Journal of Materials Processing Technology 213 (2013) 2292–2303

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Experimental and finite element analysis of temperature and energy partition to the workpiece while grinding with a flexible robot

Amir Masoud Tahvilian[a], Zhaoheng Liu[a,*], Henri Champliaud[a], Bruce Hazel[b]

[a] Department of Mechanical Engineering, École de technologie supérieure, Montréal, Québec H3C 1K3, Canada
[b] Expertise Robotique et civil, IREQ, Research Institute of Hydro-Québec (IREQ), Varennes, Québec J3X 1S1, Canada

ARTICLE INFO

Article history:
Received 31 January 2013
Received in revised form 15 June 2013
Accepted 5 July 2013
Available online 16 July 2013

Keywords:
Robotic grinding
Finite element analysis
Energy partition
Contact temperature

ABSTRACT

Grinding processes performed with flexible robotic tool holders are very unlike conventional types of grinding because of low stiffness of the robot's structure. A special flexible robotic grinding process is used for in situ maintenance of large hydroelectric equipment for bulk material removal over large areas rather than as a finishing step, as is the case for most conventional grindings. Due to the low structural stiffness of tool holder, cutting is interrupted at each revolution of wheel during the grinding process. In this study, an investigation is carried out to determine the temperatures and energy partition to the workpiece for the above-mentioned flexible robotic grinding process by a three-dimensional finite element thermal model. Experiments were undertaken using embedded thermocouples to obtain the subsurface temperature at several points in the workpiece during the process. Then, energy partition to the workpiece was evaluated using a temperature-matching method between the experimental and numerical results. This ratio is used for predicting the temperature field at the wheel–workpiece interface with a relevant heat source function. Kinematics of cut and the flexible robot's dynamic behavior are considered in applying the heat input to the model. The energy partition to the workpiece in this specific flexible grinding process is found to be lower than for analogous conventional precision grinding processes. Two models, one from the literature and one from the power model of the process, are modified and proposed for determining the energy partition. The results showed that the energy partition ratio decreases by increasing the process power. Also, this ratio slightly decreases at higher feed speeds. In addition, lower temperatures were seen at higher powers due to the lower intensity of heat input over a larger contact area. Experimental observations show close agreement between simulated contact temperatures and measured results.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Grinding has much larger specific energy in material removal than other machining processes, leading to a higher temperature at the wheel–workpiece interface. High temperature can cause thermal damage, such as burning and phase transformation, which adversely affect workpiece surface characteristics. High temperature is also an important factor in grinding wheel wear rates and significantly affects the mechanical behavior of workpiece material due to thermal softening effects. Many studies have been conducted to determine the temperature field in the workpiece during conventional grinding processes. They are usually based on a model by Jaeger (1942), who proposed a heat source of constant intensity moving over a semi-infinite workpiece surface. Brinksmeier et al. (2006) presented an overview of all types of models and simulations for grinding processes, including analytical and numerical models.

Thermal simulation of the grinding process generally involves measuring the power consumed during the process, determining the ratio of energy transported into the workpiece and defining the heat input function for the particular surface. The most challenging of these three tasks is determining the energy partition into the workpiece for all grinding parameters and conditions. Rowe et al. (1988) were among the first who introduced the concept of heat partitioning in thermal modeling of grinding process. The four main sources of heat dissipation in the grinding process are the grinding wheel, the workpiece, chips and coolant. Specifying the amount of heat entering the workpiece is a key rule for any thermal simulation of grinding processes.

Finite element (FE) methods have proven to be a reliable approach and are used extensively by researchers for thermal simulations of grinding. Several FE models with different heat functions are used to predict the temperature distribution in the workpiece. Doman et al. (2009) summarized some FE approaches used for

---

* Corresponding author. Tel.: +1 514 396 8507; fax: +1 514 396 8530.
E-mail addresses: amirmasoud.tahvilian.1@ens.etsmtl.ca (A.M. Tahvilian), zhaoheng.liu@etsmtl.ca (Z. Liu), henri.champliaud@etsmtl.ca (H. Champliaud), hazel.bruce@ireq.ca (B. Hazel).

0924-0136/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jmatprotec.2013.07.002

grinding modeling and categorized them into macro- and micro-scale models. Early simulations made a number of simplifying assumptions to obtain a two-dimensional (2D) model. However, with computer power increasing in recent years, more complex three-dimensional (3D) models have been developed and solved with fewer assumptions. Mahdi and Liangchi (1995) used FE to predict phase transformation in the workpiece assuming, surface grinding as a 2D process with a triangular heat source profile. In other study, Mamalis et al. (2003a) used a similar model with a rectangular heat flux function to investigate effect of different grinding wheels on maximum surface temperature in the workpiece. Jin and Stephenson (2004) studied transient heat transfer for high efficiency deep grinding with 3D model, evaluating effect of convective cooling on the side walls of workpiece in contact temperature. Mao et al. (2010) performed a 3D thermal simulation proposing a parabolic distribution for heat flux in the contact zone rather than a triangular one. Mohamed et al. (2012) showed the importance of using the accurate grinding power for calculating the heat flux in a numerical simulation of heat transfer in grinding process. The authors used instantaneous grinding power, average grinding power and calculated power from tangential force and cutting speed to obtain the contact temperature and compared it with experimentally measured temperatures. It is found that in steady state condition instantaneous power and calculated power give the best match results with experiments where average power underestimates the temperatures.

Although many thermal models for conventional grinding exist in the literature, less attention has been paid to grinding processes more recently performed by flexible robots.

2. Energy partition background

Energy partition is defined as the ratio of the energy that enters the workpiece to the total energy consumed by the grinding process. The energy partition largely depends on operating parameters, as well as on grinding wheel and workpiece thermal properties. Numerous studies have been conducted to determine the energy partition to the workpiece under various grinding conditions for conventional machines. A number of researchers commonly used a temperature-matching method to investigate this ratio. Using this method, the energy partition is found by matching temperatures measured during the process with the results of a thermal model or experiments. Kohli et al. (1995) found a ratio of 60–85% for conventional aluminum oxide wheels and 20% for resin bond cubic boron nitride (CBN) wheels in regular grinding. In a similar study, Guo and Malkin (1999) obtained same results with the extension that, energy partition ratio is reduced to 5–8% for vitrified CBN wheels. Guo et al. (1999) also verified that only 4.0–8.5% of total energy enters into workpiece for grinding with vitrified CBN wheels. Such a low ratio is attributed to the high thermal conductivity of the CBN grains and the enhanced fluid flow in vitrified wheels. Anderson et al. (2008b) determined the ratio of 70–90% for dry grinding with an aluminum oxide grinding wheels. Chen and Xu (2010) also performed temperature matching technique for high speed grinding and found a range of 30–75% under different grinding conditions with a brazed diamond wheel. Mohamed et al. (2011) found a relation between surface roughness of the finished workpiece and grain radius of the wheel in the contact zone. The authors used this correlation to update an existing energy partition model which needs estimation of grain radius. Hadad et al. (2012) also reported a study of energy partition of grinding in dry, minimum quantity lubrication (MQL) and fluid environments for a hardened 100Cr6 steel workpiece. The authors found a 82%, 75% and 36% ratios for grinding with aluminum oxide wheel in dry, MQL and fluid cooling respectively. Whereas these ratios are reduced to 52%, 46% and 14% for CBN wheel due to high thermal conductivity of CBN abrasive.

Some investigations are conducted to relate the energy partition to relevant grinding parameters, such as process specific energy or workpiece and grinding wheel material properties. Material removal in grinding is performed by the action of many grains and can be divided into three stages—sliding, plowing and chip formation—as proposed by Hahn (1962). Consequently, grinding specific energy (u) can be divided into three fractions based on the stages above:

$$u = u_{ch} + u_{pl} + u_{sl} \tag{1}$$

Malkin and Anderson (1973) found that in dry shallow conventional grinding about 55% of chip formation energy and almost all sliding and plowing energy enter the workpiece. Therefore, the energy partition can be rewritten in the form of specific energy (Malkin, 2008),

$$\varepsilon = \frac{\text{energy entering the workpiece}}{\text{total consumed energy}} = \frac{u_{pl} + u_{sl} + 0.55u_{ch}}{u} = \frac{u - 0.45u_{ch}}{u} \tag{2}$$

where u is the specific energy and u_{ch} is the chip formation specific energy found to be 13.8 J/mm^3 for grinding of steel workpieces (Kohli et al., 1995). This model is applicable to grinding processes with aluminum oxide wheels and it is not true for the case that a CBN grinding wheel is used. It is because of high thermal conductivity of CBN (500–1300 W m^{-1} K^{-1}) compared to aluminum oxide (36 W m^{-1} K^{-1}) which causes significant conduction of heat into the wear flat grain at the wheel–workpiece interface in the former case (Lavine et al., 1989). Therefore, although the assumption of remaining plowing energy in the workpiece still stands, not all the sliding energy is conducted in the workpiece when grinding with CBN wheels.

All studies on the temperature and energy partition were for conventional grinding processes with rigid structures, none for specific flexible robotic grinding process. In this study, a 3D transient thermal FE code is developed to account for heat generation due to a robotic grinding operation. The aim is to study thermal conditions during the discontinuous material removal, called “vibro-impact cutting”, which is the way a flexible robot performs grinding and should be distinguished from chatter in conventional machining. First, the energy partition ratio is obtained, using the proper input heat function, through several full-size workpiece simulations and comparison with test results. The predicted energy partition value is correlated with the power model implemented in the robot controller, which has been verified in several field trials (Hazel et al., 2012a). Then, on a smaller model for the contact zone, the input heat function is adjusted to the dynamic cutting conditions based on the observed impact-cutting behavior of the robot during the grinding process to find the exact contact temperature. Knowledge of the temperature distribution is important not only for studying workpiece burns and other thermal damage, but also for the ongoing study of chip formation to predict how thermal softening affects workpiece material behavior.

3. SCOMPI robot

This study concerns thermal aspects of a traverse surface grinding performed by a light flexible robotic tool holder. The robot, named “SCOMPI” (Super COMPact robot Ireq), is developed by IREQ, Hydro-Quebec’s research institute, and has been used mainly for in situ maintenance of hydro turbine runners (Hazel et al., 2012b). SCOMPI is a portable, multi-purpose, track-based 6-degree of freedom robot manipulator weighing 33 kg. The robot is capable of

Download English Version:

https://daneshyari.com/en/article/10418346

Download Persian Version:

https://daneshyari.com/article/10418346

Daneshyari.com