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Technical Paper

Torque based defect detection and weld quality modelling in friction stir welding process

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ABSTRACT

Efforts have been made towards the monitoring of friction stir welding (FSW) process using real-time torque signals in this research work. Signals were analyzed using discrete wavelet transform and statistical features namely dispersion, asymmetry and excess are computed. The computed features are further processed to develop effective methodology for internal defect identification in FSW process. A new indicator has been proposed combining the computed statistical features. The proposed indicator shows appreciable deviations for defective and defect free welds. Apart from defect detection using the computed signal features, they are also presented as inputs to a support vector machine learning based modelling tool for the prediction of ultimate tensile strength of the welded joints. The prediction accuracy of the model with computed signal features are found to be more than the model developed with process parameters. The comparison of the developed support vector regression (SVR) model with artificial neural network (ANN) model and general regression model yields that prediction performance of SVR is superior to ANN and general regression model. The proposed work can be modified for its successful use in real-time modelling of friction stir welding process.

1. Introduction

The expeditions of friction stir welding (FSW) process since its invention in 1991 is quite impressive. It brings suitable solution for joining softer materials like aluminum, magnesium etc. which were difficult to weld using fusion welding processes [1]. Due to its many advantages over other welding processes, it secures its acceptance in many industries. The demand in today's industrial environment is to meet production requirements in less time pushing the existing technologies to newer dimensions. Welding being the sub-process in many manufacturing industries; automation is the key to achieve the required output with reasonable accuracy and time. The FSW process is an automated process but monitoring of the process is quite challenging when it comes to real-time monitoring of the process.

Real-time monitoring of FSW process was targeted by few researchers incorporating different sensors to the physical process. Among different real-time signals acoustic emission signal, vertical and transverse force signals [2,3] were reported to be most capable in monitoring the FSW process. Subramaniam et al. [4] attempted monitoring of FSW process thorough acquisition of acoustic emission signal during the welding process. Effect of different pin profiles were investigated and concluded that square pin profile yielded maximum tensile properties of the joints. Acoustic emission signals were processed with wavelet transform by Chen et al. [5] for monitoring of FSW process. The objective was to detect in-process gap during FSW process. It was reported that acoustic emission signals processed with wavelet transform can lead to effective monitoring solution of the process. Boldsaikhan et al. [6] acquired vertical and transverse force signals during FSW process. Applying discrete Fourier transform to the signals and with artificial neural network, classification was performed to segregate defective welds from defect free welds. Monitoring of FSW process for defect identification was achieved by Das et al. [7] through fractal characterization of tool rotational speed signal. Fractal dimension of the signal was presented as an indicator for classifying defective welds from defect free welds. Fleming et al. [8] presented the in process gap detection methodology during FSW process. Frequency analyses of force signals were performed in order to detect gaps during the welding process. Automatic gap detection during FSW process was also reported by Yang et al. [9] using force signals. Discrete Fourier transform analysis was performed on signals to extract salient features for indicating in process gaps during welding process. Wavelet transform of acoustic emission signals

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acquired during FSW process was presented by Soundararajan et al. [10]. Power spectrum density analysis was carried out to investigate the role of different process parameters on FSW process. Vertical force signals during FSW process were analyzed with combined wavelet packet-Hilbert Huang transform by Das et al. [11]. In the work defect identification and modeling of weld quality were achieved using force signal features.

Appropriate design of FSW process demands real-time monitoring of torque and process forces as reported by Mehta et al. [12]. In the work, electrical signatures of driving motors were used for the estimation of real-time torque values along with traverse force during FSW process. The reported work offers a baseline for considering torque signal as an efficient medium for FSW process monitoring alternative to other force signals or acoustic emission signals being reported to use in FSW process. Torque based power and heat input models were developed by Pew et al. [13] for monitoring FSW process. It was reported that torque based models provide significant improvements over already existing methods. Apart from the torque in FSW process, in other manufacturing and related process researchers have established the effectiveness of torque in the monitoring of the respective processes. Kaya et al. [14] developed neural network models for the estimation of tool wear in milling operation using force and torque information. It was reported that the developed methodology offers a rich way in the estimation of flank wear of milling cutter over other methods. As FSW process closely resembles to milling process, force and torque can yield much significant information for process monitoring. In the literature attempts for developing monitoring method with force signals are more compared to torque signal information. Hence, this study is motivated to develop method for monitoring of FSW process with torque signal information. In extrusion process screw load torque dynamics had been proposed as an effective method for monitoring the process outcome by Abeykoon et al. [15]. It was commented that the developed methodology is efficient over other methods based on temperature and pressure sensors. Pena et al. [16] reported monitoring of drilling for burr detection using spindle torque values. Among different signals considered in the study, spindle torque signal was reported to be more informative. Features computed from the torque signals are correlated for the estimation of burr heights in drilling operation. Monitoring of single point cutting operation was attempted by Nguyen [17] et al. using polyvinylidene fluoride strain rosette for acquisition of force and torque signals. It was reported that the developed system is efficient over other systems used for force and torque measurement.

The aforementioned literature survey fetched that few researchers attempted monitoring of FSW process using various real-time signals. In the monitoring of FSW process, features obtained from force and acoustic emission signal is extensive compared to torque signal. The objective of the present research work is to present the effectiveness of torque signals in monitoring of the FSW process. Mehta et al. [12] commented that apart from the force signals, torque signal information is also having useful information regarding the process behaviour as it is associated with one of the most influencing process parameters namely tool rotational speed. However, efforts to address the effectiveness of torque signal in monitoring the FSW process are almost negligible when compared with force/acoustic emission signal. Therefore, this work demonstrates the effectiveness of torque signal in monitoring of the FSW process.

This study is aimed to explore the effectiveness of torque signals in monitoring FSW process that can offer a rich alternate to force or acoustic emission signals. Real-time torque signals are acquired using dedicated hardware and software during the FSW process and analyzed using discrete wavelet transform. The decomposed signals are investigated to compute three salient features namely dispersion (D_{xN}), asymmetry (S_{xN}) and excess (E_{xN}). These features are further combined to propose a new defect indicator for identification of internal weld defects exist in FSW process. Later, the three computed signal features are presented to data driven support vector regression (SVR) model for prediction of ultimate tensile strength of the joints. Similar approach has not been found in literature in monitoring of FSW process with acoustic emission signals or force signals. Thus, this can be treated as an imperative contribution of the present research work. The ideology of the current research work is represented schematically in Fig. 1.

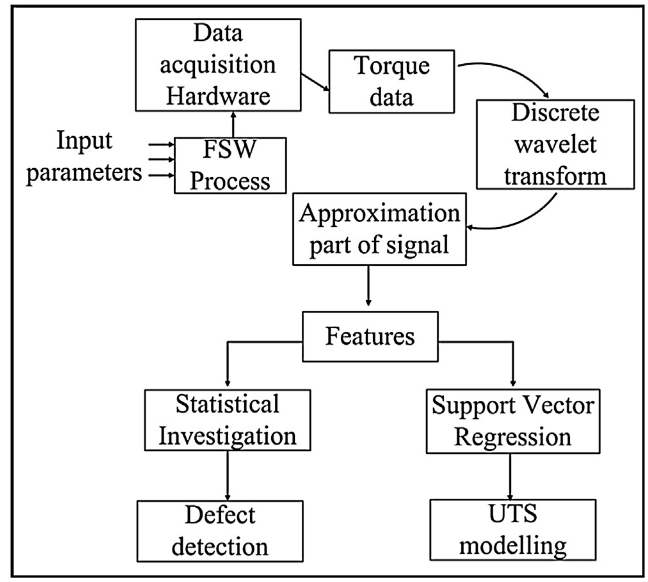

Fig. 1. Schematic representation of the ideology of the proposed research work.

Table 1
Chemical composition and mechanical properties of AA1100.

Chemical composition		Mechanical properties	
Element	wt%	Properties	Value
Si	0.2	UTS	119.8 (MPa)
Zn	0.2	YS	106 (MPa)
Fe	0.2	% elongation	17.1
Cu	0.1		
Al	99.3		

2. Experimental procedure

Aluminum alloy AA1100 was used as the base material for conducting the FSW experiments in square butt joint configuration. The chemical composition and mechanical properties of the base material are listed in Table 1. The dimension of work piece is 160 mm × 110 mm × 6 mm. A knee type vertical milling machine modified for conducting FSW process is used in this work. SS316 was used as the tool material and tools used are straight cylindrical with plain pin profile. The length of the tool pin is 5.7 mm with pin diameter of 6 mm. Tensile test specimens are prepared as per ASTM E8M standards and a servo controlled hydraulic operated testing equipment (make: INSTRON; model: 8801) is used for testing the specimens.

The design of experiment matrix is obtained by varying tool rotational speed, welding speed and shoulder diameter all in four levels and implementing full factorial design approach. A total of 64 welding experiments are conducted in a random order and one experiment is repeated to study the process variation that is chosen randomly. The respective levels of each parameter with responses