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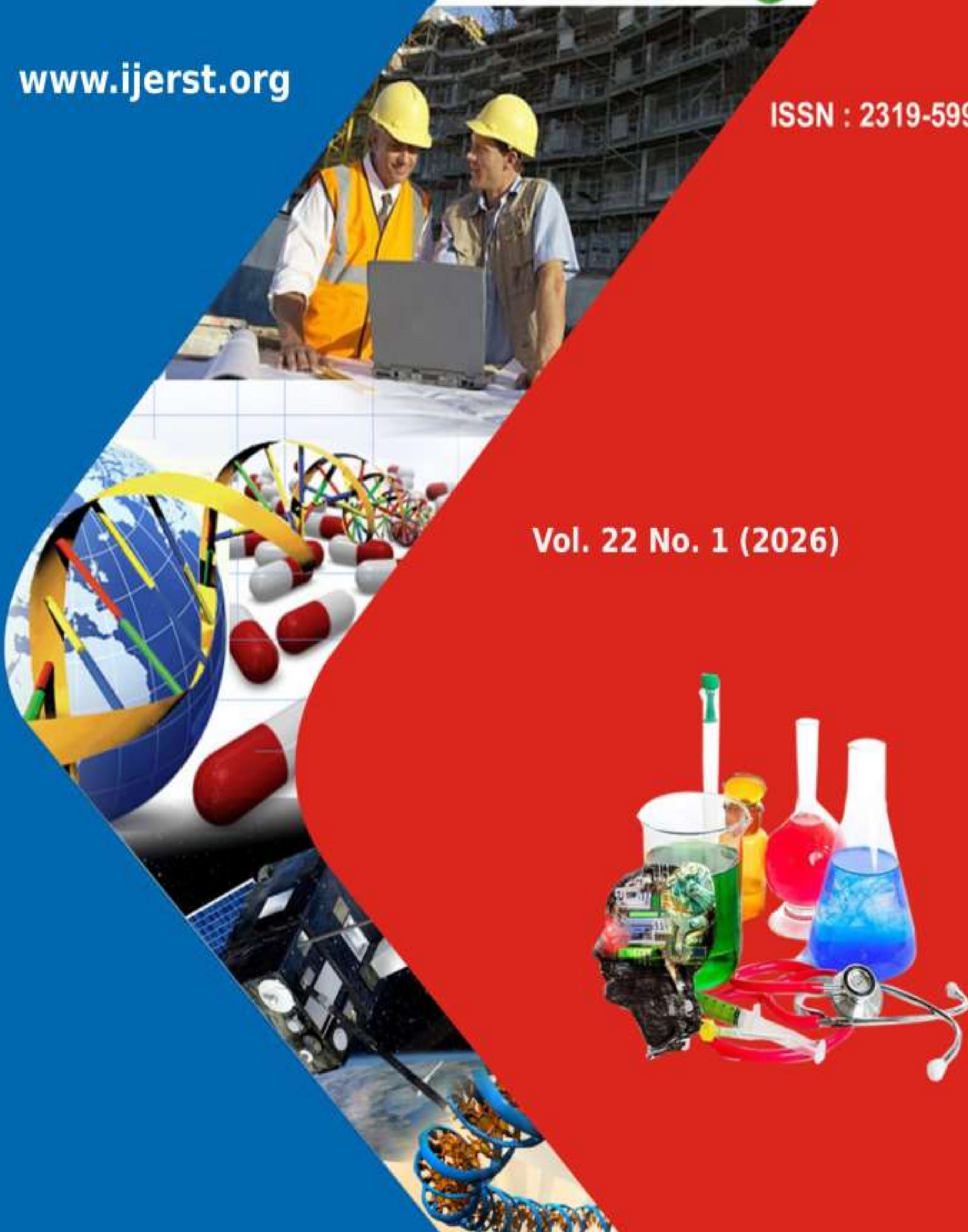

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Research

Multi Objective Optimization of Process Parameters in Abrasive Water Jet Machining Of Duplex Steel Using Topsis Method

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Abstract Abrasive water jet machining (AWJM) is an emerging machining technology for hard material parts that are extremely difficult-to-machine by convfntional machining processes. The high pressure water jet with abrasive additives known as abrasive water jet (AWJ).There are several parameters influencing the performance of abrasive water jet machining like water pressure, abrasive mass flow rate, standoff distance, and Cutting Speed. Experiments were conducted in varying these parameters for cutting Duplex steelSAF2304 grade using abrasive water jet cutting process. Material removal rate (MRR) and surface roughness (SR), are the important quality parameters of AWJM. In the present work carrying techniques, namely Taguchi design of experiment method and analysis of variance (Mini Tab) and multi objective optimization method (TOPSIS) were taken for predicting the quality parameters like Material Removal Rate (MRR) and Surface Roughness (SR) on the basis of input parameters like Abrasive Mass Flow Rate (AMFR), Stand Off Distance (SOD), Water pressure (p), Cutting Speed (CS).

Key Words: *Abrasive water jet machining, duplex stainless steel, Process parameter, Process optimization*

1. INTRODUCTION

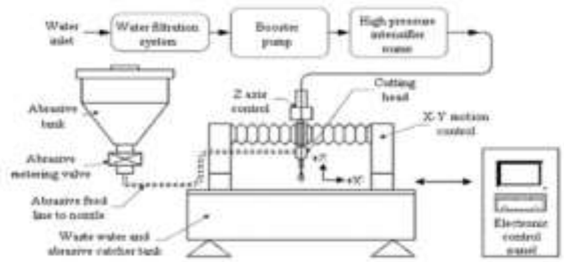
Duplex stainless steels are a family of grades combining good corrosion resistance with high strength and ease of fabrication. Their physical properties are between those of the austenitic and ferritic stainless steels but tend to be closer to those of the ferritic sand to carbon steel. The chloride pitting and crevice corrosion resistance of the duplex stainless steels is a function of chromium, molybdenum, tungsten, and nitrogen content. It may be similar to that of Type 316or range above that of the sea water stainless steels such as the 6% Mo austenitic stainless steels. All the duplex stainless steels have chloride stress corrosion cracksing resistance significantly greater than that of the 300-series austenitic stainless steels. They all provide significantly greater strength than the austenitic grades while exhibiting good ductility and toughness.

There are many similarities in the fabrication of austenitic and duplex stainless steels but there are important differences. The high alloy content and the high strength of the duplex grades require some changes in fabrication practice. This manual is for fabricators and for end users with fabrication responsibility. It presents, in a single source, practical information for the successful fabrication of duplex stainless steels. This publication assumes the reader already has experience with the fabrication of stainless steels; therefore, it provides data comparing the properties and fabrication practices of duplex stainless steels to those of the 300-series austenitic stainless steels and to carbon steel. The fabrication of duplex stainless steels is different but not difficult.

Abrasive water jet cutting machine

Abrasive Water jet Cutting [AWJC] has various distinct advantages over the other non-traditional cutting technologies, such as no thermal distortion, high machining versatility, minimum stresses on the work piece, high flexibility and small cutting forces and has been proven to be an effective technology for processing various engineering materials. It is superior to many other cutting techniques in processing variety of materials and has found extensive applications in industry. In this method, a stream of small abrasive particles is introduced in the water jet in such a manner that water jet's momentum is partly transferred to the abrasive particles.

The main role of water is primarily to accelerate large quantities of abrasive particles to a high velocity and to produce a high coherent jet. This jet is then directed towards working area to perform cutting. It is also a cost effective and environmentally friendly technique that can be adopted for processing number of engineering materials particularly difficult-to-cut materials such as ceramics. However, AWJC has some limitations and drawbacks. It may generate loud noise and a messy working environment. It may also create tapered edges on the kerf, especially when cutting at high traverse rates. As in the case of every machining process, the quality of AWJC process is significantly affected by the process tuning parameters. There are numerous associated parameters in this technique, among which water pressure, abrasive flow rate, jet traverse rate, standoff distance and diameter of focusing nozzle are of great importance but precisely controllable. The main process quality measures include attainable depth of cut, kerf width, surface finish and material removal rate. In order to effectively control and optimize the AWJC process, predictive models for depth of cut have been developed for ceramics, aluminum, stainless steel, brass, copper, titanium etc.



Abrasive water jet cutting machine

Objectives of the study

It is evident from literature survey that there exists a need to study on the effects of various parameters on material removal rate. The objective of the present work is to determine the most significant control factors affecting the surface roughness. Experiments were designed using Taguchi method so that effect of all the parameters could be studied with minimum possible number of experiments. Using Taguchi method, with chosen Orthogonal Array the experiments are performed as per the set of experiments designed in the orthogonal array. Mini Tab and multi objective optimization method (TOPSIS) are also used for calculate the prediction values compared with the experimental values and find the error %.

Results of the experimentation were analyzed analytically as well as graphically using Mini Tab. It is determined that the percentage contribution of all factors upon each response individually.

2. LITERATURE REVIEWS

[1] "Influence of the microstructure on the plastic behavior of duplex stainless steels" Alberto Moreira Jorge Júnior, Gedeon Silva Reis and Oscar Balancin When the microstructure of duplex stainless steels is essentially ferritic during hot deformation, the mechanical behavior is determined by the matrix and the plastic flow curve is typical of materials that undergo extended dynamic recovery.

The presence of austenite particles coherent with the ferritic matrix inhibits deformation of the material, increasing the initial flow stress and the hardening rate. With the extended dynamic recovery of the matrix, there is loss of this coherence and thus softening of the material.

[2]. "The influence of shot peening on the fatigue behavior of duplex stainless steels" P. Sanjurjoa, C. Rodrígueza, I. F. Parientea, F.J. Belzuncea, A.F. Cantelia. Shot peening is a well-known process which is commonly used in aeronautic and automotive industries in order to improve the fatigue behavior of many different components. In this paper, shot peening treatments were studied as an interesting method to improve the fatigue performance of civil constructions made with reinforced concrete.

[3]. "Secondary hardening behavior in super duplex stainless steels during LCF in dynamic strain ageing regime" by Guocai Chai, Marcus Andersson. Dynamic strain ageing in duplex stainless steels during cyclic loading causes the formation of a second hardening response in the temperature range of 150 - 350°C and the fatigue properties improves compared. An increase in nitrogen content in duplex stainless steel can increase the dynamic strain ageing effect and fatigue life in the strain ageing temperature range. The occurrence of strain ageing can change dislocation structures. The formation of irreversible dislocation structures and stacking faults can contribute to the formation of the second hardening in the stress response curve.

3. EXPERIMENTAL WORK

Abrasive Water Jet machine is used for conducting the experiment. Duplex stainless steel (SAF 2304) is used as a work material. In this I have measured the material removal rate of duplex steel. The experimentation for this work was based on Taguchi's design of experiments (DOE) and orthogonal array. A large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal array to study the entire parameter space with a small number of experiments only.

In this work, four machining parameters namely, Water pressure (P), Abrasive Mass Flow Rate(AMFR), Stand Off Distance(SOD) and Cutting Speed(CS)were considered for experimentation. Accordingly there are four input parameters and for each parameter three levels were assumed. For a four factors, three level experiments, Taguchi has specified L9 orthogonal array for experimentation. The response obtained from the trails conducted as per L9array experimentation was recorded and further analyzed.

Abrasive Water Jet Machining Setup

Work piece material:

Duplex stainless steel is used as a work piece for the machining. Duplex stainless steel is used in many engineering construction, industries and oil & gas refineries etc,. The dimension of work piece is 100x95x13mm.

Chemical Compositions

ELEMENT	% PRESENT
Chromium(Cr)	22.5
Nickel(Ni)	4.5
Molybdenum (Mo)	0.3
Manganese (Mn)	2.0
Nitrogen (N)	0.1
Carbon(C)	0.030
Copper(Cu)	0.3

Mechanical Properties

PROPERTY	VALUE
Yield Strength	400 Mpa
Tensile Strength	600 Mpa
Elongation	25%

Physical Properties

PROPERTY	VALUE
Density	7.75g/cm^3
Specific Heat	482J/kg K
Electrical Resistance	0.80micro Ω m
Young's Modulus	200GPa
Thermal Expansion	13.7 x10−6 /K
Thermal Conductivity	19.0 W/m.K

4. TAGUCHI EXPERIMENTAL DESIGN APPROACH

Genichi Taguchi developed a framework for a statistical design of experiments adapted to the particular requirements of engineering design. Taguchi suggested that the design process consists of three phases: system design, parameter design, and tolerance design. Taguchi separated variables into two types, namely control factors and noise factors. Control factors are those variables which can be practically and economically controlled, such as a controllable dimensional or electrical parameter. Noise factors are those variables which are difficult, or expensive to control in practice, though they may be controlled in an experiment, e.g. Parameter variation within a tolerance range.

Taguchi methods have been widely utilised in engineering analysis and experimental plan. The main advantage of this method is the saving of effort by conducting experiments, saving experiment time, reducing the cost and finding significant factors quickly than factorial experiment. The steps applied for Taguchi optimisation in this work are as follows.

- Select control factors.
- Select levels for each factor.
- Select Taguchi orthogonal array
- Assign selected factor levels to the selected orthogonal array.
- Conduct the experiments.
- Thrust force measurement.
- Surface roughness measurement.
- Analyse results.
- Optimum performance.

5. RESULTS AND ANALYSIS

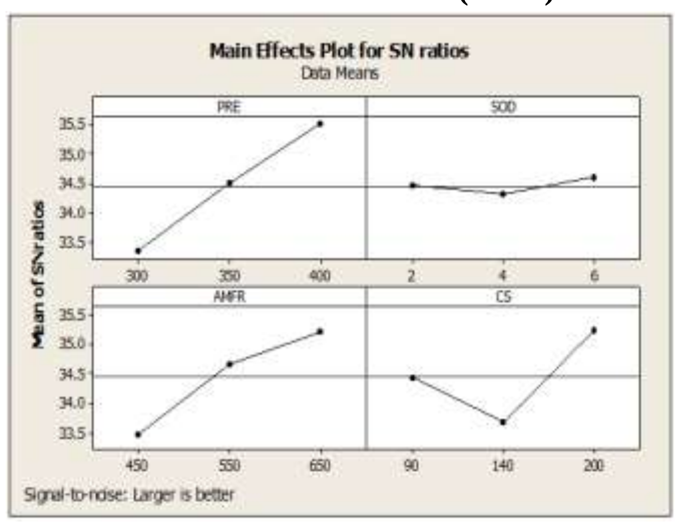
Surface roughness measurement

Talysurf Meter

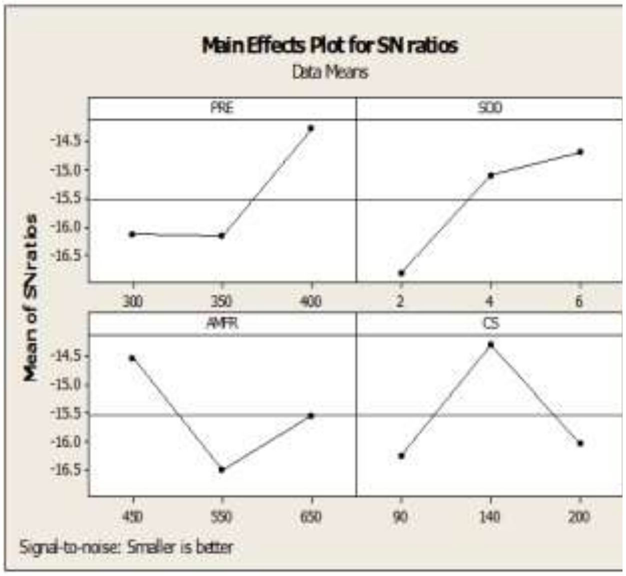
Surface roughness (Ra) of each machined surface was measured using a Talysurf SJ-201P surface roughness tester with a gauge range ±150 µm, resolution 0.014 µm, Stylus - 112/1502 diamond tip radius 2 µm and the cut-off length 0.8 mm.

The direction of surface roughness measurements is perpendicular to the hole circumference. The surface roughness values used in the analysis for each machined surface was an average of three measurements taken from the same surface.

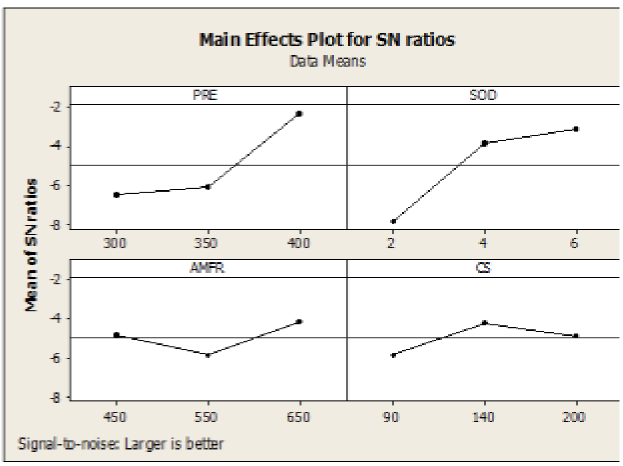
MATERIAL REMOVAL RATE (MRR)



Material removal rate



Surface finish (SR)



L9 OA for $CC_{i,}$ S/N ratios and Means

6. RESULTS OF CONFORMATION EXPERIMENTS FOR OPTIMUM SETTINGS

Optimum Settings for SR

Parameter	Level Description	Level
Water Pressure	350	2
Stand of Distance	2	1
Abrasive Mass flow rate	550	2
Cutting speed	90	1

Conformation experiment was performed, the Surface Roughness (SR) value is: 4.585μm

Optimum Settings for MRR

Parameter	Level Description	Level
Pressure	400	3
Stand of Distance	6	3
Abrasive Mass flow rate	650	3
Cutting Speed	200	3

Conformation experiment was performed, the Material Removal Rate (MRR) value is: 60.83g/min

Optimum Settings for combined SR and MRR

Parameter	Level Description	Level
Pressure	400	3
Stand of Distance	6	3
Abrasive Mass flow rate	650	3
Cutting speed	140	2

Conformation experiment was performed, the SR and MRR simultaneously value is: 4.892μm and 59.94g/min

Regression Equations:

MRR = - 25.6 + 0.127 PRE + 0.17 SOD + 0.0504 AMFR + 0.0431 CS

SR = 10.4 - 0.0126 PRE - 0.407 SOD + 0.00280 AMFR + 0.0011 CS

CC_i = - 0.714 + 0.00276 PRE + 0.0669 SOD - 0.000036 AMFR + 0.000656 CS

7. CONCLUSIONS

Though a lot of methods for multi response optimization in machining processes are studied, a new method (TOPSIS) is proposed in this work. The method represents selection of optimal process parameters in AWJM process. The main advantage of this method is that there is no need to calculate complex modeling formulations or simulations of process, which takes a lot of time and hardware to find out the optimum solution. Instead of the complex modeling formulations, a simple statistical calculation has been used to get the appreciable result. This approach also gives much more reliable solutions as exact experimental values are used to represent the process. When the results are concluded it is found that the MRR and SR which are influenced over AWJM parameters of Cutting speed, Abrasive mass flow rate, Standoff distance and water pressure. It is observed that the experimented value for MRR and SR was found through the analysis of variance (MINITAB) gives a graphical form of optimal setting results. The improvement of closeness coefficient (CC*i*) provides multi response optimal setting results for MRR and SR by TOPSIS method. Through the optimal results conformation experiment was performed; finally get an experimental result of MRR (60.83g/min) and SR (4.585µm) and closeness coefficient (CC*i*) the SR and MRR simultaneously value (4.892µm and 59.94g/min). Thus the multi response approach using TOPSIS with Taguchi approach is capable of solving any type of optimization problem.

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