5.4 CUTTING TEMPERATURE

Introduction

In cutting, nearly all of energy dissipated in plastic deformation is converted into heat that in turn raises the temperature in the cutting zone.

Since the heat generation is closely related to the plastic deformation and friction, we can specify three main sources of heat when cutting,

❶   Plastic deformation by shearing in the primary shear zone (heat source Q_1)
❷   Plastic deformation by shearing and friction on the cutting face (heat source Q_2)
❸   Friction between chip and tool on the tool flank (heat source Q_3)

Heat is mostly dissipated by,

❶   The discarded chip carries away about 60~80% of the total heat (q_1)
❷   The workpiece acts as a heat sink drawing away 10~20% heat (q_2)
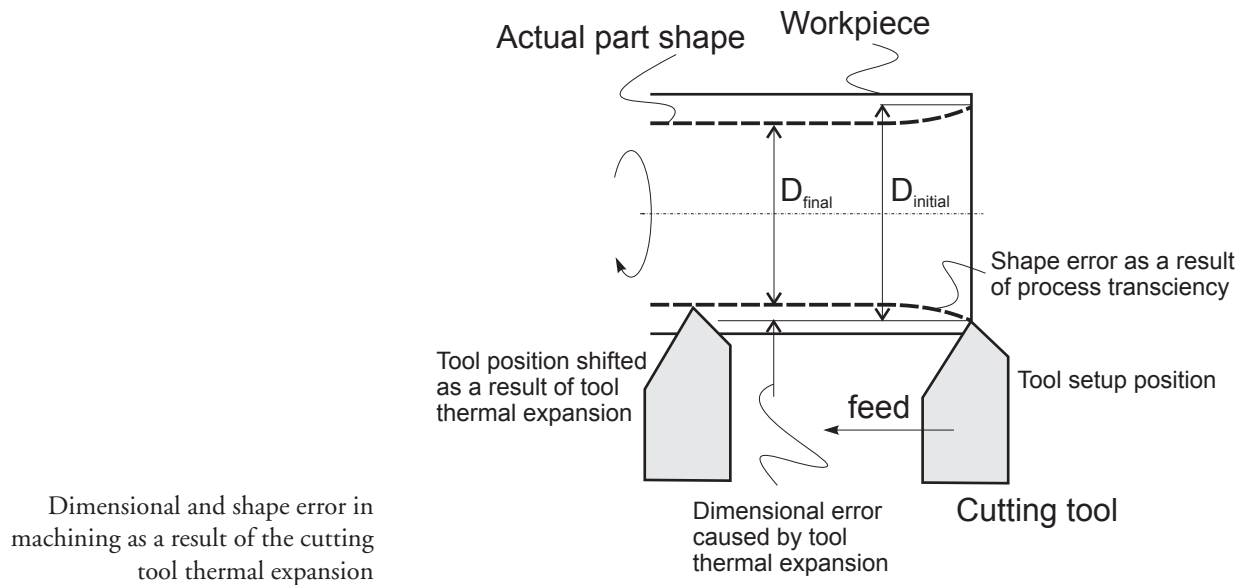❸   The cutting tool will also draw away ~10% heat (q_3).

If coolant is used in cutting, the heat drawn away by the chip can be as big as 90% of the total heat dissipated.
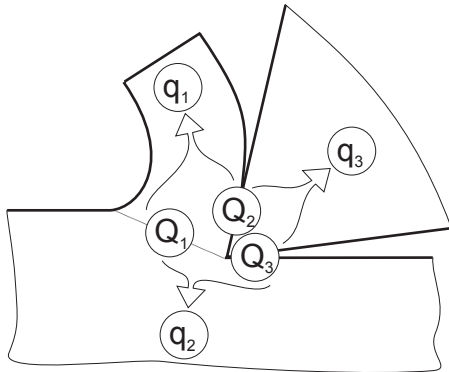
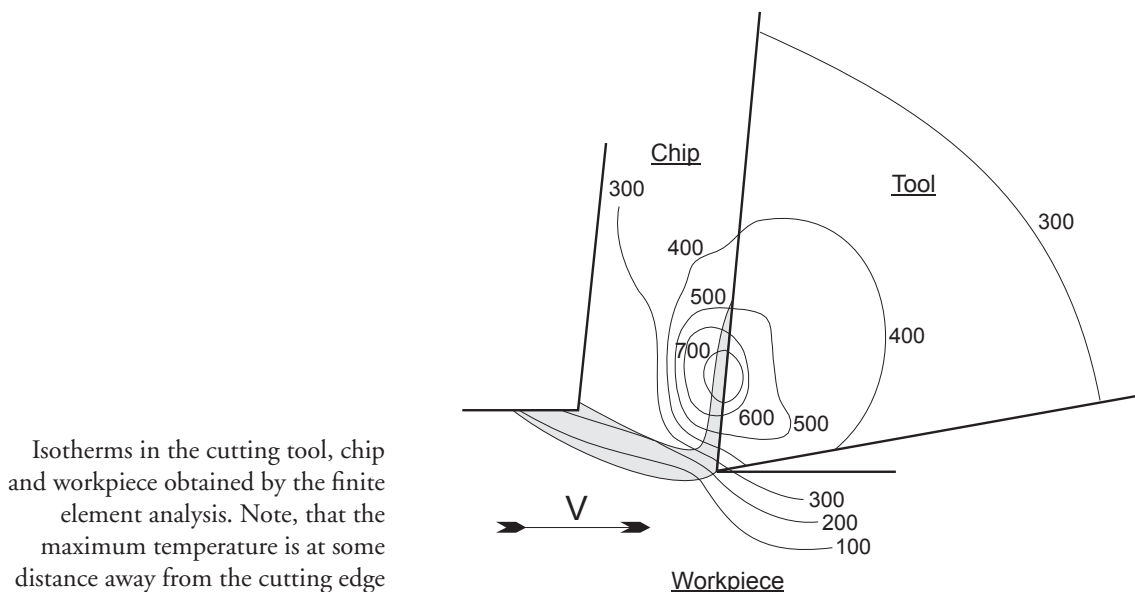

The balance of heat generation and heat dissipation in metal cutting

Knowledge of the cutting temperature is important because it:

❖   affects the *wear* of the cutting tool. Cutting temperature is the primary factor affecting the cutting tool wear as discussed in *Section 5.5*.

❖   can induce thermal damage to the machined surface. High surface temperatures promote the process of oxidation of the machined surface. The oxidation layer has worse mechanical properties than the base material, which may result in shorter service life.

❖   causes dimensional errors in the machined surface. The cutting tool elongates as a result of the increased temperature, and the position of the cutting tool edge shifts toward the machined surface, resulting in a dimensional error of about 0.01~0.02 mm. Since the processes of thermal generation, dissipation, and solid body thermal deformation are all transient, some time is required to achieve a steady-state condition. As a result, an additional shape error appears on the machined surface in the beginning of cutting as shown in the figure:

Actual part shape   Workpiece

D_{final} $D_{initial}$

Shape error as a result
of process transciency

Tool position shifted
as a result of tool
thermal expansion

Tool setup position

feed

Dimensional error
caused by tool
thermal expansion

Cutting tool

Dimensional and shape error in
machining as a result of the cutting
tool thermal expansion

Cutting temperature is not constant through the tool, chip and workpiece. The temperature field in the cutting zones is shown in the figure. It is observed, that the maximum temperature is developed not on the very cutting edge, but at the tool rake some distance away from the cutting edge.

Chip
300

Tool
300

400

500

400

700

600   500

V

300
200
100

Workpiece

Isotherms in the cutting tool, chip
and workpiece obtained by the finite
element analysis. Note, that the
maximum temperature is at some
distance away from the cutting edge

Cutting temperature determination

Cutting temperature is either

❖   *measured* in the real machining process, or
❖   *predicted* in the machining process design.

The *mean temperature* along the tool face is measured *directly* by means of different thermocouple techniques, or *indirectly* by measuring the infrared radiation, or examination of change in the tool material microstructure or microhardness induced by temperature. Some recent indirect methods are based on the examination of the temper colour of a chip, and on the use of thermosensitive paints.

There are no simple reliable methods of measuring the temperature field. Therefore, predictive approaches must be relied on to obtain the mean cutting temperature and temperature field in the chip, tool and workpiece.

For cutting temperature *prediction*, several approaches are used:

❶   *Analytical methods*: there are several analytical methods to predict the *mean temperature*. The interested readers are encouraged to read more specific texts, which present in detail these methods. Due to the complex nature of the metal cutting process, the analytical methods are typically restricted to the case of orthogonal cutting.

❷   *Numerical methods:* These methods are usually based on the *finite element modelling* of metal cutting. The numerical methods, even though more complex than the analytical approaches, allow for prediction not only of the mean cutting temperature along the tool face but also the temperature field in orthogonal and oblique cutting.

Cutting temperature control

The temperature in metal cutting can be reduced by:

❖   application of *cutting fluids* (*coolants*). The problem is further discussed in *Section 5.6*;
❖   change in the *cutting conditions* by reduction of cutting speed and/or feed;
❖   selection of proper *cutting tool geometry* (positive tool orthogonal rake angle).

Apart from application of coolants, the simplest way to reduce the cutting temperature is to reduce the cutting speed and/or feed. The next diagrams show the dependencies between the mean cutting temperature and cutting conditions:
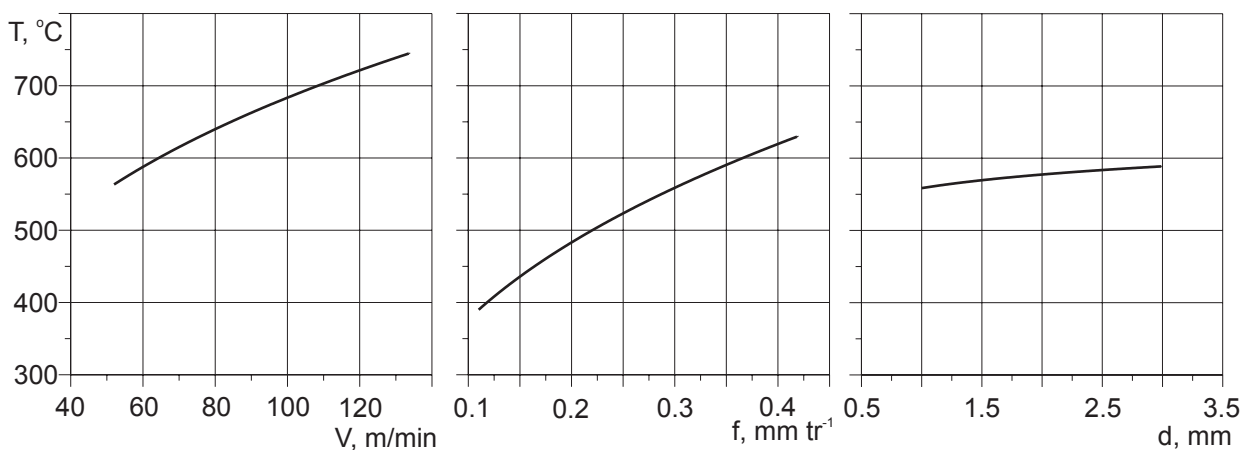
Cutting temperature T as a function of cutting speed V, feed f, and depth of cut d

From this figure is obvious, that any reduction of the cutting temperature will require substantial reduction in either the cutting speed or cutting feed, or both (the effect of depth of cut can be neglected). As a negative result, cutting time and therefore production rate will also decrease. To avoid the problem, the best solution to the problem of cutting temperature is the application of coolants.