International Journal of Pure and Applied Mathematics
Volume 119 No. 7 2018, 1069-1075
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue
ijpam.eu

Computer Aided Design of Deburring Tool and Taguchi Optimization for Minimization of Burr Size in Drilling of Al 2024

J Pradeep Kumar[1,2], K P Kishore[1,3], M Ranjith Kumar[1,4], K R Saran Karthick[1,5], S Vishnu Gowtham[1,6]

[1]*Department of Production Engineering, PSG college of Technology*

Coimbatore 641 004, India.

[2]jp.psgtech@gmail.com

[3]kishore95500@gmail.com

[4]neyranithkumar@gmail.com

[5]krsarankarthick@gmail.com

[6]vishnugowtham95@gmail.com

***Abstract*— In current industrial scenario, drilling process takes care about 35% of all the machining processes and influences the acceptability of the products. Al 2024 alloy is commonly used nonferrous material with wide variety of industrial applications such as aircraft fittings, gears, shafts and missile parts. Burr formation while drilling holes in Al 2024 alloy causes significant problems in product quality, cost and safety of workers. The existing burr removal methods are found to be cost intensive in terms of labour and time. This necessitates the need for designing a deburring tool to effectively drill holes. Drilling experiments are carried out using Taguchi's L9 orthogonal array. Significant cutting parameters like cutting speed, feed rate and point angle are considered as controllable input parameters and burr height is considered as output response parameter. Point angle is found to be the most significant parameter affecting burr size in Al 2024 alloy followed by cutting speed and feed rate. The fabricated deburring tool significantly reduces human intervention in deburring process and saves around 57.14% of time when compared to manual deburring a hole.**

***Keywords*— drilling; deburring; point angle; burr; Taguchi's L9**

I. Introduction

Burrs are undesirable or unwanted projections of the material formed as the result of plastic flow from cutting and shearing operations. This generally necessitates the application of costly additional operations such as reaming and deburring. The generation of burrs is typically influenced by various parameters including tool geometry and material, workpiece material properties, part geometry and process conditions [6]. Burrs interfere with assembly of parts, and cause jamming and misalignment. They may reduce the fatigue life of the parts since the hardened and brittle burr material can act as a crack initiation point. Debris of the burrs can cause serious damage on the moving parts. In electrical components, they can cause short circuits [8]. Furthermore, burrs can be a safety hazard to personnel in handling of the parts because of the sharp edges.

.A. *Burrs from drilling operation*

The drilling process produces burrs on both entrance and exit surfaces of the workpiece. The entrance burr forms on the entrance surface as material near the drill undergoes plastic flow. The exit burr is a part of the material extending off the exit surface of the workpiece. In drilling, the burr that forms at the entrance of the hole can be a result of tearing, a bending action followed by clean shearing or lateral extrusion. The burr that is formed when a sharp drill exists the workpiece is a Poisson burr resulting from rubbing at the margins of the drill. When a normal or worn out drill exists the uncut chip rolls, resulting in a rollover burr. Drilling burrs are categorized as uniform burr with or without drill cap, crown burr or petal burr and transient burr according to their shapes and formation mechanism [10].

The uniform burr has a relatively small and uniform burr height and thickness around the hole periphery. As the drill approaches the work exit surface, the material under the chisel edge begins to deform. The distance from the exit surface to the point where the deformation starts depends mainly on the thrust force during drilling. As the drill advances, the plastic deformation zone expands from the center to the edge of the drill. At the final step, initial fracture occurs at the end of the cutting edges creating the drill cap. The remaining material is bent and pushed out ahead of the drill to form the uniform burr with a drill cap [10].

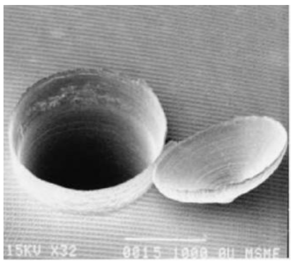

Fig. 1. Uniform burr with drill cap

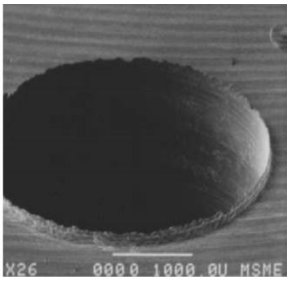

Fig. 2. Uniform burr without drill cap

The crown burr in both materials has a larger and irregular height distribution around the hole. A larger thrust force induces plastic deformation earlier in the process. The thicker material layer beneath the drill undergoes plastic deformation, and a larger maximum strain was induced at the center region of the exit surface. Therefore it is more likely that an initial fracture occurs at the center region of the exit surface, at the chisel edge, resulting in a crown burr. When there is considerable tool wear at the outer cutting edge of the drill, efficient cutting cannot be expected, and the material beneath the drill is pushed ahead rather than being cut. In this situation, there is a higher possibility of initial fracture occurring at the center region and creating a crown burr [10].

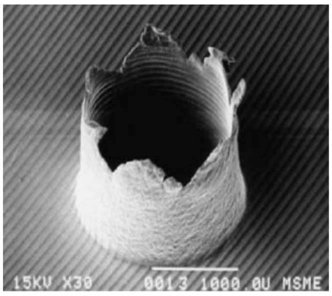

Fig. 3. Crown burr

The transient burr formed in the transient stage between a uniform burr and a crown burr. Initial fracture occurs near the end of the cutting edges similar to the uniform burr. However, this fracture occurs later than in uniform burr formation, creating a larger uniform section. As the drill advances further, the strain at the chisel edge exceeds the fracture strain of the material, and the crown burr type fracture occurs [10].

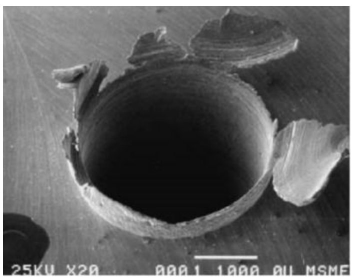

Fig. 4. Transient burr

II. LITERATURE REVIEW

Samir Ali Amin Alrabii [1] (2016) investigated on burr formation during drilling of low carbon and stainless steels and concluded that the average burr height for both steels generally reduced with increasing cutting speeds and feeds due to the change of burr type from a transient burr at lower cutting speeds and feeds to a uniform burr with and without a drill cap at higher speeds and feeds. No crown burrs were formed during drilling of low carbon and stainless steels. A.M. Abdelhafeez et al. [2] (2015) studied on burr formation and hole quality when drilling titanium and aluminium alloys and concluded that feed rate was statistically significant in relation to exit burr size for all the workpiece materials. Sanjib Kundu et al. [3] (2014) investigated on optimization of drilling parameters to minimize burr and observed that moderate cutting velocity, low feed and wet condition with water cooling were observed to minimize burr height using a back-up support. R. Das et al. [4] (2014) experimentally studied on burr formation in drilling of aluminum channels and reported that burr formation in channels highly depends on the spindle speed and drill bit diameter. The thickness of the channels also effect the burr formation. Kwon - Hee Kim et al. [5] (2012) designed a deburring tool for intersecting holes in aluminum alloys with a hemispherical cutter head mounted on a pivoted shaft which is loaded against burr edge by set of springs. The cutter head is inserted into intersecting hole upto the burr edge and is rotated counter clockwise with a return stroke. The cutter head size is selected such that it had accessibility to three dimensional burr edge. The cutting edge is selected to maintain proper range of rake angle and relief angle during deburring. The measured depth of cut on the burr edge confirms the complete removal of burrs. J.C. Aurich et al. [6] (2009) carried out an extensive review on the burr formation and control and defined that burrs are undesirable or unwanted projections of the material formed as the result of plastic flow from cutting and shearing operations. The authors indicated that the spindle speed and the feed force are important process parameters in burr formation. The authors conclude that deburring and cleaning make up for a considerable portion of manufacturing costs. Kyeong Uk Lee et al. [7] (2008) experimented three kinds of deburring tools for removing burrs at intersecting holes. The three tools were burr - off tool, burr - away tool and bier tool. Performance evaluation regarding tip size, shape of these deburring tools for cross and main holes were reported by the authors. V.N. Gaitonde et al. [8] (2008) observed that point angle has major influence on optimal burr height for drill diameters of 4 mm, 10 mm and 28 mm. Lip clearance angle has significant effect in reducing the burr height for 20 mm drill bit diameter and large point angle is required to minimize the burr height for higher drill bit diameters. K. Kim et al. [9] (2003) developed a drill capable of deburring. This tool incorporated a deburring cutter which is mounted on a cantilever located within a cavity in the shank of the drill. With the proposed design, mild exit burrs were completely removed. For large exit burrs, the deburring was incomplete. Jinsoo Kim et al. [10] (2001) categorizes drill burrs as uniform burr with or without drill cap, crown burr or petal burr, transient burr according to shapes. Different types of burr are formed depending on where the initial fracture occurs. The authors indicated that fracture at the center of the tip resulted in a larger crown burr. Fracture at the edge of the hole resulted in a smaller uniform burr. A transient burr was formed when fracture occurred at both locations simultaneously.

III. CONCEPT GENERATION

"Fig. 5," shows the concept generated for deburring tool with an objective to remove the burrs completely after drilling operation. The concept proposed such that the deburring tool can be fixed to the tool holder of the Computer Numerical Control (CNC) machine tools and deburring process can be carried out as the final operation by programming in the CNC. The concept generated for deburring tool has components such as outer casing, moving rod, top cap, spring and mounted point. The concept is spring loaded which helps the tool to adapt to the change in environment such as mounted point wear. In this concept, the spring is placed inside the outer casing below which the moving rod is assembled. A keyway is provided in the moving rod for sliding with the help of spring. Top cap is provided to support the spring. Mounted point is fixed in the moving rod.

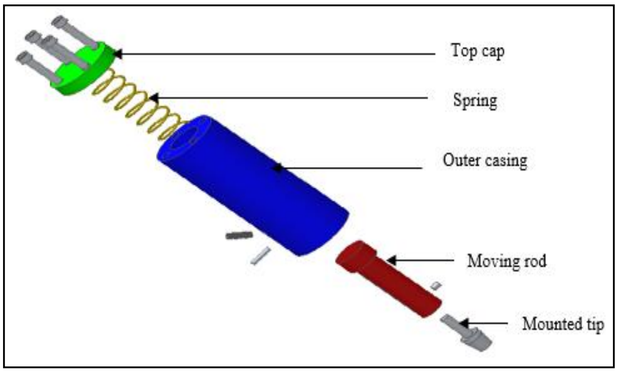

Fig. 5. Exploded view of deburring tool

IV. DESIGN CALCULATIONS

The fundamental design concepts for selection of spring in deburring tool is carried out.

- Wire diameter (d) = 1.5 mm
- Outside diameter (D_o) = 18.5 mm
- Inner diameter (D_i) = 15.5 mm
- Mean diameter (D_m) = 17 mm
- Total number of coils (n_t) = 10
- Number of active coils (n) = 8
- Modulus of rigidity (G) = 8300kgf/mm^2 {Spring steel - grade 2}
- Spring stiffness (K) = $\frac{Gd^4}{8D_m^3}$ = $\frac{83000 \times 1.5^4}{8 \times 17^3 \times 8}$ = **1.336 N/mm**
- Load on spring (F) = $\frac{\pi d^3 f_s}{8D_m}$ {f_s –shear stress} = $\frac{3.14 \times 1.5^3 \times 103}{8 \times 17}$ = **78.65 N**
- Deflection of spring = $\frac{8D_m^3 nF}{Gd^4}$ = **60 mm**

V. FABRICATION

The material selected for fabrication of deburring tool is EN 24 steel. Hardening of the components like outer casing, moving rod and top cap is carried out through induction hardening process before grinding. Hardness value of about 55 HRC to 60 HRC is achieved through induction hardening process. The functionality of outer casing is to accommodate other parts of the tool. It has a hollow chamber in which the spring is loaded. It has step at the end of the spring chamber over which the head of the moving rod will rest. The moving rod slides in and out of the outer casing and also carries the mounted deburring tip. The spring force acts on the head of the moving rod. The top cap confides the spring within the tool when pressure is applied on the moving rod. The top cap is held tightly to the outer casing by means of four M6 Allen head bolts. "Fig. 6," shows the fabricated deburring tool.

Fig. 6. Fabricated deburring tool

VI. EXPERIMENTATION

The experimentation is carried out with an objective to remove the burrs completely from drilling operation. The workpiece material used for experimentation is Al 2024 alloy and the machine tool used for experimentation is Vertical Machining Centre (VMC) LV 45.

A. Selection of parameters and drilling experiments

Taguchi method is used for execution of the plan of experiments, L9 orthogonal array is used for conducting drilling tests. Taguchi method is an experimental design technique, which is useful in reducing the number of experiments, decrease experimental time and reduce the cost. The three dominant process parameters such as cutting speed, feed rate and point angle are selected as controllable parameters for carrying out experimental trials. The range of these parameters are obtained based on initial experimental trials, machine tool capability and literature survey is shown in table 1.

Table I. Design factors along with levels

Code	Factors	Levels		
		1	2	3
A	Cutting Speed (m/min)	8	16	24
B	Feed rate (mm/rev)	0.04	0.08	0.12
C	Point angle (°)	118	126	134

The experimental treatments of combination of these parameters are shown in table 2.

Table II. L9 orthogonal array with design factors

Trial No.	Cutting speed (m/min)	Feed rate (mm/rev)	Point angle (°)
1	8	0.04	118
2	8	0.08	126
3	8	0.12	134
4	16	0.04	126
5	16	0.08	134
6	16	0.12	118
7	24	0.04	134
8	24	0.08	118
9	24	0.12	126

Experimentation is carried out on Al 2024 alloy as per L9 orthogonal array in the table 2. Blind holes of diameter 10mm are drilled in Al 2024 alloy to a depth of 20mm using HSS drill. “Fig 7,” shows burrs from drilling operation.

B. Field study on fabricated deburring tool

After the drilling tests, deburring operation is carried out in VMC LV 45. The deburring test is carried out for each and every hole at 500 rpm. “Fig 8,” shows the field study on deburring tool carried out in VMC LV 45.

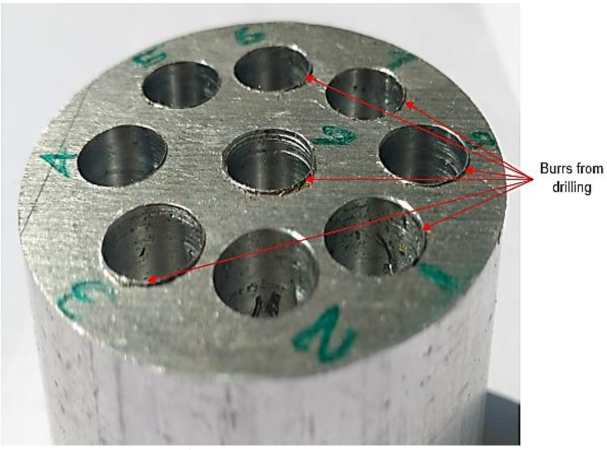

Fig 7. Burrs from drilling operation – Al 2024 alloy

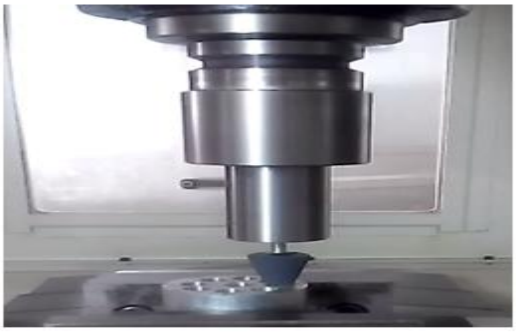

Fig 8. Deburring in VMC LV 45

“Fig 9,” shows the holes after deburring in Al 2024 alloy.

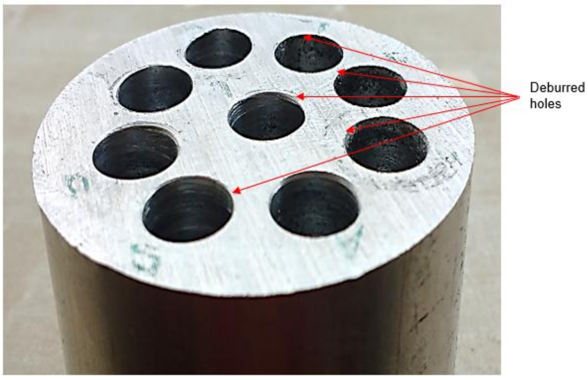

Fig 9. Holes after deburring – Al 2024 alloy

C. Experimental details – burr size and deburring time

Burr height values are recorded at four equally spaced locations around the circumference of hole with the help of profile projector ‘RPP 3000’ for Al 2024 alloy and average reading is taken as process response and deburring time for each and every hole in VMC LV 45 is recorded as shown in table 3.

Table III. Burr height and deburring time

Trial No	Burr height Al 2024 (mm)	Deburring time Al 2024 (sec)
1	0.220	12
2	0.270	13
3	0.429	16
4	0.370	15
5	0.342	14
6	0.296	16
7	0.512	15
8	0.313	12
9	0.402	16

VII. RESULTS AND DISCUSSION

Analysis of the experimental data obtained through Taguchi experimental design is carried out using MINITAB 17 software. Analysis of variance (ANOVA) is performed to establish relative statistical significance of factors in terms of their percentage contribution to the response. This analysis is performed on signal - to - noise ratios to obtain the contribution of each of the factors.

A. Influence of process parameters on burr size – Al 2024

Table 4, shows ANOVA results for S/N ratio of burr size in Al 2024 alloy.

Table 4. ANOVA for S/N ratio of burr size - Al 2024 alloy

Factor	Code	Degrees of freedom	Sum of squares	Mean squares	Contribution (%)
Cutting speed (m/min)	A	2	10.920	5.460	27.5
Feed rate (mm/rev)	B	2	4.180	2.090	10.5
Point angle (°)	C	2	21.406	10.703	53.9
Error		2	3.146	1.573	-
Total		8	39.652	-	-

A. Optimum combination of process parameters for burr size – Al 2024 alloy

It can be inferred from "fig 10," that cutting speed at low level (8m/min), feed rate at medium level (0.08mm/rev) and point angle at low level (118°) provides optimum combination i.e. A1B2C1 for minimization of burr size in Al 2024 alloy.

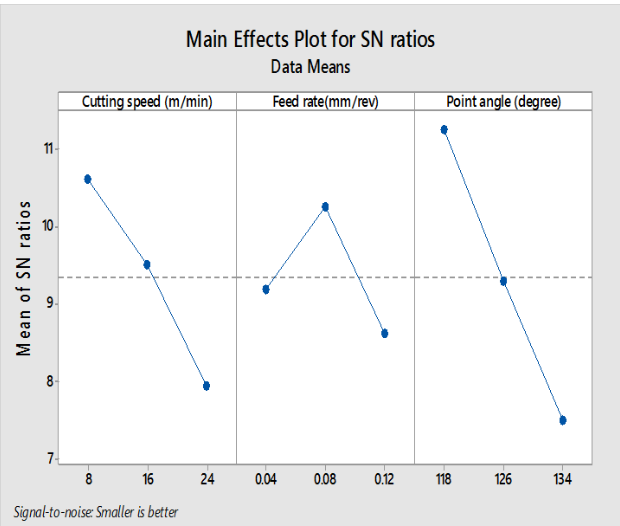

Fig 10. Main effects plot for S/N ratio of burr size - Al 2024 alloy

B. Regression equation

The relationship between the factors and the performance measures are modeled by quadratic regression. The burr height (B_h) model for Al 2024 alloy is given in equation (1). The coefficient of determination (R^2) for equation 1 is 93.66%.

$$B_h = 0.000339A^2 + 39.5B^2 + 0.000073C^2 - 0.0044A - 6.21B - 0.009C + 0.48 \quad \ldots (1)$$

Table 5. Predicted burr height values

Trial No.	Predicted B_h (mm) – Al 2024 alloy
1	0.249111
2	0.261111
3	0.408778
4	0.349778
5	0.371111
6	0.287111
7	0.503111
8	0.292778
9	0.43111

"Fig. 11," shows the comparison of experimental and predicted values of burr height in Al 2024 alloy.

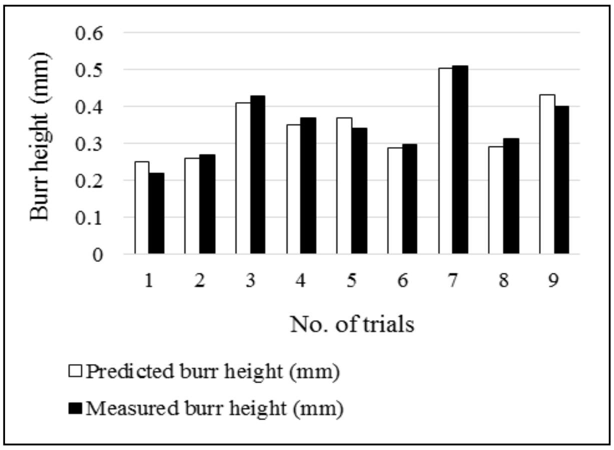

Fig. 11. Measured and predicted burr height in Al 2024 alloy

C. Confidence interval around the mean

For the present work, the formula for calculating the confidence interval (CI) around the estimated mean in the confirmation experiment is given in equation (2).

$$CI = [F(\alpha, 1, ve)\, Ve\, [1/\eta eff + 1/r]]^{1/2} \quad \ldots\ldots (2)$$

where, F (α, 1, ve) is the value of 'F' from F – tables for confidence level of (1- α), α is the level of risk, Ve is the error variance, ve is the degrees of freedom for the error, ηeff is the effective number of replications and r is the number of trials. The confidence interval (CI) is calculated as follows. η_{eff} is calculated using equation (3).

$$\eta_{eff} = \frac{N}{1 + U \text{ items in the estimate}} \quad \ldots (3)$$

N = Total number of experiments conducted = 9
U items in the estimate = 2
Substituting in the equation (3), ηeff = 3
α = 1 – confidence limits (95%) = 0.05.
Fratio (0.05, 1, 2) = 18.51 (from F tables)
CI = +/- [18.51 x 0.002003[1/3 + 1/5]] $^{1/2}$
CI = +/- 0.1406
The 95% confidence level of the predicted optimum of the burr height in Al 2024 alloy is given by:
[μ - CI] < μ < [μ + CI], 0.0495 < 0.1901 < 0.3307

D. Confirmation experiments

A successful confirmation experiment is defined as one where the average of the samples falls within the predicted confidence interval of the true mean. When the average of the results from the confirmation experiment falls within the confidence interval, it providence evidence that the significant factors as well as their levels are properly chosen. Five confirmation experiments have been conducted at the optimum settings of the process parameters obtained from the experiment. The results of the confirmation run are given in table 6.

Table 6. Results of the confirmation test

Trial No.	**Burr height (mm) Al 2024 alloy**
1	0.202
2	0.088
3	0.196
4	0.094
5	0.216
Average	0.159

E. Time study on deburring process

The time taken for deburring process in Al 2024 in VMC LV 45 is recorded and the values are shown in table 3. From the experiments conducted in the present work, the maximum time for deburring a hole in VMC LV 45 is found to be around 15 seconds. The manual deburring of a hole using hand deburring tool, file tool and pneumatic deburring tool takes around 35 seconds. The time taken for deburring a hole in VMC LV 45 by the newly designed deburring tool is found to save around 57.14% of time, when compared to manual deburring a hole. The newly designed deburring tool significantly reduces the human intervention in deburring process.

VIII. CONCLUSIONS

The following conclusions are made from the present investigation:

- Deburring a hole in VMC LV 45 by using the fabricated deburring tool significantly reduces human intervention and found to save around 57.14% of cycle time, when compared to manual deburring a hole.
- Point angle is found to be most significant parameter influencing burr size with 53.90% contribution in Al 2024 alloy.
- Cutting speed is the second significant parameter influencing burr size with 27.5% contribution in Al 2024 alloy.
- Feed rate is the least significant parameter influencing burr size with 10.5% contribution in Al 2024 alloy.
- Optimal parameters combination for minimizing burr size in Al 2024 is determined as A1B2C1 i.e. cutting speed at 8 m/min, feed rate at 0.08 mm/rev and point angle at 118°.
- The burr height in Al 2024 alloy is predicted with the help of quadratic regression model for the opted experimental conditions and the predicated values are in good agreement with the experimental values.
- The results of the confirmation test are found to be within the confidence interval around the mean which implies that the selected factors and their levels are properly chosen and are significant.

ACKNOWLEDGMENT

Authors wish to sincerely thank the management and principal of PSG college of Technology, Coimbatore for providing infrastructure and other facilities to carry out this research work.

REFERENCES

[1] Samir Ali Amin Alrabii, "Burr Formation Mechanisms during drilling operations of low carbon and stainless steels", *Engineering and Technology Journal*, Vol.34, Part (A), No.6, pp 1104 – 1115, 2016.
[2] Abdelhafeez A M, Soo S L, Aspinwall D K, Dowson A, Arnold D, "Burr formation and hole quality when drilling titanium and aluminium alloys", *CIRPe - Understanding the life cycle implications of manufacturing*, Vol.37, pp 230 - 235, 2015.
[3] Sanjib Kundu, Santanu Das, Partha Pratim Saha, "Optimization of drilling parameters to minimize burr by providing back-up support on aluminium alloy", *12th Global congress on manufacturing and management*, Vol.97, pp 230 – 240, 2014.
[4] Das R, Barik T, "An experimental study on the burr formation in drilling of aluminum channels of rectangular section", *5th International & 26th All India manufacturing technology, design and research conference,* IIT Guwahati, Assam, pp 831 – 835, 2014.
[5] Kwon - Hee Kim, Chang-Hee Cho, "Design of a deburring tool for intersecting holes in aluminum alloys", *Journal of Materials Processing Technology*, Vol.212, pp 1132 – 1138, 2012.
[6] Aurich J.C, Dornfeld D, Arrazola P.D, Franke V., Leitz V, Min S, "Burrs –Analysis, control and removal", *CIRP Annals - Manufacturing Technology*, Vol. 58, pp.519–542, 2009.
[7] Kyeong Uk Lee, Sung Lim Ko, "Development of deburring tool for burrs at intersecting holes, *Journal of materials processing technology*, Vol.201, pp 454 – 459, 2008.
[8] Gaitonde V N, Karnik S R, Achyutha B T, Siddeswarappa B, "Taguchi optimization in drilling of AISI 316L stainless steel to minimize burr size using multi-performance objective based on membership function" *Journal of materials processing technology*, Vol.202, pp 374 – 379, 2008.
[9] Kim K., Cho C., Jeon S., Lee K., and Dornfeld D, "Drilling and deburring in a single process, *Journal of Engineering Manufacture*, pp 1327 – 1331, 2003.
[10] Jinsoo Kim, Sangkee Min, Dornfeld A, "Optimization and control of drilling burr formation of AISI 304L and AISI 4118 based on drilling burr control charts", *International journal of machine tools & manufacture*, Vol.41, pp 923 – 936, 2001.