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Heat-Assisted Machining for Material Removal Improvement

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Abstract. Heat assisted machining (HAM) is a process where an intense heat source is used to locally soften the workpiece material before machined by high speed cutting tool. In this paper, an HAM machine is developed by modification of small CNC machine with the addition of special jig to hold the heat sources in front of the machine spindle. Preliminary experiment to evaluate the capability of HAM machine to produce groove formation for slotting process was conducted. A block AISI D2 tool steel with100mm (width) x 100mm (length) x 20mm (height) size has been cut by plasma heating with different setting of arc current, feed rate and air pressure. Their effect has been analyzed based on distance of cut (DOC).Experimental results demonstrated the most significant factor that contributed to the DOC is arc current, followed by the feed rate and air pressure. HAM improves the slotting process of AISI D2 by increasing distance of cut due to initial cutting groove that formed during thermal melting and pressurized air from the heat source.

1. Introduction

The demand for higher strength and high wear resistance materials is increasing, particularly in high perfromance application such as in tool and die, oil and gas and aerospace industries. However these materials are often difficult to machine due to their hardness and strength, which make the cutting tool easy to wear or damage within a short time [1]. Because the hardness and strength of materials normally decrease with increasing temperature, heat assisted machining becomes a one of the alternative techniques when performed material removal process of these hard-to-machine materials [1]. Heat assisted machining (HAM), is the combination of heating and machining actions in one material removal process. During HAM process, the workpiece material is heated and softened by a focused heated source and then removed by the cutting tools to perform required shape [1, 2]. Some example of HAM are plasma asissted machining, laser assisted machining and thermaly enhanced machining. This technique have been reported efficient in machining of materials that are difficult to cut, elimination cooling lubricants, geometrically flexible and feasible manufacture of complex component as compared to grinding.

Slotting process is material removal process to form the material in a shape of groove. It is considered one of the milling process that requires high toughness and high wear resistance cutting tools.In mold and die making, slotting is considered one of difficult task ecspecially when machining hardened steel with high ratio between widht and depth of cut**.** On the other hand,plasma cutting is the process that used a plasma torch to heat and cut steel based materialsin different thickness [3].The plasma exiting from the torch nozzle will melt localized area and remove the molten material by the force of the plasma jet. The intensity and velocity of the plasma are determined by a several factors such asthe pressure &volume the gas, type of gases, the flow pattern, the amount of arc current, the size and design of the nozzle orifice and the distance between nozzle tip to workpiece [3]. In addition, for slotting process, the efficiently to produce groove is also depended on the feed rate of the machining setup.

In this paper, the combination of air plasma cutting machine and CNC mini milling machine were carried out to investigate the effect of plasma cutting on slotting process.The plasma is used as a heat source to soften the layer of material and also to remove part of material by air pressure from plasma nozzle. Several major parameters such as arc current, feed rate and air pressure have been evaluated to

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determine their significant factors that contributed to the HAM performance, measured by distance of cut.The results from this paper is an extension of previous findings [4,5].

2. Experimental Setup

The experiment was conducted by using mini CNC machine, modified with the addition of plasma torch shown in Figure 1.A plasma cutting machine with maximum air pressure of 1MPa and arc current of 50Ampere was used. A special jig was used to hold the plasma torch for better flexibility to control of plasma torch movement [5]. For the preliminary experiments, the AISI D2 tool steel was used as the workpiece in this study. Table 1 shows the mechanical properties of AISI D2. The raw material was prepared around the size of 100mm (width) x 100mm (length) x 20mm(height)as shown in Figure 2. Three factors, arc current, air pressure and feed rate were selected as preliminary tests for the experiment in order to study the effects of HAM parameters on distance of cut (DOC). The parameter setup is shown in Table 2. Figure 3 shows the illustration of HAM process. The DOC is measured based on the peak-valley distance of the groove (Figure 4) using optical microscope.

Figure 1. Mini CNC Machine with plasma torch attached in front of the spindle.

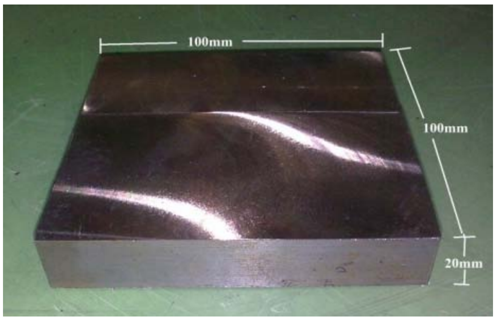

Figure 2. AISI D2 as workiece speciment

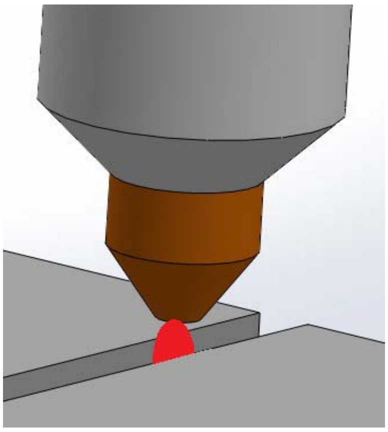

Figure 3. Illustration of HAM process

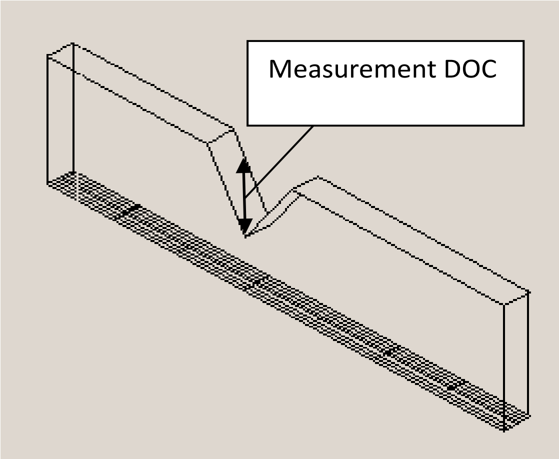

Figure 4. Measurement of DOC based on the peak-valley distance of the groove

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Table 1. Mechanical properties of work material (AISI D2) [6]

Mechanical Properties	AISI D2 Steel
Tensile Strength (Mpa)	710 – 1260
Yield Strength (Mpa)	≥ 320
Hardness (HRC)	52-62
Elongation	≥ 16
Delivery condition	Soft annealed to 3pprox. 210HB

Table 2. Parameter Setup

Control Factor	Minimum Level	Maximum Level
Arc Current (A)	20	30
Air Pressure (MPa)	0.3	0.4
Feed Rate (mm/min)	200	400

3. Results and Discussion.

In this study, the implementation of HAM process has been commenced with the modification of CNC machine by combination between milling and plasma cutting processes in one machine system. Plasma cutting is a process that utilizes an ioned compressed air with high temperature to melt and cut metal in different thickness [6]. In plasma cutting, a compressed gas is blown out from a nozzle at high speed condition. On the same time an electrical arc is formed between the nozzle tip to the surface being cut to excite a powerful amount of heat [7]. The temperatures from the plasma that formed in front of the nozzle can rise up to 16000^{o}C with maximum 6000 m/s air exits speed, which sufficiently high enough to melt and blow the molten metal away from the cutting zone [8]. As the plasma torch attached in front of the machining spindle, the feed rate can be set in automatic mode to provide the consistent plasma movement. The high temperature and high pressure of air plasma capable to produce a groove which can be partly prepared as a pre-slotting process during machining, as shown in Figures 5 and 6. The depth of groove, defined as distance of cut (DOC) depended on HAM parameters (arc current, feed rate and air pressure).

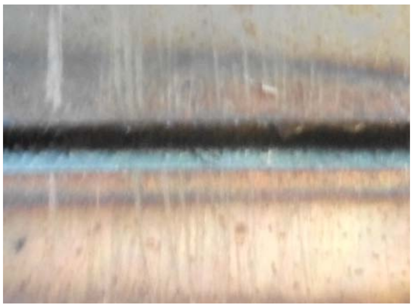

Figure 5. Groove formation after HAM process (top view)

Figure 6. Groove formation after HAM process

Table 3 shows the results of distance of cut, DOC for each parameter investigated.The results of analysis of variance (ANOVA) based on the output DOC is shown in Table 4. From the analysis, it was established that the most significant factors that contributed to the DOC isarc current, followed by the feed rate and air pressure.

For plasma arc current, it shows that the DOC increased and the arc current increased, as shown in Figure 7. The arc current within plasma welding controls the axial electrical field at the nozzle exit [9]. The current level determine the energy density required to get to heat the steel. Higher arc currents provided higher temperature and therefore increasedintensity to melt the steel, hence increased DOC.

For feed rate, it shows that the DOC decreased as the feed rate increased, as shown in Figure 8. In this study, feed rate was controlled by the CNC machine whereits defined by the time of plasma travel with respect to the work piece in certain lenght. As the plasma torch travels across the workpiece, plasma jet have adequate time to provide heat energy to melt the steel. This consequently provide greater the heat affected zone and consequently create larger area of molten metal.

On the other hand, air pressure gave less effect to the DOC as shown in Figure 9. The function of air pressure is to blow the molten metal away from the main workpiece. Even though the pressure was set at high level (0.4 Mpa), the affected area only focussed on the molten region where dominat energy was controlled by the arc current dan and feed rate. This is explained why air pressure not significantly contributed to the efficientcy of grooving process. However in this study, air pressure must be set at minimum 0.2 MPa as the electrical arc will not be formed at a lower air pressure.

Table 3. Experimental results of parameters investigated

Exp No	Arc Current (A)	Feed Rate(mm/min)	Pressure(MPa)	DOC(mm)
1	20	200	0.3	1.865
2	20	200	0.4	1.441
3	20	400	0.3	1.151
4	20	400	0.4	0.438
5	30	200	0.3	4.877
6	30	200	0.4	4.260
7	30	400	0.3	3.602
8	30	400	0.4	4.743

Table 4. Analysis of variance (ANOVA) based on the output DOC

Source of variance	Sum of square	DF	Means square	F-value	P-value Prob>F	Percentage contribution
Model	21.16	4	5.29	22.00	0.0147	20
A-Air Pressure	0.047	1	0.047	0.20	0.6885	0.17
B-Current	19.80	1	19.80	82.34	0.0028	74.87
C-Feed Rate	0.79	1	0.79	3.27	0.1682	2.99
D-Standoff height	0.52	1	0.52	2.18	0.235	1.97
Residual	0.72	3	0.24			
Cor Total	21.88	7				

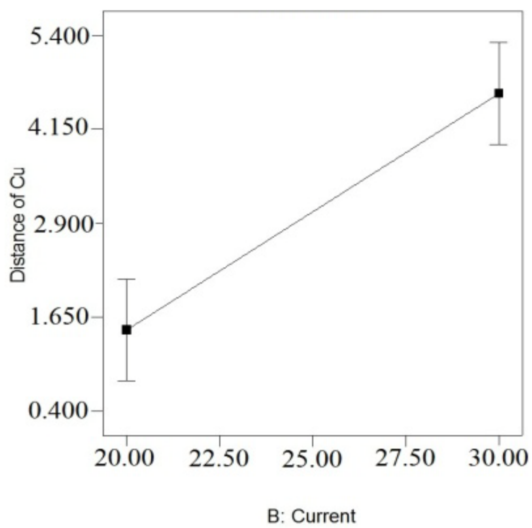

Figure 7. Effect of arc current on DOC

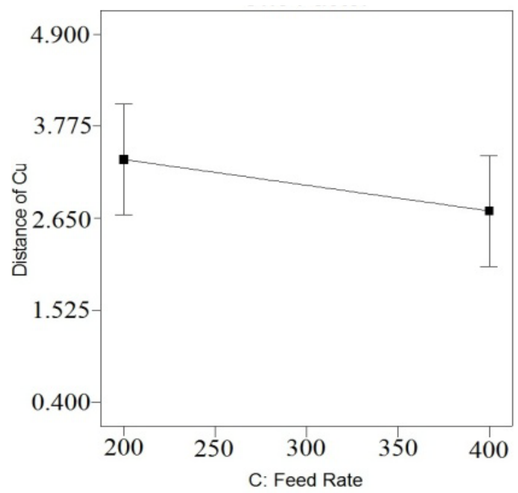

Figure 8. Effect of feed rate on DOC

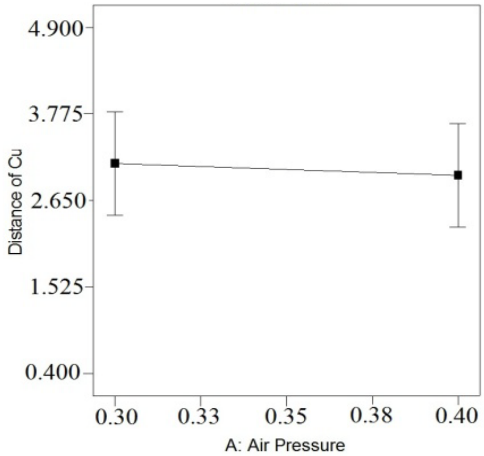

Figure 9. Effect of air pressure on DOC

4. Conclusion

From the experiment, the following findings have been determined:

1. The most significant factors that contributed to the distance of cut is arc current, followed by the feed rate and air pressure.
2. Distance of cut increased as the arc current increased
3. Distance of cut decreased as the feed rate increased
4. Air pressure not significantly contributed to the efficientcy of HAM process.

5. Acknowledgement

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