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Performance Characterization of Surface Quality and Tool Wear of Wet/Dry Drilling on Steels by Using Coated Drill Bits

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Abstract

The creation of holes by the drilling operation is a normal process which we were followed from the earlier days. Especially the drill bits' usage is an Important consideration among the different drilling operations. Here we considered the coated form of drill bits for the purpose of improving the surface quality and to overcome the tool wear by the particulate deposition over the surface of the specimen. The drilling features are to find out over the specimen EN 8 Alloy steel and mild steel which are experimentally verified. In the view of differentiating the eminence of surface roughness and tool wear an appearance of Alloy steel and mild steel specimens, the wet and dry conditioned drilling operations are performed by the manifestation of coolants. The importance of Pertura and Latuma tool coated drill bits developed by the Physical Vapour Deposition (PVD) method are used for this operation. Based on the drilling conditions whether usage or non-usage of coolants is majorly influenced on surface roughness, and the tool coatings are politely influenced on the surface roughness of each specimen have been found out. Likewise, the tool coatings and the rotational speed influenced more on machining time has been recognized. Tool wear patterns are categorized and compared with the simulation data of drilling in Deform 3D. Effective stress is identified and related to the value of surface coarseness in both conditions of drilling on different steel specimens.

Keywords: drilling, coating, surface roughness, tool wear

1. Introduction

In recent days, the tool wear and surface quality attainment are the challengeable task with an optimum level of satisfaction. To overcome this basic problem among the drilling operation, we can easily utilize some innovative ideas with less effective manner. This effective and dynamic outcome over the drilling operation with the coated tools has been implemented through the effects of drilling parameters which is utilized by Taguchi's optimization. It was found that the feed and speed are important process parameters to control surface roughness, tool wear, Metal Removal Rate, and hole diameter error. The frictional contact was initiated with the specimen while the tool has been rotated with the feed rate, the cutting profile over the specimen was placed closely. Thus, the suitable combination of rotational speed and feed rate can be affected by the quality of the holes and a number of factors also plays an important role in hole quality [1]. Deformation damage of GFRP during high speed and ultrasonic assisted drilling were discussed by the researchers for finding the most influential factor on peel up and push out the delamination of GFRP. The push out delamination is more severe than that of peel up by the contribution of thrust force [2]. For medium largely sized drill bits influenced least by the spindle speed and feed on GFRP composites. The influence of cutting parameters on delamination in drilling and the feed rate of the highly influential

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parameter on the delamination in drilling of sandwiches composites. Medium level of feed and speed were recommended [3]. In the drilling operation of an Al5005, the effect of drilling parameters on surface roughness and built up edge whereas the surface roughness was decreased with the increase of rotational speed and point angle while it is increased with the increase of feed rate and drill diameter [4]. The discussion was about the surface roughness and roundness error was measured on the holes drilled with the cryogenically treated drill bits on AISI Austenitic stainless-steel specimen. This treated tool gets hardened more in its physical characteristics and influenced on the cutting constraints. However, the travel distance of each cutting point of the tooltips is closer over the specimen surface without any frictional effects on the tool surface. The cutting speed has a significant effect on surface roughness as well as the feed rate also influenced effects on roundness error [5]. The effects of the drilling parameter to get the lowest torque value, the thickness of the specimen and drill bit size are the significant parameters influencing torque were discussed [6].

The burr size of the drilling of Al-SiC composites, the most significant parameters of feed rate, point angle, and concentrations of reinforcements were identified the burr height and thickness reduced by 25-40% of the increase of point angle. Thus, the higher the point angle is desirable for minimizing the burns produced during the drilling of Al-SiC composites [7]. SEM images clearly indicate the matrix delamination and microcracks. The effect of drilling parameters on thrust force and surface roughness, tool wear patterns are discovered at Al-SiC composite. Thrust force calculated by using tools dynamometer and the tool wears also compared with the experimental data [8]. By comparing the drilling performance of Titanium Nitrate (TiN) and Titanium Aluminium Nitrate (TiAlN) coated High-speed Steel (HSS) drill bit for the machining on EN8 material under dry machining conditions. The better tool life was achieved because of high hardness coating with the reduced wear rate during the work tool interaction. Here tool life was proved better in this TiAlN coated drill bit compared with TiN and uncoated drills for the constant tribology conditions [9].

The effects of cutting parameters speed, feed, depth of cut on metal removal rate and temperature of EN8 carbon steel was discussed. RSM method of optimization helps to increase the quality and reduce the manual effort, production cost and machining time [10]. The experimental verification showed that the influence of drill parameters point angle, clearance angle, cutting speed, feed and drill diameters on the thrust force and torque in drilling. Holes drilled on Al6061 alloy, the cutting speed, and point angle are the significant factor for thrust force similarly for the torque [11]. The analysis on the effect of machining parameters on thrust force and surface roughness of drilled CFRP composite specimens were discussed. It is evaluated that the reduction in thrust force reduces the induced delamination, surface roughness, and the drilling quality has improved. Better quality can be achieved by using high-speed feed and point angle [12]. High speed and feed with small diameter drill type used to obtain good Ra and MRR. The effects of drilling parameter were accomplished the burr height and surface roughness was evaluated using three different drill types, the less surface roughness were recorded as by using TiN and carbide drill bits at the low feed rate and higher cutting speed. Less burr height was obtained in high rotational speed and carbide drill type [13].

The fatigue stress concentration factor (Kf) of the machined surfaces determined from experiments and its predictions for the effective fatigue stress concentration using the Arola-Ramulu model was within 2% of the apparent fatigue stress concentration factors estimated from experimental results. If the fatigue stress concentration factor (Kf) is increasing the surface roughness also increased [14]. The temperature interaction in between the tool and the work area was improved by using the carbon-oriented coatings on the drilling tools which contains graphite particles or a diamond. They showed that the performance behavior of the coated drills without the cutting fluids was better to compare with the uncoated drill bits. The machining was affected without Metal Removal Fluids (MRF). But in this case, the surface was not affected with or without MRF the DLC and blend coated drill bits performed well in the heat affected zone during drilling with less power consumption [15]. The Carbon Fiber Reinforcement Plastic (CFRP) specimen drilled with the composite coated diamond films deposited over the drill bits by the CVD method. Here they confirmed that the shape of the tool acts as a shaping factor that influenced more on drilling force and hole quality for coated as well as uncoated tools. The hard coatings improved the tool life and constancy of drill holes [16]. The performance evaluation has been compared among the diamond coated and uncoated carbide drills on the drilling of aluminum silicon alloys (A356). The usage of lubrication has to be minimized and it can be verified through the experimentation. Here they showed that the minimal lubricant usage cannot be improved in hole quality, wear rates etc. There was no change has been identified in the drilling quality excluding the irregular wear can be occurred on the surface of the diamond coated drill bits [17].

Moreover the various developments in the drilling operations were obtained now a day. Some advancements were utilized in the mining operations with automated drilling processes. Especially, auto mine rotary drilling and the surface drilling are the advance cum familiar process used in the field of mining which is having the key benefits of more efficiency, productivity, fast and reliable control, utilization and safety. The operator is exactly out if hazardous atmosphere, reduced from the noise and vibration problems. The complete automation increased the productivity and the stress relief over the machines. The safety dovetails avert some accidental or hazardous actions. The accurate drill positioning was maintained here. Multi drill control also has been incorporated with the single operating console. The purpose of this paper is to perform the drilling operation for various speeds at different machining conditions. The drilling operation has performed by using the coated drill bits and evaluate the surface finish and tool wear rates. The betterment of results has been declared based on the optimization tools. The tool characterization helps to identify the reasons for tool wear and its effects on surface morphology. The possibility of new methods will be demonstrated and confirmed by the machining simulations from Deform 3D.

2. Materials and Methods

Drilling is an important operation in the assemblage of automobiles structural frames and aircraft. The lifespan of the joint can be critically affected by the quality of the drilled holes. Especially borehole instability and hole deviation will create huge problems during the assemblage of various parts in the industry sector. To overcome these surface-oriented problems, material selection and the usage of types of drill tool to be more concentrated. Here the drilling operation was performed in Universal Radial drilling machine TUV-NABCB-QM002 (SER25) powered 1 HP with the high rotational speed range of 1440 rpm.

For the different rotational speeds, the drilling operation has been performed on both steel specimens. During wet conditions, the coolant is used and it is not during the dry cutting operation. The machining conditions are shown in Table 1. The drilling operation was performed on Alloy steel and mild steel rectangular shaped bar of cross section 300 x 50 x 50 mm as shown in Fig. 2. The 10 mm diameter High-Speed Steel (HSS) drill bits (JIS-SKD61) as shown in Figs.1(a) and (b). The two conditions were to be followed (i.e) wet and dry cutting for the drilling operation. The coolant oil used for the machining process is called wet conditioned machining and when not using the coolant means its dry conditioned drilling.

(a) Coated drill bits

(b) Drilled specimen

Fig. 1 Photography of tool and the specimens

Table 1 Machining conditions of the drilling operation

Sl.No	Machining conditions	
1	Condition	Wet, Dry
2	Speed	500 rpm, 1000 rpm
3	Feed rate	0.2 mm/rev (Constant)
4	Drill Tool Material	ϕ10mm HSS drill bit
5	Coatings & Thickness	Pertura & Latuma & t= 4μm
	Work material	EN8 Alloy steel, Mild Steel bar

Table 2 Composition of EN 8 Alloy Steel

Material (EN8/AISI1040)	C	Mn	P	S	Si	Fe
Percentage (%)	0.36-0.44	0.60-1.00	0.05	0.005	0.10-0.40	Remains

Table 3 Chemical composition of Mild Steel

Material (MS/AISI1018)	C	Cu	Mn	P	Si	S	Fe
Percentage (%)	0.25-0.29	0.20	1.03	0.04	0.28	0.05	98.0

The new tool coatings were introduced over the drill bits called as Latuma and Pertura. This well bonded Physical Vapour Deposition method of coatings was deposited over the tool cutting profiles with the thickness of 4μm were performed in Oerlikon Balzers coating India Pvt. Ltd. The Pertura and Latuma coating are name wise under the brands of PVD coating which is developed over the tools and the components. The Latuma coating is the newest source of technology which contains a high amount of aluminum with excellent oxidation resistance and hot hardness. It is having excellent resistance of crater wear and also used for balancing the residual stress and coating hardness. Its productivity is good with high variables of machining conditions. It is well suited for the drilling with carbide and HSS drills. Pertura is a Nano-layer structure promises the best balancing of residual stress, hardness, and fracture toughness and thus dependably stops crack propagation. This allows higher cutting speeds than with other coatings as well as protracted tool life. It is used for deep hole drilling by using minimum quantity lubrication. Latuma and Pertura coating have been applied on the surface of the drilling tools with the standard coating thickness within the ranges of 3-6 μm for the 10 mm diameter High-speed Steel (HSS) drilling tools which were maintained and performed in Oerlikon Balzers coating India Pvt. Ltd. The drilling operation was performed on the specimen with the low and high cutting speed of 500 rpm and 1000 rpm at constant feed rate as 0.2 mm/rev is mentioned in Table 1. The chemical composition of EN 8 Alloy steel and Mild steel are mentioned here below in Tables 2 and 3. The percentage of composition showed clearly the Manganese and Silicon particulates are involved more in both MS steel and alloy steels. The carbon percentage is low in mild steel and high in alloy steel based on its density and volume contribution. The machinability was good in both alloy and mild steel components. Here in this work, the surface roughness and tool wear have to be calculated and compared with the predictive values of dynamic simulation results.

3. Experimental Methods

The experiments were carried out on a Universal Radial drilling machine TUV-NABCB-QM002 made from siddhapua enterprise. By using coated drill tools, the through all holes were performed with the uniform gap of 20 mm in the specimens as shown in Figs. 2(a), (b) and (c). The uniform feed rate is maintained for all the experiments. The chip formation is good and it is in the form of continuous chips without any damages.

The results of experimentation were evaluated after drilling in terms of the following measured machining performance: surface roughness (Ra), burr height (h). The surface roughness of drilled holes was measured by using a Mitutoyo SJ-201 surface roughness tester as shown below in Fig. 3. The instrument was set to a required length and the numbers of specimens were measured. Four directional measurements of surface roughness were taken perpendicular and parallel to the whole circumference.

(a) Universal Radial drilling machine

(b) Drilling without coolants

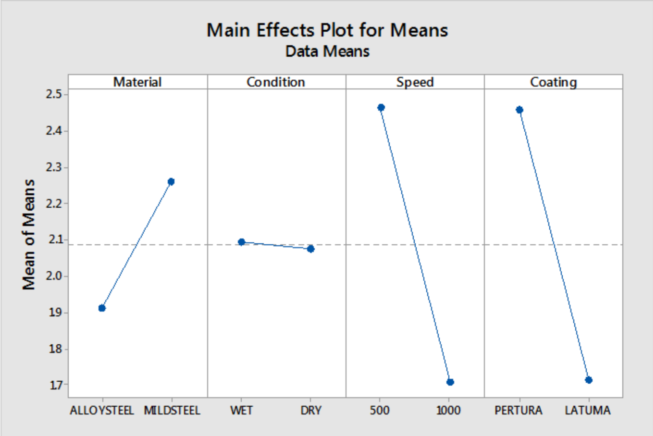
(c) Drilling with coolants

Fig. 2 Drilling operation on Mild Steel and Alloy steel with coated drill bits

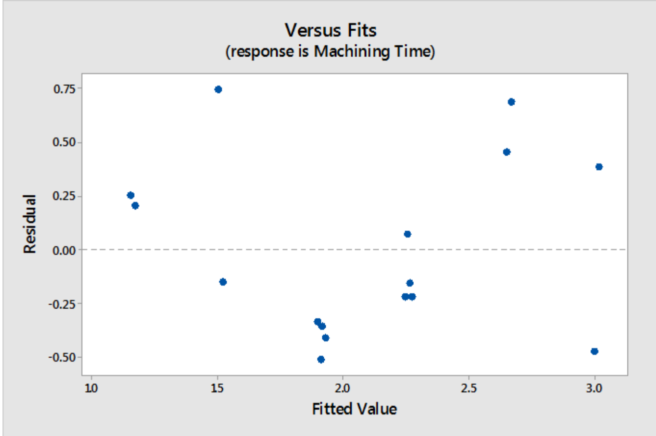
The surface roughness values given in this work are the mathematical average of four measurements taken from inside the same hole surface. The optical profile projector was used for the burr height measurements for some delaminated holes. The optical systems used in this projector used to produce the fringe patterns of the hole burr outline surface. The dark fringes were identified and denoted the height of the burrs in the edges of the drilled holes.

Fig. 3 Surface roughness measurement on drilled holes by Mitutoyo SJ-201

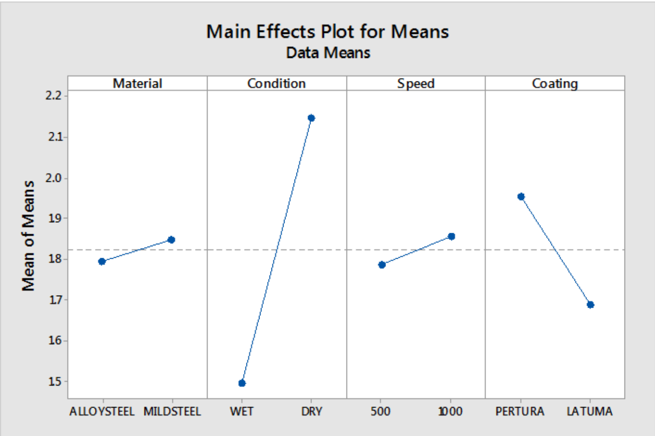
The tool wear was identified optically using a tool maker's microscope. The tip of the drill bits wears out mildly due to the dry cutting without using coolant. This wear length was measured by using the micrometer provided in the X and Y axis of the tool maker's microscope. Various tip tool wear images were captured and showed in Figs. 7(a) and(b). Also here in surface roughness and machining time from the main effects plot at Figs. 4(a) and (c), the machining conditions either wet or dry and the tool coatings are the primary and secondary influencing factors on surface roughness. The minimum value is the better option from the surface roughness responses were well predicted the dominant factors for the betterment of surface quality. The responses were spread over the residual v.s. fits chart for roughness and machining time as shown in Figs. 4(b) and (d).



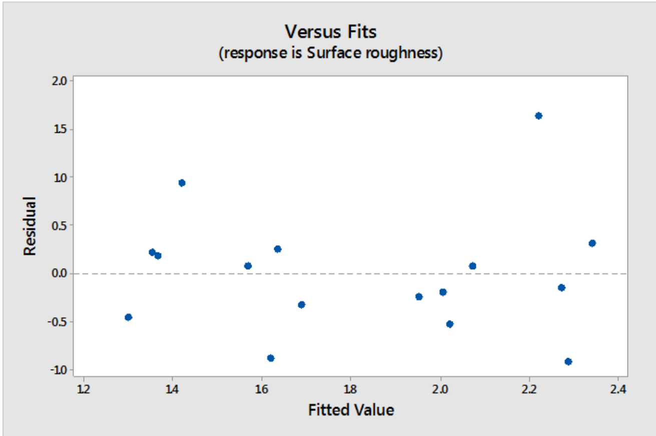
(a) The main effects plot for means of machining time



(b) Residual vs Fits for machining time



(c) The main effects plot for means of surface roughness



(d) Residual vs Fits for surface roughness

Fig. 4 Means and normal probability chart of machining time (minutes) and surface roughness (μm)

4. Results and Discussion

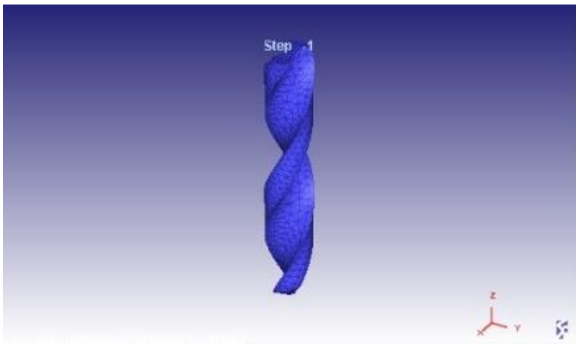
After the completion of drilling on mild steel and alloy steel by using coated drill bits, the required output responses were analyzed and measured the surface roughness and machining time. The main effects plots were identified from the optimization techniques. The fits verses residual has been plotted based on the array formation in Taguchi's method. The four variable material, machining condition, rotational speeds, and the coating types were considered for finding the mean values of the machining time and surface roughness. The most dominant parameters have easily identified these observations from the Figs. 4(a), (b), (c) and (d).

Here the machining time saved due to the rotational speed and the tool coating as the foremost parameter. Especially the Latuma coated drill bit performed well at the machining time at the higher rotational speed of 1000 RPM. Speed and tool coating are the dominant factors in machining time were identified. The variables are lying nearby the boundary level and evenly spread over in residual response by the machining time in the normal probability chart. Also here in surface roughness, from the main effects plot in Fig. 4(c),the machining conditions and the tool coatings are the primary, and secondary influencing factors on surface roughness. The minimum value is the better option from the surface roughness responses were well predicted the dominant factors for the betterment of surface quality. The responses were spread over the residual v.s. fits chart.

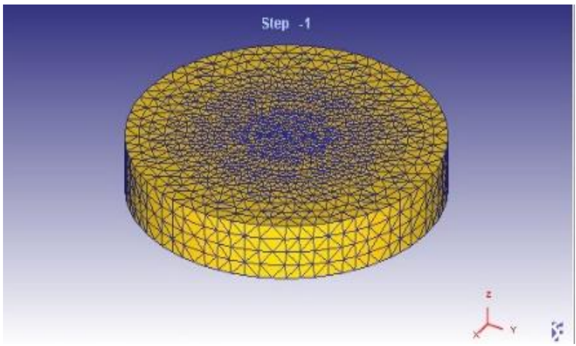
In this experiment, only two types of tool coatings were compared for the purpose of identifying the performance during drilling of different hardness materials like Alloy steel and Mild steel. So we have conducted the experiments based on the two variations of tool materials, speed, condition, and coating types. It is enough for the findings through L8 orthogonal array formation which helps in identify the significant effects on output response.

4.1. Prediction of drilling performance

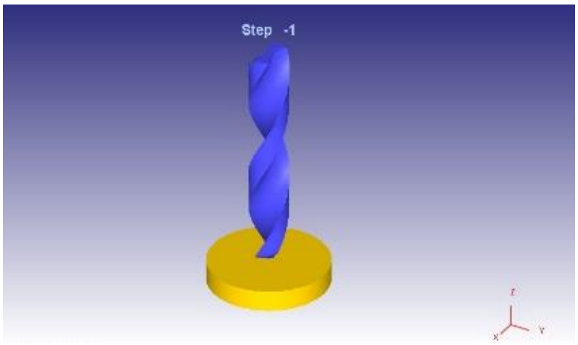
The drilling dynamic performance was accomplished by using Deform 3D dynamic simulator tool. Some predicted values of stresses and temperatures for the above-mentioned machining conditions by using coated drill bits. Simulated results from Deform 3D were utilized for the confirmation of the experimental readings of stresses and displacements. The mesh generation was done on both the drilling tool and the specimen in the preprocessor stage machining. All the required fields of input parameters were entered in the preliminary steps of machining simulation of Deform platform.



(a) Tool mesh generation



(b) Specimen mesh generation



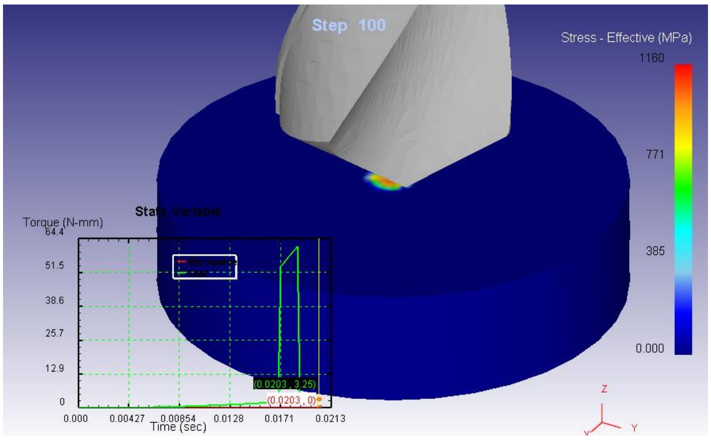
(c) Positioned view of drilling before the simulation

Fig. 5 Tool and workpiece mesh generation in deform 3D simulator in drilling machining

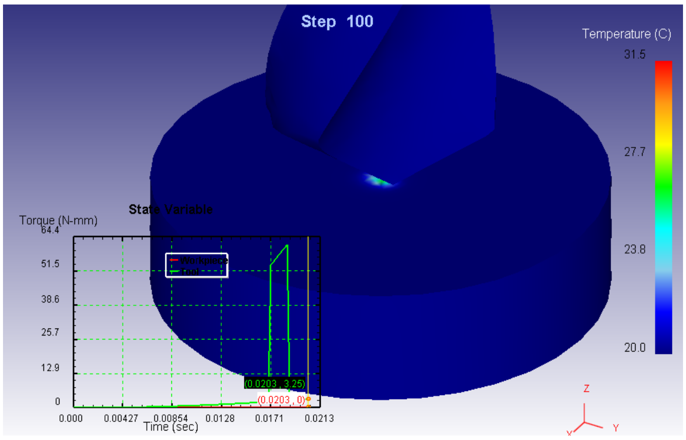
The tool mesh generated by 10697 elements and 2830 nodes and for the workpiece mesh size of 13590 elements and 3161 nodes. The boundary conditions were applied to the workpiece as fixed and the drilling tool is rotated about the Z axis as shown in Fig. 5(c). The material properties were identified as AISI 1013 from the material library. The simulation controls are specified as a number of simulation steps and increments for the required drill depth of 5 mm. Higher stresses were acted in between tool and workpiece due to the interaction effects. This was predicted thorough Deform 3D simulator as mentioned in Figs. 6(a), (b), (c) and (d). Based on these predicted values wherever effective stress becomes more, the surface roughness will get poor outcomes. Instead of using uncoated inserts, the coated inserts help to improve the surface properties and machining time in a very effective manner.

The simulation results showed the effective stress of the tool work interaction and the temperature of the cutting profiles of both alloy and mild steel drilling operation. These predicted values of σ_{eff} and T clearly stated that wherever effective stress is more, the surface roughness become less in the drilled profiles. Here the drilling of alloy steel gives the surface roughness of 0.841 μm is more than the Ra of mild steel of 0.734 μm at the same rotational speeds of 500 rpm. The temperature distribution also becomes minimum as 30.7℃ during the wet conditioned drilling of mild steel.

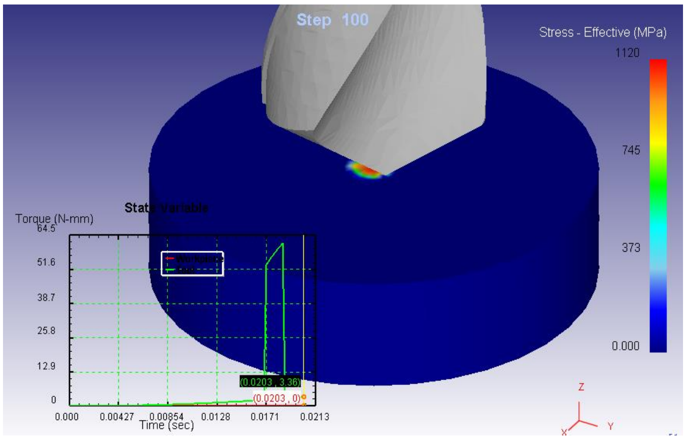
Consecutive through all holes were drilled along the surface of both alloy and mild steels with a uniform gap maintained between each hole. The fewer roughness values that mean good surface finish which had happened during the wet conditioned machining, especially with Pertura, coated drilling tool achieved a minimum surface roughness of 0.734 μm at minimum speed and 1.368 μm at both low and high rotational speeds for the Mild steel specimen.



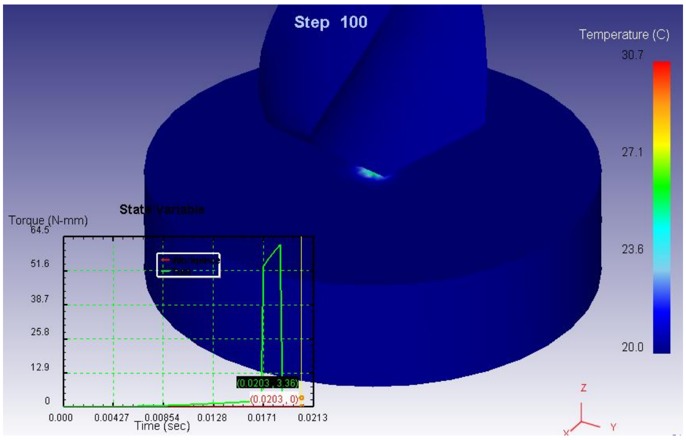
(a) Effective stress prediction (Pertura coated tool)



(b) Temperature prediction (Pertura coated tool)



(c) Effective stress prediction (Latuma coated tool)



(d) Temperature prediction (Latuma coated tool)

Fig. 6 Deform 3D simulation results of Drilling operation at 500 rpm

Table 4 Experimental results of Machining time and Surface roughness of Mild steel

Material	Condition	Speed (rpm)	Coating	Machining time (min)	Surface Roughness (µm)
Mild Steel	Wet	500	Pertura	3.41	0.734
	Wet	500	Latuma	2.06	1.575
	Wet	1000	Pertura	2.11	1.368
	Wet	1000	Latuma	1.37	2.366
	Dry	500	Pertura	2.53	2.128
	Dry	500	Latuma	2.33	1.811
	Dry	1000	Pertura	2.03	2.652
	Dry	1000	Latuma	2.25	2.150
Average				2.26	1.848

Table 5 Experimental results of Machining time and surface roughness of Alloy steel

Material	Condition	Speed (rpm)	Coating	Machining time (min)	Surface Roughness (µm)
Alloy Steel	Wet	500	Pertura	3.36	1.640
	Wet	500	Latuma	1.52	0.841
	Wet	1000	Pertura	1.56	1.893
	Wet	1000	Latuma	1.38	1.548
	Dry	500	Pertura	3.11	3.859
	Dry	500	Latuma	1.40	1.713
	Dry	1000	Pertura	1.56	1.369
	Dry	1000	Latuma	1.41	1.498
Average				1.91	1.795

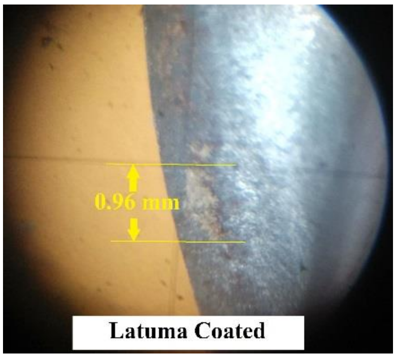
Latuma coated drills is not good for dry conditioned machining on mild steel as the specimen. Similarly, for the drilling of alloy steel, good surface finishes 0.841 µm was obtained during wet conditioned machining with Latuma coated drill bits. The surface roughness of the fluted area in the coated tooltips were recorded around 0182 µm to 0.324 µm. Here also the surface quality was achieved well at lower speeds. The machining condition and the rotational speeds are the major dominant factor here for surface roughness which was identified from Figs. 4(a) and (c). Comparatively the uncoated drill bits were verified with the coated HSS drilling tools that they were given the higher value of surface roughness ranges from 2.868 µm to 3.417 µm for the drilled holes of both alloy and mild steel. Thus, the hole inner surface quality becomes poor when it will be compared with the holes drilled by the coated tools.

4.2. Effect of coating on surface roughness

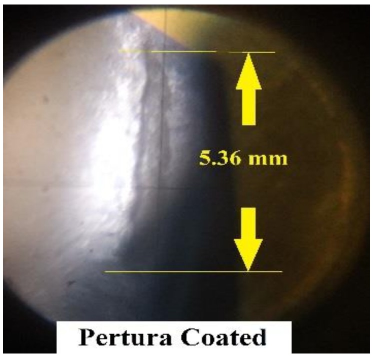
The drilling operation was performed by the Pertura and Latuma coated tools at different cutting conditions. The results revealed that the less machining time was obtained for the drilling of an alloy steel material at higher rotational speeds. Latuma coating on drill bits plays an important role in the saving of machining time by the smooth interaction of tool and the specimen. The surface roughness values are measured by using Mitutoyo SJ-201 tester and mentioned in Tables 4 and 5. Consecutive through all holes were drilled along the surface of both alloy and mild steels with a uniform gap maintained between each hole. The fewer roughness values that mean good surface finish which had happened during the wet conditioned machining, especially with Pertura, coated drilling tool achieved a minimum surface roughness of 0.734 µm at minimum speed and 1.368 µm at both low and high rotational speeds for the Mild steel specimen. Latuma coated drills is not good for dry conditioned machining on mild steel as the specimen. Similarly, for the drilling of alloy steel, good surface finishes 0.841 µm was obtained during wet conditioned machining with Latuma coated drill bits. Here also the surface quality was achieved well at lower speeds. The machining condition and the rotational speeds are the major dominant factor here for surface roughness which was identified from Figs. 4 (c) and (d).

4.3. Effect of coating on tool wear

After the dry and wet conditioned drilling was performed on the alloy and mild steel specimens, the tool wear was captured on the different coated High-speed Steel (HSS) drill bits by using the tool maker's microscope. The micrometer X and Y readings used to show the tiny wear span of the tooltips and edges of HSS drill bits as shown in Figs. 7(a) and (b).



(a) Wear length of Latuma coated drill bit



(b) Wear length of Pertura coated drill bit

Fig. 7 The span of tool wear images of coated high-speed steel drill bits by tool maker's microscope

The Latuma and Pertura PVD coatings were deposited warmly along the entire flute length of the drill bits. The margin wear was identified below the chisel edge of the Pertura coated drill bits. It was measured vertically below the lip of the drill bit by using micrometer read markings in the tool maker's microscope. The wearing length of 5.36 mm was observed along the rake face of the Pertura coated drill bit as margin wear. Similarly, the tiny margin wear on the rake face of the Latuma coated drill bit was measured as 0.96 mm. The comparison was made among these two coated drilling tools, the coated drill bits achieved less in tool wear when it was involved wet and dry cutting conditions. There were no such wear markings were identified on Latuma coated drill bits. It was measured vertically below the lip of the drill bit by using micrometer read markings in the tool maker's microscope. The wearing length of 5.36 mm was observed along the rake face of the Pertura coated drill bit as margin wear. Similarly, the tiny margin wear on the rake face of the Latuma coated drill bit was measured as 0.96 mm. The comparison was made among these two coated drilling tools, the coated drill bits achieved less in tool wear when it was involved in wet and dry cutting conditions. There were no such wear markings were identified on Latuma coated drill bits.

4.4. Interpretation of results

The surface roughness becomes good in alloy steel because it is having naturally 0.36-0.44% of carbon is relatively high and also the silicon participation is maximum up to 0.4% compared with the mild steel. This will lead to achieving less surface roughness value. At the same time, coated drill bits were deposited by the PVD method with the additive of Al and Cr combined form particulates. So the chemical interaction and temperature distribution were occurred in between the coated tool and the inner surface of the hole. The slight deposition of Al and Cr particles from Latuma and Pertura coated drill bits leads to change the surface integrity with respect to the machining conditions. Less tool wear was created from the Latuma coated drill bits compare with the Pertura coated drill bit. Margin wear marks were identified in the flute rake face of the Pertura coated drill bit as shown in Fig.7(b). The comparison was made accordingly among the surface roughness of the specimen and the tool wear level of the drill bits has been demonstrated by the Fig. 8.

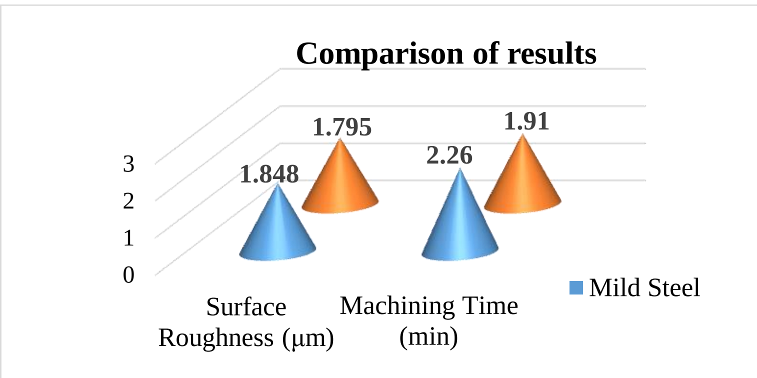


Fig. 8 Comparison of Surface roughness and Machining time

5. Conclusions

In this work, the surface quality was achieved with the contribution of Latuma and Pertura coated drill bits effectively. Especially the holes were made on both alloy and mild steel during the wet conditioned drilling operation was very successful. The surface roughness decreased at a low rotational speed of 500 rpm in the drilling of mild steel with Pertura coating. Simultaneously the Latuma coated tool achieved well during the wet machining of ally steel material. Here the rotational speed and the tool coatings are the more dominant thing on surface roughness and machining time. The optimization results can be made the things very easy to identify the influencing elements through the SN ratio and main effects plots. The tool wear was analyzed on those Latuma and Pertura coated drill bits. Very few wear images were obtained on Latuma coated compare with the Pertura coated drill bits. The wear span of Latuma coated drill tip edge is very small rather than the Pertura coated one. The dynamic simulation helps to predict and adopt a strong understanding of the stresses and temperatures of machining interactions.

Conflicts of Interest

The authors declare no conflict of interest.

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