A study on ultrasonic assisted cylindrical plunge grinding of Inconel 718

Graduate School of Akita Prefectural University Sisi Li, Akita Prefectural University Yongbo Wu and Mitsuyoshi Nomura.

Inconel 718 has high yield strength, corrosion resistance, heat resistance, fatigue resistance, and possesses a lower thermal conductivity. However, these characteristics cause high grinding forces and heavy wheel damage during grinding. Against these problems existing in its cylindrical plunge grinding (CPG), in this work, a new method is proposed in which an ultrasonic spindle is employed to perform ultrasonic assisted CPG of Inconel 718. In order to confirm the new method, experimental investigations are conducted on the fundamental grinding characteristics such as the effect of vibration amplitude on grinding force and work-surface finish under different process parameters like the grinding wheel rotational speed and work-table feed rate. Summarizing the obtained results revealed that the grinding forces in the new method are significantly smaller than those in conventional grinding. It is also found that ultrasonic vibration can improve the work-surface finish even at high feed speed.

Keywords: Ultrasonic vibration, Inconel 718, cylindrical plunge grinding, grinding force

Introduction

Inconel 718 has high yield strength, corrosion resistance, heat resistance, fatigue resistance, and possesses a lower thermal conductivity [1]. It became the world standard nickel based superalloy for gas turbine engines because it is cheaper and more readily available than competing alloys and has excellent strength properties up to 650°C [2]. Assessment of machinability of the superalloys has been a topic of research over the last three decades. Most of the available machinability data on Inconel 718 were based on turning, cutting and milling. In these machining processes, it is nonetheless hard to attain fine surface finish and accurate dimension [3].

Unlike above mentioned machining processes, it is well known that grinding process brings a particularly good surface properties but has a high cost caused by tool wear and poor material removal rate. As an advanced machining technique, ultrasonic assisted grinding (UAG) has shown its potential to greatly improve the machinability [4-7]. However, most of researches on UAG were mainly focused on the hard-brittle materials. Recently, D. Bhaduri and S.L. Soo carried out a few studies on ultrasonic assisted creep feed grinding of nickel based alloys [8-9]. In their study, a higher amplitude of vibration rendered more voids/pores on the wheel surface, which resulted in an increase in the number of active cutting points on the abrasive tool, and increasing the ultrasonic vibration amplitude resulted in lower grinding force but higher surface roughness. Unfortunately, in the investigations mentioned previously, no systematical investigations of fundamental grinding characteristics during cylindrical plunge grinding (CPG) process have been reported.

In order to investigate the probability of using ultrasonic assisted CPG in the machining of Inconel 718, the current work is to investigate the effect of the ultrasonic vibration on grinding forces in the ultrasonic assisted CPG of Inconel 718 with cBN quill.

Processing principle and experimental details

Fig. 1 shows schematically the processing principle of ultrasonic assisted CPG. A grinding quill is ultrasonically vibrating along its own axis (z-direction) at a frequency of f and an amplitude of Ayz, meanwhile, workpiece and quill are rotating clockwise around their respective own axis at a rotational speed of nq and n w, respectively. When a depth of cut Δ is given between the rotational quill and the workpiece, and the workpiece is fed in x-direction at a feed rate of vn, an ultrasonic assisted CPG operation is performed.

Grinding experiments were carried out on a commercial CNC grinder (GRIND-X IGM15EX by Okamoto Machine Tool Works Co., Ltd.) attached with a commercial ultrasonic spindle (URT40 by Takesho Co., Ltd). Fig 2 shows the main portion of the experimental setup. A 3-components piezoelectric dynamometer (9256A by Kistler Co., Ltd.) was inserted between the spindle and its bed for the measurement of grinding forces. Actual ultrasonic assisted CPG operations of Inconel 718 were conducted under the processing parameters as shown in Table 1.

Fig. 1 Schematic illustration of processing principle of ultrasonic assisted CPG.

Fig. 2 Main portion of the experimental setup.

Table 1 Processing parameters.

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>Inconel 718, 46x35x3 mm</th>
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<tbody>
<tr>
<td>Ultrasonic Vibration</td>
<td>Frequency (f): 40 kHz</td>
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<tr>
<td>Process parameters</td>
<td>cBN#140, 48x8 mm</td>
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<tr>
<td>Gridding quill rotational speed (nq): 4000~5000 rpm</td>
<td>Workpiece rotational speed (nw): 100~400 rpm</td>
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<tr>
<td>Feed speed (vn): 0.04~0.1 mm/min</td>
<td>Co coolant: No coolant (dry grinding)</td>
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</table>
Experimental results and discussion

Ultrasonic assisted CPG tests were performed under different input variables to elucidate the influences of the processing parameters on the grinding forces. For comparison, conventional CPG ($A_{p-p}=0\mu m$) tests were also carried out under the same input variables. As a result, Figs. 3(a), (b) and (d) show the influences of the parameters $A_{p-p}$, $n_p$, $v$, and $n_c$ on the normal and tangential grinding forces, $F_n$ and $F_t$ in the ultrasonic assisted CPG and the CPG, respectively. Obviously, both the $F_n$ and the $F_t$ were quickly decreased with the increase of vibration amplitude $A_{p-p}$ (Fig.3 (a)). It can be found that the $F_n$ and the $F_t$ in Ultrasonic assisted CPG at $A_{p-p}=9.4\mu m$ were decreased by 34.5% and 42.1%, respectively, compared with those in CG ($n_p=4000$ rpm, $n_c=400$ rpm, $v=0.1$ mm/min). It is also found from Figs.3(b), (c) and (d) that the grinding forces decreased with the increase in quill rotational speed $n_q$ but the decrease in workpiece rotational speed $n_w$ and feed rate $v_c$, either in the presence or in the absence of the ultrasonication. Furthermore, it is noticed that the forces in ultrasonic assisted CPG were significantly smaller than those in conventional CPG regardless of the values of $n_p$, $v$, and $n_c$. For example, at $n_q=5500$ rpm, $v=400$ rpm and $n_c=0.1$ mm/min, the values of $F_n$ and $F_t$ in ultrasonic assisted CPG and conventional CPG were decreased by 50.0 % and 41.2%, respectively. This is most likely due to the vibration leading to reduced frictional forces in grinding zone between grains and workpiece as well as inhibition in drop-out wear of grains.

These results demonstrated that the ultrasonic vibration amplitude can greatly contribute to the reduction of grinding forces, implying that the ultrasonic vibration can significantly benefit the grinding efficiency in the grinding process of Inconel 718.

Conclusions

Inconel 718 was processed by ultrasonic assisted CPG with different process parameters. The results obtained in this work are summarized as follows:

1. The grinding forces decreased as the vibration amplitude $A_{p-p}$, and the quill rotational speed $n_q$ increased.
2. The normal and tangential grinding forces, i.e., $F_n$ and $F_t$, were decreased by 34.5% and 42.1%, respectively, in the case of $A_{p-p}=9.4\mu m$ compared with those in conventional CPG.

References