Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 45 (2016) 159 – 162

www.elsevier.com/locate/procedia

3rd CIRP Conference on Surface Integrity (CIRP CSI)

Prediction and Experimental Validation of an Impact Energy Threshold for Mechanical Surface Smoothing

Peter Sticht*, Manuel Steitz, Peter Groche

Technische Universität Darmstadt, Institute for Production Engineering and Forming Machines, Otto-Berndt-Straße 2, 64287 Darmstadt, Germany
* Corresponding author. Tel.: +49 6151 16 23045; fax: +49 6151 16 23142. *E-mail address:* sticht@ptu.tu-darmstadt.de

Abstract

Dynamic processes like machine hammer peening generate a smoothing of tool surfaces, an increase in hardness and residual compressive stresses in the surface layer. So far, it is not possible to determine the energy threshold needed to smooth a rough surface based on tool parameters and workpiece characteristics. Thus, this paper focuses on the definition of an energy threshold as well as the derivation of an analytical equation to calculate the energy demand for plastic deformation. The method is validated by experimental investigations. It is shown that the defined energy threshold for mechanical surface smoothing corresponds with the experimental data.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)

Keywords: Surface Modification, Energy, Machine Hammer Peening

1. Introduction

The process stability of deep drawing operations is heavily affected by the surface integrity of the dies. Usually, the final surface quality of the tools is produced by manual polishing. However, automated processes have recently begun to replace manual finishing and can lead to significant cost savings. This paper focuses on the mechanical surface treatment technology of machine hammer peening (MHP).

MHP technology is characterized by an electro-magnetic [1], pneumatic [2] or piezo-electric [3] driven hammer head which is repeatedly accelerated against the surface to be treated. The kinetic energy is transferred into the material and allows smoothing of surface asperities [4]. At the same time, the hardness of the surface layer is increased [5] and residual compressive stresses are induced [6].

2. Scope of investigation

In order to provide a desired surface topography after MHP, the process parameters need to be adjusted to the material of the workpiece. A small hammering energy can result in an insufficient smoothing of the surface asperities, while an exaggerated energy level causes surface defects [7].

Nomenclature

r_H	Radius of the hammerhead / spherical indenter
r_I	Radius of indentation
D_P	Depth of penetration
R_z	Surface roughness of the specimen
r_I	Radius of indentation area
E_T	Threshold energy
$R_{p0,2}$	Yield strength of workpiece material
R_{pI}	Yield strength of workpiece during impact conditions
E_E	Energy needed for elastic deformation
E_P	Energy needed for plastic deformation
e	Coefficient of restitution
F_M	Mean forming force
A_I	Area of indentation
Y_{SM}	Mean flow stress
φ	Degree of deformation
E_1	Young's-Modulus of specimen
E_2	Young's-Modulus of spherical indenter
Rz_I	Roughness of spherical indenter
η	Forming efficiency
s	Step over distance

However, so far there is no model that allows for the prediction of the surface deformation from easily measured

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on Surface Integrity (CIRP CSI)
doi:10.1016/j.procir.2016.02.353

parameters like the tool geometry, workpiece characteristics, including initial roughness and mechanical properties. Therefore, this study focuses on determining the energy input required for a successful smoothing of surface asperities by MHP. Results may also be applicable to other energy related surface treatment technologies.

3. Approach

First, existing work regarding the topic of energy-bound surface deformation is described. Boundary conditions and definitions for an analytical model are proposed and consolidated in an analytical equation to determine the energy needed for sufficient plastic deformation. The theoretically determined dependence of the energy threshold on basic tool and workpiece characteristics is validated against experiments. Spherical indenters made of hard metal are dropped on the surface of cast iron and tool steel. Indentation diameters are evaluated according to the initial surface roughness and impact energy. Finally, the analytically predicted and experimentally measured results are compared and discussed.

4. Existing work and boundary conditions for dynamic energy bound processes

MHP provokes a plastic deformation of a rough workpiece surface with comparatively high strain rates. To determine the parameters needed for successful surface treatment, an analytical model of the dynamic contact between rough surfaces is required. Several authors examine the contact between two bodies under different boundary conditions. While Hertz [8] describes the contact of ideally elastic and smooth bodies with no plastic deformation, Johnson derives an analytical model for a dynamic contact of smooth bodies undergoing plastic deformation [9]. Tabor creates an analytical model for the static contact and plastically deformed rough surfaces [10]. The numerical models of Kimura, Childs [11] and Wied [4] consider dynamic contacts and rough surfaces, but are no longer solvable analytically. Also, results for the dependence of the flow stress on strain rates from Goldman [12] remain mostly unconsidered. Existing models thus fail due to incompatibility of the boundary conditions. Besides the conditions mentioned, a threshold value for the smoothing of a rough surface has to be defined.

To define this threshold, the surface asperities are idealized as triangular prisms with a squared base evenly distributed over the surface area. Their height corresponds with the roughness value R_z. To smooth the surface, the prisms have to be formed into cuboids with the same base area (Fig. 1). This is modeled by compression and plastic deformation of the triangular prisms to 0.5 times their initial height. Due to the large area ratio of the spherical indenter to the surface asperities, the assumption to form a cuboid is reasonable.

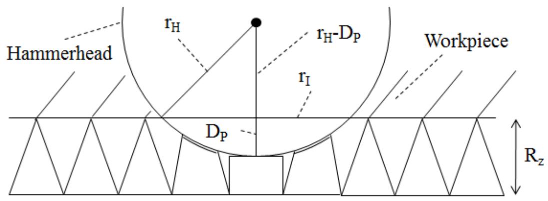

Fig. 1. Boundary conditions for a spherical indenter (not true to scale)

As Kimura and Childs [11] prove in their work, approximately 30 % of the asperities persist after a plastic deformation by a spherical indenter. Transforming this into a factor (1/0.7), it can be stated that the depth of penetration has to be

$$D_P = 0.5 \times \frac{1}{0.7} R_z \tag{1}$$

in order to deform surface asperities. The initial value for R_z can be estimated from surface roughness measurements.

Using the geometric conditions shown in Fig. 1, the radius of the indentation area can be described by

$$r_I = \sqrt{r_H{}^2 - (r_H - D_P)^2} \tag{2}$$

These boundary conditions can be used for the analysis of the problem and derivation of a calculated energy threshold in the following section.

5. Analysis

To simplify the determination of motion characteristics for the impact process, an energy budget is considered. The threshold energy E_T needed for the process consists of an elastic share E_E and a share for the plastic deformation E_P of the surface (Equation 3).

$$E_T = E_E + E_P \tag{3}$$

According to [9], friction and thermal energy can be neglected for central non-rotational impacts. The share of plastic energy is determined from Leeb-Hardness (HLD) measurements as follows, where e is the coefficient of restitution.

$$E_T = \left(\frac{1}{(1 - e^2)} \right) E_P \tag{4}$$

Starting with equation 4, it is possible to calculate the energy needed for a single impact of a sphere depending on the coefficient of restitution e and the energy needed for plastic deformation of the workpiece material. Since E_P is unknown, it is derived in the following. According to [13], the forming energy is calculated by the product of the mean flow stress Y_{SM}, the degree of deformation φ_r and the material volume, characterized by depth D_P and area of indentation A_I. η is the forming efficiency.

$$E_P = \frac{1}{\eta} A_I D_P Y_{SM} \varphi_r \tag{5}$$