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Analysis of Mechanical Quality of Nickel-Base Superalloy Machined by Short Electric Arc†

HONGSHENG LIU[1], JIANPING ZHOU[1,2,*] and QING YU[1]

[1]School of Mechanical Engineering, Xinjiang University, Urumqi 830047, P.R. China
[2]School of Mechanical Engineering, Xi'an Jiaotong University, Xi'an 710049, P.R. China

*Corresponding author: E-mail: liuxxky@163.com; lingkzhou@163.com

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It is a trial for machining GH4169 nickel-base super alloy by short electric arc machining. Since the theory is not complete, so prepare the experiment from the aspect of the parameters of the material removal rate, roughness of the finished surface, micro-hardness and heat-affected layer *etc*., which help to find the regulation of specimen surface quality on the different processing power parameters. Analyzing the alloying degree of cut tool surface based on the EDAX. Analyze the microstructure of the workpice surface by using scanning electron microscopy (SEM). Machining the GH4169 nickel-base super alloy by short electric arc machining technology can get satisfactory finished surface quality.

Keywords: Short electric arc machining, SEM, GH4169, EDAX, Specimen surface quality.

INTRODUCTION

With the development of manufacturing, the nickel-based super alloy GH4169 is more widely used for its stable ability at high temperature working condition especially in the aerospace field[1]. However, it is difficult to machine for its own characteristics, To date, there are some other cases of arc processing. The majority is arc sawing (AS)[2], the main AS research appears to have been conducted at the Japan Power Demonstration Reactor (JPDR)[3]. Russian experiment work reported by Vitlin detailed a rotating steel or aluminum disc discharging an alternating current in air [4]. This paper using short electric arc machining (SEAM) technology to process nickel-based super alloy, intends for finding new processing methods for processing the nickel-based super alloy GH4169.

EXPERIMENTAL

Fig. 1 shows the device of the SEAM system, which includes the power source, anode device, cathode device and the device of mixture working medium. The work piece is connected to anode of power source and fixed by the chuck on the spindle do rotation movement with spindle. The cutter do feed movement in the direction of radial and longitudinal. At the same time is connected to the cathode of power source which consists the cathode device. The working medium mixture device mixing and inject the compressed air and certain

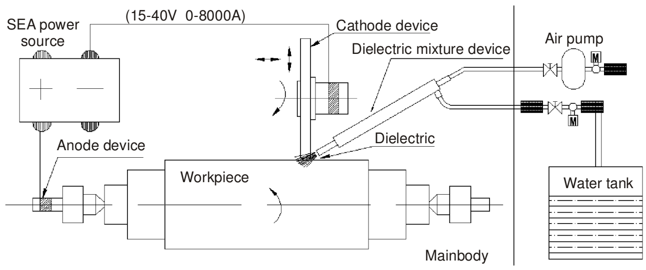

Fig 1. Schematic diagram of SEAM machining

pressure working solution to the working field. During the processing, the discharged high-current electric arc produced between the work piece and cutter, which could melting and stripping the surface materials on the work piece. At the same time, the working medium is injected to working field, which blowing away the melting material from the working fields.

The experiment short electric arc machine tool in this paper named DHZK6330 is developed by school of mechanical engineering in Xinjiang University. The maximum diameter of work piece D ≤ Φ 630 mm and length L ≤ 2000 mm, with the spindle speed (0-30) rpm, the distance of the cutter in the radial direction is 0-500 mm. Table-1 shows the parameters of power source, during the processing, the voltage is pre-installed, the current is changed with the load. The designed maximum current I ≤ 3000 A.

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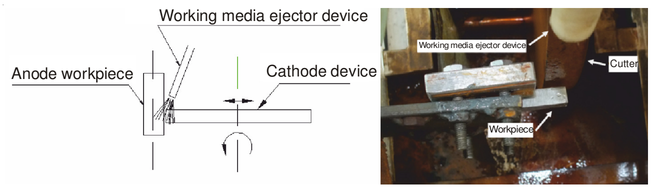
TABLE-1 PARAMETERS OF THE PROCESSING	
Parameter	Value
Peak voltage (V)	0-42
Current (A)	0-2000
Frequency (HZ)	50
Cutter speed (m/m)	154.1
Fluid pressure (Mpa)	0.1
Are pressure (Mpa)	0.3

In this paper, the material of the work piece is nickel-based super alloy GH4169. GH4169 is nickel-iron-based aging strengthening wrought super alloy. Table-2 shows the chemical component of the work piece.

TABLE-2 CHEMICAL COMPONENT OF GH4169 [Ref. 2]			
Element	Content (%)	Element	Content (%)
C	0.02-0.06	Al	0.3-0.7
Cr	17-21	Ti	0.75-1.15
Ni	50-55	Nb	5-5.5
Mo	2.8-3.3	Fe	Others

In this experiment, the specimen is made as rectangular with the size of 15 mm × 25 mm × 46 mm, which is useful to the later test. Also refit the chuck on the spindle shown in Fig. 2. Work piece is clamped at the half height of the cutter in the level and the cutting surface in the tangential direction of the horizontal axis. Workpice keep stationary during processing. To ensure the reliable of the power source during processing, painting the conductive silicone grease between work piece in the static friction and could decrease the power source loss.



(a) Schematic clamped (b) Actual processing scenario

Fig. 2. Working installation scenarios

RESULTS AND DISCUSSION

Along the perpendicular direction to the machined surface preparation the metallographic sample. Corrosion the sample after grinding and polishing with etchant as H_2SO_4: HCl: $CuSO_4$:H_2O in ratio of 5:150:20:250; observing the microstructure with upright metallurgical microscope MJ21; using the TR210 handheld measuring roughness measuring instrument analyzing the surface roughness, taking sample in eight different points with the sampling length is 0.25 mm and range is 80 µm; Do EDAX analysis for the finished surface with LEO1430VP LEO environmental scanning electron microscope. Measure the hardness on the surface at each 25 µm with HXD-1000TB Video Digital Vickers Hardness Tester. Fig. 3 shows the experimental work piece.

Macroscopic surfaces quality analysis: Fig. 3 is the SEM image of the finished surface, which shows the finished surface is consisted by many discharge pits with regular shapes A,

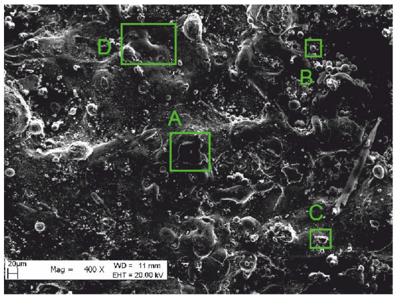
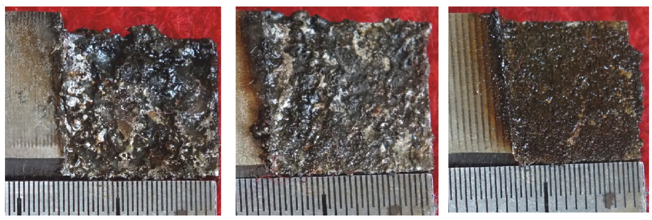


Fig. 3. SEM image of the finished surface: U = 14.3 V, I = 1875 A

spherical molten droplet B, tiny pores C and irregular shapes molten droplet D. Each pulse discharge could melt and stripping the material in a small discharge zone which lead to the discharge pit. The vaporized surface material cooled by working fluid then solidification in the surface, which lead the formation of spherical molten droplet. The unmelt material re-solidified on the surface, which lead to the irregular droplet formation. Fig. 4 shows the machined surface on different parameters.



a. U=39 V I=500A b. U=30.1V I=1023A c. U=14.3V I=1875A

Fig. 4. Specimen finished surface

Material removal rate: Material removal rate (MRR), the rate of surface material released from the base material, which indicate the machining efficiency. In present study, for the experimental conditions, using manually stepping model during processing, then getting MRR date by measuring the work piece weight before and after machining. Since the processing method is not the ideal state of processing methods, so there is still much room for improving the material removal rate of machining nickel-base super alloy machined by SEAM. Table-3 shows the MRR on the different machining parameter.

TABLE-3 MRR ON DIFFERENT MACHINING PARAMETER			
Parameter	Before machining M_1 (g)	After machining M_2 (g)	MRR ΔM (g)
U = 39 V; I = 500 A	73	54	19
U = 30 V; I = 1023 A	68	56	12
U = 14 V; I = 1875 A	73	70	3

Table-3 shows the higher the machining voltage, the higher the MRR. The explanation as follows: during the processing, the high machining voltage could decrease the time of establish discharge channel. In other words, the energy of single discharge can be transformed more to the work piece surface, which increased the MRR directly. Table-3 also showing that there is decreased trend of MRR with the decrease of machining voltage.

Surface roughness: Finding eight different points on the machined surface, obtain the roughness along and perpendicular to the direction of machining. Fig. 5 shows the roughness, where Pa is the roughness along the cutter's movement direction, Pc is the roughness in perpendicular to the cutter's movement direction.

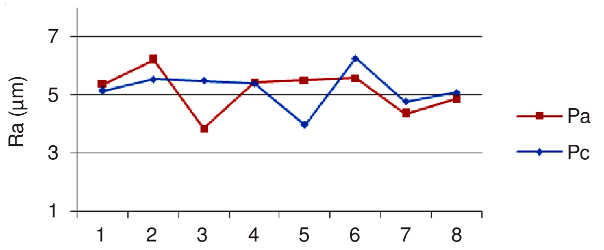
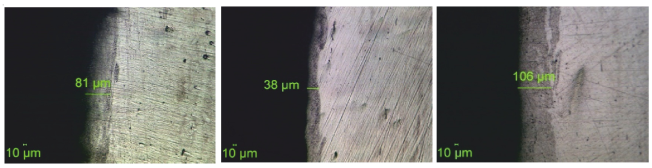


Fig. 5. Surface roughness (U = 14.3 V, I = 1875 A)

Analysis of heat-affect layer on the finished surface: Fig. 6 shows the heat-affect layer on the different machining voltage. During the machining, there is the resistant between the cutter and work piece. Changing the feed rate in proper when decrease the machining voltage, which could avoid this phenomenon occurring.



(a) U = 39; 500 A; f = 0.15 mm/rot (b) U = 30 V; = 123 A; f = 0.1 mm/rot (c) U =14 V; 1875 A ; = 0.08 mm/rot

Fig. 6. Heat-affect layer on different parameter

Fig. 6a shows the surface quality is not regular, also with a large heat-affect layer, reached 81 µm, on one hand, the discharge channel could be established in a short time in the primary of one pulse discharge. In the effective discharge cycle, the energy released by discharge channel could be transformed more to work piece material per unit are. On the other hand, the nickel-based super alloy have a poor conductive of heat, the energy on the surface could not be blow away from the work piece, all of this result in the large heat-affect layer. In Fig. 6b, the heat-affect layer have only 38¼ m, thicker than Fig. 6a. It can be explained as during the processing, the most energy released by discharge channel are used to melting the work piece material, then the melted material are flown away by working media, so the energy working on the work piece surface become less, some high melting material and refractory metals and carbides such as WC, Nb *etc*. cannot transition at all, which lead to the thinner heat-affect layer. Fig. 6c shows the heat-affect layer distributed on the surface layer evenly, but the thickness of the heat-affected has risen to about 106 µm. The reason is the lower the discharge voltage, the less energy of the surface obtain, also the less the material on the surface are melted and flow away, which lead to many irregular shapes molten droplet (Fig. 3d) distributing on the finished surface. So the finished surface is smooth than others; as the energy released by discharge channel could not stripping the melt material, the working media could not flow away the energy form the work piece. So the most energy of the discharge channel could working on the surface. All of this result in the thicker heat-affect layer. Fig. 6 shows that within a certain range, the heat-affect layer showing the ups and downs trends, which means that there is an ideal point that both having high machining efficiency and less heat-affect layer exist in this range.

Grain change analysis on heat-affect layer: Fig. 7 shows the finished surface material structure. Fig. 3A shown the recrystallization and format recast layer, which organization grain fully distributing on the surface. Below the recast layer, the phase of MC or MN melted and dissolved into tiny particles in high temperature and distributed in the grain boundaries, which further prevents grain growth. All resulting in tiny grains were evenly distributed within the material as shown in Fig. 7B. With the distance increases, the less energy the organization obtain, the large size the grain, as shown in Fig. 7C. Fig. 7D shows the normal state grain.

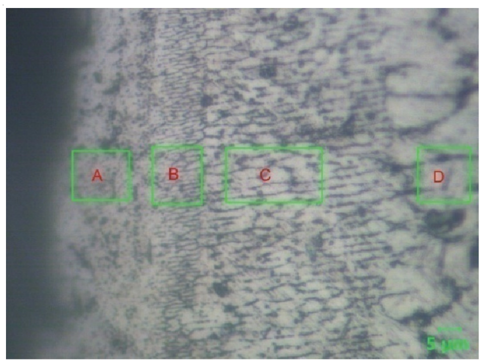
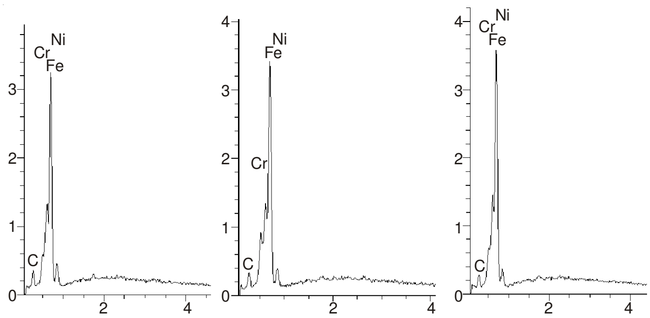


Fig. 7. Grain change on heat-affect layer (U = 30 V; I = 1023 A)

EDAX analysis: Fig. 8 shows the EDAX images of machined surface on different machined parameters. The element in surface has changed compared to Table-1. Table-4 shows the element's content in material and carbon content in high machine voltage is higher than in lower machined voltage, which comes from the cutter. During the processing, carbon in the cutter is melted into work piece and result in the material in surface alloying. Fig. 8 shows the trend is higher with machined voltage increased.



(a) U = 39 V; I = 500 A (b) U = 30 V; I = 1023A (c) U =14 V; I = 1875 A

Fig. 8. EDAX analysis on different machines surface

Micro hardness on surface: The machined surface micro-hardness on different machines parameters is shown in Fig. 9. Data show the change trend of micro-hardness in different machined parameters is similar. The highest hardness of points is on the nearest place from the surface, with increasing

TABLE-4
ELEMENT OF MACHINED SURFACE

Element	Content (%)	Element	Content (%)	Element	Content (%)
C K	5.43	C K	5.36	C K	4.27
Total	100.00	Total	100.00	Total	100.00

a. U = 39 V; I = 500 A; b. U = 30 V; I = 1023 A C. U = 14 V; I = 1875 A.

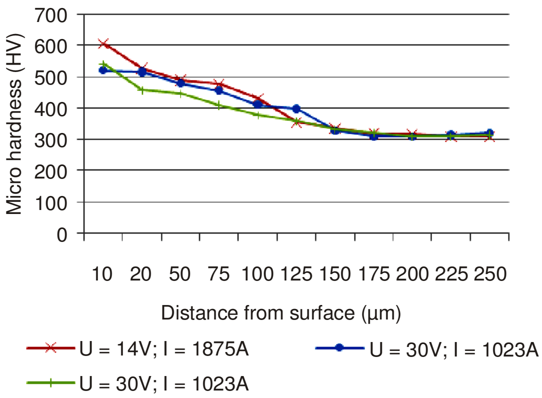


Fig. 9. Hardness on the machined surface

distance from the surface, the hardness decreased. But the higher voltage in machining, the higher value of the surface hardness, due to in high machined voltage, the alloy of the MC or MN phase dissolved into tiny particles and distributed in the grain boundary and further preventing the growth of grain. It leads to the grain distributed within the material evenly with tiny shape and result in the high value of micro hardness on the machined surface.

Conclusion

The experimental data in this paper shows the potential of using the SEAM process the nickel-based super alloy is huge and the surface quality could be improved by changing the power parameters. It broadens the field of nickel-based super alloy machining and improves the machining performance and mechanical property of the SEAM.

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