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Study on burr formation, tool wear and surface quality in machining Al6063

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Abstract

Drilling plays significant role in machining process for assembly operations. High-quality holes are possible with appropriate tools machine setup and proper selection of drilling process parameters. The significant issues in drilling are burrs formation, surface quality and tool wear, which impacts the final product's quality. This study examines the influences of process parameters on burr formation, surface roughness and tool wear. The work piece material selected is Al6063 which is commonly used in construction was drilled using different feed rates and spindle speed. The result shows that surface roughness and burr formation improve with increased spindle speed and decreased feed rate. Adhesion wear is more significant near the nose of the tool and less at cutting edges. Analysis of variance investigated that spindle speed has a high impact on surface roughness with a percentage contribution of 63.56 % than feed rate of 33.62 %.

Keywords: Drilling, Al6063, Burr formation, Surface roughness, Tool wear

1. Introduction

Aluminum and its alloys are abundantly used in aerospace, automotive and marine industries [1]. The demand for aluminum is rising globally and is anticipated to expand dramatically as more industries turn to lightweight materials [2]. Architectural alloy i.e., Al6063 is a medium strength alloy that is frequently used in construction. It is used in rail transport, road transport, shop fittings, extrusions, irrigation tubing window frames, door frames, roofs, sign frames, sports equipment and also used in architectural applications [3]. Drilling is most commonly and excessively manufacturing process used in various industries such as automotive industries, where a thousand numbers of holes are required for various assembly operations [4-6]. The drilling process is dependent on characteristics of work piece, cutting variables like n and f, and the type of coatings used on the tools. The problems related to the drilling operation is high cutting forces, generation of thick and longs chips, tool wear, high surface roughness, formation of burr and high circularity error [1, 7]. Therefore, unsuitable process parameters such as high f and n cause severe temperature which results into dimensional deviation and the failure of tool. A low quality holes generates burr formation and rapid tool wear results into parts rejection and hence increases the manufacturing cost and time [8]. High-quality holes can minimize the possibility of fatigue resulted from crack generation [3], resulting 60% parts rejection in final assembly. In order to ensure strict geometric tolerances, it is crucial to evaluate surface finish and creation of burrs in drilling process.

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Nomenclatures

HSS	High speed steel
n	Spindle speed
f	Feed rate
Ra	Surface roughness
MRR	Material removal rate
DOC	Depth of cut
BUE	Built up edge
BUL	Built up layer

In previous study different analytical and experimental methods were used to enhance the machinability or drilling performance of Aluminum alloys. Khan et al. [3] absorbed the effect of n and f on MRR and Ra in drilling Al6063 using Taguchi method. The result shows that n of 600 rpm, f of 0.10 mm/rev and tool diameter of 6 mm were absorbs to be optimal combination of drilling process for Ra and MMR. Sivaraj, Bernard et al. [9] studied of the three cutting parameters n, f and drill diameter and allowed them to optimize the thrust force produced during drilling Al6063. The result indicates that drill diameter influences thrust force more than n and f. Thamizhvalavan et al. [10] reported the machinability studies on Al6063/B4C/ZrSiO4 by using abrasive water jet machining. During the experiments abrasive flow rate, traverse rate, abrasive mesh size and water jet pressures were varied and their effects were examined on the MMR, DOC and Ra. The results indicated that abrasive mesh size was absorbed to be dominant parameter for higher MMR, depth of cut and lower Ra. Chandra et al. [11] investigated the process optimization of electric discharge machining parameters while machining three simples Al6063, Flyash and Al_2O_3 using Taguchi techniques. The result shows that tool wear and MRR depends on impulse current and increases as impulse current increases. Krishnan et al. [12] looked into how well lubrication worked using HSS drill bit during drilling in AA6063-T6. The outcome shows that minimum quantity lubrication has improved burr height. As the material's temperature rises, it becomes more malleable and forms chips, which affects the burr size. Ko and Lee et al. [13] reported a unique HSS drill bit in order to explore impact on burr height when drilling Al6061-T6 and SM45C. The findings demonstrated that a smaller cutting edge corner radius and a larger point angle had minimized burr height. Reddy et al. [14] optimized simultaneously the drilling limitations while drilling an Al6063/TiC composite based on grey relational analysis. The study clearly takes into account drilling parameters including helix angle, n, f, and response such temperature, cutting forces and Ra. The best parameter levels were determined using grey relational grading, and ANOVA was also used to measure the significant role of constraints. Under SEM, the surface of drill-holed composite specimen was examined and SEM images of the composite face that had been drilled highlighted the charisma of grooves, microcracks and dents. Ravichandran et al. [15] examine the impact of various drilling parameters in machining AA6063 in a CNC lathe using a high-speed steel drill bit. The results of the investigations show that the f, n, and depth of cut all have a direct impact on the MRR. It was found that the MRR rises steadily with respect to f, n, and frequently for depths of cut.

The above study suggests that how important is drilling process. A numerous machining studies were performed on Al6063. However, limited study is performed on burr formation, tool wear and surface roughness in drilling of Al6063 which needs further investigations. The objective of the current study is to study the effect of n and f on burr formation, tool wear and surface roughness. Therefore, the current study describes the effect of n and f on burr formation and tool wear. Moreover, the current work also analyzed surface quality in terms of Ra during dry drilling of Al6063.

2. Material and Method

In this study a single drill head was mounted on the vertical milling machine. The experimental setup has been demonstrated in Fig 2. The values of f were taken on the basis of available milling machine specification. Al6063 alloy plate has dimensions of 110 mm x 60 mm length and width respectively. The work piece dimensions are as shown in Fig 2a. It was investigated that drill vibration has a high effect on drilling performance because higher vibration causes low quality holes having low accuracy. Therefore, the workpiece was placed and fixed on milling machine table using nuts and bolts to reduce the vibrations. The systematic of fixture to hold workpiece is shown in Fig 2b. The HSS is recommended for dry condition of aluminium alloys. An uncoated HSS twist drill tool is used with a helix angle of 30º and point angle of 130º. All experiments were performed through dry drilling without the use of coolants to reduce the problems and cost associated with chips recycling. A digital microscope is used for inspected the hole quality on both inlet and exit of the holes. A surface roughness tester (Mitutoyo SJ-201) was used to measure Ra. The workpiece was rotating along its edges of 0º and 90º and then average value was taken for the evaluation. The equipment's detail and experimental condition are as shown in Table 1.

Table 1. Equipment detail and experimental conditions

Experimental details	
Workpiece material	Al6063 plate Lx W (110 mm x 60) mm, thickness = 10 mm
Drill bits	HSS, diameter 10 mm, helix angle 30º, point angle 130º
Machine tool	Vertical milling machine
Drilling condition	Dry conditions
Surface roughness	Surface roughness tester Mitutoyo SJ-201
Burr formation	Optical microscope
Tool Wear	Optical microscope

Design of experiment is used to describe drilling parameters that leads to affect the output variable significantly [6]. As indicated in Table 2, a full factorial experiment with two input factors, such as n and f, having three different levels was designed using Minitab 21. The effect of input factors on the response was finally determined using Analysis of variance (ANOVA). In a current study, n and f are input parameters and Ra is the response variables which should be investigated through ANOVA method.

Table 2 Cutting parameters

Level	**1**	**2**	**3**
Spindle speed (rpm)	308	548	720
Feed rate (mm/min)	50	150	250

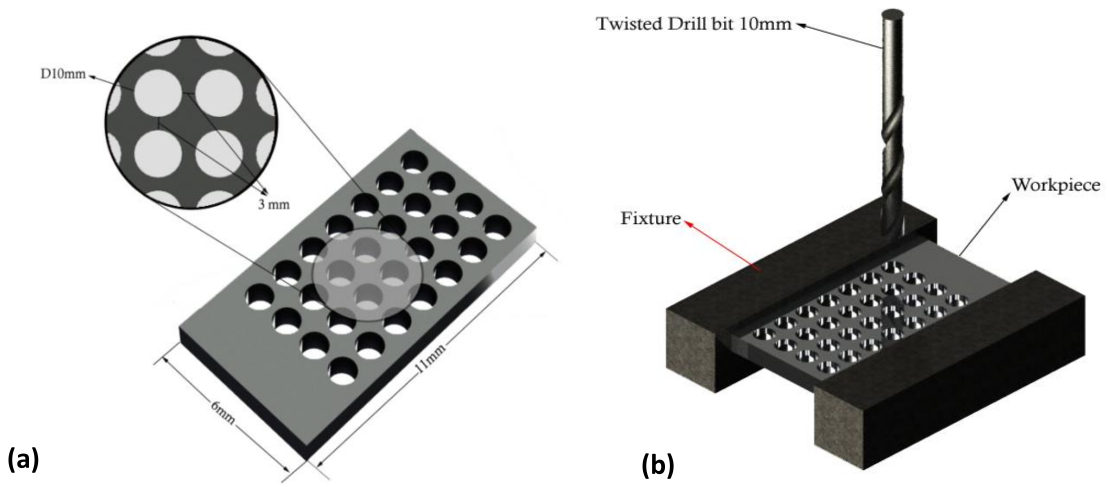

Fig. 1. (a) Work piece dimensions (b) Fixture to hold work piece

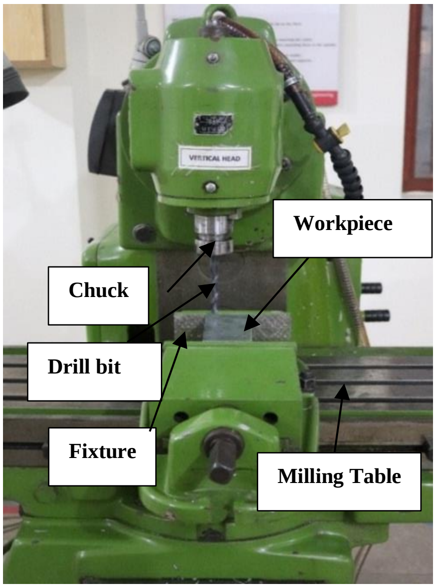

Fig. 2. Experimental setup

3. Results and Discussion

3.1 Burr formation

The burrs formation depends on various parameters like drilling parameters, drill geometry and material properties of the workpiece [16]. Burrs formation results in many problems, including dimensional deviation and arise need for deburring which employ above 30-40% of the total cost of the finished product [16]. In addition to that, deburring performed manually [17] and accounts for 40% of the total machine time which reduces the productivity [18]. The inlet and exit hole images at various drilling parameters are as shown in figure 4. Yazman et al. [19] explained three various types of burrs formation i.e. uniform, transient and crown burrs generate during drilling process as shown in Fig. 3. Among these types, crown burrs generate at the exit hole are considered worst of all burr types and require more care due to its shape irregularity, size enlargement and bend outwards [16, 19, 20].

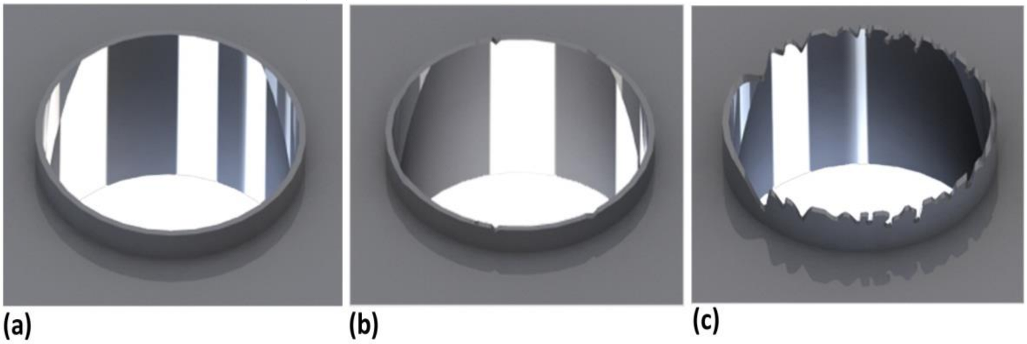

Fig. 3. Types of bur formation (a) uniform (b) Transient (c) Crown

In this work, visual inspection of the burrs formation, indicates that more prominent burr formation absorbs at exit holes than burrs generates at the inlet holes, which is in good agreement with Uddin et al. [21]. Moreover, further observation disclosed that burrs generate at the exit of drilled hole are mostly uniformed. Fig 4 shows that f is more influence on burr formation than n. However, n also has some impact on burr formation, particularly at high f. According to Kurt et al. [22] this might be due to the dynamic behavior of the tool, when the tool come in contact with the workpiece initially, high vibration is induced. Moreover, high temperature at the workpiece-tool interface due to high n and f might results in plastic deformation around the edges of the drilled holes [23].

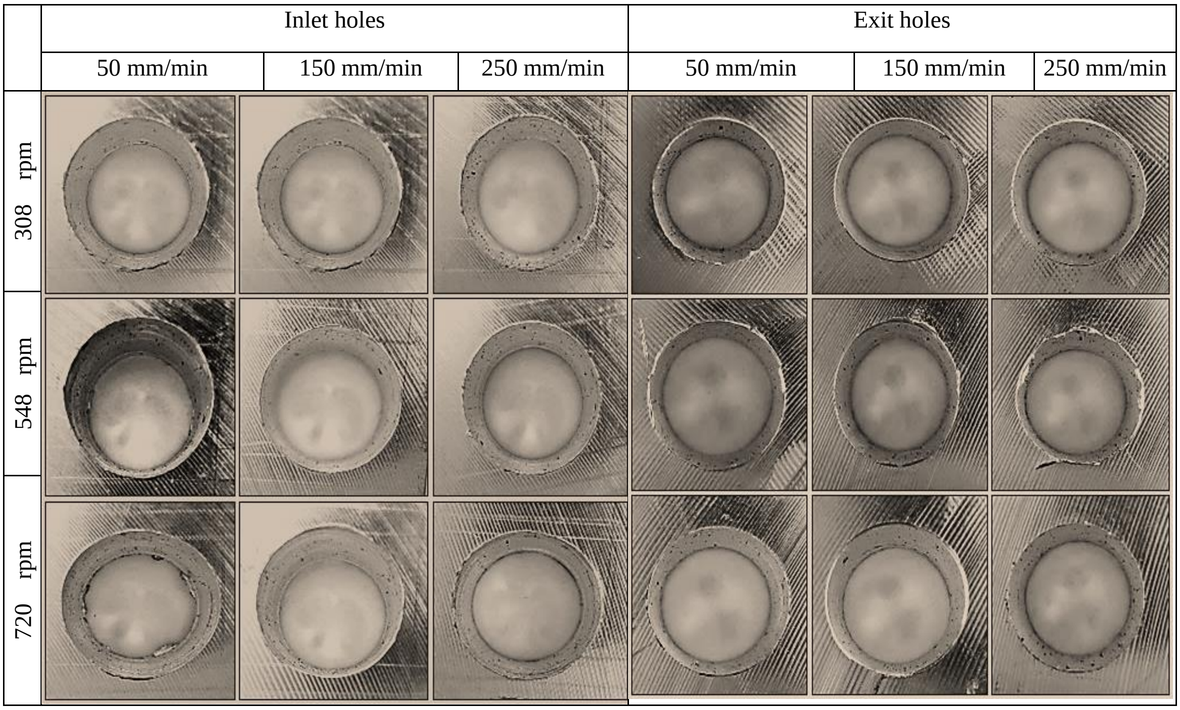

Fig. 4. Burr formation

3.2 Tool wear

Tool wear analysis is essential for enhancing productivity of manufacturing process, which has greater impact on final cost. The cutting environment, tool material and workpiece, kind of coating and the machining parameters all affect the wear modes. Based on the tool wear mechanism, the appropriate tool material selection leads to a longer tool life [24]. Tool wear is caused by metal to metal friction between workpiece and tool, which raises temperature and generates stresses [25]. The higher material removal rate and friction energy during the machining process may increase the temperature at high cutting parameters. This increase in temperature softens the material, causing it to undergo plastic deformation. As a result, the material melts and accumulates on the tool, resulting in adhesion and BUE production [26]. In current work, formation of BUE and BUL generates adhesion wear as shown in Fig 5. Chip material transfer on the tool cutting face causes BUE and BUL to occur [27, 28]. In drilling aluminum alloy, the tool-chip contact temperatures can reach significant levels and are adequate to initiate the diffusion process in aluminum [29, 30]. Furthermore, in current study the generation of high BUE is due to the formation of large chips [26].

Fig. 5. Tool wear

3.3 Surface roughness

Surface roughness play crucial role in assessment of a workpiece machining performance [31]. It is observed that both f and n have effect on Ra. The reported Ra values varied in the range of 1.6µm and 2.6µm as shown in Fig 6. Ra has direct relation with f and inverse relation with n. This phenomenon is reflected in the previous studies. The Ra value decrease with increase in n is due to the contact of tooltip with chip for shorter time that results decrease in Ra. Moreover, the other reason is the surface temperature of hole wall that softens the material and reduces resistance against tooltip [32]. The third reason might be due to the increase in ductility of material with increase in temperature [33]. However, the Ra value is directly affected by the f. This is because a considerable thrust force is required to deform a thick layer of chip, which causes the tool to vibrate more aggressively and provide a poor surface finish [31, 34]. From ANOVA table 3 it is absorbs that n has more effect on Ra than f having percentage contribution of 63.56 % while f has 34.33 %.

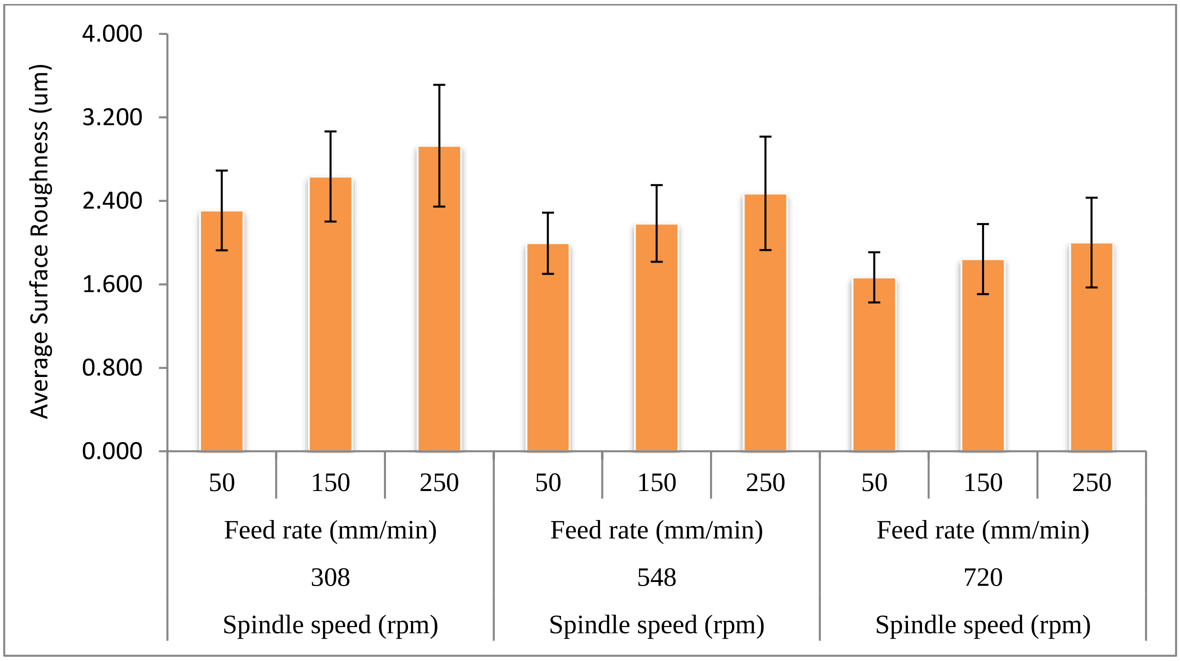

Fig. 6. Surface Roughness

Table 3 ANOVA analysis of Ra

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	4	1.2241	97.89 %	1.2241	0.851998	213.99	0.001
Linear	4	1.2241	97.89 %	1.2241	0.851998	213.99	0.001
Spindle speed	2	0.92631	63.56 %	0.92631	0.516124	127.34	0.000
Feed rate	2	0.58368	34.33 %	0.58368	0.335874	86.65	0.001
Error	4	0.01658	2.11 %	0.0165	0.003768	-	-
Total	8	1.33387	100.00 %	-	-	-	-

4. Conclusion

The effects of feed rate and spindle speed on tool wear, burr formation and subsequently on surface quality of holes during dry drilling of Al6063 is illustrated as below.

Feed rate is most effective on burr formation than spindle speed. However, spindle speed has also some impact on burr formation, particularly at high feed rate. The burr formation raises as spindle speed and feed rate increases. A visual inspection and microscopic images of the burrs formation absorbs that the burrs at exit were more prominent than the burrs observed at holes inlet. Surface roughness has direct relation with feed rate and inverse relation with spindle speed. However, spindle speed has more influence on surface roughness than feed rate. The percentage contribution of spindle speed is 63.56 % on surface roughness than feed rate of 33.62 %. An adhesion wear appears by the formation of the BUE and BUL. Adhesion wear is more significant near the nose of the tool and less at cutting edges.

Future study should consider high drilling parameter and finite element modeling to investigate how these factors hole quality.

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