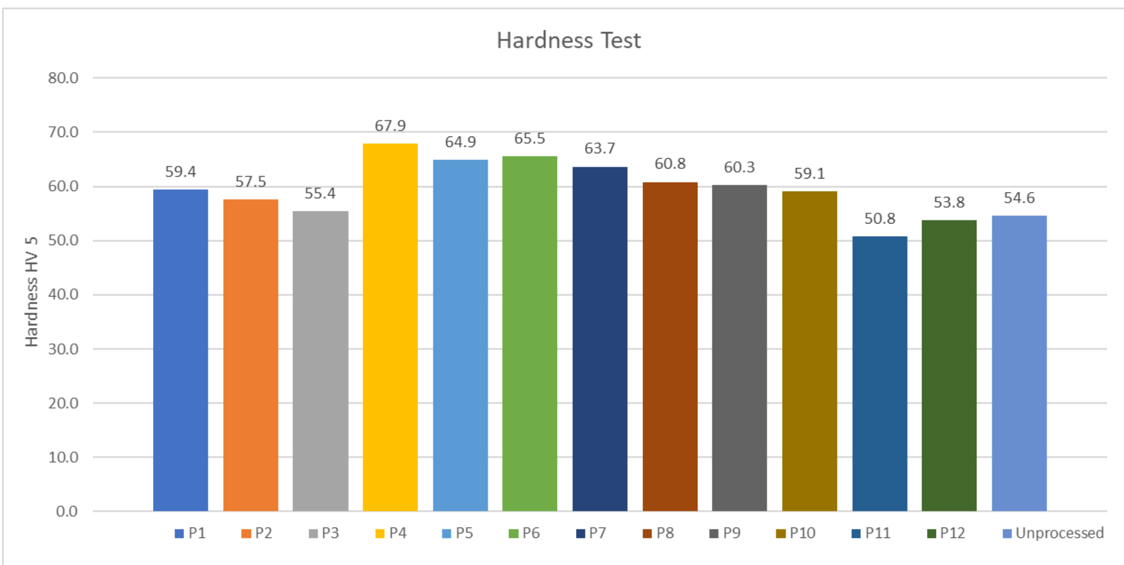

Figure 6. Hardness values of the processed regions

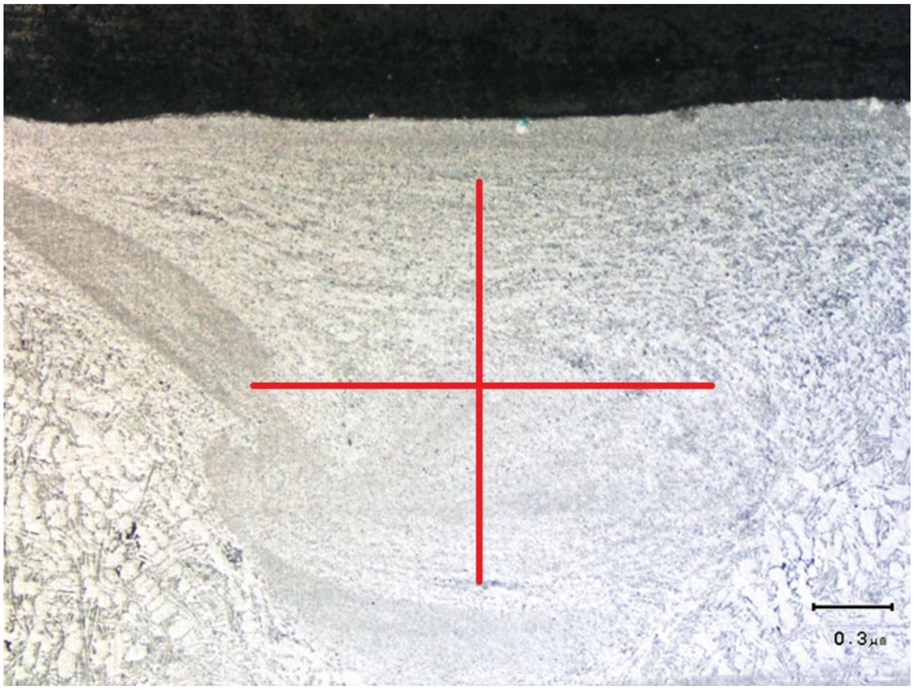

Figure 7. Cross-sectional view of the weld nugget of specimen P2, hardness indentation was conducted along the red lines.

Figure 8. Horizontal axis hardness values along the cross-section, the red line shows the processed region

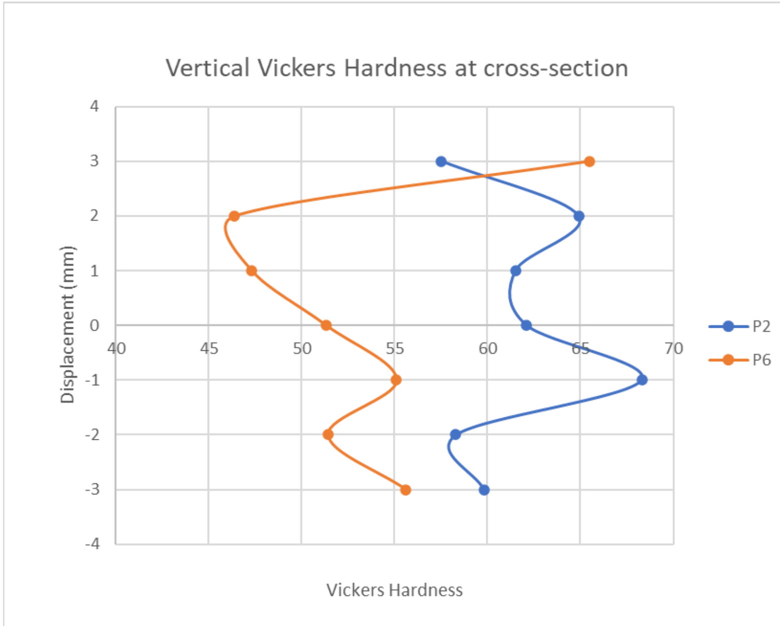

Figure 9. Vertical axis hardness values along the cross-section

4.3 Proposed Improvements

After observing the above results, the following improvements can be proposed:
The tool used in the process can be updated by adding features to the pin profile; like threads, or it can be tapered, or grooves can be added to the shoulder. These different features on the could influence the mechanical properties. Moreover, a study can be conducted on the microstructure of the material and establish a relation between the processing parameters, tool profile, and nature of microstructure. The current test examined specimens that were only processed in the center. Further tests can be conducted on specimens that have been fully processed by FSP and observe the change in mechanical properties.

4.4 Validation

Based on the literature, Friction stir process is directly linked to improvement of processed material or even the processed regions of the material. The initial hypothesis of this study was that FSP will improve the mechanical properties of LM-25. This research proved the hypothesis, hence achieving a positive effect on the mechanical properties of the aluminum alloy LM-25 after being processed.

5. Conclusion

Friction Stir processing is considered an advanced technique to process metallic parts in the manufacturing industry. FSP is used to manipulate the mechanical properties of alloys to achieve superior characteristics in automotive and aeronautical applications. In this research, we concluded that first; we can improve the strength and toughness of the material, hence handling higher loads. Second, FSP can increase the hardness of the products via creating a more indentation resistant surface. Third, there is a direct link between the processing parameters with the mechanical properties. These conclusions are that a high spindle speed is directly linked to an increase in surface hardness and a low spindle speed, and a low feed rate setting can be directly linked to the increase in material strength. The latter is true since the process is considerably slow causing more friction to happen and more distortion to occur in the material leading to strain hardening.

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Biography

Imad Amine is the head of the industrial engineering program at the American College of the Middle East. He earned his B.S. in Mechanical Engineering at the University of Balamand, Koura, Lebanon, and a M.Sc. in Advanced Manufacturing Systems at Brunel University, London, United Kingdom. Imad has a strong background in engineering education, with extensive experience in curriculum development and program management, focusing on the integration of industry-relevant skills. He has been recognized for his contributions to student development and academic excellence, receiving awards for his innovative teaching methods and commitment to enhancing the student learning experience. His research interests include advanced manufacturing systems, process optimization, metallurgy, and application of modern technology in industrial engineering.