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Effect of Manual Grinding Operations on Surface Integrity

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Abstract

Manual grinding operations are influenced by a number of variants such as a worker's posture and motion, in addition to the general parameters affecting automated grinding processes, for example, tool speed and feed rate. Moreover, dry cutting conditions and poor control of the machining process can negatively influence chip formation and part quality in terms of roughness, microhardness, microstructure, etc. The goal of this work is to analyze the processing energy, resulting surface integrity, and prospective part performance, considering the above-mentioned variants, with the aim to give a detailed insight into manual grinding processes and fill the existing knowledge gaps. For this paper, we have limited our subject to one and thus have not studied the effect of worker's skills involved in manual grinding.

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Keywords*: Manual Grinding; Surface Integrity; Dry Cutting*

1. Introduction

Manual abrasive finishing operations (e.g. manual grinding or polishing) are prominently used in repair, construction, burr removing, foundry and in welding industry. Compared to automated grinding operations, grinding with power tools is critically dependent on worker's knowledge, skills, posture, gripping forces and personal strength. Moreover, accidents with manual power tools account for 2/3 of accidents with grinding machines and cause severe health issues with irreversible medical effects [1]. In addition, poor control of the machining process may influence the geometrical and physical properties of the machined surfaces. The abrasive tool's geometry plays a major role in generating surface texture/roughness and altering part functionality, especially under dry sliding condition.

Conventionally, average surface roughness (Ra) or mean roughness depth (Rz) is the most commonly used term to characterize the surface topography. However, there are various roughness parameters other than Ra or Rz, which have close relationships to the mechanical and metallurgical properties of the surfaces, for example, depth of the roughness core profile (Rk) or skewness of the profile height distribution (Rsk) and so on. Different roughness parameters are important for different surface functionalities. For example, Ra gives an idea about the arithmetic average of the surface profile but insensitive to peak to valley variations, Rk provides information about different portions of the surface profile and Rsk is significant for tribological application, such as wear control or bearing surface functionality.

Although, manual abrasive finishing processes have a growing market (e.g., construction market, foundry, repair, or welding industries) but these sectors are under-researched. Limited research has been done in the literature about manual process parameters and their effect on surface integrity. The aim of this paper is to show how the manual grinding processes, under dry cutting conditions, affect the surface properties (i.e. hardness, force ratio, microstructure, etc.) of stainless steel surfaces. Process optimization requires minimizing the energy consumption and increasing the process efficiency. In this paper, a Dremel 4000 hand held power tool has been used for finishing operations.

Nomenclature

μ	Force Ratio
e_c	Specific energy
F_t	Tangential force
Q_w	Material Removal Rate
Ra	Average surface roughness
Rk	Depth of core profile

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Rsk	Skewness of the profile height distribution
Rz	Mean roughness depth
SI	Surface integrity
v_c	Cutting speed

2. Characterization of Surface Integrity (SI)

Grinding is a complex material removal process, where the abrasive tools consist of geometrically undefined cutting edges and engage with the workpiece to form chips. The chip formation process in grinding involves elastic-plastic deformation, cutting, rubbing, and plowing in ductile material [2]. In brittle material, crack formation and propagation lead to material removal as particles. The geometry of the abrasive tool and penetration depth of grits are responsible for rubbing and plowing conditions and affect the surface quality [2, 3]. In the automated grinding processes, the abrasive cutting wheels are running under a constant rotational speed, which apply a precise pressure on the workpiece. Whereas in manual grinding processes, the manual feed rate causes three dimensional force (tangential, normal, and axial) variations on the workpiece, which have a direct impact on friction, chip thickness, and specific energy consumption of the process (Fig. 1). Therefore, understanding the cutting forces in manual finishing operations is challenging and has an open scope for research.

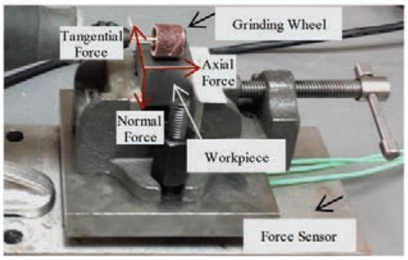

Fig. 1. Understanding Cutting Forces in Manual Grinding Processes

Compared to other conventional cutting processes, the abrasive finishing operations consume higher specific energy under small chip thickness [4]. In addition, most of the manual abrasive finishing operations are running under dry cutting conditions. Therefore, due to these 3-dimensional force variations, high specific energy consumption, and dry cutting conditions, the manual grinding operations produce high thermal effect and affect on surface integrity of the workpiece. Hence, the tradeoff between thermal effect and desired surface properties for manual grinding operations requires a closer investigation.

However, although dry cutting conditions increase the possibility of thermal damages during machining processes, the process has some added advantages over lubricated conditions. The cutting fluids have adverse health impact on workers and on the environment like chest bronchitis, skin disorder, expensive and harmful recycling processes, etc. Whereas, dry machining is eco-friendly, nullifies lubrication cost, and makes it easier to collect chips for recycling purposes [7].

In order to optimize the generated surface properties, it is very important to analyze the resource usage, costs, and sustainability of the overall process [5]. Fig. 2 shows the input-output diagram for the manual grinding operations.

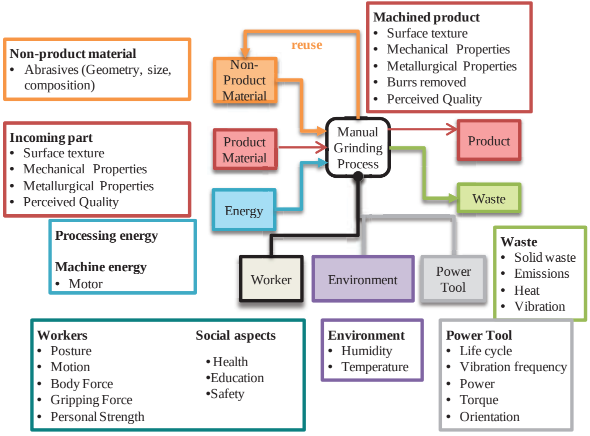

Fig. 2. Comprehensive Input-Output Diagram of Manual Grinding Process

By analyzing the process level of manual grinding operations, the correlation between different process parameters can be depicted in the following way (Fig. 3):

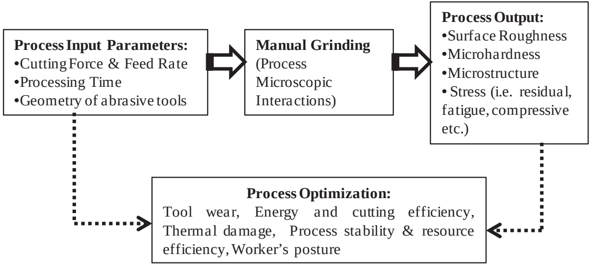

Fig. 3. Correlation between Different Process Parameters in Grinding

The process output in Fig. 3 controls the surface integrity (SI) of the machined surface. SI generally controls the mechanical, metallurgical properties of the surfaces (i.e. hardness, friction behavior, microstructure, etc.) and geometry of the machined surface (i.e. roughness and waviness) [6].

3. Experiment

In this section, we have described the experimental setup and procedure for our manual grinding experiment.

3.1 Set-up and Procedure

For the purpose of studying the effect of grinding parameters (i.e. force ratio, specific energy, material removal rate) over the SI of machined surfaces (i.e. microhardness, microstructure), one subject was used throughout the experiment to improve consistency of manual applied forces on the workpiece. Three trials were performed to make the process statistically significant. The subject was used to grind the material for a duration of about 1 min 25 sec. Both the abrasive wheel and the grinding samples were replaced for each trial.

The material used in this study was grade 304 annealed stainless steel with dimensions of 4.5cm x 1.5cm x 2cm. The ground surfaces were prepared by Dremel 4000 hand held power tool using alumina sanding bands of two different grit