SURFACES INTEGRITY OF ELECTRO-DISCHARGED MACHINED INCONEL AND STEEL ALLOYS

استقامة الاسطح المشغلة بطريقة الشرر الكهربائى لسبيكتى النيكل والصلب

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الملخص العربى :

نظرا لاهمية سبائك النيكل (٧١٨) والصلب (١١٦٠) فى صناعة المركبات الفضائية ومحطات القوى النووية ونظرا لصعوبة تشغيل هذه السبائك بطرق التشغيل التقليدية التى تؤدى عادة الى سرعة بلى ادوات القطع وتاثير ضار لاستقامة السطح المشغل فقد تم فى هذا البحث تشغيل عينات من هذه السبائك باستخدام ماكينة التشغيل بالشرر (التفريغ) الكهربائى تحت ظروف تشغيل مختلفة.

وقد تمت دراسة تاثير كل من شدة تيار التفريغ وتردد النبضات الكهربائية على استقامة الاسطح المشغلة مثل درجة نعومة الاسطح ودقة الابعاد والتركيب الميتالوروجى للطبقة تحت السطحية، وقد دلت النتائج على تحسن استقامة الاسطح وايضا تقليل طول الشقوق المجهرية وتقليل سمك كل من الطبقة المتأثرة بالحرارة والطبقة المعاد سبكها كلما قلت قيمة شدة تيار التفريغ الى اقل من ١٠ امبير او زاد تردد النبضات الكهربائية الى اكثر من ٥٫٥ كيلو هرتز او كليهما.

ABSTRACT

Conventional machining methods are ineffectively applied to hard steels and inconel 718 alloys due to excessive tool wear and lack of workpieces surfaces integrity. The success achieved in electrodischarge machining (EDM) for hard metals has stimulated the interest in exploring the machined surfaces integrity. The effects of changing the input variables such as discharge current and/or pulse frequency on the resulted surfaces integrity aspects such as surface finish, dimensional accuracy and sub-surface metallurgical structures are, hereafter probed. The results showed that employing low values of discharge currents (less than 10 Ampere) and high values of pulse frequency (more than 5.5 KHz) give better surface integrity. Moreover, all of the microcrack length, the recast and heat affected zones are decreased apon increasing the pulse frequency and/or decreasing the discharge current.

KEYWORDS

Electrodischarge machining, Inconel, steel, surface roughness, work piece accuracy, integrity, overcut, conicity, microstructure.

INTRODUCTION

The electrodischarge machining (EDM) is a process of removing materials, in a closely controlled manner from an electrically conductive material immersed in a liquid dielectric employing, a series of randomly distributed discrete electrical sparks. The energy generated at the discharge channel melts or even vaporizes the electrode material which is then ejected from the region via a complex and little known mechanism [1].

Published data on the impact of EDM on workpieces surface integrity aspects such as surface damage and workpiece accuracy for inconel 718 alloys and hardened steel is extremely limited. However, the potential, future and overview of the process are widely discussed by many authors [2-6]. Few attempts in determine the effect of discharge current on surface roughness have revealed that higher current density would cause considerable surface deteriorations [7-9].

Pandit et al. [10] indicated that the discharge current creates craters. The machined surfaces can be, thus, considered as a superposition of overlapping craters of random depth and positions. The crater size would depend on spark energy which vary very widely giving the same machined surface a wide range of surface roughness [10].

Other surface deterioration can result from the rapid quenching of the dielectric fluid and the heat sink of the workpiece. The surface or recast layer is characterized by a rapidly quenched structure, with the underneath heat affected zone HAZ, annealed or tempered. Micro-and macrocracks usually initiate in the recast layer and extends through the HAZ. The thickness of the recast layer depends on the cutting conditions, power supply type :RC or pulse generator and material properties. The formation of recast and HAZ layers generally lowers the fatigue strength. Most aerospace manufactures require that the EDM machined surface must be removed before actual service.

Surface integrity is a term which embraces metallurgical, geometrical and dimensional accuracies of machined components [6].

Inconel-718, nickel base alloys and hardened steel are chosen for this investigation because of their extensive use in aerospace and nuclear power plant applications. Surface structure aspects such as fatigue, stress crack corrosion and creep have a great impact on service life of the component employed in these applications. Besides the machining of hardened steel utilizing EDM technique would eliminate the need of subsequent heat treatment avoiding possible distortions.

The present research offers an attempt to outline some experiments in order to study the performance and feasibility of machining inconel and steel alloys by the EDM process under a variety of machining conditions. The effects of changing the machining input parameters such as current intensity and pulse frequency on the technological output parameters of surface integrity have been carried out.

EXPERIMENTAL WORK

The machining experiments were performed on a controlled pulse generator EDM machine, type (VJKS). The no-load voltage is adjusted on 100 V with variable current intensities ranging between I = 5 to 45 A and pulse frequency f = 1 to 5.5 KHz. Kerosene was used as the dielectric fluid. Copper electrodes with negative polarity were used as electrode materials having 12 mm or 18 mm diameters. The work piece materials were Inconel 718 and steel 1160 having 100x50x20 mm dimensions and compositions as given in Table 1.

Table 1 Chemical compositions of employed workpieces materials

Ni%	Ti%	Al%	Fe%	Nb%	S%	Cr%	C%	Material
45.8	0.9	4.70	18.5	5.0	-	19.0	0.04	Inconel-718
0.4	-	-	99.05	-	0.04	0.3	0.61	Steel-1160

The test duration in all cases,unless specified, was kept constant. Prior to tests the tool and work pieces were polished via polishing rotating disc covered with velvet cloth in order to achieve a surface finish of 2 µm Ra. for all cases.

Surface finish of the machined surfaces were measured employing Talysurf (Model6). The roundness measurements were carried out utilizing Talycenta at a distance of 2mm from the top surface of the machined holes. The overcut and hole conicity were measured utilizing a Tool maker microscope having an accuracy of ±0.0005mm. Metallographical examinations were carried out employing an optical microscope (Newphot 2) having magnifications up to 1500 X on longitudinal sections perpendicular to the machined surfaces.

RESULTS AND DISCUSSIONS

Effect of Current Intensity

The effects of peak current intensity on the surface finish index Ra of the two used materials Inconel and steel is shown in Fig 1. The surface roughness increased with the discharge current intensity. At low current there are little differences between the two metals in spite of their different structures and compositions. The effects on steel specimens are more pronounced at higher currents.This could be due to structural changes in surface layer transformation to martensite in case of steel. That is revealed clearly later in its microstructure.

The same effect of current intensity on surface roughness through holes is shown in Fig 2. However, the roughness for flat sinking is lower than that of through holes.The gap conditions in flat sinking are much more favorable than that for through holes. The same effect of current intensity on surface roughness was found in ref.[4] but with higher values due to their employed composite workpieces.

The effect of discharge current intensity on values of out of roundness is shown in Fig 3 .The increase in discharge current leads to an increase in out of roundness values for both steel and inconel specimens. However. at high currents intensities the effect is more pronounced in case of steel than that for inconel specimens. The measurements were taken 2 mm below the top, since out of roundness values were gradually increased from top to bottom. Out of roundness values were increased from 50 µm at 2mm depth to 290 µm at 20 mm depth

Figures 4 and 5 show some of the polar recording of roundness at various discharge currents for the inconel and steel specimens. Severe deviations of roundness are observed at higher currents for both materials. The effect is once more pronounced for steel specimens.

Fig 6 shows the effect of discharge current intensity on semi-cone angles. As the current is increased the conicity is also increased .The conicity arising in holes may be attributed to the decrease in penetration rate of the dielectric fluid as depth of the hole is increased.

Figure 7 shows the increase of the overcut, measured as double lateral gap, due to an increase in the discharge current intensity. As current is increased the liberated energy is consequently increased and hence, the sizes of the eroded particles are expected to be enlarged resulting in large hole diameters

Effect of Pulse Frequency

Figure 8 shows the influence of pulse frequency on the surface roughness. Roughness is significantly decreased from 8 µm to 3 µm when the pulse frequency is increased from 1 KHz to 5.5 KHz for both steel and inconel materials. This influence is more pronounced when measurements were taken through hole sides as shown in Figure 9, where gap condition is less favorable [11].

The decrease in pulse frequency or the increase in pulse duration is expected to allows more time for the growth of gas bubbles. The larger are the bubbles the deeper is the resulting crater cavity and consequently rougher surfaces are to be produced. However, the increase in surface roughness is usually accompanied by an increase in metal removal rate [12] .

The microstructure of the steel specimens with different discharge current intensities is shown in Figure 10 a-c. At low current of 18 A, the depth of the recast layer is small. At relatively higher values of current the recast layer thickness increases and the microcracks appear. This result shows that the depth of the recast layer is related to the energy liberated in the cutting zone. The input energy depends, mainly, on the values of current intensity since frequency has little effect on the heat energy.

The microstructure of the inconel specimens is shown in Figure 11 a-c for different current intensities. After exposure to high energy discharges, three layers can be identified. The first layer is the redeposited recast layer, formed by molten metal particles being redeposited on the work surface. the second layer is the recast layer which has reached melting point, but not dispersed, and which remains as a recast layer. The third layer is the annealed segregated layer which has reached overheated temperatures, giving opportunity to the intermetallic phase to precipitate mainly on the grain boundaries. The segregation of the intermetallic compound was intensified for higher current intensities.

Several other distinguished features can also be seen from the microstructure which include surface irregularity. The surface consists of cavities, grooves and fractured areas which vary widely in depth and shape. Moreover, the recast layer and crack length of inconel alloy specimens showed smaller values than the corresponding length of steel specimens. This is probably due to phase change, into the brittle martensite, in case of steel.

CONCLUSIONS

Certain conditions must be fulfilled, in the EDM process, in order to improve workpieces surface integrities viz;

1- Considerable deterioration in surface integrity is to be expected for higher discharge currents intensities.

2- Higher pulse frequency and lower discharge currents should be employed in order to improve surface finish.

3- There are increases in intermetallic compound segregations in inconel specimens along the grain boundaries for higher discharge currents intensities.

4- At current over 38 A, The machined surfaces of inconel specimens showed deep grooves and fractured areas.

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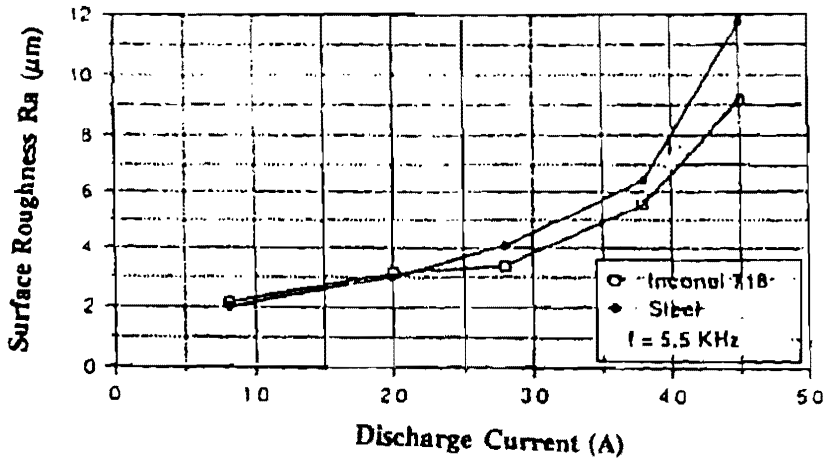


Fig. 1 Effect of discharge current on surface roughness .

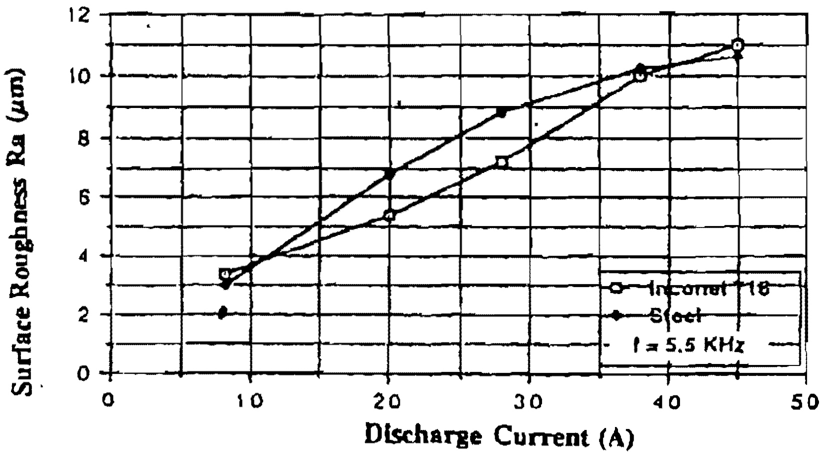


Fig. 2 Effect of discharge current on surface roughness of holes.

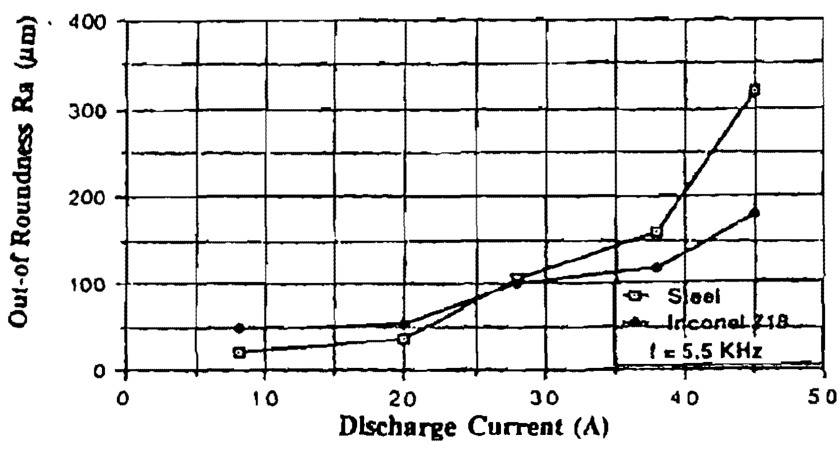
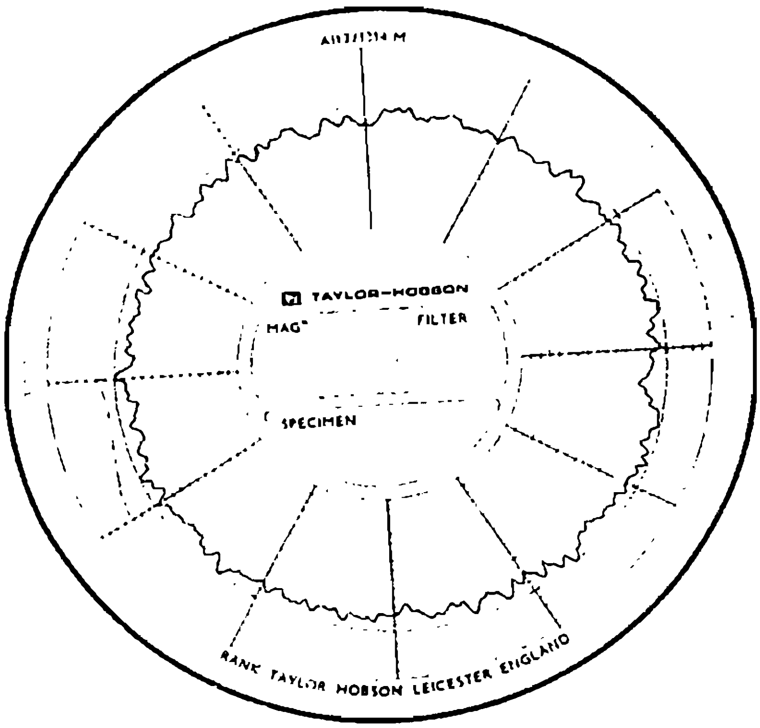


Fig. 3 Effect of discharge current on out of roundness errors.

(a)



(b)

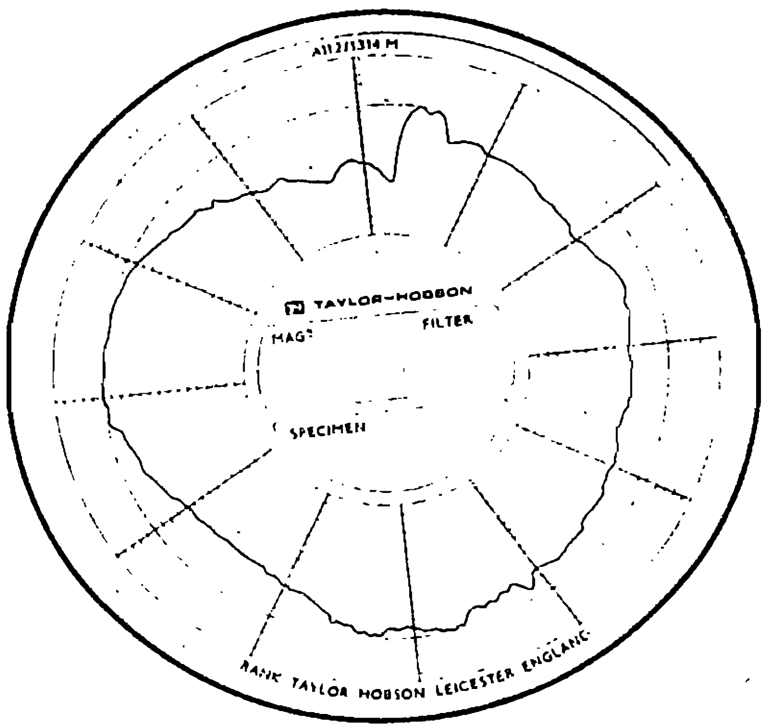
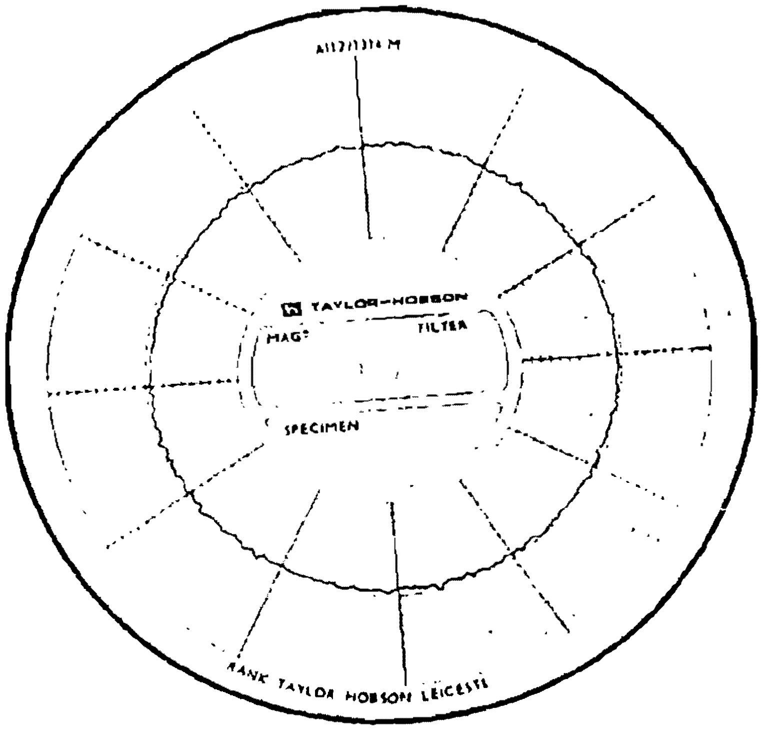


Fig. 4 Polar recording of roundness of Inconel-718 specimen.
(a) - At I = 8 A and f = 5.5 KHz. (X 150)
(b) - At I = 45 A and f = 5.5 KHz. (X 150)

(a)



(b)

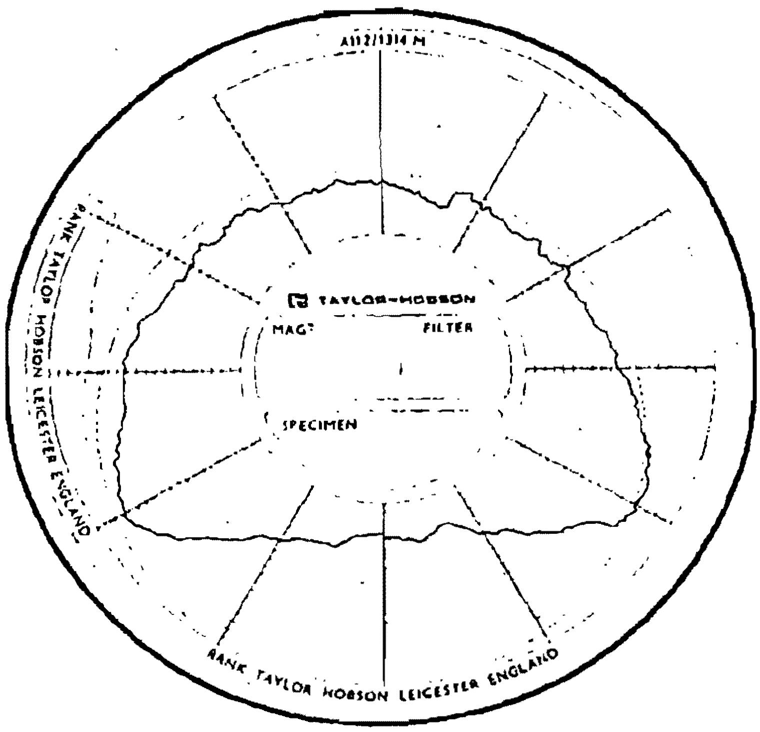


Fig. 5 Polar recording of roundness of steel 1160 specimens.
(a) - At I = 8 A and f = 5.5 KHz. (X 150)
(b) - At I = 45 A and f = 5.5 KHz. (X 150)

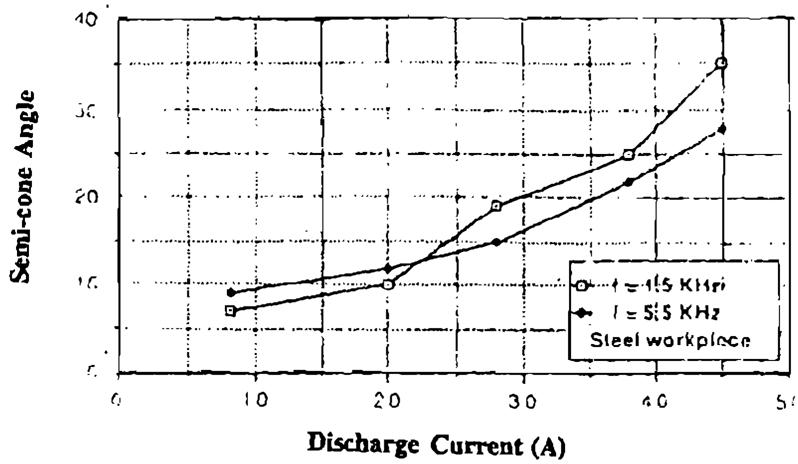


Fig. 6 Effect of discharge current on conicity.

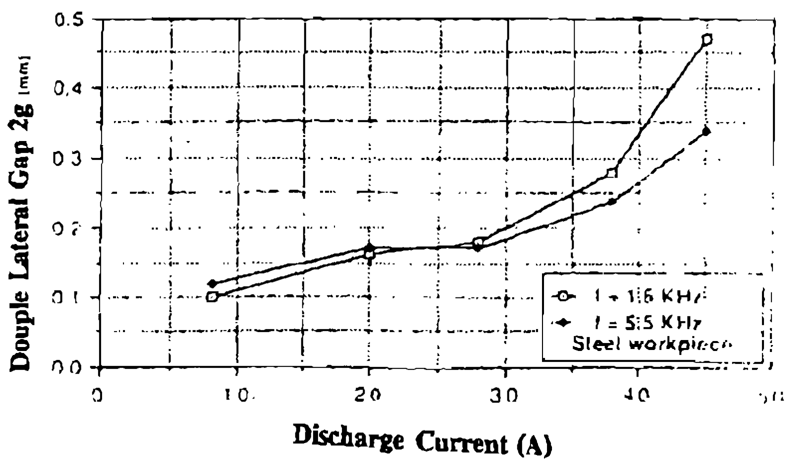


Fig. 7 Variation of overcut with increase of discharge current.

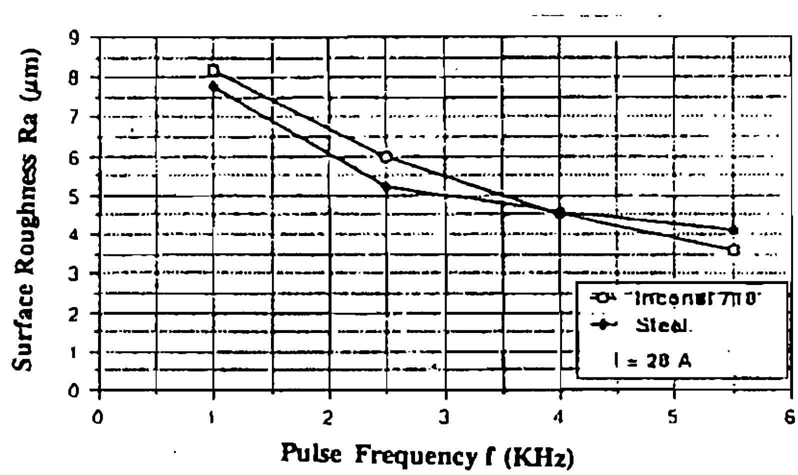


Fig. 8 Effect of pulse frequency on surface roughness of flat sinking surfaces.

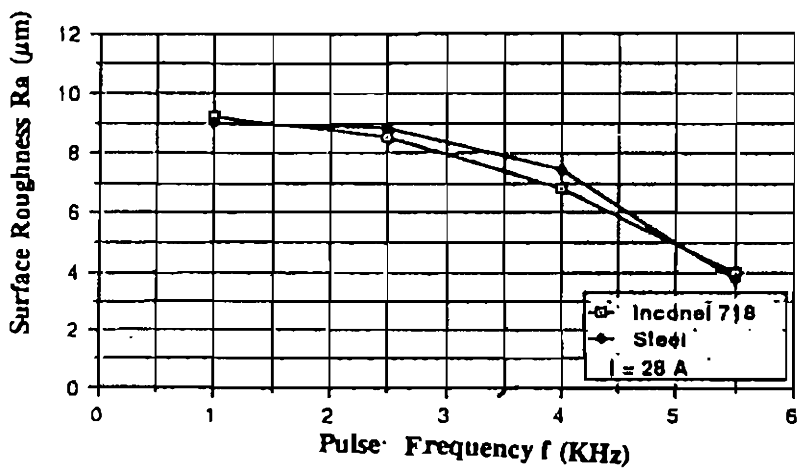


Fig. 9 Effect of pulse frequency on surface roughness of through hole sides.

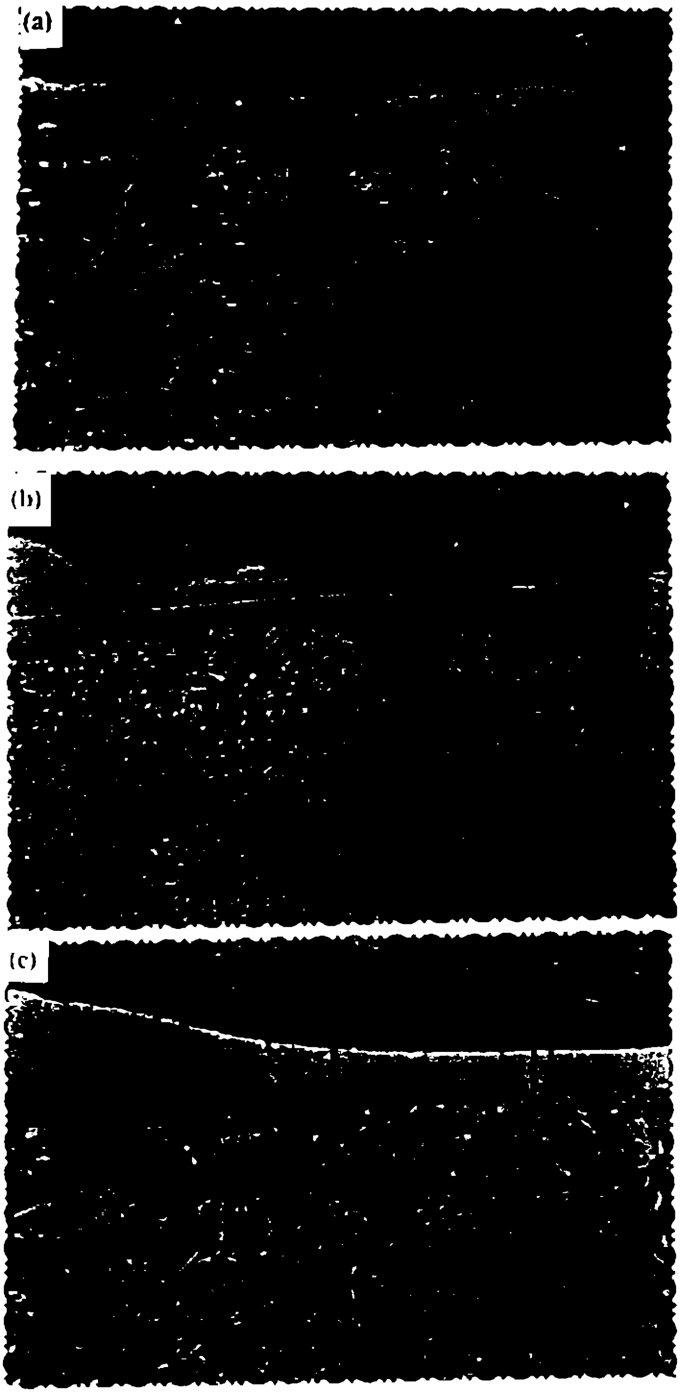


Fig.10 Microstructure observed at right angle to the EDM cut surface of Steel-1160 specimens at f = 4 KHz. (X 200)
(a) I = 8 A (b) I = 28 A (c) I = 38 A.

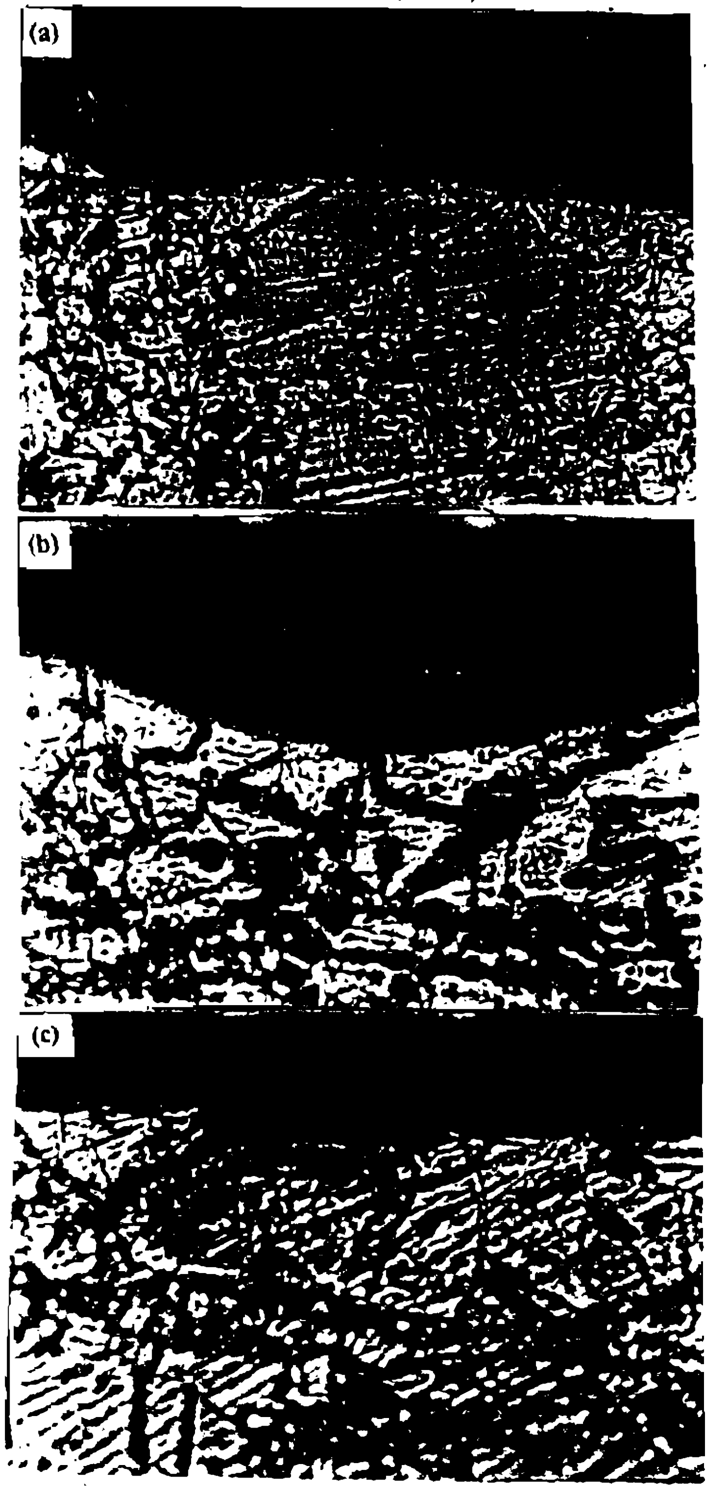


Fig.11 Microstructure observed at right angle to the EDM cut surfaces of Inconel-718 specimens at f = 4 KHz. (X 200)
(a) I = 8 A (b) I = 28 A (c) I = 38 A.