Evaluation of Interfacial Fractured Surface in Aluminum–Brass Joint by Friction welding process through Image Processing Technique.

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Abstract— Welded Interfacial cracks in the friction welding of dissimilar metals are most important aspect for assessment of welding quality and welding strength. Manual inspection of the friction welded joint is purely depends on the skilled operators observations and experience in evaluating porosities, irregularities, cracks, and voids. The defects are traced by manual inspection based on experts experience and knowledge with respect to the combination of two dissimilar metals and their compatibility. In this research, an attempt has been made to apply the effectively technique for image assessment of the welded surface known as Image segmentation technique (IST) in determining the welded surface quality of dissimilar joint by friction welding. The weld bonding quality between dissimilar metals in friction welding is dependent on coefficient of friction between the welding surfaces. In order to explore the capabilities of the image segmentation technique friction welding experiments were conducted with various factors such as Coefficient of friction, Friction time, Friction pressure, speed, Torque of rotating work piece.Experiments were validated with the image processing results and claimed that the proposed image processing technique is an effective method in the assessment of fractured surfaces. Image processing technique is found to be easier in interfacial crack detection, reducing the computation cost, high-speed method with more accuracy in tracing welded defects.

This method has a significant improvement in the quantification of fractured surface, crack detection and non-welded areas detectionin terms of segment Pixels at the desired welded region and easy when comparedto conventional detection techniques by using operator's decisions.

Keywords: Friction Welding, Aluminum, Brass, Dissimilar Joint, Image Processing Technique.

I. INTRODUCTION

One of the versatile welding process still have abundant applications in product development is friction welding process. The friction welding (FW) processes are having major advantages in terms of strength and welding dissimilar metals for various automotive and automobile applications. Friction welding has unique capability and performance in welding with different metallic compositions. Alloys such as Non-ferrous and ferrous can be joined with efficient welded joint and many dissimilar metals. During friction welding metals does not exceed their respective melting points. One of the important aspects in friction welding process is the maximum temperature attained. Frictions welding of different metals are possible with source of heat generated due to friction between the stationary held metal in a chuck and rotating metal surface. Rigorous Friction between the stationary and rotating metal surface is properly controlled such that the heat generated will increase continuously till its melting point reached and both the metals welded. The present research work investigates the influence of the rotational speed, friction time, friction pressure, and friction welding of Aluminum (Al) and Brass. The effects of friction coefficient with different process parameters considered in the friction welding are friction time, friction pressure and rotational speed. Quantification of the quality of friction welding is done by image processing technique on the interfacial surfaces of welded zones. The experimental results showed that the effect of coefficient friction plays an important role on welding strength.

In the present research work traditional friction welding process was applied shown in Fig 1.

Experimental set up and schematic layout of the friction welding process has been shown consisting of joining of Al-6065, placed in a fixture and at the top rotating Brass around their axis of spindle rotation. A fixture holds both the metals together till the metal surfaces come in contact. The friction between fixed metallic and rotating surface tends to starts due to this heat generated due to friction and heating the parts to a high temperature close to but not exceeding their melting points. In the consecutive stages namely upsetting period, in this stage friction pressure will be tends to increased. After setting for a particular instant of time the welding process reached the solid state and the metals are welded.

The Mechanical Properties of both the dissimilar metals are tabulated in Table 2.Experimental runs were conducted on a drilling machine equipped with a range of 9 variable rotational speeds such as 200, 350, 550, 800, 1250, 1300 and 1500 RPM. Friction torque and friction force were recorded with piezoelectric type sensors located near the stationary metals. Welded joint interfacial temperatures were recorded with FLUKE Thermal sensor during different process parameters of FW process. High sensitivity of the thermal sensor ensures correct measurement accuracy of 20C.

Fig.1. Experimental Set-up of the Friction Welding process

Table 1: Mechanical properties metals used in the friction welding experiment

Metal	Density, g/cm^3	Tensile Strength, MPa	Young's Modulus, MPa	Elasticity of Modulus, GPa
Brass	8.3-8.7	124-310	338-469	97
Al	2.7	170	78	48

II. RECENT LITERATURE SURVEY ON FRICTION WELDING PROCESS

Sahin (2004) and Deng and Xu (2004) have done experiments on joining plastically deformed steel with friction welding. As per them the most interesting parameters which governs the friction welding process are friction time, friction pressure, forging time, forging pressure and rotation speed.Mumin-Sahin (2005) have done experiments for the joining of high speed steel and edium carbon steel using FW. They have also performed mechanical characteristics studies of FW joints by conducting tension tests, fatigue tests, notch impact test and hardness tests. The parameters have been optimized using factorial design. The two key factors considered for the study are friction time and friction pressure.Mohandas.T et al. (2007) have done friction welding of dissimilar pure metals. Different joints considered are Fe-Ti, Cu-Ti, Fe-Cu, Fe-Ni and Cu-Ni. All the joints have been subjected to tensile and micro structure studies. Continuous drive friction welding machine has been utilized for the studies. Different testing methods utilized are scanning electron microscopy, Electron Probe Micro Analysis (EPMA), X Ray Diffraction and Tension test.Ambroziak et al. (2007) has done friction welding of In-coloy MA956 Alloys. One of the specimens is work hardened and the other is thermally treated. Micro structure, micro hardness and tensile strength of the joints have been determined. They have also found out the optimum friction welding process parameters.Madhusudhan.G and Ramana.P (2012) have conducted experiments to assess the role of nickel as an interlayer in dissimilar metal friction welding of maraging steel to low alloy steel. They have used continuous drive friction welding machine for the study. To incorporate nickel as an inter layer, maraging steel and nickel have been welded first.

Shanjeevi.Cetal.(2013) have conducted experiment to evaluate the mechanical and metallurgical characteristics of dissimilar friction welded joints. The materials used are austenitic stainless steel 3042 and Copper. Tensile tests, hardness tests and micro structure studies and EDX line tests have been performed. Taguchi analysis has been used to assess the effect of friction pressure, upset pressure and rotational speed. They have found that the highest tensile strength is 2.52 higher than the parent metal-copper.Udayakumar et al. (2013) have performed experiments on super duplex stainless steel joints using FSW. Design of experiments has been done using central composite design of response surface methodology. Phase analyser software has been used to assess the ferrite contents. It is seen that FSW joints have possessed mechanical characteristics higher than the base metal.Radoslaw-Winiczenko and Mieczyslaw-kaczorowski (2013) have conducted friction welding of ductile iron with stainless steel. Scanning electron microscopy has been used for the investigation of the fracture morphology and phase transformation.Other studies have focused on modelling the frictional process by artificial intelligence with a symbolic or qualitative description. Artificial Neural Networks have been employed using experimental data of composites and coated materials [8], [9], [10], [11] which have been employed to produce with reasonable accuracy predictions of friction coefficient and with limited success of wear. Using sets from the same frictional behavior experiments as a training sample two different architectures of ANN were trained [12]. In this way, the ability and generalization capability of the proposed ANN was evaluated. All input and output data were normalized.A multi-thresholding of an X provide a useful result for further image analysis techniques due to high sharpness of the defects illustrate this, an Otsu-based algorithm was implemented [10], [11][12]. Result for segmentation intro 3 classes. Many welding methods including soldering, brazing, fusion welding and solid-state welding have been utilized to study the metal-ceramic dissimilar welded joints [1-5]. Among these familiar methods, friction welding process has attracts many researchers due to its solid-state process and short welding time, which can reduces the thermal compatibility between the base parent materials. Sound quality joints were thus proved to be stronger from friction welding of dissimilar joints. Considerable contributions have been made towards friction welding of ceramics and metal combinations [4-9]. Estimation of mechanical properties can be achieved by reducing the interfacial metallic thickness of welded zone of dissimilar metals. The thickness of interfacial metallic layer can be maintained by optimizing the process parameters and metallic composition of weld metal [10-14]. The welded joints which fractured during friction welding had tensile properties based on their process parameters and ability of process deformation of dissimilar metals at the interfacial region [15-20]. Also Paventhan R et al explored the optimization and predicted the process parameters which affect the Al-steel joint strength and quality. The friction stir welding of Mildsteel and Aluminum alloy by Sun et al. as well confirmed the optimized parameters in his work regarding the strength of friction welded joint between AA5052 Al alloy and high strength low alloy steel by Ramachandran et al. and Surendran et al[21-22]. The welding by friction plays a vital role in those products required more strength and less processing time, whether the specimens is rotary friction welding or Friction stir welding. The present research work aims at optimizing the process parameters of friction welding to achieve the effect of process parameters on coefficient of friction at the interfacial surface required for the good quality of welded joint. The optimizations of process parameters were determined along with the regression analysis in terms of parameters such as spindle speed,friction torque, friction force and friction time to evaluate coefficient of friction coefficient. Experimental tests were carried out in order to develop a correlation within the two dissimilar metals to be welded. The evaluated results are allows to predict the optimal operating process parameters which are experimentally validated. Then the image processing technique wasapplied on welded surface to check the weld quality in terms of fractured surface and crack detection of the welded joint. It is demonstrated that a good welded quality joint can be obtained by using optimized process parameters. The proposed methodology of Image processing has been successfully implemented in evaluating the welded surface cracks.

III. IMAGE SEGMENTS PROCESSING

There are certain industrial requirements to define their quality standards to meet exactly the customer's requirements and specifications. In major industrial areas process needs some inspection and testing to be performed on final products in mass or batch productions. The components are inspected by conventional or Non-destructive techniques. In this scenario image segmentation technique is considered to be power tool for accurate data interpretation in assuring the confirmed process parameters for quality based products. Fig (2) illustrating the procedural steps of the image segmentation technique. Many latest inspection systems are based on processing an image taken from an inspected product.

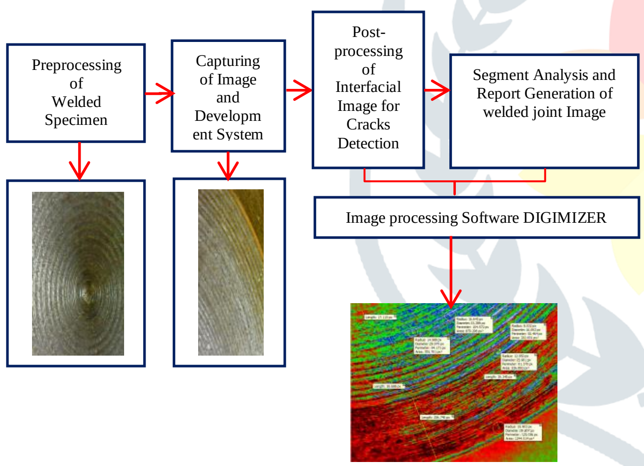


Fig 2: Processing steps of Image Segmentation Technique

In the present research work image processing technique (IST) was used for Friction Welding. Image processing techniques are applied to enhance and analyze the resultant image and with the help of knowledge based database in decision making whether the product can pass the quality inspection tests. The acquired images were captured and transferred to the computer for further processing by using DIGIMIZER Image Analysis Software for automatic inspection. The acquired images need to be pre-processed in order to be enhanced and possible flaws as segments to be evaluated and analyzed. The main objective of image preprocessing to improve the visibility of captured images to a suitable scale for the human eye. The segmentation process is one of the important images processing techniques for inspection system. It is the process of dividing, clustering the images into areas of desired segment analysis. A segmentation based routine or algorithm for a friction welding image needs to be bifurcated like porous region, edging, surface cracks, crack length, peaks, valleys and gas inclusions etc. The quantification of images for crack detection will be expressed in terms of the Pixels. Once the Image segmentation process is completed the resultant images in terms of segments are analyzed. This is a classifying process of different defects and it is considered a feature or pattern recognitions. A general feature extraction and recognition system consists of Segment processor, Feature detection unit and classification unit. From the input file flaws, pattern and segmented objects was traced. Feature detection unit extracts data information in terms of Pixels. The classification unit categorized features and patterns. In the present work analysis of the segmented image can be regarded as surface crack detection. Initially for each segmentation level feature is extracted and the features extracted from the desired region. This feature extracted is considered as a surface defect, surface crack length. Subsequently all the features are extracted and the repeated procedure will cover the desired region of inspection. The DIGIMIZER surface analysis software function starts from a fixed location as starting point in terms of pixels of the current feature to extract. Then, all similar featured pixels close to the starting pixel are evaluated, if a pixel is found to be of same grey-level as the first feature then it is confirmed to be of same featured category and the pixels are evaluated for the total region. The BRIGHTNESS will be expressed in terms of Green, Blue and Red Colors.

IV. MATERIALS AND METHODS

The metal specimens used in the friction welding experiments were cylindrical rods of length 90 mm and diameters 10 mm. The cylindrical specimens were maintained actual dimensions to 10 mm diameter by turning process. Friction welding machine used is operating with accuracy and repeatabilityof friction welding parameters. The spindle speed is maintained by an AC source, friction forces are recorded by using piezeo-electric sensor. The spindle motor capacity is of 50HP with 3 Phase AC and operating speed can be varied from 1 to 2500 RPM. All the experimental data with possible combination of welding parameters is recorded. The machine has a stroke length of 500 mm and a maximum friction force of 500 kN can be applied. The spindle speeds were varied in steps up to 2500RPM. Nine different combinations were friction welded and parameters for the nine combinations are given below in Table 3. The friction welding process was carried-out at constant pressure force, with 3 values of 65, 90 and 150MPa. The surface quality and textured surface of the welded specimens were examined by Image processing technique. Evaluation of the surface cracks and fractured welded surface arises due to various welding parameters. Welded interface region was inspected to observe changes on the surface due to effect of welding parameters by using optical microscopy. Crack length porosity and fractured surface are traced in terms of pixels of desired region and statistical analysis has been done for quantification.

Table 2: Friction welding parameters used in experiments

Runs	F_p, N/mm^2	F_f, N	F_t, sec	N_s , RPM
1	65	6217.2	5	100
2	95	9608.4	10	250
3	125	13564.8	12	500
4	65	6217.2	5	250
5	95	9608.4	10	500
10	125	13564.8	12	100
12	65	6217.2	5	250
8	95	9608.4	10	100
9	125	13564.8	12	500

V. RESULTS AND DISCUSSIONS

I. Investigation of Friction parameters on interfacial surface.

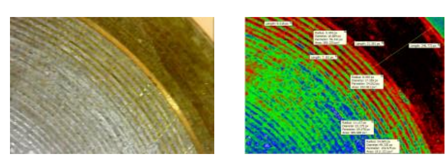
If the friction torque was increased, torque reached the initial value, the measured temperatures increased with increase in friction time. The main effective factors are friction pressure as 95MPa and friction torque as 35Nm. Although all measured temperatures were almost the same for maximum friction torque peak value. When a friction time was 0.08 s, both metal specimens had been rotated once and concentric rubbing marks were observed at the half radius portion of the weld interface. Based on the temperatures recorded with FLUKE IR camera results, it was observed that the heat input energy at the entire welded zone increases to the maximum value of the friction torque. When a friction time was 0.7s, concentric circular overlapping marks appeared on the surfaces and the almost whole weld interface fully developed at a friction time of 0.5s. As the friction torque rise to the initial maximum value, the flash on the interface welded region was also increased. Brass has a narrower heat affected zone compared to aluminum under the influence of input heat energy generated at welded region. In general the friction pressure will not be uniform with friction time as the two metal pieces possess different thermal conductivity. This is due to the higher thermal conductivity value in aluminum compared to that in Brass. The area of welded interface between the two metals changes with during welding and leads to the variation of the axial friction pressure. Due to the variation of contact area and friction pressure leads to different input heat give rise to crack and fracture of the surface during friction welding. The coefficient of friction varies widely with friction pressure and heat input energy. The increase in the friction pressure will increase temperature on the interface surfaces and coefficient of friction is considerably reduced.

II. Investigation of effect of Heat input energy and spindle speed on surface cracks.

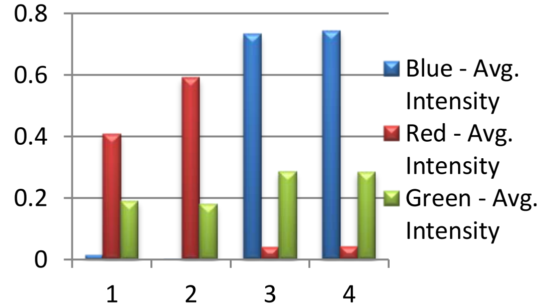
The friction time plays a vital role in generating the heat input energy also and thereby producing good weld interface welded joint. Surface crack growth decreases with more input energy from higher crack lengths to nominal interface surface thereby concluding uniform welding at the interface is achieved. From the Micro graph shown in figure 3(a) and (b) it has been observed that 74.5% welded area consists of Aluminum and brass intermetallic bonding at the welded zone as presented in Table 4. The Brass metal covers the periphery outer boundary at the interfacial zone and welded zone length has 28.6% of the total welded zone. The following observations are made at the input heat energy 150W with spindle speed 550RPM, under these process combinations good quality of the welded joint could be possible. In case of less friction time the crack growth initiates during the initial period and extended to periphery. River patterns have been observed on the fracture surfaces of the welded interface at the friction time less than 5 sec and observed river patterns are confirmed. There are crack detections and porosities distributed on the interfacial fractured surface. It can be concluded that less friction welding time leads to the fractured surfaces are relatively more when compared to the extended friction time conditions.

III. Investigation of Heat flux generated and Friction pressure on Interfacial Welded Region

It has been observed from the micro graph shown in Fig 4(a) and (b) as the friction pressure increased the fractured surfaces are decreases even on the periphery and at the center of the welded zone.There are porosities and crack detections distributed on the interfacial fractured surface. If the friction heat input energy and friction pressure increase consequently the welded surface will have uniformity in metal bonding.
The optimized friction pressure is 125N/mm^2, at this pressure the Blue colored intensity of brass metal welded with aluminums at 77%confidence limit as given in Table 5. Due to more heat input energy the fractured patterns are having less intensity on the fracture surfaces of the welded interface at the friction time less than 3 sec and observed river patterns are confirmed. It can be concluded that less friction welding time leads to the fractured surfaces are relatively more when compared to the extended friction time conditions**.** It has been observed from the Fig 5(a) and (b) as the friction time is more thefractured surfaces are decreases from high peaks to normal interface surface which means the uniform welding at the interface is achieved. The good quality of the welded joint could be possible if the friction time is more crack growth initiates decreases during the initial period and also extended to periphery.Table 6 presented the percentage of blue color intensity reached 77% and less patterns have been observed on the fracture surfaces of the welded interface are crack detections and porosities distributed on the interfacial fractured surface. It can be concluded that less friction welding time leads to the fractured surfaces are relatively more when compared to the extended friction time conditions.



(a) (b)

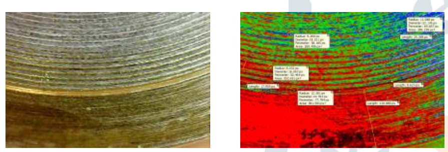


(c)

Table 3: Digimizer-Statistics of Measurements

Tool	Mean	SD	Min	Max
Length	69.71	114.20	7.18	240.7
Area	703.29	807.97	232.06	1911.2
Perimeter	0.27	0.27	0.04	0.59
Red Avg. Intensity	0.23	0.05	0.17	0.28
Green Avg. Intensity	0.37	0.42	0.002	0.74
Blue Avg. Intensity	13.46	7.54	8.595	24.6

Fig 3: (a) Friction welded tracks at the Welded Interface (b) Image Segment Analysis of the fractures surface (c) Percentage of metal bonding at the Weld Interface.



(a) (b)

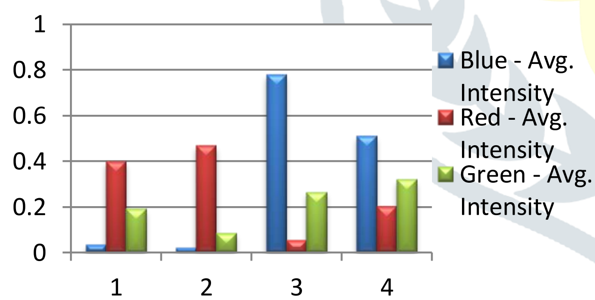


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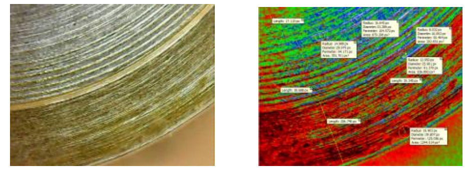
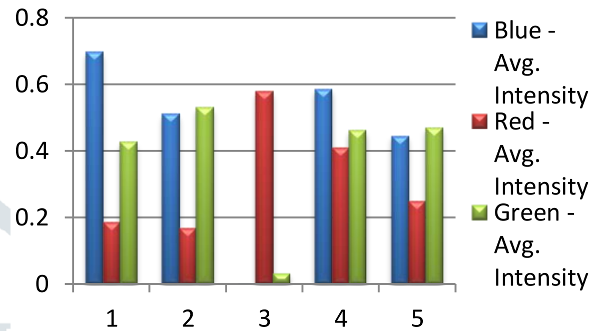
Table 4: Digimizer-Statistics of Measurements

Tool	Mean	SD	Min	Max
Length	59.01	85.34	8.62	210.868
Area	334.96	123.73	202.65	481.59
Perimeter	64.02	12.10	50.464	77.79
Red Avg. Intensity	0.28	0.18	0.05	0.468
Green Avg. Intensity	0.21	0.10	0.08	0.319
Blue Avg. Intensity	0.33	0.37	0.019	0.779

Fig 4: (a) Al-Brass Welded Interface at the edge (b) Segment Based Analysis of the crack length (c) Percentage of metal bonding at the Weld Interface.



(a) (b)



(c)

Table 5: Digimizer-Statistics of Measurements

Tool	Mean	SD	Min	Max
Length	59.01	85.34	8.62	210.868
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Blue Avg. Intensity	0.33	0.37	0.019	0.779

Fig 5: (a) Al-Brass Welded Interface at the edge Interface (b) Image Segment Analysis of the fractures surface (c) Percentage of metal bonding at the Weld Interface.

VI. CONCLUSIONS

In the present research the factors influencing the friction welding process are studied based on response surface method. The factors considered are spindle speed, friction pressure, friction force and friction time.The friction time plays a vital role for each experiment and demonstrates that as the friction time increases more heat input energy overcome the friction and penetrates more into weld interface without surface cracks.The weld quality tests were conclusive and demonstrate that the appearance of fractured surfacehas occurred at the interface with more peaks and porosities for less friction pressure values.The effect of experimental tests and results of optimization were in good agreement for the crack length and fractured surface for the less values of coefficient of friction due more friction forces acts at the interfaces. The morphology of river patterns appeared on fractured surfaces for the less friction pressure values and confirmed with the micrograph obtained from segmentation analysis having more pixels in fractured surfaces.

The appearance of micro cracks at the interface are due to thermo-mechanical coupling effects with less spindle speed and more friction forces during friction welding. The segmentation analysis technique proposed in this work is still useful for better controlling the frictionwelding method. The interface zone where fractured surface and crack length affects the strength of the welded joint are more dependent on friction pressure, Heat input energy and heat flux generated during friction welding. Therefore the optimized parameters and regression analysis proposed the effective parameters for good welded joint. The predicted optimized parameters of the friction welding are in good agreement with the experimental validations. Further studies on crack detection and study of interfacial fractured surface can be done on additives of reinforcement powder such as SiC and TiO_2 effect of these additions on different process parameters.

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