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Defect detection in friction stir welding process using signal information and fractal theory

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Abstract

Detection of defects in welding is always a challenging task. In friction stir welding process, most of the defects are subsurface which needs special techniques for its detection. In the present research work, an attempt has been made to identify the defects in friction stir welded samples through the information contained in signals acquired during the process. For this analysis, force signals, tool rotational speed signal and main spindle motor current signatures are analyzed using well known fractal theory. Higuchi's fractal dimension algorithm is implemented to extract signal based information in terms of single valued indicator known as fractal dimension. The accountable variation in the computed fractal dimensions against the signals for defective and defect free cases demonstrates the applicability of fractal theory in detection of sub surface defects in friction stir welding process.

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1. Introduction

The process of friction stir welding is relatively free from defects which are inevitable to occur in fusion welding processes [1]. Even though defects in friction stir welded samples are experienced which are the outcome of improper selection of combination of different process parameters, the defects found in friction stir welded samples are mostly subsurface [2]. This brings the limitation to visual inspection methods for identification of defects in the

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welded samples. Available non-destructive methods are applicable in detection of internal defects but these methods need high investment and precise experience for the analysis of the collected information.

Kim et al. [2] studied the effect of different combination of process parameters on defect formation in friction stir welding of die casted aluminum alloy. From the investigation, optimum welding window for the process parameters were proposed to avoid defect formation during welding. Zhang et al. [3] proposed a mathematical model correlating the plunge force, shoulder radius, pin radius and welding speed for obtaining defect free weld during AZ31 magnesium alloy. A criterion based on axial force, torque and process parameters for identifying defects in friction stir welding of 6061 aluminum alloy was proposed by Ramulu et al. [4]. The effect of tool tilt angle on defect formation in friction stir welding of 5456 aluminum alloy was investigated by Chen et al [5].

Most of the researchers contributed towards finding the optimum range of different process parameters to avoid defects. Contributions toward detection of defects in friction stir welding though non-destructive manner is less. Hence, in the present research work, an attempt has been made to develop procedure for defect identification in friction stir welded samples. Vertical force, traverse force, tool rotational speed and main spindle motor current signatures are the four process signals acquired and analyzed for the same. Signal information extracted though fractal theory will provide an indicator based on which conclusions can be drawn for samples to be defective or defect free.

2. Experimental Investigation

Friction stir welding experiments are carried out on AA1050 aluminum alloy in butt joint configuration. To carry out the experiments, a converted milling machine developed for the friction stir welding process is used. The main spindle motor is run by a three phase induction motor at a rated power of 5.5 kW with maximum possible rotational speed of 1500 rev/min and maximum line current of 16 A. For welding, tool material is chosen to be SS316 which is much harder than the base material. Two pin profiles as straight cylindrical and taper with a taper angle of 10° are selected for welding experiments. During the welding experiments, plunge depth is kept fixed at 0.06 mm. To carry out the experiments, tool rotational speed is varied as 600 rev/min, 1100 rev/min and 1500 rev/min keeping the welding speed fixed at 98 mm/min. The experimental runs with different parameters are listed in Table 1. After the welding experiments, welded samples are sectioned at suitable lengths to observe internal defects.

Table 1. Experimental runs with process parameters.

Exp. No.	Tool rotational speed (rev/min)	Welding speed (mm/min)	Shoulder diameter (mm)	Pin profile
1	1100	98	20	Taper
2	1500	98	20	Taper
3	600	98	20	Straight cylindrical
4	1100	98	20	Straight cylindrical

3. Signals acquired during welding

Four process signals, namely vertical force, traverse force, tool rotational speed and main spindle motor current are acquired during each welding experiments. Force signals are acquired using strain gauge based dynamometer developed in house dedicated for friction stir welding process. The acquired force signals are filtered using fifth order Butterworth filter in MATLAB software package and converted to actual force values using the calibration equations formulated during the development of the dynamometer. Tool rotational speed signal is acquired using a noncontact type laser sensor at a scale of 1000 rev/min = 1V. Current signal from main spindle motor is acquired through a hall effect current sensor set at scale 100 mV = 1A. All the signals are acquired at a sampling frequency of 10 kHz. Arrangement of different sensors is schematically shown in Fig. 1.

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