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Improvement of Surface Roughness of Stainless Steel AISI 316L by Electrical Discharge Machining Process

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Abstract:
The manufacturing industries are using more high-strength, high-hardness materials as a result of technological advancements. More sophisticated techniques including electro-discharge machining (EDM), ultrasonic machining (USM), electric chemical machining (ECM), and laser machining are gradually replacing conventional industrial processes in the machining of these materials. By selecting the right machining parameters to efficiently control the amount of material removed, EDM can create intricate and precise parts with ease. Larger and deeper discharge craters are produced by rough machining conditions because a significant amount of the melted material is removed, even though EDM can achieve accurate dimensions and fine surface integrity under finishing conditions. This study aims to identify the best process parameter settings for electro-displacement machining (EDM) of stainless steel AISI 316L when the material is processed on a rough surface. FORM 2-LC machine was used for the trials, and the Taguchi approach was applied. The Taguchi approach is utilized to design the experimental setup, examine how each parameter affects the machining characteristic, and forecast which EDM parameter is best. The process parameters that have a significant impact on the performance attributes and the percentage contribution of surface roughness are examined using analysis of variance (ANOVA). Controlling the level of the machining variables is generally found to enhance the average surface roughness. For instance, when the current is at its lowest, pulse on is at its medium, and pulse off is at its maximum, the optimal value of roughness can be achieved.

Keywords: Analysis of Variance, Electro- Discharge Machining, Surface Roughness, Stainless Steel AISI 316L, Taguchi Method.

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تحسين خشونة سطح الفولاذ المقاوم للصدأ AISI 316L عن طريق عملية التشغيل بالتفريغ الكهربائي

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الملخص

تستخدم الصناعات التحويلية مواد أكثر قوة وصلابة نتيجة للتقدم التكنولوجي. التقنيات الأكثر تطوراً بما في ذلك تصنيع التفريغ الكهربائي ((EDM، والتصنيع بالموجات فوق الصوتية ((USM، والتصنيع الكيميائي الكهربائي ((ECM، والتصنيع بالليزر تحل تدريجياً محل العمليات الصناعية التقليدية في تصنيع هذه المواد. من خلال تحديد معلمات المعالجة الصحيحة للتحكم بكفاءة في كمية المواد التي تتم إزالتها، يمكن لـ EDM إنشاء أجزاء معقدة ودقيقة بسهولة. يتم إنتاج حفر التفريغ الأكبر والأعمق من خلال ظروف المعالجة القاسية بسبب إزالة كمية كبيرة من المواد المنصهرة، على الرغم من أن EDM يمكنه تحقيق أبعاد دقيقة وسلامة سطحية دقيقة في ظل ظروف التشطيب. تهدف هذه الدراسة إلى تحديد أفضل إعدادات معلمات العملية لتصنيع الإزاحة الكهربائية ((EDMللفولاذ المقاوم للصدأ AISI 316L عند معالجة المادة على سطح خشن. تم استخدام آلة FORM 2-LC للتجارب، وتم تطبيق نهج تاجوتشي. يتم استخدام نهج تاجوتشي لتصميم الإعداد التجريبي، وفحص كيفية تأثير كل معلمة على خصائص المعالجة، والتنبؤ بمعلمة EDM الأفضل. تم فحص معلمات العملية التي لها تأثير كبير على سمات الأداء والنسبة المئوية لمساهمة خشونة السطح باستخدام تحليل التباين (.(ANOVAتم العثور بشكل عام على التحكم في مستوى متغيرات المعالجة لتحسين متوسط خشونة السطح. على سبيل المثال، عندما يكون التيار عند أدنى مستوياته، ويكون النبض عند متوسطه، ويكون النبض عند أقصى حد له، يمكن تحقيق القيمة المثلى للخشونة.

الكلمات المفتاحية: تحليل التباين، عملية التفريغ الكهربائي، خشونة السطح، الفولاذ المقاوم للصدأ AISI 316L، طريقة تاقوشي.

Introduction

A non-traditional manufacturing method called electrical discharge machining involves repeatedly shocking a tool, known as an electrode, and the workpiece with electric sparks while a dielectric fluid is present. This process removes material from the workpiece. It is possible to remove worn-out particles from the gap by using this fluid. EDM technology was not well-known despite early trials until the 1950s, when vacuum tubes and transistors were introduced[1]. These days, high-precision machining of a variety of conductive materials, such as metals, alloys, graphite, and ceramics, is often accomplished in Europe and the US using EDM [2]. Two key characteristics of electrical discharge machining are its capacity to machine high-hardness metals and alloys that are challenging to machine using traditional chip removal techniques. This characteristic makes it possible to machine dies and other tools made of tungsten carbide, hardened steel, etc. Many industrial sectors, including the automobile, electronics, home appliance, machine, packaging, telecommunications, aerospace, and surgical instrument industries, use EDM [3]. A significant amount of research is still required to properly comprehend the EDM process, although there has been progress in producing copper tools for the process, which has reduced prices and shortened manufacturing times. This copper was the tool material selected for the study.

Electrical conductivity is a requirement for EDM electrodes. High-purity graphite, brass, copper, copper-graphite, copper-tungsten, and zinc alloys are among the materials that are frequently utilized. Every material is offered in several grades or alloys that can be applied to certain applications [4]. Any tool material should have the following qualities in order of importance: low electrical resistance, high melting point, high electron emission, low erosion rate or acceptable work to tool wear ratio, good machinability, and low electrical resistance [5]. The electrode is pushed into the work piece through an insulating liquid or dielectric fluid, assuming the electrode is positively charged and the work piece and table are negatively charged. For vertical machines, this is often paraffin, kerosene, or silicon-based dielectric kerosene; for wire-cut machines, it is deionized water. Dielectric fluid is essential to the operation. It washes away the "chips," cools the machined region, and offers insulation against premature discharging [6]. Low-viscosity petroleum oil is the dielectric fluid most frequently utilized. Kerosene, deionized water, silicone kerosene, and ethylene glycol/water mixtures are additional fluids that are occasionally utilized. In order to achieve consistent cutting performance and high-quality finishes, it is necessary to guide a dielectric fluid flow through the arc gap to remove the chips. Chips and other objects need to be continuously removed from the fluid through filtering [7]. The plasma-hot region was rapidly growing away from the spark while current was passing through the spark gap. The vapor sheath surrounding the spark implodes and there is no longer a heat source when the current is cut off. When it collapses, a vacuum is created, and more dielectric fluid is brought in to coat and remove particles. This "off" time creates ideal circumstances for the subsequent spark and permits the dielectric fluid to finish deionizing. The length of the off-time must be long enough to remove the damaged dielectric and spark debris. This process needs to be repeatedly performed, turning on and off thousands of times in a second, in order to be machined [8]. The power used in discharge machining is called current, and it is expressed in amperage units. The surface area of the "cut" determines the maximum amperage that may be applied in certain applications; the larger the surface area, the more power or amperage that can be applied. Larger surface area details, cavities, and roughing procedures all require higher amperage [9].

On-time, also known as pulse time, is the amount of time (µs) that the current is permitted to flow in a cycle. The quantity of energy used during this on-time is exactly proportionate to the amount of material removed. The peak current and the duration of the on-time govern this energy [10]. More workpiece material is melted away over the course of a longer spark duration, the larger and deeper the resulting craters will be, and the surface finish will be rougher. As the pulse length rises, the surface roughness of the machined work piece increases gradually [11]. The length of test pauses necessary for the dielectric to reionize can have a significant impact on how quickly the operation proceeds. The job will take longer, the longer the test period (or off-time). Sadly, off-time is essential to the EDM process and is required in order for the molten material to solidify and be washed out of the arc gap.

This setting will have an impact on the cut's stability and speed. Thus, unstable sparks will result from an off-time that is too short [10].

The points of surface irregularities or roughness must bear the applied load before the other surfaces do when two surfaces are loaded together. These surfaces are rather arbitrarily divided into waviness and roughness based on wavelength, in contrast to form changes. Many facets of a surface's behavior are influenced by its roughness, and to measure and evaluate it, numerous inventive techniques have been used. The range of vertical heights and spatial wavelengths that each topographical inspection method can distinguish can be used to classify the different procedures. Observing an engineering surface optically is the most evident method of examination. A visible light beam that has been focused—that is, reduced to the smallest cross-section feasible—on the area of interest illuminates the surface. The objective lens then gathers the rays of reflected light, and an appropriate optical system creates an image of the surface. The (Ra) value, also known as the center-line average (CLA), and the (Rq) value, also known as the root mean square (RMS), are the two most basic and often used roughness parameters. The following equation defines the first of these:

$$R_{a=\frac{1}{L}}\int_{0}^{L} |Z|\ dx$$

where x is the surface coordinate, (L) is the measurement length, and z is the height of the surface measured above the mean level, or the line drawn so that the area of the metal above is equal to that of the voids below.

The Taguchi approach has been widely applied to increase quality, decrease variability, and boost overall performance in a variety of industries, including manufacturing, engineering, and product development [12] [13]. It offers an organized and effective method for designing and optimizing experiments, which makes it an important resource for projects aimed at improving quality. A useful tool for designing high-quality systems is the Taguchi approach. It offers an easy-to-use, effective approach for cost, performance, and quality optimization of designs. The Taguchi method is a useful technique for creating processes that function reliably and optimally under a range of circumstances. Surface roughness, surface texture, and dimensional variation of the final product are indicative of cutting parameters. Achieving a surface finish and consistency tolerance is crucial in a manufacturing process. Though it can also be applied to scientific study, the Taguchi technique is particularly well-suited for industrial use. An intentionally planned experiment must be used to identify the optimal design. The Taguchi approach to experiment design has become widely accepted in the scientific and technical world because it is simple to use and adapt for users with no background in statistics [14]. The major goal of this stage is to identify the optimal cutting conditions that yield the lowest surface roughness value (Ra).

Experimental Set-Up and Procedure

In this work a series of experiments on electrical discharge machining EDM of stainless steel AISI 316L was conducted on FORM 2-LC electrical discharge machine to examine the effects of input machining parameters such as for instance intensity I, pulse on time.

Figure 1: EDM (FORM 2-LC).

As mentioned above, the goal of this investigation was improvement of EDM performance. This is evaluated in terms of cost and quality. Quality is determined by accuracy and surface finish (Ra).

stainless steel AISI 316L is used as work piece material for the research. The raw materials were machined as using conventional methods such as turning and grinding. The electrode was made to a size of 20 mm diameter and length 100 mm. The specimens were made to a size of diameter 20 mm and length 20 mm. The dielectric fluid used in this study was (kerosene). The quality, viscosity and composition of the dielectric are important parameters for guaranteeing optimum spark erosion conditions. Charmilles Technologies uses FLUXELF 2.

The electrode material used in this study was Al-Cu cast Alloys 201.0 material from a use standpoint, the strongest of the common casting alloys is heat-treated 201.0. Its castability is somewhat limited by a tendency to microporosity and hot tearing so that it is best suited to investment casting. Its high toughness makes it particularly suitable for highly stressed components in machine tool construction, in electrical engineering pressurized switchgear casings), and in aircraft construction. The chemical composition, in weight percent of this material is shown in Table 1.

Table 1: Chemical composition of the workpiece material [15]:

Material	stainless steel AISI 316L							
Element	C	Cr	Mo	Mn	Ni	P	S	Si
Weight %	0.016	16.44	1.719	1.609	9.590	0.045	0.03	0.801

The electrode materials used in this research was copper. Copper is an important engineering metal since it is widely used in its unalloyed condition as well as in alloys with other metals. In the unalloyed form, it has an extraordinary combination of properties which make it the basic material in the electrical industry, some of those properties being its high electrical conductivity and corrosion resistance, ease of fabrication, reasonable tensile strength, controllable annealing properties, and general soldering and joining characteristics. The wide variety of brasses and bronzes it forms with other metals, however, also have associated useful properties that make alloyed copper indispensable for many additional engineering applications. There are various EDM tool materials which could be used in the investigation. One of the common materials used is copper section and this was chosen here because of its good thermal properties.

Roughness measurement was done using a portable stylus type profile meter, Taly surf (ALPA-SM RT-20). The profile meter was set to a cut-off length of 0.8 mm, filter 2CR, and traverse speed 1mm/s and 4 mm evaluation length roughness measurements, in the transverse direction, on the work pieces were repeated four times and average off our measurements was recorded.

Figure 2: (ALPA-SM RT-20).

The method adopted in the kerosene experiments was as follows: The electrode and specimen were cleaned and dried before every test, and then weighed before and after every run. The electrode was tightened into the spindle chuck and passed through the jig. The machining parameters were preset on the control panel generator. Once it had been verified that the ventilation was working, the machine and timer were switched on in the same action. After the specified time had elapsed, the cycle was ended by switching off the machine.

The electrode and specimen were released, and then cleaned with dry compressed air and tissue paper. The emergency switch on the machine and the mains supply were both switched off and the machine was cleaned as per scheduling. During the test, the kerosene level was maintained so that it covered the specimen to a height of 30-40 mm, to prevent the spark igniting the kerosene and the fumes becoming dissolved in it.

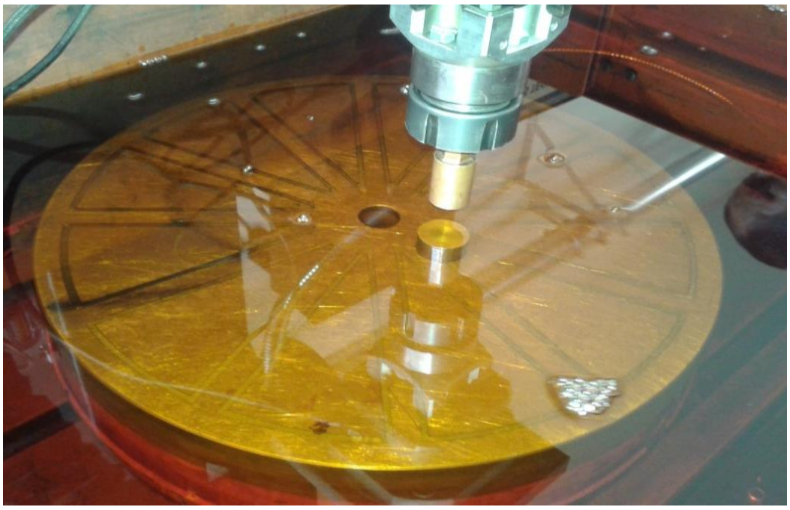

Figure 3: the fluid level.

Results and discussion

The results of this work are presented here, based on the experimental work mentioned above in the methodology. The measured values of average surface roughness, Ra are presented on the Table 2.

Table 2: Measured values of Ra

Test No.	Current	Pulse on	Pulse off	Ra
1	6	100	50	1.2
2	6	200	100	1.3
3	6	300	150	1.8
4	6	400	200	2.1
5	9	100	100	1.6
6	9	200	50	2.2
7	9	300	200	2.4
8	9	400	150	2.9
9	12	100	150	2.8
10	12	200	200	3
11	12	300	50	3.3
12	12	400	100	3.4

The graph shown figure 4 which has been made based on the analysis of the measured values of the experimental tests shows the relationship between the different factor used in this study and response, Ra, and since smaller values of roughness is the better, and then smaller signal-to-noise is better. The smallest values can be obtained when current is 6 A, pulse on is 100 and pulse off is 100.

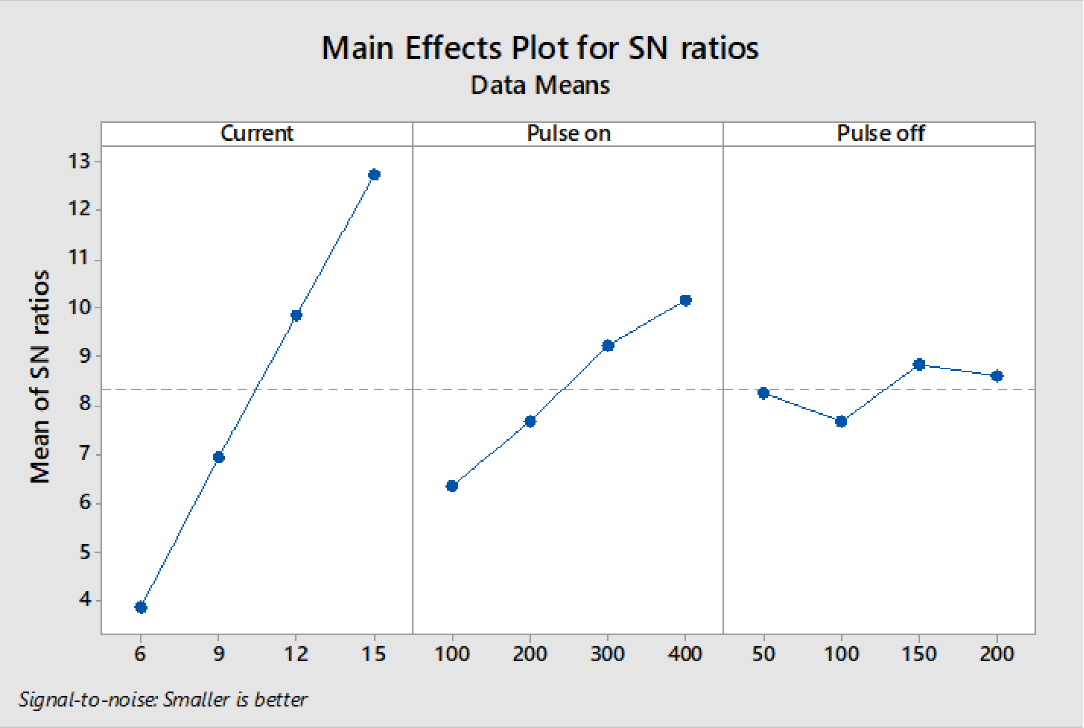

Figure 4: Signal-to-noise graph for Ra vs. Current, Pulse on and Pulse off.

Conclusion

The overall aim of this work was to investigate the effect of machining conditions of Electrical Discharge Machining Process on surface roughness during machining stainless steel AISI 316L. This section highlights the conclusions that can be drawn from this work.

1. The use of design of experiment by Taguchi technique saves time and effort without the lack of accuracy.
2. The analysis by the use of Minitab package gives clear idea about the relationship between parameter and response.
3. The average surface roughness can be improved by controlling the level of the machining factors.
4. The better value of roughness can be obtained for example when current is the minimum, pulse on is the medium and pulse off is the medium.

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