Parametric optimization of burr height reduction and machining time in drilling operation on stainless steel specimen

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Abstract: Drilling is one of the conventional methods of producing a hole of the desired shape by removing material with the help of a cutting tool named drill bit. The process of drilling a hole usually leaves behind an undesirable burr at the exit surface of the workpiece. In this experimental work, the design of experiment (DOE) has been carried out as per Taguchi’s L₂₇ orthogonal array with an objective to minimize the height of burr (exit side) of stainless steel (SS) workpieces. The effect of process parameters like varied cutting speed, changes in feed and cutting fluid on burr height as well as machining time has been explored and the optimum condition for minimizing burr height under normal condition, using adhesive and with a backup support is determined by the entire experimental analysis. Response surface methodology and analysis of variance (ANOVA) have been performed to find out the optimum process parameters on burr height and machining time. With the progress of experiment, it has been observed that burr height is greatly influenced by the variation of speed, feed and cutting fluid whereas, cutting fluid has less impact on machining time reduction as compared to the varied speed and feed with adhesive and backup material condition.

1. Introduction
Drilling is a type of machining process in which holes are made on a job by removal of material, with the help of a sharp cutting tool, called drill bit. Drilled holes are generally circular, but may have other shapes as well, which can be developed using a special type of drill bits. Holes to be generated can be through holes or blind holes and the choice of the drills to be used depends on the dimension of the hole and size of the job. Drilling can be performed on almost all solid materials, including hard materials like cast iron, glass etc. to soft materials like wood, rubber and polythene [1]. Drilling does not produce an accurate hole in a workpiece. The internal surface of the hole so produced by drilling becomes rough and the hole is always slightly oversized than the drill used due to the vibration of the spindle and drill. Edges which differ from the desired dimensional accuracy after machining are referred to as burrs [2]. The entrance burr is formed around the hole when the drill enters into the material. The exit burr is formed on the other side when the drill pierces the material and pushes out the uncut material [1-2]. Burrs generated by the process can significantly affect the functionality of the manufactured part, quality of the product, assembly process and also involve risks of injury or cause damage in following operations. So, in order to remove the burrs from the job, two methods are
commonly adopted. The first method is to remove the burrs by deburring process following the machining operations. But, deburring is the process of removing burrs from the surface which can conclude a considerable time and cost factor [3]. Therefore, the second method of burr minimization strategies can be preferred to optimize machining in order to decrease burr formation. Aurich et al. [4] experienced that, expenses for deburring can add up to 9-30% of total manufacturing and machining costs. A lot of research works had been done in this area and the burr size in different materials was being analyzed by varying the parameters on which it depends. Kundu et al. [5] managed to minimize the burr height of Al alloy by providing backup support on the exit side, even, Ko et al. [6] observed that burrs formed in step drilling operation with step edge produced smaller burr height compared to the conventional drilling operation. In order to find the effect of different process parameters on burr height, Shanmugasundaram et al. [7] came to know that for Al-Gr composite materials feed was the most influential parameters on burr height formation. Chang et al. [8] managed to develop a burr height prediction model during their experiment on aluminium alloy.

In the present work, burr formation and machining time have been studied during drilling on stainless steel workpieces in different cutting conditions like pasting adhesive to the exit side and providing backup support on the exit surface of the specimens. Comparison and analysis have been made on the different burr sizes according to Taguchi’s L₂⁷ orthogonal array to find out the optimized process parameters condition for the burr height reduction and machining time.

2. Experimental procedure
Drilling operations have been performed on a Precision Jig Boring machine having a vertical column mounted upon the base and is supplied with a power feed arrangement. The spindle attached to the supporting motor and driving mechanism can make the rotation to the drill bit of desired speed, feed rate and cutting condition and thus enables to generate hole of required shape and size considering the required process parameters. Experimental details about the workpiece being used, cutting tool and machining conditions are given in Table 1.

| Table 1 Experimental details |
|------------------------------|
| Drilling machine             |
| Machine: 220V, 3 Phase Precision Jig Boring Machine |
| Make: Aciera, Le Locle-Suisse, Switzerland |
| Speed range: 40-3600 RPM; Feed range: 0-0.5 mm/rev; Control: Digital read |
| Drill bit                    |
| Type: Twist drill bit        |
| Material: HSS; Make: Addision, Mumbai |
| Drill diameter: 5 mm; Cutting angle: 108°; Overall length: 85 mm |
| Workpiece used               |
| Material: SS (Grade 304)     |
| Composition (%): C- 0.08, Mn-2, Si-1, P-0.04, S-0.03, Cr-19, Ni-9, Fe-rest |
| Size: 50mm × 50mm × 5mm      |
| Machining conditions         |
| Level | Speed(RPM) | Feed(mm/min) | Cutting fluid |
|-------|------------|--------------|---------------|
| 1     | 1440       | 0.02         | Dry           |
| 2     | 2060       | 0.04         | Water         |
| 3     | 2470       | 0.1          | Coolant       |

Design of experiment is carried out according to Taguchi’s L₂⁷ Orthogonal Array [9]. This approach helps to understand better, how the change in levels of parameters affects the response. Speed, feed and cutting fluid type are varied three times from 1440 rpm to 2470 rpm, 0.02 mm/min to 0.1 mm/min and dry-water-coolant conditions respectively.
This investigation work has been performed on 9 different square blocks on which 3 holes have been made on each of the blocks for three different conditions i.e. normal; with adhesive and with backup material support to observe the machining time and burr height on the exit side. Dendrite glue is being used as an adhesive material whereas; wooden blocks are used as a backup material on the exit side of the workpieces. Machining time is measured using a stopwatch and burr height is measured by Vernier Caliper.

3. Results and Discussion
The experimental data obtained corresponding to the design of experiment is based on Taguchi’s L$\text{27}$ Orthogonal Array. In this work, burr height and machining time are taken as response parameters. For the analysis of signal (mean) to noise (standard deviation) (S/N) ratio, Taguchi’s smaller-the-better concept has been considered [10]. Signal to noise (S/N) ratio plots for burr height and machining time are shown in the following figures. The main effect plot of the S/N ratio for the response i.e. burr height for stainless steel in normal, with adhesive and with backup material condition, are shown in Fig.2, Fig.3 and Fig.4 respectively. Likewise, machining time for the above three conditions are plotted in Fig.5-7 respectively.
Fig.2-4 indicates the S/N ratio plot to minimize burr height under different cutting conditions. In Fig. 2 the most effective value of speed is 1440 rpm, feed is 0.04 mm/min and the most effective cutting fluid condition is dry. Fig.3 clearly states that, while using adhesive at the exit side of the specimen, the most effective values of speed is 1440 rpm, feed is 0.02 mm/min and the most effective cutting fluid condition is dry. Also from Fig.4, it is clearly observed that, during drilling process with backup material support at the exit side of the specimen, the most effective speed and feed found to be is 1440 rpm and 0.02 mm/min respectively and the most effective cutting fluid condition is dry as well. It has been observed that lowest speed 1440 R.P.M is most significant in order to reduce burr height because it can provide more precise machining rather than higher speed. Fig.5-7 indicates the S/N ratio plot to minimize machining time under different cutting conditions, the most effective values of speed, feed and cutting fluid conditions are found to be 2470 rpm, 0.04 mm/min and water respectively for normal, with adhesive and with backup material. So, from the above S/N ratio plots it is significantly understood that, for minimum machining time, the most effective parametric values are 2470 rpm, 0.04 mm/min and water respectively. Highest speed is the most effective parameter in order to reduce machining time as it takes less time to complete the operation. Using water as cutting fluid is also very effective in order to reduce M.T. as it can control the temperature of the machining zone optimally compared to other cutting fluid. Response surface methodology (RSM) is also applied for prediction of burr height (B.H.) and machining time (M.T.). The objective of generation of a surface plot is to find out the expected value of response corresponding to any of the two input parameters. Fig.8-10 depicts response surface plots of burr height for stainless steel. These plots also indicate interaction effects on the response variable.

In the Fig.8 interaction between feed and cutting fluid while the speed value of 2470 rpm is kept constant produces a significant effect on the B.H. (as the curvature of this surface plot is pronounced). In the same manner in Fig.9 interaction effect between speed and cutting fluid while the feed value 0.1 mm/min is kept constant and interaction effect between feed and cutting fluid while speed value of 2470 rpm kept constant produce significant effect on the B.H. Also in Fig.10 interaction effect between speed and cutting fluid and interaction effect between feed and cutting fluid produces significant effect on B.H. Rest of the plot does not show much bend or curvature, so they do not have significant effect on burr height.

The response surface plots of machining time for stainless steel has been interpreted and utilized in the same manner as discussed earlier in context of surface plots of burr height. The entire surface plot represents the interaction effects of parameters on machining time which is significant. Fig.11-13 represents the surface plots under various conditions. Among all the three plots there is no any significant graph which has curve or bend. So, there are no prominent factors among speed, feed and cutting fluid which is significant on the reduction of machining time.
Fig.11-13 Effect of combined parameters on M.T. in different conditions

Fig.14-16 depicts the process optimization by desirability function. Desirability function is one useful approach to optimize multiple responses by utilizing the simultaneous optimization technique. It is mainly based on the idea that the ‘quality’ of a product or process that has multiple quality characteristics [11].

At the individual desirability, it has its own factor set for each response variable which most probably has different factor setting. In fact, in a single experiment, it will have a single factor setting which is required to optimize all response variables. The problem is solved through composite desirability. The obtained values of composite desirability D for normal condition, with adhesive and with backup material, are 1.0000, 0.90187 and 0.86136 respectively to get a setting factor which will optimize all response variables. The entire investigation work has been carried out with an aim to achieve optimization of process parameters and machining conditions for effective reduction of burr height. Effective reduction of burr height has shown in Fig.17.

From the experimental work and ongoing results analysis, it is quite clear that with varying speed, feed rate and cutting fluid condition in combination with normal drilling, drilling with adhesive and drilling with backup material can cause the most significant effect on burr height as compared to machining time reduction. Following Fig.18-26 reveals the effective burr height reduction under some specific cutting parameters. These plots indicate that significant reduction of burr height can be reached up to 39.81% and 48.88% with pasting adhesive and use backup material respectively. That means, drilling with varying process parameters in combination with backup material provides the most effective burr height reduction as compared to the normal and with the adhesive condition. This may due to backup and adhesive create an obstruction in burr formation which helps to reduce burr height significantly.
4. Conclusion
In this experimental work, the objective is to reduce B.H. and M.T. of drilling operation over stainless steel specimen. It has been observed that the lowest speed (1440 R.P.M) for B.H. reduction and highest speed (2470 R.P.M.) for M.T. reduction are the most significant whereas; in case of feed it is varying under different conditions. It is also found that machining under dry condition reduces B.H. significantly rather than other conditions. But in case of M.T. reduction water used as cutting fluid provides the most significant result. The height of burrs is observed through normal drilling condition, with adhesive (exit side of the specimen) and providing back-up support of which burr height is found quite less using a back-up support compared to the other drilling conditions. The optimum testing condition is achieved indicating a significant reduction in burr height which is about 48.88% using a backup material along with other process parameters. The analysis of variance also reveals profound influence of speed, feed rate and different cutting fluid conditions on burr height for the test material. Burr height is found to be most affected by variation of speed and feed rate than cutting fluid condition while supporting backup material. Likewise, machining time is found to be influenced by changing speed and feed rate rather than varying speed and cutting fluid condition or feed rate and cutting fluid condition. Interaction effects between feed rate and cutting fluid are found most effective in controlling burr height with backup support whereas interaction effect between speed, feed rate and cutting fluid condition does not produce any such effective measurement for machining time.
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