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Grain Refinement in Aluminium 1xxx Series as Effect of Vibration Torch Welding

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Abstract. Grain refinement is the best way to improve the mechanical properties of fusion welds of the aluminium. The grain refinement was thereby found to be strongly dependent upon the aluminium chemical composition, where the pure aluminium has the highest grain refining efficiency. In order to increase the strength of the weld area is carried out by TIG welding with vibration on the torch which aims to obtain a smoother welded grain deposit so that its strength will increase. Theoretically, smoothing of the weld grain deposits occurs due to the welding along with with the torch vibrations arising from the peak pressure generation, the development of shear stress, the density power and the presence of laminar flow around the dendritic arm resulting in the intersection of the dendritic arms which smooths the grains. To observe the effect of the frequency and amplitude of the torch vibration in welding to refine the welded grain deposits, the research conducted with 5 Hz and 10 Hz torch vibration and torque vibration amplitude (0.25; 0.50; 0.75; 1.10; 1.60 and 2.00) mm and welding speed of 100 mm/minute and 200 mm/minute, respectively. As a comparison of the extent to which the effect or effectiveness of vibration on the torch on the weld deposit grain size produced, welding without vibration with welding speed of 100 mm/minute. Increase the welding speed will reduce grain size; on the other hand, increase the frequency have affected different grain size. Meanwhile, increase the amplitude to 0.75 mm will reduce the grain size then the grain size will unstable with increasing amplitude.

1. Introduction

The welding and connecting process is an essential part of the actual development of manufactured products. However, this process often appears as a high cost of production in the manufacturing process. Meanwhile, to obtain a welding process with low cost, and on the other hand, adequate quality is not an easy thing [1-3], some reasons that can explain this problem. First, welding is a work with many variations of process options (such as fastening, adhesive bonding, soldering, brazing, arc welding) as well as the broad disciplines needed for problem-solving (such as mechanics, material knowledge, physics, chemistry, and electronics) [3]. Second, the difficulty of welding or connection usually occurs deep into the manufacturing process, where the relative value of scrap is high enough [4]. Thirdly, a very large percentage of broken/failed products occur in welded joints because they are usually placed in high-voltage regions in an assembly, and also the weakest part of an assembly [5-6]. Careful attention to the connection process can provide economically sufficient results in the manufacturing process and can also produce reliable products.

However, in each case, the strength of the weld metal deposit is a critical part of the connection performance. The strength of welding is traditionally based on both tensile and yield strength of the welding deposit [7]. The engineers generally rely on the classification of the electrode to determine the strength of the weld/weld joint [8-10]. This classification provides some basic information on the nature

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of the connection, such as yield strength and tensile strength. Although this classification is used for design purposes, the level of strength of the actual weld deposit may vary, this may, among others, be due to a modified or deviating process from a common procedure.
To obtain welding results at low cost but with adequate connection quality and strength, especially in the aluminium welding process, this study is carried out. The welding is carried out by providing vibrations at the torch in certain subsonic and amplitude frequencies, in this case, to obtain fine weld deposits. By refining of the weld deposit grains, then the strength of the weld bag of welding will be higher.

In this research, welding is done by vibrating the torch in the subsonic frequency on the aluminium work. Torch vibration is expected to occur the fracture in the secondary arm of dendrite growth, where this will produce fine weld deposits [11-13]. Observations were made by drawing a graph of the relationship between the grain size of the weld hail with the amplitude and frequency of the torch vibration at a particular welding speed. With the finest grain of the weld deposit, the hardness of the weld welding deposit will increase so that the tensile strength of the weld deposit will also increase [14]. The purpose of this research is to know the effect of frequency and amplitude of torch vibration on the large grain refinement produced in welding with the vibrated torch.

2. Experimental apparatus and procedure

2.1 Vibration Torch Welder
To conduct welding research with accompanying vibration on the torch, a tool that can support the research implementation is needed. This tool must have the ability to be controlled at the variable level set at the laboratory scale, which includes welding speed, vibration frequency, vibration amplitude, and the gap between the workpiece and the electrode (tungsten). For that purpose, a device has been made in the design and manufacture is done by trial and error. The design of the tool is not specific because, in this study, the orientation is on metallurgical analysis, not on the experimental tool itself. The tool has welding speed up to 300 mm/minute, vibration frequency and amplitude of torch are up to 15 Hz and 2 mm, respectively. The gap welding has also customized by the tool, and Figure 1 shows the schematic vibration torch welding.

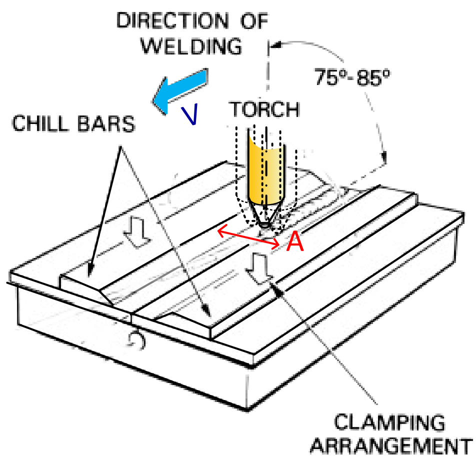

Figure 1. Schematic of vibration torch welding (adopted from [15] page 235)

2.2 Experimental Setup
The schematic diagram of the experimental setup is shown in Figure 2, consist of a vibratory torch welder which welding is done by using Tungsten Inert Gas (TIG) type Direct Current Straight Polarity (DCSP) with big current 100 A, with argon gas as a protective gas. The aluminium 1xxx series plate

was used as a specimen with 3 mm thickness. The workpiece was not cut into two parts but remains intact, and then was welded in the middle, as shown in Figure 2. Welding is performed with the torch that vibrates at frequencies 5, and 10 Hz, both of the frequency test have the amplitude of 0.0; 0.25; 0.5; 0.75; 1.1; 1.6 and 2 mm, respectively. Two welding speed of 100 mm/minute and 200 mm/minute was used at all frequencies. Direction of the torch amplitude perpendicular to the direction of welding. The gap between the tungsten and the workpiece is 2 mm, with a tungsten diameter of 1/8 inch. Figure 2 also shows the performed analysis of microstructure using a microscope and ImageJ software processing.

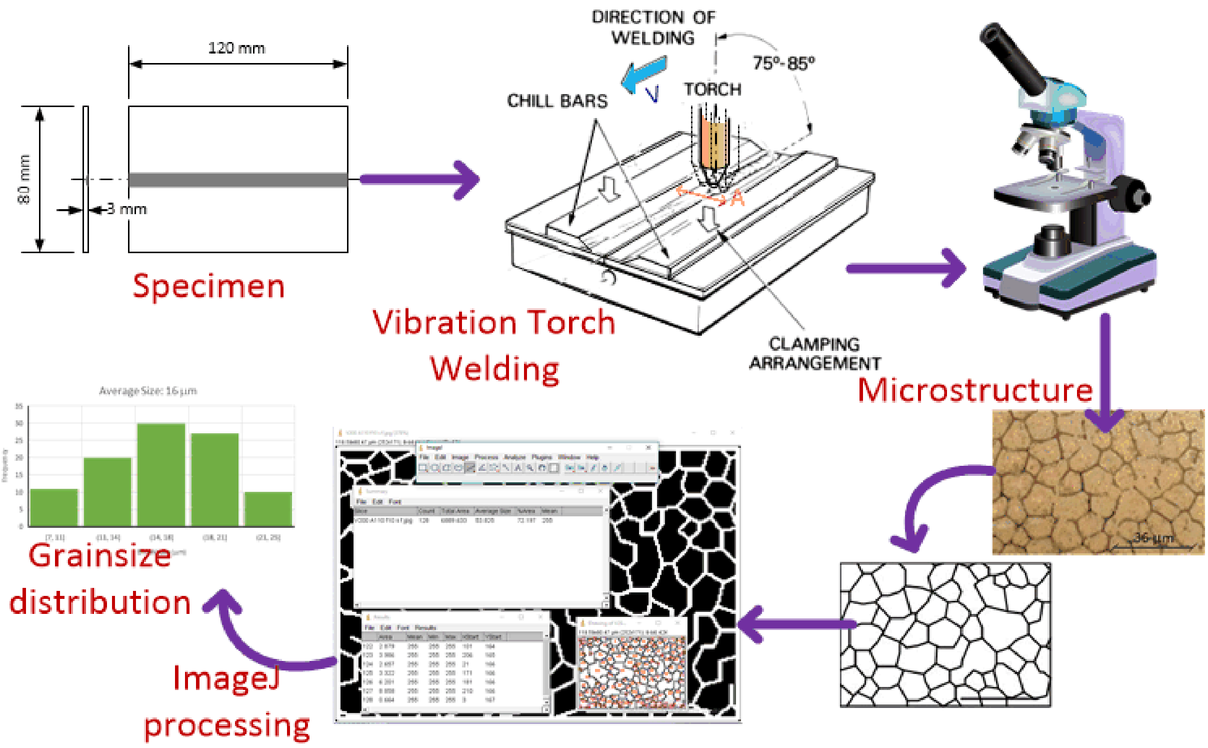

Figure 2. Schematic diagram of experimental setup.

TIG welding was used in this research because it was suitable for aluminium, and the design of the tool is simple. The welding can be done without a metal filler with a constant gap throughout the welding process. The study conducted several test variables that lead to obtaining the influence of vibration of the torch to the grain size of aluminium welding. In an attempt to obtain a larger grain of welded welder deposits, a study carried out by welding accompanied by vibrations on the torch. In this process, the main variables observed are the effect of frequency and amplitude of vibration on the torch to the smoothness of the weld deposit grain obtained. But, the other study said that the number of blowholes decreases with the decreasing frequency, and increases when the frequency is less than 15 kHz [16-17]. To observe the effectiveness of the effect of torch vibration on the refinement of the weld deposit grain, as a comparison is High-Frequency with variable welding speed, which also aims to refine the weld deposit grain. From these two studies will be obtained the answer of the effectiveness of vibration on the torch against refining weld deposit grain. Compared with the ordinary K-TIG (Keyhole TIG) weld, where the melting zone grains in High-Frequency K-TIG weld are so much refined [18]. On account of the larger welding current, the grain sizes and organizations of the welding zone in VPTIG (Variable Polarity power in TIG) welding were coarser than in DCEN (Direct Current Electrode Negative) A-TIG (Active agent TIG) welding [19]. In the welding process, HAZ (Heat Affected Zone) was subjected to higher temperatures, and thus growth of grains in HAZ was more evident than that in BM (Base Metal), and also in WM (Weld Metal) the grains become coarser with increasing TIG current and the density of the grain boundaries decreased [20-22].

3. Result and Discussion
In the results of this study, the material presented includes data and photo microstructure. The research is aimed to analyze the effect of vibration on the torch in welding to the yielded grains, where the variables used are frequency, amplitude, and welding speed. Grain size analysis was performed using ImageJ software [23-25]. Based on the microstructure images obtained, the results of grain size calculations were grouped on the influence of frequency, amplitude, and welding speed of the grain, as shown in Table 1.

Table 1. The average grain size (μm) of the vibrated torch of Aluminium 1xxx

A (mm)	V (mm/min) 100		V (mm/min) 200	
	f (Hz)		f (Hz)	
	5	10	5	10
0	36.47	20.64	33.75	36.39
0.25	28.33	29.11	19.91	17.46
0.50	18.74	19.80	15.37	18.39
0.75	16.12	10.77	13.48	9.41
1.10	16.17	17.99	17.98	13.10
1.60	27.59	26.11	16.47	20.60
2.00	20.17	19.27	13.32	16.02

The microstructure analysis was performed to confirm the grain sizes of the specimens. Figure 2 shows microstructure images of microstructure of vibrated torch welding and their distribution of grains at 0.75 mm amplitude. Figure 2 (a) shows the microstructure image with welding speed (V) 100 mm/min, and frequency (f) 5 Hz. The grain sizes spread between 2.65 to 27.94 μm and the distribution of grain size dominated by large grains. Increasing the welding speed (200 mm/min) as shown in Figure 2 (b), the average grain size decrease with the distribution of grain size center in the average range. Figure 2 (c) shows the microstructure image with welding speed (V) 200 mm/min, and frequency (f) 5 Hz. The grain sizes spread between 4.11 to 27.87 μm and the distribution of grain size also dominated by large grains. The average grain size decrease compares by the lower speed. Again, increasing the welding speed (200 mm/min) as shown in Figure 2 (d), the average grain size decrease with the distribution of grain size center in the average range. The average grain size reached the smallest size at this welding speed, with 10 Hz frequency.

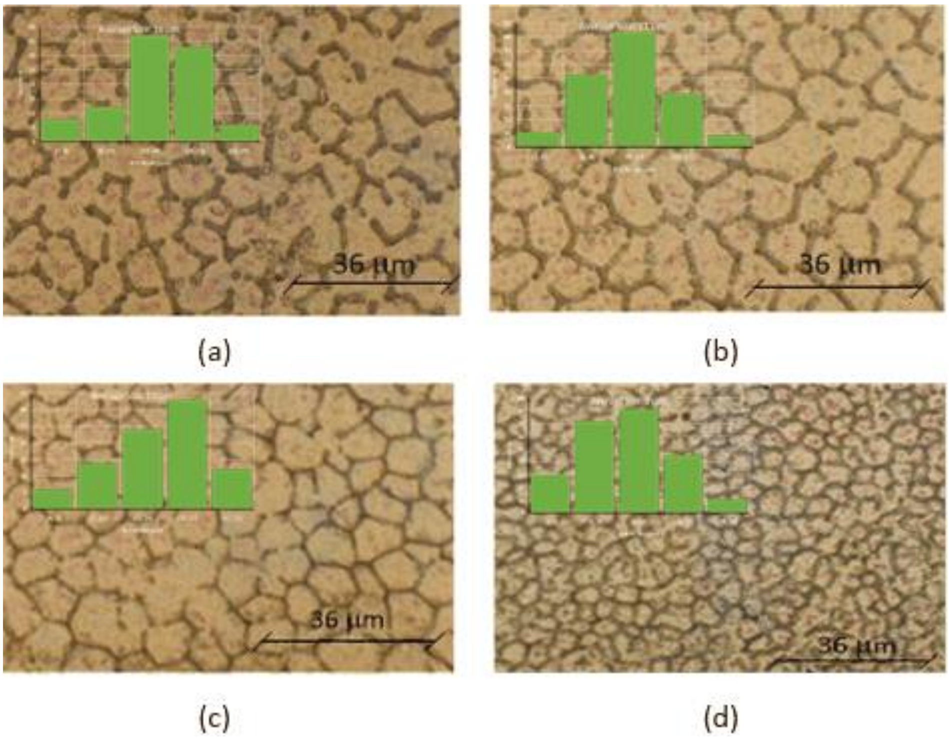

Figure 3. Microstructure of vibrated torch welding and their distribution of grains at 0.75 mm amplitude a) welding speed (V) 100 mm/min, frequency (f) 5 Hz, b) V: 100 mm/min, f: 10 Hz, c) V: 200 mm/min, f: 5 Hz, and d) V: 200 mm/min, f: 10 Hz.

The main variable in analyzing the effect of vibration on the torch in welding to grain refinement is welding speed, amplitude, and frequency. The effect of these variables can be described in detail based on the graph of the relationship between the amplitude and the grain size, as shown in figure 4.

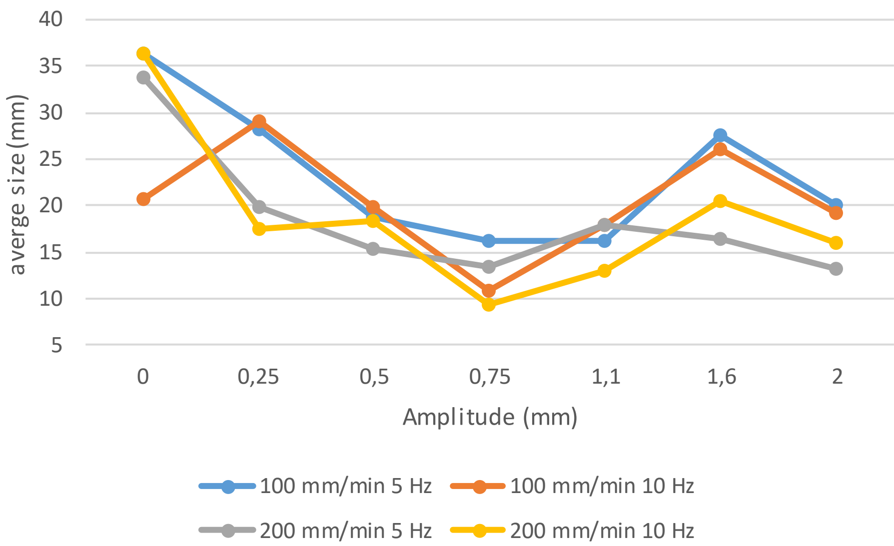

Figure 4. Average grain size as a function of the amplitude at different welding speeds and frequencies.

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Figure 4 shows that the amplitude gives optimum effect to the grain refinement. While at the 0.75 mm amplitude with 200 mm/minute welding speed and the frequency of 10 Hz obtained the finest average grain size of 9.41 μm. From these results, it is seen that at higher frequencies obtained a finer grain deposit weld at the same welding speed (0.75 mm amplitude). In other words, an increase in frequency, to some extent, can improve the refining of the weld deposit grain. The analysis results obtained that the relationship between welding speed and grain size is non-linear. Based on Sivaraj et al. [26] and Sree Sabari et al. [27], the faster welding speed will be obtained finer grains. At higher welding speed, the heat input is lower, so the crystal grains are smaller because the energy for dendrite/grain growth is also smaller. In this research, it was found that the grains decrease as increasing amplitude up to 0.75 mm then the grains increase with increasing amplitude. In welding with torch vibration at the same welding speed, increasing the frequency will refine the grain size between 52 to 67%. Grain refinement occurs because of the generation of peak pressure, the development of power density shear stress, and the presence of laminar flow around the dendritic arm [13]. The results were in the intersection of the dendritic arm due to vibrations cause the finer grains.
Figure 5 shows the comparison of increasing welding speed at 5 Hz and 10 Hz, respectively. Both graphs have an anomaly of the average size of the grain. At 100 mm/minute, and frequency 5 Hz with 1.1 mm amplitude, the average grain size is around 16 μm which finer than average grain size at the frequency 10 Hz with the same amplitude. The distribution of grain size tent to higher than the average. Meanwhile, at frequency 10 Hz in beginning welding speed of 100 mm/minute, the value drops as the distribution small and large grain size has a significant gap, the average grain size should be more than 35 μm.

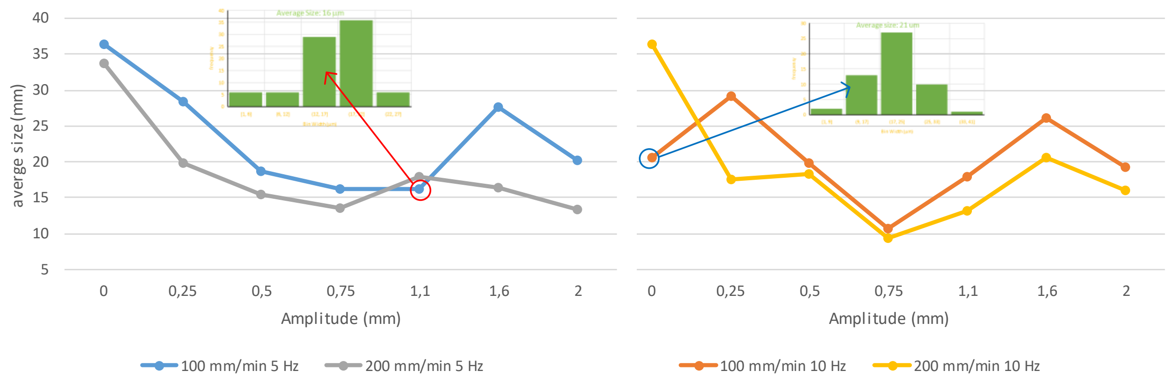

Figure 5. Increasing welding speed refining the average grain size at 5 and 10 Hz.

According to Chen et al. [28], the vibration of the welding will refine the grain because of the acceleration of the welding rate when compared to the welding speed in the direction parallel to the liquid-solid interface. The theory has limitations, where at a high enough frequency, the metal did not have time to melt. Higher frequencies will result in higher resultant speeds so that finer grains are obtained. Seen at higher frequencies the finer welding grain size of the weld is obtained at the same welding speed or in other words an increase in frequency within a certain limit can increase the refining of the weld deposit. The faster the welding rate, the finer the results will be obtained. Due to the higher welding speed, the lower heat input, so the crystal granules are smaller where the growth energy of automatic dendrite grains is smaller.

4. Conclusion

Welding speed gives the effect of grain refinement. Increase the welding speed will reduce grain size; on the other hand, increase the frequency has affected different grain size. The welding speed will smooth the grain size approximately 23% at both 5 Hz and 10 Hz. Meanwhile, increase the amplitude to 0.75 mm will reduce the grain size (approximately 52% and 67% at 5 and 10 Hz, respectively) then the grain size will unstable with increasing amplitude.

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