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Some discussions on grinding heat in mechanical processing

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Abstract
This article presents some issues about cutting heat (cutting zone temperature) when grinding. Based on the collection and analysis of results of published research on grinding, this article provides an overview of cutting heat during grinding such as: origin of cutting heat, distribution of heat during grinding. Some of the results achieved in this article are to point out the main reason why the cutting heat when grinding is higher than other mechanical machining methods and the factors that mainly lead to the heat generated when grinding being transferred to the part. . This result can be used as a reference for choosing grinding wheels and grinding modes for cases of grinding difficult-to-machine materials.

***Keyword**: cutting heat, grinding cutting heat, heat transfer, grinding*

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I. INTRODUCTION

Grinding is a machining process in the technological process of machining parts, especially parts that require high precision and surface quality. However, when grinding, there are often physical factors that affect the quality of parts after machining, such as grinding heat. That is also the reason why using coolant while grinding is mandatory. The solution used to cool when grinding often uses oils derived from mineral oil or mixed vegetable oil. The impact of these solutions on human health, the environment and the quality of the grinding process is not very positive, as has been shown by many studies. There are also many studies on the use of coolant with different mixtures or studies on optimizing the grinding process when changing cutting parameters. However, grinding heat is still a challenge for the mechanical cutting world, so this study aims to raise some issues about the heat of the grinding process.

II. FACTORS THAT CAUSE HEAT GENERATION WHEN GRINDING

Deformation of machined materials

Different from other forms of metal cutting, grinding is a machining method with an undefined cutting edge tool (grinding wheel), which has many abrasive grains with small cutting edges and geometric parameters of the abrasive grains. This is difficult to control. Normally, abrasive grains have sharp angles greater than 90o, which affects the deformation and destruction of the workpiece material (metal).

The process of metal removal in grinding, as in all abrasive methods, is fundamentally different to that of traditional metal cutting. In turning, for example, a cutting tool with defined geometry and, typically, a positive rake angle removes the swarf by a process of concentrated shear. There is little friction, and consequently a smaller part of the total energy is turned into heat, whilst chip size is usually measured in millimeters. Metal removal in grinding also involves a large amount of redundant plastic work [1]. Depending on the grinding parameters, chip size can vary, but in the micron size range, which leads to an intrinsically greater comminution energy than in traditional cutting processes.

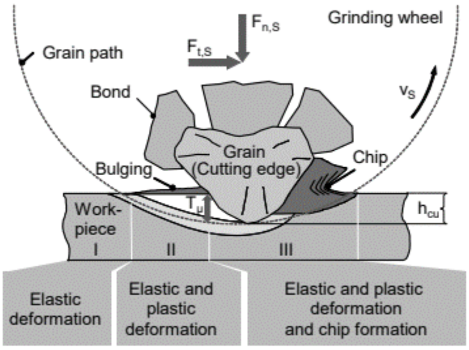

Fig 2.1 Principle of material removal during grinding

Friction during grinding

The process of metal removal in grinding, as in all abrasive methods, is fundamentally different to that of traditional metal cutting. Sliding forces are said to be generated when abrasive grains move across the workpiece surface without removing or plastically deforming the workpiece material. The wheel dressing process generates flats on the contact surfaces of abrasive grains. As grinding proceeds, the flats become further enlarged through attritious wear and the adhesion of metal particles from the workpiece [2].

The normal grinding force Fn, was expressed as the sum of a cutting component Fnc and a sliding component FnSI. The sliding component of the normal force was given by equation 1, in terms of the average contact pressure p between the wear flats and the workpiece, and the apparent wear flat area Aa, where Aa = b.lgA, and A is the proportion of wheel surface area composed of wear flats.

FnSI= p.b (de.a)1/2 A (1)

The sliding component of the tangential force FnSI, was obtained by including the friction coefficient μ is given in Figure 2.2.

FnSI = μ.p.b (de.a)1/2 A (2)

The average contact pressure, p, was obtained by differentiating equation 2 with respect to A, and solving for p. A curvature difference A, was defined and a straight line plot of p versus A showed that the average contact pressure increased linearly with increasing curvature difference for a particular value of A. It should be noted that this analysis required the use of measured values of A.

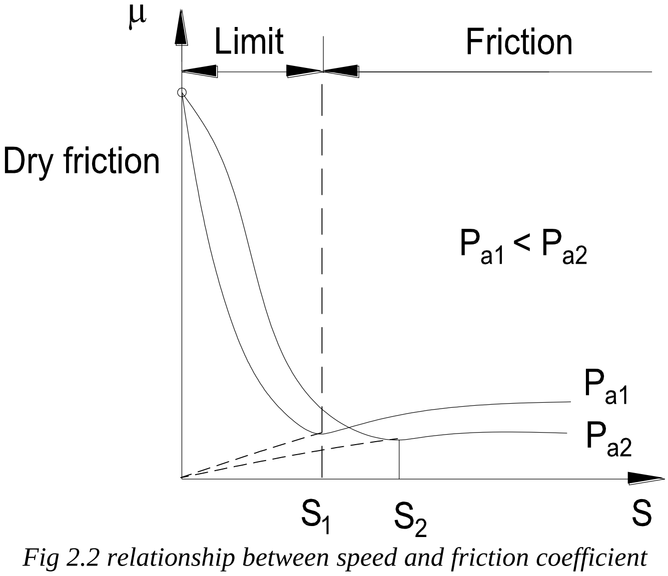

Fig 2.2 relationship between speed and friction coefficient

Chip formation process during grinding

The grinding energy remaining after subtracting the contribution due to sliding was attributed to cutting. Malkin [3] demonstrated that the magnitude of the cutting energy could not be reconciled with the classic chip formation model. The chip formation energy evaluated from earlier metal cutting theory is based on separating the chip formation mechanism into shearing deformation at the shear plane and friction at the rake face. From experimental data Malkin [4] determined that approximately 75 percent of the total chip formation energy could be attributed to shearing deformation at the shear plane region, the remainder was considered to be expended as friction energy between the grit and the workpiece. None of the chip formation frictional energy was considered to enter the workpiece.

According to Malkin, the shearing energy carried away by the chips is limited to the energy required for melting. The energy required to melt a volume of material can be obtained from enthalpy data. For iron, a change in enthalpy from ambient to melting temperature is 17,685 cal/mol, approximately 10.4 J/mm3 [2]. Malkin reasoned that since only 75 percent of the total chip formation energy was attributed to shearing at the shear plane region, the maximum chip formation energy was limited to 13.8 J/mm3 for steels. Any further increase in cutting energy was considered to be due to an increase in a mechanism other than shearing at the shear plane region. That mechanism was identified as ploughing deformation. The relationship between the ploughing and chip formation energies with material removal is illustrated in Figure 3.3.

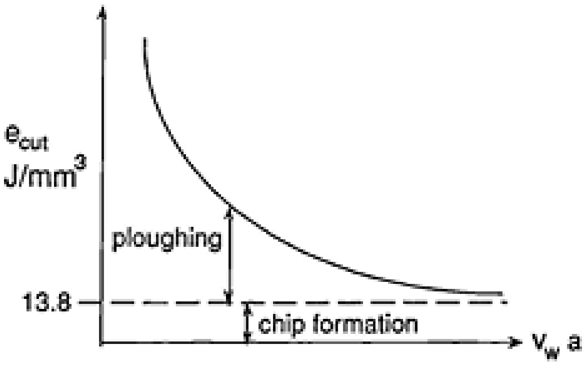

Fig 2.3 Specific cutting energy versus volumetric removal rate.

Ploughing energy is expended by deformation of the workpiece without material removal. A more extensive discussion of ploughing deformation is given in references [5] and [6]. The specific cutting energy was expressed as the sum of the specific ploughing energy component epl and the specific chip formation energy component eCh,

ecut= eCh + epl (3)

An illustration of the regions of ploughing and chip formation in grinding is given in Figure 3.4.

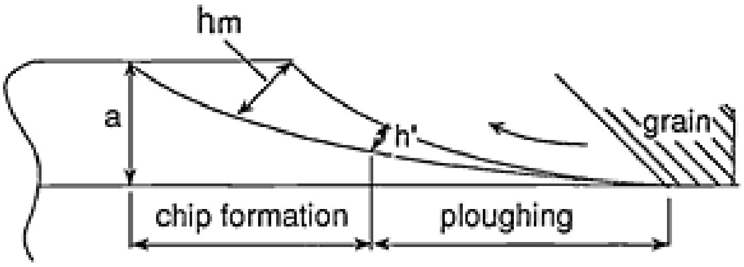

Fig 2.4 Illustration of ploughing and chip formation regions in grinding

Ploughing deformation in upcut grinding occurs as the abrasive grain penetrates the workpiece surface. Ploughing follows the initial elastic contact which is not shown.The depth of cut increases from zero to a maximum of hm at the end of the cut. Chip formation occurs when the grain has penetrated to a critical depth of cut h'. The critical depth of cut depends upon factors such as the grain sharpness, rake angle, grain orientation and the friction coefficient [6][13].

III. DISTRIBUTION OF HEAT GENERATED DURING GRINDING

Heat transfer methods during grinding

Since only 75 per cent of the chip formation energy is dissipated in the shear plane region, the total fraction of the chip formation energy conducted to the workpiece was then calculated as (0.75)(0.60) = 0.45. This corresponded to a value of 6.2 J/mm^3.

However, it was determined from calorimetric methods [9][12] that approximately 55 percent of the chip formation energy was conducted to the workpiece. The difference between the theoretically determined and experimentally determined values 7.6-6.2 = 1.4J/mm^3, was attributed to convection losses from the workpiece surface.

The fraction Rib of the total grinding energy ec entering the workpiece was therefore given by

$$\text{Rib} = \frac{e_{pl}+e_{sl}+0.55e_{ch}}{e_c} = \frac{e_c-0.45e_{ch}}{e_c} \qquad (4)$$

Where: e_{ch} chip formation specific energy = 13.8 J/mm^3
e_{pl} ploughing specific energy
e_{cut} cutting specific energy
e_{sl} sliding specific energy
e_c total specific energy
Thus $R_{ib} = 1 - 6.2/e_c$

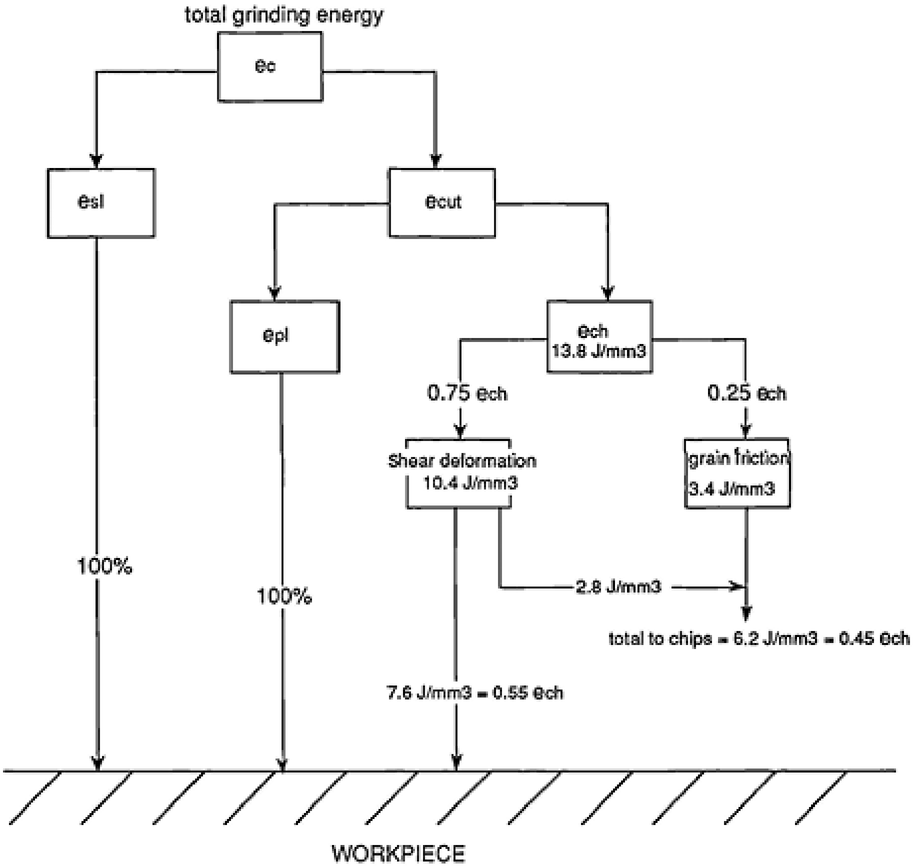

Fig 3.1 Schematic representation of the energy dissipation according to Malkin's shear plane energy model.

Coolant used in grinding and coolant methods.

There are several possible ways for the heat generated in grinding to dissipate. It has long been acknowledged that in shallow surface grinding with a short (~ 1mm) arc of cut, around 5% of the total energy input is taken away with the chips or coolant [1][14]. The remaining heat (up to 95%) is distributed between grinding wheel and workpiece. The exact partition ratio depends on the thermal properties of both bodies. If low-conductivity wheels (alumina for example) are used typically 70-90% of the heat generated will end up in the workpiece. Such a large heat input is the main cause of overheating and damage of the workpiece surface.

As grinding was for a long time considered to be just another cutting operation the cooling methods applied were (and often still are) more or less the same as in turning or milling. Usually the workpiece is simply flooded with large amount of liquid coolant (typically an emulsion of water and a small amount of mineral oil). This has long been proven to be of limited effect for several reasons – the cutting speed in grinding is much higher than in turning meaning that just a fraction of the coolant applied actually reaches the cutting zone to remove the heat. Moreover process temperatures in grinding may be much higher which can cause film boiling of a liquid coolant, dramatically diminishing its cooling potential [10][11][15]. In addition to this, there is the cost of mineral oils used with liquid coolants to be considered. They are expensive both initially and in their disposal stage.

IV. SUMMARY AND PROSPECT

- The cutting heat when grinding is high due to the high cutting speed when grinding, so in a unit of time, the phenomenon of splitting and forming chips occurs a lot, generating a large amount of heat transferred to the work piece

- The method presented is surprisingly simple and all the fluids used are cheap and clean

- Cutting heat during grinding is mostly transferred to the work piece

- The thermal conductivity of the grinding stone structural material is low.

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