Use of Machine Vision Technique to Analyze Friction Stir Weld Bead Surface of AA6082-T6 formed by Scroll shoulder Tool

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Abstract: **In Friction Stir Welding (FSW) tool shoulder plays an important role in solid state joining of materials. It interacts with materials to be joined, generating required frictional heat and hydrostatic pressure during welding along weld line. Tool shoulder enables to plasticize and hold the material beneath the shoulder, preventing it to flow out of the weld cavity. In the present investigation the interaction of tool shoulder in forming the friction stir welds of AA6082-T6 using scroll shoulder tool geometry is understood by analyzing the images of weld bead surface using Machine Vision technique. The weld bead surface have arc shaped banded bead texture, which is formed by merging of shoulder-driven material with pin-driven material behind the tool during the weld. The image data acquired via histogram and Gray Level Co-occurrence Matrix (GLCM) as first and second order statistical image parameters quantify the weld bead texture along good and defect weld regions. This enables digital image correlation to assess the weld quality.**

Keywords**: Friction Stir Welding, Machine Vision, Digital Image Correlation, Statistical Image Parameters, Shoulder Geometry.**

I. INTRODUCTION

The Aluminum alloys have mechanical strength similar to structural steel and low weight, which allows significant weight reduction finding wide applications in aerospace, automotive and shipbuilding industries. The components of Aluminum alloy components are successfully welded by FSW, a solid state welding method developed by 'The Welding Institute' (TWI), UK in 1991[1]. During welding the rotating pin of tool is plunged into the interface of the plates to be joined, until the shoulder contacts the plate's surfaces. The frictional heat is developed from tool shoulder and the deformation heat is developed from the tool pin when the tool traverses along weld line. This leads to progressively plasticizing the material from leading edge merging the materials, which flows layer wise from pin-driven region and in bulk from shoulder-driven regions to form weld. The proper contact of shoulder with base material generates sufficient amount of frictional heat and hydrostatic pressure in the weld line. This enables to fill the weld cavity with transferred material sufficiently coalescing shoulder-driven, pin-driven and base material forming defect free weld [2,3].

During welding as the tool rotates and traverse, the particles of work material which tend to attach themselves to the surface of the shoulder due to the frictional heat are plucked out of weld surface and transferred to another location [4]. This gives appearance of arc shaped banded texture to the weld bead surface. From the combined experimental and numerical investigation of texture patterns in FSW along horizontal, traverse and longitudinal directions showed banded texture of weld has close ties to the microstructure of the weld region and bands have a strong effect on mechanical behavior of welded joints [5]. Among the key functions of the tool shoulder is the control of material to ensure proper containment and consolidation. This is improved by providing the features like Scrolls, Ridges or Knurling, Grooves and Concentric circles on shoulder geometry having Flat, Concave and Convex surface. They helped in developing sufficient inwardly directed traction force to direct the contained workpiece material within features towards the pin improving weld closure by preventing the plasticized material from being expelled [6,7,8].

Quantitative analysis of the fractured surface of friction stir weld by image processing technique showed existence of linear correlation between the amount of shoulder-driven material and Ultimate Tensile Strength. This is due to the increased compactness of the weld offered by shoulder-driven material over pin-driven material, which results in defect free weld with better strength [9]. The efficiency of the shoulder in forming the defect free weld has been evaluated by the amount of flash that is produced along with surface appearance and uniformity of weld bead [10]. The images of weld bead formed at different welding conditions including tool pin failure and lesser pin depth was processed and analyzed to propose a methodology for online condition monitoring of the FSW process using image processing techniques. The presence of defects and the variations in the quality of weld are identified 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 [11].

From the above studies it can be inferred that the banded texture of friction stir weld surface formed by the tool shoulder interaction forms an important cue for understanding the FSW process. It can be viewed as characteristic feature relevant for inspection and evaluation by machine vision technology.

Image texture can be quantitatively evaluated using the properties such as fineness, smoothness, coarseness, granulation, etc., using statistical methods. This involves calculation of properties based on the gray tones of the specimens and following different orders based on the number of gray values considered for analysis and the type of relationship used. The first order statistics involves computation and extraction of features such as Mean, Standard deviation, Entropy, etc. from the histogram of the images. The higher order statistics uses Gray Level Co-occurrence Matrix (GLCM), also known as the gray-level spatial dependence matrix which considers the spatial relationship of pixels to examine the texture of image by the features such as Contrast, Correlation, Energy, etc. [12, 13, 14,15].

In this investigation the images of weld bead surface produced using selected weld parameters using Scroll shoulder geometry are processed to extract image data. Weld bead texture is quantified by evaluating first and second order statistical parameters from histogram and GLCM respectively. The variations in statistical parameters: Standard deviation, Entropy, Contrast and Energy which quantify weld bead texture by its uniformity and roughness are studied along good and defect weld regions identified by X-ray Radiography results for Digital Image Correlation (DIC) and thereby assess the weld quality.

II. EXPERIMENTAL WORK

The FSW trials are carried out on computerized ETA Friction Stir Welding machine using commercially available Aluminum alloy 6068-T6 plates of dimensions 300mm x75mm x5 mm. The scroll tool configurations used in the present work are shown in Table 1. The selected welding parameters employed for welding are rotating speed of 1000 rpm, traverse speed of 100 mm/min, plunge depth of 4.95 mm and tool tilt angle of 2^0. The holes of 3mm diameter and depth of 10mm along the width from the butting surface are drilled on the plates. This is done intentionally to induce defects and to study variations in weld bead texture formed during material consolidation in the hole region by scroll shoulder geometry. The axial load experienced by tool during welding is recorded by ETA stir welding machine. The images of friction stir welded specimens are captured using digital camera and uniform lighting.

Table 1 Tool dimensions and shoulder geometry

Tool Dimensions (mm)		**Tool with scroll shoulder geometry and frustum shaped threaded pin**
Pin length	4.7	
Pin diameter	D=6, d=4	
Shoulder diameter	20	
Shoulder length	25	
Thread pitch	1	

III. METHODOLOGY FOR IMAGE PROCESSING

The digital images of friction stir welded specimens are processed using Image Processing Tool Box of MATLAB to extract the image data for analysis. The color images are converted to gray scale images, suitable filters are applied to reduce the noise in the acquired image. Histogram equalization is carried out to enhance the contrast of image by stretching gray intensity between 0-255. The processed images of specimens are cropped along weld bead. Several Regions of Interest (ROI) along good and defect weld regions in comparison with X-ray Radiography are defined.

The surface characteristics of weld bead texture are quantified by extracting statistical image parameters of different ROIs. The statistical methods involve determination of image properties based on the gray tones and they are of two types based on the number of gray values considered for analysis and the type of relationship used. The "First order" statistics involves computation and extraction of parameters such as Mean, Standard deviation, Entropy, etc. from the histogram of the images. The "Second order" statistics involves computation and extraction of parameters such as Contrast, Correlation, Energy and Homogeneity based on the GLCM. The GLCM characterize the texture of an image by considering how often pairs of pixel with specific gray values and in a specified spatial relationship occur in an image.

IV. RESULTS AND DISCUSSION

The FSW of a specimen using plates with holes across the thickness is performed with selected weld parameters and tool of scroll shoulder geometry. The digital image processing of the images of ***Specimen welded with scroll shoulder-SS*** is carried out

The gray scale image of SS is shown in Fig.1, X-ray Radiography shown in Fig.2 of SS shows defect around the regions of holes, which is due to lack of fusion resulted from insufficient forging pressure. This is indicated by variations of axial force experienced by tool during welding of SS shown in Fig.3 around the holes regions (85-100sec, 120-150sec).

The presence of scroll feature as compared to flat shoulder without any features has better consolidation of material. The filling the hole in the initial stage of welding is seen, which is indicated by increased axial force (35-45sec). The processed weld bead image of SS with five different ROI (1,2,3,4 and 5) defined along good and defect weld regions is shown in Fig.4. Histogram of good weld region shown in Fig.5 indicates more frequency of gray values around 150 when compared to that of defect weld region. The histogram of defect weld shown in Fig.6 indicates distribution of few pixels in dark region (0-50 gray values) due to the presence of defective weld bead surface, which reflects less light. The variations in significant statistical image parameters which quantified the weld bead texture is shown in Fig.7. It indicates increased values of Standard deviation, Entropy and Energy in good weld regions due to presence of even weld bead texture.

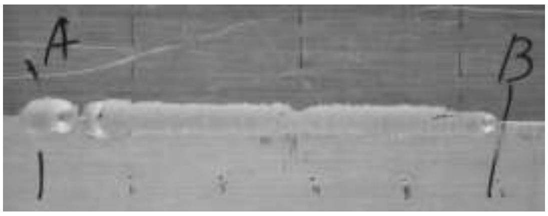

Fig. 1 Gray scale image of SS

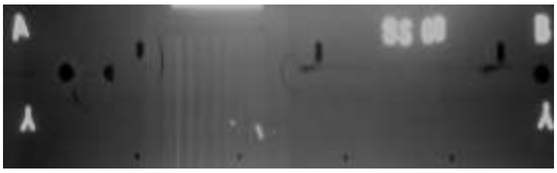

Fig. 2 X-ray Radiography of SS showing defects

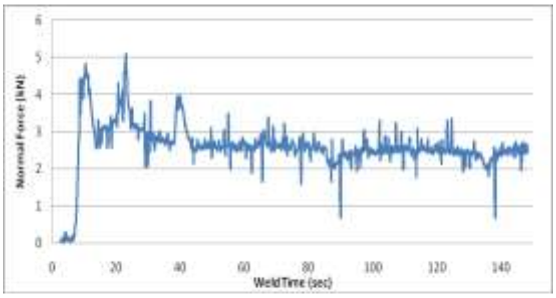

Fig. 3 Axial force experienced by tool during FSW of SS

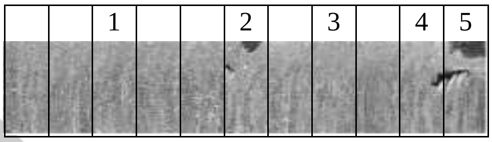

Fig.4 Processed weld bead image with ROI (1,3) along good region and ROI (2,4,5) along defect region

In defect weld regions increased value of Contrast compared to that of Entropy and Energy is observed due to presence of defects, which reduced uniformity and evenness in the texture. Similar observations have been made in respect to other ROIs corresponding to good and defect weld regions.

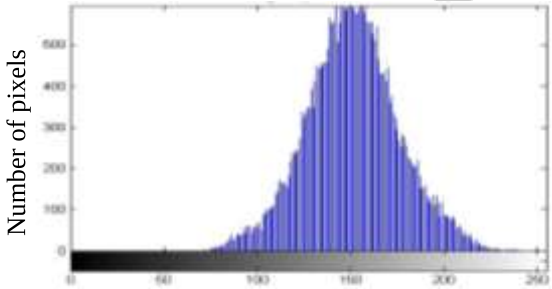

Fig.5 Histogram plot of good weld region (ROI 1)

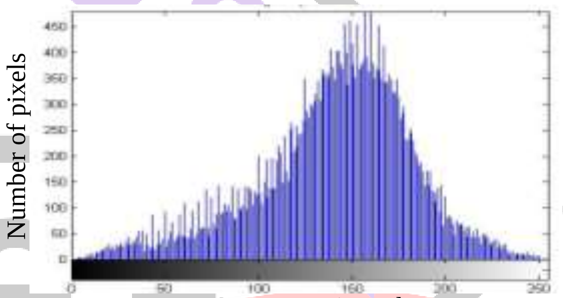

Fig.6 Histogram plot of defect weld region (ROI 5)

Table 2 Statistical image parameters of SS weld

Weld regions (ROI)	**Statistical image parameters**			
	First order		**Second order**	
	Standard Deviation	**Entropy**	**Contrast**	**Energy**
1	192.3023	0.9004	0.6745	0.1614
3	198.1608	0.9840	0.5318	0.1787
2	161.9136	0.0920	0.8075	0.1174
4	179.1353	0.3060	0.5455	0.1006
5	134.3465	0.1161	0.6753	0.1036

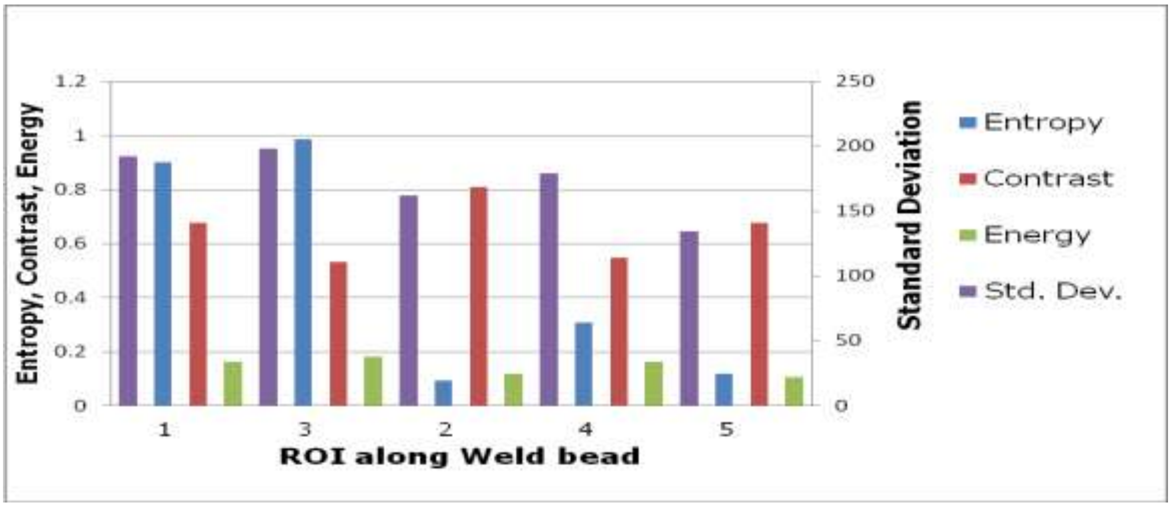

Fig.7 Statistical image parameters along good weld regions (1,3) and defect weld regions (2,4,5)

V. CONCLUSIONS

In this study application of non-contact machine vision technique is studied to assess the friction stir weld quality by analyzing weld bead surface texture produced using scroll shoulder geometry at constant weld parameters. From the results obtained the following conclusions are drawn:

The good weld regions showed more uniformity in bead surface due to better interaction of tool with scroll features on the shoulder, which is also indicated by axial force plot and histogram. This is justified by significant statistical image parameters which quantify the weld bead texture with higher values of Standard deviation, Entropy and Energy.

The defect weld regions showed rough and uneven weld bead surface due to improper tool interaction along holes region during welding. This is indicated by the axial force plot and unsymmetrical histogram. The statistical image parameters shows increase in Contrast value and reduction in Standard deviation, Entropy and Energy values compared to that of good weld regions.

The presence of Scroll feature on tool shoulder resulted in the improvement of material consolidation along holes region, which reduced defects in the weld. Hence, shoulder features on FSW tool compared to that of tool without any features (flat shoulder) helps in producing good welds.

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