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EFFECT OF ELECTRICAL DISCHARGE MACHINING ON URANIUM-0.75 TITANIUM AND TUNGSTEN-3.5 NICKEL-1.5 IRON ALLOYS

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EFFECT OF ELECTRICAL DISCHARGE MACHINING ON URANIUM-0.75 TITANIUM AND TUNGSTEN-3.5 NICKEL-1.5 IRON ALLOYS

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ABSTRACT

An investigation has been made of the effect that electrical discharge machining (EDM) has on uranium-0.75 titanium (U-0.75 Ti) and tungsten-3.5 nickel-1.5 iron (W-3.5 Ni-1.5 Fe) alloys. It was found that U-0.75 Ti alloy cracked if the EDM parameters were out of control, and precipitation of carbides adjacent to the EDM surface took place during subsequent solution quenching.

Cracks form in the "recast" layer when solution-quenched U-0.75 Ti alloy undergoes EDM, and the cracks propagated during subsequent nickel plating. If the recast layer was removed prior to nickel plating, only a slight loss in strength resulted, compared to conventional machining.

W-3.5 Ni-1.5 Fe alloy also sustained some surface damage during EDM and also experienced a small loss in strength, compared to conventionally machined material.

CONTENTS

SUMMARY

When uranium-0.75 titanium (U-0.75 Ti) alloy is electrical discharge machined (EDM) prior to solution quenching, inclusions enriched in titanium, carbon, and silicon are precipitated adjacent to the EDM surface during solution quenching.

When optimum EDM parameters are used, a "clean" subsurface structure is retained in as-rolled U-0.75 Ti alloy plate. If the EDM processing parameters are out of control, recrystallization and cracking take place.

A recast layer containing cracks forms when solution-quenched U-0.75 Ti alloy is processed by EDM, and these cracks propagate during electroplating of the alloy with nickel.

If the recast layer on the surface of U-0.75 Ti alloy is removed prior to plating the surface with nickel, only a slight loss in strength results from EDM compared to conventional machining.

The tungsten-3.5 nickel-1.5 iron (W-3.5 Ni-1.5 Fe) alloy also experienced some surface damage and a small loss in strength due to EDM, compared to conventional machining.

INTRODUCTION

The phenomenal growth of electrical discharge machining (EDM) in recent years has changed many shop procedures that affect tools, dies, and molds. EDM's greatest advantage lies in its ability to produce complicated die and mold configurations at costs lower than conventional cutting methods.[1-3] While EDM offers many benefits, it also creates conditions (such as a recast layer on the surface) that should be thoroughly understood; consequently, the effect of EDM on two alloys of current interest—uranium-0.75 titanium and tungsten-3.5 nickel-1.5 iron—was studied.

The objectives of the investigation, performed at the Oak Ridge Y-12 Plant[a], was to EDM both alloys and maintain their mechanical properties comparable to those obtained by conventional machining.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Energy Research and Development Administration.

EFFECT OF ELECTRICAL DISCHARGE MACHINING ON TWO ALLOYS

EXPERIMENTAL WORK

Uranium-0.75 Titanium Alloy

Electrical Discharge Machining before Solution Quenching - An electrical discharge machine (seen in Figure 1) was used to drill 1.19-mm (3/64-in)-diameter experimental holes in U-0.75 Ti alloy plate that was 25.4 mm (1 in) thick. History of the plate was as follows: A 101.6-mm (4-in)-thick vacuum-induction-melted casting of the alloy was homogenized at 1000^{o} C for four hours in a vacuum furnace, then the homogenized casting was reheated to 650^{o} C in molten salt and hot rolled to a 25.4-mm (1-in)-thick plate.

When a 1.19-mm (3/64-in)-diameter hole was drilled in this plate by the EDM process (using the parameters listed for Test 1, Table 1), the subsurface near the hole took on the appearance seen in Figure 2; when the Test 2 parameters in Table 1 were used, the resulting subsurface gave the appearance noted in Figure 3.

Table 1

ELECTRICAL DISCHARGE MACHINING PARAMETERS FOR URANIUM-0.75 PERCENT TITANIUM ALLOY

Test Number	Electrode Composition	Electrolyte	Amperes	Volts	Feed Rate	Remarks
1	Cu-40 W Alloy	Texaco 499 EDM Fluid	Fluctuated	80	Constant	Cracks formed
2	Brass (Cu-30 Zn)	Texaco 499 EDM Fluid	20	60	Pulsed	No defects observed.

To simulate a typical heat-treating cycle, a 50.8-mm-square section of the plate (containing an EDM hole made by the Test 2 parameters listed in Table 1) was solution treated at 800^{o} C for two hours in a vacuum of 6.7 mPa (5×10^{-5} torr), water quenched, and aged in a vacuum oven at 400^{o} C for eight hours. Figure 4 provides a view of the subsurface structure after solution quenching.

A microprobe analysis was run on the inclusions around the EDM hole, seen in Figure 4. All the inclusions that were analyzed were enriched in titanium, with carbon and silicon also being present. No additional impurities were detected.

Electrical Discharge Machining After Solution Quenching - The Ex-Cell-O (EDM) machine (Figure 5) was used to EDM a 6.35-mm (1/4-in)-wide slot in a U-0.75 Ti alloy section for a preliminary metallographic examination and for machining the notches in the double-notched tensile specimens (note Figure 6). The EDM parameters for this alloy are listed in Table 2.

History of the U-0.75 Ti alloy is as follows: A 101.6-mm (4-in)-thick vacuum-induction-melted casting of the alloy was homogenized at 1000^{o} C for four hours in a vacuum furnace; then the homogenized casting was reheated to 650^{o} C in molten salt and hot rolled to a 15.87-mm (0.625-in)-thick plate, held for one hour in vacuum at 800^{o} C and water

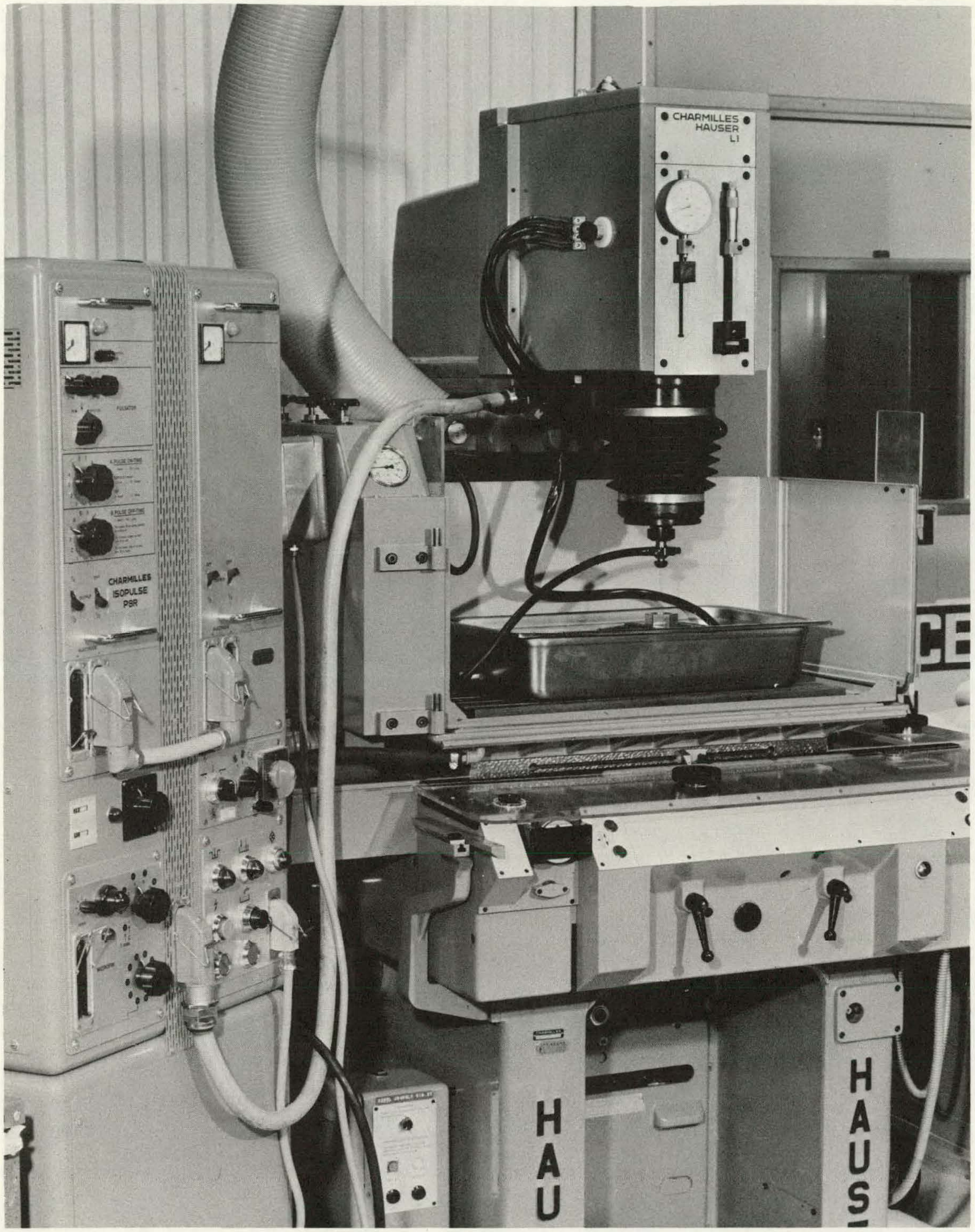

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Figure 1. A CHARMILLES HAUSER ELECTRICAL DISCHARGE MACHINE.

quenched, and aged at 380° C for six hours. Double-notched tensile specimens were also made by conventional machining to obtain control specimens from the alloy.

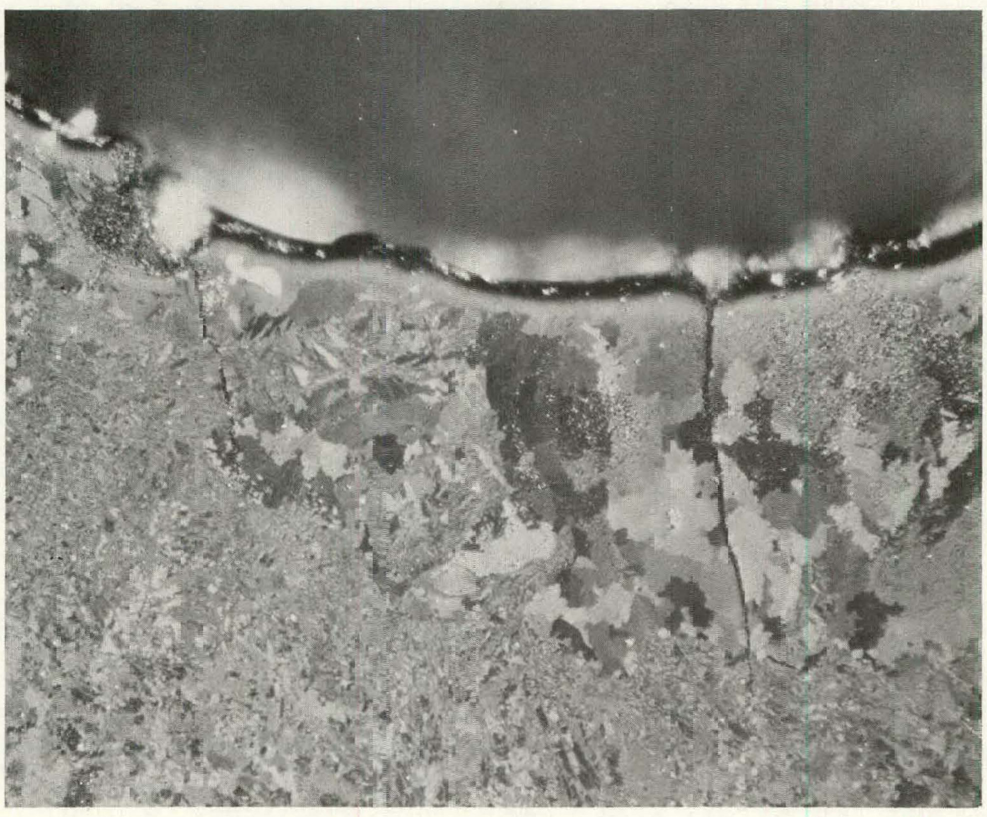

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Figure 2. PHOTOMICROGRAPH OF URANIUM-0.75 TITANIUM ALLOY AFTER ELECTRICAL DISCHARGE MACHINING BY THE TEST 1 PARAMETERS OF TABLE 1. (Polarized Light; 250X)

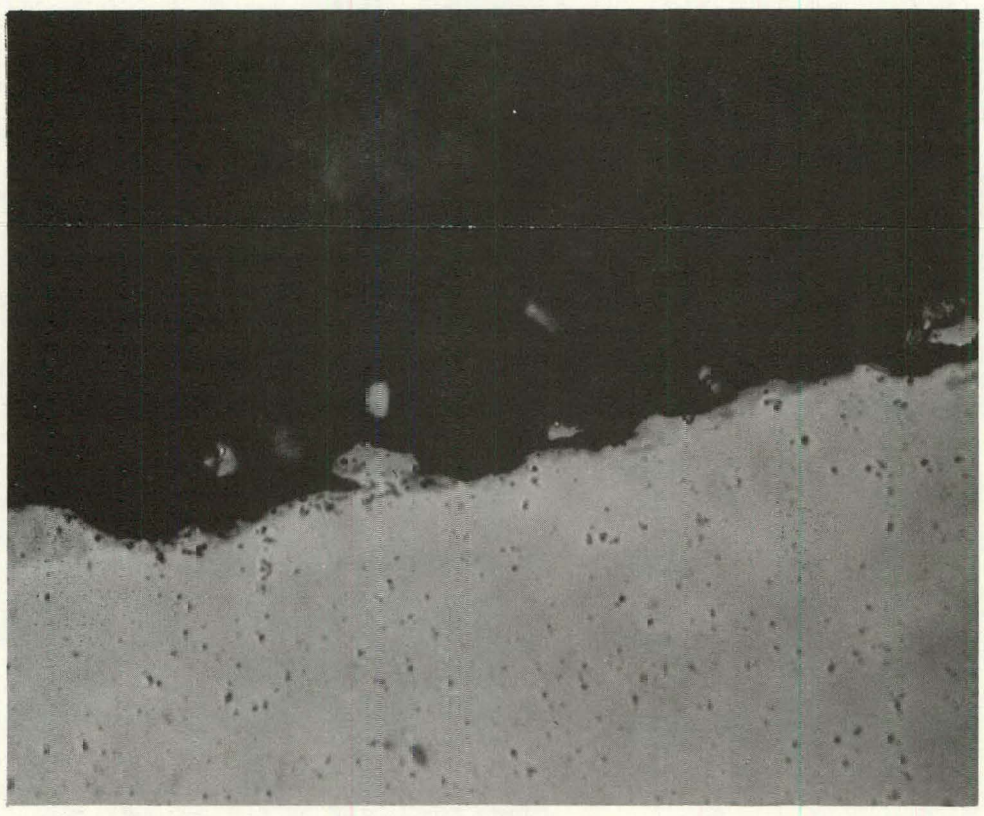

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Figure 3. PHOTOMICROGRAPH OF URANIUM-0.75 TITANIUM ALLOY AFTER ELECTRICAL DISCHARGE MACHINING BY THE TEST 2 PARAMETERS OF TABLE 1. (Bright Field Illumination; 1000X)

J162

Figure 4. MICROSTRUCTURE OF URANIUM-0.75 TITANIUM ALLOY AFTER ELECTRICAL DISCHARGE MACHINING BY TEST 2 AND AFTER SOLUTION QUENCHING. (Bright Field Illumination; 100X)

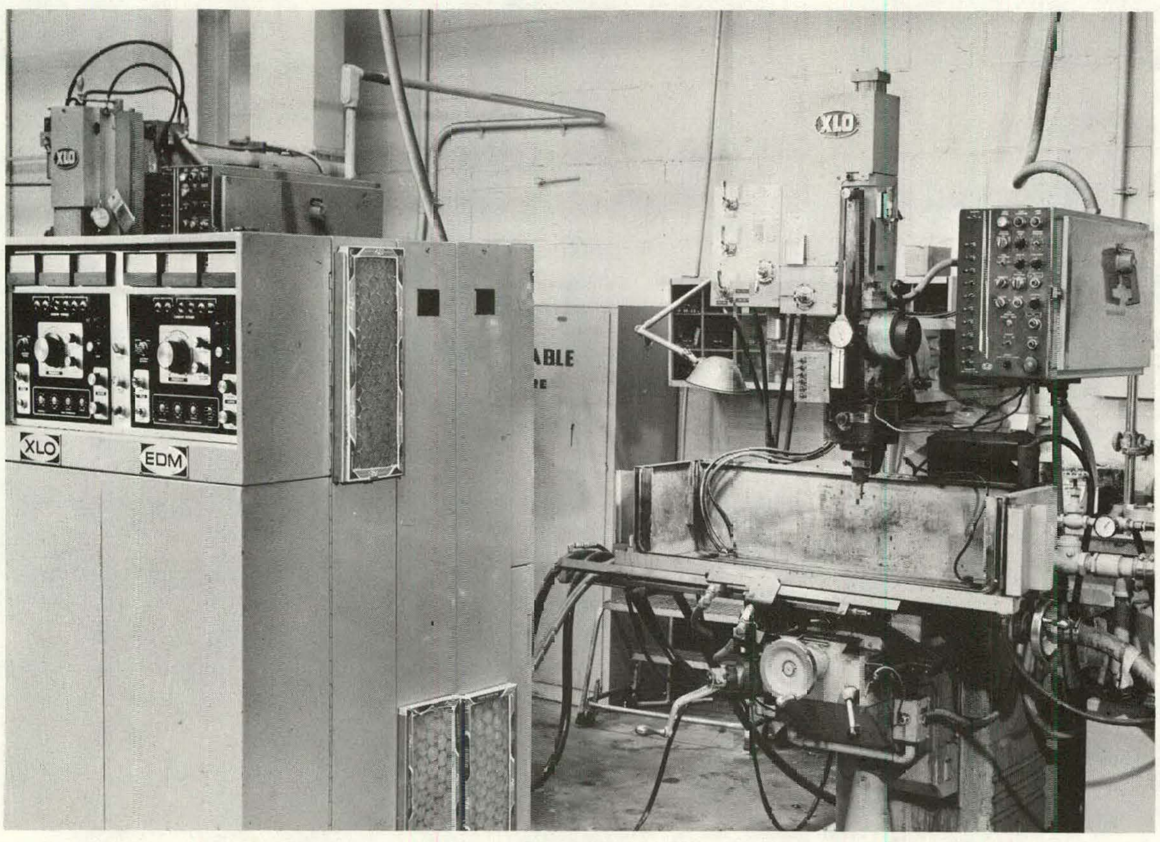

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Figure 5. AN EX-CELL-O ELECTRICAL DISCHARGE MACHINE.

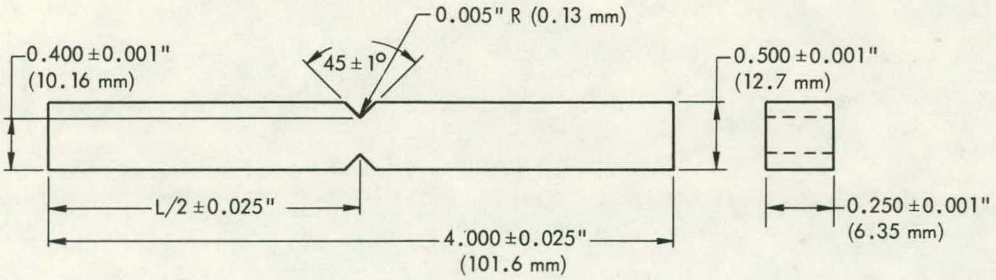

Figure 6. DOUBLE-NOTCHED TENSILE BAR.

Table 2

ELECTRICAL DISCHARGE MACHINING PARAMETERS
(For U-0.75 Ti and W-3.5 Ni-1.5 Fe Alloys)

Volts, DC	65
Amperes, DC	2
Feed	2.5(1)
Servo	6(1)
Frequency	9(1)
Duty Cycle	65(1)
Electrode Composition	Cu-40 W Alloy
Electrolyte	Texaco 499 EDM Fluid
Polarity	Normal(2)

(1) Setting on the Ex-Cell-O machine.
(2) Positively charged electrode.

A recast layer containing cracks (~ 0.012 mm long) was observed on the surface (Figure 7) after EDM of U-0.75 Ti alloy specimens. When 0.025 mm (1 mil) of nickel was deposited on the specimen surfaces by using the electroplating parameters presented in Table 3, the cracks were 0.041 mm long (Figure 8).

If the EDM surfaces are wire brushed to remove the recast layer of approximately 0.012 mm (5 mils) before nickel plating, a substrate structure shown in Figure 9 is formed. Figure 10 shows the condition of the alloy substrate after conventional machining followed by deposition of electrolytic nickel on the surface. Six double-notched tensile specimens were tested for both conventionally machined and EDM bars of U-0.75 Ti alloy that were subsequently nickel plated. Only the EDM bars were wire brushed prior to nickel plating. A 95% confidence interval on the mean tensile strength of the alloy for the two machining parameters is presented in Table 4.

Table 3

PARAMETERS FOR ELECTROPLATING NICKEL ON THE SPECIMENS

Specimen Preparation

1. Vapor degrease.
2. Caustic electroclean solution (hot).
3. 60 vol % HNO_3 solution.
4. Etch in 5 moles of ferric chloride solution (Time: 3 - 5 min).
5. Etch in 50 vol % HNO_3 solution (Time: 3 min).
6. Water rinse.

Specimen Plating

1. Nickel sulfamate bath.
   a. Temperature, 35 - 40° C.
   b. Time, one hour.
   c. Current density, 20 A/ft^2.
2. Water rinse.

Tungsten-3.5 Nickel-1.5 Iron Alloy

The same machine (Ex-Cell-O) and parameters listed in Table 2 were used to cut a 6.35-mm-wide slot in a W-3.5 Ni-1.5 Fe alloy section for a preliminary metallographic examination and for machining the notches in the double-notched tensile specimens (Figure 6).

Tungsten-3.5 nickel-1.5 iron alloy, made from General Electric tungsten powder, was blended, isostatically pressed, liquid-phase sintered in a wet hydrogen atmosphere at

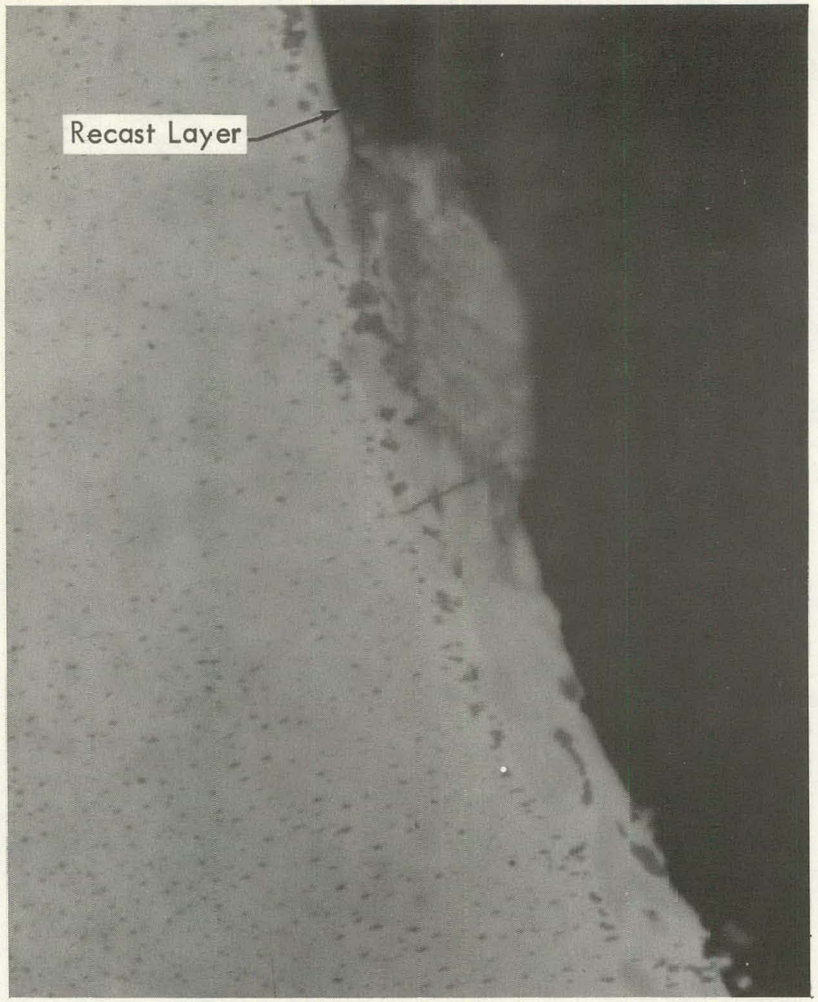

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Figure 7. PHOTOMICROGRAPH OF URANIUM-0.75 TITANIUM ALLOY AFTER ELECTRICAL DISCHARGE MACHINING. (Bright Field Illumination; 1000X)

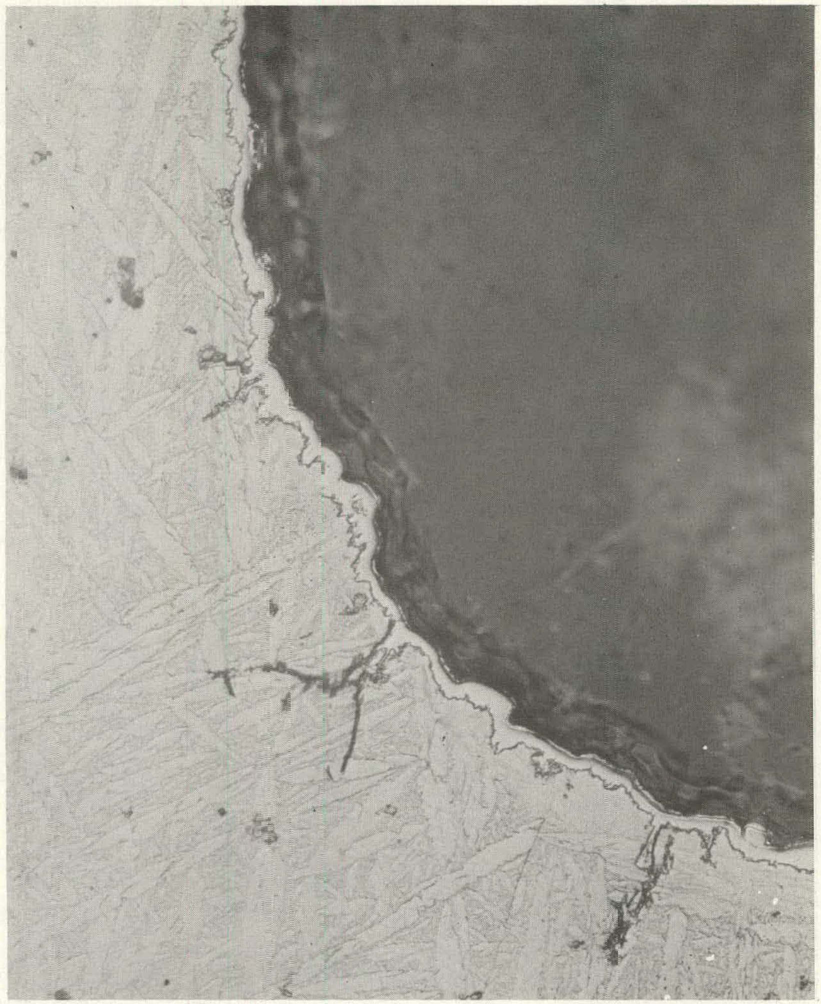

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Figure 8. PHOTOMICROGRAPH OF URANIUM-0.75 TITANIUM ALLOY AFTER ELECTRICAL DISCHARGE MACHINING AND NICKEL PLATING. (Bright Field Illumination; 400X)

MS-75-0115-5

Figure 9. PHOTOMICROGRAPH OF URANIUM-0.75 TITANIUM ALLOY AFTER ELECTRICAL DISCHARGE MACHINING, WIRE BRUSHING, AND NICKEL PLATING. (Bright Field Illumination; 400X)

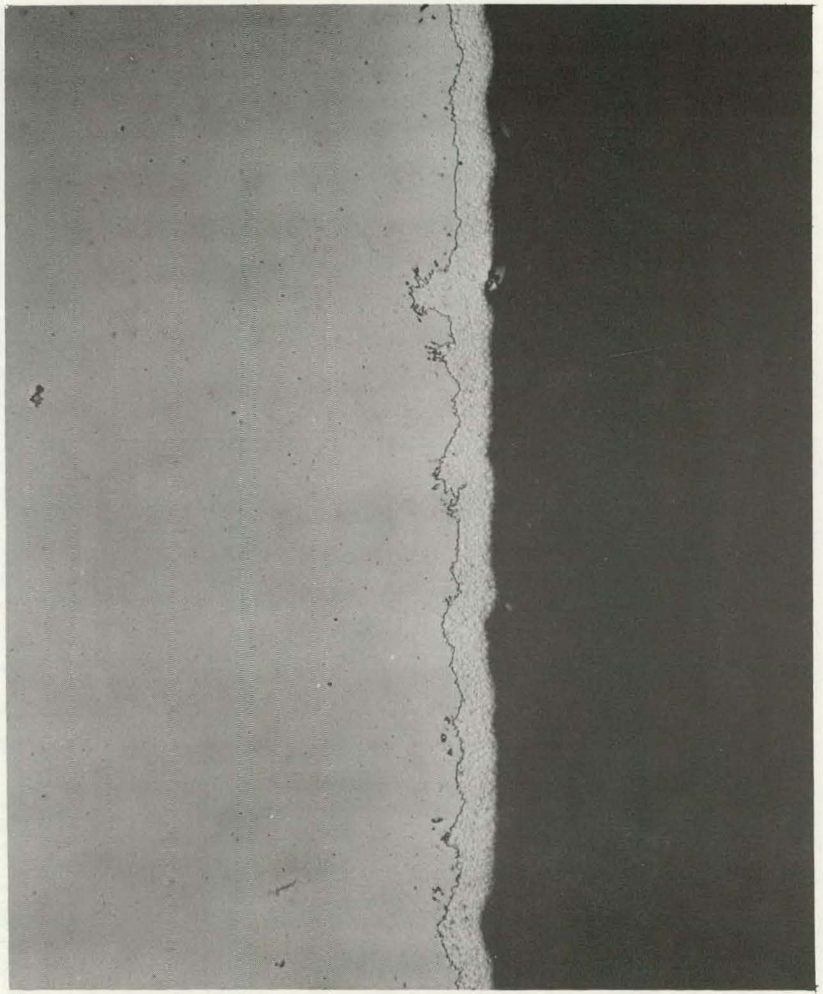

Figure 10. PHOTOMICROGRAPH OF URANIUM-0.75 TITANIUM ALLOY AFTER CONVENTIONAL MACHINING AND NICKEL PLATING. (Bright Field Illumination; 250X)

Table 4

TENSILE STRENGTH OF URANIUM-0.75 TITANIUM AND TUNGSTEN-3.5 NICKEL-1.5 IRON ALLOYS THAT WERE ELECTRICAL DISCHARGE MACHINED AND CONVENTIONALLY MACHINED

	Ultimate Tensile Strength				95% Confidence Interval on the Mean Tensile Strength (MPa)	
	Conventional Machining		Electrical Discharge Machining		Conventional Machining	Electrical Discharge Machining
	(MPa)	(ksi)	(MPa)	(ksi)		
			U-0.75 Ti			
	1473.7	213.9	1342.8[1]	194.9[1]	1458	1374[1]
	1491.6	216.5	1417.2[1]	205.7[1]	1488	1492
	1466.2	212.8	1432.4[1]	207.9[1]		
	1451.7	210.7	1499.2[1]	217.6[1]		
	1466.2	212.8	1417.2[1]	205.8[1]		
	1486.8	215.8	1486.8[1]	215.8[1]		
Average	1472.7	213.7	1432.7[1]	207.9[1]		
			W-3.5 Ni-1.5 Fe			
	897.1	130.2	879.2	127.6	878	851
	888.8	129.0	839.9	121.9	900	883
	884.7	128.4	881.9	128.0		
	872.3	126.6	865.4	125.6		
	890.8	129.3	867.4	125.9		
	901.9	130.9	866.1	125.7		
Average	889.4	129.1	866.6	125.8		

(1) Specimens were wire brushed to remove the recast layer on the surface.

1465° C for one hour, then reheated to 1100° C in vacuum for 12 hours for maximum ductility.

Six double-notched tensile specimens were made by conventional machining to obtain control specimens from the alloy. Also, six specimens were EDMed for comparison.

Those specimens that received EDM had a surface structure similar to that seen in Figure 11 and those that were conventionally machined like that of Figure 12.

The 95% confidence interval on the mean tensile strength of the alloy for the two machining parameters is presented in Table 4.

CONCLUSIONS AND RECOMMENDATIONS

When the EDM parameters of Test 1, Table 1 were used, recrystallization and cracking took place at the surface and extended into the subsurface (Figure 2). When the optimum EDM parameters were used, a clean subsurface structure (Figure 3) resulted; but, when this same specimen was solution quenched and aged, inclusions rich in titanium, carbon, and silicon were precipitated to a depth of approximately 0.127 mm (5 mils) in the subsurface structure.

A microprobe examination showed that EDM processing produces a zone adjacent to the EDM surface that has a more uniform titanium distribution than is present in the alloy some

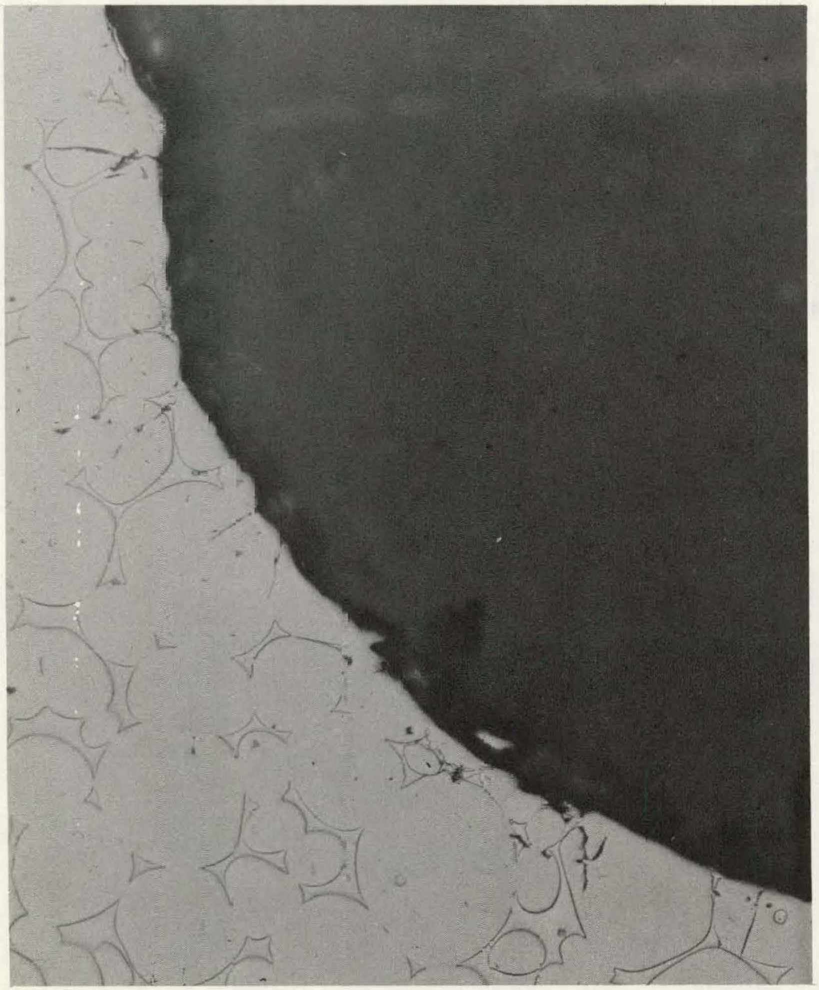

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Figure 11. MICROSTRUCTURE OF TUNGSTEN-3.5 NICKEL-1.5 IRON ALLOY AFTER ELECTRICAL DISCHARGE MACHINING. (Bright Field Illumination; 400X)

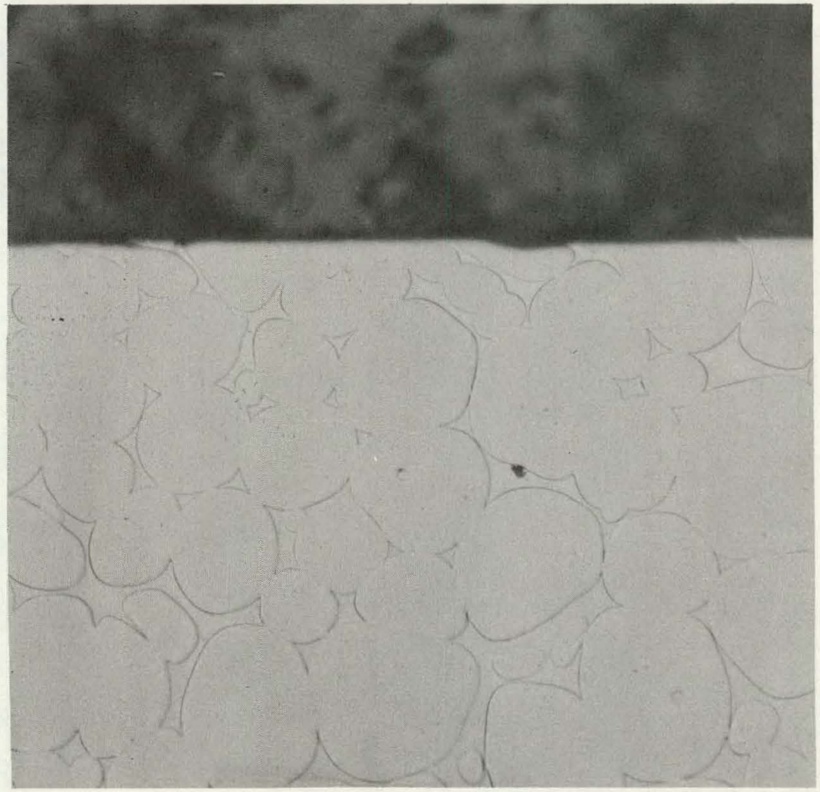

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Figure 12. SURFACE STRUCTURE OF TUNGSTEN-3.5 NICKEL-1.5 IRON ALLOY AFTER CONVENTIONAL MACHINING. (Bright Field Illumination; 400X)

distance from the hole. This zone is probably supersaturated with titanium, carbon, and silicon that subsequently precipitates during solution quenching. The EDM fluid (oil) may have decomposed during the hole-drilling operation (EDM) and carburized the adjacent surface, subsequently diffusing into the alloy during heat treatment and forming small particles of a complex carbide with the titanium and silicon in the alloy.

Additional conventional machining is required to remove the precipitated layer seen in Figure 4 if solution quenching is mandatory after processing U-0.75 Ti alloy by EDM.

Heat treating U-0.75 Ti alloy in a finished state (after EDM) would destroy the surface finish, cause distortion, and produce carbide precipitation at the EDM surface; consequently, solution quenching and aging should be completed before the EDM operation, and the recast layer (formed during EDM) should be removed prior to nickel plating to prevent crack propagation from the recast layer into the substrate. Cracks that originated in the recast layer appear to have propagated into the base metal during nickel plating, as observed in Figure 8. Nickel deposited in the cracks may have caused the propagation.

Previous work[4,5] on nickel plating of U-0.75 Ti alloy has produced various effects, depending on the atmosphere in which the testing is done.

Tungsten-3.5 nickel-1.5 iron exhibits cracks in tungsten particles, as seen in Figure 11.

It is possible to EDM either alloy with an insignificant loss in strength compared to conventional machining (Figure 4) if the necessary precautions are taken.

In a low-toughness material, the sharp crack associated with EDM would propagate at a considerably reduced stress. Conversely, in a tough material, the cracks will not lower the notched-tensile strength. Since there is a statistically insignificant change in strength between the two machining methods, the toughness must be adequate to tolerate the sharp cracks.

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