

MACHINING CHARACTERISTICS ANALYSIS OF HIGH RESISTANCE SUPER ALLOY

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Abstract:

This article presents an experimental work and investigation on electrical discharge machining (EDM) of Inconel 625 superalloys. These superalloys are used for making parts like turbine blades, marine components, and nuclear reactor components. Inconel 625 is of 100*100*5 mm is examined through electrical discharge machine - sparking with various parameters hole for turbine blade cooling hole. In this work, EDM of the above said superalloys was carried out and form tolerances were analyzed. The significance of input parameters namely peak current, pulse-on time (T on), and pulse-off time (T off) on the form tolerances were investigated. In addition to these, the influence of individual parameters were also analyzed by analysis with (DOE) technique.

Key Words: DOE CMM EDM EWR Form Tolerance MRR

Introduction:

A superalloy, or high-performance alloy, is an alloy with the ability to operate at a high fraction of its melting point. Several key characteristics of a superalloy are excellent mechanical strength, resistance to thermal creep deformation, good surface stability, and resistance to corrosion or oxidation. The crystal structure is typically face-centered cubic (FCC) austenitic. Examples of such alloys are Hastelloy, Inconel, Waspaloy, Rene alloys, MP98T, TMS alloys, and CMSX single crystal alloys. (1) Adding new elements is usually good because of solid solution strengthening, but engineers need to be careful about which phases precipitate. Precipitates can be classified as geometrically close-packed (GCP), topologically close-packed (TCP), or carbides. GCP phases are usually good for mechanical properties, but TCP phases are often deleterious. Because TCP phases are not truly close packed, they have few slip systems and are very brittle. They are additionally bad because they "scavenge" elements away from GCP phases. Many elements that are good for forming γ' or have great solid solution strengthening may precipitate TCPs. Engineers need to find the balance that promotes GCPs while avoiding TCPs. (2)

The United States became interested in gas turbine development around 1905.[1] From 1910-1915, austenitic (γ phase) stainless steels were developed for the high temperatures in gas turbines. By 1929, 80Ni-20Cr alloy was the norm, with small additions of Ti and Al. (3) Gamma (γ): This phase composes the matrix of Ni-based superalloy. It is a solid solution fcc austenitic phase of the alloying elements. Alloying elements found in most commercial Ni-based alloys are, C, Cr, Mo, W, Nb, Fe, Ti, Al, V, and Ta. During the formation of these materials, as the Ni-alloys are cooled from the melt, carbides begin to precipitate, at even lower temperatures γ' phase precipitates. (4)

Nickel-based superalloy MAR-M 247 had very good fatigue performance at temperatures of 800 and 900 °C. (5) In pure Ni3Al phase atoms of aluminium are placed at the vertices of the cubic cell and form the sublattice A. Atoms of nickel are located at centers of the faces and form the sublattice B. (6) The early Nimonic series incorporated γ' Ni3(Al,Ti) precipitates in a γ matrix, as well as various metal-carbon carbides (e.g. Cr23C6) at the grain boundaries for additional grain boundary strength.(7) About 60% of the use-temperature increases have occurred due to advanced cooling concepts; 40% have resulted from material improvements. State-of-the-art turbine blade surface temperatures are near 2,100 °F (1,150 °C); the most severe combinations of stress and temperature correspond to an average bulk metal temperature approaching 1,830 °F (1,000 °C). (8)

A new class of alumina-forming austenitic stainless steel is actively being developed for use in high-temperature applications by Oak Ridge National Laboratory. Initial research showed similar creep and corrosion resistance at 800 °C to that of other austenitic alloys, including Ni-based superalloys. Development of AFA superalloys with a 35 wt.% Ni-base have shown potential for use in operating temperatures upwards to 1,100 °C. (9) Inconel 718 has many disadvantageous properties for machining. These properties shorten tool lives. Therefore, it is difficult to increase the cutting speed of Inconel 718. (10) Higher material removal rates of the order of about 0.06 g/min with consistent average roughness in the range of 4.5-5.5 mm at the expense of 1.6-2.6 J of discharge energy are achieved in this work. The proposed models can be utilized for machining of difficult to machine material by effective utilization of energy that leads to energy conservation in wire electrical discharge turning process. (11)

Selection of Material:

Inconel alloys are oxidation-corrosion-resistant materials well suited for service in extreme environments subjected to pressure and heat. When heated, Inconel forms a thick, stable, passivating

oxide layer protecting the surface from further attack. Inconel retains strength over a wide temperature range, attractive for high temperature applications where aluminum and steel would succumb to creep as a result of thermally induced crystal vacancies. Inconel's high temperature strength is developed by solid solution strengthening or precipitation hardening, depending on the alloy.



Figure 1: INCONEL

Inconel alloys are typically used in high temperature applications. Common trade names for

- Inconel Alloy 625 include: Inconel 625, Chronin 625, Altemp 625, Haynes 625, Nickelvac 625 and Nicrofer 6020.
- Inconel Alloy 600 include: NA14, N06600, BS3076, 2.4816, NiCr15Fe (FR), NiCr15Fe (EU) and NiCr15Fe8 (DE).
- Inconel 718 include: Nicrofer 5219, Superimphy 718, Haynes 718, Pyromet 718, Supermet 718, and Udimet 718

Table 1: Specific Data of Inconel

Alloy	Solid °C(°F)	Liquid °C(°F)
Inconel600[8]	1354(2,469)	1413(2,575)
Inconel617[9]	1332(2,430)	1377(2,511)
Inconel625[10]	1290(2,350)	1350(2,460)
Inconel690[11]	1343(2,449)	1377(2,511)
Inconel718[12]	1260(2,300)	1336(2,437)
InconelX-750[13]	1390(2,530)	1430(2,610)

Inconel Alloy 625 (UNS designation N06625) is a nickel-based superalloy that possesses high strength properties and resistance to elevated temperatures. It also demonstrates remarkable protection against corrosion and oxidation. Its ability to withstand high stress and a wide range of temperatures, both in and out of water, as well as being able to resist corrosion while being exposed to highly acidic environments makes it a fitting choice for nuclear and marine applications

Table 2: Chemical Properties of Inconel 625

	Cr	Mo	Co	Nb+Ta	Al	Ti	C	Fe	Mn	Si	P	S	Ni
Min	20	8	--	3.15	--	--	--	--	--	--	--	--	Balance
Max	23	10	1	4.15	0.4	0.4	0.1	5	0.5	0.5	0.015	0.015	Balance

Inconel 625 was designed as a solid solution strengthened material with no significant microstructure. This holds true at low and high temperatures, but there is a region (923 to 1148 K) where precipitates form that are detrimental to the creep properties, and thus the strength, of the alloy.

Experimentation:



Figure 2: Electrical Discharge Machine

Electrical discharge machining (EDM), also known as spark machining, spark eroding, die sinking, wire burning or wire erosion, is a metal fabrication process whereby a desired shape is obtained by using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the tool or electrode, while the other is called the work piece-electrode, or work piece. The process depends upon the tool and work piece not making physical contact.

The method of selecting a limited number of experiments which produces the most information is known as a partial fraction experiment. Although this method is well known, there are no general guidelines for its application or the analysis of the results obtained by performing the experiments. Taguchi constructed a special set of general design guidelines for factorial experiments that cover many applications.

Table 3: Parameters for Machining

S.No	Peak Current	Gap Voltage	T _{on}	T _{off}
1	5	40	20	30
2	5	50	40	40
3	5	60	60	50
4	10	40	40	50
5	10	50	60	30
6	10	60	20	40
7	15	40	60	40
8	15	50	20	50
9	15	60	40	30

The design of experiments using the orthogonal array is, in most cases, efficient when compared to many other statistical designs. The minimum number of experiments that are required to conduct the Taguchi method can be calculated based on the degrees of freedom approach.

$$N_{Taguchi} = 1 + \sum_{i=1}^{NV} (L_i - 1)$$

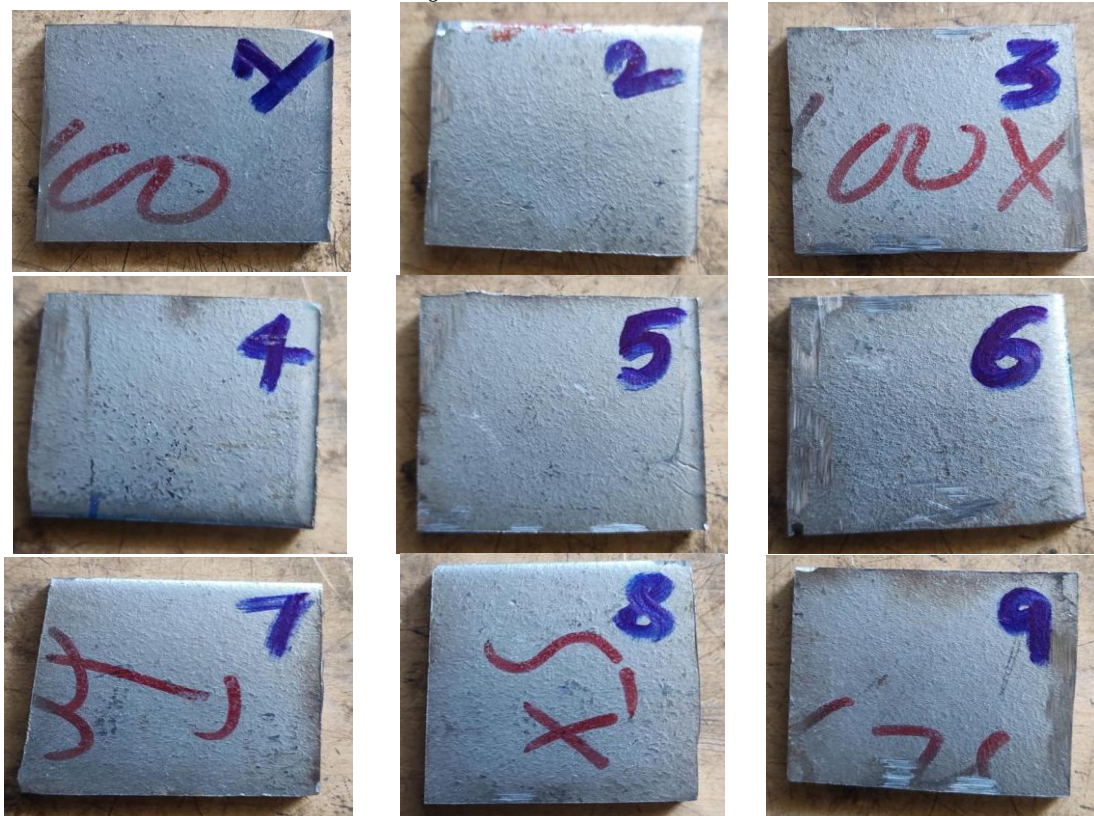


Figure 3: Specimens for Machining

The machining process will happen after imputing the parameters such as peak current, gap voltage, pulse on time (Ton) and pulse off time (Toff-) to get the values of Material Removal Rate (MRR) and Electrode Wear Rate (EWR). The process will continuous for the all 9 pieces separated from a single with the dimensions of 100*100*50 mm.

Results and Discussion:

MRR is understood as the rate at which loss of work material takes place during the machining process. The MRR can be computed by mass loss of the work piece as shown in the following Equation.

$$MRR = \frac{M_i - M_f}{(t * \rho)} \left[\frac{mm^3}{min} \right] \quad (1)$$

WR can be defined as the rate at which loss of electrode material takes place from the electrode during the machining process (Eq. (2)).

$$EWR = \frac{E_i - E_f}{(t \cdot \rho_2)} \left[\frac{\text{mm}^3}{\text{min}} \right] \quad (2)$$

Where E_i and E_f denotes initial and final mass of the tool electrode (expressed in unit kg), respectively. The term t refers to the machining time (in minutes) and ρ_2 refers to the density of the tool material (in g/cc). EWR is conventionally expressed in unit [mm³/min].

Table 4: Electrode Weight Before and After Hole

Machining	1	2	3	4	5	6	7	8	9
Electrode Weight Before Hole	8.11	8.08	8.07	8.03	8	7.96	7.91	7.89	7.85
Electrode Weight After Hole	8.08	8.07	8.03	8	7.96	7.91	7.89	7.85	7.84

Table 5: IME for Drill the Hole

Test	1	2	3	4	5	6	7	8	9
Time	27.26	23.31	24.47	22.74	16.52	44.27	17.66	41.6	21.05

Table 6: MRR and EWR Values from Calculation

Test	1	2	3	4	5	6	7	8	9
Material Removal Rate	39.26	42.69	43.57	40.64	68.85	27.29	68.43	25.63	57.41
Electrode Wear Rate	7.58	2.95	11.27	9.09	16.69	7.78	7.81	6.63	3.27
Duty Cycle	0.4	0.5	0.54	0.44	0.66	0.33	0.6	0.2	0.5

Conclusion:

The INCONEL 625 super alloy is machined using electrical discharge machining - sparking with the brass electrode to determine the material removal rate and electrode wear rate. From the numerical calculations, comparing all the 9 specimens the specimen 5 having highest amount of Material Removal Rate having parameters of Peak Current - 10, Gap Voltage - 50, Ton - 60, Toff - 30 and the specimen 2 having the least amount of Electrode Wear Rate having the parameters of peak current - 5, gap voltage - 50, ton - 40, toff - 40. From this we conclude these parameters which is used in test 2 and test 5. In Test 9 which obtain both Material Removal Rate and Electrode Wear Rate optimum of obtaining best results.

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