MATEC Web of Conferences **363**, 01011 (2022) https://doi.org/10.1051/matecconf/202236301011
AMME 2022

Crack study of recasting layer on workpiece surface in Micro-EDM

Chunmei Wang [1], Xuyang Chu [2], Yunxiang Lu [1], Hong Li [1]

[1] School of Mechanical and Electrical Engineering, Guizhou normal university, Guiyang, 550025, China
[2] School of Aerospace Engineering, Xiamen University, Xiamen, 361102, China.

Abstract: In this paper, the crack phenomenon of different materials was studied according to the surface morphology of recasting layer of micro EDM workpiece. In this paper, high-speed steel and titanium alloy are used as workpiece materials, and the RC pulse power supply is used for electric discharge machining. The surface and profile of the recast layer of the workpiece are examined by scanning electron microscopy. The difference between the two in the crack phenomenon of the recast layer in micro electric spark machining is analyzed. Finally, some improvement measures are put forward to solve the problem of recasting layer crack on the surface of micro EDM workpiece.

Key words: Micro-EDM; Recast Layer; pulsed power supply; crack.

1. Introduction

The environment and method of the fine EDM machining of the workpiece and the physical properties of the workpiece material will cause cracks on the surface of the workpiece. Moreover, it can be seen from the surface morphology of the EDM workpiece materials that different materials have different degrees of microcracking, and the surface microcracks are basically present in the recast layer and extend to the surface of the substrate[2-4]. Cracks caused by the physical properties of the material are unavoidable, and the surface of the workpiece cannot be completely crack-free, but the method of machining the workpiece can be changed. Therefore, for such a situation, the method of processing the workpiece can be improved, and the occurrence of such a crack phenomenon is relatively improved as much as possible.

2. Crack formation of surface recast layer

Due to the micro-EDM process is carried out in kerosene, the molten metal rapidly cools and solidifies after the end of the pulse discharge, and the rapid cooling shrinkage of the melt generates a large tensile stress, so that the original stress field is redistributed. When the stress is greater than the tensile stress, microcracks will occur on the metamorphic layer. Finally, a melting metamorphic layer with a thickness of 0~10 m is formed on the workpiece surface. The crack of micro EDM is mainly affected by material and discharge energy. The surface crack will reduce the corrosion resistance and fatigue strength of the parts, and seriously affect the service life and performance of the parts.

The surface microcracks of EDM workpiece are caused by the non-uniform stress in the process of EDM. On the one hand, the surface layer of the heated workpiece material produces high temperature and high pressure, which causes the surface of the workpiece material to undergo phase transition (melting and gasification), and the phase transition stress leads to the generation of microcracks. On the other hand, the surface layer of the workpiece will generate thermal stress in the process of thermal corrosion removal, and the thermal stress is caused by the unequal rate of crystallization of the material. Rapid heating and cooling in EDM results in a large temperature gradient, which is an important factor causing various internal stresses and surface cracks. In addition, in the process of electric spark machining, kerosene is used as the processing medium. Due to the distortion around the carbon atoms produced by the kerosene medium cracking, the local structural stresses are generated. These local structural stresses result in microcracks in the thin shell and microcracks can also occur where bubbles exist and where mutations occur.

3. Surface crack pattern

The surface of the micro-EDM workpiece has micro-cracking due to the influence of heat. In different processing materials and different processing parameters, the surface crack phenomenon is different. Radial crack, arc crack and local surface crack are the main forms of

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

surface crack in recasting layer. When the energy is large, all kinds of cracks appear at the same time, which is called reticular crack. As shown in Figure 1.

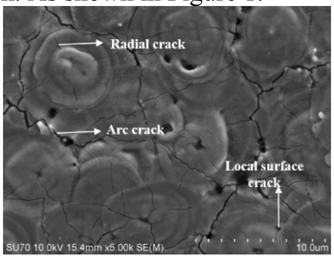


Figure 1 Surface crack representation

Radial cracks appear in the pit marks formed by a single spark, extending from the center of the pit to the edge of the pit. This is due to the fact that during the single-pulse discharge heat process, the heat source model exhibits a time-varying Gaussian distribution in the spark. The central energy density is large; the temperature of the surface of the workpiece material is high; the energy density away from the spark center is small, and the temperature of the surface material of the workpiece is low. Because the temperature of each part of the thermal effect of a single spark is different, a temperature gradient is formed, which in turn generates thermal stress, thus forming radial surface microcracks.

Arc cracks appear at the edge of the single spark discharge traces, approximately the circular arc in shape. This is because at the end of each discharge, part of the higher temperature of heat action produces the phase change processes, such as melting and gasification. Since the workpiece material beyond the boundary of the heat source model is not subjected to thermal action, the characteristics of the matrix are maintained. Thus, different or different simultaneous tissue changes occur in the process of workpiece material processing, and greater tissue stress is generated. As a result, an arc-shaped crack is formed at the junction of tissues, so the arc-shaped crack is thicker and longer than the radial crack and has a greater impact on the mechanical characteristics of the surface.

Local surface cracks appear in the local distortion of the workpiece surface, because the workpiece material, tool material and kerosene medium will appear fine particles during the processing. These fine particles are affected by the thermal effect of the second discharge, whose temperature is not the same, thus forming a temperature gradient, crack phenomenon. The cracks caused by local fine particles are local surface cracks.

4. Surface cracks in different materials

Since surface cracks are not easily quantified in terms of width, length, depth, and number of cracks, H.T. Lee et al [1]. defined "surface crack density", that is, the total length (cm)/unit area (cm2) of cracks, to assess the severity of cracking. P. Govindan et al [3]. used the number of surface cracks and the average length of surface cracks to characterize the cracks. As shown in the formula:

Surface crack density:

$$\lambda_a = \frac{\sum_{i=1}^{n} L_i}{A}$$

In the formula:

λ_a ——Surface crack density（cm/cm2）

n ——Select the number of surface cracks

A ——Assessed surface area（cm2）

L_i ——Each crack length（cm）

Surface crack number density:

$$\rho_a = \frac{n}{A}$$

In the formula:

ρ_a ——Average crack number density

n ——Select the number of surface cracks

A ——Assessed surface area（cm2）

The average length of Surface crack:

$$L_a = \frac{\sum_{i=1}^{n} L_i}{n}$$

In the formula:

L_a ——Mean crack length（cm）

n ——Select the number of surface cracks

L_i ——Each crack length（cm）

4.1 Crack phenomenon on Titanium alloy surface

Due to the difference in the energy of a single pulse in EDM, the surface crack formation process of the workpiece is different, and the number and width of cracks on the surface of the workpiece are also different. Figure 2 shows the crack condition of titanium alloy workpiece material under the surface of EDM milling with different energy. It can be seen from the figure that the surface crack of workpiece mainly includes radial crack, arc crack and local surface crack. The variation of surface crack parameters with discharge parameters is shown in table 1.

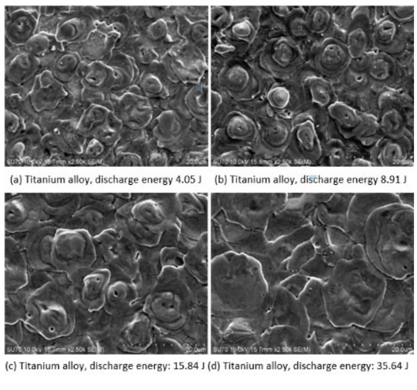
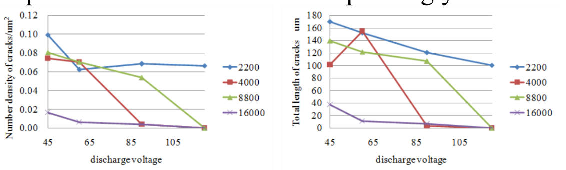


Figure 2 micro-EDM surface cracks in titanium alloy materials

Table1 RC pulse power supply titanium alloy crack parameters with discharge parameters change data table

Capaitance pF	electric V	Energy μJ	The number of crack	To evaluate the area um^2	Total crack length μm	The crack density μm/um^2	Average crack length μm	Crack number density
2200	45	2.23	48	483.87	170.16	0.35	3.55	0.10
2200	60	3.96	30	483.87	152.21	0.31	5.07	0.06
2200	90	8.91	33	483.87	120.44	0.25	3.65	0.07
2200	120	15.84	32	483.87	100.24	0.21	3.13	0.07
4000	45.00	4.05	36	483.87	101.36	0.21	2.82	0.07
4000	60.00	7.20	34	483.87	154.47	0.32	4.54	0.07
4000	90.00	16.20	2	483.87	3.70	0.01	1.85	0
4000	120.00	28.80	0	483.87	0	0	0	0
8800	45	8.91	39	483.87	139.2	0.29	3.57	0.08
8800	60	15.84	34	483.87	121.47	0.25	3.57	0.07
8800	90	35.64	26	483.87	106.9	0.22	4.11	0.05
8800	120	63.36	0	483.87	0	0	0	0
16000	45.00	16.20	8	483.87	37.18	0.08	4.65	0.02
16000	60.00	28.80	3	483.87	10.89	0.02	3.63	0.01
16000	90.00	64.80	2	483.87	6.63	0.01	3.32	0
16000	120.00	115.20	0	483.87	0	0	0	0

When using RC pulse power supply for micro EDM, the surface crack of titanium alloy workpiece is very obvious.As shown in figure 3 (a) ,When the same evaluation area is selected, when the discharge capacitance is constant, the number of cracks decreases remarkably with the increase of the discharge voltage, and the change trend of the number density of cracks is the same as the change trend of the number of cracks and this is because most of the cracks occur around a single molten pool. As the discharge voltage increases, the molten pool generated by individual pulse energy increases. In the same assessment area, the number of molten pool decreases correspondingly, so the number of cracks on the workpiece surface decreases correspondingly.



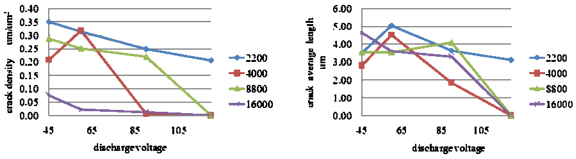
The number density of cracks in titanium alloy varies with the discharge voltage

Total length of cracks in titanium alloy varies with the discharge voltage

Figure 3.Number density of cracks and total length of cracks varies with discharge voltage in titanium alloy

As shown in figure 3(b), the total length of the surface cracks on the selected evaluation surface gradually decreases with the increase of discharge voltage and this is because the number of cracks decreases with the decrease of the occurrence of cracks. When the capacitance is fixed, the critical gap of discharge breakdown increases with the increase of discharge voltage, which results in the decrease of the temperature gradient acting on the workpiece surface. As a result, the thermal stress decreases. The crack phenomenon decreases accordingly.

As shown in Figure 4, on the surface of micro EDM workpiece, the physical properties of titanium alloy determine the inevitability of surface cracks. When the discharge capacitance remains unchanged, the surface crack density gradually decreases with the increase of discharge voltage. When the discharge voltage remains unchanged, the surface crack appearance gradually decreases with the increase of discharge capacitance. This is different from previous studies that the crack phenomenon increases with the increase of pulse energy and this is because when the discharge voltage is constant, with the increase of discharge capacitance, the monopulse discharge time gradually increases, and the same voltage drops to zero when the discharge time is longer, resulting in a smaller discharge gradient and a smaller thermal stress, resulting in less crack phenomenon. Therefore, as the energy increases, the number of cracks does not increase. On the contrary, the number of cracks, crack density, average crack length, and crack number density all decrease. Therefore, in order to reduce the crack phenomenon, the energy of single pulse cannot be reduced blindly. In these tests, when the capacitance is 4000pF and the voltage is 120V, the surface has no crack phenomenon and the surface quality is relatively good.

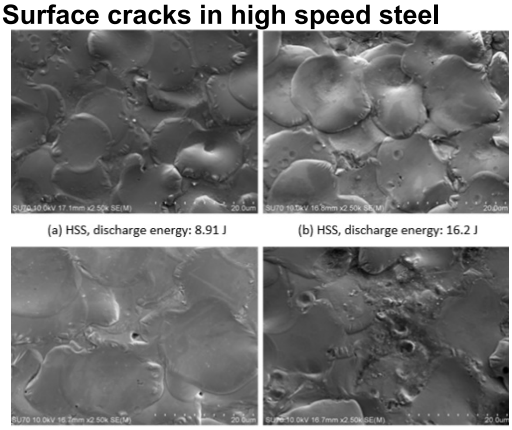


(a)The crack density of titanium alloy changes with the discharge voltage

(b)The crack average length of titanium alloy changes with the discharge voltage

Figure 4 The crack density and crack average length of titanium alloy changes with discharge voltage

4.2 Surface cracks in high speed steel



(a) HSS, discharge energy: 8.91 J

(b) HSS, discharge energy: 16.2 J

(c) HSS, discharge energy 35.64 J

(d) HSS, discharge energy 64.8 J

Figure 5. Micro-EDM surface cracks in HSS materials

As can be seen from figure 5, the surface cracks of high-speed steel workpieces are much smaller in size and number than those of titanium alloy materials. There are almost no cracks on the surface of high-speed steel workpieces, and the surface quality is much higher than that of titanium alloy and this is because the specific heat capacity of the titanium alloy is higher than that of the high-speed steel, and the thermal conductivity is lower than that of the high-speed steel. The heat transfer coefficient of the workpiece material is larger, and the heat source transmits more energy to other places, resulting in a smaller temperature gradient and less generated stress. As a result, the surface crack phenomenon is also reduced. That is, the larger the heat transfer coefficient is, the less obvious the crack phenomenon is, so the crack number and crack density of the high speed steel are smaller than those of the titanium alloy under the same energy.

Through a large number of experimental studies on high-speed steel and titanium alloy, it is found that at the same energy level, there is basically no crack in the high-speed steel, and there are a large number of cracks on the surface of the micro-EDM of the titanium alloy. This is because high speed steel has a high thermal conductivity and can quickly transfer heat from the heat source area during the processing. So the heat is far away from the heating area, which will reduce the formation of cracks, indicating that the thermal conductivity has an important effect on the crack. Therefore, the physical properties of the material itself determine that the hot crack of the high speed steel is less than that of the titanium alloy material. Whether it is high-speed steel or titanium alloy, the crack on the surface of the workpiece is deepened with the increase of EDM parameters.

5. Measures to improve surface cracks

Although the physical properties of the material determine that material cracking is unavoidable, surface cracking can be minimized by reasonable selection of processing parameters.

In order to reduce cracks, it is necessary to select a material having a small coefficient of thermal expansion and a small volume change ratio of solid-liquid phase change. The use of electrode materials with better tensile strength will reduce surface cracks and improve the quality of the machined surface.

Adopt workpiece materials with good heat transfer property. Because of good heat transfer performance, the temperature gradient between layers of materials is small in the process of thermal action, resulting in less thermal stress and less crack. For example, high-speed steel with a large thermal conductivity can be selected as the workpiece material in the material titanium alloy and high-speed steel.

The crack is caused by the temperature gradient of each part of the material during the processing, so EDM is used as much as possible with the processing parameters with lower temperature gradient, which can effectively reduce the crack phenomenon. During the processing of RC pulse machining, in order to reduce the temperature gradient, a large capacitor can be used to increase the discharge time and reduce the temperature gradient, thereby reducing the surface crack phenomenon; Similarly, when the RC pulse power supply with the same energy is used for EDM that once the voltage is increased, the critical discharge gap in the discharge circuit will become larger, so that the temperature gradient generated by the workpiece material will be smaller, resulting in less thermal stress and reducing the chance of crack formation. Therefore, when the RC pulse is discharged, the processing parameters of the larger capacitance and larger voltage are selected as much as possible, so that the crack phenomenon can be effectively reduced.

6. Conclusion

In this paper, the crack of recasting layer on the workpiece surface was studied. The results show that different materials have different crack phenomena in EDM. To reduce the crack phenomenon, the processing parameters of large current and short pulse are selected as far as possible for EDM in the processing of equal energy thyristor pulse power supply. In RC pulse discharge, the crack phenomenon can be effectively reduced by selecting machining parameters with larger capacitance and higher voltage.

Acknowledgements

Fund Code: Contract Number: [2022] No. 74
Ideological and political exploration and practice of material processingCAD/CAM course

References

1. Lee Hwa-Teng, Hsu Fu-Chuan, Tai Tzu-Yao, et al.Study of surface integrity using the small area EDM process with a copper-tungsten electrode. Materials Science and Engineering A, 2004, 364(1-2): 346-356.
2. Murray J. W., Clare A. T, et al. Repair of EDM induced surface cracks by pulsed electron beamirradiation. Journal of Materials Processing Technology, 2012, 212(12): 2642-265
3. Govindan P., Joshi Suhas S, et al. Analysis of micro-cracks on machined surfaces in dry electrical discharge machining. Journal of Manufacturing Processes, 2012, 14(3): 277-288.
4. Wujun Feng, Xuyang Chu*, Yongqiang Hong and Li Zhang, et al. Studies on the surface of high-performance alloys machined by micro-EDM. Materials and Manufacturing Processes. 2018, 33(6):616–625.