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Development of a model for friction stir weld quality assessment using machine vision and acoustic emission techniques

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ABSTRACT

The surface texture of friction stir weld is related to internal structure of weld. The statistical image parameters along good and defect weld regions are quantitatively evaluated for quality from the weld bead images, which are processed and analyzed using machine vision technique and X-ray radiography. The weld strength obtained along the weld regions showing similar variations in Acoustic Emission (AE) data, which was acquired during welding and image data of the weld bead are analyzed to assess the weld quality. The combined model developed using limiting values of image data and AE data along different regions of weld evaluate the weld quality more reliably.

1. Introduction

The Welding Institute, UK developed Friction Stir Welding (FSW) process in 1991, which is a solid-state, environment friendly joining process which provides improved way of satisfactorily joining aluminum alloys (Thomas et al., 1991). Kumar and Kailas, (2008) investigated the role of FSW tool on material flow and weld formation and reported that the defect free welds are formed by proper shoulder contact with the base material. Suresha et al. (2011) have studied the effect of geometry of tool pin profiles on strength of the welded joints produced using friction stir welding process. It has been reported that the conical pin with threads performed better. Sinha et al. (2008) established linear correlation between the amount of shoulder driven material and the ultimate tensile strength, which controlled the occurrence of defect in friction stir welds by image processing technique. Dwight et al. (2006) examined friction stir welds of aluminum alloys produced using tools with various shoulder geometry and reported that surface roughness and metal deformation in the uppermost layers of welds are greatly influenced by shoulder design. Shaowen and Deng, (2008) carried out combined experimental and numerical investigation of texture patterns in friction stir welds along different cross sections and found that the banded texture of weld has close ties to the microstructure of the weld region and the bands have a strong effect on the mechanical behavior of welded joints. Scialpi et al. (2007) studied the influence of shoulder geometry on microstructure and mechanical properties of friction stir welds and reported that the interaction of tool shoulder with base material results in different heat input power, which influence the nugget grain dimensions, grain growth and in turn weld strength. From the literatures reviewed by Mishra and Mahoney (2007) on FSW and processing the shoulder surfaces (flat, concave and convex) having features like scroll, ridge or knurling, radial grooves and concentric circles are found to increase the heat generation, deforming more amount of material resulting in increased workpiece mixing and formation of high quality welds.

The outcome of the research on achieving defect free welds show that the weld bead surface, which is formed by the interaction of tool with base material reflects the influence of tool geometry in the formation of weld. Thus, in the present work the banded weld bead surface has been viewed as a characteristic feature for assessment of friction stir weld quality by machine vision technique.

Haralick et al. (1973) suggested twenty eight image textural features which can be extracted from graytone spatial dependence matrix. Venkatramana and Ramamoorthy (1996) and Gadelmawla (2004) quantitatively evaluated image texture of machined surfaces by machine vision and digital image processing techniques

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by computing the image properties such as fineness, smoothness, coarseness, granulation, etc., using statistical methods. Bradley and Wong (2001) have described the techniques of use of magnified images of the surfaces generated to assess the condition of the cutting tool in metal cutting. Muthukumaran et al. (2008) proposed a methodology for online condition monitoring of the FSW process using image processing technique. The defects and the variations in the quality of weld are indentified by studying the texture pattern of weld bead image from histogram plot, variation in gray level from "line profile plot" and uniformity of weld bead contours from "contour plot". The line profile plot has the limitation in the sense it considers only the variation in gray values of pixels lying on the line defined. Hence in the present investigation gray values of pixels in a defined region instead of line has been considered using machine vision technique for weld quality assessment.

Acoustic Emission (AE) testing is a powerful Non Destructive Testing (NDT) method of examining the behavior of materials deforming under stress. AE refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material. When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy in the form of stress waves, which propagate to the surface and can be recorded by sensors (Pollock, 2007). Suresha et al. (2009) examined the application of AE technique to analyze the FSW process, which involves deformation, transformation and consolidation of material in solid state under the action of tool. Suresha (2013) studied the behavior of AE data during FSW of similar and dissimilar materials welded using different weld parameters and developed an on-line model to assess the weld quality and to monitor FSW process from the threshold values of AE signals extracted along good and defect weld regions. The contact type AE technique has been employed in this investigation to validate and to improve the reliability of application of machine vision technique.

In this investigation a model for friction stir weld quality assessment has been developed by analyzing the images of weld bead surface produced using optimum weld parameters and tools of different shoulder geometry having Concentric rings and Concave features. The images of weld bead have been processed to quantify the bead texture by evaluating first and second order statistical parameters from histogram and Gray Level Co-occurrence Matrix (GLCM) respectively. The variations in statistical parameters have been studied along good and defect weld regions identified by X-ray radiography results to set threshold values of image parameters. Further, the strength analysis of weld along regions showing variation in AE data, which was acquired during FSW, has been carried out to validate the results of machine vision technique. This improves the reliability of above methodology of machine vision technique, which was limited to occurrence of surface defects. The threshold values of AE data along good and defect weld regions have been combined with that of image parameters for the development of a model, which assess the quality of FSW using both machine vision and AE techniques.

2. Experimental details

2.1. Friction stir welding

The AA6082-T4 plates of dimensions 300 mm × 75 mm × 5 mm was used with tools of concentric rings and concave shoulder geometry with frustum shaped threaded pin made up of tool steel and the optimum welding parameters for AA6082-T4 employed by Suresha (2013) was adopted: welding speed 100 mm/min, tool rotation speed 1000 rpm, plunge depth 4.85 mm and tool tilt angel 2°for preparing butt welded joints. Table 1 lists the dimensions of the tools. Two specimens were welded per tool. The first specimen for each tool CN1(Weld Number 1produced having concentric rings tool shoulder) and CV1 (Weld Number 1 produced having concave tool shoulder) was welded with plates without holes across thickness to get defect free welds, while second specimen for each tool (CN2 and CV2) was welded with plates having the holes along the thickness to a length of about 10 mm from the butting edge. Welding of plates having holes has been done with an intention to induce defects and study the variations in weld bead texture formed during material consolidation in the defect region by different shoulder geometry.

2.2. AE data acquisition

The standard PCI-2 based AE testing equipment of MISTRAS, Physical Acoustics Corporation, U.S.A was used to acquire AE signals during FSW of specimens and the signals were processed and analyzed using AEwin software (Suresha, 2013). The Fig. 1 shows most widely used AE signal parameters namely, Amplitude, RMS, Counts and Energy.

Amplitude (A) is the highest peak voltage attained by an AE waveform. Root Mean Square (RMS) is the rectified, time averaged AE signal (voltage) measured continuously on a linear scale into the AE system. Counts (N) are the threshold-crossing pulses. Energy (E) is the measured area under the rectified signal envelope.

2.3. Image data acquisition

The weld bead images were captured off-line using high-resolution digital camera with uniform lighting and processed using Image Processing Tool Box of MATLAB. The Region of Interest (ROI) was defined along good and defect weld regions by comparing with X-ray radiography results. The textures of weld bead images were quantified by extracting statistical image parameters along each ROI. The "First order" statistics involved computation and extraction of significant features such as standard deviation and entropy from the histogram of the images. The "Second order" statistics involved computation and extraction of significant features such as contrast and energy from the GLCM.

Standard deviation measures the average contrast that is sensitive for both smooth and coarse surfaces. Entropy measures randomness of the surface texture. The value of entropy will be higher for coarse texture compared to periodic and smooth texture. This will be most significant parameter to assess banded weld bead texture. Contrast measures the intensity difference between a pixel and its neighbor over the entire image describing smoothness of the image. For the smooth texture, contrast value is 0. energy, which is also known as angular second-moment, measures uniformity of the texture. It considers the sum of square element in the GLCM. For the smooth texture, energy value is 1.

The tensile specimens were extracted along the regions of defect free welds, which revealed variations in AE data to study the variations in the strength of weld. The base material AA6082-T4 is a medium strength aluminum alloy with excellent corrosion resistance and Table 2 lists its mechanical properties. The tensile specimens were prepared as per ASTM-E8/EM-08 standards shown in Fig. 2 along the direction perpendicular to tool traverse and tested on Electronic Tensometer.

3. Results and discussion

The effectiveness of the shoulder in forming defect free weld was evaluated by the amount of surface roughness, and uniformity of weld bead produced during welding (Burford et al., 2006) using workpiece with and without holes across the thickness in the butted edge. The statistical image parameters obtained for different