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تحسين خشونة السطح *(Ra)* للصلب *SAE 316L* عن طريق القطع بالماء النفاث

د عبدالعزيز مفتاح بودينه

قسم الهندسة الميكانيكية والصناعية، كلية الهندسة، جامعة غريان، غريان، ليبيا

azizabodena@gu.edu.ly

Optimization of Surface Roughness (Ra) of Steel SAE 316L by Water Jet Cutting

Dr. Abdulaziz Moftah Abodena

Mechanical and Industrial Department, Faculty of Engineering- University of Gharyan, Gharyan, Libya

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الملخص:

المياه النفاثة الحاكة (**AWJ**)، عبارة عن عملية تشغيل تستخدم تيارًا عالي الضغط من الماء الممزوج بجزيئات حاكة لقطع وتشكيل المواد المختلفة. إنها طريقة قطع متعددة الاستخدامات ودقيقة تستخدم في صناعات مثل التصنيع والفضاء والبناء. لقد ثبت أنها تقنية فعالة لمعالجة المواد الهندسية المختلفة. تعد خشونة سطح الأجزاء المُشكَّلة إحدى خصائص التشغيل الرئيسية التي تلعب دورًا مهمًا في تحديد جودة المكونات الهندسية. ويمكن استخلاص بعض الاستنتاجات بناء على نتائج هذه الدراسة، فكلما زاد الضغط النفاث أصبح السطح أكثر نعومة. إذ يؤدي ذلك إلى زيادة الضغط النفاث وبالتالي زيادة الطاقة الحركية للجزيئات مما ينتج سطح أكثر نعومة. يؤثر التغير في سرعة الفوهة على خشونة سطح قطعة العمل. من أجل الحصول على خشونة سطحية جيدة، يجب تطبيق سرعات منخفضة وضغط مرتفع

الكلمات الدالة: المياه النفاثة الحاكة، تحليل التباين، الفولاذ **SAE 316L**، خشونة السطح، تصميم تاقوتشي.

Abstract

An abrasive water jet (AWJ), is a machining process that uses a pressurized water contains particles of materials with high hardness aiming to cut some materials. It is a precise cutting method used in industries such as manufacturing, aerospace, and construction. For machining different material, AWJ is proven as new and successful technology. in terms of roughness of surfaces of the produced components by machining, concerns should be considered when apply a suitable machining operation. This work shows the effect of AWJ parameters on surface roughness (Ra) when steel SAE 316L plates is cut using water jet technology. Design of experiments and analysis of results is made by the use of Taguchi's technique. the two parameters that uses in this investigation are water pressure and nozzle movement speed during cutting of SAE 316L steel using abrasive Water jet cutting process. The results are recorded based on the experimental tests. According to the experimental results and their analysis some points can be concluded, the surface becomes smoother as the jet pressure increases due to the increase of particles' kinetic energy. The change in nozzle speed influences the surface roughness of workpiece. In order to get a good surface roughness, low speeds and high pressure should be applied.

Keywords: abrasive water jet, analysis of variance, steel SAE 316L, surface roughness, Taguchi design.

Introduction

An abrasive water jet is a type of cutting operations that uses pressurized water companied with particles to machine range of different materials. It is a precise cutting method used in industries such as construction, manufacturing, and aerospace. In addition to metal fabrication, Stone and tile cutting, glass cutting, gasket and seal manufacturing, automotive industry and artistic applications [1]. Water jet operation does not use or create dangerous materials or vapors. no residual stresses are left in produced components due to effect of heat as no heat is generated [2]. Concrete slabs that are thick have also been successfully sliced through by the water jet. The expense of purchasing and sharpening diamond-tipped saws will be reduced as a result. The two materials that are most frequently cut by abrasive water jets are steel and aluminium. Titanium, brass, and tool steel are among the hardy and profitable applications that best suit these jets. Water jet can be used to cut hard materials such as super alloys, carbides and similar metals [4]. In machining, in addition to the study of the dynamics of the process, a wide amount of research and study is made to investigate the effect of parameters on the quality of the produced component in terms of accuracy and roughness. The main objectives of this work are gaining some knowledge about water jet cutting as one of the non-traditional machining processes and investigating how much the change in process parameters influence the surface roughness of the working material.

The use of cutting by pressurized water was invented as a patent in 1968 in the USA, by researcher at the University of Michigan [5]. The power of water jets has been serving mankind for long ages [1]. Mixture of water and sand was used by Egyptians thousands of years ago for cutting as well as used later in gold mining operation at California during the second half of the nineteenth century [2]. Sandblasters in this century use pressurised steam for cleaning and paint removal. The patent of water jet granted in 1968 is been used widely in modern machining processes based on the energy of a very high pressurized water jets [6]. The first cutting machine was sold to the Tennessee-based Alton Box Board Co. to cut shapes out of laminated paper tubes that were too difficult for saws and routers to handle [7]. FLOW Inc. made significant investments in the technology's development as well. Metals and other hard surfaces could be profiled by adding abrasive particles to the water jet. FLOW was granted a patent for the adding of particles to the stream in 1983 [3]. The water jet process is acknowledged as the world's most adaptable and rapidly expanding method, going beyond cost reduction [8]. In 2016, approximately 1600 water jet and abrasive water jet units operate in the United States [4] and there are approximately 120 operating units in the Nordic countries. The waterjet cutting machine market in the United States was estimated to be worth around USD 100 million in 2016 and is projected to grow more than USD 150 million by 2025 [9]. Most of the intensifier units are delivered by FLOW or Ingersoll-Rand since these companies control 90% of the market [10]. The technology is developing quickly, which suggests that there is a market for the benefits this method provides. It's also critical to remember that technology can be utilized for tasks like drilling, milling, turning, and cleaning in addition to cutting. There are two types of particle mixing jet systems on the market; injection and suspension. In the latter instance, cutting fluid is created by pressurizing an abrasive and water suspension. The performance of a suspension system is roughly the as that of injection systems but the operating pressure is substantially lower (below 100 MPa) [5, 6]. In the case of injection jet dry abrasives are added to the water jet after it has passed the orifice. The high pressure water is generated by an intensifier pump. A hydraulic pump supplies oil at pressures as great as 20 MPa (200 bar) in order to drive a reciprocating plunger pump, known as an intensifier. A 200 bars hydraulic oil system can produce a water pressure of 4000 bars because the intensifier creates high water pressure acting on a chamber full of water. The water pressure exceeds the oil pressure, with a ratio of up to 20 times. The stresses created when this water jet strikes the work piece are used to remove material from the workpiece.

Absent the drawbacks of abrasive water jet, which include a very high initial investment and difficulty in processing thick materials, there are still many benefits to the process, including water jet machining's excellent precision and ability to achieve tolerances of about ±0.005″, its eco-friendliness, and its relative speed [11]. The following are the primary topics of the AWJ cutting process parameters: abrasive parameters, such as abrasive particle, size, abrasive substance, and abrasive flow rate, and hydraulic characteristics, such as pressure and water flow rate [12]. The geometry of individual contact spots and how these asperities of real contact are distributed throughout the nominal or apparent contact area is clearly of interest to tribologists in their attempts to predict the overall performance of the contact. When two surfaces are loaded together, the tips of the surface roughness or asperities must carry the applied load first.

These surface differences are somewhat arbitrarily divided into waviness and roughness based on wavelength, as opposed to form variations. Surfaces that have undergone non-directional finishing techniques, including lapping or electropolishing, may exhibit significantly better homogeneity [13]. One element of surface finish is surface roughness. It is measured by the direction deviations of a real surface's normal vector from its ideal form. The surface is smooth if these variances are minimal, and rough if they are considerable. The center-line average (CLA) or Ra value and the root mean square (RMS) or Rq value are the most basic and commonly utilized roughness parameters. The equation defines the Ra [13].

$$Ra = \frac{1}{L}\int_0^L |z| \; dx$$

An actual object's interaction with its surroundings is significantly influenced by its surface roughness. Roughness has an impact on a number of functional characteristics of parts, including coating, friction, wear and tear, light reflection, heat transmission, and the capacity to distribute and retain lubricant [14]. As a result, in order to maintain quality, the intended surface finish is typically specified and the necessary procedures are needed. Therefore, it is crucial to check the work piece's surface roughness in order to evaluate the component's quality.

Experimental Work:

This section provides a detailed explanation of the experimental work process, from experiment design to measurement. Conventional experimentation takes a lot of time and effort, particularly when intricate processes are involved. Planned experiments are a highly effective method to increase the value of research and reduce the time required for process development. Compared to an orthogonal strategy, the proposed experiment ensures reduced inaccuracy in determining the effects of interest.

A Taguchi design method, an experimental design process, is one technique covered in this paper. Dr. Genichi Taguchi created the Taguchi design methodology, which is a collection of techniques that accounts for the inherent unpredictability of materials and production processes during the design phase [15]. After the 1980s, this approach was being used extensively in numerous US and European enterprises. The ability to take several things into account at once is what makes Taguchi design so beautiful. Additionally, it looks for nominal design points that are unaffected by changes in user environments and production yields in order to increase a product's manufacturing yield and performance reliability. As such, noise factors might be taken into account in addition to regulated parameters. Industries may drastically cut the length of the product development cycle for both design and production by utilizing the Taguchi methodology, which lowers costs and increases profit. Additionally, Taguchi design makes it possible to investigate the unpredictability brought on by noise components, which are typically disregarded in the conventional DOE method [16]. A useful tool for designing high-quality systems is the Taguchi approach. 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. Although it can also be employed for scientific study, the Taguchi method is particularly well-suited for industrial use [17, 18].

Traditional experimental design techniques are difficult to employ and excessively complex. Moreover, when the number of process factors rises, a significant number of experiments must be conducted. The Taguchi technique employs a unique orthogonal array design to explore the whole parameter space with a limited number of experiments in order to solve this challenge. After then, the experimental findings are converted into a signal-to-noise (S/N) ratio. Taguchi suggests measuring the quality features that deviate from the desired values using the S/N ratio. When analyzing the S/N ratio, three quality characteristic categories are typically identified: the lower the better, the higher the better, and the nominal the better. The S/N analysis is used to calculate the S/N ratio for each level of process parameters.

In order to determine whether process parameters are statistically significant, an ANOVA is also carried out. It is possible to predict the ideal set of process parameters using the S/N and ANOVA studies. Finding the ideal cutting circumstances that provide the lowest surface roughness value (Ra) is the primary objective of this stage. The material used in this study was commercial SAE 316L, its chemical composition is presented in Table 1. It comes in plates of thickness of 10 mm and its size is 300 by 1000mm.

Table 1: Chemical composition of working material (wt%) [19].

Element	Fe	C	Si	Mn	P	S	Ni	Cr	Mo
Content %	Balance	Max. 0.08	0.7	1.5	–	–	12.4	16.7	2.6

The plate of chosen material is placed on the table of the machine and fixed as it is shown in Figure 1. The cutting nozzle is located at the edge of the plate for referencing movement, so the edge (0, 0, 0) point is the reference point of cutting process. Using the screen of the control panel of computerized system, the movement of cutting tool (nozzle) is controlled. The size of nozzle that is chosen for this work is 1.2 mm in diameter. The garnet type that is added to the water as abrasive particles is Garnet (Mesh 80–120–30/60). The parameters that have been selected in this study are water pressure and nozzle transfer speed, these parameters can be controlled through the control panel.

According to the matrix of design of experiments shown in the following table2, each test is made based on its cutting conditions and the tests are made in sequence. As the nozzle moves over the plate, the cutting of material takes place and the specimens are numbered for later measurements. Once the experiment testing process is finished, the specimens have been taken to the measurement process. As it was mentioned previously, the surface roughness of the workpiece is the response of change in cutting conditions of water jet cutting process. The instrument used to assess average surface roughness (Ra) is the *Surtronic* 3+.

Figure 1: Photo of machine during water jet cutting process.

Results

The results and discussion are presented here. The results which are recorded from this study are shown in Table 2, the average value of three readings of measurements for each test in this work is shown in front of each test conditions.

Table 2: Experimental test matrix and results.

Test No.	Speed (mm/s)	Pressure (Mpa)	Ra
1	70	180	2.7
2	70	200	2.4
3	70	240	1.6
4	90	180	2.9
5	90	200	2.8
6	90	240	1.8
7	120	180	3.9
8	120	200	3.3
9	120	240	2.3

Figure 2 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 speed is 70 mm/s and pressure is 240 MPa. As the nozzle speed increases the surface roughness increases which means bad surfaces are produced. Rough surfaces are recorded at higher speeds and lower pressure.

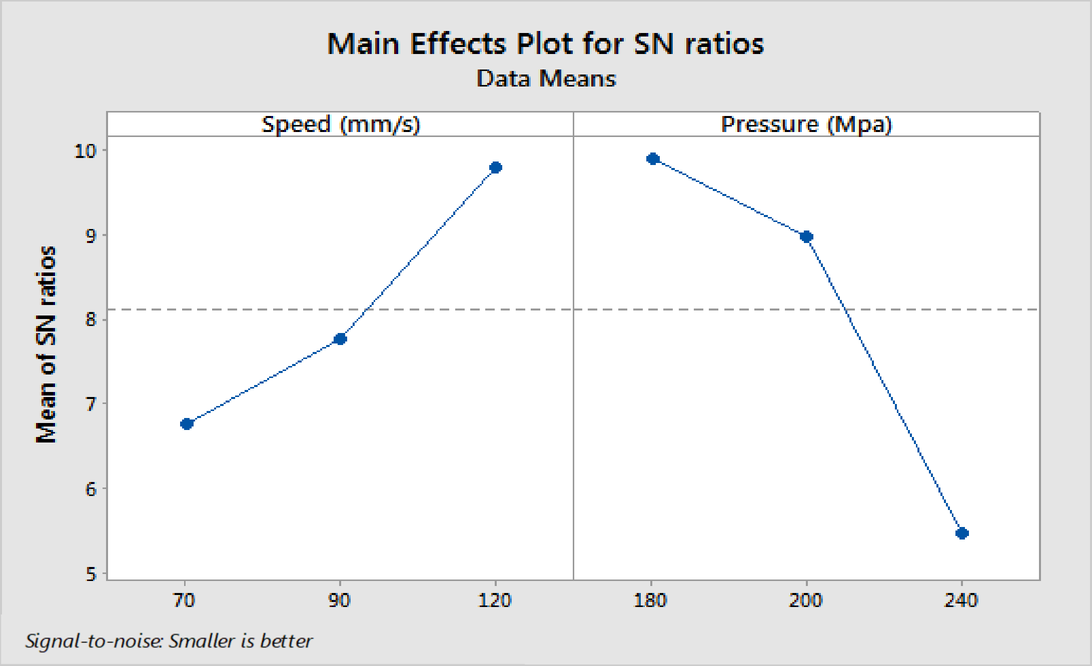

Figure 2: Main effect plot for SN ratios for speed and pressure.

Conclusions

The overall aim of this work was to investigate the effect of change in water pressure and movement speed of nozzle on the surface roughness of the workpiece. Based on the results of this study, the following conclusions can be drawn:

1. The change in water pressure affects the surface roughness of the produced workpiece. As the jet pressure increases, the surface becomes smoother. This is due to an increase in jet pressure, the kinetic energy of the particles increases which results in a smoother machined surface.
2. The change in nozzle speed influences the surface roughness of the workpiece.
3. To get a good surface roughness, low speeds and high pressure should be applied.
4. Water jet as one of the non-traditional machining processes has a good chance to be at the top of techniques because of its varsity in machining a wide range of materials.

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