TOOL PROFILES EVALUATION BASED ON VIBROACOUSTICAL SIGNALS GENERATED BY FRICTION-STIR WELDING

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ABSTRACT

This paper presents a study to assess the relationship between the tool design and vibro-acoustic signals of the friction stir welding process in the aluminium AA1050. The characterization in time and frequency domains (Martinez-de-Pison et al., 2012) of vibro-acoustical signal and the statistical analysis have been carried out in order to correlate them with the design of two different tools (Jimenez-Macias et al., 2010). Vibro-acoustical signals have been filtered in order to eliminate the noise of the friction stir welding machine. Additionally, the Wavelet Transform has been used as an efficient tool for filtering vibration signal waveforms. The statistical analysis has confirmed that the vibro-acoustical signals were significantly affected by the tool design. It was found that there is valid information to assess changes in the tool profile in the frequency range of 0 to 100Hz. Analysis techniques based on the Wavelet Transform constitute a tool that can be efficiently used in the assessment of changes in the tool profile.

Keywords: Friction stir welding, signal processing, tool design, Wavelet Transform

1. INTRODUCTION

Friction stir welding (FSW) is a solid-state welding process with several advantages such as: energy efficiency, environment friendly, and versatile. Furthermore, it is a versatile joining technique, energy-efficient and with low environmental impact. The process is relatively simple: the pressure, friction and stir generated by tool, composed of a probe and a shoulder moving forward throughout the line of joint, plasticizes and forges the surrounding metal, achieving the welded joint. The material plastically deformed is transferred from the advancing side of the tool to the retreating side which allows the joint of two metal sheets in solid state (Threadgill 2007).

This process is considered to be the most relevant in terms of metal welding over the last two decades. It is widely used in automotive and aeronautics applications with remarkable results (Uday 2010; Aldanondo 2011; Martinez-de-Pison et al., 2010). Many researches have been devoted to FSW of aluminium alloys (Hassan 2010; Szkodo2010; Xunhong 2008; Cavaliere 2008).

Hassan (2010), reported the effect of the tool rotation speed and travel speed on the microstructure and the mechanical characteristics of the aluminium weld made of different metal sheets from the alloys A139 and the laminated A356 by friction stir welding. The authors proved that an increase in the rotational speed reduces the resistance to traction but increases the softness of the joint.

Szkodo (2010), assessed the parameters of the friction stir welding process of the aluminium alloy AW7075-T651 by means of a non-destructive technique so they could analyse and prove the relationship between the deformation in the mixture and the thermo-mechanically affected zones by the parameters of the process.

Several studies have covered the influence of the welding parameters and the tool profile in the microstructure and the properties of welded joints of aluminium (Cederqvist 2009; Mahmoud 2009; Hattingh 2008; Padmanabanand Balasubramanian 2009; Vijay and Murugan 2010).

Mahmoud (2009) analysed the effects of three different diameters and four different tool probes in the production of aluminium surfaces reinforced with SiC particles.

Hattingh (2008), developed a characterization of the influence of the FSW tool profile in the forces that take place in the process and the tensile strength of the welded joint. They took into consideration the influence of the tool profile as well as the visual information of the interaction between tool profile and plastic stir zone.

Valdameri and Esmerio (2009), performed an experiment in which they analysed the influence of the tool profile and the parameters of the FSW process of the aluminium alloy AA5052 and compared their results with other welding with the same metal sheets but using the MIG process. To achieve that, they used three different tools designs and different welding conditions. Finally, through a macro-graphic analysis and a set of tests of the mechanical properties, they reached to the conclusion that the AA5052 metal sheets welded by FSW with the proper tool and parameters have better mechanical properties than those welded with the MIG process (Martinez, Eguia and Godinez, 2012).

Tool profile is considered one of the main parameters in the control of the flow of material, heat generation and joint quality. Rai (2011), asserted that, within the tool profile, factors such as, shoulder diameter, shoulder surface angle, probe design and the nature of the tool surface play a key role in the process.

The feasibility of the application of the analysis of the vibro-acoustic emission generated by the FSW process is a topic of great interest for the field of Engineering due to the need of non-invasive techniques for the characterization and control of this kind of process. Nowadays, there are not enough studies available regarding the subject (Suresha, Rajaprakash and 2009; Burford 2010; Soundararajan, Atharifar and Kovacevic 2006; Fernández et al, 2012; Orozco et al, 2013,2013b).

Soundararajan, Atharifar and Kovacevic(2006) and Macias el al (2013), evaluated the possibility of the application of techniques of analysis of acoustic emission (AE) to monitor the FSW process. Based on the AE signal generated, the author determined the correlation between the loss of contact of the tool and the parts and the state of the welding process. The characteristics of the signal corresponding to the interaction with the parts and the state of the welding were studied using the Fast Fourier Transform (FFT) and the Discreet Wavelet Transform (DWT). The author explained how through the identification of frequencies during the process and the analysis of the signal by means of the Wavelet Transform, it is possible to monitor effectively the contact or lack of contact of the tool, or the transition state of the welding, and thereby accurately identify the changes in the process.

Other studies from Chen, Kovacevic and Jandgric (2003), show the application of the AE signals in the FSW processes. The authors assert that the FFT methods are no appropriate for these processes. Their research focuses on processing AE signals to determine how valid their use is to determine the abrupt changes on the tool profile.

All the bibliography consulted focuses on FSW for aluminum alloys, their parameters and their influence in the micro-structural changes and mechanical properties of the joint. However, there is no information available of the influence of the tool profile analysed through AE techniques.

The main objective of this work is the assessment of the influence of tool profile in the vibro-acoustic signals in order to prove the possibility of the application of this technique to characterize FSW processes (Roca et al., 2007, 2008, 2009).

2. MATERIALS AND METHODOS

The metal sheets used for the Research were made of aluminium AA1050 H24 with the following dimensions: 200 mm (L), 100 mm (A) and 3 mm (E). This alloy is well known for its conductivity and it is commonly used in the automotive industry, for the equipment of the chemical and food industry, light reflectors, and heat transfer units. This alloy is also used in other studies about the FSW process.

The chemical composition (wt%) of the AA1050 H24 used was as follows: Si = 0,25; Fe = 0,40; Cu = 0,05; Mn = 0,05; Mg = 0,05; Zn = 0,07; Ti = 0,05, Al = 99,5 and 0,03 corresponding to other elements.

The FSW process was made by means of a conventional CNC machine with position control in the three axes. The plates were butt-joined and locked in position using mechanical clamps and the direction of welding was normal to the rolling direction.

An on-line monitoring system was implemented to detect the changes of the tool profile reflected in the vibroacoustic signal (Figure 1).

Two vibroacoustic sensors (piezoelectric accelerometers) were placed at right angles in the upper (axis Z) and lateral (axis Y) surfaces of support plate. The sensors were placed in the base in order to make the experiments to be as close to an industrial environment as possible. A threaded coupling was used in order to guarantee a proper vibroacoustic transduction between the support plate and the sensor.

The values of the acceleration of the vibroacoustic signal in the directions Z and Y were taken using an NI USB-9234 instrument connected to a PC. All signals were sampled at 51.2 KS/s and processed using a software designed specifically for this purpose. Initially the generated vibroacoustic signal was acquired while the machine worked in a vacuum, with the objective of characterizing the noise contained in the signal.

The diameters of the probe and shoulder were 3 and 10 mm respectively. Two different probe designs were considered: a conventional grooved cylindrical probe (Tool 1) and a cylindrical probe with horizontal flutes (Tool 2). The shoulder profile for these tools was concave and similar for both tool designs.

During the tests, three levels of rotation speed (ω) and travel speed (v) were used (two boundaries and a central level). A factorial experimental design was used. To reduce the experimental error, the welding was carried out three times under the same conditions.

2.1. Methodology to evaluate the tool profile using the vibro-acoustic signals

Initially, a comparison of the vibro-acoustic signal in the time domain was made for each one of the analysed tool profiles. Also, a characterization of the frequency range of the background noise was performed in order to remove it from the vibro-acoustic signals.

Taking into account that the analysed signals are stationary, the assessment was made by means of the Wavelet Transform as an efficient tool for this kind of signal processing (Chen, Kovacevic and Jandgric (2003). It allows obtaining a higher resolution at the low frequencies, which turns to be of interest in the analysed process, taking into account the range of rotation speed evaluated in the research.

In this paper, for the decomposition of vibro-acoustic signals in the frequency ranges of interest, a level-8 Wavelet and a Daubechies mother Wavelet (Db5) were used.

Finally, the statistical analysis was carried out for the validation of experimental results. The results of the statistical tests were used to demonstrate the relationship between the design of the tool and the vibro-acoustic signals generated by the FSW process.

3. RESULTS AND DISCUSSION

In the FSW process, tool geometry is one of the main causes of mixing and flow of material. Probe and shoulder design, and the relative dimensions of their geometry are decisive (Widener,Burford and Jurak 2010).

Taking into account the above statement, it was verified that the tool profile may influence the flow of the material during the FSW process as well as the vibro-acoustic signal generated as a result of the physical phenomena taking place. The results for selected conditions are shown below.

Figure 1 shows the vibro-acoustic signals corresponding to two conditions with the same process parameters (ω = 450 rpm, v = 100 mm·min-1) and for the two different tool profiles evaluated.

Figure 3a corresponds to the results of the use of the conventional grooved cylindrical probe (Tool 1) and Figure 3b corresponds to the cylindrical probe with horizontal flutes (Tool 2).

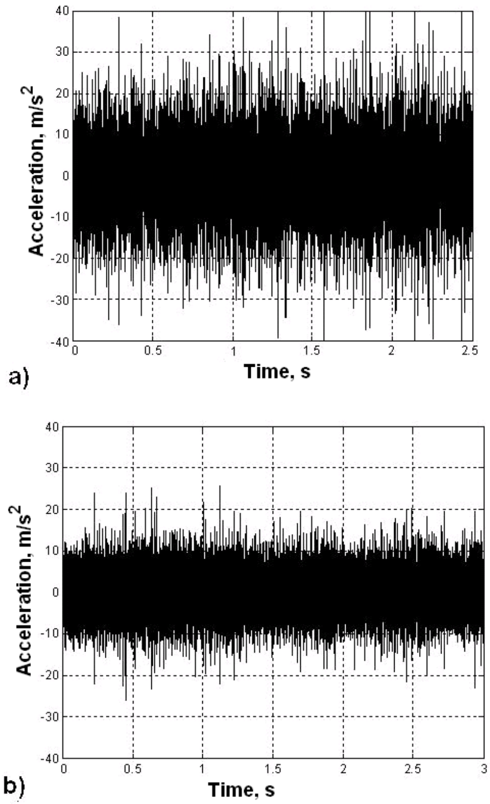

Figure 1: Vibro-acoustic signals for the two tool profiles (ω = 450 rpm, v = 100 mm•min-1). a) Tool 1; b) Tool 2

As shown in Figure 1, the vibro-acoustic signal level is higher for ω = 450 rpm, v = 100 mm•min-1and Tool 1.Vibro-acoustic signals are generated mainly by the friction between the tool and the material and the deformation undergone by the material.

This increase in the vibration levels may be associated with an increased contact surface between the tool and the material.Table 1 shows the values of the statistical parameters of the analyzed signals, and allows observing the changes of the tool profile in the parameters of the vibro-acoustic signals obtained during the process.

Table 2: Statistical characterization of vibro-acoustic signals.

Condition	RMS	Variance
Tool 1	6.35	40.34
Tool 2	4.01	16.11

In the case of cylindrical probe with horizontal grooves, much of the material flow occurs by simple extrusion, and the material does not seem to have vertical movement, which is apparently necessary to stabilize the rotational zone and provide enough deformation of the material to obtain a high quality welding.

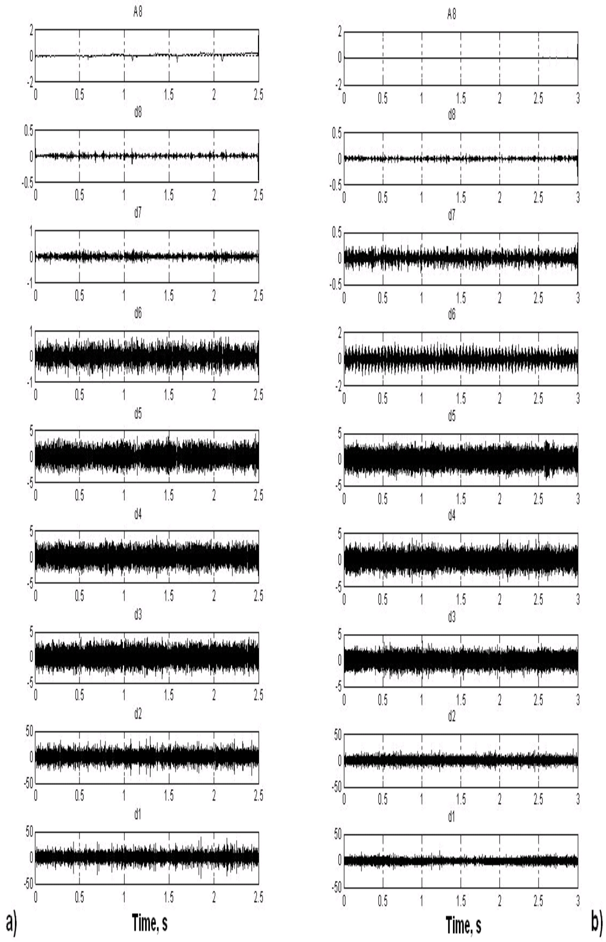

Figure 2: Wavelet transform for the Tool 1.

The presence of the grooves inTool 1 improves the vertical flow and mixing, causing an increment in the vibro-acoustic signal levels, as shown in Figure 1

3.1. Wavelet Transform

Considering that the FFT cannot properly describe the characteristics of the AE signal at low frequencies, it was decided to use other signal processing techniques that are feasible for this purpose.

The result of the DWT is a series of decomposed signals belonging to different frequency bands.

The graphs of Figures 2 and 3 shows the Wavelet transforms of the vibro-acoustic signals for the analyzed conditions. In this case, the DWT decomposition is applied using 8 levels and a Mother Wavelet Daubechies (Db5).

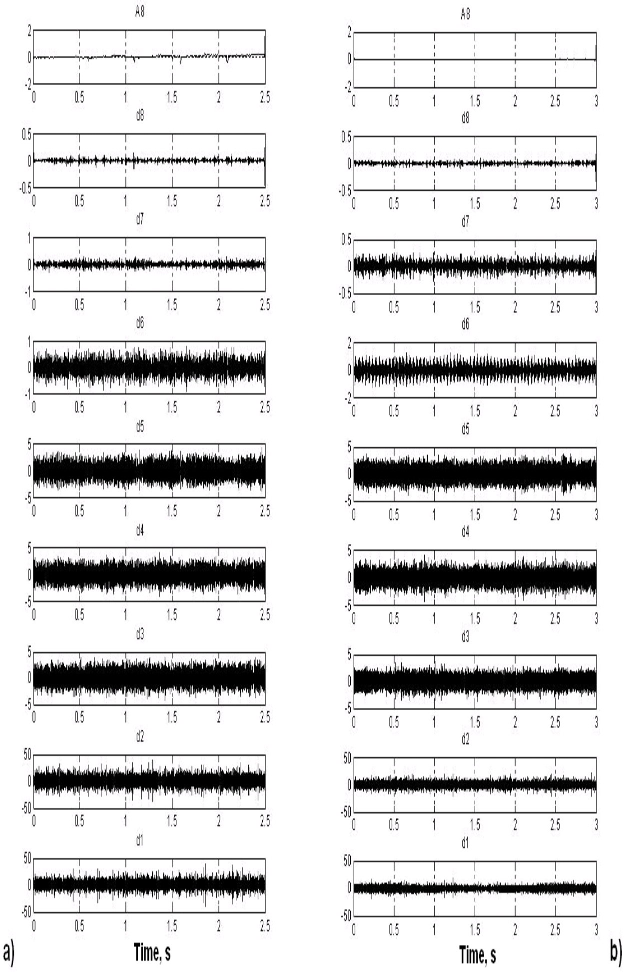

Figure 3: Wavelet transform for the Tool 2

A8 signal (Figures 2 and 3) can be considered as the result of making a lowpass filter to the vibro-acoustic signal with a resulting bandwidth of [0, 100 Hz]. D1-D8 correspond to the frequency bands [100, 200 Hz], [200, 400 Hz], [400, 800 Hz], [800 Hz, 1.6 kHz], [1.6, 3.2 kHz], [3.2, 6.4 kHz], [6.4, 12.8 kHz] and [12.8, 25.6 kHz], respectively.

A similar behavior for the two types of tool analyzed showed the decompositions D2, D3, D4, and D5. A comparison of D8 decomposition in the two conditions studied shows a difference in the signal frequency band [12.8, 25.6 kHz].

Therefore, in this work the Wavelet Transform has been used to obtain a series of vibro-acoustic signals decomposed in the frequency ranges of interest.

Figure 4 shows the approximation A8 for both conditions corresponding to the two tool profiles analyzed.

The analysis of the A8 approximations presented in Figures 4a and 4b (with a bandwidth [0, 100 Hz]) shows a visible difference at low frequencies between signalsof the different tool profiles.

With the objective of comparing the two types of tool profile and correlate them with vibro-acoustic signals at low frequencies some signal characteristics have been extracted, as shown in Table 2. The root mean square (RMS) and the variance are the statistical parameters that have represented the changes in the signals extracted from the DWT.

Table 2: Characterization of the A8 DWT of the vibro-acoustic signals.

Condition	RMS	Variance
Tool 1	0.09	0.009
Tool 2	0.03	0.0008

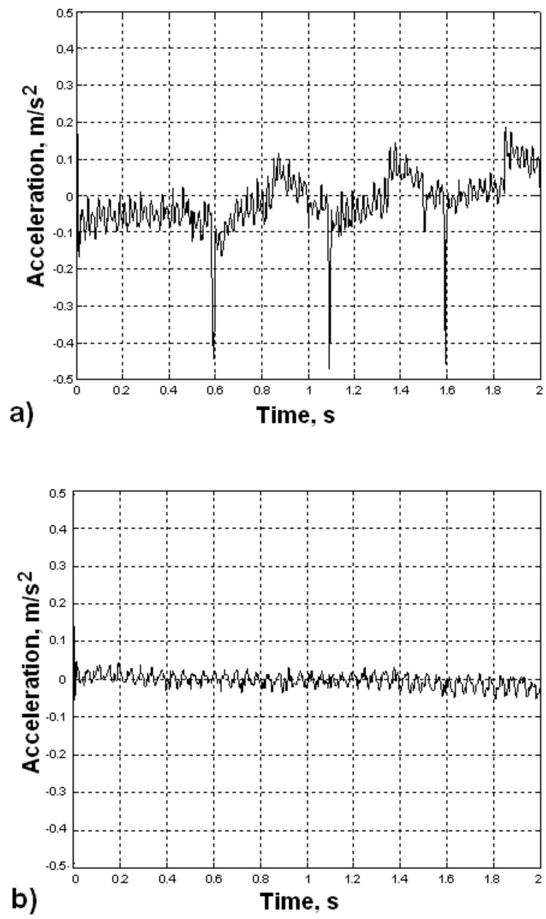

Figure 4. Approximation A8 for the tool profiles (ω=450 rpm y v = 100 mm·min-1). a) Tool 1; b) Tool 2.

Based on the statistical analysis, the fact that the tool profile significantly affects signals studied at low frequency (A8) is proved. This result may be related to the presence of the three grooves in Tool 1. This feature of the tool increases the resistance offered by the motion of the probe through the work piece.

An assessment of the effect of changes in parameters of the FSW process in the vibro-acoustic signals, weld quality, and mechanical properties of the joint, will be made in successive works as a continuation of this subject.

4. CONCLUSIONS

This research examines the impact of the tool profile on vibro-acoustic signals generated during FSW of the aluminum alloy AA1050 H24.From the analysis made it is concluded that:

1. The features of the vibro-acoustic signals in the frequency range of 0-100 Hz hold valid information to evaluate the changes in tool profile during friction-stir welding.
2. Vibro-acoustic signals may be applied as an effective on-line monitoring method of the changes in tool profile.
3. Junctions free of wormhole-type defects were obtained with the tool that incorporates a conventional grooved cylindrical probe; it was corroborated in the macro structural analyses made to all the test-tubes.
4. Analysis techniques based on the Wavelet Transform constitute a valid instrument that can be efficiently used to evaluate the changes in tool profile.

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