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Flaw Detection and Characterization in Butt Friction Stir Welded Joints of Aluminium 6061 Alloy

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Abstract

Aluminium Al6061 is a highly weldable alloy which find applications in the production of aircraft, yacht as well as automobile components. Friction stir welding, being a high quality solid phase metal joining method, is used widely in these industries. Though the quality of welds are claimed to be much higher than that of welds made by conventional welding procedures, tunnel-type, void and root-flaw defects occur frequently depending on the welding parameters. These defects are of very high prominence in industries because of the associated reduction in fatigue life. Main intention of this paper is to specify the defects of butt friction stir welded joints, which can be identified through micrographs taken using scanning electron microscope and non destructive testing methods such as ultrasonic testing and X-radiography, in aforementioned alloys.

Index Terms— Non Destructive Testing, NDT, Friction Stir Welding, Welding Defects, Aluminium.

I. OBJECTIVE

The purpose of this paper is to characterize the various defects occurring in butt friction stir welded joints of Al6061 alloys, that can be recognized through standard non-destructive testing methods such as ultrasonic testing and X-radiography. Evaluation of cross-section is also carried out utilizing scanning electron microscope, to observe the variation in material structure, alongside Energy Dispersive Spectroscopy(EDS) for analyzing the changes made to constituent elements in weld nugget zone. This can be of use to end user in order to assist in awareness of various defects that could occur during FSW of the specified alloy. Despite helping to make decisions regarding quality of entire weld, NDT methods have the advantage of ensuring safe, reliable and cost effective real time assessment of the weld during the welding procedure, thus assisting in real time optimization of various process parameters involved. Effort has been made to find out the capability of ultrasonic testing, radiography and scanning electron microscope micrograph to recognize some of the defects occurring in butt FSW Al 6061 alloy joints.

II. LITERATURE REVIEW

Friction stir welding(FSW) is a solid-phase metal joining process in which materials are welded together below their melting temperatures. It is a relatively new welding technique developed by The Welding Institute(TWI), UK, which is now being increasingly used in industries for welding aluminium et al [1]. Absence of consumables such as electrodes, gas and filler wires is a major advantage of FSW processes. Quality of welds attained by joining aluminium alloys using FSW are much higher in comparison with traditional fusion welding processes, which causes various undesirable effects such as porosity, cavities and hot cracking et al [2]. Variations in quality of welds in the case of FSW processes are affected primarily by three weld variables which are plunge feed, travel feed and rotation speed et al [3]. Based on these variables, various defects such as void, porosity, defective tightness, surface groove, excessive flash, 'z-curve', tunnel, 'kissing-bond' and crack like root flaw occurs in the welded region, which are much different from conventional fusion welding flaws. Analysis on these defects has been carried out by et al [4] on Al 2219-T6.

Al 6061 contains silicon and magnesium as the major alloying elements. Because of its ability to be precipitation hardened alongside good weldability, the alloy finds many general purpose applications, mainly in aircraft and automobile industries et al [5]. Fatigue strength is an obvious priority in these industries and hence detection of defects like root-flaws, which could develop into cracks during fatigue loading conditions, have to be determined.

III. EXPERIMENTAL PROCEDURE

3.1 Setup

Al6061 alloy in 260x160x12 mm dimension was cut into three equal sections and clamped as represented in the Fig 1. These three sections were welded together Fig 2.

An HSS tool with tapered cylindrical profile, as represented in Fig 4 was used. Tool tip had minor diameter of 5mm and 8mm major diameter. Welding process was carried out outside the standard optimized set of welding parameters, as in otherwise circumstances, non destructive detection of defects can become extremely cumbersome, specially without prior prediction of possible defects.

3.2 Welding

FSW was carried out in Hurco VMX 30, a CNC vertical machining center. Both the welds were obtained by utilizing the same welding parameters. Spindle speed was maintained at 800 rpm, plunge feed at 2.5mm/min and traverse feed at 10mm/min. Flash formed on the surface of the workpiece was filed before conducting NDT tests.

Fig 1. Clamping of workpiece

3.3 Non Destructive Tests

Radiographic inspection was done using Iridium-192 source for gamma rays, with 90 seconds exposure time. Fig shows the resultant image obtained on AGFA D4 film, 4x12 inches in size, for each weld. Ultrasonic test was carried out using Einstein-II TFT equipment utilizing a compensation wave at 5Mhz, with a 9mm diameter probe. Apparently, FSW process leave top surface of welds with high roughness, because of which the probe had to be placed on root surface.

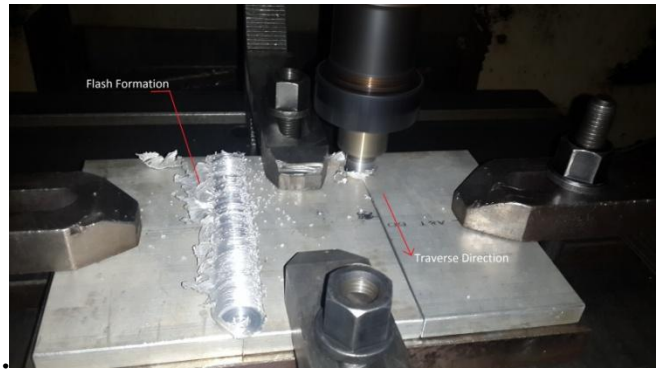


Fig 2. Welding process

3.4 Micrograph

Micrograph for the specimen was taken after making a transverse cut on the work piece. A smaller section of the cross section was seperated and obeserved under scanning electron microscope. Analysis was carried out at three different zones i.e. unaffected zone, Heat Affected Zone (HAZ) and Weld Nugget Zone (WNZ) as represented in Fig 3. Zeiss EVO-18 SEM was the apparatus utilized for this purpose. In the same instrument, EDS was also carried out to determine variation in element composition at the three zones.

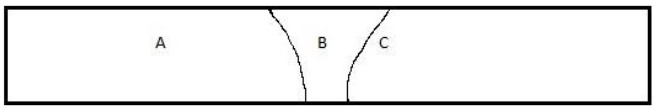


Fig 3. A- Unaffected zone, B- WNZ, C- HAZ

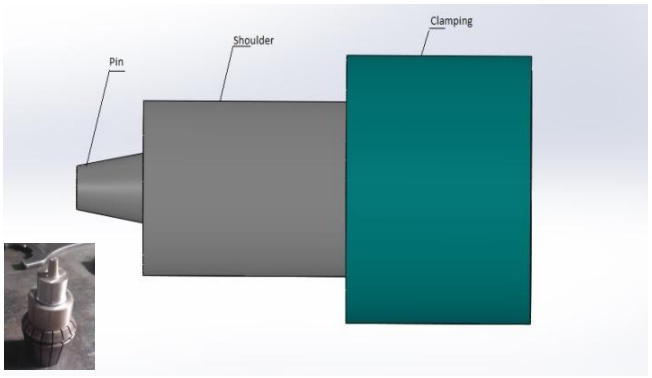


Fig 4. FSW Tool

IV. RESULTS AND DISCUSSION

Radiographic and ultrasonic tests revealed presence of voids in the weld nugget zone,

however better quantification of size of the defect was achieved through ultrasonic testing. For determining depth in case of radiographic analysis, gamma rays will have to pass through entire 160mm thickness, which would include multiple areas containing voids, hence significantly altering the accuracy of analysis. Fig 5 shows the radiographic image on film, showing location of voids and porosity. In ultrasonic testing, since the cap layer had very rough finish, graph was not specific because of the scattering of sound waves, Fig 6. The entire welded line was represented to be defective. While considering this variation, further analysis represented a void of 7mm depth from the root.

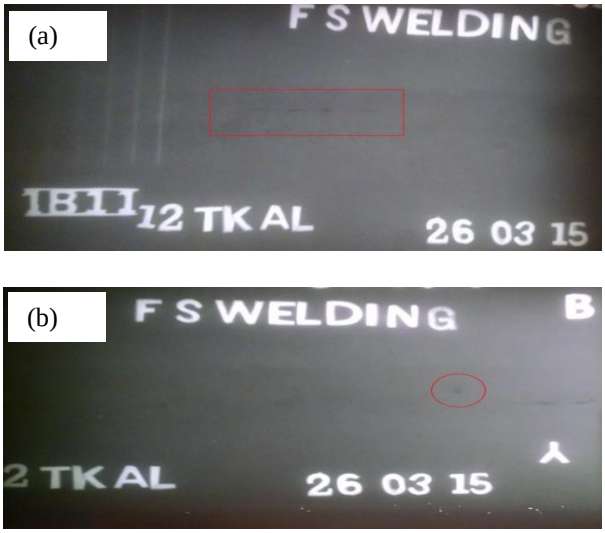


Fig 5. (a) and (b) represents two separate welded joints with voids and porosity

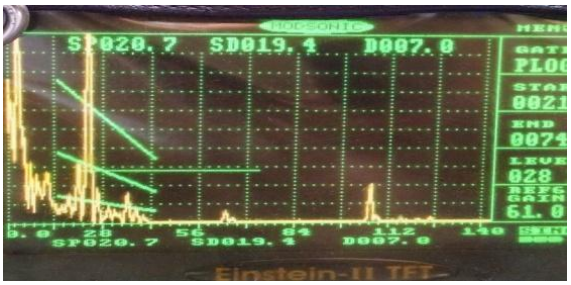


Fig 6. Graph from ultrasonic testing

Images obtained at the three different zones through SEM represented crack like root flaws, kissing bond alongside abrasions. This is represented in Fig 7. Towards the top part of fig 7 (b), slight porosity can also be observed.

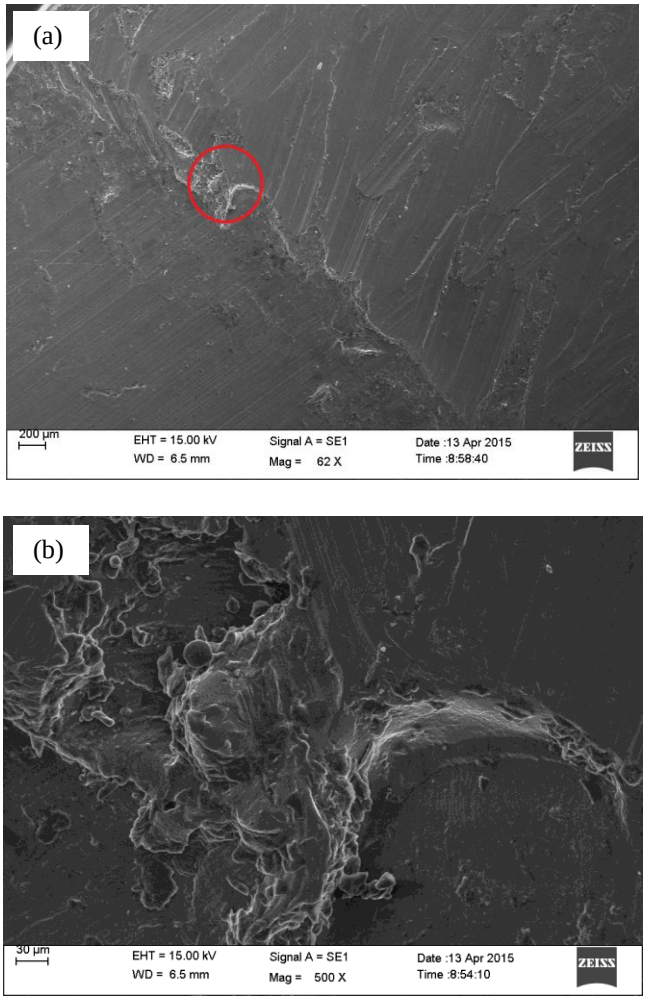


Fig 7. SEM images (a) Abrasion with formation of root flaws. (b) Magnified view from (a) showing kissing bond formed in boundary of WNZ.

As expected, coarse grain structure was observed at heat affected zone. Even at some distance from HAZ, away from WNZ, some variation in grain structure was observed. This could be because of the heat conducted to different parts of alloy during continous FSW process, at low feed and traverse rate, during the entire welding process. These images are represented in Fig 8 and Fig 9. Variation in grain structure around unaffected zone was relatively low, but conducted heat had some impact on these areas as well.

EDS taken at WNZ also revealed considerable variations in aluminium content thereby confirming the reduction of strength at this region, increasing the probability for defects. Also, multiple element compositions at HAZ and unaffected zone were found to vary only to very low values, confirming the variation in grain structure at unaffected zone, Fig 9.

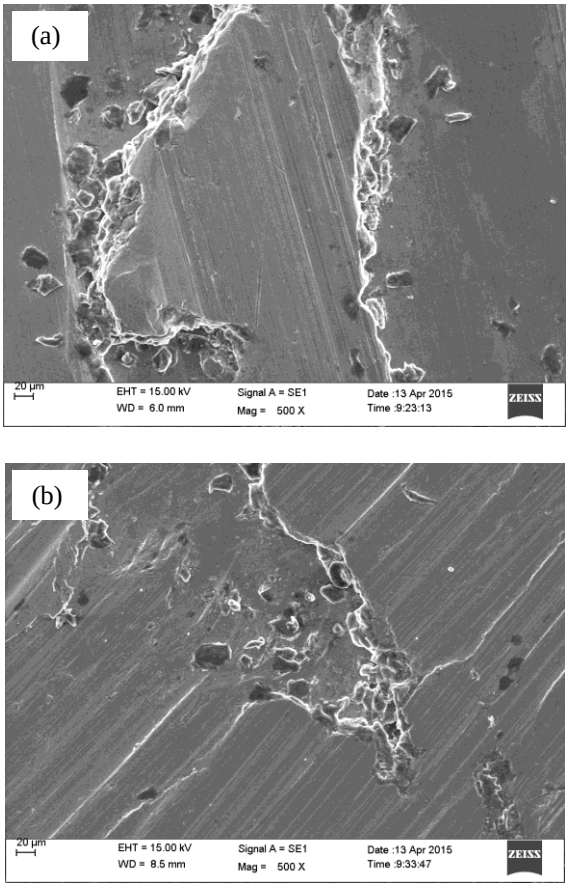
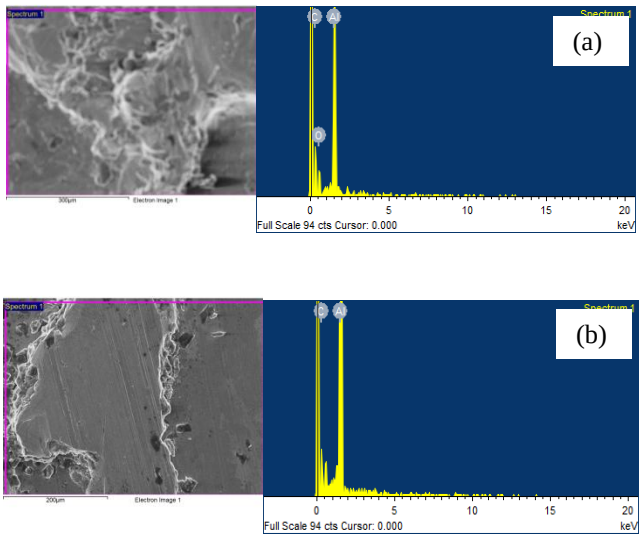


Fig 8. SEM image of (a) HAZ (b) Unaffected zone representing slight variations in grain structure



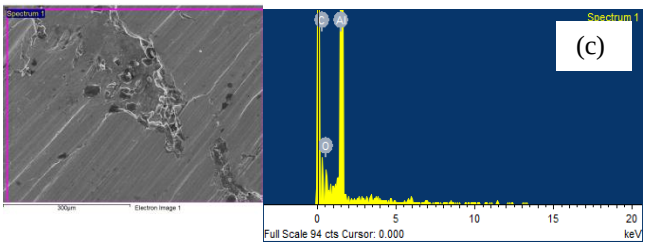


Fig 9. EDS Results for (a) WNZ (b) HAZ (c) Unaffected zone

V. CONCLUSION

Through radiography and ultrasonic testing, voids can be identified although, ultrasonic testing can be more useful in the quantification of depth. Radiography is particularly useful to determine the location of defects like voids and macroscopic porosity inside the weld. By combining these two methods, exact location as well as depth of pre mentioned defects can be identified, making the combination a very practical testing method. However, considering fatigue loading conditions, even smaller defects like voids can become detrimental to the material at operating conditions because of possible crack initiation at the point. Any of these two methods can be successfully utilized in such scenario considering time and other operational constraints involved.

SEM can be utilized for finding out various defects such as kissing bonds, porosity, crack initiation, making it very suitable for complex analysis done during statistical evaluation procedures. EDS will be useful to determine if any variations has occurred to otherwise unaffected zones. Variations can happen at unaffected zones due to heat conduction in highly thermal conductive material like aluminium. This can be minimized by techniques such as using coolant and submerged welding, which is now being extensively researched about.

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