Experimental Study to Minimize The Burr Formation in Drilling Process With Artificial Neural Networks (ANN) Analysis

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Abstract. In present work, drilling of a through a hole in an aluminium bar has been observed the formation of a burr. The unwanted material raised beyond the work piece called burr. The minimization of the burr is important for manufacturing aspect which reduces cost and increases the life of the product. In this paper drilling on aluminium work piece experimental test has been conducted three parameters drill diameter, Point Angle and spindle speed and each of the parameter three different level (maximum, intermediate and minimum)value has been chosen. The each set of an experiment the burr height and thickness has been measured. The effect of each parameter which reduces the burr height and thickness has been identified. In this paper, artificial neural networks (ANN) model are developed for comparing the experimental results. The ANN modeled values show very close matching with the experimental results.

1. Introduction
The drilling process is the most commonly used in any manufacturing industry, any industry about 25\% operation is carried out hole-making operation [1]. The plastically deformation of the work piece material which is attached beyond work piece surface termed as burr, the quality of the product depends upon it. The precision application Burr is the major problem, the extra cost is required for duburring operation. The deburring operation suggested by Gillespie [2] and Tankazawa[3]. An Analytical model is developed by Kim and Dornfeld [4] for related to the burr formation for the ductile material. The many researchers are investigated using coolant, exit surface modification, backup support for minimization of burr in drilling process[5-8].Some researchers did the analysis and optimization with the help of optimization tool like as Taguchi’s orthogonal array, response surface methodology, etc. for designing experiments [9], GA and RSM based[10], ANN based [11], and many others for making models to predict and minimize burr formation. Karnik et al. [12] tried to minimize burr size in drilling stainless steel workpieces with the use of genetic algorithm (GA) and Taguchi method of designing experiments.Gaitonde and Karnik [13] utilized artificial neural networks (ANN) and particle swarm optimization (PSO) approaches for optimal selection of drilling parameters to achieve minimum burr size (height and thickness) during drilling within the domain of experiments.
The objective of the experiment is to measure the burr height and thickness of the burrs obtained under different sets of the machining parameters. The parameters chosen are spindle speed, drill bit diameter, point angle, and to find out the condition for quite low or no burr formation and artificial neural networks (ANN) analysis to compare the experimental data analysis.

2. Experimental Setup
The objective of the experiment is to measure the burr height and thickness of the burrs obtained under different sets of the machining parameters. The parameters chosen are spindle speed, drill bit diameter, point angle. The Table 1 shows for the experimental setup.

Table 1. Experimental setup

| Machine Tool | Drill | Drill Material | Job Material | Job Size       |
|--------------|-------|----------------|--------------|----------------|
| A press drill | Drill dia of 8.65mm, 9.50mm, 11.45mm (HSS) | High-Speed Steel | Aluminum Bar | 150mm x 39mm x 12 mm |

3. Experiment Procedure
The aluminum bar was tightly clamped in the vice. The spindle speed was measured with help of Tachometer. During the experiment, the 3 different spindle speeds are chosen 626, 1262 and 2213 rpm. This was done to obtain the exact spindle rotation speed. The bars were initially marked and punched for the sake of making the holes at an even distance of separations. A pilot drill run was initially, made before actual drilling process. Initially, it was ensured that the Twist drills of 3 different diameters: 8.65mm, 9.50mm, 11.45mm had the same point angle (118°). Then a total of 9 observations were recorded for each of the twist drills (3) corresponding to 3 different spindle speeds. All the drill bits were then ground to a smaller point angle (104°) and the next set of observations taken. For the third and final set of observations, the drill bits were ground to 86°. Thus a total of 27 observations were taken. Cutting fluid was used every time a hole was drilled. Digital Vernier Caliper in Fig 1 was used to measure the height of the burrs on a surface plate. The height at four diametrically opposite positions was taken and the average was taken as the final burr height. The same procedure of measurement and calculations was adopted for burr height.

4. Experimental results and discussion
The drilling experiments were done by the following Table 2. The effect of the drill dia, point angle and spindle speed on drilling burr height and burr thickness studied, the experimental and artificial neural networks (ANN) results showing burr height and burr thickness. The Details of ANN analysis will be discuss section 5 and section 6.

The photographic view of the set of experiments according to the Table 1 is given in Fig 2.

Fig. 1 Digital Vernier Caliper
Fig. 2 Photographic view of the experiment
Table 2. Experimental and ANN predicted results of burr height and burr thickness

| Hole NO | Point angle (degree) | Drill bit dia. (mm) | Speed rpm | Burr height (mm) | ANN Predicted burr height (mm) | Burr thickness (mm) | ANN Predicted burr thickness (mm) |
|---------|----------------------|---------------------|-----------|-------------------|-------------------------------|---------------------|----------------------------------|
| 1       | 86                   | 8.65                | 626       | 5.69              | 6.095                         | 0.783               | 0.8748                           |
| 2       | 86                   | 8.65                | 1262      | 3.44              | 3.558                         | 0.485               | 0.4813                           |
| 3       | 86                   | 8.65                | 2213      | 6.66              | 56.58                         | 0.655               | 0.6713                           |
| 4       | 104                  | 8.65                | 626       | 4.80              | 4.718                         | 0.38                | 0.4013                           |
| 5       | 104                  | 8.65                | 1262      | 3.91              | 3.993                         | 0.68                | 0.661                            |
| 6       | 104                  | 8.65                | 2213      | 4.40              | 4.46                          | 0.85                | 0.8432                           |
| 7       | 118                  | 8.65                | 626       | 2.90              | 3.079                         | 0.43                | 0.3958                           |
| 8       | 118                  | 8.65                | 1262      | 4.57              | 4.708                         | 0.39                | 0.5106                           |
| 9       | 118                  | 8.65                | 2213      | 4.30              | 4.286                         | 0.505               | 0.5147                           |
| 10      | 86                   | 9.50                | 626       | 6.65              | 6.645                         | 0.770               | 0.7865                           |
| 11      | 86                   | 9.50                | 1262      | 6.84              | 6.833                         | 0.95                | 0.9596                           |
| 12      | 86                   | 9.50                | 2213      | 4.63              | 4.645                         | 0.845               | 0.8513                           |
| 13      | 104                  | 9.50                | 626       | 4.62              | 4.142                         | 0.403               | 0.3733                           |
| 14      | 104                  | 9.50                | 1262      | 3.36              | 3.315                         | 0.445               | 0.4595                           |
| 15      | 104                  | 9.50                | 2213      | 3.67              | 3.337                         | 0.760               | 0.7822                           |
| 16      | 118                  | 9.50                | 626       | 3.50              | 3.329                         | 0.356               | 0.3908                           |
| 17      | 118                  | 9.50                | 1262      | 6.10              | 6.077                         | 0.445               | 0.439                            |
| 18      | 118                  | 9.50                | 2213      | 5.23              | 5.194                         | 0.595               | 0.6036                           |
| 19      | 86                   | 11.45               | 626       | 5.78              | 5.828                         | 0.835               | 0.8138                           |
| 20      | 86                   | 11.45               | 1262      | 6.98              | 7.036                         | 0.69                | 0.6824                           |
| 21      | 86                   | 11.45               | 2213      | 4.695             | 4.618                         | 0.785               | 0.7918                           |
| 22      | 104                  | 11.45               | 626       | 2.65              | 2.706                         | 0.57                | 0.5737                           |
| 23      | 104                  | 11.45               | 1262      | 4.43              | 4.223                         | 0.485               | 0.514                            |
| 24      | 104                  | 11.45               | 2213      | 3.59              | 3.594                         | 0.40                | 0.3844                           |
| 25      | 118                  | 11.45               | 626       | 2.445             | 2.531                         | 0.410               | 0.3955                           |
| 26      | 118                  | 11.45               | 1262      | 6.36              | 6.378                         | 0.703               | 0.6789                           |
| 27      | 118                  | 11.45               | 2213      | 3.26              | 3.3                            | 0.290               | 0.31                             |

Fig. 3 Burr Height (mm) vs Point Angle (degree) at 8.65 mm Drill Bit diameter

Fig. 4 Burr Height (mm) vs Point Angle (degree) at 9.50 mm Drill Bit diameter

The Fig 3 shows the intermediate point angle (104°) was found to be the optimum parameter in minimizing the burr height at varying speeds. This can be attributed to the fact that when the step edge passes the exit side of the workpiece, the work material at the bottom side of the step edge remains...
rigid and the cutting operation continues since it withstands the thrust force until the step edge exits. For too small a point angle the resistance offered would be higher and hence the temperature rise would aggravate the burr formation while too large a point angle would require a large piece of material to remain rigid till the step edge exits thereby maximizing the burr height. It is interesting to note here that the above explanation holds only for the maximum speed data. For intermediate speed, though the burr height increases on increasing the point angle (to 118° from 104°) the same is not true if the point angle is reduced. The positive influence of shifting the point angle from an intermediate level on the burr height is thus negated by the favorable machining provided by low feed. Similar arguments hold for the curve plotted for minimum speed.

For Fig 4 shown the deviation from the expected trend of increase in burr height with a shift in point angle from an intermediate level for the minimum speed is not observed due to the varying feed provided during operation. Fig 5 shows the for minimum spindle speed at higher point angle decreasing the burr height.

For Fig 6 and Fig 7 the spindle speed increases, heat generation increases at the interface between the tool and work piece. It increases the plasticity of the Al alloy which increases the burr height. For the latter part of the curve in case of maximum point angle the trend is explained due to lowering of feed. Also in the initial part of the curves for minimum and intermediate point angle the decreasing trend of the curve with increasing spindle speed is again due to decrease in feed on respective occasions.

For Fig 8 we see that the curve for burr height with spindle speed follows the expected trend. The latter part of the curves are explained due to a decrease in feed which provides a favorable condition for machining. The similar pattern observed in the Fig 9.

Fig. 5 Burr Height (mm) vs Point Angle (degree) at 11.45 mm Drill Bit diameter  
Fig. 6 Burr Height (mm) vs Spindle Speed(rpm) at 8.65 mm Drill Bit diameter

Fig. 7 Burr Thickness(mm) vs Spindle Speed(rpm) at 8.65 mm Drill Bit diameter  
Fig. 8 Burr Height (mm) vs Spindle Speed(rpm) at 9.50 mm Drill Bit diameter

Fig. 9 Burr Height (mm) vs Spindle Speed(rpm) at 11.45 mm Drill Bit diameter

5. Artificial Neural Networks (ANN) Modeling
The ANN is computer model of process and mechanisms, its consists of an interconnected group of artificial neurons similar to the biological nerves system. ANN has ability to learn from the
environment and adapt to it in an interactive manner similar to biological counterpart. The training process involves set of input patterns with known outputs (target output). The system adjusts the weights of the internal connection to minimize errors between the network output and target output. After the neural network satisfactory trained and tested, it is able to generalize rules and will be able to respond to input data to predict output, within the domain covered by the training example. There are several algorithms used in a neural network, in present study Levenberg-Marquardt multi-layer feed forward back propagation training algorithms of the Artificial Neural Networks (ANN) used in this work in Matlab package. In this algorithms is an iterative gradient designed to compute the connection weights minimizing the total mean-square error between the actual output of the multilayer network and desired output. Multilayer feed forward back propagation consists of an input layer, hidden layers and an output layer. A general feedforward neural network for present study is shown in Fig10.

Fig. 10 A typical feed forward neural network

6. Using ANN for Testing and Experiment Validation

ANN based burr size modeling is done using MATLAB software using neural network tool box with maximum number of epochs 1000. Initial and maximum values of mu (a factor promoting convergence of a network by a typical iterative method) are 0.001 and $10^{10}$ with the decreasing and increasing factors of 0.1 and 10, respectively. Minimum performance gradient (MSE) considered is $10^{-7}$. The number of input 3 (Point angle, Drill Dia and Speed) and the output is 2 (burr height and burr thickness) for the network design maximum number of hidden neuron in hidden layer is equal to (2x number input + number of output) for each layer here considering 2 hidden layer and total number of hidden neuron8 for each layer and also observing after setting 2 hidden layers there is no such much change in result when hidden layer is one so network design is optimize design. The neural networks are first trained with a date set. There are total 27 experimental data sets. These dataset are shown in Table 2, Train ratio 80/100, validation ratio 10/100, and testing ratio 10/100 has been chosen from the dataset. The comparison of experimental findings and neural network estimates of burr height is displayed in Fig 11 and burr thickness displayed Fig 12. It is found that the NN model estimates are having quite close matching with the experimental data, barring few deviations, and showing the effectiveness of the algorithm for modeling the input output system to outline the possibility of estimation of burr height within the experimental domain. Occasionally, only small deviations are observed between the estimates and measured burr height. This may be due to the inherent experimental variability of the machining system and possible existence of high degree of nonlinearity in the system[13].

Fig.11 Experimental and ANN estimates of burr height for training patterns.     Fig.12 Experimental and ANN estimates of burr thickness for training patterns
7. Conclusion
Drilling covers a wide spectrum of machining operations and is inherently accompanied with burr formation. It is observed from results that at maximum drill dia, higher point angle and minimum spindle speed minimum burr height is produced, also observed that higher drill dia, higher point angle and maximum spindle speed minimum burr thickness produced. The neural network analysis shows that the experimental and predicted ANN model results are very much close matching small deviation observed. This may be due to the inherent experimental variability of the machining system and possible existence of high degree of nonlinearity of system.

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