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Effect of traverse speed on three-point bending behavior and surface quality of AA5083-H111 friction stir welds

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ABSTRACT

The FSW was developed to obtain a good joint in terms of surface quality, mechanical property and microhardness in aluminum and other alloy systems. This study investigates the effect of traverse speed on the three-point bending behavior and surface quality of friction stir welds in AA5083-H111 aluminum alloy by using with different parameters such as weld speeds (16, 20, 25, 30, 40, 50 and 63 mm/min) while maintaining constant rotational speed (1400 rpm) and tool geometry. The resulting welds were subjected to three-point bending tests to evaluate their mechanical performance, specifically focusing on yield strength, ultimate tensile strength, and ductility. Additionally, the investigation includes macrostructure, microhardness, and fracture toughness evaluations. The findings indicated that an augmentation in traverse speed led to elevated tensile strength and hardness levels due to enhanced material flow and bonding, while higher speeds led to increased surface roughness and reduced weld integrity. The study suggests that superior joints with favorable mechanical properties can be achieved by utilizing an intermediate rotational speed of 1400 rpm and a traverse speed of 20 mm/min.

KEYWORDS

friction stir welding • surface roughness • aluminum 5083H111 • parameters • bending test

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Introduction

Friction stir welding (FSW) is a recently invented solid state welding process, especially for aerospace or aeronautics applications and for welding of large tank for launch vehicles involving aluminum alloys [1,2]. In many industrial programs steels are conveniently replaced by non-ferrous alloys, in most cases using aluminum alloys, the joining of those materials can occasionally cause serious problems [3]. Various joint configurations can also be assembled by FSW process like lap, but T joint which gave wide use for technology [4,5]. Tool geometry, rotating speed and welding speed among the factors influenced on quality joint welded by FSW [6]. In one study, increasing the rotational speed results in an increase in the peak temperature, leading to the expansion of the nugget zone (NZ) and the softened region within the joint [7]. Raj Kumar et al. [8] studied the influence of post-weld heat treatments (PWHT) on friction stir welded joints of AA2014 and AA7075 dissimilar alloys, such as PWHT conditions, namely artificial aging (AA), solution treatment and artificial aging, solution treatment (ST), and natural aging (NA). The study revealed that natural aging showed the best strength of 347.5 ± 7.78 MPa among all the PWHT conditions and that in other PWHT welds, fractures occurred outside the weld region. Saravanakumar et al. [9] recommends that the nugget zone (NZ) exhibits recrystallized fine grains with an equiaxed structure as a result of dynamic recrystallization (DRX), resulting in improved mechanical properties of the joint.

AA5083-H111 is a high-strength magnesium alloy primarily composed of aluminum. This alloy is commonly used in various applications (marine, shipbuilding, aerospace and automotive industry due to its favorable combination of properties, including excellent corrosion resistance, good weldability, and high strength.

Bending in friction stir welding (FSW) refers to the effect of bending on the strength and microstructure of the welded materials. Several studies have investigated the impact of bending on FSW joints, and the result varied depending on the welding conditions [10–12]. Saravanakumar et al. [13] studied that the mechanical properties of the AA5083 UWFSW joint, such as its average ultimate tensile strength and hardness, have been greatly improved using a straight hexagonal tool profile, tool rotational speed of 1200 rpm and welding speed of 20 and 40 mm/min.

For better understand the phenomenon of FSW and the impact of process parameter on welded joint, depth research was investigated on microhardness and surface roughness of joint. Sumit et al. [14] used three passes on the FSW of AA5083 and 6082 dissimilar joints and the observed that FSWeld reinforced joint exhibited the highest tensile strength, strain (%), and microhardness due to higher grain refinement. Xu et al. [15] conducted a study on the microhardness of friction stir welded (FSW) joints in different plate thicknesses of AA2219-O aluminum alloy. Oluwaseun et al. [16] suggests that understanding the effect of microstructure and defects on FSW joint failure will facilitate optimization of process variables, weld quality assurance and decision making. They found that the maximum hardness was on the advanced side of the nugget, and the upper part of the weld joint was harder than the bottom in the nugget due to the high temperature and intense mechanical agitation [15,16]. Miloudi et al. [17] found that decrease in rotation speed leads to better hardness quality of AA3003 aluminum alloy welded joint. In [18], it was mentioned that the surface roughness (R_a) of the welded area is influenced by the rotational speed of the tool, with higher tool rotary speeds resulting in decreased surface roughness. Optimizing the welding parameters can lead to improved surface roughness of FSW joints, enhancing their functional properties and durability. In a study [19], the effect of welding parameters on mechanical properties and fracture behavior of FSW for aluminum alloy 5083 H111, a joint coefficient C_j is evaluated for the qualification of the good mechanical strength of welded joints.

This study contributes to the growing research focused on optimizing friction stir welding parameters for superior joint quality and mechanical properties (tensile, hardness). The impact of the shoulder's side surface on heat generation is also taken into account.The research investigates the effect of various processing parameters(rotating speed, welding speed, dwell time) on the quality and mechanical properties of joints made by FSW using AA5083 aluminum alloy. In addition to optimize the FSW parameters which will led to significant improvements in the mechanical properties of aluminum alloy welds, making it a promising technique for various industrial applications.

Materials and Methods

AA 5083H111 alloy of 5 mm thickness was used. Samples were cut according to the shape shown in Fig. 1. The samples of the three-point bending test were chosen (as GB/T 232-999 standard). The external sheets were welded parallel to the rolling direction while the central sheet was put in the long transverse direction for FSW process in order to limit potential effect of rolling texture. The chemical composition of the aluminum 5083H111 sheet is presented in Table 1 and the mechanical properties of the sheets are presented in Table 2. The chemical composition was obtained by SEM-EDX (scanning electron microscopy-energy dispersive X-ray analysis) method [19].

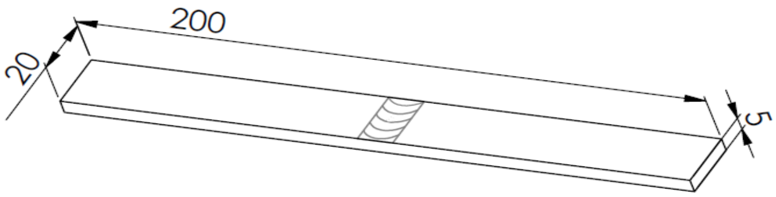

Fig. 1. Geometry of three-point bending specimen

Table 1. Chemical composition of 5083 H111 aluminum alloy (BM)

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.50	0.40	0.40	0.10	0.10	4.90	0.25	0.25	0.15

Table 2. Mechanical properties of 5083 H111 aluminum alloy

E, MPa	*YS*, MPa	*UTS*, MPa	*A*, %	*K*, J/cm^2	HV
71008	155	236	16.5	45	88

Fig. 2. Profil of tool used for FSW

Fig. 3. Vertical milling machine

The welding tool used for the joint is made of steel type 42CrMo4 (Fig. 2), it has the mechanical properties (R = 750/1300 MPa, A = 10–14 %, R_e = 500/900 MPa and E = 210000 MPa), a threaded cylindrical pin (5 mm in diameter and 4.7 mm in length) and shoulder (20 mm diameter). This selection of material was also motivated by cost and availability. The geometry of the tool, including the pin and shoulder design, significantly affects the material flow and heat distribution and, consequently, the distribution of hardness in the weld zones.

A vertical milling machine was used for the production of the joints. It is characterized by: a power of 5 KW,a rotation speed range of 45 to 2000 rpm and a range of feed speeds from 16 to 800 mm/min. The fixture was first fixed on the machine bed with help of clamps . The plates were held in the fixture properly for friction stir welding as shown in Fig. 3.

Welds by FSW was conducted at selected a constatnt rotation speeds of 1400 rpm and selected travel speeds of 16, 20, 25, 30, 40, 50 and 63 mm/min. An example photo of the joints produced with the different used welding speed is presented in Fig. 4. After the FSW welding process, the tensile test were carried out on an CONTROLAB bending machine, as shown in Fig. 5. The hardness on the weld cross-section was measured point wise for each specimen with a load 1000 g and a dwell time of 10 s.The surface quality of the FSW sample was obtained by the arithmetic average roughness value (R_a) using a Mututiyo surf test sv-400 roughness meter.

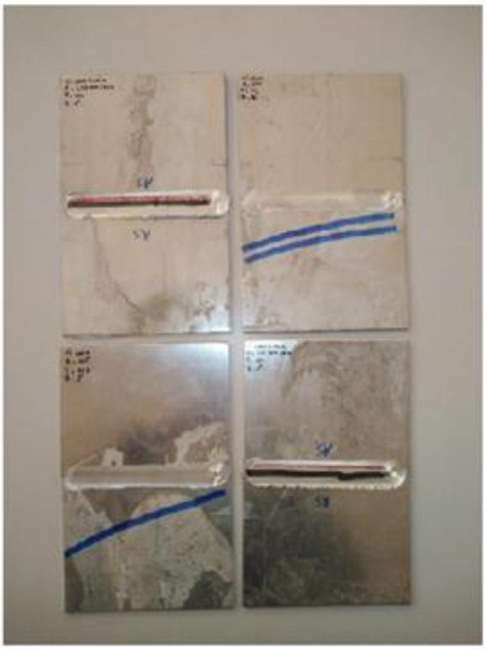

Fig. 4. Example of welded joints obtained with different welding speed

Fig. 5. Testing machine CONTROLAB and specimen for three-point bending test

Results and Discussions

Effect of welding speed on surface roughness

Figure 6 shows the effect of welding speed on the quality of the joint measuring by arithmetic average roughness value (R_a). An increase in welding speed effect directly the increase of surface roughness of the joint. Reducing surface roughness can lead to improved corrosion resistance, better mechanical properties, and enhanced aesthetics.

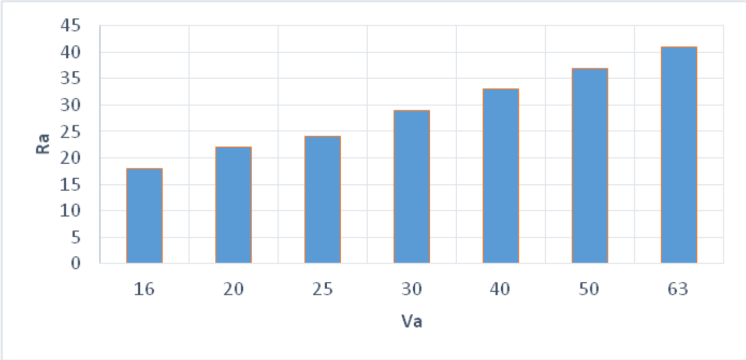

Fig. 6. Surface roughness of different welding parameter

The result of each specimen show that the highest value of surface roughness obtained at 1400 rpm of rotational speed and when we increase welding speed at 63 mm/min which is 41 μm, however, lowest surface roughness of 18 μm was obtained at 1400 rpm and feed rate of 16 mm/min. R. Kumar et al. [20] observed that value of surface roughness increase when they increase welding speed. However, in [21,22], another study surface roughness decreases when we decrease welding speed.

Microhardness measurements

In the majority of welds made, it was found that there was significant hardness variation in the weld zones in AA5083-H111 FSWeld joints, as shown in Fig. 7. The cylindrical pin achieved symmetrical hardness distribution with regard to the center line of the FSW keyhole for all the applied tool welding speeds and constant rotational speed. The hardness in the HAZ is generally the lowest compared to the SZ and TMAZ. The grain coarsening, combined with the loss of strengthening precipitates (due to over-aging effects), causes a significant reduction in hardness. The hardness in this zone is 20−30 % lower than in the base material and can be the weakest point in the weld, making the HAZ more susceptible to failure under stress.

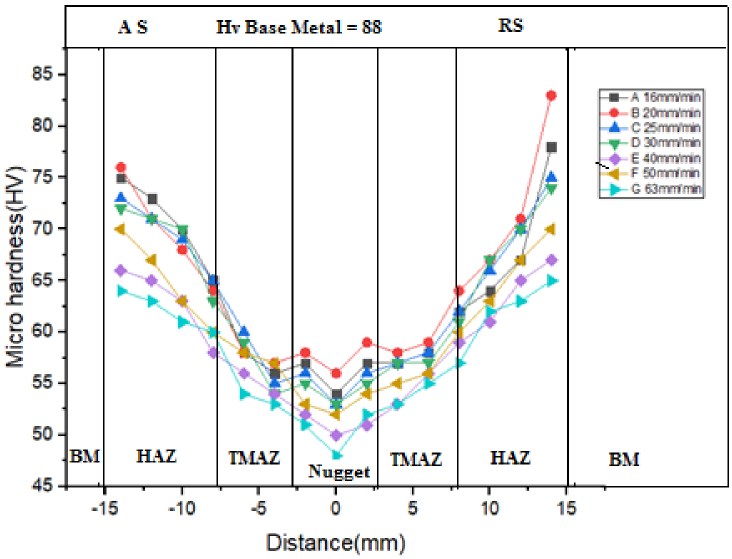

Fig. 7. Variation of the hardness for the rotational speed 1400 rpm

The outcome of hardness higher values 82 HV in TMAZ region on retreating side (RS) for welding speed 20 mm/min and decreases at 75 HV in the advancing side (AS). It is due to the much-refined grain size and higher dislocation densities in the stir zone [23]. It should be emphasized that the size of the ZS area is governed by the pin diameter while the TMAZ area is generated by the size of the tool shoulder of the tool. This degradation in hardness is mostly characterized in the TMAZ. This is attributed to a combination of high stresses and large strains resulting in the deformation of the grain structure, where re-crystallization did not take place, caused a coarse grain structure [24,25]. This dynamic recrystallization observed in the weld region results in a decrease in grain size and an increase in hardness in the joints [26–29].

Bending test

The bending test is a crucial evaluation method in assessing the mechanical properties and performance of friction stir welded (FSW) joints, particularly for AA 5083-H111 aluminum alloy**.** Three-point bending tests were conducted using a CONTROLAB machine for all specimen (A to G) the results are presented in Fig. 8 and 9. The bending tests were performed on the face and the root of the joint as an important tool to understand the ductility and toughness of friction stir welds (bond strength). Most of the welds presented good ductility, especially in case the joint made at 1400 rpm and 20 mm/min

Fig. 8. Three-point bending test

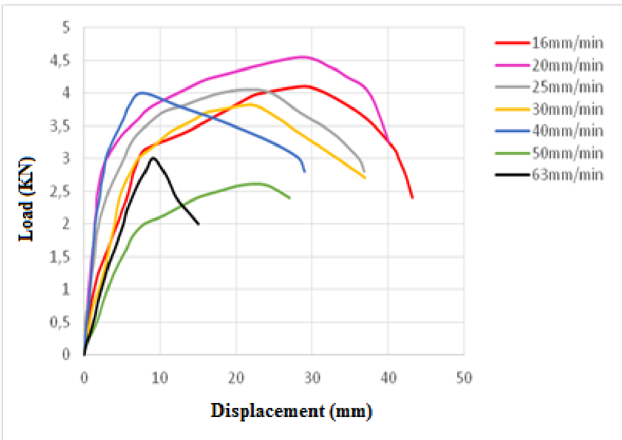

Fig. 9. Three-point bending test-displacement

Table 3. Fracture position on the specimens

V, mm/min / Angle of Bend, °	**Weld photos**	**Observations**
16 / 80		No fracture
20 / 83		No fracture
25 / 83		No fracture
30 / 86		Crack on bend surface
40 / 80		Crack on bend surface
50 / 80		Crack on bend surface
63 / 82		Crack on bend surface

(configuration A) where the maximum deflection reached to 43 mm with efficiency of about 90 % compared to the base metal, this is due to higher temperatures involved during FSW, so the Base Metal adequately soften to go higher bending strength [30].The immediate growth in force that appear in configuration G (63 mm/min) at about 15 mm deflection came from some slipping occurred between bending specimens and device jaw so that slipping didn't affected on the total results because that shifting occurred in all specimens and the comparison between base metal and welded specimens stilled in the same values [31]. Finally, these results of bending tests can be correlated with microstructural characteristics of the welds, such as grain size and distribution, heat-affected zone (HAZ) properties, and the presence of defects. This correlation helps in understanding how microstructural changes due to FSW affect the mechanical performance of the joints. The results of the bending tests conducted on all the FSW weld joints produced at rotation speed of 1400 rpm and welding speeds of 16, 20, 25, 30, 40, 50, 60 mm/min are hereby presented in Table 3.

The defects found are mainly lack of penetrations, wormholes or voids, as well as root flaws [32]. Other defects observed include inclusions which were rich in iron and from analysis these inclusions can be classified as iron oxide particles in the weld. For the first three samples for welding speeds 16, 20 and 25 mm/min, the post-bending results showed the tested specimens without failure. This means that the welded materials have bonded well during welding. For all the FSW experimental work and because rotational speed and welding speed significantly the bowing quality the bending strength by influencing the heat generated in the weld zones [32].

Weld microstructures and properties of FSW joint

Friction stir welding (FSW) of AA 5083-H111 commonly used aluminum alloy in marine and automotive applications, results in distinct microstructural changes in the weld metal. The microstructures of weld region of weldments were perceived using an optical microscope, and the relevant micrographs are presented in Fig. 10. While all the fracture surfaces display dimples, the size and shape of the dimples show differences. However, there are dimple-free flat regions, as can be seen in Fig. 10(a,c,e), and a ductile fractured surface can be identified. Figure 10(b,d,f) shows many defects such as voids, cracks and porosities. Conversely, the rise of the heat input decreases the hardness of the heat-affected zone, where recrystallization does not occur. The river marks diverging downwards on the surface of the tool marks (Fig. 10(b)) and upwards at the ending of the unconsolidated onion rings (Fig. 10(d)), indicated that they were the primary regions of crack initiation in the weld tunnel.

What's more, the HAZ had the highest grain size in contrast with the stir zone in which the finest grain size could be seen [33]. In the stir zone, the temperature is the highest, and the material experiences intense plastic deformation due to the rotating tool. This causes significant grain refinement, leading to a fine-grained microstructure. The grain size in this region is typically much smaller than in the base material. As the SZ presents the smaller and more significant quantity of second-phase particles, therefore a greater number of cracking sites is available, the SZ is a favorable crack initiation site [34,35]. Consequently, this synergistic effect promotes a more rapid and thorough process of dynamic recrystallization which refines the grains in the stir zone and forces the fracture

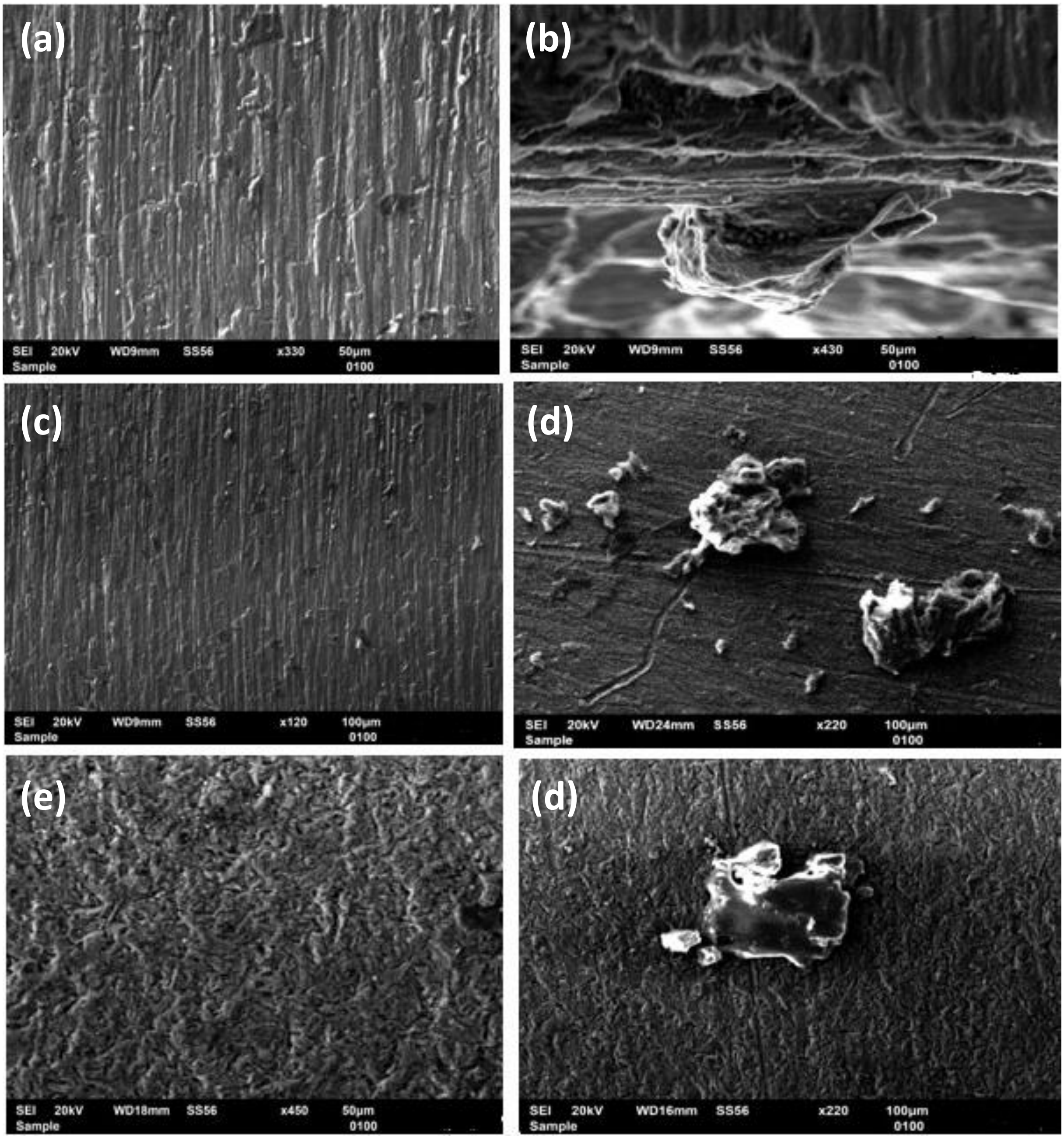

Fig. 10. SEM-images of the welded specimen

outside the stir zone [36]. The stir zone may also exhibit "onion-ring" patterns, which are a result of the material flow around the rotating tool. These patterns are typically visible in the microstructure and can influence local variations in the mechanical properties.

Conclusions

In friction stir welding (FSW) of AA5083-H111 aluminum alloy, traverse speed significantly influences both the three-point bending behavior and surface quality of the welds. An optimal traverse speed ensures adequate heat input and material flow, leading to improved mechanical properties and surface finish. Conversely, excessively high traverse speeds can result in inadequate bonding and surface defects, adversely affecting the weld's mechanical performance.

The main findings of this investigation are:

1. Highest bending strength by using rotation speed 1400 rpm and travel speed 20 mm/min because of no necking or cracking were noticed in the weld zone.
2. Most of the defects produced in the root surface because of the effect of unwelded zone. while the defects in the face of welded region because of the tunnel hole or internal crack defect.
3. The highest hardness at 1400 rpm and 20 mm/min due to the very fine grain size created by FSW.
4. The weld nugget/TMAZ interface was not a weak region in FSW AA5083-H111.
5. Increased welding speeds resulted in a reduction in vertical pressure that caused increased size, number, and severity of weld defects.

The fracture almost always took place in the heat affected zone in particular on the retreating side.

CRediT authorship contribution statement

Mohamed Amine Adda Hanifi: investigation; **Mokhtar Zemri**: investigation; **Mohammed Merzoug**: writing – original draft, conceptualization, supervision.

Conflict of interest

The authors declare that they have no conflict of interest.

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