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Optimization of process parameters for improving drilling quality and machining performance of abrasive assisted drilling on AISI D2 steel

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This research is concerned with optimization of roughness and material removal rate, as a result of AISI D2 steel drilling with abrasive assisted high speed steel drill. Experimentation include drilling of AISI D2 steel with supply of Sic and Al_2O_3 abrasive slurry having mesh size 800, 1200 and 1500 with slurry concentration of 20, 25, and 35%. The drilling parameters namely types of abrasive, abrasive mesh size, spindle speed, slurry concentration and feed rate were optimized using L_{18} orthogonal array for surface roughness and material removal rate. Analysis of variance is employed to find the percentage contributions of each control parameters. The results show that the type of abrasives and abrasive mesh size are the most significant factors which affect the roughness of drilled hole walls. The material removal rate affects significantly by feed rate and type of abrasive. The performance in the conventional drilling can be effectively improved by using hybrid drilling.

Keywords: Abrasive assisted drilling, Surface roughness, Material removal rate, AISI D2 steel, Taguchi, ANOVA

Modern manufacturing technology helps to machine the hard material for the use of present industrial application. Drilling is a basic operation which consist of removal of material from the particular point in a metal piece. There are some conventional and non-conventional methods in practice to drill the hard material, like AISI D2 steel. The main problems associated with these processes are short tool life and poor surface finish[1]. Non-conventional drilling methods faces low material removal rate, which affects the production rate. Surface roughness (SR) and Material removal rate (MRR) are the most important factors in manufacturing industry[2,3]. For better surface finish and improved material removal rate, the abrasives are most commonly used in the course of different surface finishing processes. After drilling, reaming and some other non-conventional finishing process like abrasive flow machining (AFM) and magnetic lapping are used to finish the surface and remove the debris[4-12]. These extra actions will directly affect the final cost of the product. This problem can be countered by using a hybrid technique termed as abrasive assisted drilling (AAD).

Material used as AISI D2 steel is an air hardened, having high-carbon and high-chromium tool steel. It has comparatively high wear and scratch resistant properties. It is heat treatable and having hardness within the range 55-62 HRC[13], and allowed to machine in the annealed condition. The high chromium content present in D2 steel protect it from mild corrosion in the hardened condition[1]. This material shows its applicability and plays an extremely important role in manufacturing industry because of its applications in manufacturing of dies and punches for hydraulic presses. Some other application of D2 steel is forming rolls, knives, slitters, shear blades, machine tools, scrap choppers and Tire shredders[2]. The machining of D2 steel is a tough work as generally it gives short tool lives, poor surface roughness, comparatively low metal removal rate, large cutting forces and high power consumption due to their high temperature strength. Rapid work hardening is also observed during machining with most of tool material at high cutting speeds[3]. Some of the above stated problems are countered using non-conventional machining. But non-conventional machining has its own complications and limitations. So a process modification must be impart in the case of these hard materials to improve productivity and quality.

In previous studies, researchers tried to find the suitable way to machine these hard materials and establish some non-conventional techniques of machining like Electric discharge machining (EDM),

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ultrasonic machining(USM) and laser beam machining (LBM). Previous researches include many numerical and experimental methods and used in order to predict and determine significant parameters which affect the drilling process. Guu *et al.*[13] studied the EDM process to drill the AISI D2 steel and atomic force microscopy used to surface roughness and morphology. The AFM results shows that very good surface finish achieved using EDM process at low pulse energy. AFM also generated information regarding depth of micro cracks around the drilled specimen. Goyal *et al.*[14] investigated the effect of rotational speed of tool, drill bit diameter, abrasive size and feed rate on surface roughness, during drilling of stainless steel SS304 with HSS drill bit using RSM model and found that the surface roughness was reduced by the 10.81%. Which reduced the cost with enhanced of quality simultaneously. Kivak *et al.*[15] investigated the effect of drilling process parameters for drilling of AISI 316 stainless steel with two kind of tools one is PVD monolayer and other one multilayer coated HSS drills using Taguchi technique. The result shows that the surface roughness is mainly affected by type of tool used for drilling with percentage contribution of 39.14%. Golapsamy *et al.*[16] uses Taguchi and ANOVA approach for optimizing the process parameters in case of hardened steel and results show that increasing rotational speed and feed arte give better surface finish. The cutting speed is found as most influencing parameter for surface roughness. Kilikap *et al.*[17] develop a mathematical model and optimize the drilling parameters for AISI 1045 using response surface methodology and genetic algorithm. The results show that the parameters, cutting speed, feed rate and cutting environment has significant effect on response characteristics. The mathematical predication model gives results very close to the experimental results. Cicek *et al.*[18] described the quality and machining performance of cryogenically treated M35 HSS drills in drilling of austenitic 304 and 306 stainless steels and performance was evaluated for the response factors as thrust force, surface roughness, tool wear, tool life and chip formation. The results of the experimentation shows that treated tool gives good results than untreated tool for surface roughness and tool wear for both types of steel. Tool life was found to be 32% and 14% improved for both types of steel respectively. Along with the conventional method some non-conventional methods are used to improve the surface properties of drilled specimens. Ciurana *et al.*[19] studied the drilling of AISI H13 steel using plused laser process. During this study neural network modeling and particle swarm optimization was employed to study the process parameters of laser drilling. During total 27 experiments surface roughness was found to be in the rage of 0.323-3.375 Ra. From results it has been concluded that proposed ANN model and optimization technique are very helpful to identify the optimum process parameters. Singh *et al.*[20] performed the same type of hybrid drilling for Al6063/10% SiC metal matrix composites. In this study author optimize the processing parameters for better hole quality, i.e., surface roughness and hole oversize. Results conclude that the abrasive assisted drilling (AAD) shows the burnishing effect on drilled walls of hole. Results shows the significant effect of all involving parameters on quality characteristics of drilled holes. Singh *et al.*[21] performed a comparative study to found the surface roughness of drilled hole in bones. Bones are brittle material gives very rough texture with conventional drilling. Using loose abrasive drilling technique roughness of drilled hole is improved remarkably with a clear surface topography. Singh *et al.*[22] developed the abrasive assisted drilling setup and optimize the parameters for Al6063/10%SiC metal matrix composites. Results show that the technique used will help to eliminate the supplementary surface finishing process such as abrasive flow machining or deburring of drilled hole. Kumari *et al.*[23] optimize the drilling parameters using RSM technique for SS304. The technique used for optimization is successfully employed to achieve the best set of parameters for better surface finish, high MRR and reduced tool wear.

From all these previous studies, it was concluded that surface roughness of drilled specimens need to pay some more attenuation. Some additional finishing processes increase the cost of product for improving quality of product in terms of surface finishing. Abrasive assisted drilling can eliminate the finishing and debarring process from the production of fine drilled holes. From the previous literature, it is also evident that abrasive assisted drilling process has not been studied as much with metals having high hardness and brittleness. In this paper, effect of drilling parameters on drill hole quality and machining performance has been studied using Taguchi technique. The drilling parameters like rotational speed, feed rate and some variation in slurry (type, mesh size, % concentration) was trying to be optimized. Therefore, the main objective of this study is to introduce hybrid method of drilling for D2 steel and trying to suggest a best combination of parameters for superior products.

Experimentation

Abrasive assisted drilling (AAD)

Abrasive assisted drilling is a hybrid machining process in which orthogonal cutting and abrasive machining together works to give the final product. It consists of high speed rotating drill bit with abrasive slurry flowing around the rotating drill bit. Centrifugal force of rotating drill helps to scrub the abrasive particle with the walls of drilled hole. The direct contact of flowing abrasive particles and hole walls results as the finishing effect to the walls of drilled hole. This abrasive slurry rotates along with the rotating drill throughout the drilling process and provide a drill hole which is having fine surface finish and free from the debris.

Experimental setup

The drilling experiments were performed on 3-axis high speed vertical milling machine (Model No. VF3). Material used as work-piece is D2 steel, which is one of the hardened engineering material and difficult to machine. Material composition and mechanical properties of work-piece are shown in Tables 1 and 2. A standard HSS twist drill having 2-flute, right hand cut drill with a 30^{o} helix angle and 118^{o} point angle has been used for drilling. Tool material has density 7.9 g/cm^3 with modulus of elasticity 224 GPa and hardness of HSS is about 65 HRC. Chemical composition of tool material is shown in Table 3. Special designed experimental setup shown in Fig. 1 was used to hold the work-piece and guide the tool with abrasive slurry during the drilling operation. The process parameters, type of abrasive, abrasive size, rotational speed and slurry concentration was used to optimize the surface roughness and material removal rate of D2 steel. Total 18 experiments are performed as suggested by the Taguchi methodology with L_{18} orthogonal array (OA). The range of parameters is selected on the basis of pilot experiments and there level are shown in Table 4.

Methodology

Experiments are designed according to 5 factors and 3 level. Four process parameters were nominated for investigation at three level and one parameter at two level. L_{18} mixed array has been used to optimize the process parameters for surface roughness and material removal rate. The design matrix for L_{18} orthogonal array is shown in Table 5. Drilled holes in the D2 steel after experimentation with three set of repetition are witnessed as shown in Fig. 2. Total 54 (18*3 repetitions) = 54 experiments were performed

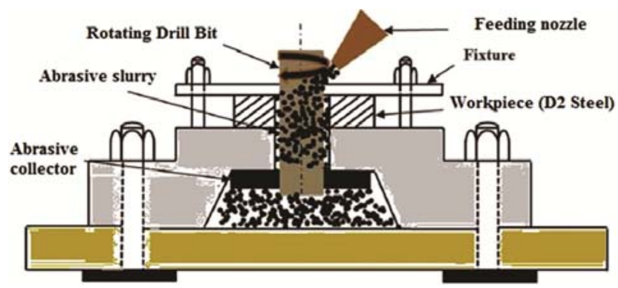

Fig. 1 – Schematic diagram for abrasive assisted drilling (AAD)

Table 2 – Mechanical properties of D2 steel[13]

Material Properties	Value
Hardness	57HRC
Tensile strength	1736 MPa
Yield Strength	1532 MPa
Density	7700 kg/m^3
Poission ratio	0.27-0.30

Table 3 – Chemical composition of HSS drills[23]

C	Cr	Co	Mo	V	Si	Mn
0.9	4.2	4.8	5.0	6.5	2.0	0.3

Table 1 – Composition ranges for AISI D2 steel[22]

Elements	C	Si	Mn	S	P	Cr	Mo	V	Fe
%age	1.49	0.42	0.29	0.028	0.029	11.38	0.80	0.68	Balance

Table 4 – Control factors and their levels

Sr.No	Factors	Designation	Level 1	Level 2	Level 3
1.	Type of abrasive	T	Silicon carbide	Alumina	………
2.	Abrasive size (Mesh)	A	800	1200	1500
3.	Rotational speed (RPM)	R	1500	2500	3500
4.	Slurry concentration (%)	S	20	25	35
5.	Feed rate(mm/min)	F	100	150	200

Table 5 – Design matrix for mixed L_{18} orthogonal array used for experimentation

Type of abrasives (T)	Abrasive size (A)	RPM (R)	Slurry concentration(S)	Feed rate (F)
SiC	800	1500	20	100
SiC	800	2500	25	150
SiC	800	3500	35	200
SiC	1200	1500	20	150
SiC	1200	2500	25	200
SiC	1200	3500	35	100
SiC	1500	1500	25	100
SiC	1500	2500	35	150
SiC	1500	3500	20	200
Al_2O_3	800	1500	35	200
Al_2O_3	800	2500	20	100
Al_2O_3	800	3500	25	150
Al_2O_3	1200	1500	25	200
Al_2O_3	1200	2500	35	100
Al_2O_3	1200	3500	20	150
Al_2O_3	1500	1500	35	150
Al_2O_3	1500	2500	20	200
Al_2O_3	1500	3500	25	100

SiC: Silicon carbide, Al_2O_3: Alumina

Fig. 2 – Drilled holes on D2 steel with abrasive assisted drilling

and results were studied for drilling quality and machining performance, i.e., surface roughness and material removal rate. Mitutoyo SJ-400SR surface roughness tester was used to check the surface roughness of drilled hole wall at four points. The average reading of four points of surface roughness (R_a) values was considered as the surface roughness (R_a) of drilled hole. The material removal rate is calculated for each experiment using the formula in Eq. (1). To find the effect of process parameters on surface roughness and material removal rate the mean and signal-to-noise ratio were calculated for each set of experiment as shown in Table 6. The quality criteria for surface roughness is lower should be minimum for better results and for material removal rate should be maximum for better machining performance. Thus, smaller-the-better equation was used to examine the surface roughness and larger-the better was used for material removal rate. The formula used as smaller-the-better and larger-the-better are shown as in Eqs (2) and (3).

$$\text{Material removal rate} = (\pi D^2/ 4)\ (N\ f_r)\ \text{mm}^3/\text{min} \quad \ldots (1)$$

Where D is drill diameter, N is rotational Speed and f_r is feed rate

$$\text{Smaller-the better equation: S/N} = -10 * \log(\Sigma(Y^2)/n) \quad \ldots(2)$$

$$\text{Larger-the better equation: S/N} = -10 * \log(\Sigma(1/Y^2)/n) \quad \ldots(3)$$

Results and Discussion

Effect of process parameters on surface roughness (SR)

Average value of surface roughness (raw data) and S/N ratio at the different set of parameters are shown in Table 6. The individual effect of each parameters on the S/N ratio is plotted as response curve by using experimental data. The effect of parameters on surface roughness (SR) are shown in Fig. 3. The smaller values of surface roughness are considered to be optimum by using smaller-the-better equation. The average values (S/N ratio and mean data) for each parameters for surface roughness is shown in Table 7. It can be seen from the response curve that 2nd level of type of abrasive (A2), third level of abrasive size (S3), third level of rotational speed (R3), first level of

Table 6 – Mean and S/N ratio for surface roughness and material removal rate

T	A	R	S	F	Mean (SR)	S/N(SR)	Mean (MRR)	S/N(MRR)
SiC	800	1500	20	100	0.91	0.819	10.300	20.256
SiC	800	2500	25	150	0.81	1.830	15.770	23.956
SiC	800	3500	35	200	1.00	-0.002	21.540	26.664
SiC	1200	1500	20	150	1.44	-3.185	16.910	24.562
SiC	1200	2500	25	200	1.38	-2.822	23.310	27.350
SiC	1200	3500	35	100	1.44	-3.221	11.310	21.069
SiC	1500	1500	25	100	2.00	-6.020	11.846	21.471
SiC	1500	2500	35	150	2.11	-6.485	19.620	25.854
SiC	1500	3500	20	200	2.23	-6.959	24.050	27.622
Al_2O_3	800	1500	35	200	1.19	-1.577	19.753	25.912
Al_2O_3	800	2500	20	100	1.13	-1.100	9.860	19.877
Al_2O_3	800	3500	25	150	1.11	-0.906	13.850	22.829
Al_2O_3	1200	1500	25	200	1.72	-4.733	17.780	24.998
Al_2O_3	1200	2500	35	100	1.61	-4.160	10.380	20.323
Al_2O_3	1200	3500	20	150	2.00	-6.020	15.680	23.906
Al_2O_3	1500	1500	35	150	2.16	-6.681	16.220	24.201
Al_2O_3	1500	2500	20	200	2.11	-6.485	25.070	27.983
Al_2O_3	1500	3500	25	100	2.18	-6.785	11.260	21.030

SR: surface roughness; MRR: material removal rate; S/N: signal-to-noise ratio; SiC: Silicon carbide; Al_2O_3: Alumina

Table 7 – Response table of S/N ratio and mean values for SR

Parameters	Response of S/N ratio for SR			Response of mean for SR		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
T	- 4.271	-2.89	-----	1.693	1.481	------
A	-0.155	-4.023	-6.56	1.027	1.602	2.131
R	-3.562	-3.203	-3.981	1.572	1.527	1.662
S	-3.820	-3.239	-3.687	1.637	1.535	1.588
F	-3.411	-3.574	-3.761	1.549	1.605	1.607

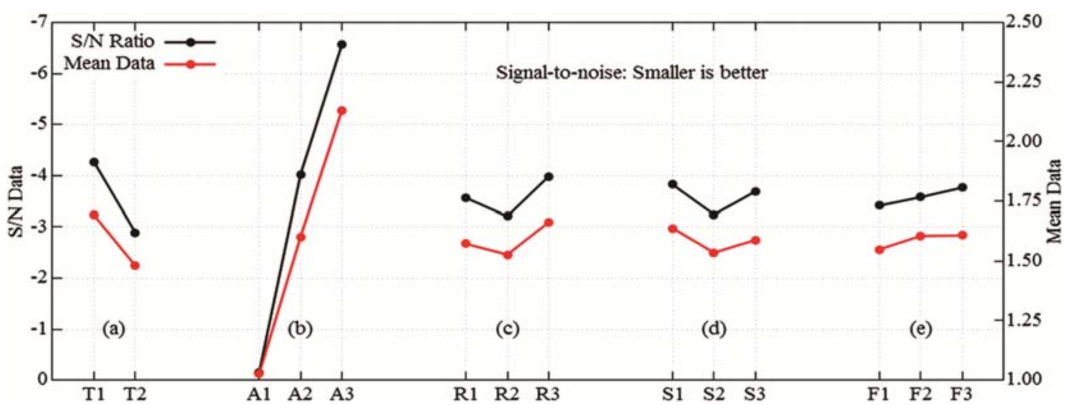

Fig. 3 – Variation of surface roughness with variation of process parameters

slurry concentration (C1), and third level of feed rate (F3) are observed as best combination of parameters for lower surface roughness.

The variation of surface roughness along the drilled wall with variation of different drill parameters are shown in Fig. 3. Result from the graphs 'a' in between S/N ratio and parameters involved shows that with alumina gives finer surface roughness than the silicon carbide. This may be because of alumina particles are less hard then the silicon carbide abrasive and give smooth finishing to the drilled hole as compared to silicon carbide abrasive. The graph 'b' in Fig. 3 shows the effect of abrasive size on surface roughness, graph shows that as the abrasive size increased from 800 to 1200 and then to 1500 the surface roughness decreases continuously. This is because of number of abrasive strike in prescribed area of drilled wall will be more and gives scrubbing effect in between tool and drilled wall. The third graph ‘c’ gives the effect of increasing RPM on surface roughness and results shows that first surface roughness increased with increase of RPM but further increasing of RPM shows deeply decrease in surface roughness. It is because of an increase in centrifugal force with increasing the RPM and the abrasive particles strike with the surface of wall with more force. This action of abrasive particles helps to remove the debris and surface flutters. The next graph ‘d’ on Fig. 3 shows the effect of slurry concentration on the surface roughness. Graph shows that with 20% concentration the surface roughness is low as compared to other. It is because of with 20% concentration number of particles strike per unit area may be less and with increasing it more than 25% it may be more viscous and particles dose not strike with full impact to the surface. The next graph ‘e’ from Fig. 3 shows the curve in between the increasing feed rate and surface roughness. The graph shows that increasing feed rate also supports better surface roughness. The analysis of variance (ANOVA) for mean values shows the level of effectiveness of all the parameters on the surface roughness in Table 8.

Effect of process parameters on material removal rate (MRR)

The mean values of MRR and S/N ratio for the different process parameters at different levels are given in Table 6. The S/N ratio for MRR was calculated using Eq. (3) (“larger is better”). The response curves for the all included process parameters on the mean value and S/N ratio were plotted and shown in Fig. 4.

The higher values for the MRR are considered to be optimum. The average higher value for each parameter is taken from the response table of S/N ratio and mean data shown in Table 9. The response curve is plotted with the help of these values. From

Table 8 – Analysis of variance for mean data of SR

Source	SS	DOF	Variance	F ratio	P value
T	0.200	1	0.200	14.81	0.005
A	3.659	2	1.829	134.96	0.000
R	0.056	2	0.028	2.07	0.188
S	0.031	2	0.015	1.15	0.363
F	0.013	2	0.006	0.49	0.630
Error	0.108	8	0.013		

SS: sum of squares; DOF: degree of freedom

Table 9 – Response table of S/N ratio and mean values for MRR

Parameters	Response of S/N ratio for MRR			Response of mean for MRR		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
T	23.45	24.31	------	15.54	17.18	------
A	23.25	23.70	24.69	15.18	15.90	18.01
R	23.57	24.22	23.85	15.47	17.33	16.28
S	24.03	23.61	24.00	16.98	15.64	16.47
F	20.67	24.22	26.76	10.83	16.34	21.92

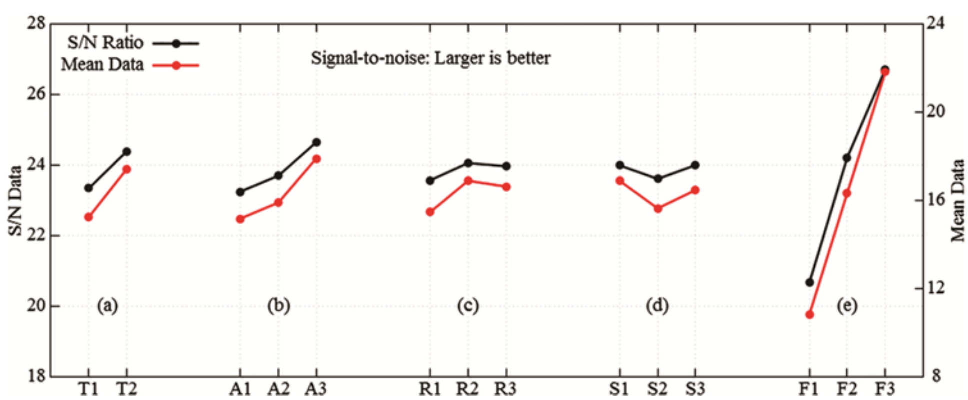

Fig. 4 – Variation of material removal rate with variation of process parameters

the curve it is shown that the maximum values for the respectively parameters, i.e., abrasive (T2), abrasive size (A3), rotational speed (R2), slurry concentration (S1), and feed rate (F3) are the best higher values of MRR in both mean value and S/N ratio. The variation of MRR with type of abrasive is presented with image (graph a). It was observed that the MRR is more with silicon carbide abrasive the alumina abrasive, because of its hardness and sharp edges as compared to alumina abrasives. In second image (graph b) shows the effect of abrasive size on MRR. With increasing the abrasive size the MRR increasing significantly. Because of large size of abrasives gives more burnishing effect and does not lose its shape and size until the drilling completed. In third image (graph c), for rotational speed MRR is increasing and shows a significantly effect on MRR when increasing from level 1 (1500 RPM) to level 2 (2500 RPM). The reason for this is that the impact energy with which the abrasive particles strikes on the drilled hole wall surface increases with increasing the rotational speed. But after increasing it from level 2(2500 RPM) to level 3 (3500 RPM) the variation is insignificant. From image d, slurry concentration shows its effect with MRR. Graph shows that first it decreases with increase the concentration but after that it increases with increasing more the concentration level. At level 1, (20%) the concentration is less viscous and flow without any interruption and gives better machining with drill bit. After increasing it up to level 2 (25%) viscous slurry get stuck in some parts of drill bit and gives less MRR as compared to level 1 (20%) and as we increasing the slurry concentration to level 3 (35%), the paste of slurry get stick with flutes and edges of drill bit and shows increasing MRR as compared to level 2 (25%). In the last image e, the effect of feed rate on MRR is shown. As the feed rate is directly proportional to the MRR, i.e., same result can be observed from level 1(100 mm/s) to level 3 (200 mm/s). The ANOVA table of MRR is shown in Table 10 which shows the parameters significance respectively.

Estimation of optimum surface roughness and material removal rate

The optimum significant value of surface roughness is predicted considering the effect of process parameters involved in experimentation. The optimized set of process parameters for minimum surface roughness are T_2, A_1. So the mean value of surface roughness can be calculated by Eq. (4). The optimized value of process parameters for maximum material removal rate are T_2, A_3, R_2, F_3 and the mean value of material removal rate can be calculated by Eq. (5)[22,26,27].

$$\mu SR = T_2 + A_1 + R_2 + S_2 + F_1 - 4T_{SR} \quad \ldots(4)$$

$$\mu MRR = T_2 + A_3 + R_2 + S_1 + F_3 - 4T_{MRR} \quad \ldots(5)$$

From Eqs (4) and (5) the μSR and μMRR are calculated as follows:

$$\mu SR = 1.481+1.027+1.527+1.535+1.549 - 4\times 1.585 = 0.779\ R_a$$

$$\mu MRR = 17.42+17.91+16.89+16.88+21.28 - 4\times 16.328 = 25.08\ \text{mm}^3/\text{min}$$

The confidence interval (CI) for surface roughness and material removal rate can be calculated using Eq. (6)[22,26,27].

$$CI = \pm\sqrt{\frac{F_{\alpha:v1:v2}\, V_e}{\psi_{eff.}}} \quad \ldots(6)$$

Where $F_{\alpha\ (v1:v2)}$ is the F ratio at the confidence level of (1-α) against degrees of freedom (DOF) equal to 1 and error DOF (f_e):

Now $F_{\alpha\ (v1:v2)} = F_{0.01(1:8)} = 5.317$ (this value noted from the F table with 95% confidence level)

V_e = SS value of Error / DOF for Error

$V_e = 0.108/8 = 0.0135$

Table 10 – Analysis of variance for mean data of MRR

Source	SS	DOF	Variance	F ratio	P value
T	12.17	1	12.17	19.17	0.002
A	26.02	2	13.01	20.49	0.001
R	10.51	2	5.25	8.28	0.011
S	5.51	2	2.75	4.34	0.053
F	362.04	2	184.52	290.58	0.000
Error	5.08	8	0.63		

SS: sum of squares; DOF: degree of freedom

Ψ_{eff} =18/ (1+ DOF of T_2 + DOF of A_1 + DOF of R_2 + DOF of S_2+ DOF of F_1) = 1.8

Putting these values in Eq. (6), C.I. = ± 0.039

The confidence interval around the estimated surface roughness is : 0.818 < μSR <0.740.

The confidence interval (CI) around the estimated mean for material removal rate:

$$CI = \pm \sqrt{\frac{F_{\alpha:v1:v2} V_e}{\psi_{eff.}}}$$

Now $F_{\alpha\ (v1:v2)} = F_{0.01(1:8)}$= 5.317 (this value noted from the F table with 95% confidence level)
V_e = SS value of Error / DOF for Error

V_e = 5.080/8 = 0.635

Ψ_{eff} =18/ (1+ DOF of T_2 + DOF of A_3 + DOF of R_2 + DOF of S_1+ DOF of F_3) = 1.8

Putting these values in Eq. (6), C.I. = ± 1.87
The confidence interval around the estimated material removal rate is : 23.2 $\leq$ μMRR $\leq$ 26.94.

Confirmation experiments

Three confirmation experiments were conducted at the optimum level of process parameters recommended by the experimental investigation. The suggested combination of parameters is shown in Table 11. The observations of confirmation experiments are compared with the predicted range. The comparison of confirmation results and predicted results are shown in Table 12.

Scanning electrode microscopy (SEM)

The drilled specimen undergone scanning electrode microscopy to study the surface at micro level. Three types of drilled specimen are studied, i.e., with coolant only, with silicon carbide abrasive slurry and with alumina abrasive slurry. The effect of abrasive particle on the surface topography can be easily apparent. Figure 5(a) shows the SEM image of drilled specimen having drill with coolant only. This is conventional form of drilling and delimited debris of drilled metal can be seen with metal surface. These

Table 11 – Optimum value of process parameters for confirmation experiments

Sr. no	Process parameters	Level	Value
Surface roughness (SR)			
1	Type of abrasive	T_2	Alumina
2	Abrasive size (Mesh)	A_1	800
3	Rotational speed (RPM)	R_2	2500
4	Slurry concentration (%)	S_2	25
5	Feed rate(mm/min)	F_1	100
Material removal rate(MRR)			
1	Type of abrasive	T_2	Alumina
2	Abrasive size (Mesh)	A_3	1500
3	Rotational speed (RPM)	R_2	2500
4	Slurry concentration (%age)	S_1	20
5	Feed rate(mm/min)	F_3	200

Table 12 – Comparison of conformation experiments with prediction values

Response characteristics	Predicted range	Actual value
Surface roughness (SR)	0.818 $\leq$ μSR $\leq$ 0.740	0.80 R_a
Material removal rate (MRR)	22.197 $\leq$ μSR $\leq$ 26.843	25.020 mm^3/min

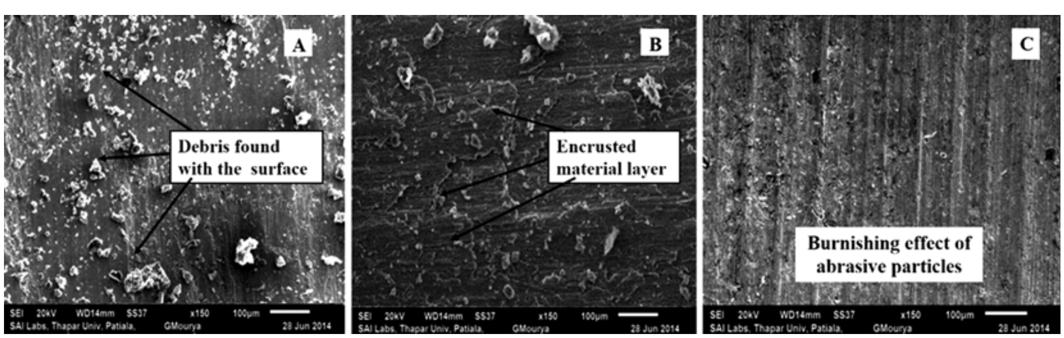

Fig. 5 – SEM image of drilled hole at 150X (a) coolant only, (b) silicon carbide abrasive slurry, and (c) alumina abrasive slurry

tiny metal particles create a sliding contact in between the drill bit and metal piece, i.e., leads to more surface damage. In Fig. 5(b) the SEM image of abrasive assisted drilled hole with silicon carbide abrasive is shown. Silicon carbide abrasive are hard as compared to alumina so gives rough surface finish with encrusted metal layers. Along with silicon carbide has great affinity with the ferrous metal so the abrasive may get stick with the AISI D2 steel. Figure 5 (c) consist of SEM image of abrasive assisted drilled specimen with alumina abrasive. Alumina particles show the burnishing effect on the surface in the form of parallel stream lines and result as a finer surface finish.

Conclusions

Abrasive assisted drilling is a modern hybrid drilling process which is used to improve the finishing of drilled hole and also eliminate the burnishing process after drilling. This study shows the improved productivity of abrasive assisted drilling process. Some other conclusions drawn from this invetigation are as follows:

(i) Abrasive assisted drilling helps to improve the quality of drilled holes and also improve the productivity of machining process. In case of surface finishing (SR), abrasive and abrasive size plays a vital role and shows its significance in ANOVA table. So to attain better surface finish these abrasive assisted drilling proves its capability. From SEM images it is also evident that abrasive has an effect on surface properties of drilled specimens. Silicon carbide abrasive is hard as compared to alumina and having strong affinity with ferrous metals, so it gives encrusted layers and alumina give the burnishing effect gives stream lining flow on metal surface with better surface finish as compared to silicon carbide.

(ii) In case of material removal rate (MRR), the feed rate is directly affected the material removal rate. But other parameters also show there implication with the abrasive assisted drilling of D2 steel. Other parameters like abrasive and its size shows a significant effect on material removal rate. Material removal rate is directly linked with the productivity so abrasive assisted drilling will help to improve the productivity with jobs involves hard materials like D2 steel.

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