PROCESS SIGNAL RESPONSE OF JOINING THIN MATERIAL AA1100 USING BOBBIN FRICTION STIR WELDING TECHNIQUE

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ABSTRACT: There are limited investigations of welding thin material focusing on process signal response and relate it to the welding parameter especially the AA1100. The AA1100 is known as difficult to weld using the fusion method because high Aluminum content. In this study, a thin material of AA1100 was joint using bobbin friction stir welding. The range of rotational and welding speed parameters were 1500-1600 rpm and 150-210 mm/min, respectively. The runs were arranged based on response surface method Box-Behnken design. There were 13 runs were conducted. During the process, four responses were recorded that were temperature, vibration, current supply and force. The weld specimens were tested for tensile, microhardness and observed under the Scanning Electron Microscope. Based on the data recorded, it found that the high harness and tensile was produced by 1550 rpm and 180 mm/min of rotational and welding speed. The welding speed was an important parameter in bobbin friction stir welding technique due to the heat generated was controlled by the welding speed. It is also found that the optimum welding temperature lied within 20.2-30.9% of melting point for the high strength joint. A pattern of an increased trend on the current measurement and measurement can be observed at a tool entry, which a valuable data for further study of the process setting like rigidity.

KEYWORDS: *Friction Stir Welding; Bobbin Tool; Thin Material; Process Signal Response; Mechanical Testing*

1.0 INTRODUCTION

Friction Stir Welding (FSW) process is categorized as one of the solid-state processes. The mixture of the material is occurred by stirring process that heated up by the friction through a rotating tool on the material to be welded [1]. Esmaily et al. [2] mentioned that for FSW, bobbin tool is a better process. This process is called Bobbin Friction Stir welding (BFSW). The application of BFSW is an improved process due to the downforces that required in FSW is eliminated through the existence of two shoulders. The additional shoulder of bobbin tool develops full penetrate weld that provides an advantage to the product to be welded by eliminating the root flaws defect [3]. In BFSW, rotational speed (ω) and welding speed (ν) is the process parameters that most important besides the tool design. It was mentioned by Arora et al. [4] that by having the additional shoulder, bobbin tool has an advantage in term of heat generation. However, Marie et al. [3] found that this process is more suitable in the application for medium and thick material compared to the thin material.

Colligan et al. [5] believed that there are higher difficulties experienced in joining thin material using the BFSW technique. It was supported by Wan et al. [6] that the difficulties are due to the material that easy to be teared, deformed and distort. During the process, the material flow is important to make sure joint can be formed in preventing non-uniform stress-strain fields and distortion. Proper setup in term of parameter selection, tool features and rigidity of the fixturing need to be closed monitored. By applying bobbin tool, an approximately symmetrical microstructure is created on top and bottom surfaces that known as hourglass pattern [7]. Mirzaei et al. [8] stated that the movement of the material is from advancing side (AS) toward the retreating side (RS) known at the stirred zone which influenced by the tool features. High heat generation when using bobbin tool opens the process for fast travel speed and low spindle speed. Therefore, to understand the influence of the process parameter in joining thin material using, the BFSW technique is adopted in this study. The lack of the study that focusing on joining thin material and process signal support the needs of this study.

Various respond data were recorded for the basis of process signal of joining thin material using the BFSW technique. The recorded data are analyzed based on 3 main areas which are at the entry (EN), middle (MD) and exit (EX) area of the welded part. By investigating the result for EN, MD and EX, it is believed to contribute new knowledge regarding the influence of process parameter in joining thin material using BFSW technique.

2.0 EXPERIMENTAL PROCEDURE

2.1 Design of Bobbin Tool and Features

Figure 1 shows the fixed bobbin tool design while Table 1 represents the dimensions of the tool used in this experiment. H13 tool steel was selected as the material for the tool. The tool features were a pin with a thread along with the top and bottom shoulders having a convex angle.

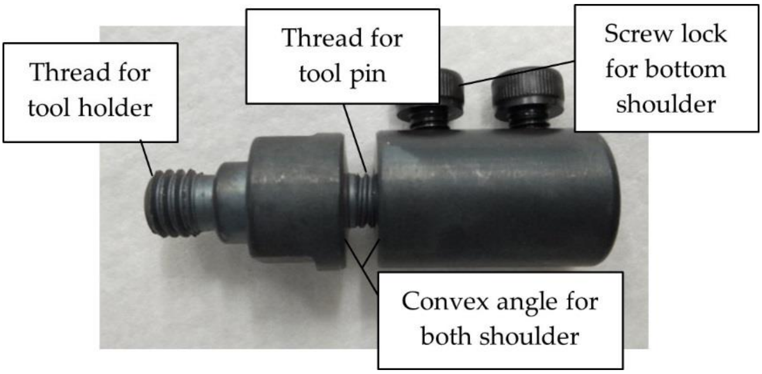


Figure 1: Bobbin tool used for experimental test

Table 1: Dimensions of bobbin tool

Parts	Dimension (mm)
Shoulder diameter	20
Distance between shoulder	2.89 (96.25% from plate thickness)
Angle of convex shoulder	5°
Length of upper shoulder	12
Length of bottom shoulder	30
Pin diameter (feature)	9 (clockwise thread)

2.2 Process Parameter and Material Selection

Aluminium Alloy 1100 (AA1100) series was used as a main material with 3 mm of thickness. This material categorized as thin material since it is below 6 mm [6]. A set of process parameters selected was in the range of 1500-1600 rpm for rotational speed and 150-210 mm/min for welding speed. This range of parameters was selected based on previous pilot test conducted in identifying a suitable range of parameters for joining thin material.

Table 2 shows the set of parameters used for this study. Total of 13 runs were arranged using Box-Behnken design were conducted during the study.

Table 2: Set of parameters with the range of both parameters, rotational and welding speeds

Std Run	Rotational Speed, rpm	Welding Speed, mm/min
1	1500	150
2	1600	150
3	1500	210
4	1600	210
5	1500	180
6	1600	180
7	1550	150
8	1550	210
9	1550	180
10	1550	180
11	1550	180
12	1550	180
13	1550	180

For the welding process, the material was rigidly fixed on a fixture, thermocouples were set on the plate, vibration meter on the fixture, current clamp meter was clamped at the current supply of the spindle motor, and a dynamometer beneath the fixture for force measurement. The tool was rotated clockwise through the material that was set using a butt weld setting. The tool stays in the entry area for 15 s. This is known as a dwell time. For thermocouple, 8 positions were used to record temperatures during the process whereby 4 positions on each side (AS and RS). Figure 2 shows the setup of the material with the tool rotation direction and the location of the thermocouple during the process.

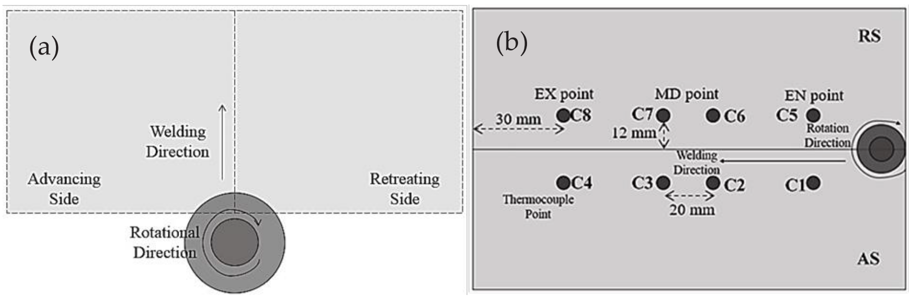


Figure 2: Process setup with (a) rotational direction, ω is clockwise during the process and (b) location of thermocouple along the welding path

2.3 Approach for Tensile and Microhardness Testing

Figure 3 shows the arrangement of the specimens used for tensile and microhardness test taken from the welded part, following ASTM-E8. Then, a 0.025 kg load was applied to the microhardness testing. Microhardness samples, then polished by following 8 steps of grit paper started from the grit paper type of #240, #320, #400, #600, #800, #1200 and the polishing paste (0.3 μm and 0.05 μm alumina). The scanning electron microscope (SEM) machine then was used for analyzing the images of microstructure at the weld area.

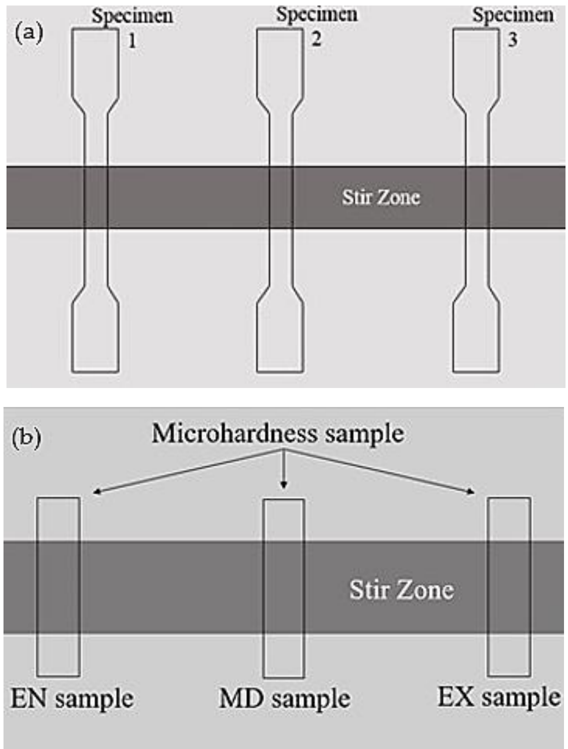


Figure 3: Arrangement of the specimens from the welded part using BFSW technique: (a) tensile specimens and (b) microhardness specimens

3.0 RESULTS AND DISCUSSION

3.1 Tensile and Microhardness Analysis at EN, MD and EX

Table 3 represents the average of tensile result obtained from three distinguished areas which are EN, MD and EX. While Table 4 represents the average of microhardness result. For tensile result, the spread of data is not consistent which sometimes MD is greater than

EN. Meanwhile for microhardness result, the decreasing of data is obtained when the EN is better compared to MD and EX. It shows that different process parameters resulting different strength of joining. The reason is that the amount of heat generated during the process that related to the spindle and welding speed. It is believed that the welding speed contributed to the heat dissipation while spindle speed plays the main role of heat generation.

Table 3: Average of tensile result for each specimen at EN, MD and EX

Std. Run	Avg. Entry (EN), N/mm^2	Avg. Middle (MD), N/mm^2	Avg. Exit (EX), N/mm^2
1	110.1936	105.266	108.4286
2	113.2936	104.926	108.9784
3	114.5006	111.26	115.6901
4	111.4041	112.901	111.0972
5	109.7264	111.787	100.7182
6	109.6697	111.297	109.9531
7	114.8796	109.383	108.7285
8	116.1901	113.197	93.8554
9	114.4831	115.097	111.7972
10	76.5564	112.105	83.7258
11	115.5726	114.997	109.7285
12	100.8505	111.701	81.3493
13	124.1433	109.506	80.8405

Table 4: Average of microhardness result at EN, MD and EX

Std. Run	Avg. Entry (EN), HVa	Avg. Middle (MD), HVa	Avg. Exit (EX), HVa
1	37.8	36.5	35.9
2	37.5	36.6	35.3
3	38.1	37.1	36.9
4	37.8	37.2	35.0
5	37.2	36.8	35.0
6	37.6	36.9	36.3
7	38.2	37.7	36.6
8	38.4	37.9	35.0
9	38.7	38.4	36.0
10	38.6	38.3	36.5
11	38.5	38.1	35.4
12	38.5	38.2	37.1
13	39.4	38.0	36.5

From the observation of tensile test result, it is found that the fracture occurred at the AS of the joined area. Esmaily et al. [9] mentioned that AS is normally having the weakest strength. This is because, the movement of the material from AS to the RS resulting the joint of the particles at AS is lower compared to the RS. Material is more packed at the RS area. Furthermore, greater heat generated causing decrease strength of the joining material. This is supported by Abrahams et al. [10] that by increasing the welding speed, it would improve the microhardness strength. It is believed that due to the increasing of welding speed can limit the heat absorption. If the temperature is high, the material tends to easily soften and grain growth occurs. However, low heat formation minimizing grain growth that reduces the impact of hardness and strength.

3.2 Process Response Focusing on Temperature, Vibration, Current and Force

Figure 4 shows the temperature plotting that measured during the welding process. It shows channels 1-4 are for the temperature at AS area while channels 5-8 are at RS area. It was clearly found that the temperature at AS is higher than RS. It is also found that during the initial of the process, the highest temperature was achieved. This is because the material travel from AS to RS; a new fresh material is stirred which still in a solid state condition. Hence, in preventing high impact on the pin of the tool, 15 s of dwell time is applied which also contributed to the heat formation. This is important for the material readiness by weakening the bonds before easing the plasticizing phase

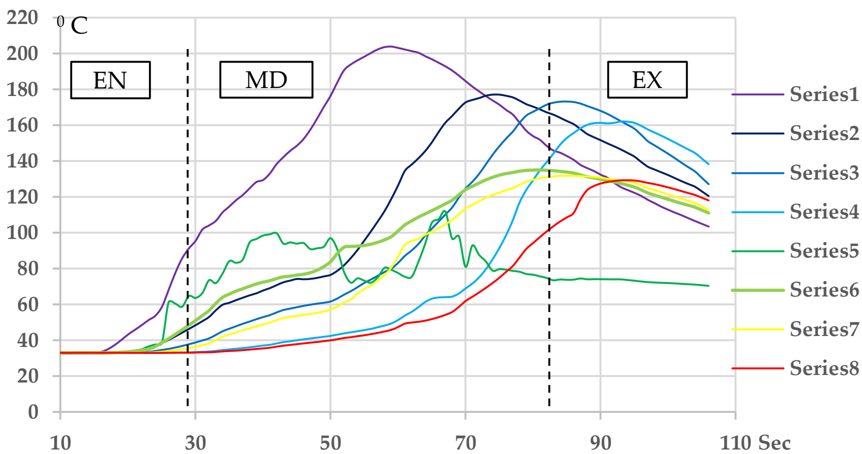


Figure 4: Temperature recorded along the weld process for EN, MD and EX

Figure 5 shows the vibration data obtained during the process. It is observed that when the tool enters the material, high vibration is occurred. It was mentioned that tool is distorted and tilted because of solid material of the tool meeting the solid material to be welded hence thermomechanical stress occurred on the tool, resulting higher vibration observed during welding [12]. At EN, higher vibration is recorded due to the material is still hard and the stirring just started to generate the heat, hence the material readiness is not yet at optimum condition. This is also agreed by Lorrain et al. [13] that stated the material at AS is being force at the entry of the BFSW process. It is also observed that, at high frequency vibration, defects such as tunnel and void can be observed on the weld area after the post-weld inspection.

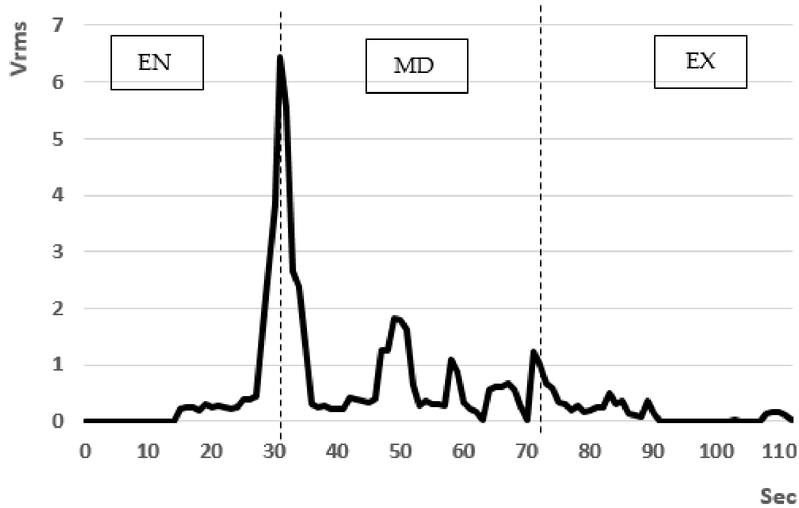


Figure 5: The vibration along the welding process at EN, MD and EX

Figure 6 shows the current supply data obtained during the process. At the entry, high and fluctuating current is observed. This is due to the machine to ensure the tool able to enter and stirred the material to be welded. Then, a constant current supplied pattern is observed. This shows that optimum power required is achieved to stir the material and appropriate heat has been generated in the process. However, mentioned by Jaber et al. [14], due to the higher vibration during process, it distracted the current provided to the machine by reducing the torque and motor speed of the machine, hence, fluctuation of current can be seen.

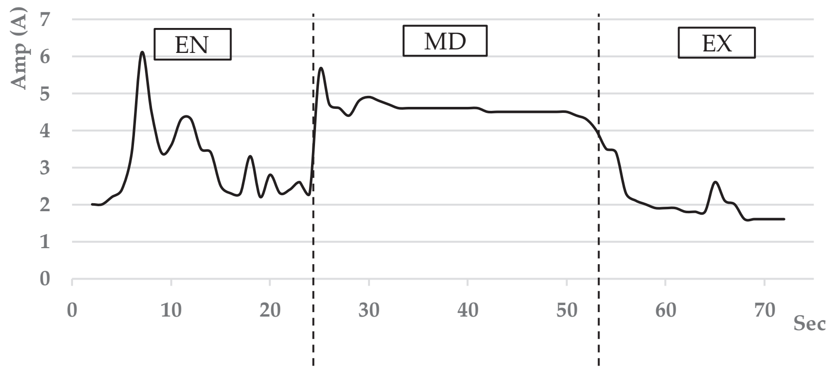


Figure 6: The recorded current along the joining process of BFSW technique at EN, MD and EX

Figure 7 shows the force measurement obtained by the dynamometer. Similar to current and vibration it is found that higher force is measured. Although high force at the initial of the process, Chikamhi et al. [15] mentioned that the equal and opposite axial forces is cancel out to each other and known that near to zero force. Therefore, a fluctuating force at X, Y and Z axes can be found. Threadgill et al. [16] mentioned that the magnitude of the force is depends on the type and material thickness.

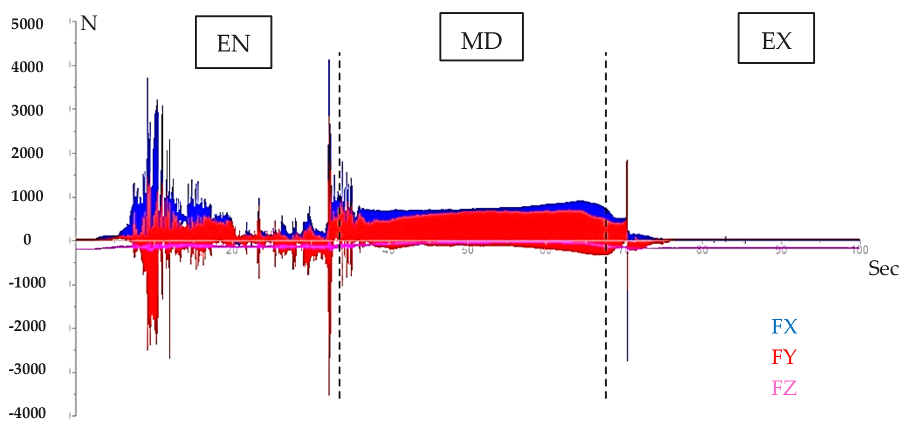
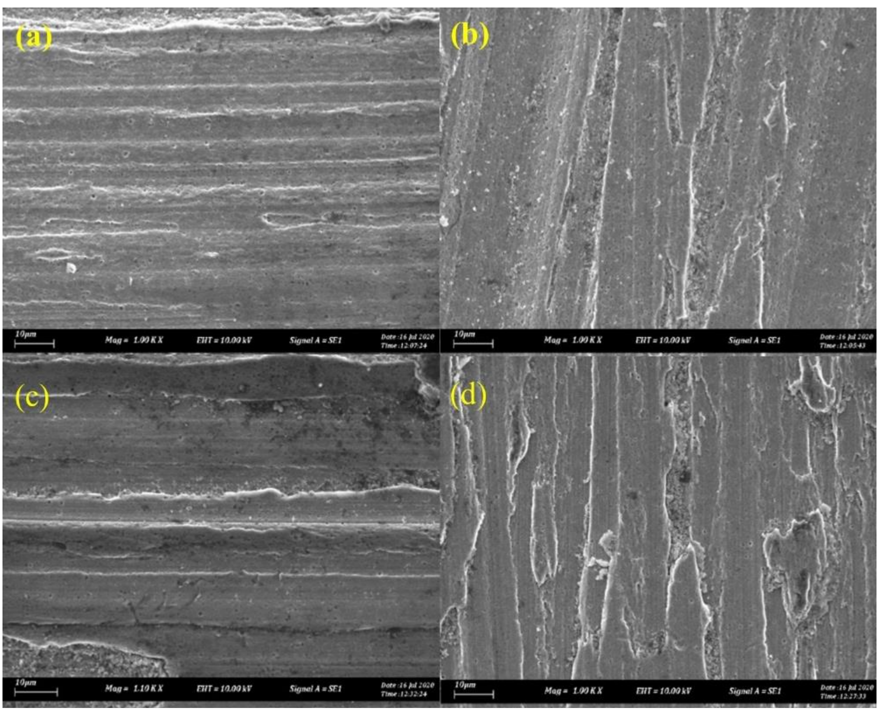


Figure 7: The force measured at EN, MD and EX during the joining process

The amount of heat generated is important because it provided a huge contribution in producing a good quality of joining. As the melting point of AA1100 is 643-657.2 ˚C, the welding temperature to obtain a good quality of joining is around 20.2-30.9% of the melting point that based on temperature measurement. Vibration and rigidity during the process is the consequence from the heat generated during the process. Higher vibration can cause the defects at the weld area.

3.3 Microstructure Analysis of Stir Zone and Heat Affected Zone Area at EN, MD and EX

Figure 8 depicts the cross-sectioned of the Stir Zone (SZ) and Heat Affected Zone (HAZ) for each area which are at the EN, MD, and EX. According to the figure obtained, it is clearly found that material orientation is changed between SZ and the HAZ area. This is belief because of threaded pin which is pulling the material. The thread at the pin tool is important for material transportation and improving material flow as mentioned by Da Silva et al. [17]. Moreover, it is found that the grain size is not similar between each EN, MD, and EX. At EN, the elongated grain is thin. This is due to the room temperature of the parent material at the initial of the process. It is observed that the grain size grows bigger towards exit because the material expose to the heat the longest. AA1100 consists of FCC structure, which the material is easily to plastically deform if experience higher heat during the process, whereby large uniform grain affecting the strength of the joint [18]. In term of welding zone, it also found that the grain growth at the HAZ is the biggest. The grain size obtained at the HAZ, shows that the temperature expose is longer as the heat dissipate that affecting weld strength [19-20].



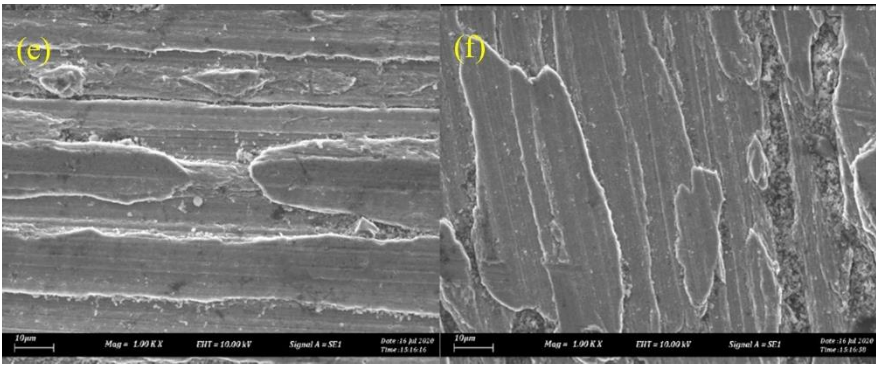


Figure 8: Microstructure of the cross-sectioned specimens: (a) SZ of the EN, (b) HAZ of the EN, (c) SZ of the MD, (d) HAZ of the MD, (e) SZ of the EX and (f) HAZ of the EX

4.0 CONCLUSION

This study has focused on the influence of the process parameter which are the rotational and welding speed towards the joining of thin material AA1100 using BFSW technique and it processes signal output. Therefore, the following conclusions have been made:

i. By applying a suitable welding speed, the heat generated during the process can be controlled to enhance the strength of the joint.
ii. Welding temperature to produce the best quality of joint of thin AA1100 plate is in the range of 20.2-30.9% of melting point. If the welding temperature is less or exceed the range given, it may cause defects and decrease the strength of the joint.
iii. Each of the response which are temperature, vibration, current, and force during the process is important data that can be used to trigger the quality of joint to be produced.

Further study regarding the heat management after the process can be carried out to reduce the grain growth at the HAZ area that occurred due to the heat generated during the process.

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