N. ASHOK
NEGUSSIE TADEGE DEMEKE
and
P. SHANMUGHASUNDARAM

# Influence of heat treatment on the exit burr height in drilling of Al alloy 7075 – a statistical analysis

*In this work, the effect of heat treatment on the burr height is investigated with three different cutting speeds and feeds in drilling of Al alloy 7075. Al alloy was chosen in three different conditions such as As-cast condition, annealed condition and hardened condition. Three different feeds such as 30 m/min, 60 m/min, 90 m/min and three different cutting speeds such as 12.56 m/min, 37.68 m/min, 62.8 m/min are chosen. Drilling tests are conducted as per the Taguchi's L9 orthogonal array. The experimental results are analyzed using Analysis of Variance (ANOVA) to study the influence of the factors on burr height.*

***Keywords:*** *Drilling, burr height, Al alloy 7075, As-cast condition, heat treatment, Taguchi, ANOVA.*

## 1. Introduction

Burr is an unwanted projection of material in the drilled hole due to the plastic deformation during drilling operation. It caused obstruction of way in hydraulic and pneumatic paths. It also degrades the performance of the components during the operation. Compared to exit burr, entrance burr is smaller and easily be eliminated by chamfering. The de-burring operation cost is approximately 20% of total manufacturing cost and takes time. Hence exit burr should be minimized by optimizing the parameters with suitable drill type. Çakýroðlu, and Acýr [1] optimized the drilling factors on measurement of drill bit temperature. Coated and uncoated drill bits are used to perform the drilling operation. Taguchi method is used to evaluate the contribution of the drilling factors. Drilling tool, cutting speed and feed rate are taken as factors. Thirukkumaran, et al [2] studied on temperature of the drill bit, wear, and surface roughness in drilling of Al–SiC composite. Cutting parameters such as drill bit's point angle, feed and speed are considered. It is reported that the temperature of the tool and tool wear tend to drop with an increase in point angle while temperature increases with spindle speed. Costa et al [3] investigated the burr formation during the drilling process with respect to tool wear and lubricant conditions. Reports show that the burr height increases with the wear of the tool. Moreover, the smallest burr height obtained for the dry machining and the largest for the MQL systems. Yahya et al [4] studied the influence of drilling factors on the burr height, surface roughness and chip formation in drilling of the Ti-Al-V alloy. It is reported that the surface roughness increased when the feed rate and the point angle are increased. Conversely, the surface roughness decreased as the cutting speed increased. When the feed rate is increased, the burr height decreases. In contrast, the burr height increases with speed. Ankit Rana et al [5] developed analytical modelling of exit burr in drilling of Ti-Al-V alloy considering physical phenomena. It is reported that the burr size increased with feed and point angle. However cutting speed and the drill diameter did not influence the burr size. Rezende [6] investigated the effect of drill geometry on thrust force and burr height during drilling an aluminium/PE sandwich material. It is concluded that the lowest burr height was obtained using the Brad and Spur drill geometry. Tian et al [7] studied the control of interlayer burr in dry drilling of stacked aluminum alloy plates. The outcome of feed rate and force on interlayer burr height and interlayer gap is discussed. Feed had considerable effect on burr height. Bi and Liang [8] optimized the drilling parameters in dry drilling of stacked metal materials for burrs. Drilling factors were optimized in drilling of hard TI-Al-V alloy on SR and vibration. Drilling characteristics was analyzed by applying Response Surface Methodology [9]. Drilling operational parameters and reinforcement are optimized in drilling of SiC and talc reinforced Al alloy hybrid MMC through grey relational analysis on thrust force, circularity and SR [10].

Various researchers have employed Taguchi method and ANOVA to explore the effect of the operational variables and their interactions which have influence on the machinability of the composite materials. Davim et al [11] investigated the impact of drilling operational parameters on wear of the tool and surface finish. Ugur Köklü [12] assessed the effect of the cutting parameters and the mechanical properties of aluminum alloys on the burr height and the surface roughness in dry drilling. The results inferred that the feed rate and cutting speed minimize significantly both the height of the exit burrs and the surface roughness. Kundu et al [13-14] optimized the

Messrs. N. Ashok, Negussie Tadege Demeke, Assistant Professors, Faculty of Mechanical & Production Engineering, Arba Minch Institute of Technology, Arba Minch University, Ethiopia 21 and Dr. P. Shanmughasundaram, Karpagam Academy of Higher Education, Coimbatore 641021, India. E-mail: sunramlec@rediffmail.com

drilling parameters to reduce the burr of Al alloy as well as polymer matrix composite materials.

It is inferred from the literature study that the exit burr height of the drilled hole could be reduced by choosing the optimal cutting parameters and drill bit's geometry in relation to the materials to be drilled. This work intends to explore the effect of the material and cutting parameters on the exit burr. Dynamometer was employed to obtain the force signals which are obtained during drilling operation through a data acquisition system and analyzed.

## 2. Materials and methodology

### 2.1 Materials

In this study, Al alloy 7075 is chosen as work piece material. Al alloy 7075 is chosen in three different conditions such as As-cast condition, annealed Al alloy 7075 and hardened Al alloy 7075.

### 2.2 Drilling experimental set up

Drilling test is performed on a vertical machining center which is shown in Fig.1. Carbide step drill (8 mm diameter and point angle 118°) is employed. Drilling experiments are carried out according to L9 Taguchi orthogonal array. Summary of experimental conditions is given in Table.1. Thrust forces are recorded by the Kistler dynamometer during drilling operation and processed by data acquisition system.

Fig.1 Experimental set up showing the drilling of Al alloy

Table 1: Summary of experimental conditions

| | |
|---|---|
| Drill | Multi faceted carbide: dia 8 mm |
| Drill types | Twist drill |
| Work piece material (Al alloy 7075) | As cast Al alloy, Annealed Al alloy, hardened Al alloy |
| Twist Drill | Point angle 118° |
| Drilling parameters | Feed: 30,60,90 mm/min<br>Spindle speed: 500, 1500, 2500 rpm<br>Cutting speed:12.56m/min, 37.68m/min, 62.8 m/min |

Burr height is measured with the help of dial indicator with 0.001 mm accuracy which is portrayed in Fig.2. Exit burr height is measured at 90° intervals in 4 positions around its circumference and average value is taken.

Fig.2 Measurement of burr height using height gauge

### 2.3 Taguchi design of experiments

In the present work, "smaller is better" S/N ratio is chosen to predict the optimum parameters because a lower burr height of the specimens was desirable. Mathematical equation of the S/N ratio for "smaller is better" is represented in the Equation (1).

$$\frac{S}{N} = -10 \, \mathrm{Log}_{10} \frac{1}{n} \Sigma y_i^2 \qquad \ldots (1)$$

where, y is the observed data and n is the number of observations

The factors and the corresponding levels are presented in Table 2. Measured exit burr height and SN ratios are presented in Table 3. In this three factors are chosen. In order to find the effect of heat treatment on the burr height, Al alloy 7075 is chosen in As-cast condition, annealed condition and hardened condition.

Table 2: Parameters and levels

| Level | Material (A) | Feed.(mm/min) (B) | Cutting. speed (m/min) (C) |
|---|---|---|---|
| I | As cast alloy (1) | 30 | 12.56 |
| II | Annealed alloy (2) | 60 | 37.68 |
| III | Hardened alloy (3) | 90 | 62.8 |

Table 3: Measured exit burr height and SN ratios

| | Parameters | | | Exit burr height | |
|---|---|---|---|---|---|
| | Material (A) | Feed. (mm/min) (B) | Cutting. speed (m/min)(C) | Measured value | S/N ratio |
| 1 | As cast alloy (1) | 30 | 12.56 | 1.69 | -4.02794 |
| 2 | As cast alloy (1) | 60 | 37.68 | 1.93 | -5.71115 |
| 3 | As cast alloy (1) | 90 | 62.8 | 1.86 | -5.52924 |
| 4 | Annealed alloy (2) | 30 | 37.68 | 1.15 | -1.21396 |
| 5 | Annealed alloy (2) | 60 | 62.8 | 1.58 | -2.79758 |
| 6 | Annealed alloy (2) | 90 | 12.56 | 1.35 | -2.60668 |
| 7 | Hardened alloy (3) | 30 | 62.8 | 0.87 | 1.83030 |
| 8 | Hardened alloy (3) | 60 | 12.56 | 0.61 | 2.97483 |
| 9 | Hardened alloy (3) | 90 | 37.68 | 0.85 | 1.41162 |

## 3. Results and discussion

Table 4 illustrates that the key parameter is the material subsequently cutting speed and finally feed on the burr height of the tested specimens. Material which has the highest delta value of 7.162, feed has 1.104 and cutting speed has 0.946. Hence material is the dominant factor in deciding the desired exit burr height. It can be concluded that burr formation depends on the material properties in association with drilling parameters.

Table 4: Response table for SN ratios

| Level | Material (A) | Feed. (mm/min)(B) | Cutting speed (m/min) (C) |
|---|---|---|---|
| I | -5.089 | -1.137 | -1.220 |
| II | -2.206 | -1.845 | -1.838 |
| III | 2.072 | -2.241 | -2.166 |
| Delta | 7.162 | 1.104 | 0.946 |
| Rank | 1 | 2 | 3 |

Fig.3 demonstrates the response diagram of SN ratio for exit burr height. Drilling parameter which has highest S/N ratio provides the optimum quality in obtaining the desired output. The obtained optimal level of parameters which are obtained from the response diagram are hardened Al alloy (material), cutting speed (12.56m/min) and 30mm/min (feed). Burr height increased with increasing feed and cutting speed. Hardened Al alloy exhibits lowest burr height compared to annealed alloy and As-cast alloy.

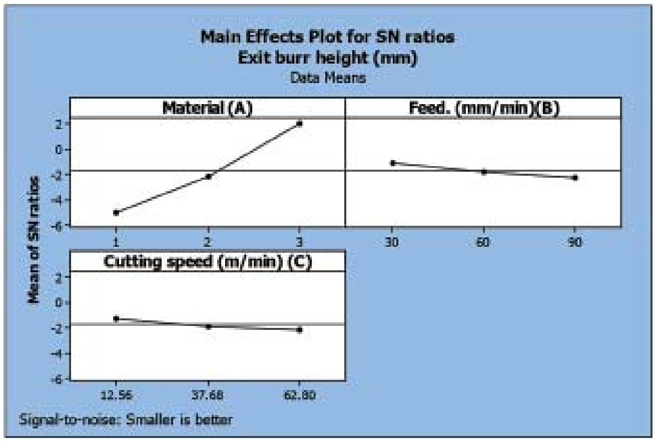


Fig.3 Response diagram of SN ratio for exit burr height

With the help of ANOVA, the relative significance among the drilling parameters is assessed. Software package MINITAB15 is used to find the association of drilling parameters with respect to exit burr height for a level of significance of 5%. ANOVA analysis for burr height is presented in Table 5. In the ANOVA table, there is a P-value for each independent parameter for the model. If the P-value of the parameters has less than 0.05, then the parameter is taken as statistically noteworthy. In this analysis, the parameter material has less than 0.05, indicating that it is well significant at 95% confidence level. The last column of the Table 5 shows the percentage contribution (Pc %) of each variable in the total variation indicating their degree of influence on the burr height. Material contributes 93.29% feed contributes 3.48% and cutting speed contributes 1.92% on the burr height of the material.

The experimental results revealed that the hardened Al alloy exhibits the lowest burr height compared to As-cast Al alloy and annealed Al alloy. It can be explained that the burr formation is closely associated to the hardness of the work piece. As hardened steel has highest hardness compared to the annealed and As-cast conditioned alloys, hardened steel

Table 5: Results of Anova

| Parameter | Dof | SS | F-value | P-value | Pc |
|---|---|---|---|---|---|
| A- Material | 2 | 1.54029 | 71.68 | 0.014 | 93.294 |
| B- Feed. (mm/min) | 2 | 0.05749 | 2.68 | 0.272 | 3.48 |
| C- Cutting speed (m/min) | 2 | 0.03176 | 1.48 | 0.404 | 1.92 |
| Error | 2 | 0.02149 | | | 1.30 |
| Total | 8 | 1.65102 | | | 100 |

DoF: Degrees of freedom; Seq.SS: sequential sums of squares; Adj.MS: Adjusted mean squares; Pc: percentage of contribution.

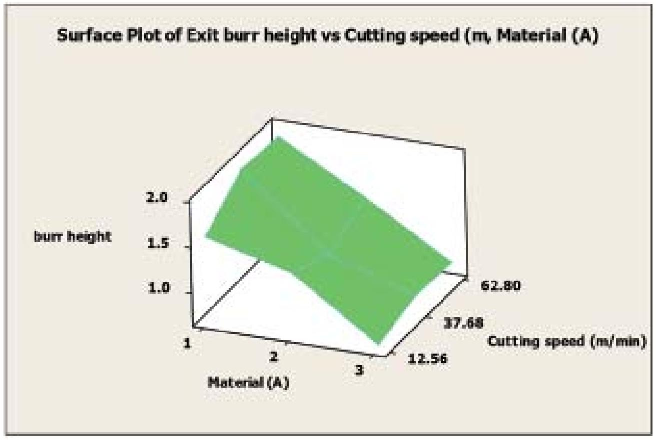


Fig.4 Contour plot of exit burr height versus cutting speed and material

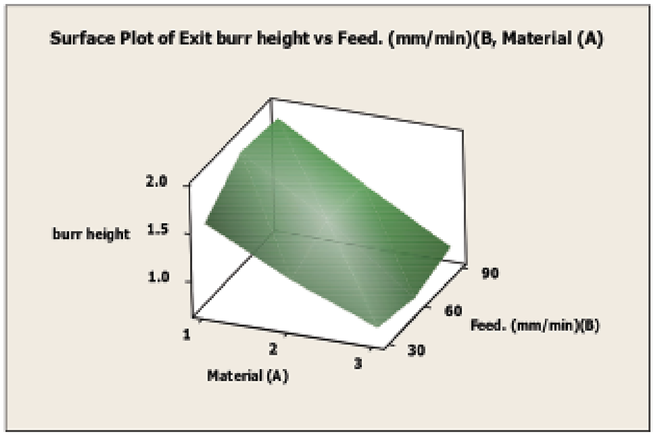


Fig.5 Contour plot of exit burr height versus feed and material

resists deformation and hard to deform in the shear zone during drilling operation.

## 3.1 Construction of contour plot

The contour plot, Fig.4 illustrates that the burr height tends to reduce in accordance with the gradual decreasing of feed.

The contour plot, Fig.5 illustrates that the burr height tends to reduce in accordance with the gradual decreasing of f cutting speed. Hardened Al alloy exhibits the lowest burr height compared to As-cast Al alloy and annealed Al alloy irrespective of feed and cutting speeds.

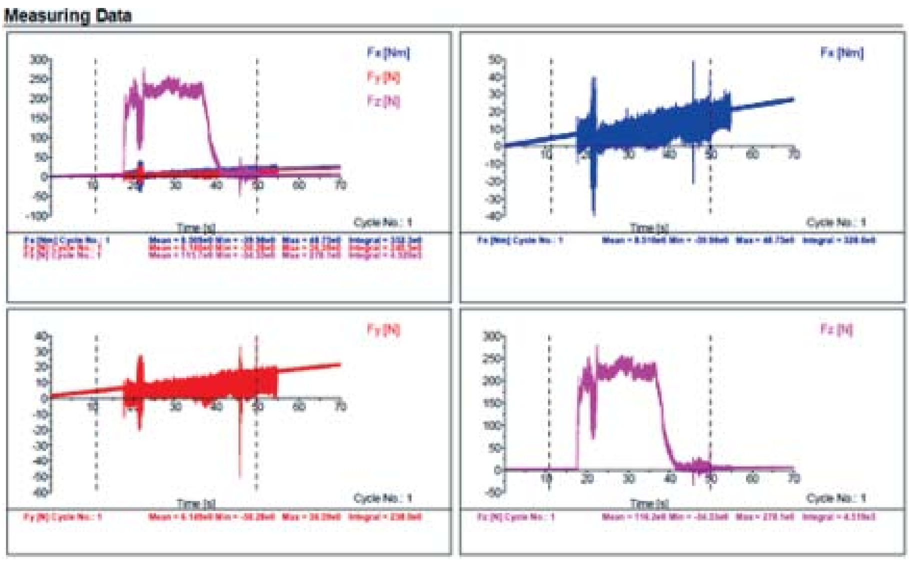


Fig.6 Thrust force obtained in drilling of hardened Al alloy 7075 at a cutting speed of 62.8m/min and feed of 60mm/min

## 3.2 Thrust force measurement

Thrust force measurement during drilling is carried out to understand its significance during drilling. Computerized multi-component dynamometer was sued to obtain the thrust (Fz) – time curves during drilling.

Thrust force obtained in drilling of hardened Al alloy 7075 at a cutting speed of 2.8 m/min and feed of 60mm/min is shown in Fig.6. Thrust force obtained in drilling of hardened Al alloy 7075 at a cutting speed of 62.8 m/min and feed of 90 mm/min is shown in Fig.7. Figs. 6 and 7 show that the maximum thrust force increased from 278 N to 291 N when the feed is increased 60 mm/min to 90 mm/min at a constant cutting speed of 62.8 m/min. Moreover cutting force increased by

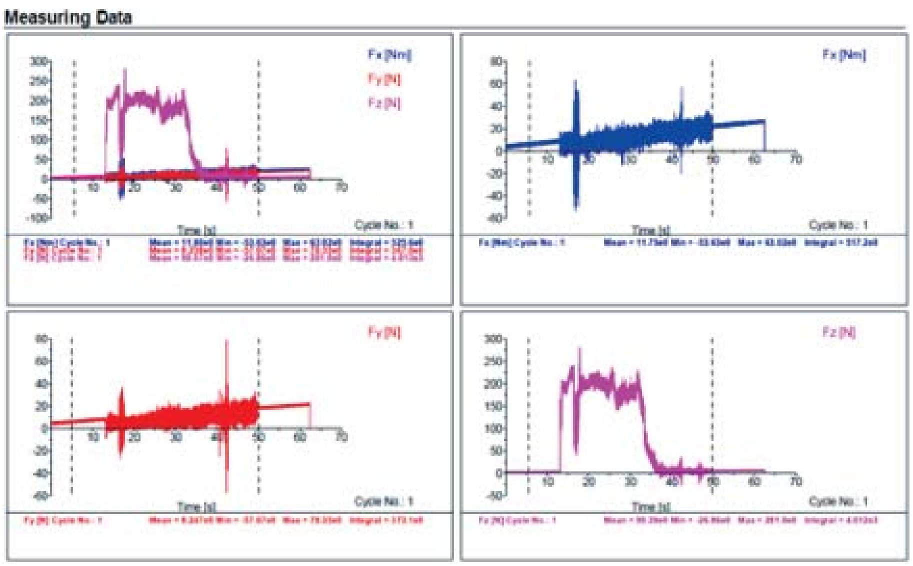


Fig.7 Thrust force obtained in drilling of hardened Al alloy 7075 at a cutting speed of 62.8m/min and feed of 90mm/min

approximately 5% when the feed was increased. Hence as the thrust force increases, material undergoes the plastic deformation, resulting in larger burr height at exit of the hole.

### 4. Conclusions

The following conclusions are drawn from the results. The material (93.29%) is the foremost contributing factor followed by feed and finally cutting speed in influencing the burr height. It is observed that burr height increased with feed and cutting speed. The obtained optimal level of parameters are hardened Al alloy (material), cutting speed (12.56m/min) and 30mm/min (feed). The experimental results revealed that the hardened Al alloy exhibits the lowest burr height compared to As-cast Al alloy and annealed Al alloy.

### References


[1] Çakiroglu, R., and Acir, A. (2013): Optimization of cutting parameters on drill bit temperature in drilling by Taguchi method. *Measurement,* 46(9), 3525–3531. doi:10.1016/j.measurement.2013.06.046

[2] Thirukkumaran, K., Menaka, M., Mukhopadhyay, C. K., and Venkatraman, B. (2020): A Study on Temperature Rise, Tool Wear, and Surface Roughness During Drilling of Al–5% SiC Composite. *Arabian Journal for Science and Engineering*. doi:10.1007/s13369-020-04427-4

[3] Costa, E. S., Silva, M. B. da, and Machado, A. R. (2009): Burr produced on the drilling process as a function of tool wear and lubricant-coolant conditions. *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* 31(1), 57–63.

[4] Yahya, Hýþman, Çelik (2014): Investigating the effects of cutting parameters on the hole quality In drilling the Ti-6al-4v Alloy, Materiali in tehnologije/*Materials and technology* 48 (2014) 5, 653–659.

[5] Ankit Rana, Ganesh Dongre and Suhas S Joshi (2019): Analytical modeling of exit Burr in drilling of Ti6Al4V alloy, *Sådhanå* (2019) 44:133

[6] Rezende B A, Silveira M L, Vieira L M, Abra˜o A M, Faria P E and Rubio J C (2016): Investigation on the effect of drill geometry and pilot holes on thrust force and burr height when drilling an aluminium/PE sandwich material. *Materials* 9: 774

[7] Tian, W.; Hu, J.; Liao, W.; Bu, Y.; Zhang, L. (2016): Formation of interlayer gap and control of interlayer burr in dry drilling of stacked aluminum alloy plates. Chin. J. Aeronaut. 29, 283-291.

[8] Bi, S., and Liang, J. (2010): Experimental studies and optimization of process parameters for burrs in dry drilling of stacked metal materials. *The International Journal of Advanced Manufacturing Technology,* 53(9-12), 867–876.

[9] Balaji, M., K. Venkata Rao, N. Mohan Rao and B. S. N. Murthy (2018): Optimization of drilling parameters for drilling of TI-6Al-4V based on surface roughness, flank wear and drill vibration. Measurement, 114: 332–339. doi:10.1016/j. *Measurement.* 09.051.

[10] Ramesh Kumar, C., V. Jai Ganesh and R. Ravi Raja Malarvannan (2019): Optimization of drilling parameters in hybrid (Al6061/SiC/B4C/talc) composites by grey relational analysis. *Journal of the Brazilian Society of Mechanical Sciences and Engineering,* 41(4). doi:10.1007/s40430-019-1694-y.

[11] Davim, J. P. and C. Conceição António (2001): Optimal drilling of particulate metal matrix composites based on experimental and numerical procedures. *International Journal of Machine Tools and Manufacture,* 41(1): 21–31. doi:10.1016/s0890-6955(00)00071-7.

[12] Ugur Köklü (2012): Influence of the process parameters and the mechanical properties of aluminum alloys on the burr height and the surface roughness In dry drilling, Materiali in tehnologije / *Materials and technology*, 46 (2012) 2, 103-108

[13] Kundu, S., Das, S., and Saha, P. P. (2014): Optimization of Drilling Parameters to Minimize Burr by Providing Back-up Support on Aluminium Alloy. *Procedia Engineering,* 97, 230-240.doi:10.1016/j.proeng.2014. 12. 246

[14] R. Rajesh (2017: Effect of Chemical Treatment on the Mechanical Properties of Palm Fiber Reinforced Polymer composites, *Research Journal of Science and Engineering Systems,* Vol.1, pp.8-18.





Printed by Pradip Kumar Chanda at The Indian Press Pvt. Ltd. 93A Lenin Sarani, Kolkata 700 013 and published by him for Books & Journals Pvt. Ltd. from 62 Lenin Sarani, Kolkata 700 013.