Abstract

Drilling is one of the widely used and complex processes in manufacturing. Burr is one of the most commonly encountered problems in drilling. These burrs interfere with assembly of parts, cause jamming and misalignment. The burrs pose reliability problems and performance degradation in precision parts. The burrs produced on components lead to many undesirable features in practice, such as improper contact between current carrying members and improper seating of mating surfaces. Burrs are injurious during machining; as they hit the cutting edge and cause the groove wear.

The formation of exit burr on part edges during drilling has several undesirable features with regard to product quality and functionality. When the exit burr is formed inside a cavity, there are no tools available for deburring. In this case, very special tools must be used, thus increasing the deburring cost. Usually, this deburring process is done manually because of difficulties in automation, requires additional time and may damage the edges resulting in workpiece rejection. It may also cause high cost in edge finishing of precision parts. Hence, it is essential to understand the factors affecting the formation of burrs at the exit of the holes in drilling so as to reduce the burr size at the production stage.

The principal objective of this research work is to carryout the drilling process optimization, influenced by the cutting conditions and the drill geometry during drilling of AISI 1045, AISI 1018 and AISI 316L work materials using HSS twist drills. The drilling optimization is performed to determine the optimal values of cutting speed, feed, point angle and lip clearance angle for a specified drill diameter that simultaneously minimize burr size, namely, burr height and burr thickness.
The multi-objective drilling optimization problem is carried out using two different approaches. In the first approach, genetic algorithms (GA) is employed with mathematical models of burr size developed using response surface methodology (RSM). Taguchi optimization methods using the existing techniques of utility concept and quality loss function have been employed in the second approach. In addition to these existing methods, a method based on a new concept of fitness function has been introduced for multi-objective Taguchi optimization. The fitness function is derived through mapping of the objective functions of drill optimization problem.

For the development of mathematical models on the basis of experimental data, careful planning of the experiments is essential. The experimental planning based on design of experiments (DOE) requires minimum number of experiments and hence reduces cost and time of experimentation. A five level half replicate second order rotatable central composite design is used to study the linear, quadratic and two factor interactions between the five process variables and the responses. Hence, the drilling experiments have been performed as per design matrix and corresponding burr height and burr thickness values are recorded.

The regression coefficients of the burr size models are determined and the response surface equations are statistically validated. ANOVA is used to check the adequacy of the burr size models. The goodness of fit of the models is checked by the coefficient of determination. The second order burr size models are validated by the chi-square test and the model diagnostic checking has been done by the graphical analysis of the residuals. The random experiments are conducted within the ranges of the selected process parameters to test the reliability of the prediction models.

The response surface analysis has been carried out to analyze the direct and significant interaction effects of the drilling process parameters on burr size. The direct effects are used to analyze the burr size with the variation of one parameter at a time, while all the remaining process parameters are held at the center levels. On the other hand, the interaction
effects, represented by the response surface plots, are used to analyze the
burr size due to variations of two dominant factors keeping the other factors at
the center level. The analysis reveals that AISI 316L work material produces
larger exit burrs as compared to AISI 1018 and 1045 materials. Due to high
degree of interaction, the effects of the process parameters on burr height and
burr thickness are different and vary from material to material. Thus, from the
response surface analysis, it becomes difficult to decide on a suitable
combination of input process parameters.

The traditional methods of optimization and search do not fare well
over a broad spectrum of problem domains. The traditional techniques are not
efficient when practical search space is too large and are inclined to obtain a
local optimal solution. Hence, it has been decided to employ GA as an
optimization technique. The computations of GA are carried out in three
stages, namely, selection, crossover and mutation, to get a result in one
generation. The optimization is carried out for specified drill diameter values
and finding the optimal values of cutting speed, feed, point angle and lip
clearance angle. Thus, the chromosome consists of 4 genes corresponding to
four searching parameters. In the present study, each gene is represented by
7 bits of binary codes and hence a chromosome is of length 28 bits. The
decoded values of genes along with the specified diameter are employed with
the developed RSM burr size models of all the materials selected to predict
burr height and burr thickness. The chromosome fitness is obtained by linear
mapping of the predicted burr height and burr thickness. The simulation of the
genetic optimization is performed with maximum number of 100 generations.
The experimental values are then compared with the GA predicted values.

Experiments are also performed as per $L_9$ orthogonal array for
specified drill diameter values for the Taguchi optimization. The multi
response signal to noise ratio associated with the burr height and burr
thickness for each trial of orthogonal array is determined for three different
methods, namely, Taguchi with utility concept, Taguchi's quality loss function
and Taguchi with fitness mapping method. ANOM is carried out to determine
the optimal levels of the process parameters. ANOVA is performed on multi
response signal to noise ratio to obtain the percentage contribution of each of the factors. The optimal values of the process parameters are then validated with the verification experiments.

The optimization results indicate that the optimal parameter settings vary from material to material and depend upon the drill diameter in order to minimize the burr size. From the optimization studies, it has been demonstrated that the results of GA optimization closely agree with that of the Taguchi design using fitness mapping. It is also observed from the optimization results of AISI 316L work material that all the methods exhibit low levels/values of cutting speed, feed, point angle and clearance angle for all the drill diameter values. Hence, it has been decided to investigate the effects of the process parameters on optimal burr size for the higher drill diameter values during drilling of AISI 316L materials. From the optimization results of GA and Taguchi, it is observed that the optimal values of cutting speed and lip clearance angle are independent of drill diameter for minimizing the burr size. On the other hand, larger point angle and low to medium feed values are required to minimize the burr size at higher drill diameters in drilling of AISI 316L materials.