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FSW kaynağında kaynak kuvveti, titreşim ve sıcaklığın mekanik özellikler ve mikroyapı üzerine etkilerinin incelenmesi

Investigation of the effects of welding force, vibration and temperature on mechanical properties and microstructure in fsw welding

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Investigation of the Effects of Welding Force, Vibration and Temperature on Mechanical Properties and Microstructure in FSW Welding

Highlights

- *Stirrer pin geometry has a significant influence on the microstructure and mechanical properties of welded joints.*
- *When the welding feed rate has been increased, the welding temperature has decreased; welding forces and vibration have increased.*
- *The highest tensile and fatigue strengths have obtained from high spindle speed and low welding feed rates.*
- *With increasing spindle speed, while the temperatures formed during welding increased, welding forces decreased.*
- *Worse weld transition zones were obtained in the joints where the triangular stirrer pin was used.*

Graphical Abstract

AA5182 materials were welded by FSW at different pin geometry, spindle speed and feed rates. Microstructural analyses and mechanical tests were carried out to observe the effect of welding parameters. it was given experimental procedure at figure 1.

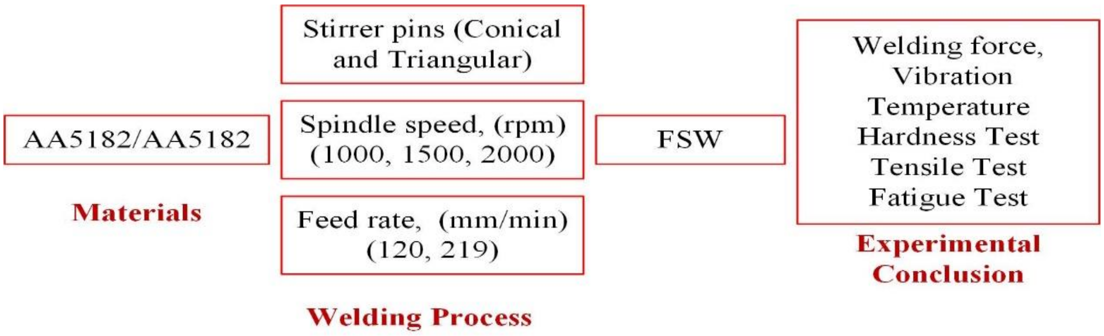

Figure 1. Experimental process

Aim

the effects of welding parameters like tool geometry, spindle speed, and feed rate on the forces, vibrations, and temperature in FSW of Al alloys have not been made a comprehensive study. That's why, in this study the effect of stirrer pin geometry, spindle speed, and feed rate on the welding force, vibration, and temperature has been investigated.

Design & Methodology

AA5182 plates were joined by FSW in different welding parameters.

Originality

The effects of welding parameters between welding force, vibration and temperature during welding were investigated. In addition, the effects of these effects on microstructures and mechanical tests were studied in comprehensive.

Findings

Effect on obtaining a homogeneous joint.

Conclusion

Coarse grains were formed in the weld transition areas of the joints where TT was used. Microhardness values decreased in TMAZ. High tensile and fatigue forces are obtained at high spindle speed and low feed rates.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Investigation of the Effects of Welding Force, Vibration and Temperature on Mechanical Properties and Microstructure in FSW Welding

Araştırma Makalesi / Research Article

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ABSTRACT

Defects such as porosity and cracking are serious problems in the joining of aluminium and its alloys by melt welding methods. In this case, it is important that the aluminum pairs are welded by friction stir welding (FSW), which is depend on joining at a temperature below the melting temperature by means of a stirrer pin. In this study, AA5182 pairs were joined in the different welding parameters by FSW. The effects of tool pin profily, feed rate and rotation speed on the temperature, force and vibration formed during welding were experimentally investigated. As the rotation speed rised, the temperature increased and the welding force decreased. But, with increasing feed rate, the temperature decreased and welding force and vibration have increased. Mechanical properties of the joints were adversely affected by low temperature, high welding force and high vibration.

Keywords: Fatigue, FSW, tensile force, welding force, vibration.

1. INTRODUCTION

Aluminium and its alloys are of the light metal class to three times lighter than iron. When these materials are exposed to the atmospheric environment, a very thin oxide layer forms on their surface. This layer prevents to subject further oxidation of the aluminum and its alloys. This property of aluminium and its alloys is the main cause of high corrosion resistance. This property also, aluminium and its alloys increase the resistance to many acids. In addition to high corrosion resistance, aluminium alloys have excellent electrical and thermal conductivity, good machinability and plastic formability. Because of these properties, they are extensively used as structural materials in railway, ship, defense, automotive, aviation, electrical, medical, construction and chemical industries and their branches. The widespread use of these alloys in different industrial applications has made these alloys the most preferred material after iron and steel [1].

Aluminum and its alloys are usually shaped by casting or forging. In some cases, several parts need to be joined later. The first thing that comes to mind in this case is the welding process, which provides a strong insoluble joint. However, the joint of aluminum or its alloys with traditional weldings can sometimes cause serious problems.

such as, in the joining of aluminum or its alloys with melt welding methods like electric arc welding, some defects such as porosity and crack formation in the weld center and the heat-affected region may be observed [2]. These defects in the welding of aluminium alloys are caused by oxidation of these materials as a result of high temperatures. In melt welding, these defects can be eliminated if the welding zone is controlled by protective gases such as argon. These processes lead to loss of time and cost. Therefore, in the 1990s, friction stir welding (FSW) was improved by the British welding industry to joint the material at a temperature below the melting temperature [3].

The FSW method is based on to plunge and advances, a pin with designed and shoulder, intended to be used an at high endurance alloys that are difficult to weld by traditional techniques, into plates that are mutually abutting along the line of joining. For the joining process, the plates to be joined are brought to a temperature below the melting temperature by means of a stirrer pin. Then, the plates are joined by the plastic deformation, as a result of travel of the pin along the weld line. In recent years, works on welding aluminium alloys by FSW method, which are difficult to welded by melting-based welding methods, have been increasing. Moreira et al. [4], examined the influences of joining methods on tensile strength, hardness and fatigue behavior in the joint two different aluminum alloys such as 6082-T6 and 6061-T6 with FSW and MIG welding methods. They correlated the mechanical behavior of welds with microstructure properties of welds. In welded joints, they indicated that the 6082-T6 alloy exhibited lower tensile strength and hardness than the 6061-T6 alloy. However, 6082-T6 alloy in the FSW method and 6061-T6 alloy in MIG method showed better fatigue behaviour. Çetkin et al. [5], studied the influenced of spindle speed, feed rate and agitator pin geometry on microstructure, hardness and, strengthes of tensile and fatigue in joining AA7075 and

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AA5182 aluminum alloys by FSW welding. In the experiments using stirrer pins with conical helical geometry, they indicated that welded joins joined with low rotation and feed values had the highest mechanical properties. They stated that the highest tensile and fatigue strengths were 265 MPa and 159 MPa, respectively. Elangovan et al. [6], researched the mechanical properties of AA6061 aluminum alloys joined at five different (800–1600 rpm) rotation speed parameters and different tool tip geometry such as flat cylindrical, tapered cylindrical, threaded cylindrical, triangular and square, using the FSW method. it was obtained the best tensile strength and hardness values in welded joints from a square geometric stirrer pin with a rotation speed of 1200 rpm. it was stated that this is due to the fine-grained structure formed in the welding zone.

Feng et al. [7] analyzed the microstructure of the welding region in the joint of the AA2219 alloy, whiche was welded by FSW. In addition, the influence of the rotation speed of the stirrer tip on the hardness in the welding region was determined. it was defined that welding's grain size is much smaller than the grain size of the alloy AA2219, but the hardness was lower than the hardness the welding. The microstructure analyze and mechanical properties of EN AW-5083-H321 aluminum sheets investigated by Taban and Kaluc (2006), which were joined by MIG, TIG and FSW methods. it was determined the hardness of the weld and the tensile strength and bending strength of the samples get from the welded sheet according to EN 895 and EN 910 standards. it was emphasized that FSW welded joints have higher and superior properties [8]. Mahoney et al. [9] investigated the microstructures of AA7075 alloy joined with the FSW method. it was observed that fine-grained structures were formed because of the welded joints took place under the alloy's melting temperature. Liu et al. [10] determined to ideal welding parameters in the joint of 2017-T351 aluminum alloy by FSW. it was observed that the tensile and fracture behavior of joinings were remarkably affected by FSW parameters.

When the studies on the FSW method were examined, some properties of the joined materials such as microstructure, microhardness, tensile strength were investigated. In addition, a few studies have been made regarding the fatigue behavior of FSW welding. However, the effects of welding parameters like tool geometry, rotation speed, and feed rate on the forces, vibrations, and temperature in FSW of Al alloys have not been made a comprehensive study. That's why, in this study the effect of stirrer pin geometry, rotation speed, and feed rate on the welding force, vibration, and temperature were investigated.

2. MATERIALS, FSW PARAMETERS AND PROCEDURES.

In this study using the FSW method, AA5182 alloy, which is widely used in the marine industry, has been chosen as the test material because of its corrosion resistant, high fatigue strength and cold formable properties. AA5182 alloy has 320 MPa tensile strength, 25% elongation, 69.6 GPa elastic modulus and 71 HV hardness value and its chemical composition was given in Table 1. As can be seen from Table 1, AA5182 alloy contains the most Mg element after Al element. This is the main feature of the AA5182 alloy.

Table 1. Chemical compositions of AA5182 aluminium alloy (% wt)

Mg	Cu	Cr	Fe	Si	Zn	Mn	Ti	Al
4.49	0.15	0.10	0.35	0.20	0.25	0.45	0.1	93.91

The AA5182 alloy material which was welded by the FSW was supplied commercially in dimensions 2100 mm x 1500 mm x 5 mm. later, the alloy material supplied was cut to dimensions of 170 mm x 120 mm x 5 mm by means of a plasma machine, taking into account the dynamometer (Kistler 9257 B) dimensions in order to calculate the welding forces during welding. In order to fix the alloying elements to the dynamometer, 2 holes were drilled on each welding sample with a 10 mm diameter drill. In addition, a 2 mm diameter and 2 mm depth guide hole was drilled at the welding start point of the alloy pair to provide the required frictional heat in the FSW process.

A dynamometer was mounted to a moulder milling table bearing the Smarc brand in order to perform the FSW procedure. To prevent the dynamometer from being harmed by heat, a 170 mm x 240 mm x 3 mm wooden plate was positioned between the alloy pair and the dynamometer. In addition, channels were opened on the surfaces of the wooden plate to place the thermocouple in the dimensions given in Figure 1.

A thermocouple was placed in the opened channels and the alloy pair to be joined was fixed. In order to monitor vibrations during welding, a dynamic signal acquisition device was mounted oon the parts to be joined. The axes of both the dynamometer and the vibration measuring device were positioned in the same direction. In figure 2 was given the experimental setup.

The stirrer tips for the FSW welding process were constructed of K100 steel and had triangular and conical geometries. The pin length and shoulder width of these pins are 4.2 mm and 20 mm, respectively. TFor better welding, these pins or milling heads must be angled. In our experimental study, the milling head angle was given 3° angle in accordance with the literature. In addition to the angle of the milling head, additional factors that affect welding quality include welding feed rate and tool rotation speed. For welding the aluminum alloy AA5182, three rotation speeds and two different feed rates were choosed. The parameters used in the welding process are given in table 2.

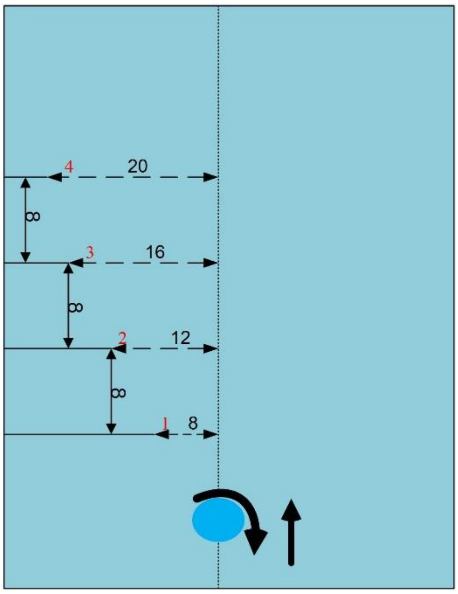
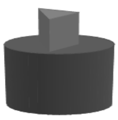
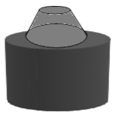


Figure 1. Thermocouple joints positions

Table 2. Parameters used in FSW of AA5182

Rotation speed, (rpm)	1000	1500	2000
Feed rate, (mm/min)	120	219	
Stirrer tip profile	 Triangular	 Conical	

After checking the parallelism of the stirring line with the joining line of the plates and adjusting the stirring tip to fit into the guide hole, the machine was run clockwise and the tool was plunged in the Z-direction part at a shoulder depth of 0.2 mm. The tool is held for about 45 seconds in this position to increase the temperature of the sample due to friction. After the temperature of the friction was obtained, the milling machine was allowed to advance along the joint line at the automatic feed rate and the welding process near the end of the plates was completed. for microstructure analysis of the welding joining were taken the samples from the weld region. The samples were analyzed by scanning electron microscopy (SEM). In addition, the hardness values of the weld zone were measured by Shimadzu HMV microhardness tester.

According to ASTM E8 standards tensile specimens were prepared to define the tensile strength of welded joints. Tensile tests were made on the SHMADZU tensile tester with a constant tensile speed of 1 mm / min. Tensile strengths were repeated 3 times in each parameter and average tensile strength was determined. Then, with these average values were obtained tensile force plots

Samples were cut in accordance with ASTM E466 standards in the welded plates in order to define fatigue strength. The cutting samples were carried out to fatigue test in Shimadzu brand fatigue tester. Tensile / tensile fatigue test was applied to the samples with amplitude ratio R = 0.1. Frequency for all experiments was determined as 10 Hz and made axial sinusoidal loading on all joins.

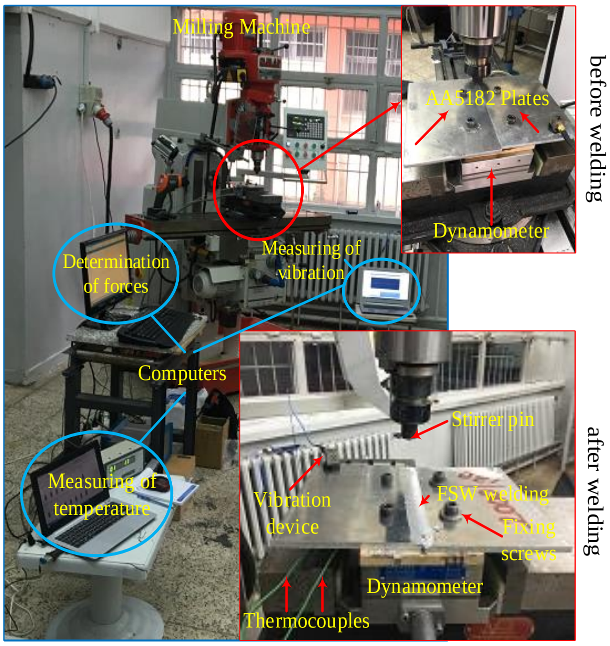


Figure 2. Experimental setup

3. RESULTS AND DISCUSSION

3.1. Welding Forces

The basic principle of welding with the FSW method is to provide that the friction temperature required for welding is formed by immersing the stirrer pin on the plate to be joined. When the stirring tip comes into contact with the material, forces are generated on the X, Y and Z axes. In order to determine the effect of these forces on welding quality, AA51852 alloy pairs were fixed to Kistler 9257 B dynamometer. Welding forces were measured depending on the welding parameters. The signals taken from the dynamometer during the experiment were transferred to the Kistler 5070A amplifier and then to the computer with DynoWare software and graphed. The forces generated in the AA5182 alloy pairs fixed with a rotation speed of 1000 rpm and a welding feed rate of 120 mm/min are given in Figure 3.

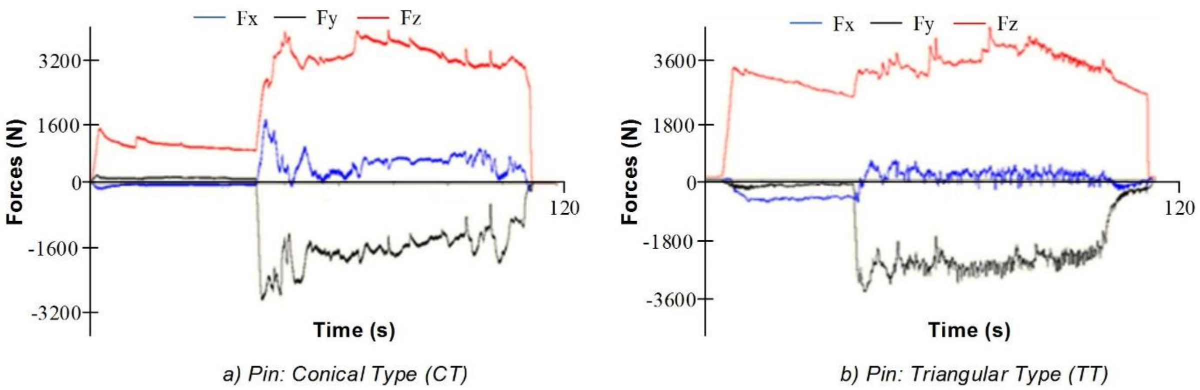


Figure 3. Variation of forces depending on the time in AA5182 alloy pairs joined by FSW

Figure 3 shows the force Fx in the normal direction, the force Fy in the direction of feed, and the force Fz in the radial direction. During the test, the force in the radial direction was increased to approximately 1600 N in the conical type (CT) stirring pin and about 3600 N in the triangular type (TT) stirring pin by immersion of the stirring tips in the alloy material. In some theoretical and numerical studies, it has been observed that radial force is quite large in FSW welding [11-12]. During the dwell time, the heat was generated due to friction and the radial force tended to fall. However, with the commencement of the welding process, the force in the direction of travel has increased in addition to the radial force. The force in the normal direction was partially increased. Radial forces during welding showed different behaviors including sudden increase and decrease. However, a partial decrease in the feed force has been observed. This was thought to be due to the tendency of the material to soften during welding. The forces in the direction Fx, Fy and Fz can be measured by replacing the forces in equation 1 with the welding force (F).

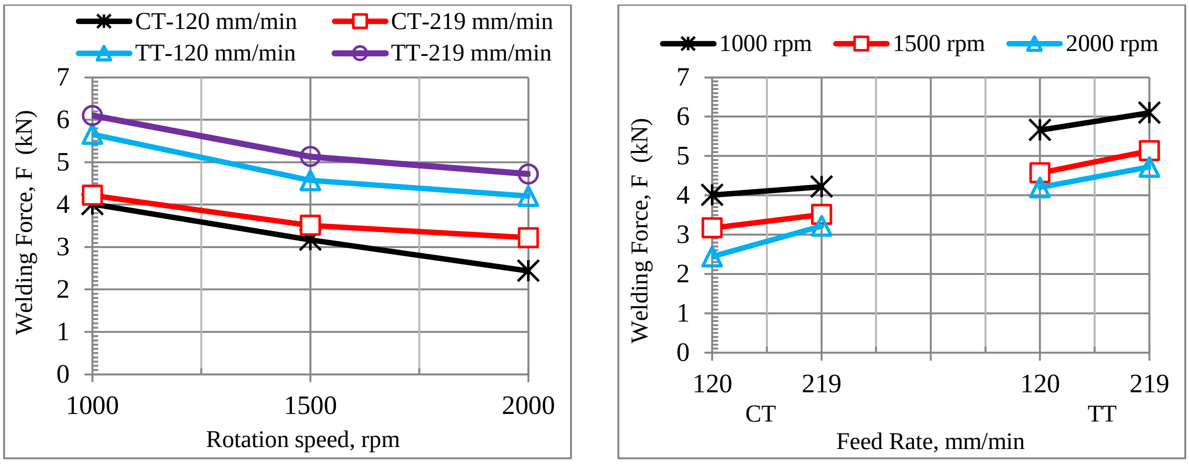
$$\mathrm{F} = \sqrt{Fx^2 + Fy^2 + Fz^2} \tag{1}$$

The welding force generated by welding parameters is given in Figure 4 depending on the rotation speed and feed rate.

In Figure 3, when the welding forces of the conical type (CT) and triangular type (TT) stirrers used in FSW method was analyzed, it was seen that the forces decrease with increasing rotation rotation speed for both stirrer tips. This was due to the increased friction as the rotation speed increases. Because at high friction, the material exhibits more softening behavior.

When Figure 4 was analyzed, it was seen that the welding forces formed during the welding process increase with increasing welding feed rate. The increased welding feed rate makes the stirrer pins move faster on the AA5182 alloy pair. This was due to the reduction of friction per unit time, which means that the heat generated was lower. Figure 4 also show that the TT stirrer tip produces higher welding forces than the CT stirrer tip. Due to the geometry of the TT stirrer tip, it was due to the fact that during the welding process the CT was forced more than the stirrer tip. Trimble et al. [13], stated that increasing the welding feed rate triggered an increase in the welding force, and also the welding forces changed significantly due to the stirrer pin geometry. Amini and Amiri proved that the stirrer pin geometry has an important effect on the welding forces by using four different stirring pins [14].

In experiments using CT stirrer pin, minimum welding force was resulted from max rotation speed and min feed rate, maximum welding force low rotation speed and high welding feed rate. The minimum and maximum values obtained were 2440.492 N and 4226.494 N, respectively. In the experiments using TT stirrer pin, minimum and maximum forces were obtained from the same welding parameters as 2647.3 N and 6090.8 N, respectively. The difference between the maximum and minimum welding forces was observed about 2 times.



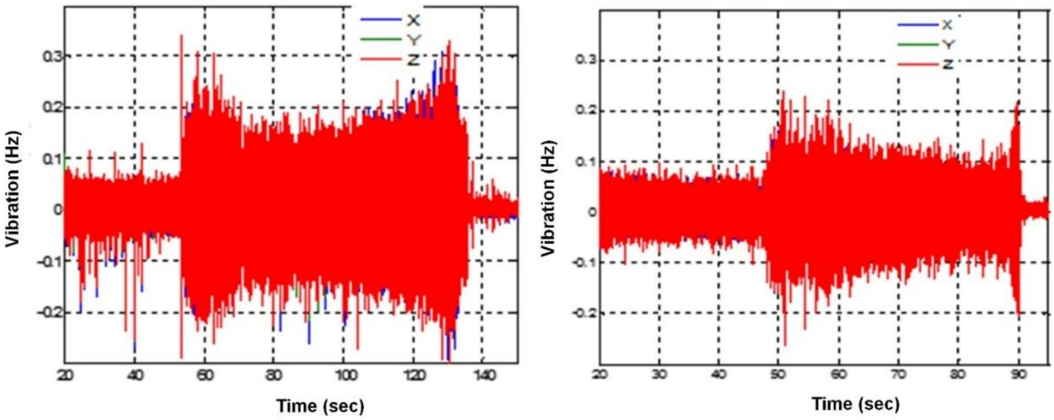
a- The effect of rotation speed on welding forces b- The effect of welding feed rate on welding forces

Figure 4. The effect of rotation speed and feed rate on welding forces

3.2. Welding Vibrations

Vibration affects the quality of the welding as well as the welding force during the welding with FSW method. Vibrations occur on the X, Y and Z axes when the stirring tip comes into contact with the material. Figure 5 shows the vibration amplitude values measured at rotation speed of 2000 rpm and two different feed rates using the conical stirrer tip.

When the vibration amplitude graphs were examined, the highest vibration amplitudes were obtained in the Z axis as well as the strength of the radial direction in the Z axis. Vibrations were also observed in X and Y axes. The vibration was suddenly increased when the stirrer pin plunged into the AA5182 alloy pair. When the welding process was finished, the vibration increases are observed again because the movement in both the direction of rotation and abruptly stops.

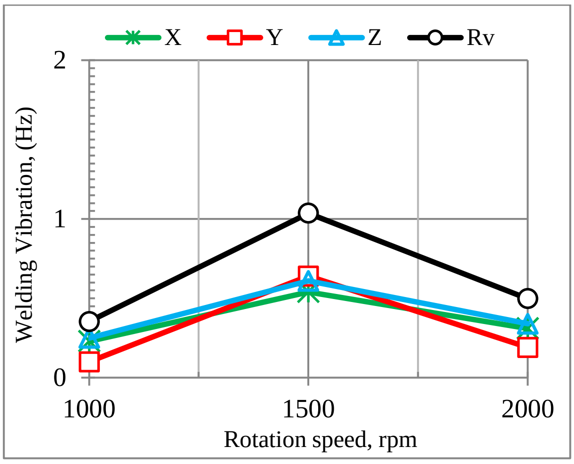


a) Welding feed: 120 mm/min b) Welding feed rate: 219 mm/min

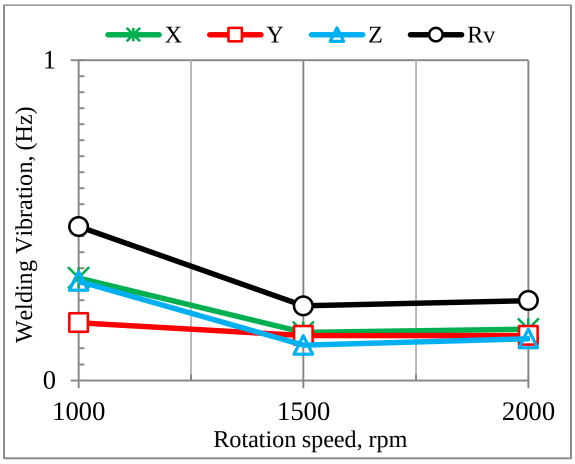
Figure 5. CT amplitude and vibration amplitudes for 2000-rpm rotation speed

As in welding force, heat has been generated due to friction during the dwell time and the amplitude of vibration has tended to decrease. The resultant vibration amplitude (Rv) can be calculated by replacing the vibration amplitude values that occur in X, Y and Z directions in equation 2. Vibration amplitudes due to welding parameters are given in Figure 6.

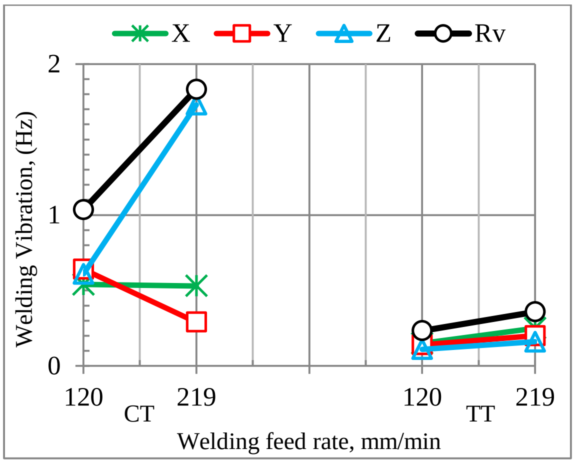
$$Rv = \sqrt{X^2 + Y^2 + Z^2} \qquad (2)$$



a) Pin type: CT, Welding feed rate: 120 mm/min



b) Pin type: TT, Welding feed rate: 120 mm/min



c) Rotation speed: 1500 rpm

Figure 6. The effect of welding feed rate on vibration

As shown in Figure 6. (a), the vibration increased when rotation speed raised from 1000 rpm to 1500 rpm, while vibration decreased when rotation speed raised from 1500 rpm to 2000 rpm in the FSW of AA 5182 made with CT stir pin. In FSW made using TT stirrer pin, the vibration was initially low and vibration increased with the rotation speed (Figure 6.b). When the vibration values given in Figure 6.c) were examined, the vibrations in the X, Y and Z axes increased with increasing welding feed rate in the joining operations with TT stir tip. In FSW with CT stir tip, vibration was constant in the X axis, decreased in the Y axis and increased in the Z axis. As a result, Rv increased with increasing welding feed rate on both stir pins. Less vibration was observed in joints with TT stirrer pins than joints with CT stirrer pins.

3.3. Welding Temperature

In FSW welding, the temperature is the most important parameter affecting welding forces, vibration and welding quality. The maximum temperature in the welding center decreases to the ambient temperature as it travels out of the welding center. Jain et al. [12], supported this by using the finite element approac, which examined the changing between forces and temperature in the FSW with Deform-3D. Temperature values measured according to welding parameters are given in Figure 7 for CT stirrer tip and Figure 8 for TT stirrer tip.

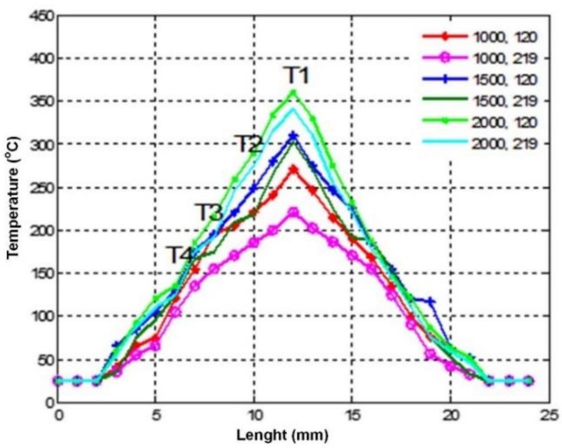


Figure 7. Temperature values measured in welds using CT stirrer tip

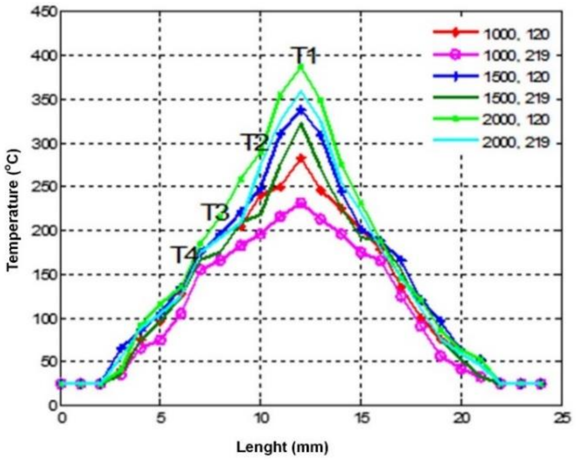


Figure 8. Temperature values measured in welds using TT stirrer tip

It was observed that the maximum temperatures measured in FSW joints with CT and TT stirrer tips varied from about 220 °C to 390 °C depending on the welding feed rate and rotation speed. The high temperature at both ends were The resulted from the max rotation speed and min feed rate where the rotation speed was 2000 rpm and the feed rate was 120 mm/min. The maximum temperature measured at the CT tip increased to 360 °C while the high temperature measured at the TT tip increased to 390 °C.

In max rotation speed and min feed rate, friction was greater as the stirring pins interact more with the AA5182 alloy pair. This increased the welding temperature. On the other hand, at lower rotation speed and higher feed rate values, less friction results in less temperature. In the low rotation speed and high feed rate, welding temperature was measured around 220 ° C. Lambiese et al. [15], have investigated the relationship between force and temperature at the friction stir welding of aluminum alloy AA6082-T6. They point out that rotation speed was an important factor in temperature formation and in parallel with our study, temperature increases with increasing rotation speed. However, in contrast to our study, it was stated that higher welding feed rate causes a higher temperature in the stirrered region. This was associated with contact pressure.

3.4. Macro and Micro-structures

In welding by FSW, the parameters there were a great effect on the joined alloy pairs. Because welding parameters affect the welding force, vibration and temperature. High force, high vibration and low temperature can adversely affect the welding zone. AA5182 alloy pairs were successfully welded by FSE method in different welding parameters. In Figure 9, the welded plate obtained from the welding process with the parameters CT-2000 rpm-120 mm/min and the tensile and microstructure samples cut from it was given. Microstructures was given in Figure 11 for different welding parameters where maximum and minimum force, vibration and temperature were obtained. Also, it was given XRD pattern of TT-2000 rpm- 120mm/min parameter in figure 10.

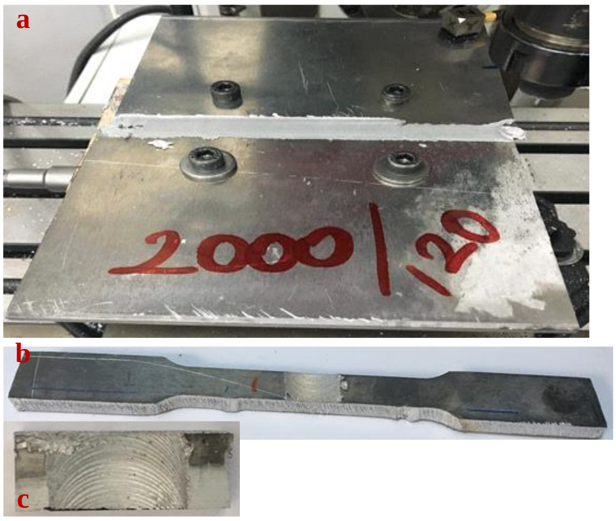


Figure 9. Tensile (b) and microstructure (c) samples cut from FSW welded AA5182 plates (a)

From the microstructure images, it was seen that a very good weld transition zone was formed in experiments using CT stir pin for 2000 rpm and 120 mm/min of parameters. However, the weld transition zone deteriorated for parameters low rotation speed and high feed rate. The worst transition zone was obtained in experiments using TT stirrer tip at 1000 rpm, 219 mm/min. This was an important effect of force, vibration and temperature. Because welding force and vibration were obtained higher at the TT stirrer tips. In Figure 11 (b), the presence of Al_3Mg_2 compound in the welding region was detected together with the XRD peak given in Figure 11. Wang et al. [16], Yıldırım and Özyürek [17] stated in their studies that Al-Mg compounds can be formed.

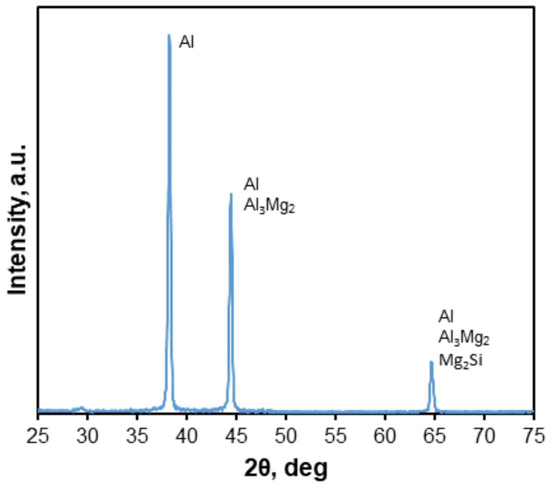
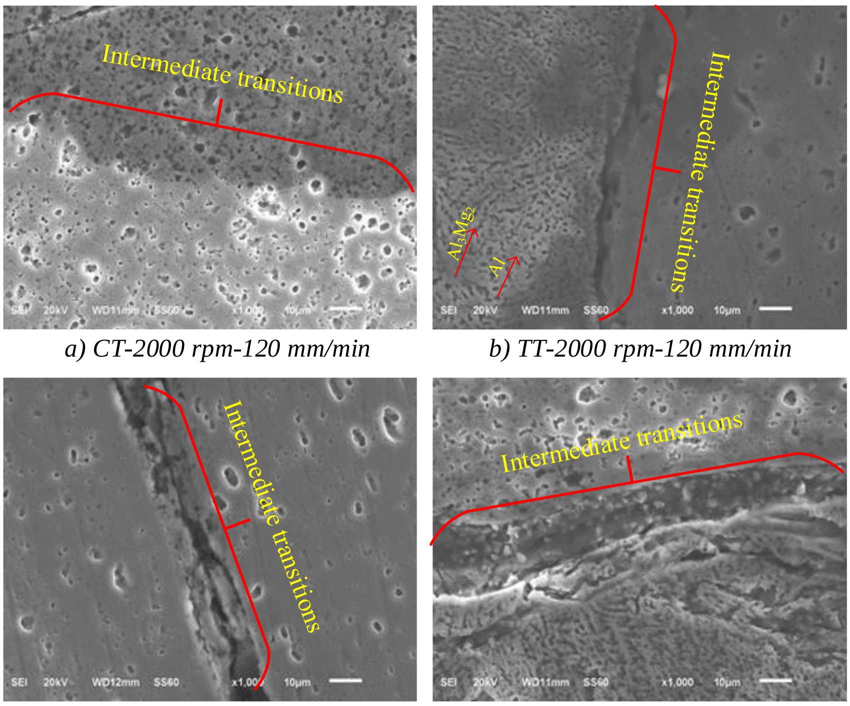


Figure 10. XRD pattern of TT-2000 rpm- 120mm/min parameter



a) CT-2000 rpm-120 mm/min *b) TT-2000 rpm-120 mm/min*

c) CT-1000 rpm-219 mm/min *d) TT-1000 rpm-219 mm/min*

Figure 11. Microstructures in welded AA5182 alloy pairs

3.5. Microhardness

The variation of hardness values of the AA5182 alloy pairs, which were joined in different welding parameters, under the heat affect zone (HAZ), under thermo-mechanical zone (TMAZ) and dynamic crystallization zone (DCZ), was given in Figure 12. The hardness of the AA5182 alloy was 71 HV, while the hardness of the HAZ, TMAZ region decreased. The hardness of the TDCZ zone was higher than the hardness of the MAZ zone. Although the hardness of the welding zone increases, it was lower than the hardness of the main alloy material. The low hardness in the DCZ zone was due to the fact that the plastic forming was hot due to the heat generated during welding. Although the grains in the microstructure grew in hot forming, hardness decreased. Sarsılmaz was stated that different hardness results occur between the parts joined with the weld metal. Indicated that one of the most crucial factors was the welding parameters chosen [18].

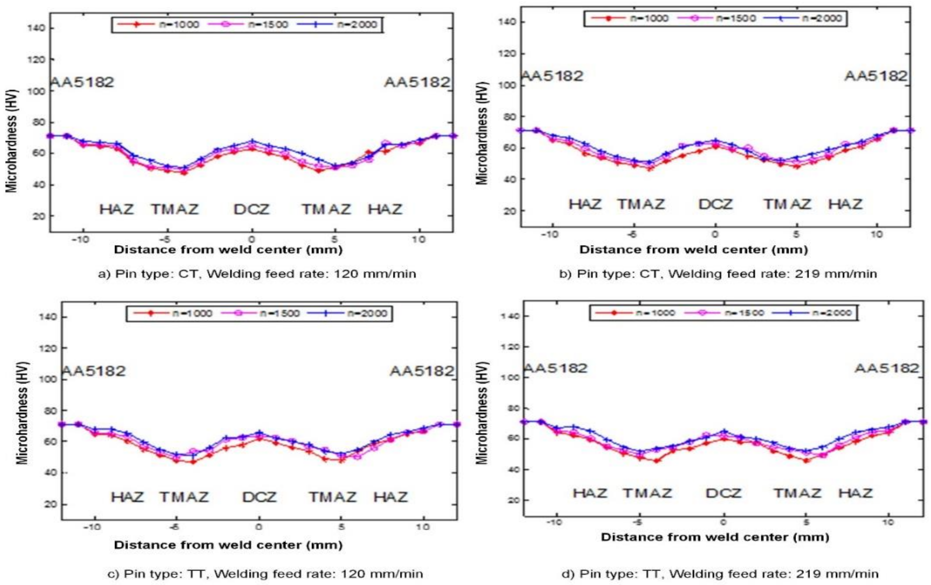


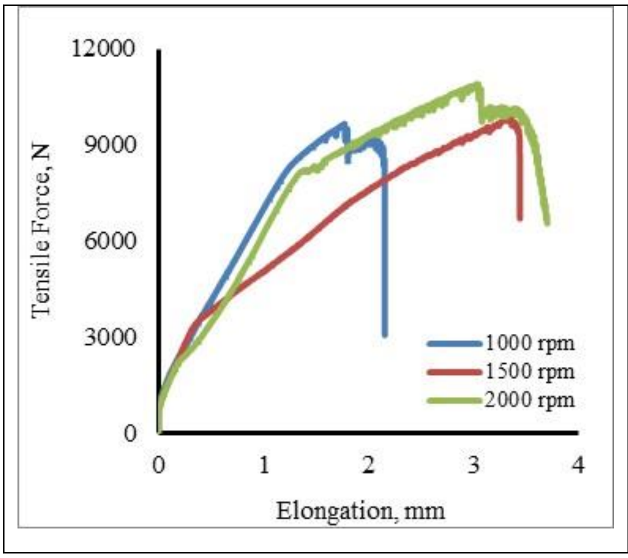
Figure 12. Variation of hardness in welded AA5182 alloy pairs by region

3.6. Tensile Tests

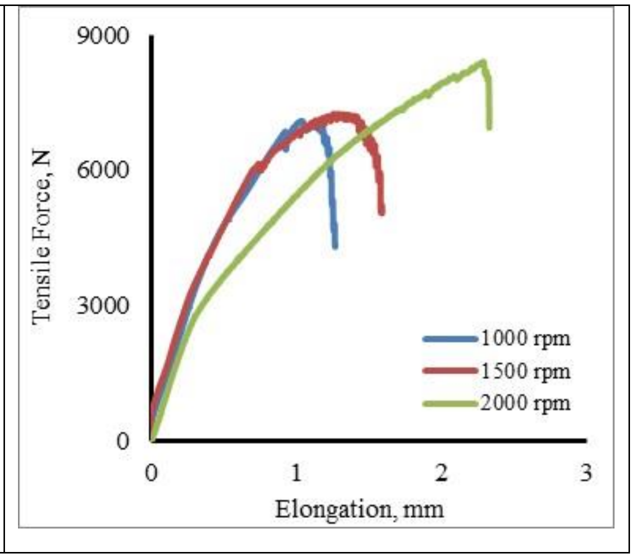
Tensile tests of AA5182 aluminum alloy pairs joined by FSW in different welding parameters were given in figure 13. The maximum tensile force was obtained for 2000 rpm rotation speed at the welded joints with both stir tips. As welding feed rate increased, the tensile force decreased. The tensile force of the welding with the conical pin was higher. At the joining with the CT stir pin and 120 mm/min, the tensile forces determined for 1000, 1500 and 2000 rpm were obtained 9664, 9854 and 10910 N, respectively. However, welded joints with a feed rate of 219 mm/min tensile forces are reduced. These values were obtained as 7098, 7262 and 8414 N, respectively feed rate of 120 mm/min were obtained as 7051, 7422 and 7543 N for the rotation speed of 1000, 1500 and 2000 rpm, respectively. For the welding feed rate of 219 mm/min the tensile forces are 6324, 6750 and 6988 N, respectively.

3.7. Fatigue Tests

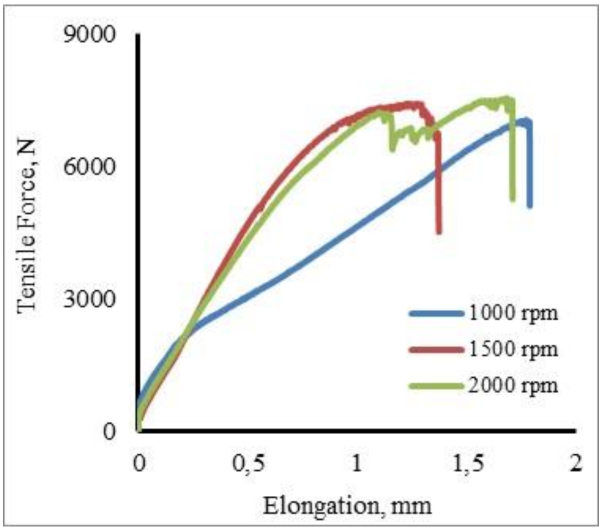
S/N graphs of welded joints joined with the lowest and highest rotation speeds was given in Figure 14 for the CT stirrer tip and in Figure 15 for the TT stirrer tip. The best fatigue strengths have been reported in circumstances where the rotation speed was high and the feed was low, similar to tensile tests. These values were 5500 N for CT



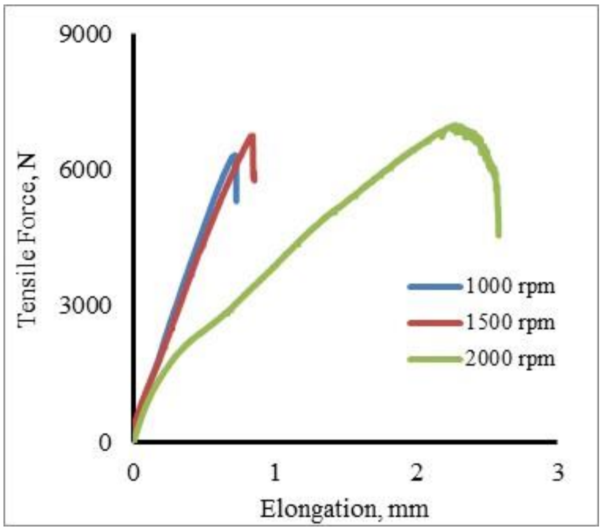
a) Pin type: CT, feed rate: 120 mm/min



b) Pin type: CT, feed rate: 219 mm/min



c) Pin type: TT, Welding feed rate: 120 mm/min



d) Pin type: TT, Welding feed rate: 219 mm/min

Figure 13. Variation of tensile forces due to welding parameters in welded AA5182 alloy pairs

When the tensile forces of the welded joints using TT pin were examined, the tensile forces of the welded joints made with 120 mm/min were higher than 219 mm/min, as in the welds using the CT pin. The tensile forces of the welded joints using the TT stirrer pin and welding and 4200 N for TT. Feed rate negatively affected fatigue strength. This was due to the tunnel voids of the microstructures in the weld transition zone of welded joints.

In particular, the welded joints joined with the welding feed rate of 219 mm/min and the rotation speeds of 1000 rpm and 2000 rpm, using both stirrer tips, have a low fatigue strength and close to one another. Similarly, Sarsilmaz et al. [19], stated that welding parameters such as stirrer tip and rotation speeds, and feed rates have significant effects on fatigue strength.

vibration amplitude increased when the rotation speed raised from 1000 rpm to 1500 rpm and decreased after 1500 rpm. However, in the TT stirrer pin, vibration amplitude first decreased, after remained constant with increasing rotation speed.

- ✓ When the feed rate has been increased, the temperature has decreased; welding forces and vibration have increased.

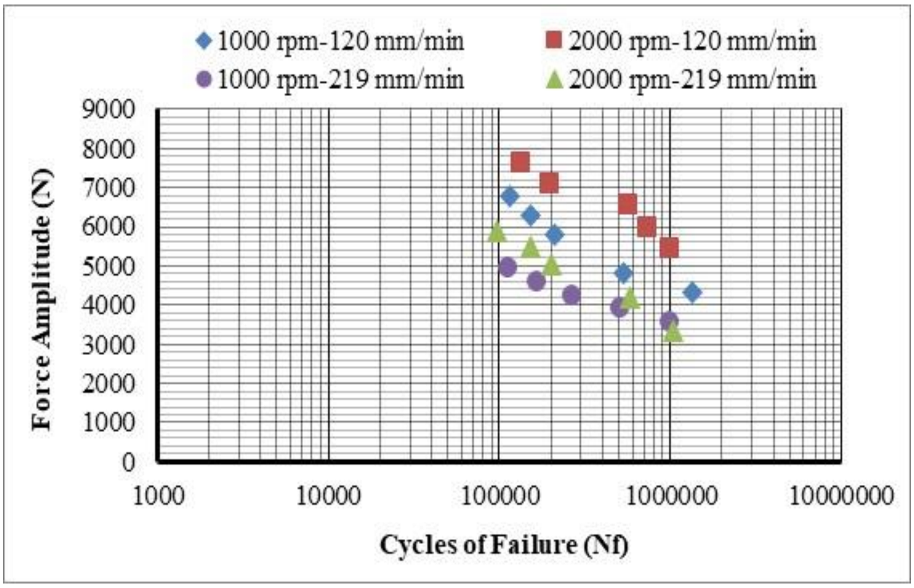


Figure 14. S / N graph of welded joints joined by CT stirrer tip

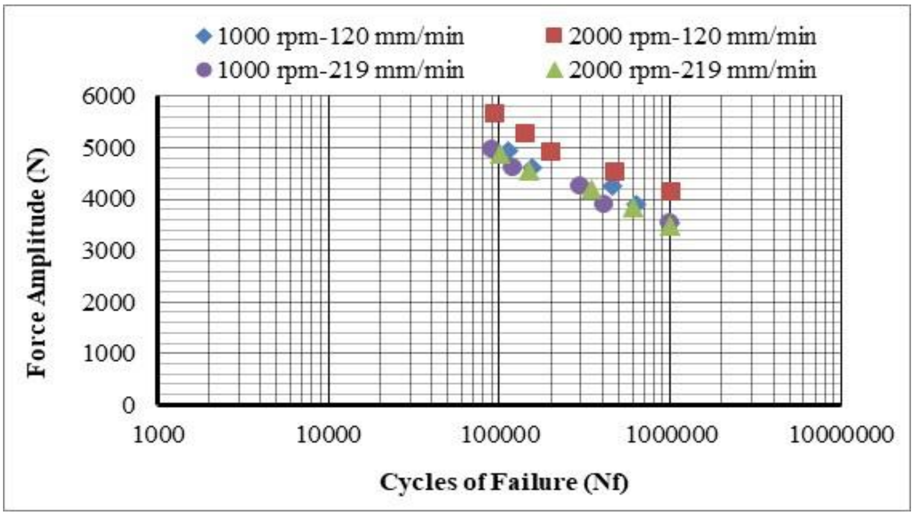


Figure 15. S / N graph of welded joints joined by TT stirrer tip

3. Conclusions.

AA5182 alloy were welded in different welding parameters by FSW method. Image analyzes and experimental tests were carried out to determine the microstructural and mechanical effects of the welding parameters on the connections. The results obtained are given below.

- ✓ With raising rotation speed, while the temperatures formed during welding increased, welding forces decreased. In the experiments using CT stirrer pins, the
- ✓ min feed rate and max rotation speed, high temperature, low vibration and forces occurred in the welding regions. High temperature, low force, and low vibration have contributed to occur fewer cavity damages in the microstructure.
- ✓ While from AA5182 alloy to toward the TMAZ region has decreases hardness values, to have starts to increase again from the TMAZ region to the DCZ region, and finally, the hardness in the DCZ region has been measured partially lower than from the hardness of the AA5182 alloy.

- ✓ The highest tensile and fatigue strengths have occurred the high rotation speed and low feed rates. The best tensile and fatigue force values have obtained from the CT stirrer pin have been 10910 N and 5500 N, respectively, while these values have 7543 N and 4200 N at the TT stirrer tip. The maximum tensile and fatigue strength values have obtained in the experiments using CT stirrer pin.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Edip ÇETKİN: Perofrmed the experiments and analyse the results.

Erol KILIÇKAP: Wrote the manuscript.

Yahya Hışman ÇELİK: Perofrmed the experiments and analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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