Thermal Effects in Vibration Assisted Grinding

P. Chen, W. Qu, M. H. Miller, A. Chandra

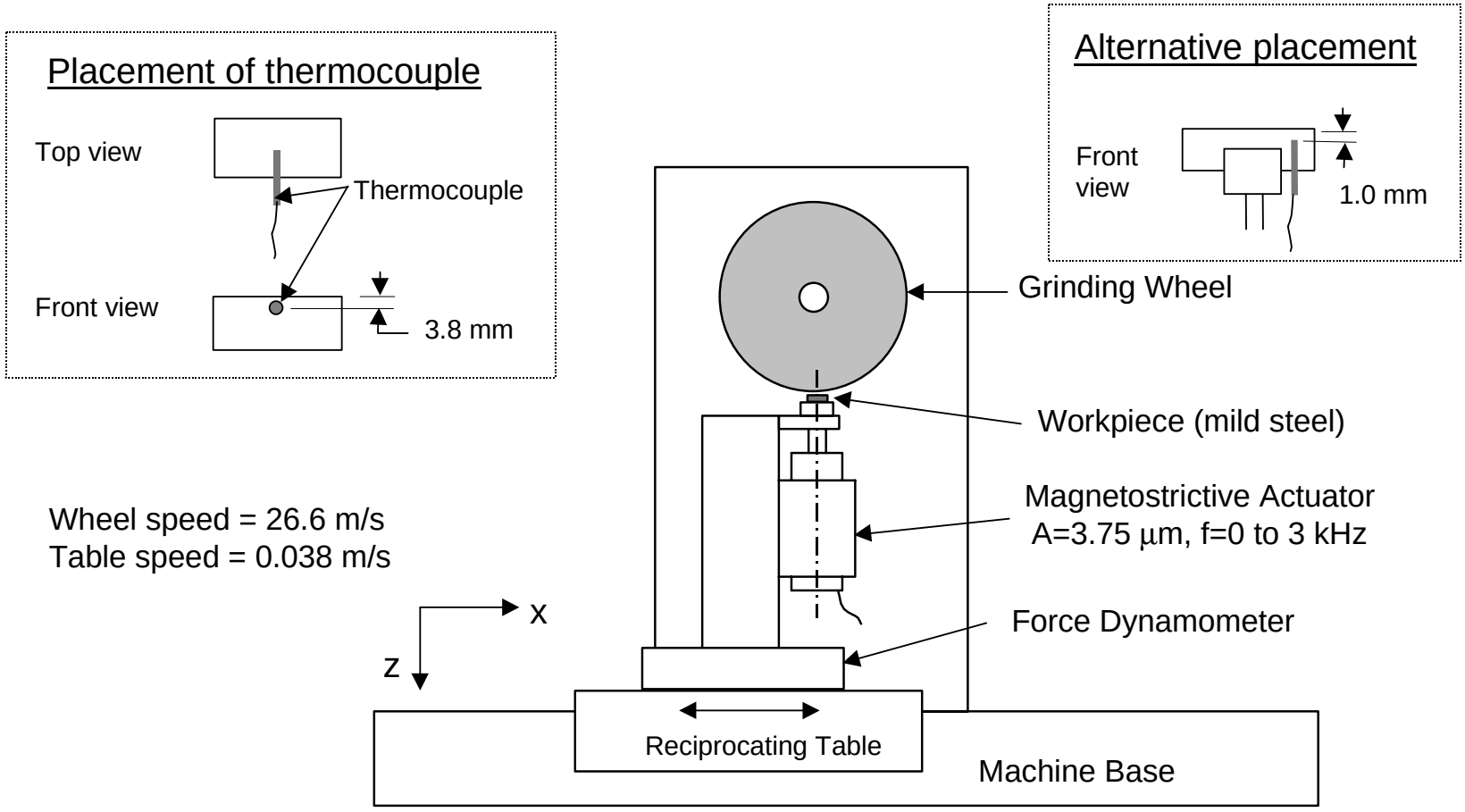
Introduction

Compared to other machining processes, grinding is a high energy process that generates significant heat. A number of researchers have investigated thermal aspects of grinding and other machining processes. Of particular interest are the total heat generated and its partitioning between the workpiece and elsewhere (chips, coolant, wheel).

The amount of heat that enters the workpiece is important because it impacts the quality of the finished part. Excessive temperature can lead to workpiece burn, thermal softening, and dimensional distortion. In addition to workpiece effects, heat generation in the grinding process accelerates wheel wear and necessitates coolant usage. Temperature also influences the mechanism of material removal: temporary softening of the workpiece, due to high temperatures, promotes ductile flow in the grinding of brittle materials. (In one of our tests the temperature rose to more than 400 $^{\circ}$C at a point 40 μm below the surface.)

This paper further investigates the effect of high frequency vibrations on grinding temperatures. It describes tests at moderate vibration frequencies (up to 3 kHz) and ultrasonic frequencies. Based on measurements of grinding energy and workpiece temperature, estimates of the portion of heat energy that enters the workpiece (the energy partition) are made.

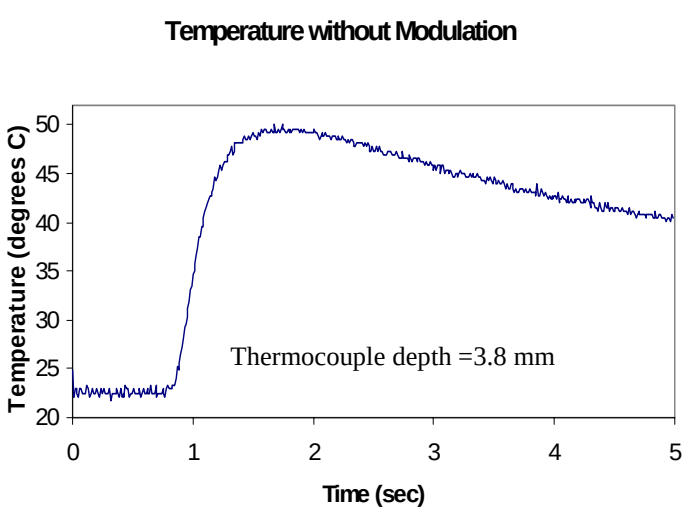
Experimental Setup for Experiments at Moderate Vibration Frequencies

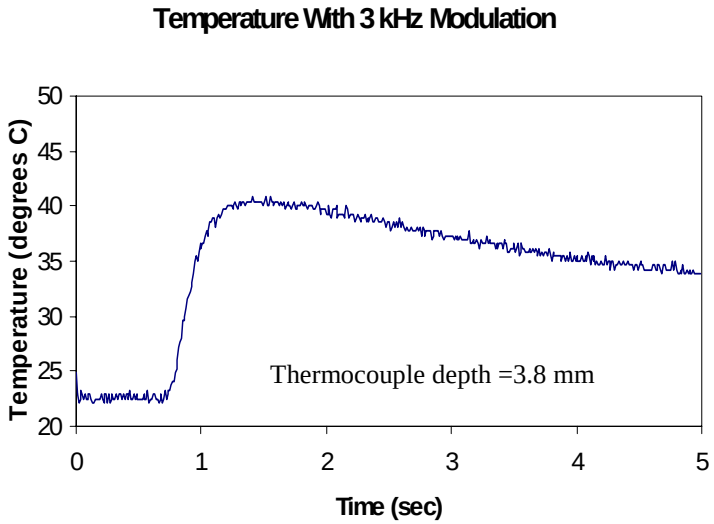


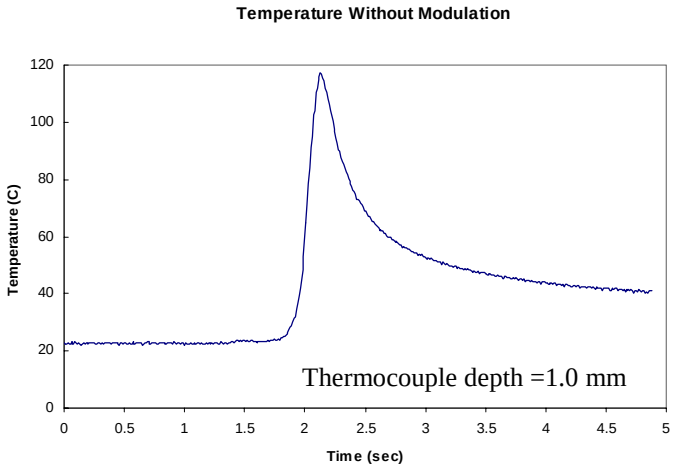
Conditions for Experiments at Moderate Vibration Frequencies

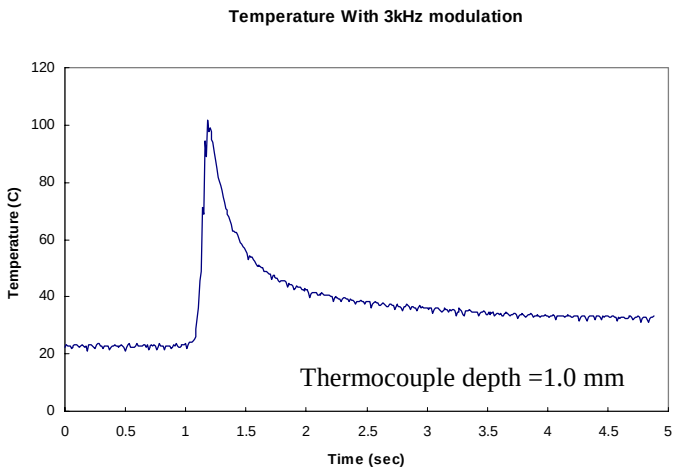
Workpiece mat'l	4140 mild steel Hardness : RC19 25.4 x 10.2 x 10 mm
Grinding wheel	Carborundum 32AR46-JV40 178 mm dia. x 12.7 mm
Wheel speed	26.6 m/s
Table speed	0.038 m/s
Wheel depth of cut	10 μm (dry tests) 25 μm (wet tests)
P-V vibration ampl.	7.5 μm
Vibration frequency	0, 1, 2, and 3 kHz (dry tests) 0 and 3 kHz (wet tests)

Effect of Modulation and Thermocouple Placement on Grinding Temperature

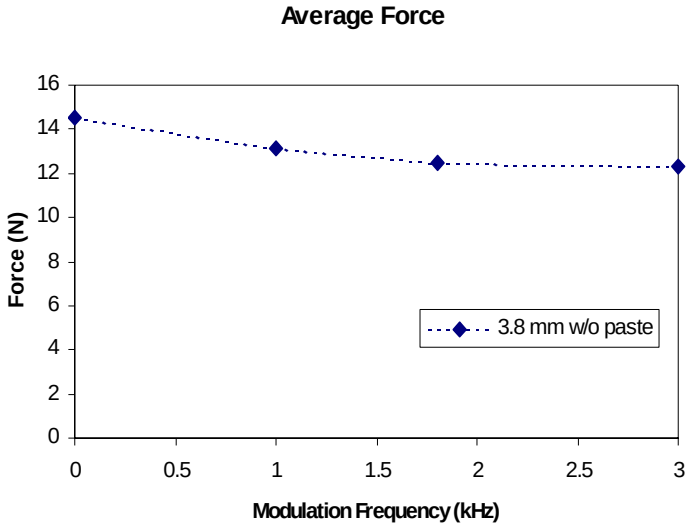


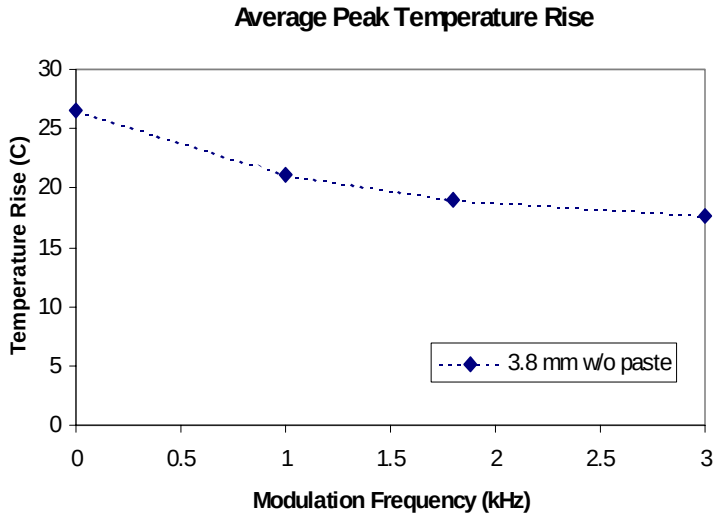






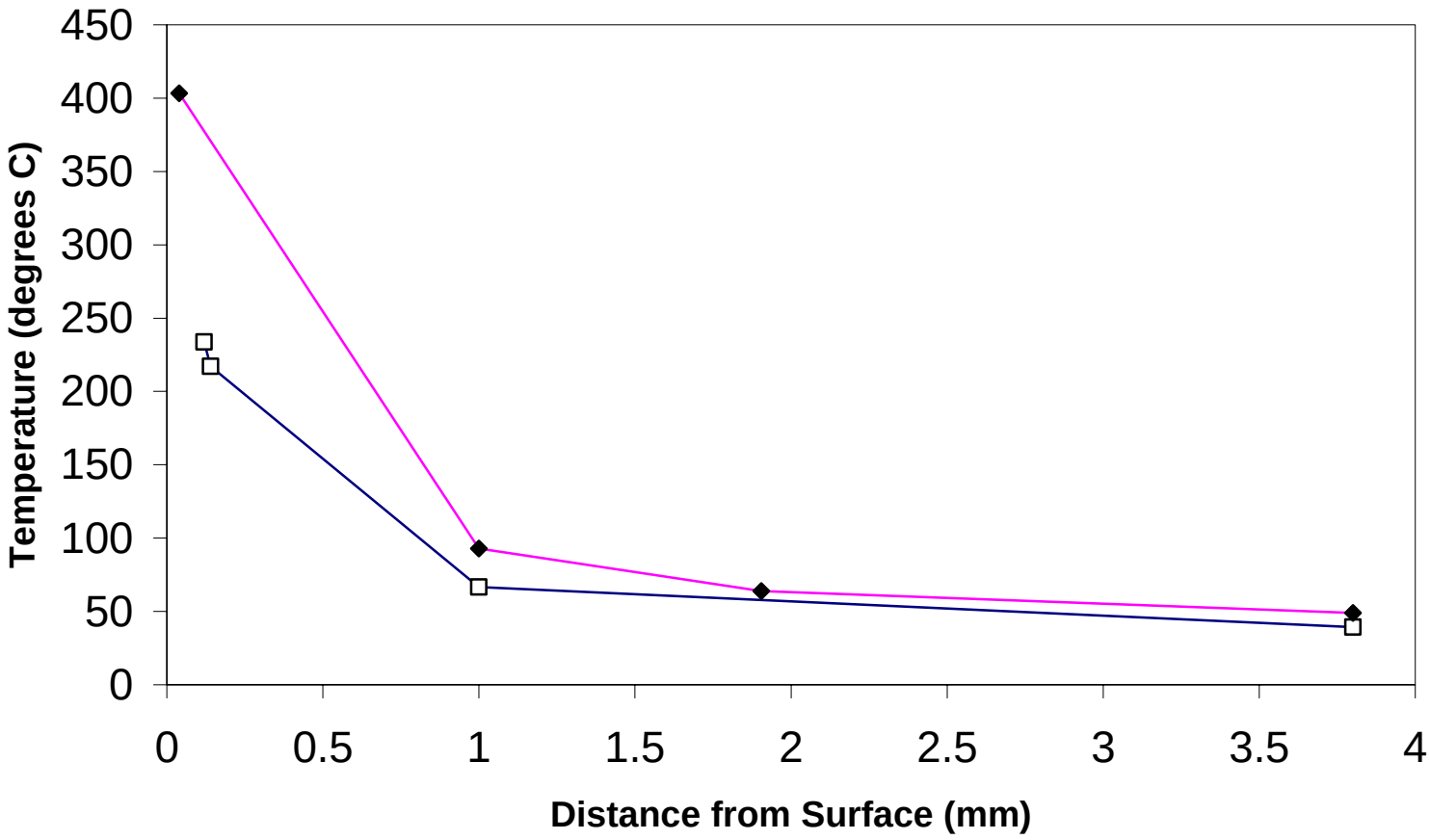
Effect of Modulation Frequency on Force and Temperature Rise



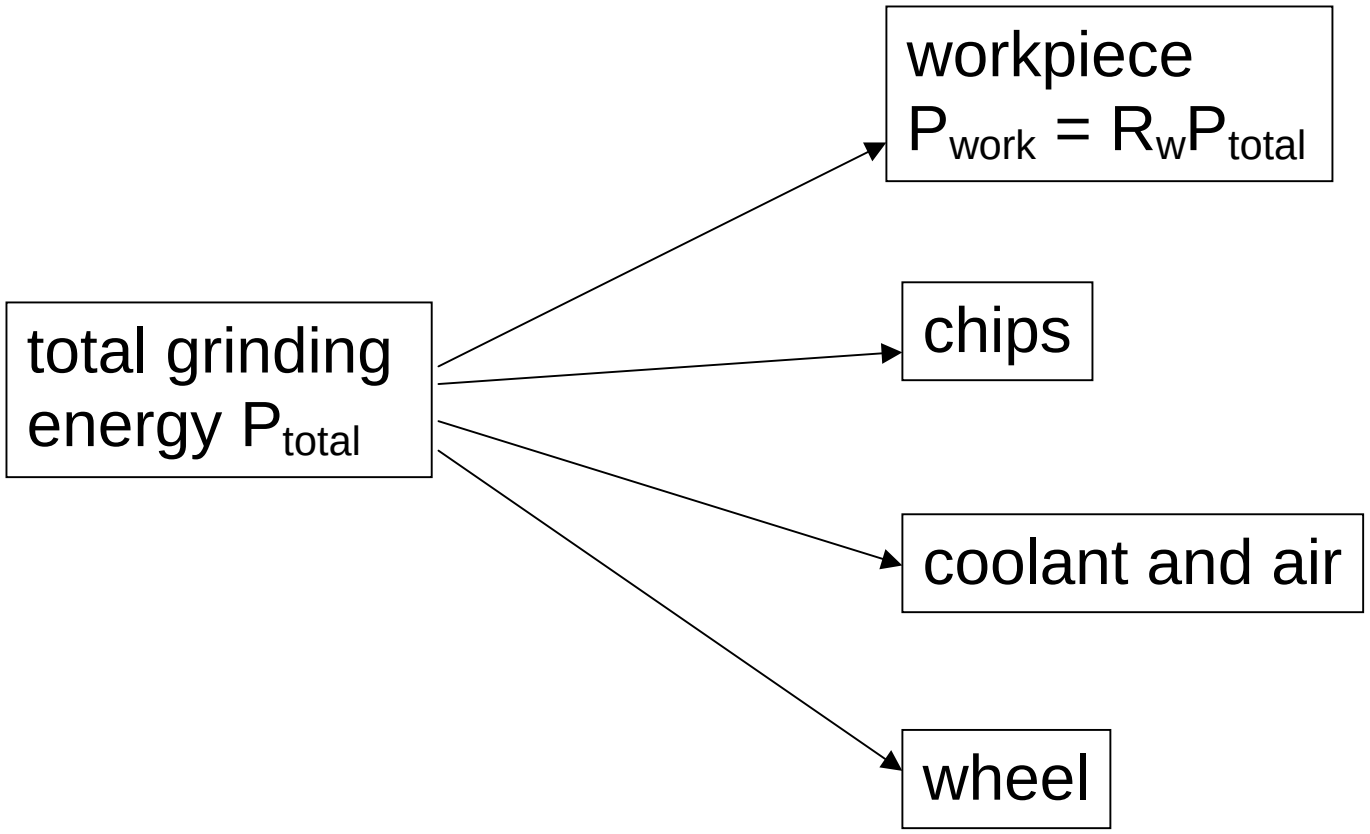


These figures present the average results of the grinding tests performed under dry conditions at a 10 μm depth of cut. Four tests were performed at each condition and averaged. From 0 kHz to 3 kHz, the average force decreases by 15% and the average peak temperature rise decreases by 34%.

Effect of Thermocouple Placement on Measured Temperature



Partitioning of Grinding Energy



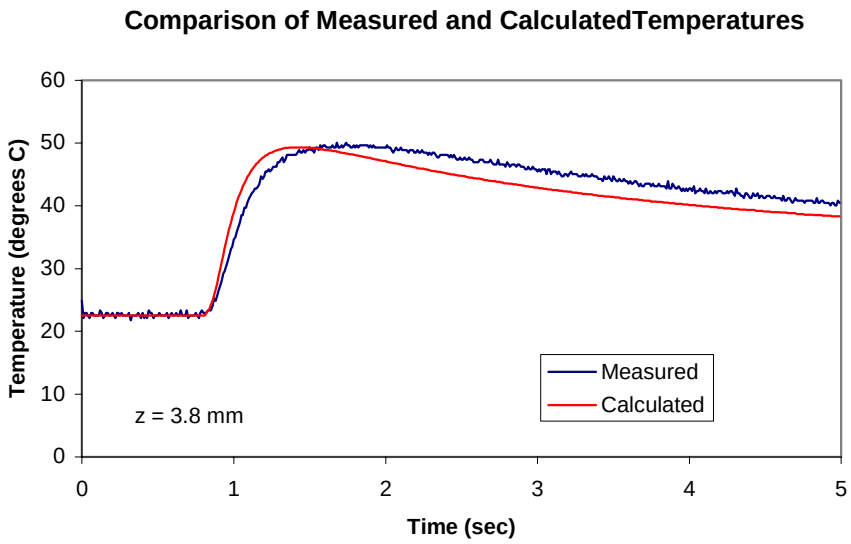
Estimate of Energy Partition

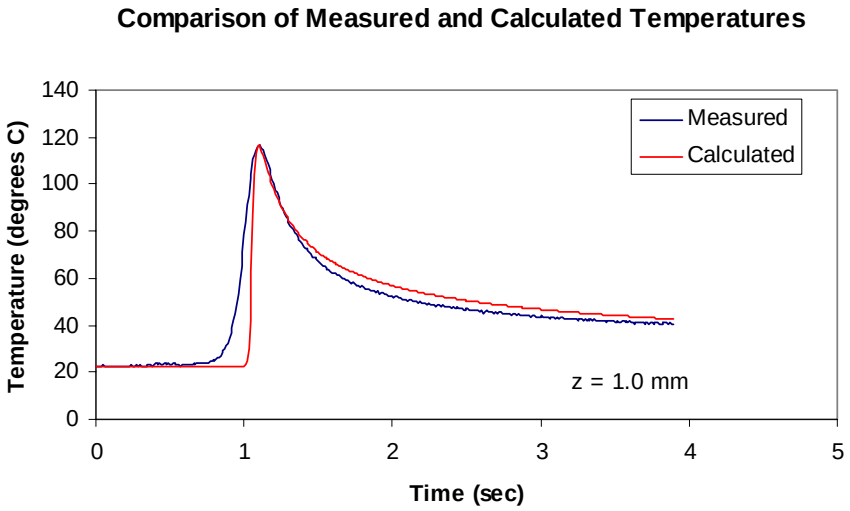
$$R_w = \frac{P_{work}}{P_{total}}$$

$$P_{total} = F_c V$$

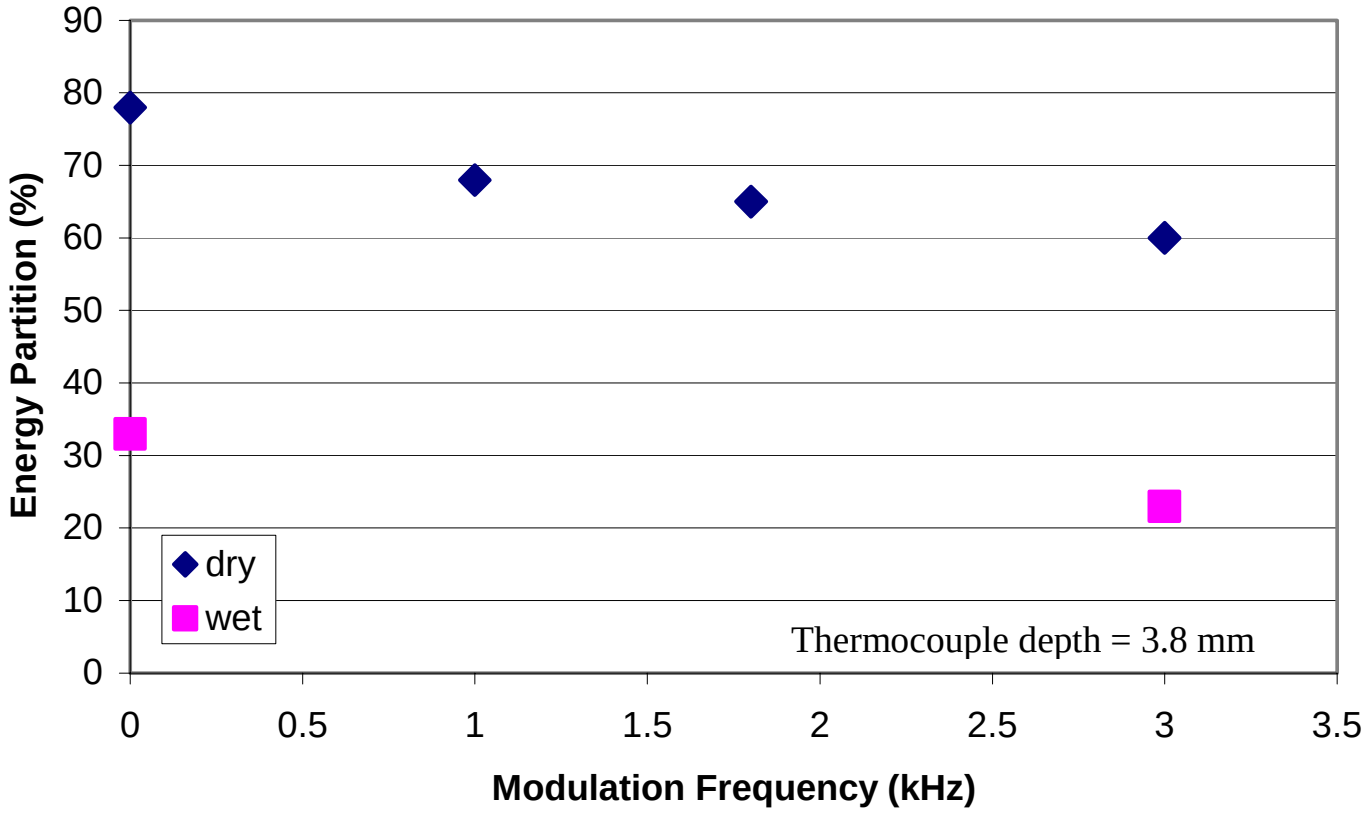
$$P_{work} = q' w$$

$$T(x,z) - T_o = \frac{q'}{\pi k} e^{\frac{vx}{2\alpha}} K_o \left[\frac{v\left(x^2 + z^2\right)^{1/2}}{2\alpha} \right]$$

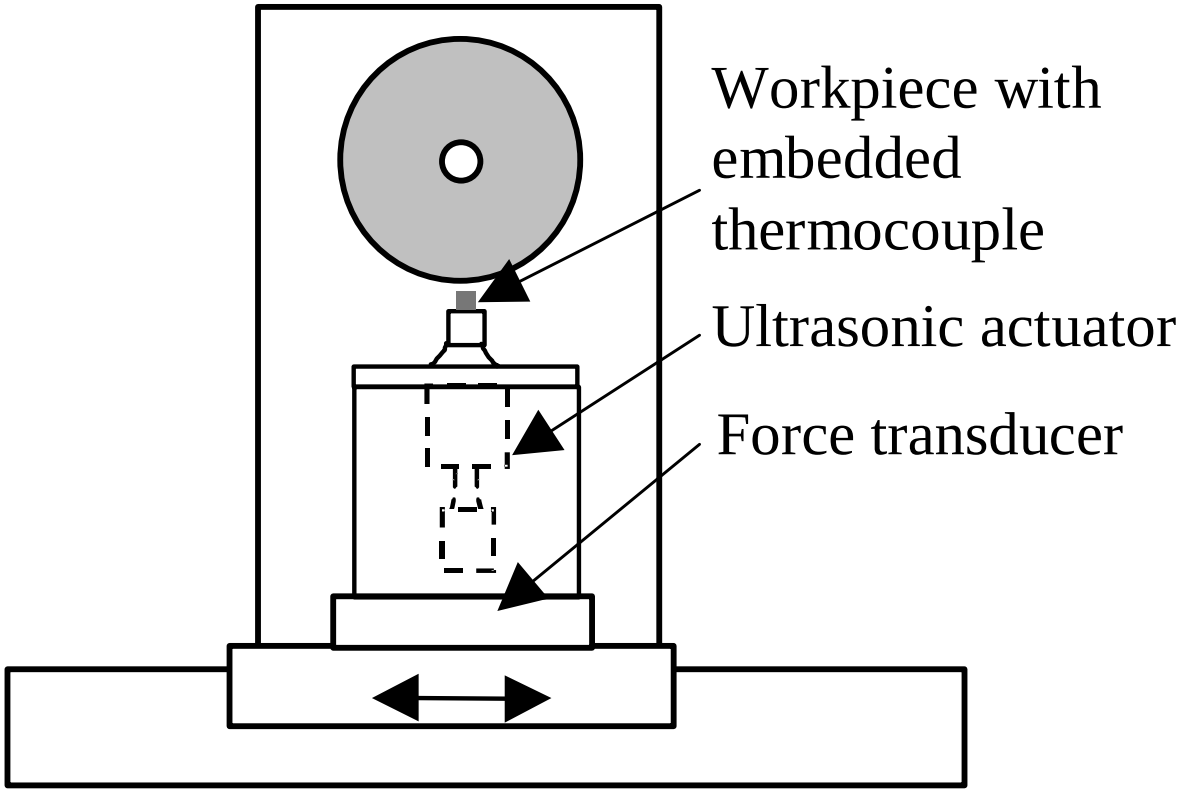




Effect of Modulation on Energy Partition



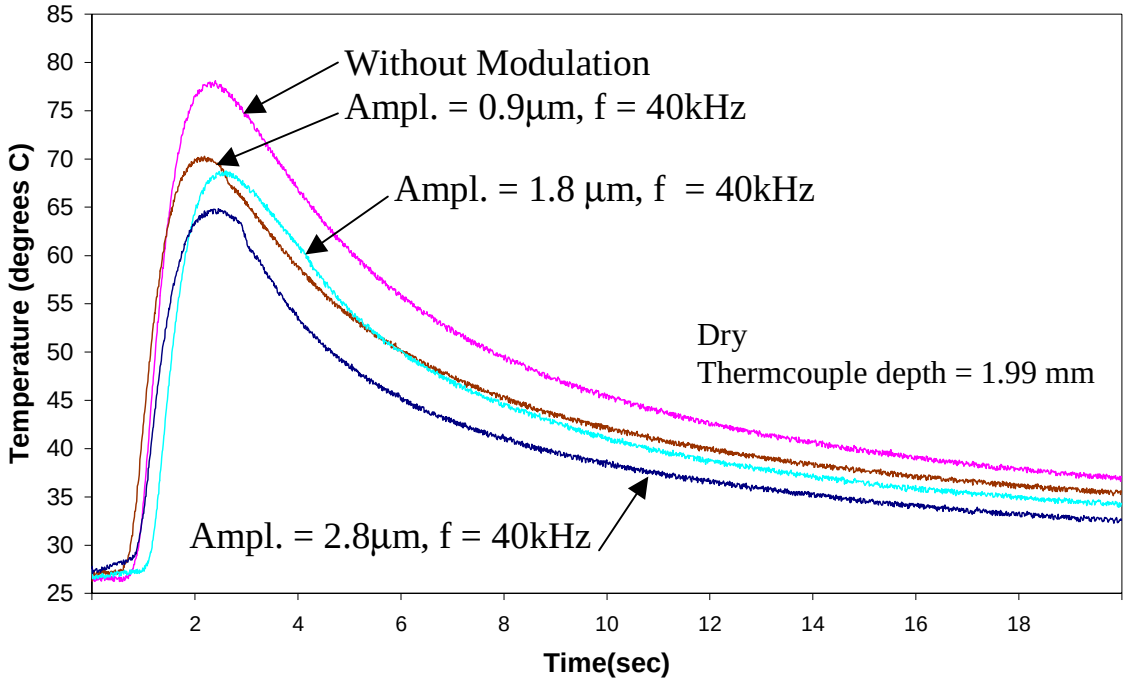
Experimental Setup for Experiments at Ultrasonic Vibration Frequencies



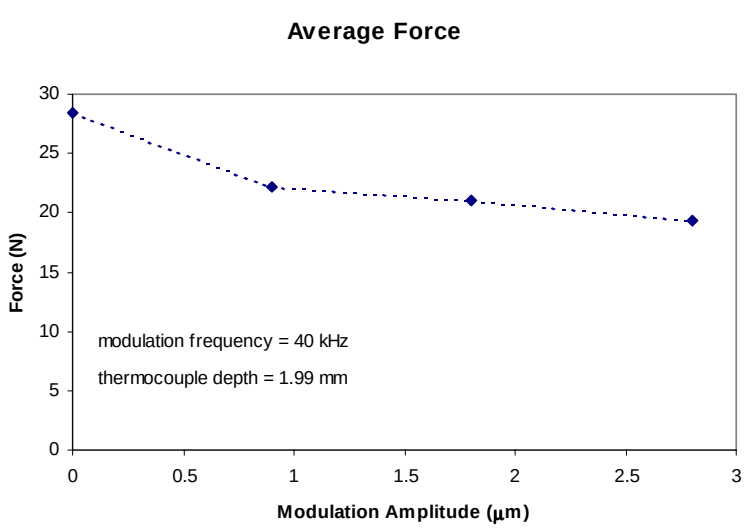
Conditions for Experiments at Ultrasonic Vibration Frequencies

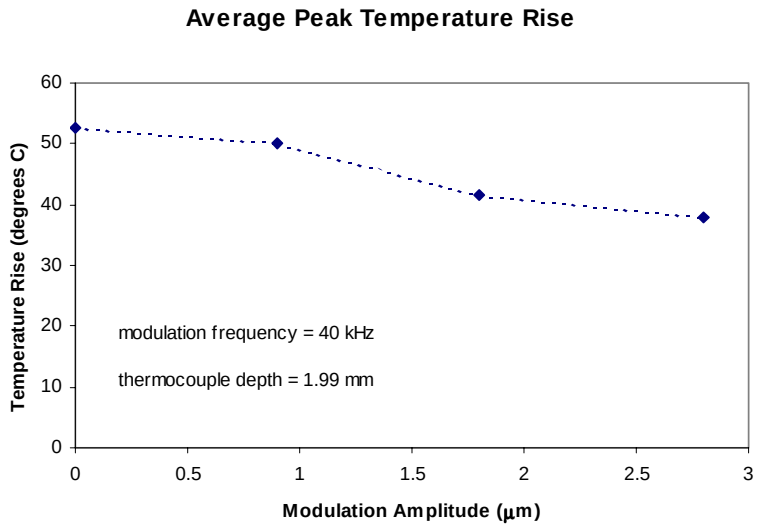
Workpiece mat'l	Steel, Hardness: RC31 12.34 x 6.24 x 3.0 mm
Grinding wheel	Carborundum 32AR46-JV40 178 mm dia. x 12.7 mm
Truing Speed	0.353mm/s
Wheel speed	26.6 m/s
Table speed	0.025 m/s
Wheel depth of cut	10 μm
P-V vibration ampl.	0, 0.9, 1.8, 2.8 μm
Vibration frequency	40 kHz

Effect of Modulation Amplitude on Temperature in Ultrasonic Tests



Effect of Modulation Amplitude on Force and Temperature Rise





These figures presents the average results of grinding tests performed under dry conditions at 40 kHz. Three tests were performed at each condition and averaged. Increasing the modulation amplitude from 0 to 2.79 μm reduces the average force by 31% and the average peak temperature rise by 28%.

Conclusions

Vibration assisted grinding experiments at relatively modest frequencies as well as ultrasonic frequency indicate that modulation reduces cutting force and temperature. Modulation at 3 kHz and 7.5 μm amplitude reduced the force by 15% and peak temperature rise by 34% over the unmodulated case. Modulation at 40 kHz and 2.8 μm amplitude reduces the cutting force by 31% and the peak temperature rise by 28% over the unmodulated case. The reduction in temperature is on the order of several hundred degrees near the work surface. Somewhat surprisingly, moderate modulation frequencies appear to produce as much benefit as ultrasonic frequencies (with reduced amplitudes). The effect of frequency and amplitude on energy partition requires further study. The mechanisms for the force and temperature reduction are currently under investigation.

Acknowledgments

This work was supported in part by NSF grant numbers DMI9610454 and DMI9875251. The authors thank Hiroshi Hashimoto for use of the ultrasonic actuator.