Influence of dressing parameters on surface roughness of workpiece for grinding hardened 9XC tool steel

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Abstract. The quality of final machining surfaces in a grinding process, such as the surface roughness and the accuracy depends on the grinding and dressing parameters. In order to improve the surface smoothness and precise tolerances, many grinding and dressing parameters need to be optimized. However, several dressing parameters, i.e., the rough dressing, the final dressing, and the dressing without depth of cut affected on the surface roughness have not yet been mentioned in the grinding process. This paper presents an optimization of these parameters on the surface roughness for grinding the hardened 9XC steel using grinding wheel Cn80MV1 400x40x203. An experimental system was set up to evaluate those parameters. The optimal values of these parameters were determined by using Minitab® 16 for analyzing data from the experiment.

1. Introduction
Grinding is one of the most important methods used in a machining process. The grinding process is widely used for the final shaping of elements that require very smooth surfaces and high precise tolerances. Due to this reason, the number of grinding machines can be accounted up to 30% in manufacturing industry and up to 60% in various special industries, i.e., a ball bearing manufacturing process [1].

In order to improve the smoothness of surfaces and precise tolerances, there are numerous researches focused on optimization of grinding and dressing parameters. The Taguchi method has been used to optimize the surface roughness of AISI 1040 steel plates using EKR46K grinding wheels [2]. In this research, the optimal parameters, such as the cutting speed, the rate of feed, and the depth of cut were determined by minimizing the surface roughness. To continue the minimization of the surface roughness, Ganesan et al. [3] also used the Taguchi method, ANOVA, and the regression analysis to predict the optimal value of the cylindrical grinding parameters, i.e., the cutting speed, the feed rate, and the depth of cut. In order to improve the surface finish and the surface characteristics, a research proposed the effect of grinding parameters on surface finish of EN8 steel [4]. The optimization of the ceramic grinding process using the genetic algorithm has been developed by Agarwal [5]. This work also suggested the effect of several parameters including the depth of cut, the

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table feed, the size, and the density of grit on the metal removal rate, the surface roughness, and subsurface damages. The aim of this work is to obtain the best metal removal rate and surface finish and to decrease subsurface damages. Rabiey et al. [6] presented the influence of dressing parameters to grinding forces, the workpiece roughness, and the wheel wear of hybrid bond CBN grinding wheels. The multi-objective function, which depends on dressing parameters, such as the dressing speed, the dressing depth, and the dressing cross-feed, was exhibited to minimize the tangential grinding force and the surface roughness [7]. The result of this research has been given for optimizing the grinding process. Another optimization of dressing parameters in the cylindrical grinding is presented in [8].

Based on the results of this research, a model was established for simulating the wheel lifetime, the cutting ability, the production rate, and cutting forces during the grinding process. Dressing processes were displayed for cylindrical grinding using CBN and Seeded Gel hybrid wheels to compute the optimal dressing parameters [9]. In addition, Mohite et al. [10] proposed a method to determine the optimal dressing parameters, i.e., the dressing depth of cut, the dressing of cross feed rate, the drag angle of dresser, and the number of passes of dresser in order to minimize the surface roughness of EN19 steel bar by using the CNC cylindrical grinding machine.

From the brief literature review, it can be noticed that the quality of surfaces and the accuracy of elements in the grinding process have been affected by grinding and dressing parameters. However, little attention has been paid to the effect of the rough dressing, the final dressing and the dressing without depth of cut on the roughness of surfaces. This paper, thus, presents an optimization of these parameters applied for grinding hardened 9XC steel to improve the surface roughness of the ground parts.

2. Experimental design

This section presents an experiment to determine the influence of dressing parameters, such as the rough dressing, the final dressing and the dressing without depth of cut on the surface roughness and cutting forces of the hardened 9XC steel. Figure 1 shows the experiment system. The details of the experimental system and cutting parameters are shown as follows:

**Experimental system:**
Cylindrical grinder: CONDO - Hi-450 HTS (Japan);
Grinding wheel: Cn80MV1 400x40x203, 35 m/s (Vietnam);
Dresser: Multi-point - 3908-0088C; Type 2; diamond group: APC4; diamond mass: 1 carat (Russia);
Surface roughness tester: Mitutoyo 178-923-2A, SJ-201 (Japan);
Workpiece: hardened 9XC steel with 22 mm in diameter and 170 mm in length, 58-62 HRC, and surface roughness is not larger than 4 μm.

**Cutting parameters:**
- Depth of cut: \( t = 0.01 \) mm;
- Longitudinal feed rate: \( S_d = 1 \) (m/min);
- Cross-feed rate: \( S_n=0.01 \) (mm/stroke);
- Velocity of wheel: \( V_d = 30 \) (m/s).

In this study, Box-Behnken design was selected for the experiment with three types of dressing modes including coarse dressing, fine dressing, and non-feeding dressing (or dressing without depth of cut). The experimental matrix was designed by Minitab® 16 and was shown in Table 1. The surface roughness of the ground parts was measured. Figure 2 presents the relationship between the number of the ground parts and the surface roughness with five experimental runs. From this results, with the requirement of the surface roughness (in this case \( R_s \leq 0.4 \) μm), we can define the maximum number of ground parts with each experimental run. As a results, the number of ground parts is shown in Figure.3.
3. Experimental results and analysis

| Runs | Coarse dressing depth (mm) | Fine dressing depth (mm) | Non-feeding dressing (times) |
|------|---------------------------|--------------------------|-----------------------------|
| 1    | 0.07                      | 0.03                     | 4                           |
| 2    | 0.06                      | 0.02                     | 4                           |
| 3    | 0.06                      | 0.02                     | 2                           |
| 4    | 0.07                      | 0.02                     | 3                           |
| 5    | 0.06                      | 0.01                     | 3                           |
| 6    | 0.06                      | 0.03                     | 3                           |
| 7    | 0.07                      | 0.02                     | 3                           |
| 8    | 0.08                      | 0.01                     | 3                           |
| 9    | 0.07                      | 0.02                     | 3                           |
| 10   | 0.07                      | 0.01                     | 2                           |
| 11   | 0.07                      | 0.03                     | 2                           |
| 12   | 0.07                      | 0.01                     | 4                           |
| 13   | 0.08                      | 0.03                     | 3                           |
| 14   | 0.08                      | 0.02                     | 4                           |
| 15   | 0.08                      | 0.02                     | 2                           |

Figure 1. Experimental system
The wheel life $T$ of each experiment can be calculated by the following equation [1]:

$$T = \frac{95 \times n}{60} \text{ (min)}$$  \hspace{1cm} (1)

where, $n$ is the number of ground parts. The values of the wheel life of each experimental run are presented in Table 2.
Table 2. The wheel life of each experiment

| Runs (P) | Number of ground parts (-) | Wheel life (min) |
|----------|----------------------------|------------------|
| 1        | 25                         | 39.58            |
| 2        | 25                         | 39.58            |
| 3        | 23                         | 36.42            |
| 4        | 28                         | 44.33            |
| 5        | 23                         | 36.42            |
| 6        | 26                         | 41.17            |
| 7        | 29                         | 45.92            |
| 8        | 24                         | 38.00            |
| 9        | 28                         | 44.33            |
| 10       | 26                         | 41.17            |
| 11       | 24                         | 38.00            |
| 12       | 23                         | 36.42            |
| 13       | 23                         | 36.42            |
| 14       | 24                         | 38.00            |
| 15       | 24                         | 38.00            |

The wheel life of each experiment

| Term                          | Coef | SE Coef | T     | P     |
|-------------------------------|------|---------|-------|-------|
| Constant                      | 42.2222 | 0.0531 | 45.495 | 0.000 |
| Rough dressing                | -1.5792 | 0.0563 | -2.864 | 0.063 |
| Finish dressing               | -5.6736 | 1.4964 | -3.807 | 0.013 |
| Dressing without depth of cut | 1.5833 | 0.8363 | 1.897  | 0.065 |
| Rough dressing*Rough dressing | -3.8264 | 0.7056 | -5.423 | 0.000 |
| Finish dressing*Finish dressing | -5.0347 | 0.7056 | -7.101 | 0.000 |
| Dressing without depth of cut* | -5.0347 | 0.7056 | -7.101 | 0.000 |
| Rough dressing*Finish dressing | -1.5833 | 0.6779 | -2.335 | 0.067 |
| Rough dressing*                | -6.7917 | 0.6779 | -1.080 | 0.284 |
| Dressing without depth of cut* | 1.5833 | 0.6779 | 2.335  | 0.067 |

Estimated Regression Coefficients for Y(T)

\[
Y(T_{Ra}) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1^2 + \beta_5 x_2^2 + \beta_6 x_3^2 + \beta_7 x_1 x_2 + \beta_8 x_1 x_3 + \beta_9 x_2 x_3,
\]

In which, \(x_1\), \(x_2\), and \(x_3\) are the fine dressing, the coarse dressing and non-feeding dressing, respectively. \(Y(T_{Ra})\) is the objective function of the regression equation; \(\beta\) are impact factors of variables \(x_i\).

The coefficients in Equation 2 are determined by using Minitab\textsuperscript{®} software 16 to analyze the data in Table 2. Thus, Equation 2 is rewritten as:

\[
Y(T_{Ra}) = 42.2222 - 1.9792 x_1 - 5.6736 x_2 + 0.5833 x_3 - 3.8264 x_1^2 - 3.0347 x_2^2 - 3.0347 x_3^2 - 1.5833 x_1 x_2 + 0.7917 x_1 x_3 + 1.5833 x_2 x_3
\]

Figure 4: Analysis results by Minitab\textsuperscript{®} 16
Figure 5. Optimum values of parameters.

| Parameters | Goal | Lower | Target | Upper | Weight | Import |
|------------|------|-------|--------|-------|--------|--------|
| Y(T)       | Maxi | 36    | 46     | 46    | 1      | 1      |

Starting Point:
- Rough dressing = 0.06
- Finish dressing = 0.01
- Dressing without depth of cut = 2

Global Solution:
- Rough dressing = 0.0592929
- Finish dressing = 0.0299591
- Dressing without depth of cut = 3.03030

Predicted Responses:
- Y(T) = 44.8043, desirability = 0.889432
- Composite Desirability = 0.889432

Optimization Plot

Figure 6. Interaction effect of dressing factors

Figure 7. The average surface roughness

The optimal values of the dressing parameters can also be obtained by using Minitab® 16 as seen in Figure 5. Figure 6 shows the effect of the dressing parameters on the wheel life. From these figures,
the optimal values of the dressing parameters are achieved as follows: the coarse dressing depth of 0.07 (mm); the fine dressing depth of 0.02 (mm); the number of non-feeding dressing times is 3.

4. Conclusions
This paper addressed an experimental study on the optimum dressing parameters in grinding 9CrSi tool steel using grinding wheel Cn80MV1 400x40x203 for getting the minimum surface roughness.
- Three types of dressing modes including the coarse dressing, the fine dressing and the non-feeding dressing were investigated.
- The influence of the dressing parameters on the wheel life was described.
- The optimum dressing parameters for getting the minimum surface roughness as follows: The coarse dressing depth of 0.07 (mm); the fine dressing depth of 0.02 (mm); the number of non-feeding dressing times is 3.

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