CIRP Journal of Manufacturing Science and Technology 7 (2014) 97–105

Contents lists available at ScienceDirect

CIRP Journal of Manufacturing Science and Technology

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

Efficiency in contamination-free machining using microfluidic structures

Carlo Ferri [1], Timothy Minton *, Saiful Bin Che Ghani [2], Kai Cheng

Brunel University, AMEE – Advanced Manufacturing and Enterprise Engineering, Kingston Lane, Uxbridge, Middlesex UB8 3PH, UK

ARTICLE INFO

Article history:
Available online 3 January 2014

Keywords:
Cutting temperature
Internally-cooled tool
Contamination-free machining
Dry machining
Linear mixed-effects statistical models
Sustainable manufacturing

ABSTRACT

The plastic deformation of the material in the chip formation and the friction when the chip slides on the rake face of the insert generate heat. The heat generation is responsible for a temperature rise of the chip, of the insert and of the newly created surface on the workpiece. Adhesion and diffusion between the chip and the insert are thus facilitated with detrimental effects on the tool wear. A cooling system based on microfluidic structures internal to the insert is considered in this study as a means of controlling the temperature at the chip–insert interface. The coolant and the part never enter in contact. Hence contamination of the part by coolant molecules is prevented. The aim of this study is to identify and to quantify the effect of the cutting parameters on the effectiveness of the internal cooling system. To measure this effectiveness an efficiency ratio r is defined as the percentage of the mechanical power actually needed at the tool to remove material that is thermally dissipated by the internal flow of the coolant. Similarly, a specific efficiency ratio r' is also defined by considering the mechanical power per volume flow rate of the material removed and the dissipated thermal power per volume flow rate of the coolant. Both r and r' are then analysed in a 3^3 factorial experiment within the space of the technological variables depth of cut, feed rate and cutting speed. The cutting trials were conducted in turning operations of AA6082-T6 aluminium alloy. Linear mixed-effects models were fitted to the experimental results using the maximum likelihood method. The main finding was that the efficiency ratio r depends only on the feed rate and the cutting speed but not on the depth of cut. An interaction effect of the feed rate and the cutting speed on the efficiency was also found significant. Higher efficiency is attainable by decreasing cutting speed and feed rate. The maximum efficiency predicted in the technological region investigated was 10.96 %. The specific efficiency once log-transformed was found linearly increasing with the depth of cut and the feed rate, whereas being insensitive to the cutting speed.

© 2013 CIRP.

1. Introduction

Dry cutting of key engineering materials is the epitome of sustainability in metal cutting. The removal of metal working fluids (MWF) from the machining processes is of benefit to the machine operator, swarf recycling and ultimately the environment. Reducing the temperature of the cutting tool and workpiece is one of the main purposes of the MWF, together with facilitating the removal of the chip from the machining area. Using an external supply of coolant makes it difficult for the fluid to penetrate into the tool–chip contact area. It is also difficult to quantify the amount of heat transferred between the cutting edge and the MWF. Dry machining removes the externally supplied coolant from the machining process at the expense of the cooling effect it provides. Although this method is acceptable for certain materials like aluminium, it may be problematic for high strength materials and certain grades of aluminium which contain harder elements like silicon. High temperatures which are uncontrolled due to lack of cooling can cause high wear rates and can dramatically reduce the useful life of the tooling insert. In some extreme cases the tool can become damaged not via traditional wear mechanisms but through deformation of the cutting edge [1]. Monitoring of the cutting temperature is a well-established research goal and has been presented using many differing technologies including an embedded thermocouple [2], the tool–work thermocouple [3], the calorimetric method [4], an embedded sensor film [5] and optical methods [6,7]. Some of these methods are not applicable when using an external coolant supply. Dry machining allows the monitoring of the tool/chip temperature via the tool–work thermocouple [3] or optical methods [6,7]. These methods however require time

---

* Corresponding author. Tel.: +44 1895 267945; fax: +44 1895 267583.
E-mail address: timothy.minton@brunel.ac.uk (T. Minton).

[1] Present address: Via XI Febbraio 40, 24060 Castelli Calepio, BG, Italy.

[2] Permanent address: Universiti Malaysia Pahang – Mechanical Engineering, Lebuhraya Tun Razak, 26300 Gambang, Malaysia.

1755-5817/$ – see front matter © 2013 CIRP.
http://dx.doi.org/10.1016/j.cirpj.2013.12.001

consuming set-ups or expensive auxiliary equipment and are hence better suited to a laboratory environment.

The method of indirect cooling is known in the area of metal cutting and has been steadily increasing in popularity since 1970 when Jeffries published the idea of an internally cooled single-point cutting tool [8]. The main benefit of the internally cooled tool is the indirect application of a cooling effect to the tool–chip interface. Previous research in the field of indirect cooling methods has shown that it is possible to reduce significantly the cutting temperature. In particular, Ferri et al. [9] compared the chip temperature in dry turning of the aluminium alloy AA6082-T6 when using conventional and internally cooled tools. Their main finding was that the internally-cooled tools appeared increasingly effective in containing the chip temperature whilst increasing the depth of cut. In a research effort jointly sponsored by the US Environmental Protection Agency and the Department of the Army, Rozzi et al. [10] patented a device to cool indirectly the tool–chip interface by creating micro-channels and a finned heat exchanger within the tool suitable for the use with cryogenic fluids (typically liquid nitrogen). Sanchez et al. [11] proposed a similar apparatus where the cooling fluid flowing within the tool evaporates in proximity of the cutting edge, with the latent heat being provided by heat transfer with the tool–chip interface. In a condenser outside the tool holder, the fluid is then condensed again. The resulting liquid phase is re-conveyed within the tool, thus realising a close-loop circulation of the coolant. Liang et al. [12] studied the use of the heat pipe technology in turning operations. A heat pipe is a heat conductor in which the latent heat of evaporation is used for heat transfer purposes in experimental situations where differences in temperature are small. Moreover, a heat pipe operates without any external power supply. Shu et al. [13] presented a study based on the finite element method to simulate numerically turning operations in presence of both liquid coolant flowing in channels internal to the tool and a heat pipe. Uhlmann et al. [14] compared wet machining, dry machining and machining with an internally-cooled tool. They investigated the influence of different coolant temperatures on the tool flank wear (VB) and on the workpiece surface roughness. Their main finding is that the tool wear in dry machining appears larger than in the other cases. They tested internally-cooled tools with coolant temperatures of 20 °C and -10 °C. The tool flank wear in both these cases and in the wet machining were most similar. The internally-cooled tool with coolant at 20 °C appeared only slightly less worn (cf. figure 3 in Uhlmann et al. [14]).

Moreover, internally cooling the tool also provides the unique possibility to manipulate the cutting temperature without necessarily changing core machining parameters such as the cutting speed, the feed rate or the depth of cut. Whilst specifically focusing on a closed loop coolant supply within the tool shank, the introduction of two additional control variables such as the coolant supply flow rate and the coolant temperature can be deployed to affect the metal removal process. The concept of a coolant supply within the cutting tool itself also presents a great opportunity to quantitatively assess the thermal energy that the coolant conveys away from the cutting zone. The metal cutting process generates high heat and large thermal gradients [3]. According to Micheletti (cf. page 203 in [15]), heat is almost instantaneously generated where work is done during cutting. Thus, the location of the heat sources is identified in the areas where the work due to the plastic deformation of the metal and to the friction of the chip on the rake face happen. If the tool is not in ideal conditions, i.e. if it is not perfectly sharpened, friction work also happens between the surface of the workpiece and the clearance face of the tool (also known as flank face) [15]. Boothroyd [16] measured the temperature distribution and constructed isotherm patterns in the workpiece, the chip and the tool by making joint usage of infra-red photography and thermocouples. From those measurements, Boothroyd was also able to derive the heat transferred into the chip, the tool and the workpiece. Boothroyd's results, displayed in the table on page 797 in [16], appear consistent with those reported by Micheletti (cf. page 209 in [15]): most of the heat generated during the cutting process is transferred into the chip, say about 60 and 80 %, depending on the machining conditions; the remaining part is transferred into the tool and into the workpiece in similar proportions.

When the coolant flows internally to the insert and close to the cutting edge, a part of the generated heat is transferred into the coolant and away from the cutting zone. The heat transfer occurred is evidenced through the increment of the coolant temperature which is also instrumental to its measurement. This can all be achieved without the contamination of the tool and of the workpiece which instead occurs with external coolant supplies. For this reason the authors used in the title and elsewhere the terms 'contamination-free machining'. At first sight, this may appear as an oxymoron. In fact, for a metal cutting process to happen a tool must enter in contact with the workpiece. The cutting edge of the insert must be harder than the material to cut. Thus cutting edge and workpiece are of different materials. It is a reasonable expectation that during the cutting process a proportion of the material worn off the flank face (clearance face) of the tool will contaminate the workpiece at least on a sub-micrometre scale. Thus, strictly speaking, as long as flank wear exists on the tool, a cutting process is always most likely to pollute the workpiece with tool material. The term 'contamination-free' is therefore to be considered within these limitations.

In some cases reducing the temperature of the workpiece or cutting insert by too great a margin might be a problem. For example, if there is a strong work-hardening effect on the material the cutting forces may increase dramatically and induce additional issues with the surface finish and the surface integrity [17]. Another issue might be a thermal shock of the cutting insert. However, the manipulation of the coolant flow rate and/or the coolant temperature would make the management of these events possible. The benefits of a reduced cutting temperature appear to out-weigh the potential troubles by far. An increase in tool life is possible and a control of the critical temperature above which thermally induced wear mechanisms take place is achievable [18]. In this study, a tool system is designed and manufactured to cool the cutting insert by the adduction of the coolant in the proximity of the cutting insert via microfluidic structures within the tool. These structures prevent any possible contact between the coolant and the part. A cooling efficiency ratio is then defined and computed in a range of experimental conditions defined by the triplets of machining parameters cutting speed (v_c), feed rate (f) and depth of cut (a_p). This efficiency ratio denotes the portion of the total machining power which is transferred to the coolant in the form of thermal power. From a conceptual point of view, establishing experimentally how this efficiency ratio depends on (a_p, f, v_c) provides other researchers a further potential means of validating their theories regarding the thermal characteristics of the machining process. From a practitioner's point of view, this efficiency ratio can become a useful instrument in the selection of the coolant flow rate and coolant temperature at the inlet of the tool system. For example, cutting speed, feed rate and depth of cut may be set to comply with productivity requirements and/or the optimisation of some cost function. By setting the triplet (a_p, f, v_c), the power request for machining a given geometry from a given blank is uniquely determined. The knowledge of the efficiency ratio of the cooling system for the selected triplet (a_p, f, v_c) allows then the practitioner to know how much thermal power would be transferred away by the cooling system, had he or she set the flow

Download English Version:

https://daneshyari.com/en/article/1679703

Download Persian Version:

https://daneshyari.com/article/1679703

Daneshyari.com