Grinding of Soft Steel with Assistance of Ultrasonic Vibrations

Taghi Tawakoli[1], Bahman Azarhoushang[2] , Mohammad Rabiey[3]

[1,2,3]KSF Institute, Furtwangen University, Germany

[1] tawakoli@hs-furtwangen.de, [2]B.Azarhoushang@hs-furtwangen.de, [3]rabiey@hs-furtwangen.de

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Abstract. Compared to other machining processes, conventional grinding has a low material removal rate and involves high specific energy. A major part of the specific energy in grinding is changed to heat which makes harmful effect on surface quality. A recent and promising method is the use of ultrasonic assistance to increase the material removal rate along with decreasing the thermal damage on the workpiece and reducing cutting forces. The advantages of Ultrasonic Assisted Grinding (UAG) were proved mostly for the brittle material. Our investigations show the improvement on the surface roughness, reduction of the grinding forces and thermal damage in case of using UAG comparing to Conventional Grinding (CG) for a soft material of 100Cr6. The designed and developed ultrasonically vibrated workpiece holder and the experimental investigation show a decrease of up to 40% of normal grinding forces.

1. Introduction

Among the different machining processes, grinding is one of the most complex one because of the undefined cutting edge and statistical nature of the process. Due to the low material removal rate and high specific energy in conventional grinding, this production process is mostly considered only as a secondary finishing operation. A recent and promising technique to increase the material removal rate but simultaneously decrease the thermal damage on the workpiece and reduce cutting forces is known as ultrasonic assisted grinding (UAG). The principle of this technique is adding high frequency (16–40 kHz) and low peak-to-peak (pk-pk) vibration amplitude (2–30 μm) in the feed or crossfeed direction to the tool or the workpiece. UAG is a hybrid process of conventional grinding (CG) and ultrasonic oscillation. By using ultrasonic assisted machining, significant improvements in thrust force, burr size, material removal rate, tool wear, heat generation, noise reduction and surface finish have been reported. Zhang et al. [1] have both theoretically and experimentally concluded that there exists an optimal vibration condition such that the thrust force and torque are minimized. Onikura et al. [2, 3] found that the use of ultrasonic vibration reduces the friction between chip and rake face, resulting thinner chips which lead to the reduction of cutting forces. Jin and Murakawa [4] have showed that Tool life can be prolonged by applying ultrasonic vibration. Azarhoushang and Akbari [5] achieved significant improvements in the circularity, cylindricity, surface roughness and hole oversize by applying ultrasonic vibration to the tool without using any cutting fluids. Mult et al. [6] and Uhlmann [7] found that for ceramic materials, ultrasonic assisted grinding can be applied as an efficient production technology and the ultrasonic assisted creep feed grinding provides enormously reduced normal forces at slightly increased wheel wear and surface roughness. Tawakoli et al [8,9] demonstrated that in ultrasonic assisted dressing of CBN grinding wheels, considerable reduction in grinding forces and dresser wear is achievable.

In this investigation, an UAG system has been designed, fabricated and tested. Improvements in the Rz (parameter of surface roughness) of the ground surfaces and reduction of the normal grinding force due to superimposing of ultrasonic vibration in the grinding of 100Cr6 have been achieved. Besides, the effect of vibration amplitude, feed speed and depth of cut on surface roughness and the normal grinding force have been presented.

2. Design and fabrication of UAG system

In order to study UAG, an actuated workpiece holder was developed. The workpiece holder consists of a piezoelectric transducer, a booster, a horn and a special fixture. The ultrasonic power supply converts 50 Hz electrical supply to high-frequency (21 kHz) electrical impulses. These high frequency electrical impulses are fed to a piezoelectric transducer and transformed into mechanical vibrations of ultrasonic frequency (21 kHz), due to the piezoelectric effect. The vibration amplitude is then amplified by the booster and the horn and transmitted to the workpiece attached to the horn. The resultant vibration of the workpiece fixed in the tool holder reaches 10 µm (i.e. 20 µm peak to peak) at a frequency of about 21 kHz. Vibration is applied to the workpiece in the crossfeed direction of the grinding wheel. The amplitude of the ultrasonic vibration can be adjusted by changing the setting on the power supply.

3. Experiments

The experimental equipments consist of the following:

- Machine tool: Elb Micro-Cut AC8 CNC universal surface grinding machine
- Ultrasonic Vibration Generator: Mastersonic MMM generator-MSG.1200.IX, Power of 12000 W, Frequency ranges of 17.000 to 46.728 kHz.
- Eddy current displacement measurement system: Micro epsilon eddyNCDT 3300, to measure the amplitude of vibration. Measuring ranges 0 – 0.5 mm, Linearity 0.2 %, Resolution 0.005 %, Measuring rate 100 kHz
- Surface roughness tester: Hommel-Werke: T-8000
- Dynamometer: Kistler piezoelectric dynamometer model 9255B

The settings of main machining parameters for the present study are summarized in Table 1.

Table 1, Major machining parameters

Grinding wheel	Vitrified bond CBN grinding wheel, B126 C125; Ø400 mm * 16 mm
Workpiece	100Cr6, 82 HRB, (60*47*29 mm*mm*mm)
Grinding conditions	Feed speed v_{ft}= 1000- 2000 mm/min; Cutting speed v_c= 60 m/s; Depth of cut a_e= 0.050- 0.300 mm
Grinding process	Surface grinding
Coolant	120 l/min, Emulsion (Castrol Syntilo 2000)
Dressing conditions	Dressing ratio q_d=0.8, Wheel speed v_{cd}= 60, Depth of dressing a_{ed}= 5 µm, Overlapping ratio U_d =4, Total depth of dressing $a_{ed\text{-}total}$= 10 µm
Dressing tool	Diamond disc dresser radius R_{sp} = 0.2 mm
Direction of ultrasonic vibration	Cross feed direction (perpendicular to feed)
Ultrasonic vibration conditions	Frequency f=21 KHz, Amplitude A=10µm

In this experiment, the tests were carried out for both UAG and CG with the same instrument. However, during the CG the ultrasonic generator was switched off.

4. Experimental results and discussion

The experimental set-up used in this study for CG as well as UAG is shown in Fig. 1. In CGs, thermal damages on the ground surface were found whenever the depth of cut increased to more than 100 µm. This is due to high grinding forces and resulted high specific energy and corresponding heat generation in the contact zone. In case of UAG there was found no damages on the ground surface up to depth of cut of 200 µm with the same grinding parameters. Fig. 2 shows photograph of the ground surfaces and comparison of two cases of CG and UAG. It is apparent that the right section (ultrasonically assisted ground surface) has experienced much less thermal damage compared to the left section (conventional ground surfaces).

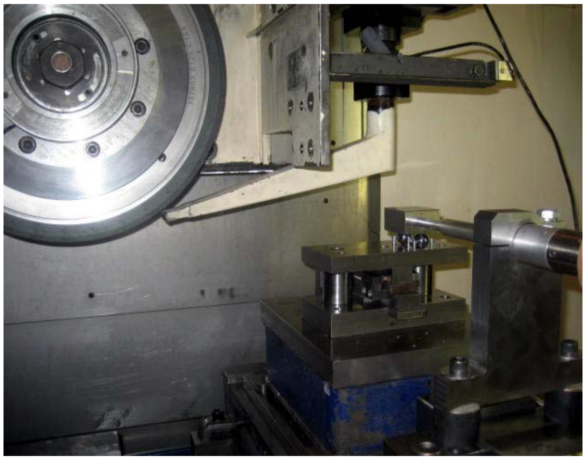

Fig. 1. Experimental set-up for ultrasonic assisted grinding.

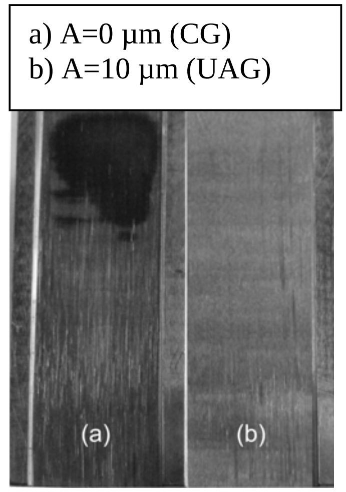

Fig. 2 Ground surface v_c=60 m/s v_{ft}=1000 mm/min a_e=200 µm

In order to achieve reliable data each test was repeated 4 times. Fig. 3-7 show the effect of vibration amplitude, feed speed and depth of cut on surface roughness and normal grinding force for both CG and UAG. In all the figures, lines were formed by calculating the least-squares fit through the data points for a second-order polynomial equation. Fig. 3 shows the relationship between vibration amplitude and normal grinding force. Amplitude zero in this figure represents results of conventional grinding. The experimental Results show significant improvement for UAG compared to CG in different vibration amplitudes. Apparently, the reason for these improvements is the change of the nature of the cutting process, which is transformed into a process with a multiple-impact interaction between the abrasive grits and the formed chip.

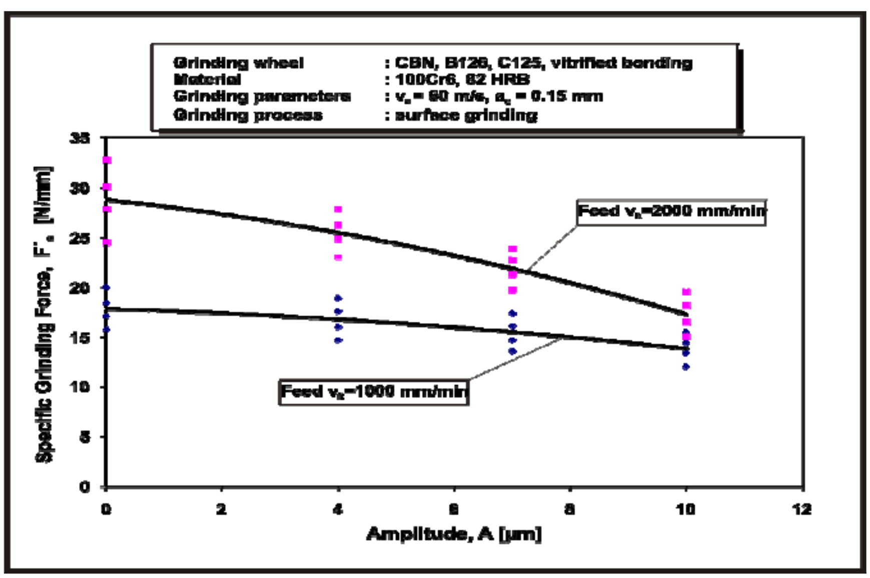

Fig. 3. Grinding force vs. Vibration Amplitude

Figs. 4–7 compare the normal grinding force and surface roughness produced by UAG with CG under different depth of cuts. Experiments were carried out at v_c=60 m/s, f=21 kHz, A=10 µm. The fire symbol shows the burning and thermal damages of the ground surface.

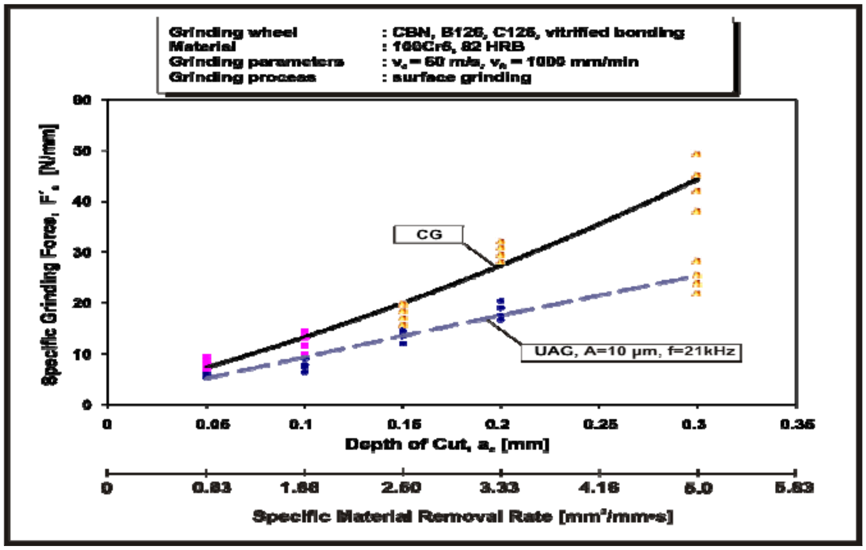

Fig. 4. Grinding force vs. Depth of cut v_{ft}=1000 mm/min (UAG: A=10µm, f=21 kHz).

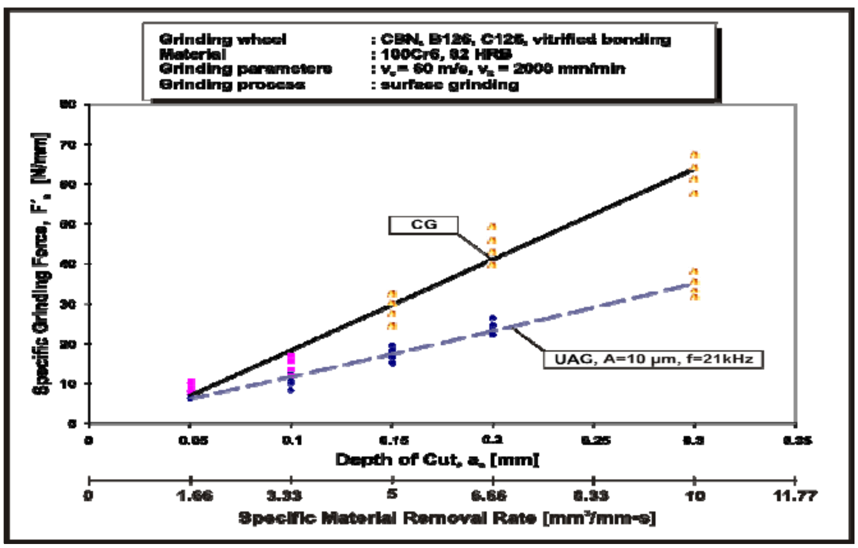

Fig. 5. Grinding force vs. Depth of cut v_{ft}=2000 mm/min (UAG: A=10µm, f=21 kHz).

The maximum oscillating accelerations (up to 174,100 m/s^2) are generated at the amplitude of 10 µm and a frequency value of 21 kHz. Due to the high frequency interaction of active grains on the workpiece, ultrasonic impact action occurs, causes the material to begin to rollover more easily as well as more micro cracking propagation in the cutting zone which both make an effective interaction between grits and workpiece surface. Therefore the grinding forces and frictional effects are decreased, so that less plastic deformation occurs.

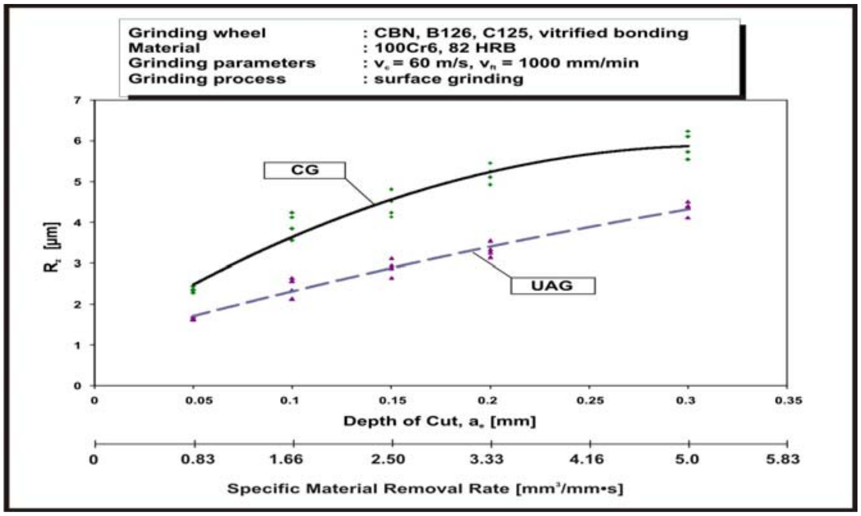

Fig. 6. R_z vs. Depth of Cut, v_{ft}=1000 mm/min (UAG: A=10µm, f=21 kHz).

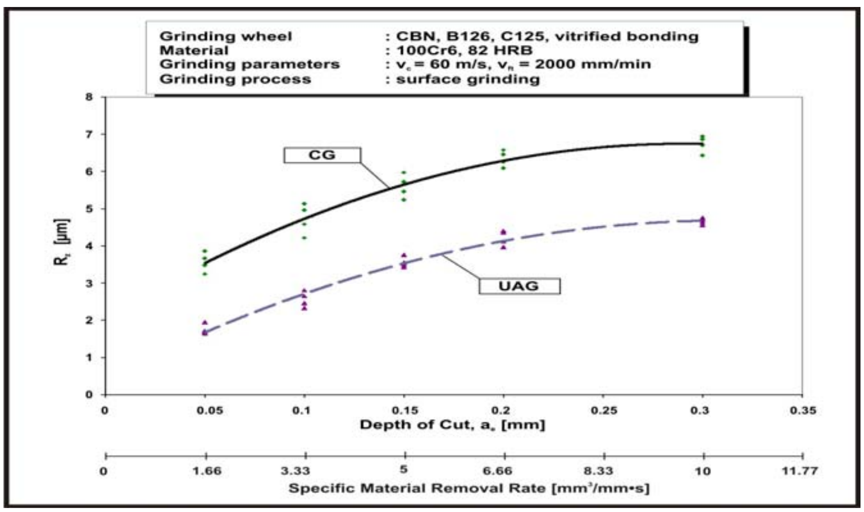

Fig. 7. R_z vs. Depth of Cut, v_{ft}=2000 mm/min (UAG: A=10µm, f=21 kHz).

Authors assume that by oscillation of the workpiece in crossfeed direction, the rubbing and plowing regimes which cause the major part of heat generation are reduced so that the grinding specific energy is also reduced and the thermal damage on the ground surface is significantly decreased.

6. Conclusion

Experimental studies of UAG and CG demonstrate considerable advantages of the former technology for grinding 100Cr6.

- Comparative experiments of the grinding forces demonstrated up to 40% reduction in normal grinding force for the workpieces machined with superimposed ultrasonic vibration. Most of CGs were unsuccessful due to the thermal damage on the ground workpiece surface. The reason for this phenomenon was due to the high grinding forces resulting to the considerable heat generation in the contact zone. These improvements are subjected to the changing in the nature of the cutting process in UAD, which is transformed into a process with a multiple-impact interaction between the tool and the formed chip resulting in interrupted cutting and reducing the grinding forces, frictional effect and plastic deformation zone.
- It was also found that UAG leads to significant improvements on the R_z parameter. It is assumed that the improvement in the R_z parameter is due to the fact that the grit in UAG has

a higher chance to cut the peak of the surface due to the crossfeed ultrasonic oscillation (sinusoidal movement of the workpiece in crossfeed direction) and increasing the possibility of the interaction of the grit and the workpiece surface in each contact length.

Our universe was structured based on the harmonic waves which their interaction makes our world so wonderful. Nature always uses the best and the simplest way, for example sound and electromagnetic waves move in a sinusoidal way. From this point of view the ultrasonic assisted grinding is a step forward to close the process to the harmony of the universe.

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