Optimising cutting parameters in boring operation for C45 steel

G Jangali Satish*, H K Madhusudhana, Bentur H Nishant, B B Kotturshettar
School of Mechanical Engineering, KLE Technological University, Hubballi, Karnataka, India
E-mail: jangalisatish@gmail.com

Abstract: This paper describes the work carried out on C45 steel subjected to boring operation and development of an optimum set of parameters to be adopted for boring process to get better surface finish and increase the material removal rate (MRR). The design of experiments (DOE) technique is used to carry out the experiments and the results are analysed using the statistical tool. From the analysis, it is observed that the spindle speed and rake angle has a significant effect on the surface roughness, whereas the variations in the rake angle did not have any effect on the MRR.

Keywords: Boring operation; C45 steel; cutting parameters; design of experiments; material removal rate; optimisation; surface finish

1. INTRODUCTION

In machining, boring is the way toward developing a gap that has just been drilled by methods for a solitary point cutting devise, for example, in drilling a weapon barrel or a motor chamber. Boring is utilised to accomplish more prominent precision of the breadth of an opening and can be used to cut a tapered hole. Boring can be seen as the internal-diameter complement to turning, which cuts exterior diameters. Boring carries the opening to the correct dimension and finish. The boring tool can work to any distance across and it will give the necessary wrap up by modifying speed, feed and nose radius. The exactness of holes can be bored using micro adaptable boring bars. Boring will fix the first drilled or cast opening. Drills, particularly the more drawn out ones, may stray focus and cut at a slight point as a result of unusual powers on the drill, intermittent hard spots in the material, or lopsided honing of the drill. Cored openings in castings are rarely totally straight. The boring tool being moved straight along the ways with the carriage feed will address these mistakes. Boring will make the hole concentric with the outside diameter within the limits of the precision of the chuck or holding devise. For best concentricity, the turning of the outer diameter and the boring of the inside diameter is done in one set-up-that is, without moving the work between tasks.

The literature survey was carried out to know the characteristics, different properties along with the study of the process of boring and its process parameters for the C45 steel material, further optimisation is carried using Design of Experiment concept from various sources.

Peter Michalik et al. have performed the geometrical parametric study on milling of thin-walled components. They studied the effect of parameters on surface roughness. The experiment has been done in two phases- up milling and down milling for left and right side of thin-wall components with a thickness of 10 mm. The surface roughness (Rz) was evaluated and the mathematical model was generated for constant cutting conditions and different geometrical parameters [1]. M. Stembalski et
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al. presented a technique for deciding the coefficient of erosion as a component of sliding velocity and normal weight for various contact sets of materials utilised in rubbing dampers [2]. Creators have depicted a scientific connection portraying the impact of sliding rate and ordinary weight on the grinding coefficient for C45 and 40HM steel. The creators have made a 3D numerical model and calculations were performed utilising the Abacus/Standard programming bundle.

I. Magnabosco et al. investigated to break down the impact of acceptance heat treatment on an ISO C45 steel bar during the experimentation both standardised and toughened examples were considered. The procedure parameters were executed in a numerical with the point of anticipating the warm and metallurgical history of the material. The point of this work was to make a thermo-metallurgical model of the acceptance heat treatment approved by trial results [3]. The test results (microstructure and small scale hardness profiles) were contrasted with the numerical qualities and a palatable understanding was found. Marcin Hojny conducted a test to examine the mechanical conduct of C45 Grade Steel Deformed in Semi-Solid State in which the demonstrating of strain-stress relationship, which is the principal mechanical property normal for the conduct of C45 grade steel exposed to plastic distortion in a semi-strong state [4, 5, 6]. The correlation between numerical and exploratory outcomes is additionally a piece of the introduced paper. Tadeusz Leppert published an article on the impact of cooling and oil conditions on surface geography and turning procedure of C45 steel. Here utilised the traditional strategy for cooling and greasing up, high-pressure stream helped to the machine, and least amount oil procedure. The information acquired by exploring is being used to make two unique models; to be specific, counterfeit neural system (ANN) and versatile systems based fluffy derivation frameworks (FIN) for the expectation of cutting parameters on surface geology [7]. Hae-Sung Yoon et al. presented a paper wherein the investigation gives an outline of the force effectiveness of machining forms at different scales, and contrasts the productivity and different procedures and revealed information [8, 9, 10]. Force effectiveness was determined to utilise trial results from ordinary processing, miniaturised scale boring, and brushing. It was additionally determined dependent on provides details regarding traditional processing procedures and laser-helped turning [11, 12].

Wit Grzesik studied the surface trustworthiness created by diagonal turning of C45 carbon steel was evaluated by methods for 2D and 3D surface harshness parameters, strain-solidifying impacts and related leftover burdens. It was archived that diagonal machining performed with moderately higher feed rate permits getting lower surface harshness and, all in all, bettering bearing qualities. Besides, compressive worries with the most significant worth found near the machined surface and with an illustrative profile can be drafted into the surface layer [13].

1.1. Introduction to Design of Experiments
Design of Experiments (DOE) is a deliberate strategy to decide the connection between factors influencing a procedure and the output of that procedure. At the end of the day, it is utilised to discover circumstances and logical results connections. This data is expected to oversee process contributions to request to streamline the output. When all is said in done use, DOE or trial configuration is the arrangement of any information-gathering rehearses where assortment is accessible, whether or not under the full control of the experimenter or not.

Notwithstanding, in insights, these terms are normally utilised for control. Formal arranged experimentation is used frequently in assessing physical items, synthetic plans, structures, parts, and materials. Different kinds of study, and their structure, are examined in the articles on PC trials, surveys and genuine reviews (which are sorts of observational examination), regular analyses and semi tests (for instance, semi exploratory plan) [15].

In the structure of tests, the experimenter is frequently intrigued by the impact of some procedure or intercession (the "treatment") on specific articles (the "test units"), which might be individuals,
portions of individuals, gatherings of individuals, plants, creatures, and so forth. Structure of examinations is in this way, control that has widespread application over all the regular and sociologies and designing.

1.2. Properties of C45 steel
C45 steel is medium carbon steel (roughly 0.3–0.6% carbon content) is utilised when more prominent quality and hardness is wanted than in the "as moved" condition. Extraordinary size precision, straightness and concentricity join to limit wear in fast applications. Turned ground and cleaned. It is cold worked steel [14].

| Chemical properties of C45 steel | C | Si | Mn | Cr | Mo | Ni | Others |
|---------------------------------|---|----|----|----|----|----|--------|
| Percentage composition of carbon| 0.4-0.5 | 0.4 | 0.65 | 0.4 | 0.1 | 0.4 | (Cr+Mo+Ni)=0.63 |

From the table 1, the percentage composition of carbon is between 0.4-0.5 and hence C45 is medium carbon steel.

| Mechanical properties of C45 steel | Density (Kg/m3) | Elongation (%) | Tensile strength (MPa) | Yield strength (MPa) | Young's modulus (MPa) |
|-----------------------------------|----------------|----------------|-----------------------|---------------------|----------------------|
| 7850                              | 16             | 600-800        | 340-400               | 210000              |

One can understand the mechanical properties of C45 steel from table 2. The C45 steel material process parameters for the boring operation are considered and then optimised. A process variable, process worth or procedure parameter is the present status of a procedure levelled out. Estimations of procedure factors are significant in controlling a method. The procedure variable is a powerful component of the process which may change quickly.

Accurate measurement of process variables is essential for the maintenance of accuracy in a process. The process is optimised without violating constraints.

1.3. Need analysis
C45 steel finds its applications in spindles of machine tools, bolts, shafts, keys, bigger gears, mould housing, fasteners, window frames, mould plates etc.

Referring to the different contents for C45 steel material and undergoing through various journal papers the drawn issue was that almost all the mechanical property testing was done for C45 steel material and process parameter analysis and optimisation was done for turning operation. In today's world of manufacturing, hole-making activities find a lot of applications in many components. Hence, it is necessary to study the parameters affecting the hole making processes which would increase the yield.

Also, many of the small scale industries can’t afford to purchase CNC machines in which high quality of surface finish can be obtained. Hence, they will go for process optimisation by undertaking experimental studies to reduce the investment on machines, to get a better surface finish and increase the material removal rate (MRR).

1.4. Problem definition
To study the effect of process parameters during boring operation on C45 steel using Turret Ram Milling Machine (M1TR) and optimise the cutting parameters (tool geometry, cutting speed and feed rate) to increase the surface finish and material removal rate.
1.5. Objectives
Objectives are essential tools that underlie all planning and strategic activities of the work to be carried out. They serve as the basis for evaluating performance. The goals were set for the optimisation of the process parameters for boring operation on C45 steel by considering different constraints.

- Identify the relationship between causes (tool geometry, cutting speed and feed rate) and effects (surface finish and material removal rate).
- Facilitating the understanding of interactions among the factors and their combined effect on responses in the experiment.
- Finding the levels at which the controllable factors are to be fixed to optimise the measure of performance of the experiment.

Scope provides the deadline or the boundary within which the work has to be carried out. The scopes for the presenting work are as follows:

- This study is restricted to boring operation only.
- In this study, only three factors and three levels of each factor are considered.
- Two responses are considered for optimisation.
- The experiment is done accordingly with the specifications of the Turret Ram Milling Machine (M1TR).

2. METHODOLOGY

The methodology is the systematic, hypothetical investigation of the techniques applied to a field of study. It includes the hypothetical examination of the collection of methods and standards related to a part of the information.

2.1. Experimental procedure

- Identification of process parameters, levels and responses.
- Design the experiment based on the factors, levels and responses. Also mention the number of replications.
- Preparation of workpiece by turning, facing and drilling.
- Drilling operation is carried out on the lathe machine.
- The drilled hole is enlarged by using a boring tool. The boring tool is attached to a boring head which is attached to the machine tool.
- The bored holes are tested for surface roughness using the talysurf, and the Ra values are noted.

MRR is obtained using the formula:

\[ MRR = V_c \times f \times DOC \]  \hspace{1cm} (1)

Where,

\( MRR \) – material removal rate (mm³/min)
\( V_c \) – cutting speed (mm/min)
\( f \) – Feed rate (mm/rev)
\( DOC \) – depth of cut (mm)

The results are analyzed for optimization.

2.2. Workpiece preparation

A C45 bar of 32 mm diameter is cut down into the pieces of length 23 mm. then the bar is turned to 31 mm diameter by lathe machine at 750 rpm. And further, the length is reduced to 22 mm. After
turning and facing the workpiece is pallet hole of 10 mm drilled by drill bit on lathe itself at 750 rpm, then it enlarged by 23 mm drill bit at 120 rpm, then the workpiece is finally chamfered to remove sharp edges.

2.3. Tool design and grinding

The tool used in the experimentation is prepared by grounding the High-speed steel (HSS) tool bits of 4” × 3/16” × 3/16”. The tool nomenclature for the tool is decided by referring to the standard nomenclature for C45-HSS work-tool combination. The tool is initially modelled in modelling software. Based on the design, the HSS tool bits are ground in the Surface Grinding Machine.

For grinding, inclining and setting up the tool at an angle, the following instruments were used:

- Sine vise
- Bevel protractor
- M-83 Slip gauges

Initially, the sine vise is mounted on to the surface grinding machine, and the angle is set to 7° using the slip gauges. Figure 1 shows the setup of Sine vise. The measurement of an angle is performed using the following relation:

\[
\sin \theta = \frac{H}{L}
\]

(2)

Where,

- \( \theta \) – Angle of inclination of sine vise
- \( H \) – Height of slip gauges to be mounted on the sine vise
- \( L = 100 \text{ mm} \), the length of the sine bar (fixed)

![Figure 1. Sine vise](image)

Apart from this, the tool bit, in turn, is inclined at 52° so that 7° relief angle is formed on the tool apart from the 45° reference angle. This is because; the boring operation is carried out at the 45° tool approach to the workpiece.

Similarly, the other angles are formed based on their corresponding slip gauge heights.

Once the bits are ground as per the nomenclature, they are mounted on the boring head. The boring head is in turn mounted on the M1TR machine tool, and the experimentation is carried out.

2.4. Experimental design

The experiment is designed considering three factors and three levels of each factor and three replications are carried out.

Factors are cutting speed, feed rate, and back rake angle of the boring tool. Responses are material removal rate (MRR) and surface finish.

\[
(\text{Level})^{\text{factor}} \times \text{no of replications} = \text{No of experiments}
\]

\( 3^3 \times 3 = 81 \)
Table 3 is the factorial table showing different levels of factors considered concerning MITR machine specifications.

| Factors/levels     | Units | 1   | 2   | 3   |
|-------------------|-------|-----|-----|-----|
| (A) Spindle speed | rpm   | 550 | 925 | 1460|
| (B) Feed rate     | mm/rev| 0.038| 0.074| 0.15|
| (C) Rake angle    | degree| 10  | 12  | 15  |

Surface finish, additionally known as surface texture or surface topography, is the idea of a surface as characterised by the three qualities of lay, surface roughness, and waviness. It includes the little nearby deviations of a surface from the impeccably level perfect (a true plane).

The Talysurf is an electronic instrument working on carrier modulating principle. This instrument gives information much more rapidly and accurately.

3. RESULT AND DISCUSSIONS

As a part of the study to test the effect of speed, feed rate and back rake angle of the tool upon the Surface Roughness and MRR, the assessment was made of the three levels of each factor. In the study, determination of the optimum Ra value and MRR can be predicted by the optimum value of spindle speed, feed rate and rake angle.

From the analysis of variance measured at 5% level of significance for 95% confidence interval, it is observed as seen from table 4 that the spindle speed and back rake angle are 0.001 which is less than the 0.05 of probability. Hence it implies that both factors, i.e., spindle speed and back rake angle, are having a significant effect on the surface roughness.

Table 4. Analysis of Variance for surface Roughness (Ra)

| Source             | DF | Seq SS | Adj SS | Adj MS | F    | P    |
|--------------------|----|--------|--------|--------|------|------|
| Spindle speed (rpm)| 2  | 36.600 | 36.600 | 18.300 | 7.81 | 0.001|
| feed (mm/rev)      | 2  | 7.147  | 7.147  | 3.587  | 1.53 | 0.223|
| rake angle (deg)   | 2  | 37.320 | 37.320 | 18.660 | 7.96 | 0.001|
| Error              | 74 | 173.378| 173.378| 2.343  |      |      |
| Total              | 80 | 254.473|        |        |      |      |

Whereas for feed rate, the p-value is 0.223, hence there is no significant effect of feed rate on the surface roughness.

Table 5. Analysis of Variance for MRR

| Source             | DF | Seq SS | Adj SS | Adj MS | F    | P    |
|--------------------|----|--------|--------|--------|------|------|
| Spindle speed (rpm)| 2  | 15.1508| 15.1508| 7.5754 | 99.45| 0.000|
| feed (mm/rev)      | 2  | 33.5577| 33.5577| 16.7789| 220.28| 0.000|
| rake angle (deg)   | 2  | 0.0000 | 0.0000 | 0.0000 | 0.00 | 1.000|
| Error              | 74 | 5.6367 | 5.6367 | 0.0762 |      |      |
| Total              | 80 | 54.3452|        |        |      |      |

From the table 5 analysis of variance measured, it can be observed that the p-value for the spindle speed and feed rate are 0.000; hence it implies that both of these factors are having a significant effect
on the MRR. But for the back rake angle, the p-value is 1, so it means that it has no significant impact on the MRR at all.

The main effect plot in figure 2 shows the response means for each factor level in sorted order. The effects are the difference between the main and reference line; the feed rate effects on surface roughness are small as compared to spindle speed and back rake angle. It is also seen that spindle speed when move from the lower level to higher-level surface Roughness decreases. And for feed rate, it is understood that when it moves from low to high level, the surface Roughness increases at 0.74 mm/rev of feed rate and further decreases on the next level. Similarly, for rake angle when it moves from low to a high level, the surface Roughness decreases at 12 degrees of rake angle and further becomes slightly increases on the next level.

An interaction plot is a plot of means for the level of two factors with the level of 3rd factor held constant. This interaction plot in figure 3 shows the effect of the interaction of various factors on surface roughness at different levels. The legend shows different levels of the factors used in the above representation. From the above interaction plot, it is noticed that there is apparent interaction between the factors because the lines are not parallel, since greater the departure of a line from the parallel state the higher the degree of interaction. So this is implying there is an effect of interactions of factors on the surface roughness. The spindle speed with minimum Ra value depends on the feed rate. Specifically, at spindle speed 1460 and 925, the surface roughness is minimum at feed rate 0.038 mm/rev. The spindle speed with minimum Ra value depends on the rake angle. Specifically at spindle speed 1460rpm and rake angle 12degrees the surface roughness decreases. The feed rate with minimum Ra value depends on the rake angle. Specifically at feed rate 0.038mm/rev and rake angle
12 degrees the surface Roughness is minimum.

The main effect plot in figure 4 displays the response mean for each factor level in sorted order. The rake angle effect on MRR is negligible as compared to spindle speed and back rake angle as there is no deviation from the reference line. It is also seen that spindle speed when moving from lower level to higher level MRR improves. And for feed rate, it is understood that when it moves from low to a high level, the MRR increases with a great extent. For rake angle when it moves from low to high, there is no effect on MRR at all.

This interaction plot shows the MRR for each of the factor. The legend shows different levels of the factors used in the above representation. From above interaction plot, i.e. figure 5, it can be noticed that there is very less interaction between the factors, because the lines are parallel since greater the departure of a line from the parallel state the higher the degree of interaction. But only in the first plot, there is little interaction between the spindle speed and feed at feed rate 0.074 mm/rev. So this is implying that the effect of factors on the MRR. In the second plot, there is no interaction at all between the spindle speed and rake angle because all the lines are parallel at every level. Similarly, from the third plot, there is no interaction at all between the feed rate and rake angle because all the lines are parallel at every level.
4. CONCLUSION

By experimenting with the effect of speed, feed rate and back rake angle upon the Surface Roughness and material removal rate (MRR). From the analysis of variance, it is observed that there is a significance effect of speed and rake angle on the surface roughness, whereas there is no significant effect of feed rate on it. From the main effect plot, it is also observed that the feed rate effect on surface roughness is small as compared to back rake angle and spindle speed, and the main effect plot slope also implies when spindle moves from the lower level to higher-level surface roughness decreases. And for feed rate, it is seen that when it moves from low to high level, the surface roughness increases at 0.74 mm/rev of feed rate and further decreases on the next level. Similarly, for rake angle when it moves from low to a high level, the surface Roughness decreases at 12 degrees of rake angle and further becomes poor on the next level.

From interaction plot, it can be observed that there is an effect of the interaction of factors on the surface roughness but there is very less effect of the interaction of spindle speed and feed. The main effect plot shows the minimum surface roughness of 3.02 µm can be achieved by fixing the spindle speed at 1460rpm, feed rate at 0.038mm/rev and rake angle at 12 degrees. From the main effect plot, the maximum material removal rate of 3.02mm³/min can be achieved by fixing the spindle speed at 1460rpm, feed rate at 0.150mm/rev since rake angle doesn’t affect the material removal rate so it can be set at any level.

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