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Experimental Investigation of High Speed Micro-Drilling on SS 316L Material Using GRA

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Abstract:SS316L is considered for the study as it is used as a best substitute for titanium alloys which are used for trauma and orthopedic medical implants.Objective of the project is to investigate and optimize the process parameters when drilling at high speed for machining a micro hole on SS316L using tungsten carbide micro drill. There are two machining parameters of this experiment which are spindle speed, and feed rate to be varied to investigate the optimum condition for response parameters like Temperature, thrust force, machining time and MRR. To overcome the difficulty of wandering motion of tool, increased machining time, or sudden failure of drill tool Peck drilling Cycle has to be used for drilling holes. SEM analysis is carried out to compare the surface roughness and burr formation in holes and VMS (Video Measuring System) is used for carrying out the roundness measurement. Additionally, the GRA (Gray relational analysis) has been applied to determine the most significant factors to influence the response.

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I. INTRODUCTION

In recent years, rapid advances in manufacturing industries have given rise to miniature and lightweight products with increasing and more powerful functions. With the increasing demand for micro parts and structures in many industries, and rapid developments in micro-electro-mechanical systems (MEMS), micro-manufacturing techniques for producing these parts has become increasingly important. Dr. K. K. Gupta et al. [2] has done research in order to find the best quality of drilling for different types of work piece material (MS, Aluminum alloy & PCB). Redzuan, et.al Azlan Abdul Rahman et al.[4] performed a study on optimum drilling process parameter for HSS drilling tool in micro-drilling processes in to find the best drilling process parameter for brass as a work material and investigated the effect of Spindle Speed , feed rate, Drill diameter on MRR, Surface roughness, burr formation and dimensional accuracy. M. Malik et al. [5] studied the Surface finish, tool failure modes and tool life were evaluated at various conditions to determine the optimum condition of the process. It was found that point angle and the interaction of cutting speed and feed rate are the pronounced effect on the tool performance. Result also showed that feed rate was the dominant factor affecting the surface roughness.

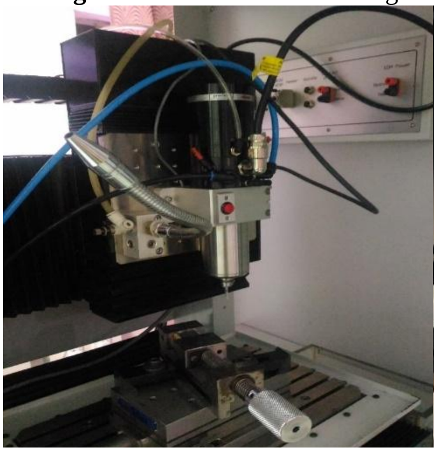
Micro drilling and Macro scale drilling is same but slightly different in some aspects. This uses a special drill tool geometry, Spindle Speed tool holding devices and speeds of drilling. P. Marimuthu et al.[3] performed the experiments in AHUJA Mini drilling machine using drill with 0.5 mm along with different spindle speeds, feed rates and depth of cut on SS sheets, Signal to noise ratio and Analysis of variance used to analyze the experiments. S. Sivasankar et al. [6] studied simple and efficient methodology and algorithms to evaluate the surface roughness, waviness and roundness. Roundness is measured using one of the internationally defined methods of Minimum Zone Circles. Roughness is measured using arithmetic deviation of the roughness and peak to peak height. Waviness was measured using waviness step height. These parameters were measured and studied using video measuring machine and image processing technology through Matlab. Anil Jindal et al. [7] investigated experimental study, the application of the DOE (Design of Experiment) method and Scanning Electron Microscope (SEM) is utilized. In the experimental investigation, a micro drilling system comprising of a high speed air spindle was used.

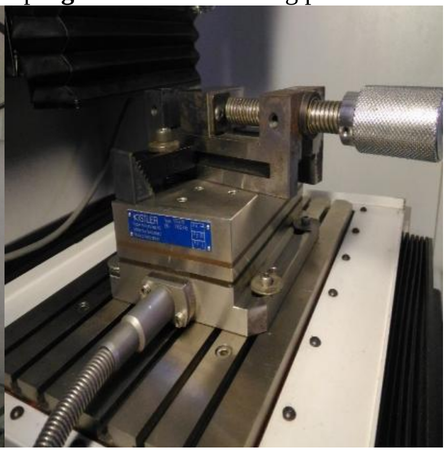
Xavier et al. [10] concluded special machining cycles can be used to control the chip size and shape. Deep-hole cycles and peck drilling cycles were employed to avoid the damage and premature failure to the the tool.

II. EXPERIMENTAL SETUP

DT-110 is a 3-axis automatic multi-process integrated machining process with high accuracy (Figure1.1).This machine was used for conducting the Micro-Drilling experiments. The maximum travel range of the machine is 200 mm (X)×100mm (Y)×100mm (Z) with the resolution of 0.1µm in X, Y and Z directions and full closed-feedback control ensures sub-micron accuracy. Measurement of forces have been done with the piezoelectric dynamometer of Kistler and for Temperature measurement optical pyrometer is used. MRR calculated by weight removed per unit time, and weight is calculated by precision weight measuring device.

Figure 1. DT110 Micro-Drilling Setup**Figure 2**.Micro-Drilling process





Work & Tool Material

The work piece material used in this study was SS316L. The selection of electrodes plays a vital role as it influences the machining performance of micro-drilling. In this study, tungsten carbide drill tool with a diameter of 800µm is used.

Experimental Procedures

There are two process parameters that must be controlled to obtain the optimum performance of micro-drilling process. From earlier studies, it was inferred that speed and feed rate are the most influential parameters of the micro-drilling process. Hence in this investigation, these two parameters, were taken as independent variables, keeping diameter of drill tool constant in all experiments. MRR, Force, Machining Time and Temperature are taken as response parameters to observe the results.

Table no 1: Parameters and their level for micro-drilling

Parameters	Level 1	Level 2	Level 3
Speed (RPM)	15000	20000	25000
Feed (mm/min)	1	2	3

III. RESULTS AND DISCUSSION

Machine time, MRR, Force and temperatures are obtained from the experiment using calculation. The calculation is based on the two parameter Speed and feed and drill bit diameter is constant. After the set up for experiment is designed experiment is conducted. Total nine no. of drilling operation was done with WC tool drill bill 0.8 mm on SS 316L 20x20x0.8 mm with three different Speeds and Feeds in micro machining center with designed parameters.

Table no 2 : Experimental results of micro-drilling

Exp. No.	Speed (RPM)	Feed (mm/ min)	Machining Time (min)	MRR (mm3/min) X10-3	Force (N)	Temperature (°C)
1	15000	1	7.3166	70.0455	18	29.1
2	15000	2	3.7333	76.1932	26	29.3
3	15000	3	2.5833	145.0555	44	29.7
4	20000	1	7.1166	57.9630	20	29.9

5	20000	2	4.8666	82.2030	27	31.2
6	20000	3	3.3833	125.617	49	31.7
7	25000	1	8.4833	69.2537	16	32.0
8	25000	2	4.4166	75.0953	29	33.2
9	25000	3	3.0666	118.232	45	33.5

Grey relational Analysis (GRA)

This approach converts a multiple response process optimization problem into a single response optimization situation, with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated which would result highest grey relational grade.

Table no 3: Quality characteristics of the machining performance

Sr. No.	Characteristic	Quality Characteristic
1	MRR(Material removal rate)	Maximum
2	Force	Minimum
3	Machining Time	Minimum
4	Temperature	Minimum

Above table shows the response parameters and their quality characteristics for calculating the GRC value.In grey relational analysis, experimental data i.e. measured features of quality characteristics are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade.

Table no 4. Normalization Table for Response Parameters

EXP. No.	NORMLIZATION			
	Machining Time	TEMP.	FORCE	MRR
1	0.1977	1	0.939394	0.138731
2	0.8051	0.954545	0.69697	0.209319
3	1.0000	0.863636	0.151515	0.999994
4	0.2316	0.818182	0.878788	0
5	0.6130	0.522727	0.666667	0.278323
6	0.8644	0.409091	0	0.776802
7	0.0000	0.340909	1	0.12964
8	0.6893	0.068182	0.606061	0.196713
9	0.9181	0	0.121212	0.692007

The grey relational coefficient is use to express the relationship between the ideal (best) and actual normalized experimental results. In grey relational analysis total performance of multi objective optimization is depending on value of grey relational grade and it is calculated by average value of grey relational coefficient.

Table no 5.GRC and GRG Table for Response Parameters

Gray Relational Co-efficient				Gray Relational Grade (GRG)	Order
Machining Time	TEMP	FORCE	MRR		
0.3839496	1	0.891892	0.367304	0.437813	3
0.7195122	0.916667	0.622642	0.387392	0.505893	2
1	0.785714	0.370787	0.999989	0.696426	1
0.39421111	0.733333	0.804878	0.333333	0.365219	5
0.56369786	0.511628	0.6	0.409274	0.37115	8
0.78666667	0.458333	0.333333	0.691373	0.484093	4

0.33333333	0.431373	1	0.364868	0.282393	7
0.61672904	0.349206	0.559322	0.383645	0.337395	9
0.85923164	0.333333	0.362637	0.618818	0.452846	6

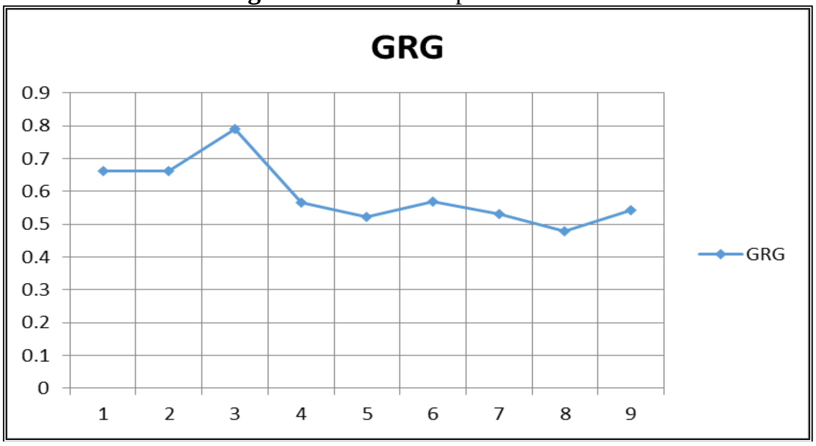
Above table shows that experiment number 3 gives the most preferable quality characteristics.

Table no. 6. GRC and GRG Table for Process Parameters

Factor	Average grey relational grade		
	Level 1	Level 2	Level 3
SPEED	0.703821	0.55167	0.51771
FEED	0.58654	0.55331	0.63335

Above table suggests lowest level of speed and highest level of Feed gives the best result according to GRA. The graph below shows the GRG variation according to experiment No.. Hence experiment No.3 is suitable according to GRA.

Figure 3. GRG vs Experiment No



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Scanning Electron Microscope (SEM) Analysis

Scanning Electron Microscope (Make: VEGA3 TESCAN) was used to observe the drilled holes. Hole produced using WC drill are compared to other holes. SEM image at 100X magnification are shown in Figure {A} to {I}. Numbering is given as per the experiment sequence. SEM images shows that at higher levels of speed and feed combined resulted in more burr formation and lower levels show less value of surface roughness.

Figure 4. 15000RPM, 1 mm/min

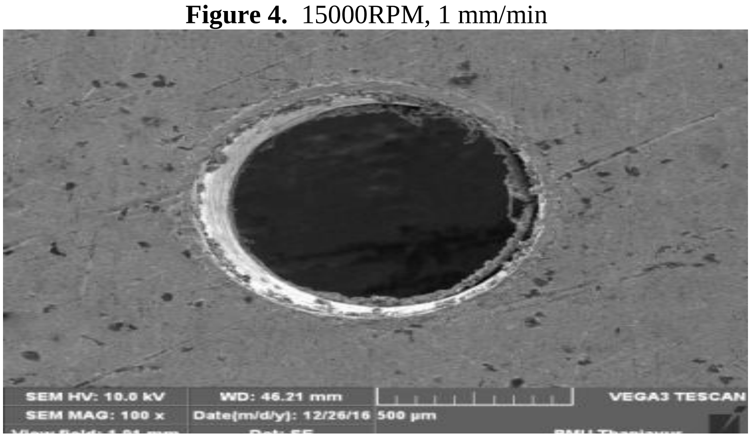


Figure 5.15000RPM, 2 mm/min

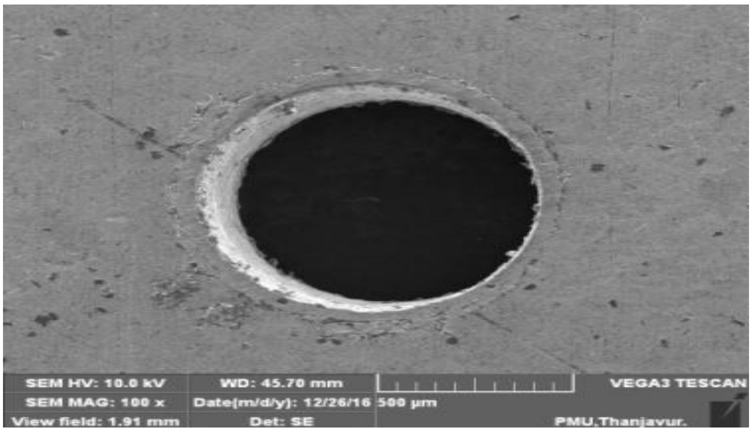


Figure 6. 15000RPM, 3 mm/min

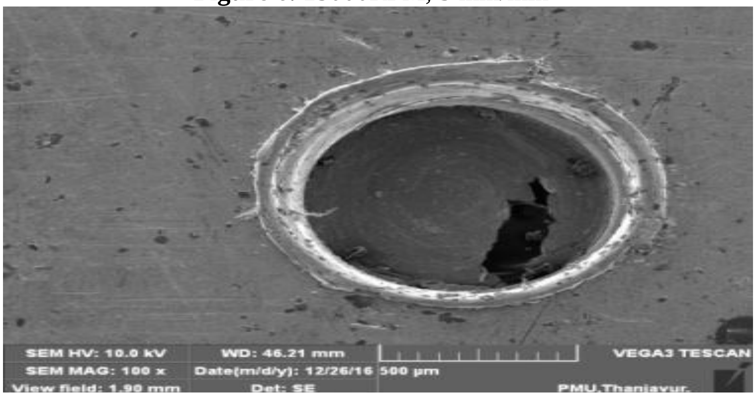


Figure 7. 20000RPM, 1 mm/min

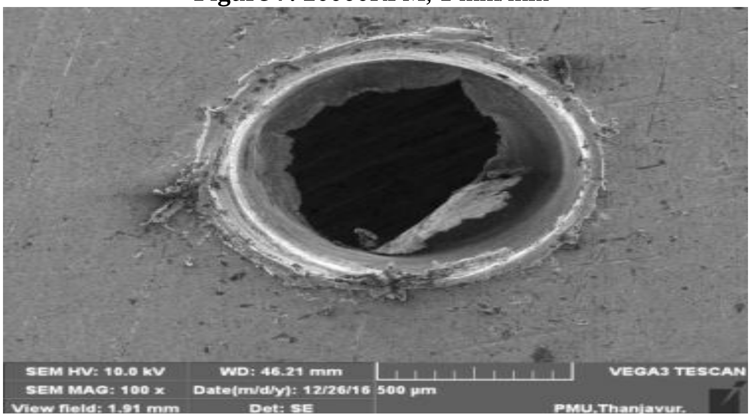


Figure 8. 20000RPM, 2 mm/min

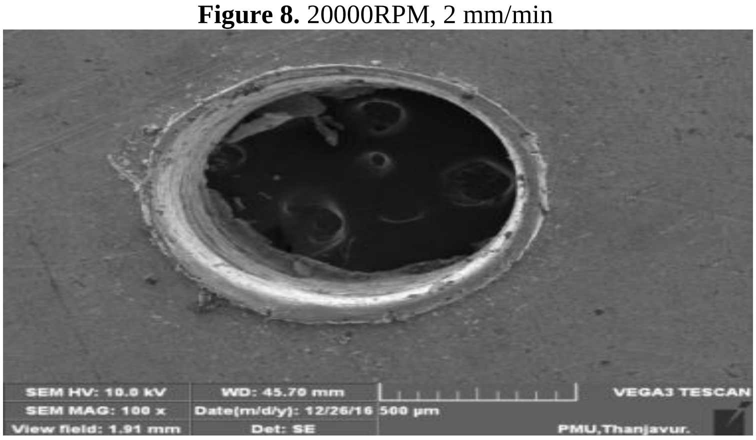


Figure 9. 20000RPM, 3 mm/min

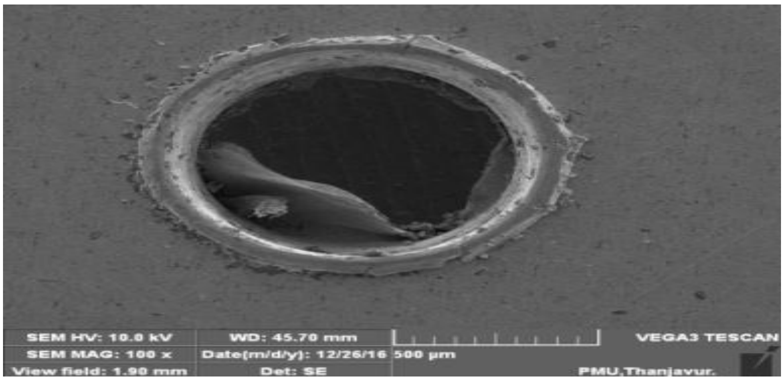


Figure 10.25000RPM, 1 mm/min

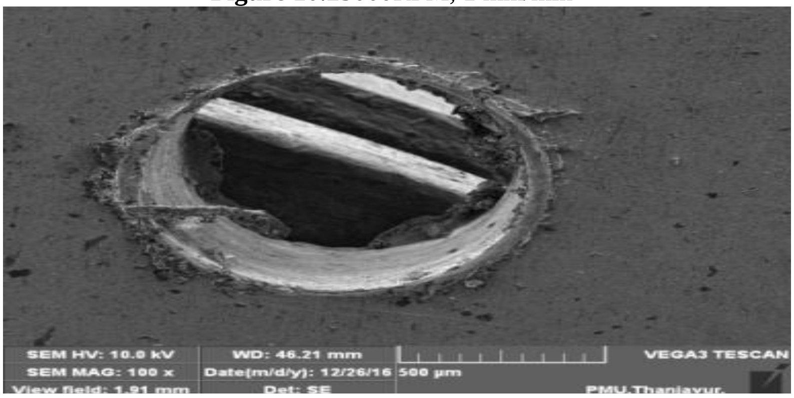


Figure 11. 25000RPM, 2 mm/min

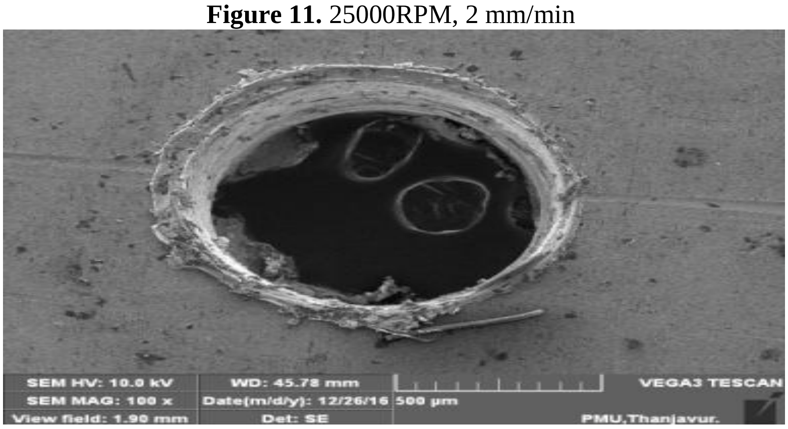
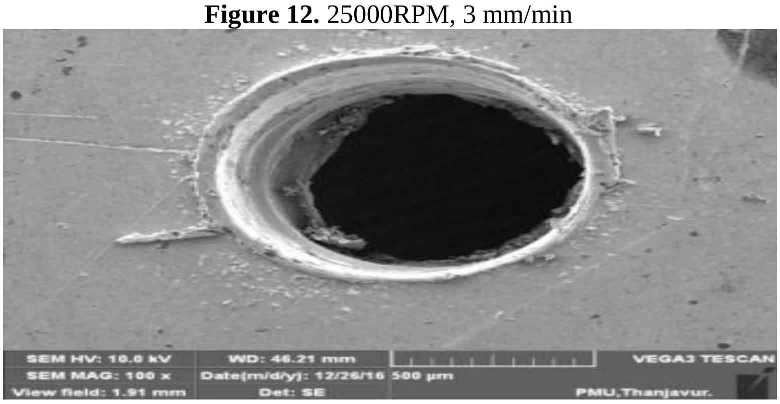


Figure 12. 25000RPM, 3 mm/min



IV. CONCLUSIONS

The objective of this study was to find out the optimized combination of Feed and Spindle speed so that the thrust force, temperature and Machining time can be minimized and MRR to be maximized. The conclusions can be summarized as follows:

[1] Results have shown that Machining time is largely affected by feed as compared to speed and it is reduced in case of higher levels of feed rate, MRR is maximized for higher levels of speed and feed both. Temperature is effected from both Speed and feed and is increasing with increasing levels of speed and feed. Force has dominant effect by feed as compared to speed and force increases with respect to higher feed.

[2] In the micro drilling process, the experimental work carried out by following the Taguchi design, Optimal Parametric combinations were found out. Design of Experiment (DOE) is the efficient method in establishing relations with process and response parameters.

[3] Through the GRA analysis, it can be observed that process parameters correspond to the factors producing maximum MRR, minimum drilling thrust, minimum machining time and minimum temperature. Thus, the optimal conditions are feed of 3mm/rev and spindle speed of 15000 rpm. GRA results shows that both Feed and spindle speed are highly significant for MRR, Thrust force, Machining time and temperature.

[4] From SEM analysis it can be concluded that less burr formation is observed in case of higher Speed coupled with lower feed.

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