Defects Analysis of Tee-Section Welding Using Friction Stir Welding Process of Aluminum

Prof. Dr. Qasim M. Doos
University of Baghdad ,
E-mail: kasim_daws@yahoo.com

Kamaal Sahib Makki
Dean of College of Engineering
E-mail: Abukamellah@yahoo.com

ABSTRACT

Friction stir welding (FSW) of Tee-joints is obtained by inserting a specially designed rotating pin into the clamped blanks, through top plate (skin) to bottom plate (stringer), and then moving it along the joint, limiting the contact between the tool shoulder and the skin. The present work aims to investigate the defects occur for Tee-joint of an Aluminum alloy (Al 5456) with dimensions (180mm x 70mm) for the skin plate, (180mm x 30mm) for stringer plate and thickness of (4mm).

The effects of welding parameters such as rotational speed, linear speed, plunging depth, tool tilting, and die radii of welding fixture on the welding quality of Aluminum Alloy will be studied. Weld defects had been summarized and studied, and then the best conditions that led to good welds had been estimated.

Key words: FSW, T-Section, Aluminum 5456, defects analysis, 4mm thickness.

تحليل العيوب لمفصل لحام نوع (T) بأستخدام عملية اللحام بالاحتكاك والمزج على الالمنيوم

أ.د. قاسم محمد دوس
جامعة بغداد / كلية الهندسة / قسم ميكانيك

كمال صاحب مكي
جامعة بغداد / كلية الهندسة / قسم ميكانيك

الخلاصة

يتم الحصول على مفصل من النوع (T) بطريقة اللحام بالاحتكاك والمزج بغرس أداة دوارة بتصميم معين في الصفيحة العليا الأفقية المكونة للمقطع(skin) وصولا إلى الصفيحة السفلى العمودية (stringer) بعمق معين ثم إعطاءها (الأداة) سرعة تغذية مناسبة مع التماس التام لكتف الأداة الدوارة مع سطع الصفيحة العليا على طول خط اللحام وذلك بعد تثبيت الصفيحتين المكونتين للمفصل الى بعضهما بواسطة فكوك حديدية.

يهدف هذا البحث الى التحري عن العيوب التي ممكن أن تظهر في هذا النوع من اللحام لهذا المفصل باستخدام صفائح مصنعة من سبيكة الألمنيوم-المغنيسيوم (Al5456) بأبعاد (70x180) للصفيحة العليا و (30x180) للصفيحة السفلى وبسمك (4 ملم) لكليهما حيث تم دراسة تأثير متغيرات العملية مثل (سرعة دوران الأداة , سرعة اللحام, عمق تغلغل الاداة , نصف قطر حافة المثبت , و زاوية إمالة محور الاداة) على جودة اللحام. كما تمت دراسة و تحليل العيوب ومن ثم تعيين الظروف التي تقود للحصول على لحام ذو جودة عالية .

1. INTRODUCTION

Friction Stir Welding (FSW) is a well-established joining process for welding aluminum and other low melting temperature metals. The application of this process to steels and stainless steels has primarily been limited by the availability of suitable tool materials. Friction stir welding was recently identified by leading aircraft manufactures as "key technology" to replace riveting for fuselage and wing manufacturing, **Thurlby,2009.**

FSW of T-joints is obtained by inserting a specially designed rotating pin into the clamped blanks, and then moving it along the joint. The pin is inserted at a rather small nutting angle, limiting the contact between the tool shoulder and the blank. As the pin is inserted into the upward sheet (skin), the blank material undergoes a local backward and forward extrusion process in order to penetrate the vertical blank (stinger) and to reach the tool shoulder contact, **Fratini,et.al.,2005**.

Aluminum 5xxx series is the Al-Mg group, it is high strength alloys, (AL5456) is an alloy of aluminum and magnesium with good strength; it is good for structural use because it is of good weldability. It is commonly used in the manufacture of high strength welded structures, pressure vessels, marine applications, and in storage tanks ,**Thurlby,2009.**

Actually investigating the scientific literature of the last years, very few contributions are found to be focused on FSW operations of T-joints. Some of the authors carried out fundamental investigations regarding the mechanical performances of the FSW T-joints undergoing bending mechanics in comparison to traditionally welded T-parts and the study of corrosion resistance of FSW T-joints.

Colligan,2009, Investigated two new techniques for visualizing material flow patterns in friction stir welds are presented. Based on measured results in welds of 6061 and 7075 aluminum, material movement within friction stir welds is by either simple extrusion or chaotic mixing. **Cederqvist, et. Al. ,2002,** carried out an extensive investigation on FSW lap joints. Two materials, Alclad 2024-T3 and Al 7075-T6, sheet materials were commonly joined and used in the aerospace industry. Welding variables used included welding speed, rotational speed and, of particular importance, and tool dimensions.

Larsson, et. Al.,2000, studied report on microstructural observations and provide information about the mechanical properties of joints welded using FSW. In a cross-section of a welded joint, the central part had a shape of a “nugget” (often asymmetrical), in contrast to the well-defined beads of a MIG weld compared FSW welds with MIG welds and noted that the presence of the “annual rings” (or onion ring structure) in the FSW weld area which typically consists of concentric ovals. **Adamowski, et. al., 2007,** investigated the properties and microstructural changes in friction stir welds in the aluminum alloy 6082-T6 as a function of varying process parameters. **Al-Ani, 2007,** investigated the effect of welding parameters on mechanical properties of welded joints using different mechanical tests. **AL-Joudi, 2009**, investigated an attempt to understand the effect of tool pin profile and rotation diameter on microstractur and mechanical properties of aluminum alloy (2218-T72). **Thurlby,2009,** evaluated the effects of high rotation speed friction stir welding (HRS-FSW) on the microstructure, mechanical, and corrosion properties of aluminum welds.

2. EXPERIMENTAL WORK

2.1 Welded Plates

The plates of Al-alloy 5456A, **Table1**. were prepared with the dimensions (180mm x 70mm x 4mm) for the skin and (180mm x 30mm x 4mm) for stringer.

2.2 Welding Fixture

Because the milling machine didn't organize directly to the (FSW), fixture system should be added to be suitable for the job. Welding fixture consist of two parts, these were manufactured from cast iron, with base dimensions (135mm x 200mm x 30mm) and side wall dimensions (92mm x 200mm x 30mm) as shown in **Fig.1** and prepared to be suitable with the table of the Milling Machine. Both parts could be fixed. on the machine table by using three bolts type (M16).

2.3 Welding Tool

A low alloy steel welding tool was manufactured to perform the welding of the Tee-joint aluminum plates. Welding tool was consists of two geometries, the former called shoulder and the second called probe or pin. Tool was manufactured with shoulder of (22mm) diameter; it is the source of heat input to the welding zone **Fig.2**.

Pin is the second part of the tool. Two types of tool pin had been tried in this work; first type was progressive pin, **Fig.3**. with dimensions of (5mm) diameter for first (4mm) length starting from shoulder face and (3mm) diameter for last (1mm) of length. Progressive did not use because of insufficient ability of stirring; this causes defects in welded joints such as Groove – Like defect. Conical pin tool, **Fig.**4 was used with base diameter of (5mm), final diameter of (3mm) and pin length of (5mm).

A group of welding parameters [(640, 960, and 1200) RPM rotational speed and (60, 90, and 110) mm/min welding speed] was used with different profiles of welding fixture and tool and tool tilt angle to study the effect of each parameter on properties and quality of welded joints.

3. TESTS

3.1 Non-Destructive Inspection

3.1.1 Visual inspection:

Perhaps the most straight forward and simplest inspection technique, it is an excellent means for inspecting surface features including excess flash, galling, shoulder voids and even weld misalignment. These defects are visible to the naked eye and are attributed to out of family welding parameters such as excessive travel speed (mm/min), excessive rotational speed (RPM) , inadequate plunge force loads, and improper joint tracking. characteristics are, likewise directly linked to the weld process itself. Primary factors affecting lack of penetration (LOP) during welding include heat input or material flow and, most importantly, the depth of the FSW pin tool.

3.1.2 Liquid penetrates inspection:

Liquid penetrates inspection is a technique, which can be used to detect defects in a wide range of components, provided that the defect breaks the surface of the material. The principle of the technique is that a liquid is drawn by capillary attraction into the defect and, after subsequent development, any surface -breaking defects may be rendered visible to the human eye, **(Yousuf ,2007).** Penetrate inspection of the FSW welds have been conducted on the root-side of as welded condition of the stir welds.

4.Results and Discussion:

4.1 Non-Destructive Inspection Results

4.1.1 Visual examination results:

After conducting (FSW) process and several welded joints were obtained with different welding parameters, several non-destructive inspection or examination techniques were used to computation the soundness of welded joints and to complete the destructive tests for the defect free welded joints. The first technique used was visual examination using a magnifying lens, visual examination of welded joints was applied in three stages:

1. Visual examination of joint preparation.
2. Visual examination during welding.
3. Visual examination of the finished weld.

Different effected features due to repeated welding experiment cause these defects.

1. **Fixture die radii:** large die radii cause a large gap between skin and stringer plates appear as a hole along welding line; the cause of this gap is the metal flow into die radii without additional metal. When the die radii was been reduced the hole cross section area was reduce. After many trials of redaction this gap, the best results die radii was obtained (2mm) that led to welded joint without effected gap but a fine horizontal crack was reside, **Fig.**5.

2. **Tool tilt angle:** Tilting angle of the tool by (2 degs.) improved welded joint in two sides:

- Good surface finish obtained due to improving metal flow, then no excess flash of metal on skin surface, because of high leading edge and low trailing edge, **Fig.6**.
- Improving the wavy metal flow between skin and stringer plates that led to remove the horizontal crack due to improving forging action by forced the metal inside the joint, **Fig.**7.

3. **Welding operating parameters (rotation and travel speed).** The range of travel speed was limited by trying many speeds. When low rotation speed (below 640 R.P.M.) or high travel speed (above 110 mm/min) was used, the plastic flow of the material would be incomplete because of inadequate input heat and insufficient metal stirring. In this case many types of defects were accrue such as kissing bond defect, tunnel-type defect, and groove-like defect**, Acerra ,et al.,2009.**

   When high rotation speed or low travel speed was used, surface defects were appearing due to high input heat **Fig.8.**

4.1.2 Liquid penetrates inspection (LPI) results:

Liquid penetrate inspection technique has been used to detect any surface defects on weld root that cannot be detected by visual inspection.

The results of this inspection firstly reveal the defects, which were detected by visual inspection, and secondly other surface defects, which were not revealed by visual inspection. **Figs.9 – 11.**

5. ANALYSIS OF FRICTION STIR WELDING DEFECTS

According to (NDT) results, weld defects can be summarized and analyzed as follows:

5.1 Excess Flash

Shoulder voids and even weld misalignment. These defects are visible to the naked eye and are attributed to out of family welding parameters such as excessive travel speed (mm/min.), excessive rotational speed (RPM) , inadequate plunge force loads, and improper joint tracking, **Fig.** 12.

5.2 Incomplete Welding

At the beginning of welding line , this defect can be attributed to low heat input in the weld start and this can be overcome by preheating (using welding tool) in weld beginning (dwell time) **Fig.13.**

5.3Tunnel-Type Defect

Defect that occurs when the plastic flow of the material is incomplete, **Fig.14** because of inadequate input heat when the tool rotates at low speed and the welding speed becomes high,**KaijiKyokai ,2010.**

5.4 Kissing Bond

Defect that occurs when stirring by the probe tip becomes extremely small. This defect is difficult to detect by standard non-destructive inspection of incomplete welds in which the bonding force was extremely small, **KaijiKyokai , 2010**, **Fig.15**. According to the weld defect summary mentioned above, defect free joints can be made by selecting adequate conditions, and the most important were (rotational speed, welding speed and plunging depth).

5. CONCLUSIONS

According to the results of the present study of Tee-joint FSW process on Al-Alloy (Al 5456) several conclusions can be written as follow:

1. There are many types of defects were accrued such as Excess flash, incomplete welding, tunnel-type defect, and kissing bond. Incomplete welding defect was the mostly appears.
2. Excess flash defect accurse due to excess plunge depth, this defect can be eliminated when choosing a suitable plunging depth (0.3 mm).
3. Incomplete welding defect accurse when low heat input use. This defect can be overcome by preheating using welding tool in beginning of welding process (about 30 sec).
4. Tunnel –Type defect appears due to low heat input. This defect can be overcome by using low traveling speed or high rotational speed of tool.
5. Kissing bond defect accurse when stirring becomes extremely small due to high traveling speed (more than 110 mm/min).
6. Defect free joints can be made by selecting adequate conditions such as fixture design, tool profile and tilt angle, and using of proper operation parameters.

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Table 1.Chemical composition of welded plates.

Element	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al
Quantity %	0.251	0.382	0.046	0.584	0.461	0.120	0.005	0.088	0.014	Balance

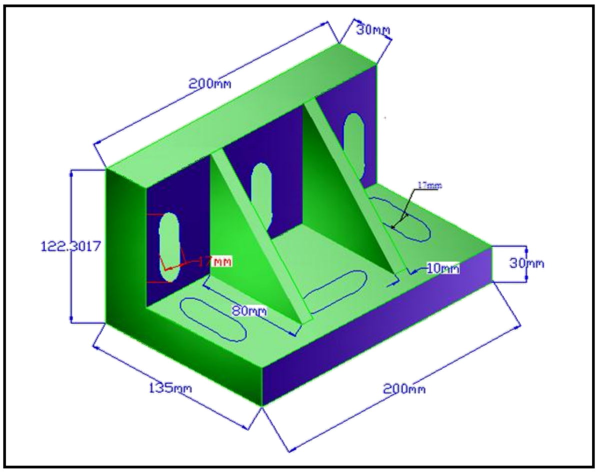


Figure1. Sketch of process fixture (one part).

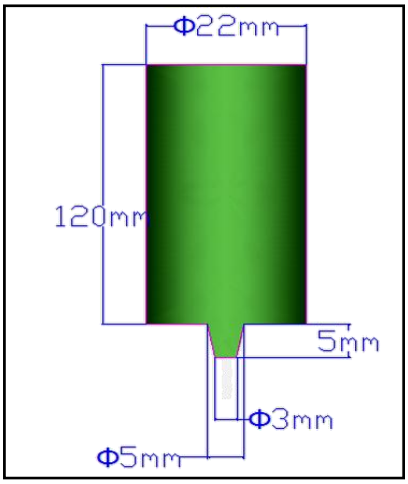


Figure2. Sketch of welding tool.

Figure3. Progressive welding tool.

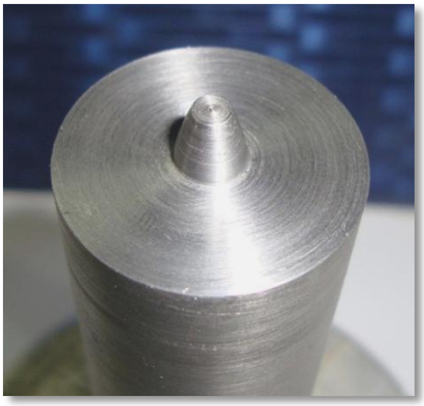
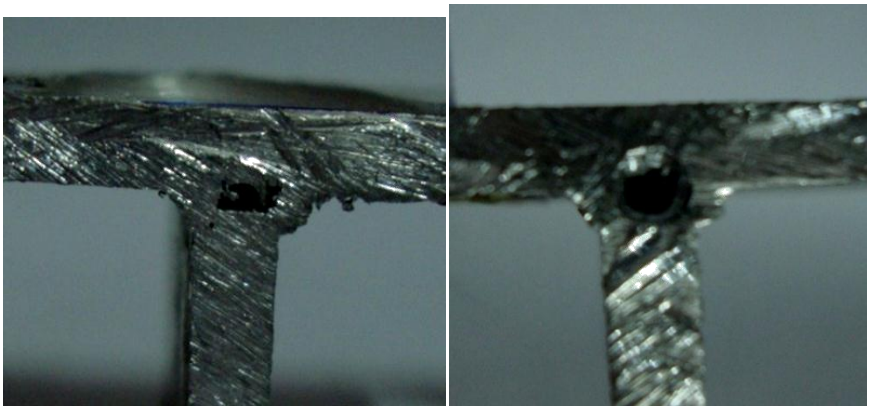
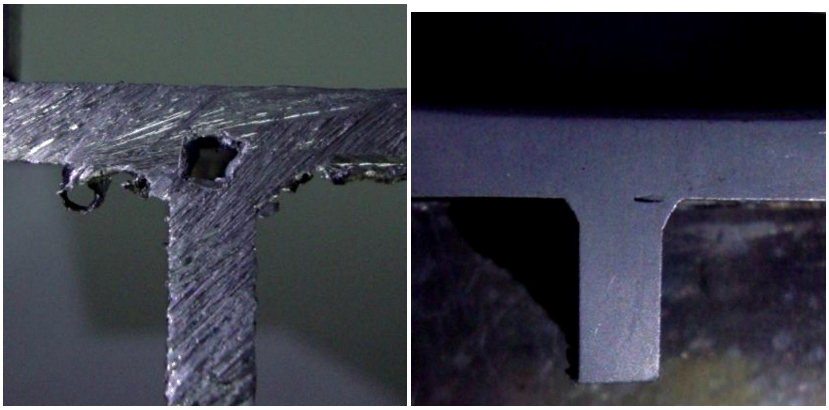


Figure 4. Conical welding tool.

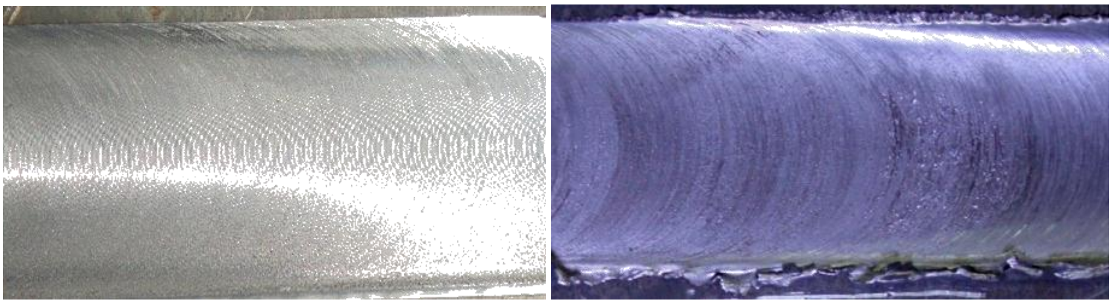


(a) r =4mm **(b) r =4mm**



(c) r =3mm (d) r =2mm

Figure5. Stages of gap redaction due to reducing die radii.



(a) Zero-tilt angle (b) (2 degs.) tilt angle

Figure6. Different surfaces due to tilt angle of tool.

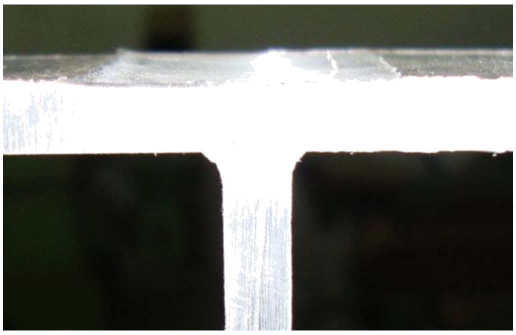


Figure7.(2 degs.) tilt angle (no defects).

Figure8. Surface defects due to high input heat.

Figure9. LPI image of (TFS11: 960 RPM ,140mm/min) skin side.

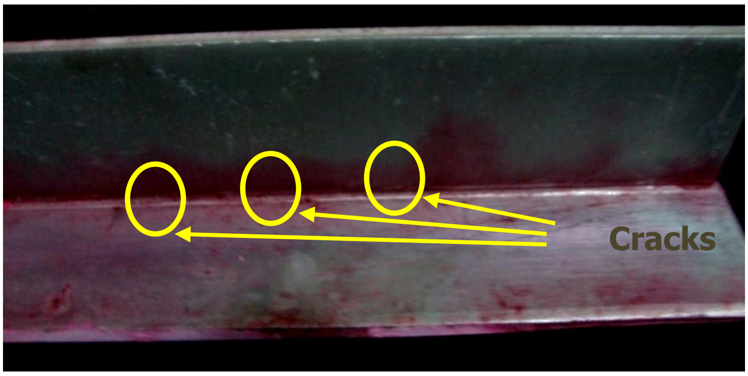
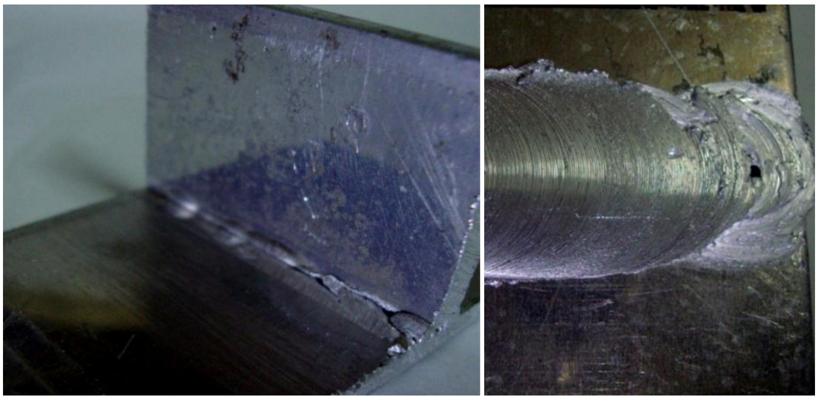


Figure10. LPI image of (TFS 11) stringer side (crack due to high travel speed).

Figure11. LPI image of (TFS 4) stringer side (no defects).

Figure12. Excess flash.



(a) (S.V.) **(b) (T.V.)**

Figure13. Incomplete welding at starting point.

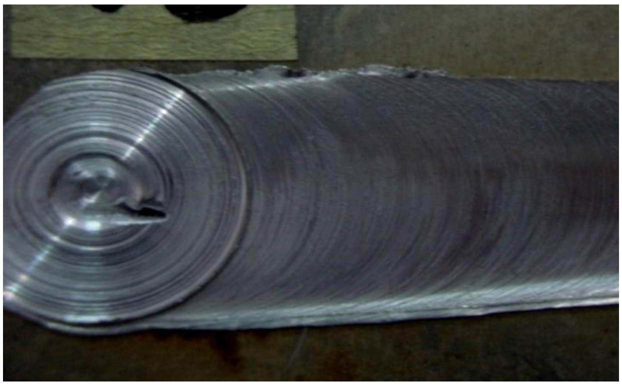


Figure14. Tunnel-type defect.

Figure15. Kissing bond defect due to high welding speed (140 mm/min).