Process Analysis and Monitoring of Process Parameters in Abrasive water jet cutting during Machining of AISI 4140 Steel

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ABSTRACT

Abrasive water jet Machining (AWJM) is one of the widely used non-traditional machining process. It is capable of machining geometrically complex and hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, and aeronautics industries. In present study, Experimental investigations were conducted to assess the influence of process parameters like Abrasive mass flow rate(gm/min), traverse speed (mm/min) and Stand of Distance (mm) on Material Removal Rate (mm^3*/min) and Surface Roughness(µm) of AISI 4140 steel. Here, using garnet and Aluminum oxide mixer as an abrasive material. The optimization for Abrasive water jet Machining process parameters of AISI 4140 Steel work piece using Taguchi method will done. Nine experimental runs (L9) based on an orthogonal array Taguchi method will performed and investigate the effect of Abrasive water jet cutting process parameters like Abrasive mass Flow Rate (gm/min), Traverse speed (mm/min) and Stand of Distance (mm) on MRR and SR. The MRR and SR were measured for each specimen after AWJC and the effects of these parameters were researched.*

Keyword: -*Abrasive Water Jet Cutting, AISI 4140 Steel, Process Parameter, Material Removal Rate and Surface Roughness.*

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1. INTRODUCTION

The technique of cutting materials using high pressure water jets was first time patented in 1968 by Dr. Norman Franz, researcher at University of Michigan, USA. He selected the company Ingersoll – Rand to manufacture the prototype of a water jet cutting equipment, as this company was skilled in manufacturing of high pressure pumps used in various industrial applications. First industrial equipment was installed at a furniture manufacturing company – ALTON BOXBOARD Co. – which used it to cut wood panels with 10 mm thickness.

From this date the company manufactured thousands of water jet cutting equipment. Today, the company sold this division to other company – Flow Systems – which is world number one in manufacturing high pressure water jet pumps and equipment.

High pressure abrasive water jet technology has a relative recent history, its development starting in early ‘80s of 20th century. This technology was developed to broaden the range of materials possible to be cutes by water jet technology mainly for materials with high mechanical characteristics.

Bellow is presented a classification of high pressure / high speed water jets used in cutting and cleaning technologies Water jets can be classified by the following criteria[1].

Pressure

• Low pressure water jets (p < 150 MPa);

• High pressure water jets (150 MPa <p< 550 MPa)

Continuity

• Continuously water jets;

• Discontinuously water jets: single impact jets, multiple impact jets

Number of phases

• Single phase jets (only water);

• Two phases jets (water + additives);

• Three phases jets (water + abrasive particles + air);

Regarding above classification, the difference between continuously and discontinuously jets is that discontinuously jets are obtained by means of mechanical mechanisms or other kind of external mechanisms. Here it is not considered the internal discontinuity of water jets due to pressure and flow variations (drops formed at the external layer of a water jet).

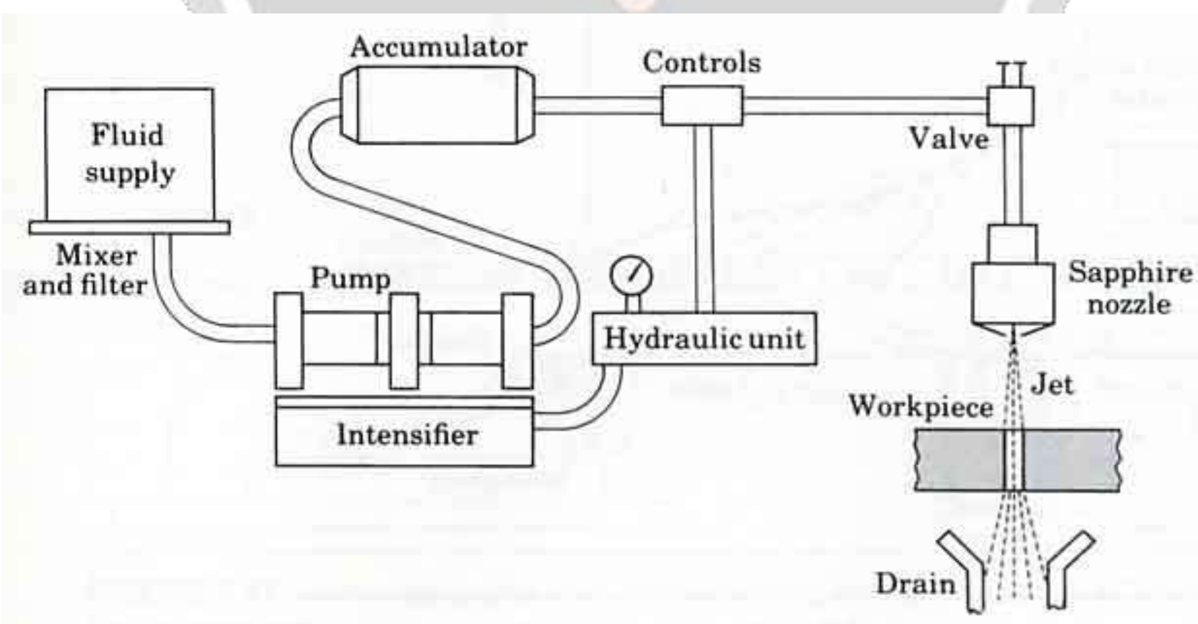

Fig.1 Schematic Diagram of AWJC process [1]

2. LITERATURE REVIEW

"A study of abrasive water jet machining process on glass/epoxy composite laminate" by M.A. Azmir et al. M.A. Azmir et al. studied Surface roughness (Ra) and kerf taper ratio (TR) characteristics of an abrasive water jet machined surfaces of glass/epoxy composite laminate. They took Hydraulic pressure and type of abrasive materials considered as the most significant control factor in influencing Ra as shown in and TR, respectively. They showed that Increasing the hydraulic pressure and abrasive mass flow rate may result in a better machining performance for both criteria. Also they found that the decreasing the standoff distance and traverse rate may improve both criteria of machining performance. They revealed that the Cutting orientation does not influence the machining performance in both cases [2].

"P.Hreha, S,Hloch, P.Monca, K.Moncova (2014) investigation of sandwich material surface created by abrasive water jack(AWJ) vie vibration emission. Abrasive water jack cutting of heterogeneous "sandwich" material with different young modules of elasticity of the catted surface geometry by means of vibration emission. An experiment in heterogeneous material consisting of stainless steel (DIN 1.400/AISI 410) and allow AlCuMg2 has been provided. A sandwich semi-product composing of two metal plates bonded together by epoxy adhesive was prepared as an experimental material. This plates where made of stainless steel with marking according to DIN 1.4006(AISI410) standard with thickness of 32 and of Al alloy AlCUMg2 with thickness of 20ml. the sensors were placed. The first cutting the experimental material was oriented upwards by means of the Al alloy plate. In the second cutting the orientation of material was the opposite one. The vibration signal was scanned from a side perpendicular to the cutting direction time records of the scanned signal are so in figure to. The signals of both layers of material possess similar development due to trans mission of oscillations in the material higher amplitudes where again recorded in the case of softer material (Al alloy). That material was placed in the zone in which the abrasive water jet lost a high amount of kinetic energy due to passing through the material with higher modules of elasticity (stainless steel). The results of frequency analysis of scanned signals are shown in the figure 3. Material with law modules of elasticity is not capable of sufficient resistance and generates a negative to the expanded instruments shape. When the instrument had passed in to the material with higher modules of elasticity in upward work piece orientation by means of aluminium alloy plate the mechanism of the surface generation was realized a new with the instruments which lost part of its initial energy[3].

"Fuzzy logic-based expert system for prediction of depth of cut in abrasive water jet machining process" by Pandu R. Vundavilli et al. developed process modeling of Abrasive Water Jet Machining with the help of Mamdani-based fuzzy logic controller. They has been investigated on depth of cut depends on various process parameters, such as diameter of focusing nozzle, water pressure, abrasive mass flow rate and jet traverse speed with using mild Steel (MS-A36) Three approaches have been developed to predict the depth of cut in AWJM using FL system. The first Approach deals with the construction of Mamdani- based fuzzy logic system. It is important to note that the performance of the FL depends on its knowledge base. In Approach 2, the data base and rule base of the FL-system are optimized, whereas in the third Approach, the total FL-system is evolved automatically. A binary-coded genetic algorithm has been used for the said purpose. In this study, an attempt has been made to carry out the modeling of abrasive water jet machining process using FL-based approaches. A batch mode of training, which requires a large amount of data, has been employed. The training data is generated artificially (at random) with the help of response equations obtained through the regression analysis. Three different FL approaches are developed for forward modeling, and their performances are compared with the help of 15 randomly generated test cases. The developed expert system eliminates the need of extensive experimental work, to select the most influential AWJM parameters on the depth of cut. The performances of the developed Fuzzy Logic -systems have been tested to predict the depth of cut in AWJM process with the help of test cases. The prediction accuracy of the automatic FL-system is found to be better than the other two approaches [4].

"Tool wear analysis and improvement of cutting conditions using the high-pressure water-jet assistance when machining the Ti17 titanium alloy" by Y. Ayed et al. Y. Ayed et al. presented study provides a contribution to the optimization of this process when machining Ti17 titanium alloy. They have been investigated on tool wear and cutting Forces by the influence of the cutting speed and the water jet pressure. The cutting speed has been varied between 50 m/min and 100 m/min and the water jet pressure has been varied from 50 bar to 250 bar. The optimum water jet pressure has been determined; the effect of HP assistance is clearly discernible. In fact, experimental tests have shown that tool life can be increased up to 9 times with a pressure of 100 bar and increase of about 30% in productivity [5].

"**Investigation on glass/epoxy composite surfaces machined by abrasive water jet machining" by M.A. Azmir et al. M.A. Azmir et** al. conducted experiment to assess the influence of abrasive water jet machining (AWJM) process parameters on surface roughness (Ra) of glass fibre reinforced epoxy composites. It has been found that the type of abrasive materials, hydraulic pressure, standoff distance and traverse rate were the significant control factors and the cutting orientation was the insignificant control factor in controlling the Ra. They revealed that the forms of glass fibres and thickness of composite laminate showed the greatest influence on Ra. It was confirmed that the determined optimum combination of AWJM parameters satisfy the real need for machining of glass fibre reinforced epoxy composites in practice [6].

"A study of taper angles and material removal rates of drilled holes in the abrasive water jet machining process " by MahabaleshPalledaMahabaleshPalleda conducted experiment to the effect of using different chemicals on material removal rate, with varied standoff distances and chemical concentration in abrasive water jet machining with using glass material . They showed that the material removal increases with the increase in S-O-D, up to certain limit and further increase in the S-O-D beyond the limit results in decrease of the material removal. It found highest in the case of slurry mixed with polymer. They showed that the chemical concentration was observed to be having an influence over the taper of the holes produced. The hole taper in case of polymer combination showed almost nil taper [7].

"Modelling of abrasive particle energy in water jet machining" by Chidambaram Narayanan et al.modelling of abrasive particle energy in water jet machining. They took process parameter with wide variations in cutting-head geometry, operating pressure, and abrasive mass flow rates. The cross-sectional averaged abrasive particle velocity at the exit of the focussing tube has been predicted with good accuracy over the whole range of experiments [8].

"Processes and apparatus developments in industrial water jet applications" by Mustafa Kemal Kulekci et al. Mustafa Kemal Kulekci et al. investigated work on surface roughness and depth of cut to influence process parameter like water pressure, grain diameters of abrasive feed rate, and traverse speed using experimental data with using stainless steel and aluminium alloys material. They found that the two limitations of AWJ are speed and cost of abrasives. The AWJ processes are environmentally friendly when compared to other cutting operations. The process is clean, does not create dust, grindings, chips or chemical air pollution. The WJ carries away the eroded material, practically eliminating dust, and does not generate fumes associated with other cutting methods .They found in cutting both aluminium alloy and stainless steel, depth of cut increases with water pressure. Increasing water jet energy increases cutting volume per abrasive grain and consequently depth of cut. The relation between garnet grain size and depth of cut is increases up to 200 μm of grain size. In cutting applications with grains sizes larger than 200 μm, cutting performance for a constant feed rate decreases. With increase of abrasive feed rate depth of cut increase up to 10–12 g/s .with increase of traverse speed depth of cut decrease and surface roughness increases [9].

"Quantitative evaluation of abrasive contamination in ductile material during abrasive water jet machining and minimising with a nozzle head oscillation technique ." by Keyurkumar J. Patel, Keyurkumar J. Patel investigated quantitative evaluation of abrasive contamination using scanning electron microscopy (SEM) in ductile material (aluminium Al–Mg4, 5Mn) during abrasive water jet machining and minimising with a nozzle head oscillation technique. They indicated that as the depth of cut increases the grit contamination decreases .A comparison was made between straight cutting and oscillation cutting, and it was observed that oscillation cutting is 10 times better than straight cutting for ductile material with respect to particle contamination [10].

"Optimisation of abrasive jet cutting by means of taguchimethods " by Deaconescutudor et al. Deaconescutudor et al. optimisation of abrasive jet cutting by means of taguchi methods. They influence process parameter like jet pressure, feed speed, stand-off distance, abrasive graining, mass flow, etc. The roughness of the machined surfaces and the thickness of the cut part are output quantities of the system, their values depending on the input parameters and the influence of various disturbing factors (noises). They obtained surface roughness consequently to abrasive jet cutting. applying the method of fractioned orthogonal factorial arrays of experiments devised by G. Taguchi, five controllable input factors were selected By assigning these optimum set points to the input quantities the machining system becomes robust, and consequently the roughness of the machined surfaces will not deviate from the desired and predicted value [11].

"Assessment of Process Parameters in Abrasive Water jet Cutting of Granite" by M. Chithiraiponselvan et al. M. ChithiraiPonSelvan et al. carried out experiment to influence of process parameters on depth of cut which is an important cutting performance measure in abrasive water jet cutting of granite. Experiments were conducted in varying water pressure, nozzle traverse speed, abrasive mass flow rate and standoff distance for cutting granite tiles using abrasive water jet cutting process. When increase water pressure and abrasive mass flow depth of cut increases .When increase traverse speed and standoff distance depth of cut decreases .They developed an empirical model for the prediction of depth of cut in abrasive water jet cutting of granite is using regression analysis. This developed model has been verified with the experimental results that reveal a high applicability of the model within the experimental range used [12].

3. DESIGN OF EXPERIMENT

DOE is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels each within the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. The design of experiment is used to develop a layout of the different conditions to be studied. And experiment design must satisfy two objectives: first, the number of trials musty be determined; second, the conditions for each trial must be specified.

Three factors are chosen the design becomes a 3 level 3 factor taguchi design. The version 17 of the MINITAB software was used to develop the experimental plan for L09 Orthogonal Array. In this experiment other parameters are fixed,

Table.1 Input parameter with Levels value

Sr. No.	Machining process parameter	Level 1	Level 2	Level 3
1	Abrasive Flow Rate(gm/min)	200	250	300
2	Traverse Speed(mm/min)	100	120	140
3	Stand Of Distance(mm)	3	4	5

4. EXPERIMENT SETUP

The machine used for experiments is **JETLINE JL-1 50**

Fig. 2 Abrasive water Jet pump (JETLINE JL-1 50)

4.1 Work-piece material

AISI 4140 Chrome - Moly High Tensile Steel, generally supplied hardened and tempered to Condition “T” in sections up to 100mm, with a tensile strength of 850 – 1000 MPa and aiming for this strength range in larger sections. It offers a very good balance of strength, toughness and wear-resistance. AISI 4140 is a chromium-molybdenum alloy steel. The chromium content provides good hardness penetration, and the molybdenum content ensures uniform hardness and high strength. AISI 4140 chrome-molybdenum steel can be oil hardened to a relatively high level of hardness. The desirable properties of the AISI 4140 include superior toughness, good ductility and good wear resistance in the quenched and tempered condition. The AISI 4140 cold finished annealed chromium-molybdenun alloy steel can be heated using various methods to yield a wide range of properties, hence it is often used as stock for forging as it has self-scaling properties. AISI 4140 is capable of resisting creep in temperatures up to 538°C (1000°F) and maintaining its properties even after long exposure at comparatively high working temperatures. The AISI 4140 cold rolled rounds are available in the 41L40 variant that contains 0.15-0.35 lead. The lead content improves machinability, but has significant effect on other desirable properties.

Table 2 Chemical composition of work-piece material

ELEMENT	CONTENT
Carbon, C	0.380 - 0.430 %
Chromium, Cr	0.80 - 1.10 %
Iron, Fe	96.785 - 97.77 % (As remainder)
Manganese, Mn	0.75 - 1.0 %
Molybdenum, Mo	0.15 - 0.25 %
Phosphorous, P	≤ 0.035 %
Silicon, Si	0.15 - 0.30 %
Sulphur, S	≤ 0.040 %

5. EXPERIMENT RESULTS

The effect of process parameters on the machining parameter for AISI 4140 steel is recorded in the table. Total 9 experiments done on the AWJC machine based on the taguchi method and summarized in the following table.

Table 3 Experiment Results by AISI 4140 STEEL

Run Order	Actual values			MRR (mm^3/min)	SR (μm)
	Abrasive flow rate (gm/min)	Traverse speed (mm/min)	Standoff Distance (mm)		
1	200	100	3	902.15	3.641
2	200	120	4	929.23	3.246
3	200	140	5	968.23	2.859
4	250	100	4	721.56	3.535
5	250	120	5	773.89	3.133
6	250	140	3	981.18	3.236
7	300	100	5	662.32	3.378
8	300	120	3	782.49	3.577
9	300	140	4	831.13	3.121

6. RESULT AND DISCUSSION

After performing the experiment for all 9 runs and measuring the output parameters like material removal rate, surface roughness for Abrasive water jet cutting (AWJC) of AISI 4140 steel, whatever results generated are discussed in this chapter.

6.1 Main effect plots of input parameter v/s output parameter for AISI 4140

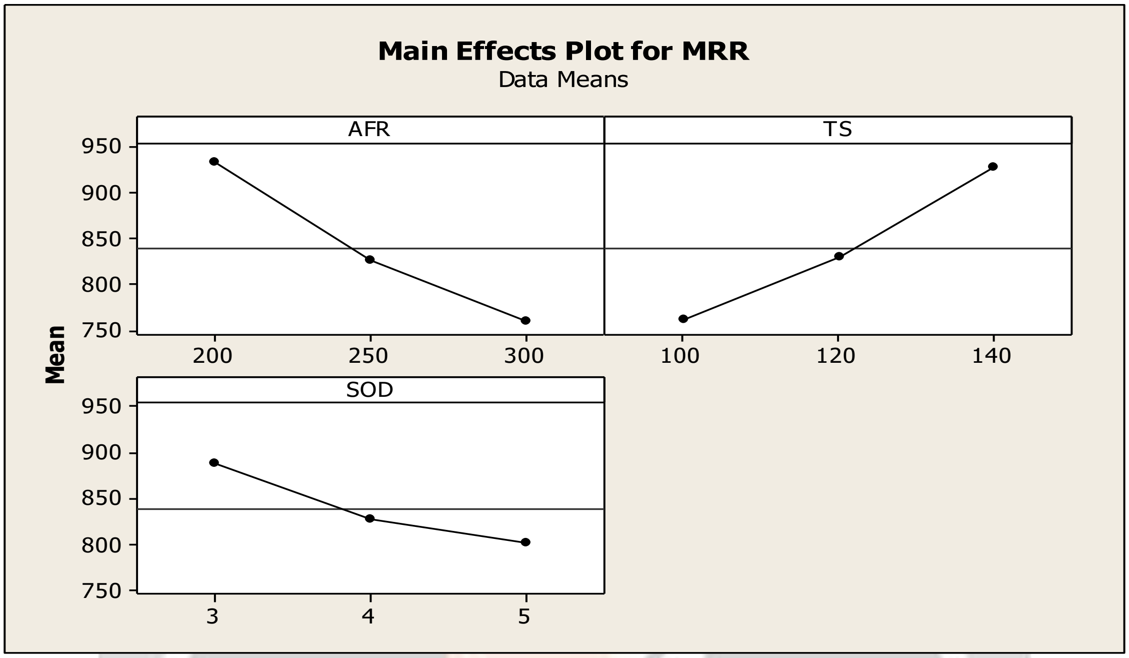

Figure 6.1 Graph of input parameter v/s MRR for AISI 4140

The first chart of fig 6.1 demonstrates that the expansion in abrasive flow rate, MRR decrease. At the point when abrasive flow rate increments from 200 to 250 gm/min, MRR decreases from 933.20 to 825.54mm3/min. what's more, when abrasive flow rate increments from 250 to 300 gm/min then MRR additionally decreases from 825.54 to 758.65mm3/min.

The second chart of fig 6.1 demonstrates that the expansion in traverse speed, MRR rises. At the point when traverse speed increments from 100 to 120 mm/min, MRR rises from 762.01 to 828.54mm3/min. at the point when traverse speed again increments from 120 to 140 mm/min, MRR again rises from 828.54 to 926.85mm3/min.

The third diagram of fig 6.1 demonstrates that the expansion in servo stand of distance, MRR diminishes. At the point when stand of distance increments from 3 to 4 mm, MRR diminishes from 888.61 to 827.31mm^3/min. at the point when stand of distance again increments from 4 to 5 mm, MRR again diminishes from 827.31 to 801.48mm^3/min.

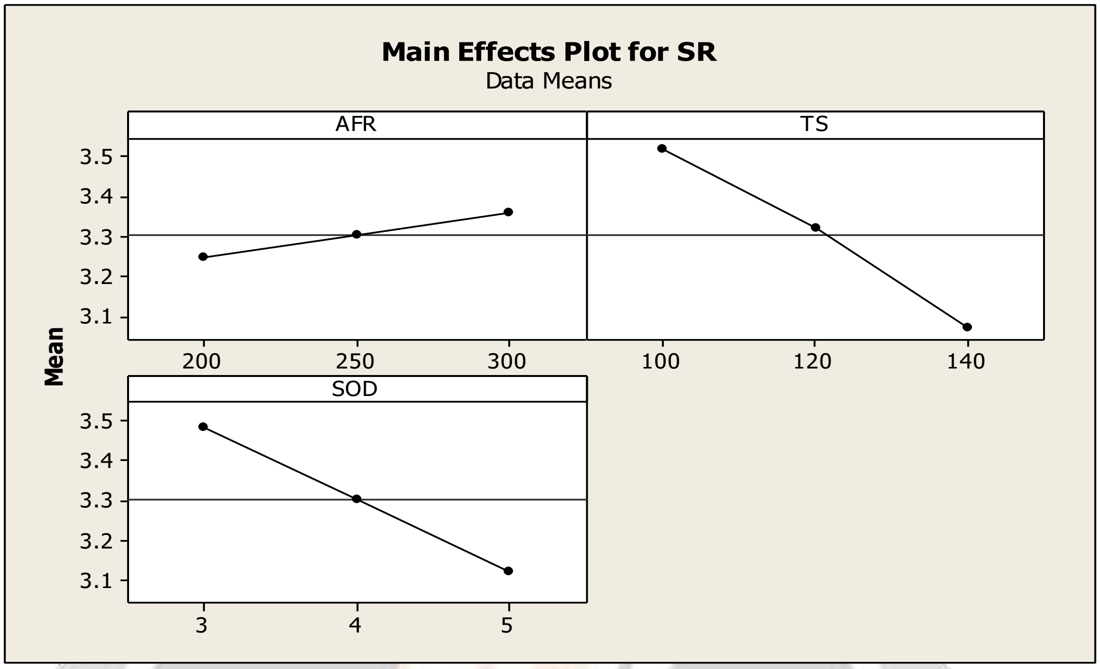

Figure 6.2 Graph of input parameter v/s SR for plain brass wire

The first chart of fig 6.2 demonstrates that with the increments in abrasive flow rate, SR increments. At the point when abrasive flow rate increments from 200 to 250 gm/min, SR increments from 3.249 to 3.301 µm. at the point when again increment in abrasive flow rate from 250 to 300 µs, SR again increments from 3.301 to 3.359 µm.

The second diagram of fig 6.2 demonstrates that with the expansion in traverse speed, SR diminishes. At the point when traverse speed increments from 100 to 120 mm/min, SR diminishes from 3.518 to 3.319 µm. at the point when traverse speed again increments from 120 to 140 mm/min, SR again diminishes from 3.319 to 3.072 µm.

The third chart of fig 6.2 demonstrates that with increments in stand of distance, SR diminishes. At the point when stand of distance increments from 3 to 4 mm, SR diminishes from 3.485 to 3.301 µm. at the point when servo voltage again increments from 4 to 5 mm, SR again diminishes from 3.301 to 3.123 µm.

In this part, one has examined on fundamental impacts of input parameters like abrasive flow rate (gm/min), traverse speed (mm/min), stand of distance (mm) and output parameters like material removal rate (mm^3/min), surface roughness (µm).

7. CONCLUSION AND FUTURE SCOPE

In this exhibited work, examinations are completed for MRR, SR with factors abrasive flow rate, Traverse speed and stand of distance with AISI 4140 steel. There are add up to 9 tests taken for each parameter and for all factors to direct parametric examination.

At long last from all examinations it can be inferred that:

- The ANOVA is directed to know the rate commitment of the input parameters on output parameters for AISI 4140 steel. ANOVA comes about that the rate commitment of abrasive flow rate is 45.83%, traverse speed is 40.63%, stand of distance is 11.83% for Material Removal Rate, which demonstrates that stand of distance is less contrasted with different parameters. The rate commitment of abrasive flow rate is 3.52%, traverse speed is 58.08%, stand of distance is 37.98% for Surface Roughness, which demonstrates that the impact of abrasive flow rate is less contrasted with other input parameters.

- Grey relational investigation is done to discover optimum parameter levels. After grey relational investigation, it is found that optimum parameter levels are abrasive flow rate at level 1 (200 gm/min), traverse speed at level 3 (140 mm/min), stand of distance at level 3 (5 mm) for AISI 4140 steel.
- Grey relational investigation is done to discover optimum parameter levels. After grey relational investigation, it is found that optimum parameter levels are Abrasive flow rate, Traverse speed and Stand of distance is level 1 (200 gm/min), level 3 (140 mm/min), and level 3 (5 mm) respectively.
- Traverse speed is most critical variable for MRR and SR contrasted with different parameters.
- Increase of traverse speed produces more start vitality as the abrasive flow rate that the MRR rise and SR diminishes with traverse speed. Abrasive flow rate is most critical parameter in all outputs. Surface roughness likewise increments with increment of abrasive flow rate on the grounds that the increments of abrasive flow rate create hole with more extensive and more profound trademark.
- Traverse speed has inverse impact to abrasive flow rate. MRR rises with increment of traverse speed, while surface roughness decreases.
- The MRR diminishes with increment in stand of distance. This is because of increment in stand of distance result in higher release vitality per start as a result of expansive abrasive particle between working crevice; subsequently the MRR diminishes.

FUTURE SCOPE

- The numerical model can be produced with various work-piece and terminal materials for WJC and AWJC forms.
- Parametric analysis can be carried out with Abrasive Flow Rate, Traverse Speed and Stand of Distance. Effect of Nozzle Working life time, Nozzle wear, Nozzle size increase this research area is still open for future work.
- Responses like roundness, circularity, machining cost and so forth are to be considered in further research.

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