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Influence of polarity on the performance of Blasting Erosion Arc Machining

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ABSTRACT

Blasting Erosion Arc Machining (BEAM) is proposed to achieve high-efficiency machining for difficult-to-cut materials such as high-temperature alloys. By creatively controlling the arc plasma with the mechanism named hydrodynamic arc breaking, BEAM can remove bulk material with a high material removal rate (MRR). However, the BEAM generated surface is rough and requires additional post processing. In order to improve the resulting surface quality, positive electrode polarity BEAM was performed by using graphite bundled electrode to machine AISI D2 steel workpiece in this study. Experimental results demonstrate that compared with negative electrode BEAM, machining with positive polarity achieves a better surface quality with less MRR and high relative tool wear ratio (TWR). The explanation of the differences can be attributed to the performance of arc plasma resulting from the variation of the flushing velocity in the discharge gap. Therefore, it is possible to machine with high efficiency and a better control of the profile and surface quality of the workpiece by combining negative and positive (N-P) BEAM processes together.

1. Introduction

In order to improve the machining efficiency of difficult-to-cut materials, arc machining was attempted to achieve a high machining efficiency. Compared to the plasma in EDM, the arc plasma in arc discharges ionizes more efficiently and results in a higher temperature and thermal density, and thus erodes the material more efficiently [1]. Early in the 1980s, Meshcheriakov found that the hydrodynamic pressure of the working fluid in the gap influenced the physical features of the arc and proposed Arc Dimensional Machining [2]. Afterwards, electro contact discharge machining [3], electrochemical arc machining [4] and high speed electro-erosion milling [5] were proposed to utilize arc for material removal. Wang and Liu et al. achieved a high MRR of 15,062 mm^3/min (current 920 A) by using compound power with high current density to machine Inconel718 with negative polarity [6]. Zhao and Gu et al. proposed a Blasting Erosion Arc Machining (BEAM) on the basis of the hydrodynamic arc-breaking mechanism [7]. This technology composes of several key elements, such as high density energy input carried by arcing, multi-hole electrode with three-dimensional contour, high velocity flow field in the discharge gap, and multi-axis feed control, which substantially differ from EDM. When machining Inconel718, BEAM achieved a MRR as high as 14,000 mm^3/min (current 600 A), and the minimum TWR was less than 1% with negative electrode. The advantages of BEAM are not only high material removal rate, but also the ability to machine 3D concave cavity with sinking mode. Generally, when the workpiece material is carbon steel, the specific material removal rate in arc machining is about 20–25 mm^3/(A min), much higher than that of EDM [8]. However, the surface generated by arc machining is rather coarse, which requires subsequent semi-finishing processes. How to improve the surface quality is still a big challenge in arc machining process.

This study investigates the influence of polarity on the machining performance of BEAM. The machining characteristics of BEAM with different polarity are described and a 3-factor, 4-level comparison experiment is conducted and analyzed by using a bundled electrode to machine AISI D2 steel. Finally, an analysis of results is presented to achieve a high MRR as well as acceptable surface quality using BEAM.

2. Experimental conditions and procedure

2.1. Setup and conditions

The experimental setup for BEAM is illustrated in Fig. 1. It consists of a flushing sub-system, and an electrode fixture with a bundled multi-hole electrode. The flushing sub-system is capable of supplying an extremely high velocity fluid flow into the discharge gap through the holes of the bundled electrode to enable hydrodynamic arc breaking during machining. The electrode is bundled by a number of tubular cell electrodes of 100 mm length with outer and inner diameters of 5 mm and 2 mm, respectively. The cross-sectional area of the electrode is 431 mm^2. The workpiece material is AISI D2 steel and the

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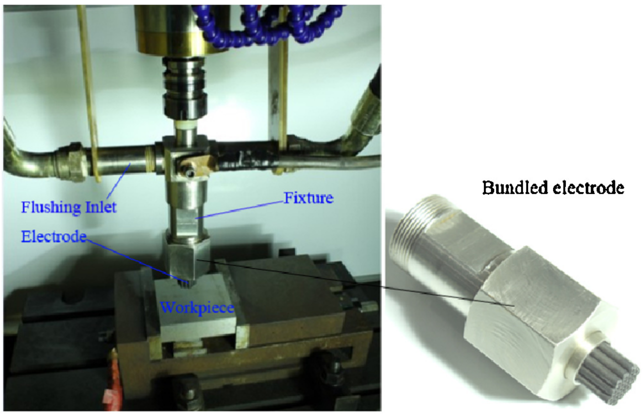


Fig. 1. Experimental setup with multi-hole bundled electrode.

Table 1
Experimental conditions.

Electrode polarity	Negative, Positive
Pulse duration t_{on} (μs)	2000 4000 6000 8000
Pulse interval t_{off} (μs)	500
Peak current I_p (A)	200 300 400 500
Flushing inlet pressure p (MPa)	0.7 1.0 1.3 1.6

machining depth for each run is 10 mm. Other experimental conditions are listed in Table 1.

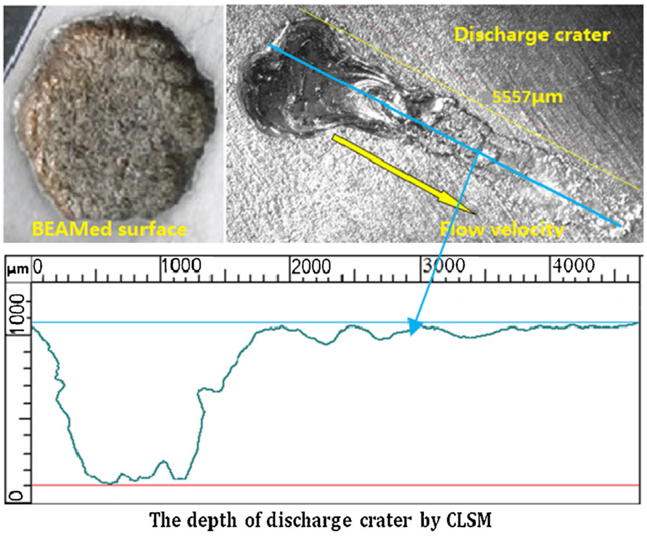
2.2. Experimental procedure

During BEAM, electrode is fed in "sinking" mode. A helical motion was applied to avoid the formation of residual thorns on the workpiece surface that form under the holes of cell electrodes. The material removal rate (MRR) is the workpiece material removed volume per minute. The tool electrode wear ratio (TWR) is the ratio of volumetric loss of the tool electrode material over that of the workpiece. The experiments are randomized and the machined surface, MRR, TWR as well as surface roughness, Ra, are observed/measured and compared to determine the influence of polarity on the machining performance.

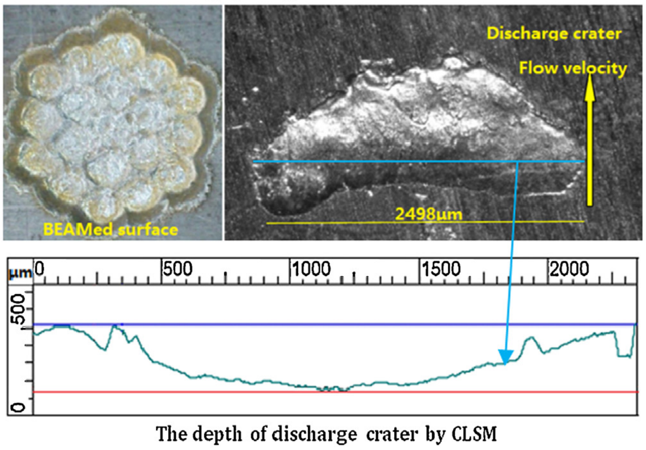
3. Results and discussions

3.1. Comparison of workpiece surface

With negative electrode polarity, the machined surface has surface roughness about 300 μm. Such a rough surface will generate a higher cutting force leading to tool failure in the machining processes. The machined workpiece and a single crater formed by negative BEAM are shown in Fig. 2(a). Tailing discharge craters [7] are observed at the peripheral of the machined area and this phenomenon is explained as the trace of the distorted or elongated plasma column swept on the workpiece surface. And the plasma column distortion is the result of the hydrodynamic force caused by the intense flushing in the discharge gap. Beside the marks of trailing discharge craters, the depth of the discharge crater is measured by confocal laser scanning microscopy (CLSM). The figure shows that the maximum depth is about 974 μm, indicating a high volume of material removal by a single arc plasma in negative BEAM. However, there is no evidence of long tailing discharge crater on the BEAM generated surface with positive polarity and the corresponding surface brightness is much better than that of the negative polarity, as shown in Fig. 2(b). Meanwhile, the measured depth of discharge crater in positive BEAM shows that the maximum value is 321 μm which indicates a better surface quality with less MRR.



(a) Negative BEAM



(b) Positive BEAM

Fig. 2. Workpiece surface and crater machined by a single arc discharge.

3.2. Comparison of the influence of pulse energy

The influence of peak current on the performance of different polarity BEAM is shown in Fig. 3. In negative BEAM, the MRR increases with the increasing of peak current, and the maximum MRR reaches up to 14,000 mm^3/min when the peak current is 500 A, indicating a high specific material removal rate (28 mm^3/(min·A)). It means that the energy density of the arc column in negative BEAM is very high and the molten material is removed efficiently. However, the TWR decreases gradually with the increasing peak current, which is opposite to the trend of MRR.

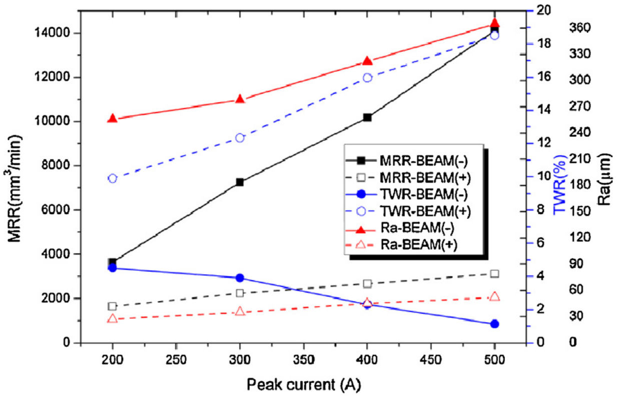


Fig. 3. Influence of polarity on BEAM performance with peak current (t_{on} = 8000 μs, p = 1.6 MPa).

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