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ORIGINAL ARTICLE

# Analytical modeling of grinding wheel loading phenomena

**H. Adibi · S. M. Rezaei · Ahmed A. D. Sarhan**

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**Abstract** Wheel surface condition plays an important role in the grinding operation. Grinding wheel loading, meaning chip accumulation in the space between grains, leads to deteriorating wheel cutting ability and causes excessive force and temperature. This paper presents an analytical model of wheel loading phenomena as a function of cutting parameters, wheel structure, and material properties. The model is based on the adhesion of workpiece material to abrasive grain surface. It is validated by experimental results from grinding nickel-based superalloy with cubic boron nitride vitrified wheel. This model considers wheel specifications including abrasive grains size and the number of cutting edges. Cutting parameters and process temperature are the other determinant factors. On the basis of this model and empirical results, the effects of the various process parameters are presented.

H. Adibi (✉) · S. M. Rezaei
Department of Mechanical Engineering,
Amirkabir University of Technology, Tehran, Iran
e-mail: h_adibi@aut.ac.ir

S. M. Rezaei
e-mail: smrezaei@aut.ac.ir

S. M. Rezaei
New Technology Research Center,
Amirkabir University of Technology, Tehran, Iran

H. Adibi · S. M. Rezaei · A. A. D. Sarhan
Center of Advanced Manufacturing and Material Processing,
Department of Engineering Design and Manufacture,
Faculty of Engineering, University of Malaya,
Kuala Lumpur 50603, Malaysia

A. A. D. Sarhan
e-mail: ah_sarhan@um.edu.my

A. A. D. Sarhan
Department of Mechanical Engineering, Faculty of Engineering,
Assiut University, Assiut 71516, Egypt

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## 1 Introduction

Due to the properties of difficult-to-machine materials, grinding is among the more effective machining methods for superalloys [1]. When grinding such materials, detached chips may adhere in porous spaces between abrasive grains or weld to the top of cutting grains, something known as wheel loading [2, 3]. This phenomenon produces dull wheel grains which results in excessive rubbing and vibration. It also increases cutting force and temperature, reducing wheel life [4]. Many investigations have been conducted to explain the loading mechanism. Recent work in the analysis of cubic boron nitride (CBN) grinding wheel operations is showing continued interest in the wheel loading phenomenon and methods of counteracting its development [5, 6]. CBN vitrified grinding wheels provide an ideal solution to many applications due to the wheel porosity and structure control in vitreous bonds [7]. However, this type of wheel is prone to loading, particularly when grinding superalloys [3]. Srivastava et al. [8] presented a simple analysis to evaluate loading based on adhesion between the workpiece and abrasive grains. There is a lack of comprehensive analytical models for wheel loading assessment. Loading is classified into two major types: adhesive loading and filling loading. In adhesive loading, grinding chips adhere to abrasive grains and bonding materials. In filling loading, chips fill up the cavities in the grinding wheel's surface. Literature indicates that the main cause for wheel loading in ductile materials is the adhesion between active wheel grains and chips [6, 8, 9]. In this paper, a theoretical model based on adhesive wear is presented. This model considers the workpiece material properties, wheel specifications and topography, cutting parameters, and temperature as the effective parameters.

Matlab software was used to simulate the theoretical model. Image processing, as an effective method, was applied to measure wheel loading [10, 11]. Experiments under various conditions were carried out to validate the analysis. The outcome of the mentioned parameters on wheel loading in the grinding of nickel-based superalloys using a CBN vitrified wheel was studied. It is expected that the research work detailed in this project will have potential applications in the grinding industry.

## 2 Theoretical analysis

When two interacting surfaces come into contact, material transfer between the two surfaces occurs due to localized bonding among the contacting asperities [12]. The schematic geometry of surface grinding is shown in Fig. 1a. A typical abrasive grain, roughly spherical in shape, acts upon a metal surface as illustrated in Fig. 1b–d. It can be seen that the actual contact area along a single abrasive grit workpiece interface is made up of asperities [13]. The mechanism of chip formation in grinding is like an extrusion process in which the die walls are replaced by an elastic–plastic boundary [8]. The plastic deformation of asperities along with the associated adhesion at junctions under high temperatures and high stress leads to microweld formation. Owing to the relative movement between the abrasive grains and the workpiece, shearing can take place either at the original interface or along a path below or above it, causing adhesive wear. Generally, joint shearing is more likely to happen either at the interface or within the asperities of the softer material [13]. The abrasive grains on the wheel surface are random in geometry with large negative rake angles and also have many micro-asperities. In the vicinity of an active grain, these conditions hasten the process of adhesion, which in turn leads to workpiece material loading into the grain asperities and the pores on the wheel surface. Calculating the loaded volume on the grinding wheel was initiated by an analysis of a single active grit, after which it was multiplied by the number of active grits on the wheel. Thus, the whole loading volume could be obtained.

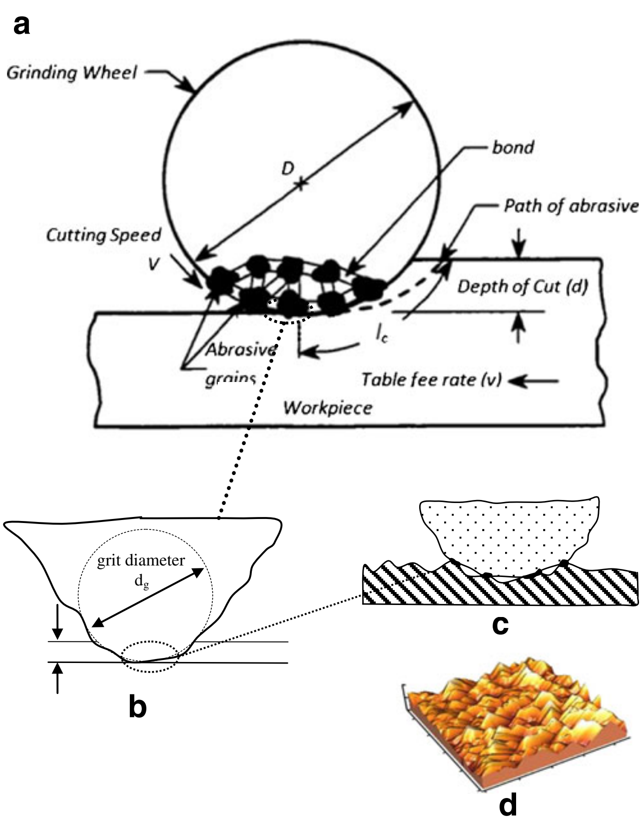


**Fig. 1** **a** Schematic of surface grinding geometry. **b** An abrasive grain modeled as a sphere. **c** Schematic of abrasive grain and workpiece interface. **d** Schematic on workpiece cutting surface asperities

### 2.1 Calculating loaded volume for a single active grit

On the cutting workpiece surface, there are $n_{\mathrm{w}}$ microwelds per unit area. Each microweld that adheres to the active abrasive grain contributes $V_{\mathrm{w}}$ to the loaded volume. The total loaded volume per unit area can be calculated as:

$$V_{\mathrm{adhesion}} = n_{\mathrm{w}}.V_{\mathrm{w}} \tag{1}$$

Assuming that $h_w$ is the characteristic height of the asperity portion adhered to the abrasive grain and $A_{\mathrm{w}}$ is the average joint cross-sectional area for each microweld, $V_{\mathrm{w}}$ can be expressed as:

$$V_{\mathrm{w}} = h_{\mathrm{w}}.A_{\mathrm{w}} \tag{2}$$

As shown in Fig. 1c, microwelds support partial normal force along the grain–workpiece interface. This force is equal to $W$ as shown in Fig. 2. The actual contact pressure is equivalent to the hardness of the asperity $H_{\mathrm{asperity}}$.

$$H_{\mathrm{asperity}} = \frac{W}{n_{\mathrm{t}}.A_{\mathrm{w}}} \tag{3}$$

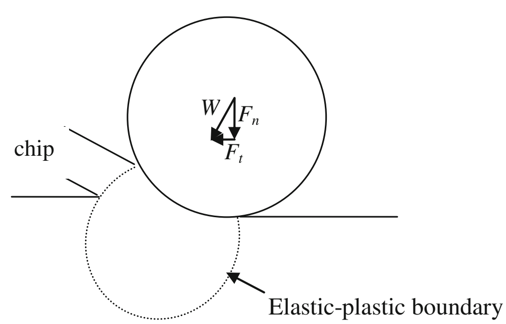


**Fig. 2** Force along grain–workpiece interface