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Quality Assessment of Drilled Holes in Al 6063 Plate at Sub Zero Temperature

[1]Shanmugam Murugappan, **[2]Sanjivi Arul**, **[3]Surendran K.Narayanan**.

[1]M.Tech student, [2]Associate Professor,
Mechanical Eningeering Department, Amrita School of Engineering,
Coimbatore campus, Amrita Vishwa Vidyapeetham, coimbatore - 641 112, India.
[3]Lecturer, Mechanical Engineering Department, Amrita School of Engineering,
Amritapuri campus, Amrita Vishwa Vidyapeetham, Amritapuri - 690 525, India.

Abstract

Drilling plays a key role in machining operation. The quality of hole is measured based on many metrics. Heat created during drilling affects the hole quality. A 11.9 mm (15/32") diameter hole is drilled in 10mm thick AL 6063 plate at two different environments, at room temperature without coolant and another at -55˚C Celsius using dry ice as pre cooling agent. The hole is drilled at nine different combinations of speed and feed using three cutting speeds 25, 40 & 66 m/min and feed rate 0.04, 0.08 & 0.15 mm/rev. Hole quality is assessed based on diameter deviation, conicity, surface Roughness Ra and Rz. The effect of cooling at sub zero temperature is discussed based on above quality metrics.

Keywords: Dry drilling, Dry ice, Cryogenic, Sub Zero temperature, Hole quality, surface roughness Ra, Rz, Conicity.

Introduction:

Most of the machined parts have cylindrical holes. Drilling operation is one of the widely used, economical and easiest hole making process. The quality of hole is important invariable of its function. J.F. Kellya & M.G. Cotterell [1] suggest that coolant selection is important in drilling aluminum alloys a) Due to reaction of silicon with them which increases the adhesiveness and b) Formation of aluminum oxides which causes galling and smearing. A.Rivero et al [2] outlines the benefits of avoiding cutting fluids while drilling in terms of legal aspects, cost, productivity especially in aerospace industry where drilling is extensively used for riveting the structures. D.M.Haan et al [3] evidenced that there is a second chip tool interface at drill margins which also takes part in heat generation in drilling and concluded that one of the function of cutting fluid is to lubricate the drill margins. Durval U. Braga et al [4] proved that minimum quality lubrication (MQL) gives same result as high amount of soluble oil in aluminum silicon alloy A356. Anshu D. Jayal et al [5] experimented with mist lubrication, dry drilling and flooding cooling while drilling A390.0 aluminum alloy and found that mist lubrication gives better results in terms of hole quality. I.S. Shyha et al [6] used hole size, out of roundness, cylindricity, burr height, surface roughness Ra as metrics to assess quality of drilled hole in metal composite stacks. Eder Silva Costa et al [7] co-related burr height and cooling environment. Tian Xia [8] used cryogenically cooled drill for drilling CFRP composites and measured surface roughness Ra, diameter deviation and burr formation. D. Biermanna and H. Hartmanna [9] supplied cryogenic coolant at bottom of work piece while drilling and studied its effect on hole quality in steel and aluminum alloy. Some researchers [10][11] used dry ice as pre & post cooling agent to improve the surface characteristics of material. In this work, AL6063 plate of 10mm thick is cooled using dry ice up to 12 hours and 12mm hole diameter is drilled at combinations of three cutting speeds 25, 40 & 66 metres/minute and feed rates 0.04, 0.08, 0.15 mm/rev. Hole size, conicity & surface roughness Ra and Rz are used as metrics to assess the hole quality. The experiment is repeated in dry drilling to compare the results.

Experiment:

A. Set up:

The experiment was conducted in Argo make Vertical turret milling machine model 3H. 11.9 mm (15/32”) diameter HSS 2 flute taper shank drill was used with point angle 118 degree. AL 6063- ‘o’ grade 10mm thick plate was used for experiment. It gives an L/D ratio of 0.83. The chemical composition of AL 6063 based on test report is given in Table 1. The plate is cut and sized to 38mm square pieces and a 3mm hole is drilled on one side face of the plate to insert thermocouple probe as shown in Fig 1.The hole was drilled in such a way that there will be a 2mm wall between thermocouple probe inserting hole and experiment hole. The prepared material is kept in dry ice chamber for 12 hours. The chamber is sealed around to avoid letting of air inside. Dry ice has temperature up to -78˚ Celsius [12]. The temperature of work piece will increase by 23˚ Celsius during the period in between taking out from chamber to setting in machine. The temperature of material will be 55˚C +/- 2˚C at the start of drilling.

Table.1 Chemical composition of AL 6063 alloy by % weight.

Composition	Al	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Sn	Ti	Pb	Ca
%	98.74	0.312	0.223	0.092	0.056	0.426	0.012	0.019	0.096	0.021	0.005	0.0	0.001

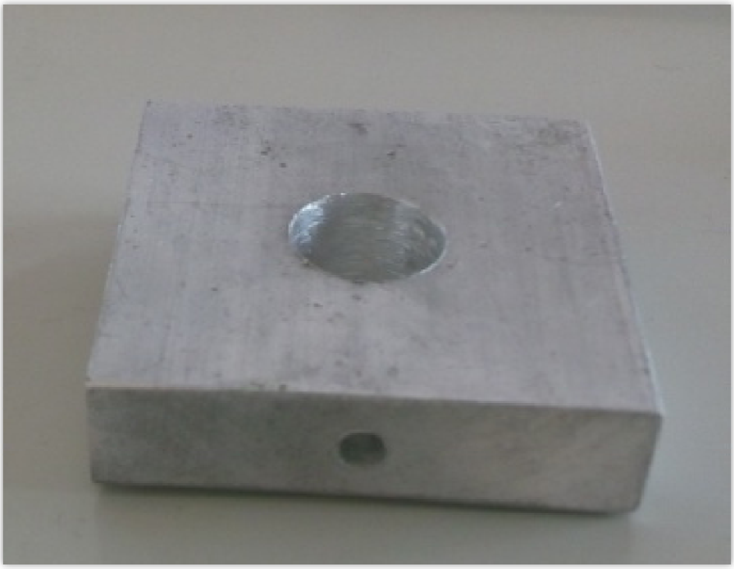

Fig.1 Drilled hole in side face of material to insert Temperature probe.

The drilling is done at three different speeds and at three feed rates as shown in Table.2 at two different environments. Totally 18 experiments are carried out in which nine are at room temperature and another nine are at sub zero temperature of -55˚C using dry ice.

Table.2 Experiment combinations.

Experiment Combination No	Feed rate (mm/rev)	Cutting speed (m/min)	Spindle speed (Rpm)
1	0.04	25	660
2		40	1115
3		66	1750
4	0.08	25	660
5		40	1115
6		66	1750
7	0.15	25	660
8		40	1115
9		66	1750

B. Measurement of surface roughness Ra and Rz.

Surface roughness Ra and Rz is measured with TESA make surface roughness tester RUGOSURF10G. The cut-off length of 0.8mm and traversing length of 4mm is selected. The measurement is done at middle portion of drilled plate. Ra is average of peak and valley over the sampling length where as Rz is average of five highest peak and valley [13]. Surface roughness parameter Rz is more important while assembling two mating parts as peak values affect the tolerance between them [14]. V. Rodriguez et al [15] shown that for same Ra (µm) value, surface roughness parameter Rz (µm) value may differ. They also prove that the ratio between Ra and Rz parameter depends on measuring direction. The ratio of Rz and Ra depends on machining operation, time and environment [16]. The surface roughness parameters measured from experiments are listed in Table.3. The difference between surface roughness values is Ra Value in dry ice cooled drilling minus Ra value in room temperature dry drilling. Similarly for Rz value, difference in surface roughness is calculated.

Table.3 Surface Roughness Ra and Rz in µm.

Experiment Combination No	Feed rate (mm/rev)	Spindle speed (Rpm)	Surface Roughness Ra in µm		Difference between Ra Value in µm	Surface Roughness Rz in µm		Difference between Rz Value in µm
			Dry Ice cooled	Room Temperature		Dry Ice cooled	Room Temperature	
1	0.04	660	4.994	3.609	1.385	22.279	17.118	5.161
2		1115	4.914	4.004	0.91	25.502	18.362	7.14
3		1750	5.673	4.088	1.585	27.661	20.473	7.188
4	0.08	660	6.66	5.569	1.091	30.548	29.348	1.2
5		1115	6.74	6.114	0.626	33.742	31.046	2.696
6		1750	6.422	4.078	2.344	33.106	19.344	13.762
7	0.15	660	5.475	4.629	0.846	22.648	23.663	-1.015
8		1115	4.983	4.815	0.168	20.473	21.236	-0.763
9		1750	4.703	5.214	-0.511	22.269	24.472	-2.203

C. Measurement of Hole Size.

The hole size is measured in TESA make CMM - MH 3D DCC NS model. The nominal diameter is taken as 12mm. The hole diameter is measured at a depth of 2mm and 8mm. The measurement is taken at 8 points angularly equally spaced in the hole at each depth. The diameter of probe is 1mm. The hole size is tabulated in Table.4

Table.4 Hole size measured at 2mm and 8mm depth.

Experiment Combination No	Feed rate (mm/rev)	Spindle speed (Rpm)	Hole Size in mm at 2mm depth		Hole Size in mm at 8mm depth	
			Dry Ice cooled	Room Temperature	Dry Ice cooled	Room Temperature
1	0.04	660	11.946	11.925	11.918	11.884
2		1115	11.942	11.902	11.956	11.9
3		1750	11.934	11.923	11.977	11.951
4	0.08	660	11.956	11.956	11.941	11.925
5		1115	11.981	11.941	11.964	11.941
6		1750	12.043	11.925	11.963	11.926
7	0.15	660	11.992	11.952	11.944	12.03
8		1115	12.018	11.984	11.995	12.007
9		1750	12.011	11.958	12.038	11.967

D. Calculation of Conicity.

R. S. Jadoun et al [17] calculated conicity to measure the accuracy of ultrasonic drilling in engineering ceramics. Durval U. Braga et al [4] measured taper of experiment work piece in %. Conicity is calculated for both environments using the formula [1]. The length is difference between depth values where measurement is carried out (8-2 = 6mm). The conicity values are tabulated in Table.5.

$$\text{Conicity} = \frac{\{\text{Diameter at 2mm depth } (-) \text{ Diameter at 8mm depth}\}}{\text{Length}} \times 1000 \qquad [1]$$

Table.5 Conicity.

Experiment Combination No	**Feed rate (mm/rev)**	**Spindle speed (Rpm)**	**Conicity**	
			Dry Ice cooled	**Room Temperature**
1	0.04	660	4.67	6.83
2		1115	-2.33	0.33
3		1750	-7.17	-4.67
4	0.08	660	2.50	5.17
5		1115	2.83	0.00
6		1750	13.33	-0.17
7	0.15	660	8.00	-13.00
8		1115	3.83	-3.83
9		1750	-4.50	-1.50

E. Measurement of Temperature of Work Piece.

The temperature of work piece is measured in work piece by inserting a K type thermo couple in the hole as shown in the Fig.1. The measurement is read thru Handy Digital read out. The temperature in ˚ C is listed in Table.6.

Table.6 Temperature of Work Piece (˚ C) For Two Different Drilling Environments

Speed(m/min)	660		1115		1750	
Feed (mm/rev)	Dry Ice Cooled	Room Temp	Dry Ice Cooled	Room Temp	Dry Ice Cooled	Room Temp
0.04	37	58	25	70	32	68
0.08	37	58	22	60	22	58
0.15	37	58	20	60	14	57

Results and discussion:

A. Surface Roughness Ra

Fig.2 & Table.3 shows that Surface Roughness Ra value is higher in dry ice drilling environment than room temperature dry drilling except for 66 m/min and 0.15mm/rev combination. At 0.04 mm/rev feed rate, the percentage (%) change in Ra value shows a positive trend from lower cutting speed of 25m/min to higher cutting speed (66 metres /minute). At 0.08mm/rev feed rate, the percentage (%) change is in negative trend. But at higher feed rate (0.15mm/rev) as cutting speed is increased, surface roughness value is getting decreased by 14% in case of dry ice cooled environment where it is increased by 12% in case of room temperature dry drilling environment. J.F. Kellya & M.G. Cotterell [1] did a similar analysis on variation of surface roughness Ra value between different combination of feed rate and cutting speed. Dry ice cooled environment is not much effective at lower cutting speed and feed rate can be co-related with temperature of work piece during drilling.

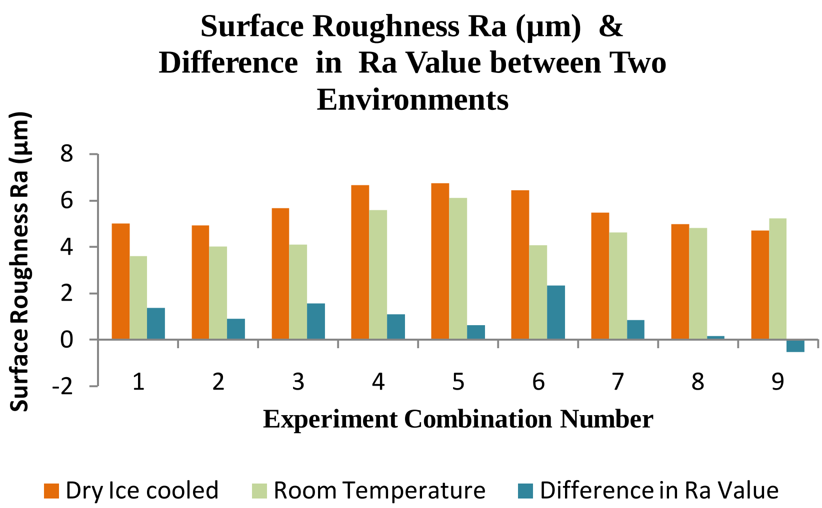

Fig.2 Surface Roughness Ra value for Different Experiment Combinations.

The work piece temperature is higher (37˚C) than or closer (20˚C) to room temperature which is around 27˚C on experiment day. The more temperature in work piece is due to more contact time between tool and work piece at lower cutting speeds and feeds. The dry ice cooling environment yields result at 66m/min and 0.15mm/rev when the temperature of work piece (14˚C) is lower than room temperature which is evidenced from Table.6 The lower work piece temperature makes the work piece more ductile [18] and reduced heat at drill margin and work piece interface which assists in reducing the surface roughness Ra value at higher feed rate and cutting speed.

B. Surface Roughness Rz

Table.3 shows that when cutting speed increased from 25m/min to 66m/min the % change in Surface Roughness Rz value at 0.04 and 0.08 mm/rev feed rate has a similar trend for both dry ice and room temperature environment. The % change is negative (-2%) for dry ice environment and (+3.5%) for room temperature environment at feed rate of 0.15mm/rev. The surface roughness Rz is also reduced at higher cutting speed (66 m/min) at dry ice cooled environment that room temperature dry drilling environment for any feed rate. This reduction in surface roughness Rz is due to built up edge is not formed on drill in dry ice cooled environment at higher cutting speed. The increase of Rz value at higher cutting speed in room temperature environment indicates built up edge (BUE). This sort of phenomenon is reported by some researchers [16]. The phenomenon is affirmed by lower temperature of work piece (14 to 32˚C) at 66m/min (1750 rpm) which is listed in Table.6

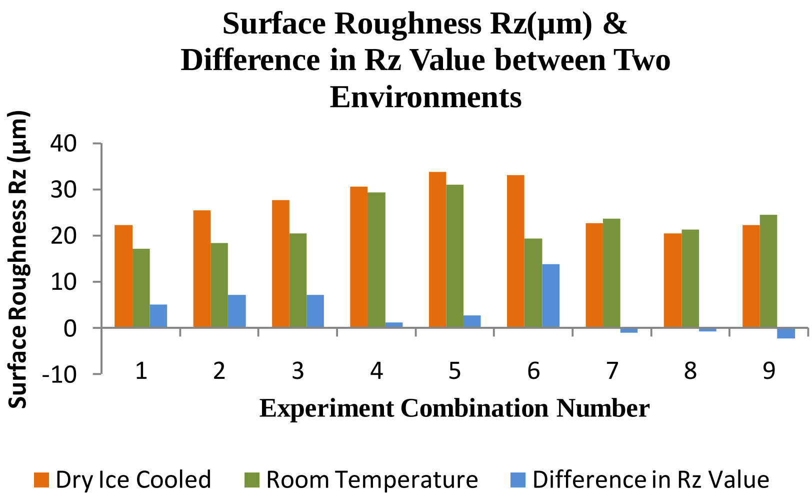

Fig.3 Surface Roughness Rz value for Different Experiment Combinations.

C. Deviation in Hole diameter

From Fig.4 ,Fig.5 & Table.4, it is evidenced that hole diameter is lesser by 0 to 53µm in room temperature dry drilling than dry ice cooled drilling at 2mm depth and 10 to 70µm at 8mm depth except for 0.15mm/rev feed rate and 40,66 m/min cutting speed combinations. This is attributed to thermal expansion of aluminum alloy which expands during drilling and later shrinking due to cooling effect. This expansion and shrinkage is more in case of room temperature dry drilling compared to dry ice cooled drilling. This phenomenon is supported by Temperature of work piece tabulated in Table.6 which shows that the temperature of work piece is always higher in room temperature dry drilling than dry ice cooled drilling. The similar phenomenon is reported by some researchers [3][9] when they compared dry drilling with drilling under flooded cutting fluid and Mist.

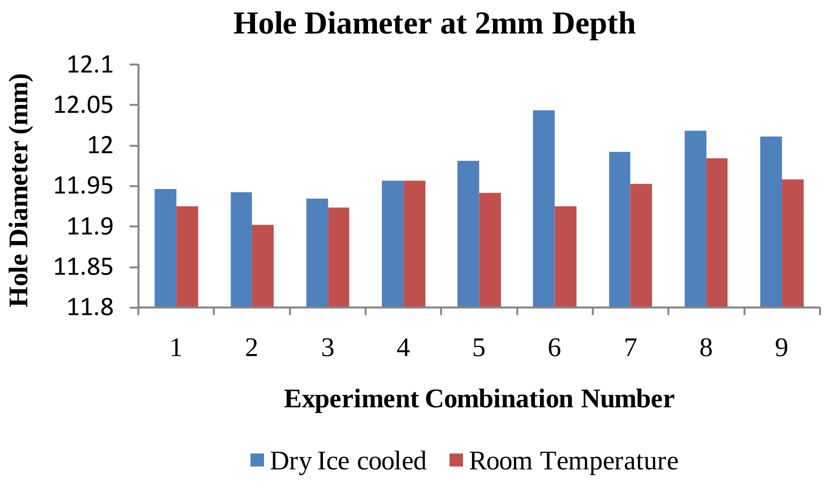

Fig.4 Drilled Hole Size measured at 2mm depth of work piece.

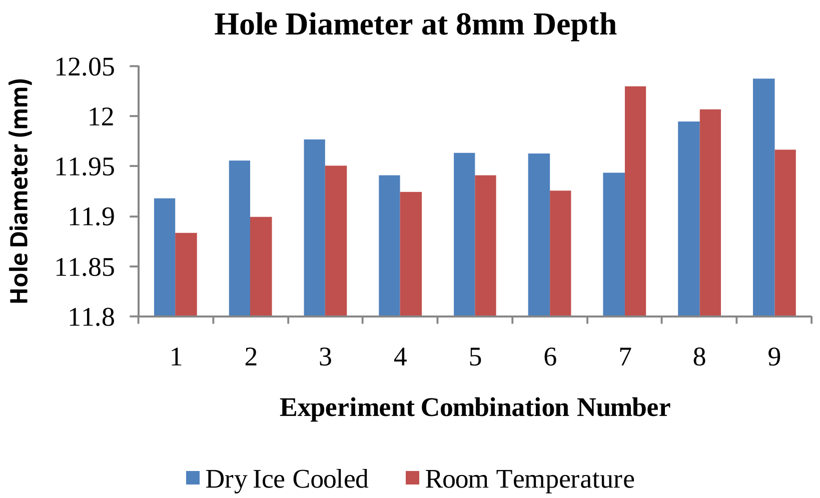

Fig.5 Drilled Hole Size measured at 8mm depth of work piece.

D. Conicity in Hole

The conicity plays an important role in a) assembling when closer tolerance are necessary and b) in pressure building parts like nozzle assemblies where performance of part will increase or decrease based on type of conicity produced in manufacturing process [19]. From Fig.6 and Table.5 it is evident that at lower cutting speed and feed the conicity has positive values in dry ice cooled temperature and has less value than room temperature dry drilling. The positive value represent convergent type conic shape as shown in Fig.7a where as negative value represent divergent type (bell mouthed) conic shape as shown in Fig.7b. This phenomenon is due to long curled chip produced during drilling and while going out of hole, they create bigger size hole in case of room temperature dry drilling. The room temperature dry drilling produces either zero or divergent type conicity at medium and higher cutting speed and feed rate. The divergent type shape is because of more heat created at top surfaces of work piece where drill margin and work piece interaction takes place. Hence thermal expansion will be more at top surface. Later cooling takes place after drilling which will make the hole much smaller. In case of dry ice cooled drilling this phenomenon is avoided due to heat energy is less absorbed by work piece due to pre cooling effect.

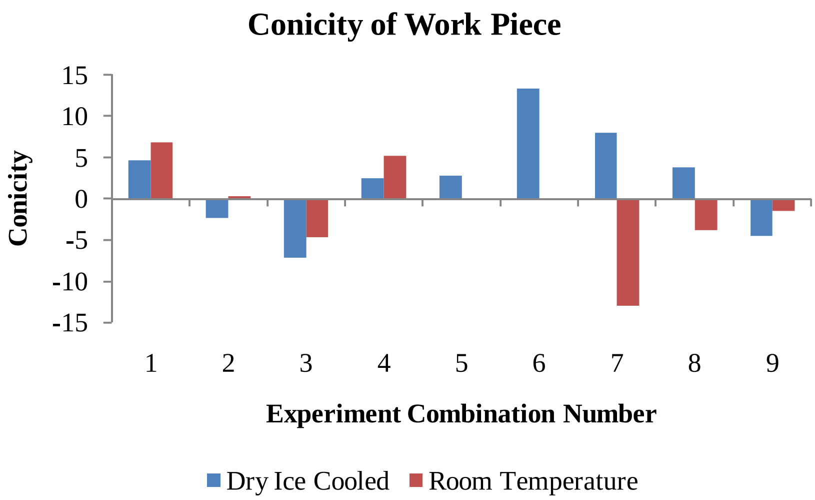

Fig.6 Conicity of work piece.

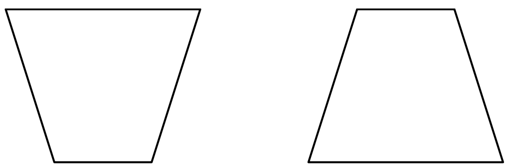

Fig.7a **Fig.7b**

Fig.7 conicity a) Convergent shaped b) divergent shaped

Conclusion:

The work piece is drilled at nine combinations of cutting speed and feed rate using cutting speeds 25, 40 & 66 metres/minute and 0.04, 0.08 and 0.15 mm/rev feed rates in two different environments namely dry ice pre cooled environment and room temperature dry environment.

1. Dry ice cooling is effective at higher cutting speed 66 metres/minute and feed rate 0.15 mm/rev in terms of Surface roughness Ra and Rz.
2. The hole is always smaller by 0 to 70µm at different depths in dry ice cooled environment than room temperature dry drilling due to less thermal expansion.
3. Conicity is convergent shaped at lower cutting speed and it is lesser in dry ice cooled environment that room temperature dry drilling.
4. Conicity is divergent shaped in room temperature dry drilling in combination of higher cutting speed 66m/min and medium and higher feed rates 0.08,0.15mm/rev due to interaction between drill margin and work piece at top surfaces which leads to thermal expansion and shrinkage later on due to cooling effect.

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