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Optimal Machine Parameters to Maximize the Accuracy of Producing Aluminum Dovetails Using WEDM

J.F. Oberholzer, Dr. G.A. Oosthuizen*, P. de Wet

Industrial Engineering Department, Stellenbosch Univeristy, Stellenbsoch,7600, South Africa

Abstract

Dovetail joints are one of the strongest joining methods used to connect two perpendicular components together. Dovetail joints are predominantly used in wooden components but can also be found in other non-wood components and products such as lathes, turbine blades, clock gears, and large 3D printed components. The manufacturing of these joints have largely been done by CNC milling machines that use specialized tools. The objective of this study was to determine the optimal machine parameters to produce a dovetail joint in Aluminum 7075-T6 plate with the highest accuracy as possible using a WEDM process. The experimental results were analyzed through ANOVA and the optimal results were presented. Further work is also discussed to incorporate the manufacturing time into the model.

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Keywords:; ANOVA;Dovetails; Process chains; WEDM

1. Introduction

Manufacturing is defined as an industrial activity in which the form of raw materials is changed to create products and is derived from the Latin phrase, *manu factus*, which literally translates to “made by hand” [1]. Manufacturing has changed its emphasis from product volume and product variety a number of times since the industrial revolution. These changes are driven by societal changes, changes in market imparitives and the development of new and enabling technologies [2]. Figure 1 illustrates some of the changes in the manufacturing paradigms over the years. Here it can be seen that a new manufacturing paradigm is emerging in the form of social manufacturing. Social manufacturing can be described as a manufacturing community which integrates many distributed, socialized resources and enterprises onto one localized, open design platform [2]. These manufacturing

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clusters allow organizations to tap into personal and social networking relationships which provides added value to all of the parties in question [3].

Certain challenges rose as the advancement of materials have brought with it the need for modern manufacturing techniques with the ability to produce complex shapes from non-traditional materials. Non-conventional machining processes such as electrical discharge machining (EDM), electrochemical machining, laser machining and ultra-sonic machining have answered many of these challenges [5]. The electrical discharge machining process uses an electrode submerged in a dielectric to create electrical sparks between the workpiece surface and the electrode. This

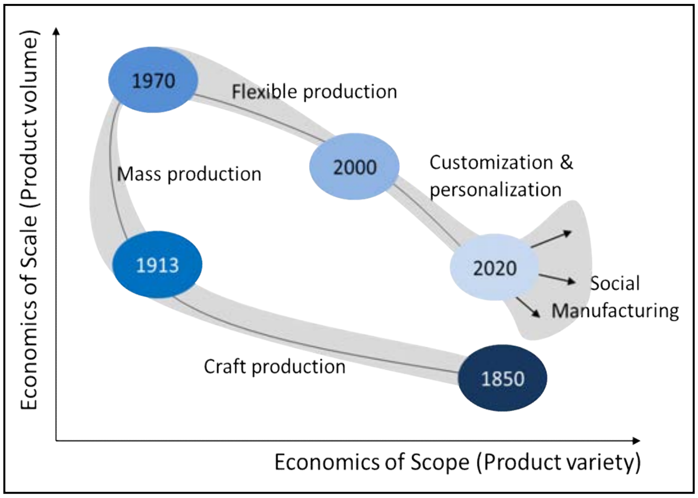

Figure 1: Changes in Manufacturing Paradigms with Regards to Economics of Scale and Scope [4].

process removes the workpiece material by means of melting and erosion [9]. This process is widely used in the machining of hard metals and alloys in both the aerospace and tool and die industries [6].

A unique adaptation of the EDM process is wire electrical discharge machining (WEDM), and is used to manufacture complex parts with intricate shapes and profiles [7]. The WEDM process utilizes a thin wire electrode that is constantly feeding through the workpiece by a microprocessor and kept under tension using a mechanical tensioning device while submerged in a bath filled with dielectric fluid. A series of discrete sparks between the workpiece and the wire then erodes the material from the part producing exceptionally high dimensional accuracy with a good surface finish [8]. The wire thickness ranges from 0.02 to 0.33mm in diameter and is usually plain brass, zinc coated brass or coated steel wires [9]. The microprocessor maintains a gap varying from 0.025 to 0.05mm between the wire and the workpiece [7].

This paper serves as a capability study for a WEDM machine to produce accurate dovetail joints from 7075-T6 aluminium plate. Three different dovetail sizes were compared to three different surface roughness values of the WEDM machine and the data was analysed using a two-factor factorial design of experiments (DOE).

2. Research Methodology

This paper will provide insight into the feasibility of using a WEDM process to create accurate dovetail joints with the required tolerances to achieve a sliding fit with interference. A plate size of 110 mm x 8 mm x was used and the dovetails were cut along the entire length of the plate. Figure 2 illustrates the process chain that was used to manufacture the dovetails.

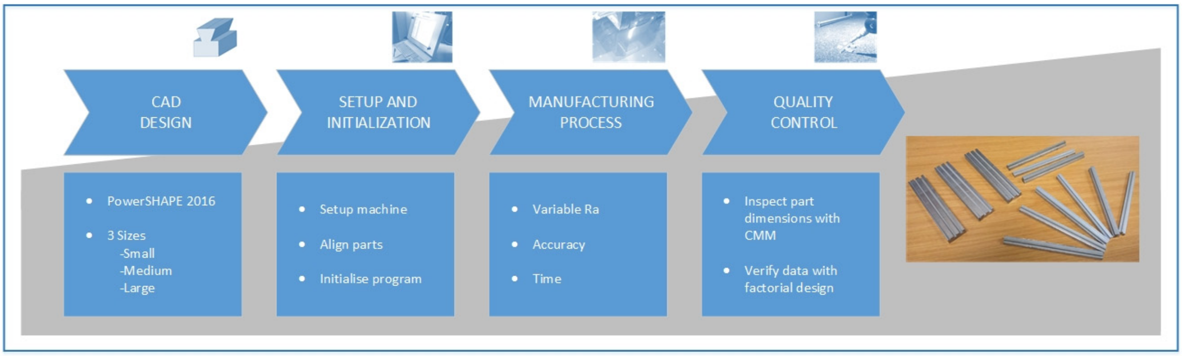

Figure 2: Process chain that was used to manufacture the dovetails using a WEDM machine.

After the CAD designs were completed for each of the dovetail sizes, the files were exported to the WEDM machine for manufacture. Setting up the plate in the machine was a tedious process. It was of high importance to secure the plate perfectly perpendicular to the wire as to ensure a straight cut throughout the length of the plate. Once the plate was in place, the designs were loaded and the manufacturing process was initiated. Each of the three sizes were cut with each of the different surface roughness (Ra) values to ensure that the optimal data was acquired for the factorial design. Table 1 below illustrates how the different factors were combined during the WEDM experiment. A coordinate measuring machine (CMM) was used to determine the final geometry of the manufactured parts and this data was analysed through the use of a two-factor factorial design of experiments.

Table 1: Illustration of how the different factors of size and Ra were combined during the experiment

			Ra Value		
			Low	Medium	High
			0	1	2
Size	Small	0	00	01	02
	Medium	1	10	11	12
	Large	2	20	21	22

3. Experimental Setup and Design

After the completion of the cutting process, the parts were transferred to the reverse engineering laboratory to measure how closely the actual part measurements resembled that of the theoretical values. It was decided to use the CMM machine to plot a profile around the dovetail at three places, as to accurately resemble the full profile of the entire part and not just at one point. These coordinate plots were then measured to determine the average tail width and the average tail depth respectively. The coordinate measuring machine that was used to gather the data is a Mitutoyo Bright Apex 710 with an accuracy of ±5µm. The machine is fitted with a Renishaw PH10M swivel head and a TP2 touch trigger system. The probe consisted of a 10mm staff connected to a 0.5mm diameter tip. The CMM machine was programmed to set a coordinate system for each part when it was measured. This ensured repeatability of the measuring method that was used and minimized the human error on the output without having to use a jig to keep the parts in place. The program used a plane and line system to locate the part and determine its orientation, before the measurement process was initiated. Each part has a length of 110mm and the three measurements were taken in the middle and 20mm from each end point, as indicated in Figure 3a. Figure 3b is a representation of one of the coordinate plots obtained by the CMM machine.

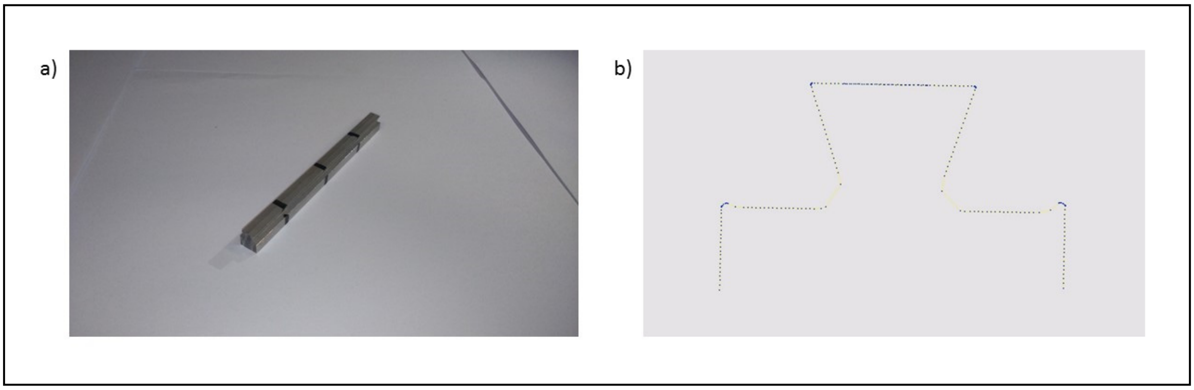

Figure 3: a) Positions at which the dovetails were measured by the CMM; b) Coordinate plots obtained by the CMM at one of the measurement points.

Once the measurements were completed, the accuracy of each part was calculated as a fraction of the total deviation from the theoretical size, as seen in Equation 1, where π is the theoretical size and α is the actual measurements.

$$A = 1 - \frac{\pi - \alpha}{\pi} \quad (1)$$

A 2–factorial interaction model was developed to test the validity of the data with the use of Design Expert 10.0.03 software. The proposed relationship between the interaction of the surface roughness and the part size is described in Equation 2, where y is the response variable, x_1 is the change in part size, x_2 is the change in surface roughness, ε is the experimental errors and β_0, β_1, β_2, and β_3 are the model parameters to be estimated.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \varepsilon \quad (2)$$

4. Experimental Results and Discussion

The postulated model for accuracy based on the measurements of the 9 parts is:

$$y = 0.99036 + 7.17 \times 10^{-4} x_1 - 4.5 \times 10^{-3} x_2 + 7.57 \times 10^{-4} x_1 x_2 \quad (3)$$

The ANOVA analysis of the model is displayed in Table 2. Here the model F-value of 13.07 implies that the model is significant with only a 0.84% chance that an F-value of this size could occur due to noise. All values of “Prob > F” that are less than 1.05 indicates that the model terms are significant. In this case, the part size A, the surface roughness B, and the interaction between the two AB are significant.

Table 2: ANOVA table for response surface 2-FI model

Source	Sum of Squares	df	Mean Square	F-Value	p-Value Prob > F	
Model	0.000274114	3	9.13712E-05	13.0697426	0.008401261	significant
A-Size	*0.000169939*	*1*	*0.000169939*	*24.30806743*	*0.00435839*	
B-Ra	*8.61811E-05*	*1*	*8.61811E-05*	*12.32735054*	*0.017081815*	
AB	*5.73591E-05*	*1*	*5.73591E-05*	*8.204654019*	*0.035225558*	
Residual	3.49552E-05	5	6.99105E-06			
Corr Total	0.000309069	8				

The normal probability plot of the studentized residuals can be seen in Figure 4a, and it clearly indicates the normality of the residuals as the data points tend to follow a linear equation. Figure 4b displays the results of the model in a 3D plot. Here it is seen that the surface roughness has little effect on the accuracy if the part size is large compared to the significant effect is has when the part size is small.

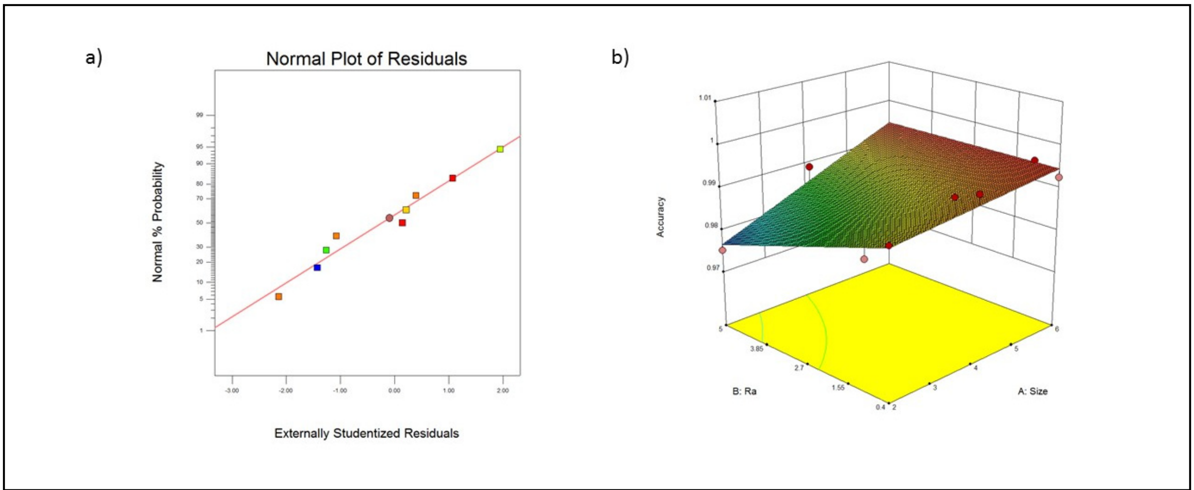

Figure 4a) Normal probability plot of studentized residuals; b) 3D plot of the results of the model.

5. Conclusion

To achieve the highest part accuracy when manufacturing dovetails using a WEDM process, it can be observed that the best results were achieved with larger part sizes and smaller surface roughness value. The interaction plot between the surface roughness and the part size can be seen in Figure 4b. It is important to note that all of the experimental results falls within the 95% CI confidence band. This is an indication that the model can accurately predict what the accuracy would be, should any of the parameters change.

Even though this model provides a good representation of the influence that the part size and the surface roughness has on the accuracy, further work should be done to investigate the effects that these parameters will have on the manufacturing time. Once this is done, it will be beneficial to develop a model that will incorporate both these response variables and determine the optimal combination of surface roughness and dovetail size to produce the most accurate part in the shortest time.

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