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# Predictive Surface Roughness of Workpiece in Surface Grinding

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## Abstract
In this paper, based on the theory of grinding process, we get the relationship between surface roughness of workpice in surface griniding ($R_a$) and cutting parametres (grinding wheel velocity - $v_G$, workpiece velocity – $v_W$, depth of cut - $t$) and grinding wheel parameters (diameter - $d_G$, the mesh number used in the grading sieve – $M$, volume fraction - $\epsilon$. This relationship used to predict surface roughness of workpice, its values is good agreement experiment value. So, results of this paper can be used for predictive the surface roughness in practical cases.

## 1. Introduction

Like other machining methods, the quality of the surface finish by grinding is evaluated using many parameters. Of which, the surface roughness of the workpiece surface is the most important element which may significantly impact the usefulness of the workpiece. The surface roughness of workpiece forming mechanism is complex and mostly dependent on other factors (cutting mode, dressing mode, cooling and lubrication) and the machining factors (geometrical parameters, stability and contact behavior). Simulating the grinding process to predict the value of surface roughness in particular cases will help reduce the time spent for machine adjustment and trial processing, which will lead to the processing cost reduction and the enhancement of the product quality [1]. In this paper, based on the theory of grinding process, we get the relationship between surface roughness of workpice in surface grinding and grinding wheel velocity, workpiece velocity, depth of cut, wheel diameter, mesh number used in the grading sieve and structure number of the wheel. This relationship used to predict surface roughness of workpice, its value is good agreement experiment value. So, results of this paper can be used for predictive the surface roughness in practical cases.

## 2. Literature Review

In the empirical method, surface roughness models are normally developed as a function of kinematic conditions [2]. The empirical model developed by Suto et al. [3] Relates surface finish to the number of active cutting edges using the experimental data and it has been found to be having a logarithmic relationship. Although empirical models have the advantage that they require minimum efforts to develop and are used in all fields of grinding technology but the inherent problem associated with this method is that the model developed under one grinding condition, cannot be used for surface roughness prediction at other conditions, i.e. it can be used for accurate description of the process within the limited range of chosen parameters only. Hence the scope is limited.

To overcome the above-mentioned problem, analytical models for surface roughness were tried out to predict the surface roughness at different grinding conditions. The analytical models are always preferred to empirical models as these models are based on the fundamental laws which use mathematical formulations of qualitative models. Hence, these results can be made applicable to a wide range of process conditions. The analytical models for surface roughness have always been characterized by the description of the microstructure of the grinding wheel in one dimensional form taking the grain distance, the width of cutting edge and the grain diameter into account and in two dimensional forms by considering the grain count and the ratio of width of cut to depth of cut. Lal et al. [4] used similar approach to describe the surface roughness based on chip thickness model. But this model does not require the microstructure of the grinding wheel, thus it is moresuccessful in industry as it does not need the effort of wheel characterization. Cui et al. [5] have built dynamic model of material removal process in grinding process. Described the state of art in the modeling and simulation of grinding processes comparing different approaches to modeling by Tonshoff et al. [6]. Furthermore, the benefits as well as the limitations of the model applications and simulation were discussed. This work identified one simple basic model where all the parameters such as wheel topography, material properties, etc. are lumped into the empirical constant. Models developed forthe grinding process in the surface roughness analysis [7–9] have assumed an orderly arrangement of the abrasive grains on the grinding wheel. Have used a conventional method to determine the surface roughness based on the model using the mean value of the grain protrusion heights by Zhou et al. [10]. However, the predicted value of the surface roughness based on traditional method is found to be less than the measured value. To overcome this problem, some authors proposed method takes into consideration the random distribution of the grain protrusion heights. Used fuzzy set theory to predict surface roughness in grinding process operations by Tzu-Liang Tseng et al. [11]. But, this method had used many values of experimental processes, so it method is difficult for application in manufacturing. Developed the relationship between grinding tool surface characterization and surface roughness by E. Uhlmann et al. [12]. But, cutting parameters have more signifficant on surface roughness, that were absented in this work. Predictive surface of roughness with the form of grinding wheel as a pineapple had proposed by Haiyue Yu et al. [13]. But this form of wheel it is unsuitable for surface grinding process. Investigation of different grain shapes and dressing to predict surface roughness in grinding by YuemingLiu [14]. But, like as reference 12, cutting parameter were absent in this work.

Several random models have been proposed to simulate the surface profile generated during grinding based on the stochastic nature of the grinding process [15–18]. In these models, the abrasive grains on the grinding wheel have been thought of as a number of small cutting points distributed randomly over the wheel surface. Assuming a particular probability distribution of these random cutting points, output surface profiles have been generated for known input surface profile and input grinding conditions. To simulate the relative cutting path of grains, Performed a closed loop simulation, presupposing that thermo-mechanical equilibrium has been established during the grinding process by Steffens [19]. The input for this simulation program will be the quantities like grinding wheel topography, physical quantities of the system, set-up parameters of the machine tool, and the temperature dependent material properties, etc. Simulations can closely reproduce the ground surface using probabilistic analysis; however, the applicability of this programme is limited since the simulation programme is based on the measurement of microstructure of grinding wheel. This method is timeconsuming. Although many analytical models have been developed based on the stochastic nature of the grinding process but Basuray et al. [20] have proposed a simple model for evaluating surface roughness in fine grinding based on probabilistic approach. The concept of radial distribution parameter and an effective profile depth associated with the stochastic model have been used to obtain the distribution of the grains on the wheel surface. Results of the approximate analysis yield values that agree reasonably well with the experimental results. However many parameters and properties of materials were merged into the empirical constants in this analysis.

Developed an analytical model for the prediction of the arithmetic mean surface roughness based on the probabilistic undeformed chip thickness model by Hecker et al. [21]. This model uses ground finish as a function of the wheel microstructure, the process kinematic conditions and the material properties. The material properties and the wheel microstructure are considered in the surface roughness through the chip thickness model. A simple expression that relates the surface roughness with chip thickness was found, which was verified using experimental data from cylindrical grinding. However, in this work, form of grain has been assumed to be triangular. And, as in opinion of Sanchit Kumar Khare et al. [22] a simple abrasive grain on the wheel surface generally has many tiny cutting points on its surface. Therefore, it is evident that the groove produced by an individual grain can be better approximated by an arc of a circle. Then, they had developed a method to predict value of surface roughness with form of grain assumed to be an arc.

Based above analysis, suggestion that method of Sanchit Kumar Khare et al. [22], which has most advancement.

## 3. Establishment of Surface Roughness Equation

The analyzing of chip forming in grinding by probabilistic approach, Sanchit Kumar Khare et al. [22] proposed the surface roughness equation:

$$R_a = 0{,}471.h_m \quad (1)$$

Where: $h_m$ is maximum of undeformed chip thickness.

The existing chip thickness model proposed by Anne Venu Gopal et al. [23]. The equation is as follows:

$$h_m = 2\sqrt{\frac{1}{Nr}\frac{v_w}{v_G}\sqrt{\frac{t}{d_e}}} \quad (2)$$

Where:

$v_w$ – workpiece velocity.

$v_G$ – grinding wheel velocity.

$t$ – depth of cut

$d_e$ –equivalent wheel diameter. The equation is as follows:

$$d_e = d_G.d_w/(d_G + d_w) \quad (3)$$

With $d_G$, $d_w$ are grinding wheel diameter and workpiece diameter respective. In surface grinding, $d_w \to \infty$ then $d_e = d_G$.

$r$ - is the chip width to thickness ratio. The value of 'r' is difficult to determine and is assumed in the range of 10-20 [24]. In this work 'r' was assumed to be equal to 10 [24, 25].

$N$ - The number of active grits per unit area 'N' derived by Xu. Hockin et al [26] is as follows:

$$N = 4f\frac{1}{d_g^2}\frac{1}{\sqrt[3]{\left(\frac{4\pi}{3\epsilon}\right)^2}} \quad (4)$$

Where:

$f$ – the fraction of diamond particles involved in active grinding. The value of 'f' is difficult to determine. For calculating the number of active grits per unit area, it is assumed that only one half of diamond particles are engaged in cutting [27], $f = 0.5$.

$d_g$ – The equivalent spherical diameter of diamond grit, is given [2] as:

$$d_g = 15.2/M \quad (5)$$

Where: M is the mesh number used in the grading sieve $\epsilon$-volume fraction of diamond in grinding wheel. The grinding wheels used in the present study have a concentration of 80, or volume fraction $\epsilon = 0.2$ [28]:

Substituting the eq (2), (3), (4), (5), (5) in (6) and after mathematical simplification, the value of surface roughness will be:

$$R_a = 3{,}2148.M^{-1}\left(\frac{1}{f.r}\right)^{1/2}.\left(\frac{v_w}{v_G}\right)^{1/2}\left(\frac{4\pi}{3\epsilon}\right)^{1/3}.\left(\frac{t}{d_G}\right)^{1/4} \quad (6)$$

From equation (6) so that, value of surface roughness will be increase if value of workpiece velocity and volume fraction are increased. Beside, if value of the mesh number used in the grading sieve, the fraction of particles involved in active grinding, grinding wheel velocity and chip width to thickness ratio are increased, these make surface roughness will be reduced. This equation will be used for calculating value of surface roughness in next part of this paper.

## 4. Result and Discussion

For evaluation the predictive value of surface roughness, the comparison between value of surface roughness of experimental [29] and predictive value, with the same in-put parameters. The work material taken was SUJ2 (58 ÷ 60HRC), grinding wheel was 1A1-250D-20T-2X-75H-SL80N80BI, machine was M7120A (Figure 1), measurement equipment was SJ201 surface roughness tester (Figure 2).

*Figure 1. M7120A surface grinder.*


*Figure 2. SJ201 surface roughness tester.*

The kinematic parameters considered for each experiment are depth of cut $(t)$ workpiece velocity $(v_w)$ and wheel velocity $(v_G)$ . The value of surface roughness in experimental $(R_{a(1)})$ and of predictive $(R_{a(2)})$ as shown in Table 1 and Figure 3. From these so that there is a very good agreement between $R_{a(1)}$ and $R_{a(2)}$.

***Table 1.*** *Experimental $R_{a(1)}$ and calculated $R_{a(2)}$ of surface roughness.*

| Runs | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| $t(mm)$ | 0.005 | 0.005 | 0.002 | 0.012 | 0.002 | 0.012 | 0.002 | 0.005 |
| $v_w(m/min)$ | 7 | 7 | 12 | 12 | 12 | 7 | 20.5 | 12 |
| $v_G(m/min)$ | 1700 | 1905 | 1700 | 1700 | 1905 | 1800 | 1800 | 1800 |
| $R_{a(1)}(\mu m)$ | 0.50 | 0.46 | 0.52 | 0.64 | 0.49 | 0.66 | 0.71 | 0.68 |
| $R_{a(2)}(\mu m)$ | 0.47 | 0.45 | 0.49 | 0.77 | 0.47 | 0.57 | 0.63 | 0.60 |

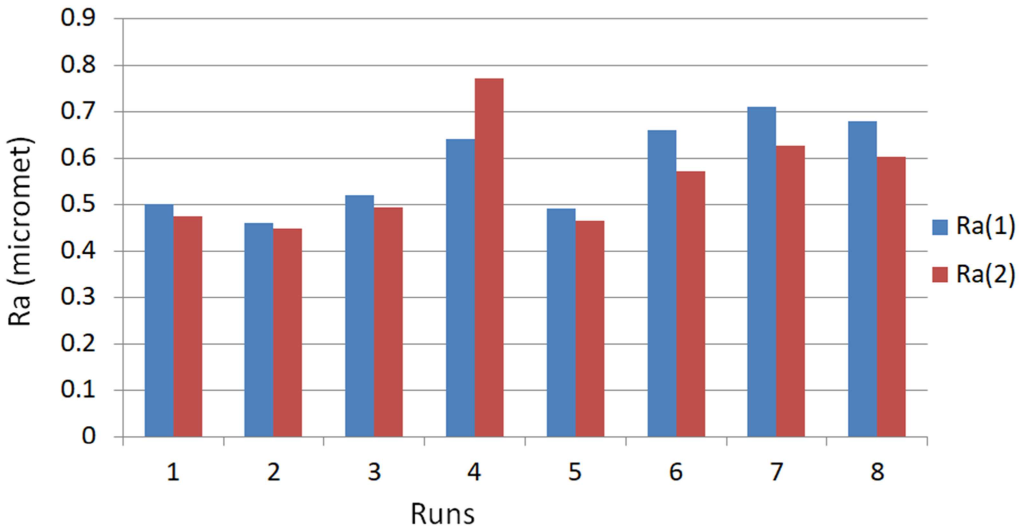


***Figure 3.*** *Comparison of experimental and calculated of surface roughness.*

## 5. Conclusions

The value of surface roughness is depended many factors, of which are cutting parameters, wheel parameters, interaction parameters between wheel and workpiece surface. The value of surface roughness is expensive to determine by experimental processes.

In this paper, a simple equation is proposed for predicting the surface roughness in surface grinding. From that equation so that, value of surface roughness will be increased if value of workpiece velocity and volume fraction are increased. Beside, if value of the mesh number used in the grading sieve, the fraction of particles involved in active grinding, grinding wheel velocity and chip width to thickness ratio are increased, these make surface roughness will be reduced. Predictive surface roughness is good agreement with experiment value. This equation can be used for predictive the surface roughness in practical cases.

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