Journal of Materials Processing Technology 229 (2016) 329–337

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Some critical issues in cryo-grinding by a vitrified bonded alumina wheel using liquid nitrogen jet

Prudvi P Reddy, Amitava Ghosh*

Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600036, India

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form
19 September 2015
Accepted 23 September 2015
Available online 28 September 2015

Keywords:
Cryo-grinding
G-ratio
Bond strength
Dimensional inaccuracy
Residual stress
Phase transformation

ABSTRACT

Beneficial effects of liquid nitrogen (LN_2) as a metal working fluid (MWF) in high speed machining applications are well recognized. However, adequate attention is not given on possible deleterious effects because of its extremely low boiling point. In the present work, an in-depth investigation has been carried out to explore pros and cons of LN_2 application when a vitrified bonded Al_2O_3 wheel was used for grinding hardened AISI 52100 steel. It was observed that LN_2 application in place of soluble oil could substantially enhance G-ratio. Although, this observation is in agreement with the reported literatures, the other findings contradicted the notion that cryogenic application is favorable for grinding. Unlike under soluble oil environment, the vitrified bonded wheel failed to produce a good finish when LN_2 was used. There were evidentially more number of microscopic zones having smeared, re-deposited chips and micro-folded ridges on ground surface. Interestingly, larger wear flat areas on wheel topography were observed under LN_2 environment. When critically investigated, it was found that its extremely low temperature unfavorably strengthened bond, which led to undesirable retention of progressively wearing grits. Such an unfavorable alteration in wheel topography led to higher power consumption in the process. Additionally, ground specimen suffered from higher dimensional inaccuracy. Microscopic morphology of chips indicated prevalence of low temperature in the vicinity of grinding zone under this environment but interestingly the ground specimen experienced unfavorably more tensile residual stress with LN_2 than with soluble oil.

1. Introduction

Liquid nitrogen (LN_2) has emerged as a green metal working fluid (MWF), in high speed machining applications. Its extraordinary heat dissipation capability from machining zone due to its low boiling temp (approximately, -196° C), helps in improvement of tool life. It also satisfies the requirements of sustainability, which include minimization of environmental, economic and societal hazards as reported by Aurich et al. (2013). When LN_2 is delivered to machining zone, it immediately evaporates without leaving any residue. Therefore, the hazardous effects of poisonous coolant vapors can be avoided with this green alternative. In addition to this, recycling and disposal cost of conventional coolants can also be avoided. However, economy of LN_2 application is debated time and again. Application of cryogenic technology requires high initial investment. Pušavec and Kopač (2011) has cited a statistical representation to prove that the LN_2 technology is more economical and energy efficient compared to other cooling lubrication technologies using conventional MWFs if the overall production and quality of machined work are considered.

Technological benefits of LN_2 applications have been reported by many researchers. Most of the works involve high speed machining of difficult-to-machine materials like titanium alloys, nickel based alloys and high strength steels. High shear strength of these materials at elevated temperature generates large amount of heat in machining zone and this heat tends to dissipate more through the tool, especially in case of lower thermal conductivity materials. As a result, the cutting tool receives rapid flank wear thereby deteriorating the quality of machined surface. Hong et al. (1999) observed that application of LN_2 was potentially capable of improving hardness, wear resistance and toughness of tool materials, thereby dramatically increasing the tool life. Wang and Rajurkar (2000) reported substantial improvement in tool life when LN_2 was used in machining difficult-to-machine materials. Similar findings on tool life were also reported by Hong et al. (2001a) in case of Ti-6Al-4V, Pušavec and Kopač (2011) in case of Inconel 718 and Wang et al. (2002) for tantalum. Dhar et al. (2002b) demonstrated significant reduction in

* Corresponding author at: MES, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai 600036, India. Fax: +91 44 22574652.
E-mail address: amitava_g@iitm.ac.in (A. Ghosh).

http://dx.doi.org/10.1016/j.jmatprotec.2015.09.040
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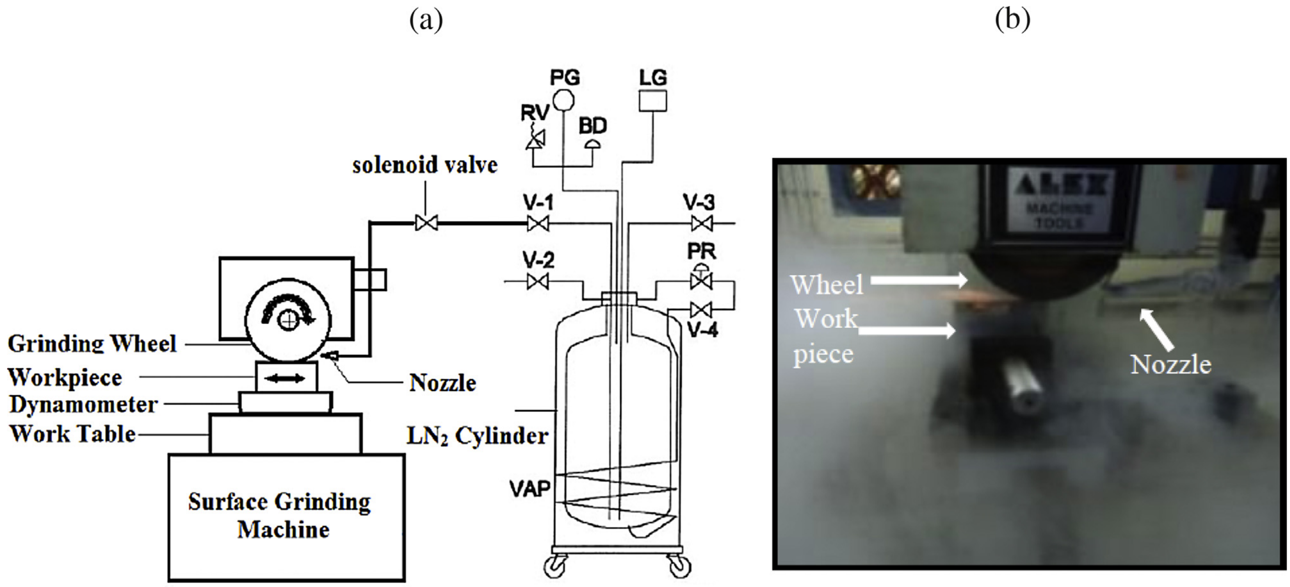

Fig. 1. (a) Schematic view of experimental setup. (b) LN_2 delivery during the grinding.

average flank wear of uncoated carbide tools in turning of AISI4140 steel under cryogenic cooling condition, which could finally lead to improved surface finish and dimensional deviation of work specimen. Khan and Ahmed (2008) noted a four times improvement in tool life under LN_2 environment. Similar findings were observed by Ravi and Pradeep Kumar (2011) in case of milling. The beneficial effect of LN_2 was found to be highly pronounced in improvement of tool life during milling of different steels. Hong et al. (2001b) claimed that such an improvement was not only due to extreme low temperature of LN_2 but also because of its lubrication ability, which reduced frictional force at chip-tool interface. It was observed by Dhar et al. (2002a) and Dilip Jerold and Pradeep Kumar (2012) that the principal component of cutting force was reduced when LN_2 was applied instead of conventional coolants. Such a beneficial effect was attributed to the retention of sharpness of cutting tool under LN_2 environment. Hong et al. (2001b) demonstrated that an exception could also take place, for example, in case of turning Ti-6Al-4V. It was inferred that the extreme low temperature of LN_2 led to strengthening and hardening of the alpha–beta alloy of titanium. However, unlike other high speed machining processes, cryo grinding was less investigated. Chattopadhyay et al. (1985) made an attempt to grind different steels under cryogenic environment and observed significant reduction in cutting force and grinding temperature. Paul et al. (1993) has extensively studied cryo-grinding of steels and also reported similar findings. Paul and Chattopadhyay (1995a,b) mentioned that reduction of grinding force was possibly due to retained sharpness of grits. It was also reported that surface defects like cracks, burning, oxidation marks and metal redeposition were absent in case of cryo grinding. Paul et al. (1993) further concluded that the grinding chips carried the impression of predominant shearing and fracturing during the removal process under cryo-cooling. Paul and Chattopadhyay (1996) also attempted to measure grinding zone temperature under cryogenic cooling condition in spite of practical difficulties. When Paul et al. (1993) concluded that retained sharpness of grits under LN_2 environment probably led to increase of surface roughness, Manimaran et al. (2014) reported the reverse trend.

Conflicts in the available literatures are noted regarding the surface roughness of ground surface and concerned inferences. Authors of the present paper strongly felt that an in-depth and systematic investigation should be directed to resolve the conflicts and to have better understanding on the performance of LN_2. Available literatures did not adequately focus on power consumption in the process, estimation of wheel life, any possible alteration of bond characteristics, dimensional deviations and especially the surface integrity which is influenced by residual stress under cryogenic

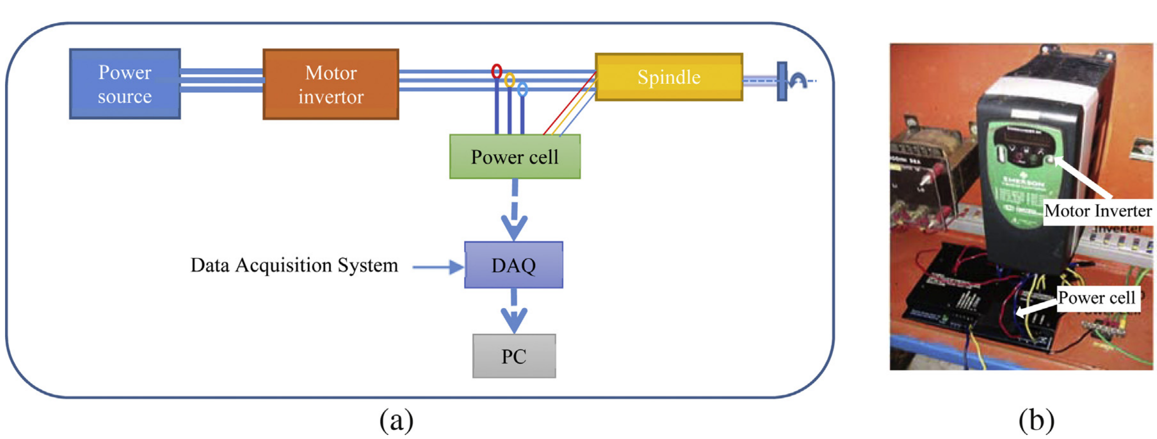

Fig. 2. (a) Schematic of power measurement. (b) Power cell fixed to the spindle motor.