Experimental Investigation of Machining Characteristics of AISI D3 Steel with Abrasive Assisted Surface Grinding

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Abstract - *Grinding is a very important technique in which material is removed at a high rate with high level of surface finish. In this research work Taguchi method is applied to find optimum process parameters for abrasive assisted surface grinding of AISI D3 tool steel. Experiments are conducted on horizontal spindle reciprocating table surface grinding machine with L_{18} orthogonal array with input machining variables as type of wheel, depth of cut, table speed, grain size and slurry concentration. After conducting the experiments, MRR is calculated and surface roughness is measured using surface roughness tester. Results are optimized by S/N ratio and analyzed by ANOVA. This study demonstrates that c-BN grinding wheel is preferred for higher MRR and Al_2O_3 grinding wheel for better surface finish. Depth of cut is the most significant factor for both MRR and surface roughness.*

Key Words: Surface grinding, MRR, surface roughness, Taguchi method, Abrasives

1. INTRODUCTION

Today in modern scenario technology is developing day by day. With this development of technology, designers & manufacturers are facing more & more challenges. So more & more researches are going on machining processes and further more researches are required. Machines, tools, materials and processes need to be improved. In machining, raw material is converted into finished goods. Manufacturer spends money, machinery, manpower and most precious time for converting raw material to useful goods. If finished product is not as per customer requirements, then whole efforts go waste. Also these days, competition is increasing. If any organization wants to be in market, it requires continuous improvement as per customer needs.

It is a fact that with the increase in material removal rate surface finish goes down. . Increased rate of material removal result in low time consumption but at the same time surface finish is also important. Machining processes need to be optimized for more material removal and higher surface finish. Surface texture is property of a material which needs to be optimum. It is not necessary that always a smooth surface required. As in some cases like brakes, clutch plates, etc rough surface is required. So the surface finish should be optimum.

Grinding is the most common form of abrasive machining. It is a material cutting process which uses an abrasive tool whose cutting elements are grains of abrasive material known as grit. The grits are held together by a suitable bonding material to give shape of an abrasive tool. Grinding is a true metal-cutting process.

2. LITERATURE REVIEW

The History of Grinding begins at the start of agriculture and size reduction developed over the centuries. In 1870 Poole built a cylindrical grinder for Norton that appears to be a first for large scale and accuracy. As per S Vulc [20] the roughness of the tungsten carbide depends on the grit of the grinding wheel and on the cutting regime parameters. PV Vinay [19] analysis the grinding of AISI D3 steel with a production level grinding wheel. Dry grinding yields good surface finish than wet grinding.

The most acceptable abrasive machining process is grinding process. Metal removal rate and surface finish are the important output responses in the production with respect to quantity and quality respectively. To achieve the maximum metal removal rate, employ highest depth of cut, lowest work speed and high grinding wheel speed [9]. Taguchi's method of off-line quality control is most comprehensive and effective system. This method eliminates the need for repeated experiments [10]. Abrasives not only used for cooling purpose but also increases the surface finish, MRR and reduce tool wear. The study was concerned with optimization of surface roughness when drilling of stainless steel SS304 with HSS drill [22]. While grinding AISI H11 steel with aluminum oxide grinding wheel under dry, wet & compressed gas conditions, it is observed that under compressed gas, increase in depth of cut and decrease in feed rate resulted in significant increase in material removal rate [6]. Surface roughness decreases with increase in speed and changing grain size from G46 to G60 [7]. The use of air helps to improve the surface finish of machined surface [1]. The use of coolants reduces surface roughness, although not necessarily the cutting forces [17]. The surface roughness decreases when speed increases, similarly when depth of cut increases, surface roughness decreases [11]. Chipping and adhesion are the main cause of tool wear & cutting speed is the most influencing parameter for surface finish [4]. The use of various coolants reduces surface roughness and increase material removal rate [23]. Cutting speed is a dominating parameter of cylindrical grinding [8]. Feed rate played vital role on responses surface roughness and metal removal rate [13]. Increasing the grinding wheel speed reduces the average chip thickness and increase the effective hardness of the wheel, resulting in more efficient work-piece material removal rates when the work-piece material is ceramic or steel. As the grinding wheel speed increases, the surface finish also increases [2]. The parameters feed rate, depth of cut and grit size are the primary influencing factors which affect the surface integrity of silicon carbide during grinding [3]. For a specific material removal rate, surface cracks along the grinding direction are generated on the ground surface. The problem of chatter vibration is identified at high material removal rates. The SiC grinding wheel can be utilized for precision form grinding of Si3N4 to achieve good surface integrity under a limited material removal rate [12]. Compared to flood cooling, Minimum Quality Lubrication grinding can achieve the same level of material removal rate without increasing the grinding forces. CBN MQL grinding is feasible in high volume production [5]. In case of surface finish, Aluminum oxide grinding wheels are better than the cubic Boron Nitride grinding wheels [18]. The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality particularly when the work piece is quite strong, hard and heat resistant. Conventional cooling methods are not very effective. cryogenic cooling significantly reduce tool wear rate, dimensional inaccuracy and surface roughness [15].

3. EXPERIMENTATION

Horizontal spindle and reciprocating table type surface grinding machine was used for experimentation. The tool design for this experiment was finalized keeping in view the properties of work-piece to ensure optimum performance in machining the work-piece. Stop-watch was used to determine material removal rate (MRR). For measuring surface roughness Mitutoyo (SJ-210P) was used. The corresponding MRR and surface finish was recorded for each experiment.

3.1 Machining Setup

Jones Shipman-540 surface grinding machine was used for machining the work-piece. It consisted of a saddle containing table, frame containing hand wheels for longitudinal, cross & vertical feed and a vertical column containing a horizontal spindle & grinding wheel. An electric motor of 1.5 KW used to drive the grinder.

Fig-1 Machining setup

Aluminum oxide ($Al_2 O_3$) and Cubic boron nitride (c-BN) grinding wheel were used for experiment. Size of both the grinding wheel used was 200*20*31.75 mm. Silicon carbide powder was used to prepare abrasive slurry. Three different mesh sizes (800, 1000, and 1200) were used in slurry percentage of 20%, 25%, 35% respectively. AISI D3 tool steel was used as a work material. It is a high carbon high chromium tool steel. Material was cut into rectangular flats of 65*30*6 mm.

3.2 Parameters selected

Table-1 Parameters & their levels

Factors	Level	L 1	L 2	L 3
Type of wheel (A)	2	$Al_2 O_3$	c-BN	
Depth of cut (B)	3	0.05	0.08	0.15
Table speed (C)	3	14.26	8.75	6.35
Grain size (D)	3	800	1000	1200
Slurry concentration (E)	3	20	25	35

3.3 L18 orthogonal array

In the present investigation, five different process parameters have been selected. As per the requirements of the study, L18 orthogonal array has come out as one of the possible solutions for designing the experiments.

Table-2 L_{18} orthogonal array

Exp. No.	Type of wheel	Depth of Cut	Table Speed	Abrasive size	Slurry Con.
1	Al_2O_3	0.05	14.26	800	20
2	Al_2O_3	0.05	8.75	1200	25
3	Al_2O_3	0.05	6.35	1000	35
4	Al_2O_3	0.08	14.26	800	25
5	Al_2O_3	0.08	8.75	1200	35
6	Al_2O_3	0.08	6.35	1000	20
7	Al_2O_3	0.15	14.26	1200	20
8	Al_2O_3	0.15	8.75	1000	25
9	Al_2O_3	0.15	6.35	800	35
10	c-BN	0.05	14.26	1000	35
11	c-BN	0.05	8.75	800	20
12	c-BN	0.05	6.35	1200	25
13	c-BN	0.08	14.26	1200	35
14	c-BN	0.08	8.75	1000	20
15	c-BN	0.08	6.35	800	25
16	c-BN	0.15	14.26	1000	25
17	c-BN	0.15	8.75	800	35
18	c-BN	0.15	6.35	1200	20

3.4 Experimental procedure

The initial weight of work-pieces was measured with the help of electronic balance. Then machine was allowed to grind the material up to desired depth in the presence of abrasive slurry using both Al_2O_3 and c-BN grinding wheels. 18 experiments were performed with different parameters. Time taken for grinding the work piece was recorded with the help of stop watch. Weight of work piece was again measured after grinding. Material removal rate was calculated by below mentioned equation [MRR= $(W_b\text{-}Wa)/t$]. Then surface roughness of machined surface was measured with the help of Mtiutoyo SJ-201P surface tester for all the samples.

4. RESULTS & DISCUSSIONS

The analysis of the results obtained has been performed according to the standard procedure recommended by Taguchi. Vale for S/N ratio corresponding to MRR and surface roughness is given in table-3

Table 3 Observation table

Exp. No.	Ra	S/N Ratio	MRR	S/N Ratio
1	0.74	2.615366	0.63	-4.0824
2	0.51	5.848596	0.47	-6.54718
3	0.6	4.436975	0.68	-3.39905
4	0.55	1.480015	1.59	1.723723
5	0.84	4.340997	1.22	1.960272
6	0.61	5.245548	1.26	3.93693
7	0.89	1.209615	1.65	4.860761
8	0.87	1.044792	1.75	4.340997
9	1.41	-2.96382	1.95	5.912025
10	0.72	2.85335	0.88	-1.08715
11	0.77	2.307868	0.7	-3.05935
12	0.62	4.198991	0.64	-3.93443
13	0.95	0.415104	1.53	3.665397
14	0.79	2.047458	1.31	2.351136
15	0.9	0.947379	1.68	4.524271
16	1.49	-3.44427	1.92	5.671371
17	1.7	-4.60898	2.07	6.317461
18	1.33	-2.49877	1.83	5.232718

4.1 Effect on MRR

It is observed that, material removal is comparatively more with c-BN grinding wheel than aluminum oxide wheel. Hence, the use of c-BN as a grinding tool results in faster erosion of work surface thereby improving the MRR. Percentage improvement of material removal is calculated by following equation:

$$\text{Percentage Improvement} = \frac{\text{MRR by c-BN wheel} - \text{MRR by } Al_2O_3}{\text{MRR by c-BN wheel}} X100$$

After calculation it is observed that there is a improvement of 10.98% on material removal rate when c-BN grinding wheel is used.

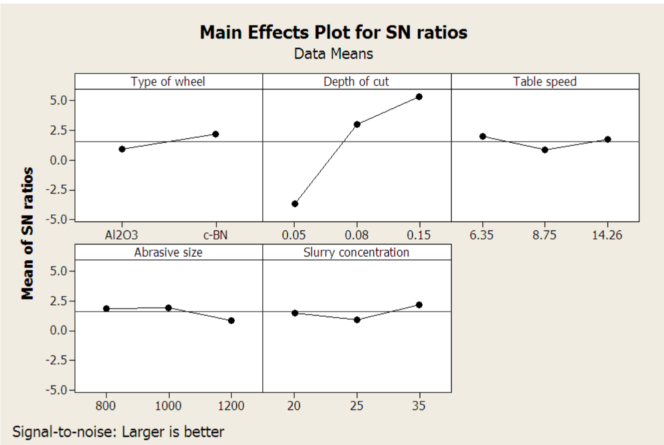

Chart-1 Plot for S/N Ratio (MRR)

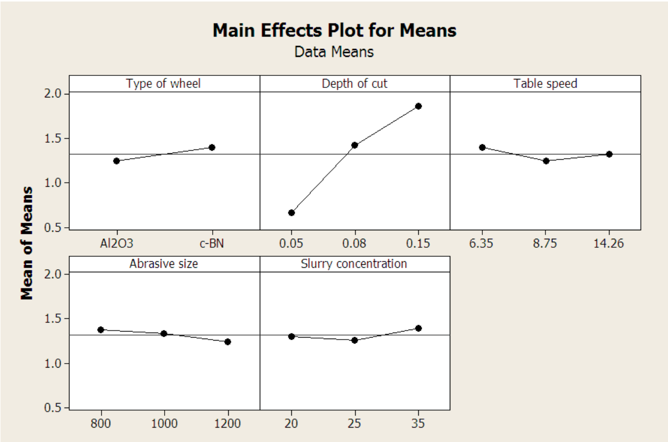

Chart-2 Plot for Mean (MRR)

As the depth of cut increases there is increase in material removal rate. With lower depth of cut, material removal rate is also low. The MRR obtained has been found to increase with the increase in coarseness of the abrasive grains. Material removal rate is higher at bigger size of grains. Material removal is higher if slurry concentration is 35% and it reduces if concentration drops to 25 and 20%.

4.2 Effect on Surface Roughness

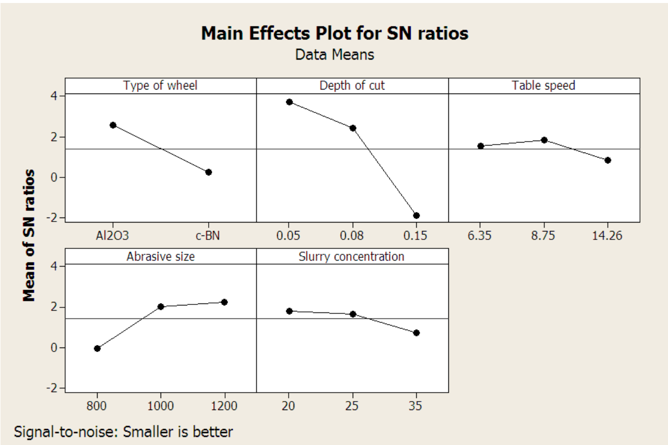

Chart-3 Plot for S/N Ratio (Surface Roughness)

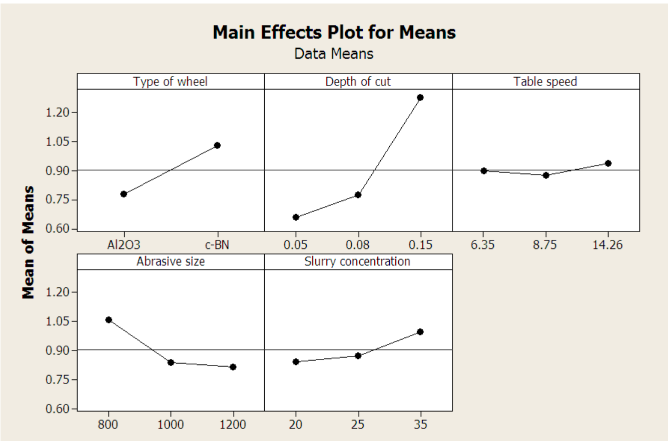

Chart-4 Plot for Mean (Surface Roughness)

There is 24.19 % improvement in surface finish if Al_2O_3 wheel is used as grinding wheel than c-BN. With the increase in depth of cut, surface roughness also get increased. Surface roughness is higher if table speed is 14.26 mm/sec. The use of coarser grit size promotes the increase in surface roughness, thus deteriorating the surface quality. Surface finish is best when slurry concentration is 20% and 25%. Above this value surface became rough.

4.4 Comparison-abrasive & coolant assisted grinding

For comparing abrasive assisted grinding with coolant assisted grinding, nine experiments were performed with Al_2O_3 grinding wheel & SS 5200 as coolant.

Table-4 Percentage comparison

S. No.	MRR (Coolant assisted)	MRR (Abrasive assisted)	Percentage Comparison
1	0.5	0.63	20
2	0.41	0.47	12.87
3	0.5	0.68	26.05
4	1.36	1.59	14.22
5	1.1	1.22	9.48
6	0.99	1.26	21.35
7	1.48	1.65	10.3
8	1.63	1.75	6.94
9	1.5	1.95	22.88
Average			16.01

It observed that there is an average 16% increase in MRR when silicon carbide slurry is used instead of coolant.

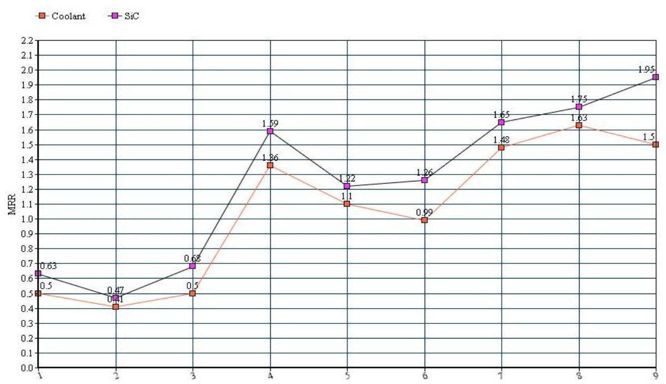

Chart-5 Comparison of MRR

4.3 Analysis of Variance (ANOVA)

The percentage contribution of various process parameters on the selected performance characteristic are estimated by performing analysis of variance test (ANOVA). The total variation in the result is due to various controlled factors and their interactions and variation due to experimental error. The ANOVA (general linear model) for S/N data have been performed to identify the significant parameters and to quantify their effect on the performance characteristic. Percentage contribution of each factor is given in Table-5

Table-5 ANOVA (MRR)

Source	DOF	SS	MS	F	P	% Contribution
A	1	6.692	6.692	11.53	0.009	2.30
B	2	265.94	132.97	229.19	0	91.40
C	2	4.394	2.197	3.79	0.07	1.51
D	2	4.482	2.241	3.86	0.067	1.54
E	2	4.813	2.407	4.15	0.058	1.65
Error	8	4.641	0.58			1.60
Total	17	290.962				

After investigating the above data it is found that depth of cut with percentage contribution of 91.40% leads the table. It is the only significant factor for material removal rate.

Table 6 ANOVA (Surface Roughness)

Source	DOF	SS	MS	F	P	% Contribution
A	1	24.593	24.5933	28.9	0.001	15.34
B	2	102.6	51.3002	60.28	0	64.02
C	2	3.044	1.5222	1.79	0.228	1.90
D	2	19.132	9.566	11.24	0.005	11.94
E	2	4.097	2.0487	2.41	0.152	2.56
Error	8	6.808	0.851			4.25
Total	17	160.274				

Depth of cut played an important role in surface quality while grinding AISI D3 steel with a percentage contribution of 64.02%. Type of wheel, abrasive size & slurry concentration are significant factors, where as table speed is in-significant factor.

5. CONCLUSIONS

I. Depth of cut is a major factor for both surface roughness and material removal rate with a percentage contribution of 63.91 and 95.84 respectively.
II. It has been concluded from the results that input parameters settings of grinding with c-BN as grinding wheel, grit size of 800 with slurry concentration of 35%, depth of cut of 0.15 and table speed 8.75mm/sec have given highest result for material removal rate.
III. It has been observed from experiment work that input parameters setting of grinding with aluminum oxide wheel, depth of cut 0.05 mm, table speed 8.75 mm/sec, abrasive grain size 1200 and slurry concentration 25% have given the best results for surface roughness
IV. When Al_2O_3 wheel is compared with c-BN wheel, it is found that MRR is 10.98% more with c-BN wheel whereas surface quality get improved by 24.19% when Al_2O_3 wheel is used.
V. When compared with simple coolant, there is 16% increase in MRR during abrasive assisted grinding with Al_2O_3.

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