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Technical Paper

Classification and identification of surface defects in friction stir welding: An image processing approach

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ABSTRACT

Friction stir welding (FSW) is a new entrant in welding technology and getting a defect-free weld is the final objective. But different defects are generated due to various reasons and needs to be analyzed to eliminate them. The aim of the research work is to identify and classify different kinds of surface defects generally encountered during the FSW process using digital image processing techniques. The defects on the surface of the weld are identified using image pyramid and image reconstruction algorithms. Further, using these algorithms the defects can be classified into voids, grooves, cracks, key-hole and flash with the help of unique features of each kind of defect. Vertical intensity plot and the area plot of the defect blobs are represented for the proper localization and analysis of severity of defects.

1. Introduction

The friction stir welding process (FSW) is comparatively a new entrant in the welding technology. This solid state joining process was invented by The Welding Institute (TWI) in 1991 [1]. The process is simple, eco-friendly and energy efficient, and has wide applications in various industrial areas such as automobile, aircraft and aerospace industries, as it can weld low density material like aluminum and magnesium efficiently [2,4,5]. It is observed that the FSW joints have high strength; almost close to the base metal and also helps in weight savings considerably than the other joining processes as no filler material is added during welding. It is reported that during FSW there is no presence of a state of liquid weld pool and thus temperature rise in FSW is less and is nearly 0.7–0.9 times the melting temperature of the metal [3–5].

Weld quality is affected because of various kinds of defects occurring during the FSW process. A good amount of efforts are being made in this regard to identify the defects in welding.

Several researchers have worked on the analysis of surface defects in the FSW process. Defects like cavity, surface grooves and flash could occur due to inappropriate set of process parameters which results in excessive or insufficient heat input or abnormal stir [3]. Kim et al. [6] reported that, volumetric defects develop in FSW at colder process parameters like low rotational and high transverse speed. Sizes of these defects depend on the magnitude of forging forces in force control mode. Insufficient forging force can result in extended grooves on the surface which may be discontinuous, periodic or continuous. They pointed out that at low rotational speed, wormhole (void) develops in advancing side because at low rotational speed heating is not sufficient, and hence less material stirring occurs nearby nugget zone. Chen et al. [7] studied effect of tool tilt angle on welding defect on AA5456 aluminum alloys. They observed long groove defect along advancing side on top surface and void in nugget zone. However, at higher tilt angle, 2–3°, they observed good results but on contrary at 4–5°, channel defects are observed below the nugget zone along the advancing side and more flash observed in retreating side. Defect analysis in FSW could be done by several non-destructive methods like immersion ultrasonic and phase array ultrasonic techniques [8], X-ray radiography [9], thermography [10], eddy current testing [11], synchrotron radiation [12], etc. In phase array ultrasonic technique, defects like cracks and voids could easily be detected by the excitation of piezo-composite element which can generate focused beam where beam's parameters like angle and focal distance can also be

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modified [8]. Saravanan et al. [9] studied the effect of welding parameters like rotational speed, penetration depth and travel speed by using X-ray radiography technique which was able to detect micro-pores, voids and a tunnel defect in friction stir weld of aluminum–zinc coated steel lap joints. Mezyk and Kowieski [10] used thermographs of the FSW weld surface including burrs, discontinuities and uneven edges. Surface and sub-surface defects present in the weld were identified with the help of temperature plots extracted along the cross-section of the weld from thermally recorded sequence of images.

In welding processes, several researches have been made to detect the defects using the image processing techniques. In gas arc welding, it becomes difficult to capture clear images because of the bright welding arc, which makes the welding environment harsh. In order to detect the shape and size of the droplet more accurately, several image processing techniques like bilinear interpolation, double threshold, moving kernel filter algorithm, etc. have been used [13–16]. In comparison to the gas arc welding, images acquired in the FSW process does not have the above issues of lightning conditions and the images captured are more clear and do have high resolutions. Therefore, different image processing techniques like image pyramid, image reconstruction have been used in this research work.

Texture analysis techniques used for analysis of machined surfaces help in determining the surface roughness and weld quality analysis [17]. Sinha et al. [18] used image processing techniques like contour plots and gray-level intensity plots along the length of the weld for comparing the changes in weld surface texture patterns in cases of tool pin failure and pin depth at the time of online monitoring of FSW. Researchers have also exploited the advantages of using image processing techniques over other invasive or non-invasive techniques (like linear profile plot and contour plots) to distinguish between a good and a defective weld [19]. Usage of digital image correlation technique has been reported for the analysis of weld surface quality by extracting first and second order statistical image parameters which showed clear variations in their intensities with respect to good and defective weld regions [20]. Bhat et al. [21] have applied discrete wavelet transform on weld images to identify to defective and good weld. They have achieved accuracy of 99% and 97% with Gaussian and polynomial kernel respectively. Cox et al. [22] have studied the effect of tool rotation on spot weld quality. They found a linear relation between tensile shear strength and number of tool rotation. Gibson et al. [23] discussed the various aspects of the FSW process including input variables, joint configurations, tool design, etc. They have also discussed about the various variant of the process like stationary shoulder, self-reacting, friction stir processing along with application of the process and future research scope. Kim et al. [24] developed an algorithm to predict weld quality using image processing during high frequency electric resistance welding. They have used a vision sensor to capture the image at the proximity of weld spot. Zhang et al. [25] have examined parameters from weld pool surface to determine the backside bead width measurement to identify the penetration during gas tungsten arc welding. They have used machine vision system to measure specular weld pool surface in real time.

Among the available literature on the analysis of the surface defects in FSW process, there is hardly any report on classification and exact localization on the type of surface defect. Until now, the image processing techniques have only been applied to analyze the weld texture quality. This research work mainly aims in identifying and classifying the type of surface defects into voids, grooves, rough texture or crack, flash and key-hole that usually occur during the welding process using image processing techniques. The image processing techniques applied in this research work, results in yielding the exact location of the surface defects. The output produced by the proposed algorithm gives a vertical intensity plot of each kind of defect and an area plot of overall defects. Though the results obtained by the methodology proposed in this research work are carried out by taking offline images of the weld surface, it could be used in future online monitoring process, giving a feedback for controlling the welding parameters during the FSW process.

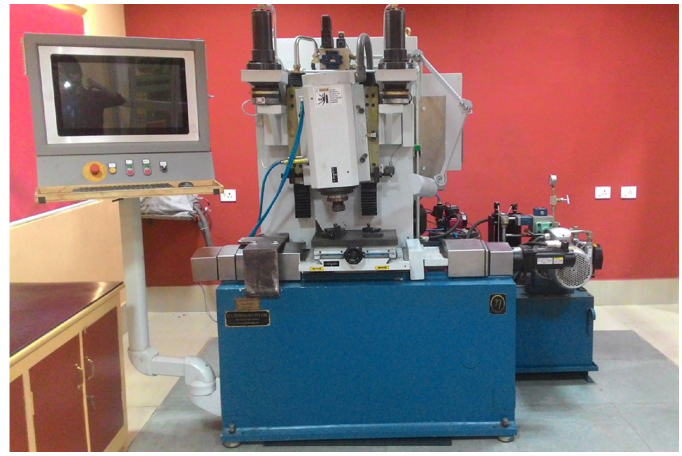

Fig. 1. NC controlled friction welding machine.

2. Experimental procedure

Experiments have been carried on a 2 Ton linear NC controlled FSW machine manufactured by ETA Bangalore, India Ltd., as shown in Fig. 1. The machine consists of strain gauge type load cell along Z and X axes to measure the reaction and welding force, respectively. Work piece material is AA1100, pure commercial alloy, whose composition is mentioned in Table 1. Work piece thickness is 2.5 mm and each work piece sample has a length and width of 100 and 40 mm, respectively. Tool is made up of tool steel H13 and has following dimensions: diameter of shoulder is 20 mm; diameter of pin is 5 mm; and the height of pin is 2.1 mm. Plunge depth in all experiments was kept at 0.1 mm with a spindle tilt angle of zero degrees. Flat tool shoulder is selected with cylindrical tool pin profile for the experiment. Rotational speeds for two different levels are chosen as 800 and 3000 rpm, while welding speeds at two different levels are 50 and 125 mm/min. Welding is performed in butt configuration and no pre or post treatment on weld sample is performed. Another welding has been performed to obtain the lap joint between AA6061-T6 sheet and AISI304 sheet each of thickness 1 mm. For this the FSW tool has a cylindrical pin whose diameter and height is 5 and 1 mm, respectively, whereas diameter of the shoulder is 18 mm. The shoulder part of FSW tool is made from H13 steel whereas the pin part is made up from tungsten carbide. All experiments for lap joint are carried out at a tilt angle of zero degree plunge depth of 0.2 mm. The aluminum sheet was placed over the steel sheet in each experiment with an overlap length of 30 mm. The weld sample shown in Fig. 11(a) was obtained at a rotational speed of 1800 rpm and a welding speed of 63 mm/min whereas the weld sample shown in Fig. 12(a) was obtained at a rotational speed of 1400 rpm and a welding speed of 31.5 mm/min. Detailed discussion on Fig. 11 and Fig. 12 are mentioned in the Section 4. The composition of both the materials used is mentioned in Tables 2 and 3. Images of the welded sample is taken with a digital camera in RGB format and cropped to the size of 2231×500. The entire image processing algorithm was developed in MATLAB 2012a.