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Research Article

Vibration Signature Based Monitoring on FSW Process and Verification by FEA

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Abstract

Experimental study conducted during joining butt weld in FSW process on Al 6061 alloy of size 50 mm width X 100 mm length X 8 mm thickness of two plates wherein the effect of the interaction between the plates, tool and the vibration that occurs during the process are investigated, are reported. In this study, joining sides of the workpiece samples are artificially induced with air gaps of drilled holes in 2mm, 3mm, 5 mm diameter holes and 3mm width X 4 mm depth of slots in random distances. The vibration behaviour of the tool and workpiece joining system are characterized by a frequencies arrived in modal analysis using Finite Element Analysis (FEA), each mode corresponds to tool and workpiece system. Variations in the amplitudes of vibration signals in the particular range of frequencies from 6.0 to 7.0 kHz are proportional to workpiece and significant changes in linear pattern indicate the defective and steady joining area of workpiece. So, this method is effective in monitoring of workpiece joining in FSW process. The Fast Fourier Transform (FFT) analysis of vibration signal shows the changes in individual frequencies and is used for identifying the frequency range of monitoring workpiece with gap and without gap conditions. The steady joining portions cause the vibration which corresponds to 4thregion frequencies of workpiece.

Introduction

The friction stir welding process is a solid state combined that uses a non-expendable tool to link two non-melting material. This method can progress the mechanical properties of the joint, such as the strength and hardness etc. The heat will be created due to friction and plastic distortion between the tool and the work pieces. This friction and plastic distortion result in the mixing and agitation of the materials around the pin from the front to the rear. The heat generated by friction leads to the softening of metals, especially near the friction welding tool. This means that mechanical energy is converted into thermal energy in the contact areas, without the need for heat from other sources. The main function of the friction welding tool is to heat the parts, and then to induce the materials to flow and restrict under the shoulder and Impression action will generate friction between two surfaces and relative motion between two parts. People are studying to optimize process parameters for active connection of materials [2].

Literature

Premature failure of the welding tool can lead to unacceptable welding joint quality and loss of welding productivity. Friction welding is a completely machined process. The forces and vibration generated by the process are high enough that manual operation is not possible, except possibly for very fine materials. Therefore, for online monitoring of vibration is therefore in demand.

Lambiase et al. (2018) have investigated force variation, temperature and torque distribution in process with an al-Si-Mg aluminium alloy that varies the tool's rotation speed and welding speed. Temperature measurements were made using an IR camera. *Prasanna et al.* (2010) have observed the experimental and numerical evaluation with aluminium alloy aa6061. Temperature variation and simulation model is tested parameter with experimental results. *Buffa. G et al* (2008) have developed the distribution of temperature and tension in welding nugget was investigated. Projected the relationships between the forces of the tool and the variation in the parameters.Temperatureprofile almost symmetrical in the welding area was found. *Reza-E-Rabbya et al* (2013) have found pin characteristics in the flow of material and the weldability by stirring by friction of two aluminium alloys (AA 7050 and AA6061) with a pin tool cylinder, including the pin smooth/without thread attached to a geometry of shoulder displacement single invariant. Welds were made under a range of process parameters (welding and rotation speed). *Sadeesh Pa et al* (2014) conducted with plates of aluminium AA2024 and AA6061 dissimilar, and obtained the optimal parameters of the process. Different tool designs have been used to analyze the properties. Investigated the effect of welding speed on the microstructure hardness and tensile properties of the welded joints. As the process parameters varied, seamless, high-efficiency welded joints were produced. *Jalay Shukla et al* (2016) have observed mechanical and metallurgical properties by changing various parameter that FSW can be used to study the parameters on the process in laboratory. Experiments have been conducted to validate some of the simulation results of the ANSYS software. *Ramesh et al* (2016) have investigated (FSW) of aluminium alloy 6082 to study the tensile strength and hardness by changing the process parameter Speed of rotation and welding of the tool. And different weld condition. They found the effect of tool design on mechanical properties in FSW of AA6061. *Sakala Ramya Sree et al* (2018) studied the double-sided agitation friction welding of aa6061 plates using a hexagonal tool and process parameters was the speed of rotation and the welding speed. The resistance analysis is carried out on the welded joints AA6061. They used technique of order preference by similarity to ideal solution is used to identify the process parameters [1, 3-8].

In this paper, modal analysis of workpieces and hard tool using Finite Element Analysis (FEA) are compared with the range of frequency occurring during experiments in the fast Fourier transform (FFT) analysis of vibration signals. The fact of this approach is presented from friction stir welding (FSW) experiments using hard tool and an aluminium alloy workpiece.

Materials and Methods

Experimental Procedure

The workpiece materials used for experimental study are commercially available Al 6061. The size of the samples of workpiece plates are 100 mm length X 50 mm width X 8 mm thickness. The chemical compositions and material properties are tabulated in Table 1 &2 [9, 10]. The two plates were mounted using a clamp and retrofitted on a CNC milling machine which is shown in Fig.1 (photograph of the experimental set-up used to study friction stir process).Tool pin was made with D/d ratio (Shoulder/pin) of 3 in which Tool shoulder and pin made up of diameter 16 mm X height 60 mm pin diameter of 6 mm X height 7.5 mm respectively. The chemical composition and material properties are given in Table 3 & 4 [11]. Joining of workpiece samples were performed on a 3-axis CNC milling machine which has 3-axis movement and carried using a special CNC program which was run at speed 800 rpm and feed 33 mm/min [Ref]. Both workpieces are properly secured using a clamp. The vibration signals were measured using a (Kistler model- 8702B50) accelerometer sensor which is positioned on the clamp, used for holding dynamometer. A data acquisition card (NI 9133) used to convert analog output signals into digital signals. Among four of its channels, single analog input channel was used to collect the data by sampling the signals at 25 kHz and interfaced with a personal computer and simultaneously processed and recorded by LabVIEW software 8.5 (Sound and Vibration assistant).

Fe%	*Si%*	*Mn%*	*Cu%*	*Ni%*	*Cr%*	*Ti%*
0.244	0.741	0.095	0.157	0.01	0.125	0.007

Sn%	*V%*	*Co%*	*Zn%*	*Pb%*	*Mg%*	*Al%*
0.006	0.006	0.002	0.020	0.005	0.901	97.699

Table 1: Chemical composition of AA6061.

Yield Strength	*Ultimate Tensile Strength*	*Elongation*	*Shear Strength*	*Fracture Strength*
276 MPa	310 MPa	12%	207 MPa	94 MPa

Table 2: Mechanical properties of AA6061.

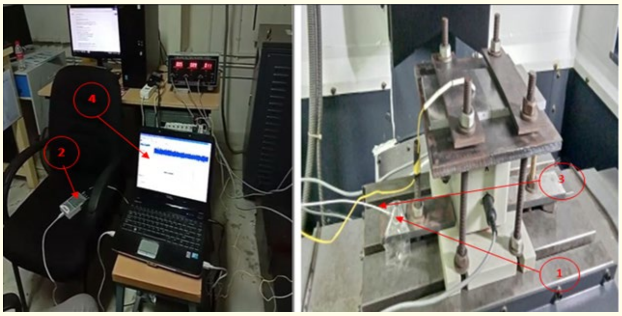

Figure 1: Photograph of experimental set-up with vibration monitoring system (i) Accelerometer (ii) Data Acquisition card (iii) Connecting cable (iv) Laptop.

Cr%	*Mo%*	*Si%*	*V%*	*C%*	*Ni%*	*Cu%*	*Mn%*	*P%*	*S%*
4.75-5.5	1.1-1.75	0.80-1.2	0.80-1.2	0.32-0.45	0.3	0.25	0.2-0.5	0.03	0.03

Table 3: Chemical composition of H13.

Density	7800 kg/m3
Melting point	1427°C
Tensile strength(Ultimate)	1.2 to 1.5GPa
Tensile strength(Yield)	1 to 1.3GPa
Modulus of elasticity	215 GPa
Poisson's ratio	0.3
Thermal conductivity	28.6 W/mK

Table 4: Properties o H13.

Methodology and experimental procedure

Fig. 3 shows the flow diagram of methodology followed for comparison through extracting the features from Fast Fourier Transform (FFT) of the sub module of Sound and Vibration software in the LabVIEW and modal anlysis of FEA. First step, it was planned to record vibration signals for beginning of the plate joining to ending of the plate joining for the size of 100mm length X 50 mm width X 8 mm thickness. Once the vibration signals were recorded through data acquisition card of converted analog to digital signal then further signal processing was carried in LabVIEW for feature extraction from time domain and frequency domain. In this project Vibration characteristics such as amplitude and frequencies are extracted in the FFT and used for comparison of frequencies arrived through modal analysis of free vibration in ANSYS 18.1.

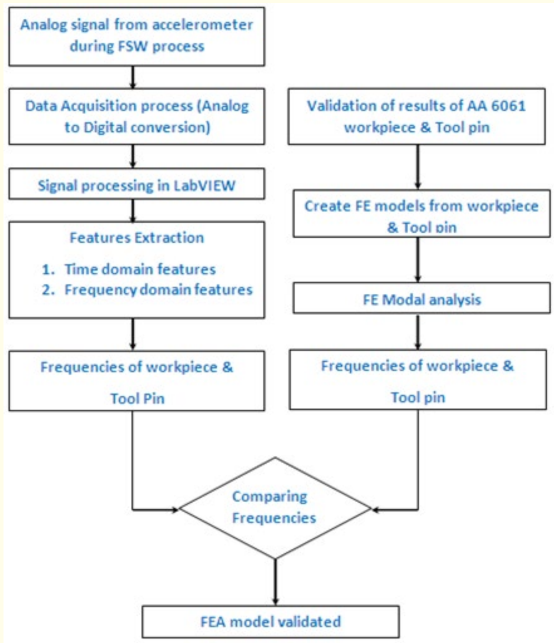

Figure 2: Flow chart of describing feature extraction from FFT and comparison with FEA.

Results and Discussions

FEA analysis

The workpiece with the size of 100 mm length X 50 mm width x8 mm thickness of two plates have been modeled together and outer perimeters are arrested to the dimensions equal to the dimensions of clamp of 20 mm on both sides which is used for holding the workpiece and input parameters are given such as mass density is 2710 kg/m^3 Young's modulus is 68.9 X109 N/m^2 and Poisson's Ratio is 0.3. Entire model is meshed and allowed to runthe rectangular plate in free vibration, arrived modal values for 30 modes. Table 5 shows that first 4 modal values of the rectangular plate. Figure 3(a) shows the meshing model of two workpieces and Fig. 3 (b) shows the modal analysis result of rectangular plates which are performed by FEA software (ANSYS 18.1) and shown for the first mode.

Component	***Modes of free vibration***	***I mode***	***II mode***	***III mode***	***IV mode***
Workpiece	By FEA, F_n (Hz)	6674.8	12960	13213	18614
Tool pin	By FEA, F_n (Hz)	3051.9	3052.2	13533	15817

Table 5: Modal values of workpiece in free vibration.

Tool pin is modeled for size of diameter 16 mm X height 60 mm of tool shoulder and diameter of 6 mm X height 7.5 mm of tool pin. Top surface of tool pin is arrested and input parameters are given such as mass density, Young's modulus and Poisson's Ratio of 7800 kg/m^3, 2.15 X10^{11} N/m^2 and 0.3 respectively. Entire model is meshed and is showed in Fig. 4 (a). Meshing model is used to run for free vibration and 1st mode result of tool pin is shown in Fig. 4 (b).

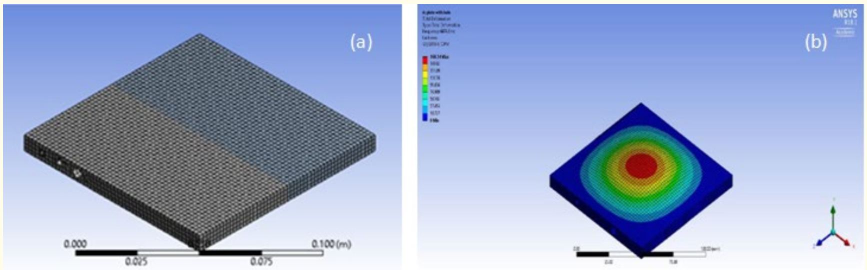

Figure 3: (a) Meshing model of two workpieces (b) 1st mode result of rectangular plates.

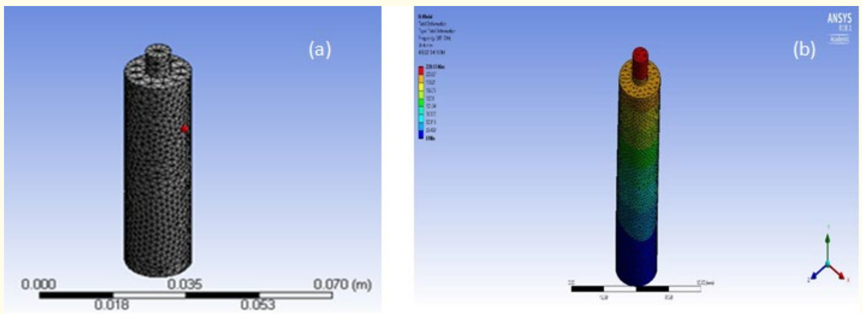

Figure 4: (a) Meshing model of Tool pin (b) 1st mode result of Tool pin.

Power Spectrum Analysis

Joining operations on plates have been performed using spindle speed of 800 rpm, feed of 71.2 mm/min. Fig.5 shows that the plates are joined with defects and the joined plates are separated into three segments such as metal joining at entry, steady joining and exit. Segmented areas are monitored through FFT and used for analysis. During entire process of joining, sensor was positioned at the fixture of the base plate. While joining plates, accelerometer sensor measured the vibration signal and LabVIEW software used to store the information in the computer. Totally 2 plates were used for joining up to 100 mm length. Time domain and corresponding frequency domain signals of three segments are shown in Fig.6. The amplitude was measured 4.5 X 10^{-3} m/s^2 at entry and exit of joining. While the metal in steady joining the amplitude level was 6.6 X 10^{-3} m/s^2. This is captured in the frequency range between 6000 to 7000 Hz. The variation in the amplitude level occurs because of friction between the contacting materials, due to which temperature also raises to solidification stage for joining metal. The results of the experiments conducted are shown inFig. 6, which provides time domain and corresponding power spectrum graph. Power spectrum indicates the corresponding frequencies (Hz) arrived in the FEA analysis. The figure 7 shows the bar graph of amplitude level against the various stages of plates.

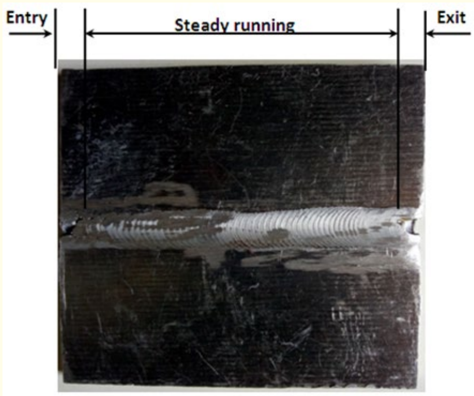

Figure 5: Plate segmented at three stages.

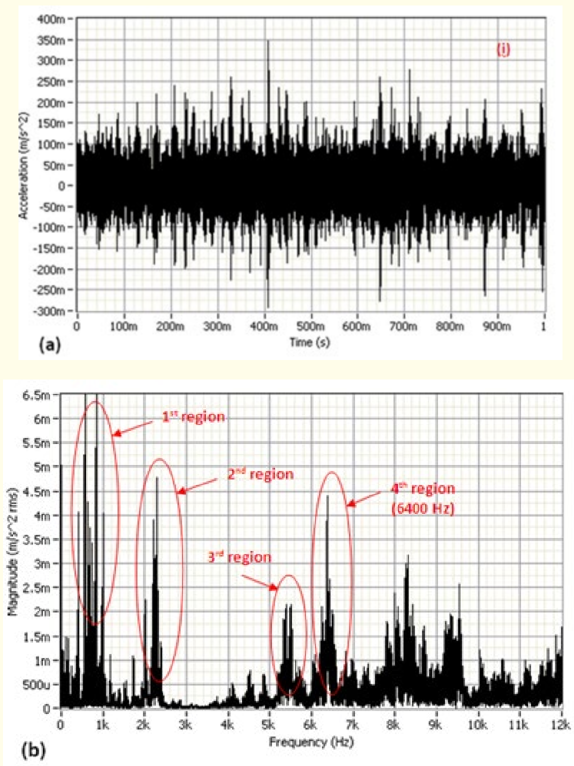

Figure 6: i.(a) Time domain and i.(b) corresponding FFT during entry.

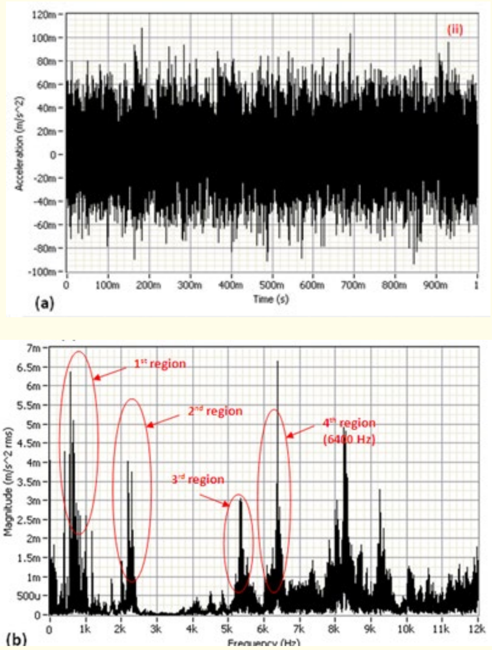

Figure 6: ii.(a) Time domain signal and ii.(b) corresponding FFT during steady joining.

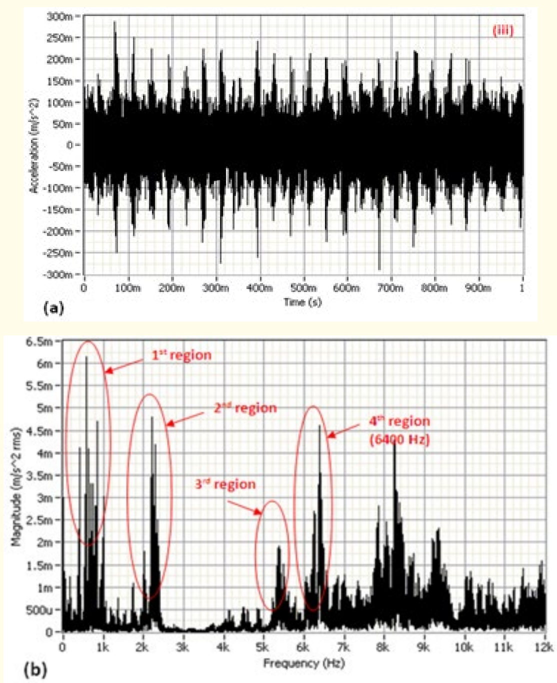

Figure 6: iii.(a) Time domain signal and iii.(b) corresponding FFT during exit of FSW process.

Figure 6: Comparison of Power spectrafor different stage joining of workpiece.

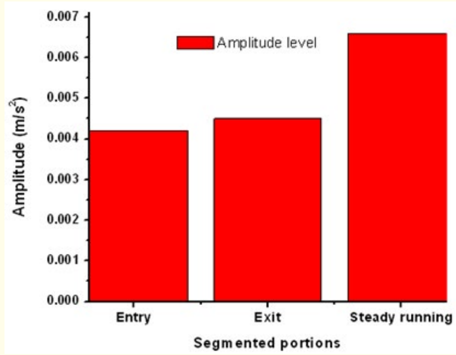

Figure 7: Effect of friction on amplitude.

Conclusions

In this study, a relation between the workpiece, tool stiffness and the vibration signals in joining process are reported. The stiffness of the workpiece is the most influencing parameter causes high frequency components in FSW process. The friction with temperature raise also causes notable changes in high frequency components of power spectrum. It was found that 4thregion of frequency 6400 Hz of workpiece frequency is affected by changes in metal joining pattern. This increases the vibration amplitude in the range of frequencies from 6.0 to 7.0 kHz. The increases in the vibration amplitude are observed in this frequency band and that are most sensitive during the metal process. This significant increase of amplitude by two times indicates the friction increases between tool and workpiece. It is concluded that the monitoring of 4^{th}region frequency of the workpiece can be utilized for effectively monitoring of defects during FSW process.

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