Module
2
Mechanics of Machining

Lesson
12
Control of cutting temperature and cutting fluid application

Instructional objectives

At the end of this lesson, the students would be able to

(i) State the possible ways of controlling cutting temperature
(ii) Identify the purposes of application of cutting fluid in machining
(iii) Ascertain the essential properties of cutting fluids
(iv) Illustrate the principle of cutting fluid action
(v) Classify the types of cutting fluids and state their application
(vi) Demonstrate the methods of application of cutting fluid in machining and grinding.

(i) Basic methods of controlling cutting temperature

It is already realised that the cutting temperature, particularly when it is quite high, is very detrimental for both cutting tools and the machined jobs and hence need to be controlled, i.e., reduced as far as possible without sacrificing productivity and product quality.
The methods generally employed for controlling machining temperature and its detrimental effects are :

- Proper selection of cutting tools; material and geometry
- Proper selection of cutting velocity and feed
- Proper selection and application of cutting fluid

- **Selection of material and geometry of cutting tool for reducing cutting temperature and its effects**

Cutting tool material may play significant role on reduction of cutting temperature depending upon the work material.
As for example,

- PVD or CVD coating of HSS and carbide tools enables reduce cutting temperature by reducing friction at the chip-tool and work-tool interfaces.
- In high speed machining of steels lesser heat and cutting temperature develop if machined by cBN tools which produce lesser cutting forces by retaining its sharp geometry for its extreme hardness and high chemical stability.
- The cutting tool temperature of ceramic tools decrease further if the thermal conductivity of such tools is enhanced (by adding thermally conductive materials like metals, carbides, etc in Al_2O_3 or Si_3N_4)

Cutting temperature can be sizeably controlled also by proper selection of the tool geometry in the following ways;

- large positive tool–rake helps in reducing heat and temperature generation by reducing the cutting forces, but too much increase in rake mechanically and thermally weakens the cutting edges
- compound rake, preferably with chip–breaker, also enables reduce heat and temperature through reduction in cutting forces and friction

- even for same amount of heat generation, the cutting temperature decreases with the decrease in the principal cutting edge angle, ϕ as

$$\theta_C \; \alpha \; [V_C^{0.5}(s_o \sin\phi)^{0.25}] \qquad (2.8.1)$$

- nose radiusing of single point tools not only improves surface finish but also helps in reducing cutting temperature to some extent.

o **Selection of cutting velocity and feed**

Cutting temperature can also be controlled to some extent, even without sacrificing MRR, by proper or optimum selection of the cutting velocity and feed within their feasible ranges. The rate of heat generation and hence cutting temperature are governed by the amount of cutting power consumption, P_C where;

$$P_C = P_Z.V_C = ts_o\tau_s fV_C \qquad (2.8.2)$$

So apparently, increase in both s_o and V_C raise heat generation proportionately. But increase in V_C, though further enhances heat generation by faster rubbing action, substantially reduces cutting forces, hence heat generation by reducing τ_s and also the form factor f. The overall relative effects of variation of V_C and s_o on cutting temperature will depend upon other machining conditions. Hence, depending upon the situation, the cutting temperature can be controlled significantly by optimum combination of V_C and s_o for a given MRR.

o **Control of cutting temperature by application of cutting fluid**

Cutting fluid, if employed, reduces cutting temperature directly by taking away the heat from the cutting zone and also indirectly by reducing generation of heat by reducing cutting forces

(ii) Purposes of application of cutting fluid in machining and grinding.

The basic purposes of cutting fluid application are :

- Cooling of the job and the tool to reduce the detrimental effects of cutting temperature on the job and the tool
- Lubrication at the chip–tool interface and the tool flanks to reduce cutting forces and friction and thus the amount of heat generation.
- Cleaning the machining zone by washing away the chip – particles and debris which, if present, spoils the finished surface and accelerates damage of the cutting edges
- Protection of the nascent finished surface – a thin layer of the cutting fluid sticks to the machined surface and thus prevents its harmful contamination by the gases like SO_2, O_2, H_2S, N_xO_y present in the atmosphere.

However, the main aim of application of cutting fluid is to improve machinability through reduction of cutting forces and temperature, improvement by surface integrity and enhancement of tool life.

(iii) Essential properties of cutting fluids

To enable the cutting fluid fulfil its functional requirements without harming the Machine – Fixture – Tool – Work (M-F-T-W) system and the operators, the cutting fluid should possess the following properties:

- For cooling :
    - high specific heat, thermal conductivity and film coefficient for heat transfer
    - spreading and wetting ability
- For lubrication :
    - high lubricity without gumming and foaming
    - wetting and spreading
    - high film boiling point
    - friction reduction at extreme pressure (EP) and temperature
- Chemical stability, non-corrosive to the materials of the M-F-T-W system
- less volatile and high flash point
- high resistance to bacterial growth
- odourless and also preferably colourless
- non toxic in both liquid and gaseous stage
- easily available and low cost.

(iv) Principles of cutting fluid action

The chip-tool contact zone is usually comprised of two parts; plastic or bulk contact zone and elastic contact zone as indicated in Fig. 2.8.1

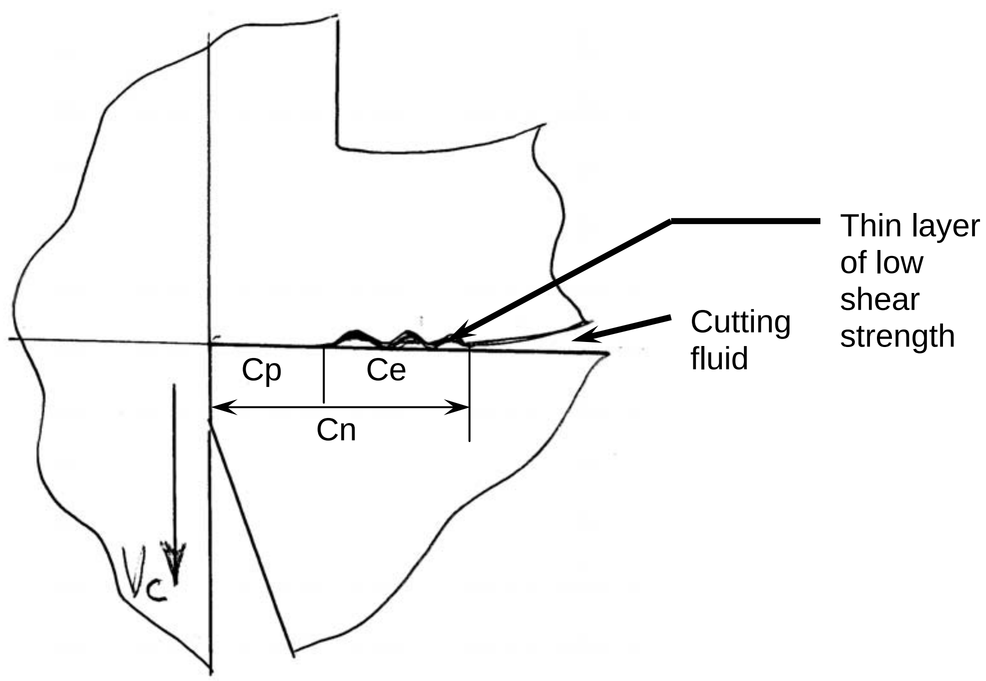

Fig. 2.8.1 Cutting fluid action in machining.

The cutting fluid cannot penetrate or reach the plastic contact zone but enters in the elastic contact zone by capillary effect. With the increase in cutting velocity, the fraction of plastic contact zone gradually increases and covers almost the entire chip-tool contact zone as indicated in Fig. 2.8.2. Therefore, at high speed machining, the cutting fluid becomes unable to lubricate and cools the tool and the job only by bulk external cooling .

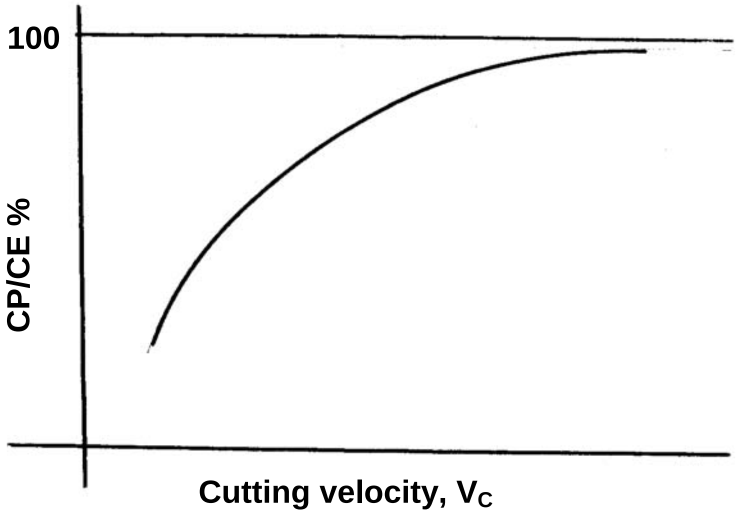

Fig. 2.8.2 *Apportionment of plastic and elastic contact zone with increase in cutting velocity.*

The chemicals like chloride, phosphate or sulphide present in the cutting fluid chemically reacts with the work material at the chip under surface under high pressure and temperature and forms a thin layer of the reaction product. The low shear strength of that reaction layer helps in reducing friction.
To form such solid lubricating layer under high pressure and temperature some extreme pressure additive (EPA) is deliberately added in reasonable amount in the mineral oil or soluble oil.
For extreme pressure, chloride, phosphate or sulphide type EPA is used depending upon the working temperature, i.e. moderate (200^{o}C ~ 350^{o}C), high (350^{o}C ~ 500^{o}C) and very high (500 ^{o}C ~ 800 ^{o}C) respectively.

(v) Types of cutting fluids and their application

Generally, cutting fluids are employed in liquid form but occasionally also employed in gaseous form. Only for lubricating purpose, often solid lubricants are also employed in machining and grinding.
The cutting fluids, which are commonly used, are :

- **Air blast or compressed air only.**
  Machining of some materials like grey cast iron become inconvenient or difficult if any cutting fluid is employed in liquid form. In such case only air blast is recommended for cooling and cleaning

- **Water**
  For its good wetting and spreading properties and very high specific heat, water is considered as the best coolant and hence employed where cooling is most urgent.
- **Soluble oil**
  Water acts as the best coolant but does not lubricate. Besides, use of only water may impair the machine-fixture-tool-work system by rusting
  So oil containing some emulsifying agent and additive like EPA, together called cutting compound, is mixed with water in a suitable ratio (1 ~ 2 in 20 ~ 50). This milk like white emulsion, called soluble oil, is very common and widely used in machining and grinding.
- **Cutting oils**
  Cutting oils are generally compounds of mineral oil to which are added desired type and amount of vegetable, animal or marine oils for improving spreading, wetting and lubricating properties. As and when required some EP additive is also mixed to reduce friction, adhesion and BUE formation in heavy cuts.
- **Chemical fluids**
  These are occasionally used fluids which are water based where some organic and or inorganic materials are dissolved in water to enable desired cutting fluid action.
  There are two types of such cutting fluid;
  - Chemically inactive type – high cooling, anti-rusting and wetting but less lubricating
  - Active (surface) type – moderate cooling and lubricating.
- **Solid or semi-solid lubricant**
  Paste, waxes, soaps, graphite, Moly-disulphide (MoS_2) may also often be used, either applied directly to the workpiece or as an impregnant in the tool to reduce friction and thus cutting forces, temperature and tool wear.
- **Cryogenic cutting fluid**
  Extremely cold (cryogenic) fluids (often in the form of gases) like liquid CO_2 or N_2 are used in some special cases for effective cooling without creating much environmental pollution and health hazards.

Selection of Cutting Fluid

The benefits of application of cutting fluid largely depends upon proper selection of the type of the cutting fluid depending upon the work material, tool material and the machining condition. As for example, for high speed machining of not-difficult-to-machine materials greater cooling type fluids are preferred and for low speed machining of both conventional and difficult-to-machine materials greater lubricating type fluid is preferred. Selection of cutting fluids for machining some common engineering materials and operations are presented as follows :

- Grey cast iron :
  - ∆ Generally dry for its self lubricating property
  - ∆ Air blast for cooling and flushing chips

- Steels :
    - ∆ Soluble oil for cooling and flushing chips in high speed machining and grinding
    - ∆ If machined by HSS tools, sol. Oil (1: 20 ~30) for low carbon and alloy steels and neat oil with EPA for heavy cuts
    - ∆ If machined by carbide tools thinner sol. Oil for low strength steel, thicker sol. Oil (1:10 ~ 20) for stronger steels and staright sulphurised oil for heavy and low speed cuts and EP cutting oil for high alloy steel.
    - ∆ Often steels are machined dry by carbide tools for preventing thermal shocks.
- Aluminium and its alloys:
    - ∆ Preferably machined dry
    - ∆ Light but oily soluble oil
    - ∆ Straight neat oil or kerosene oil for stringent cuts.
- Copper and its alloys :
    - ∆ Water based fluids are generally used
    - ∆ Oil with or without inactive EPA for tougher grades of Cu-alloy.
- Stainless steels and Heat resistant alloys:
    - ∆ High performance soluble oil or neat oil with high concentration with chlorinated EP additive.

The brittle ceramics and cermets should be used either under dry condition or light neat oil in case of fine finishing.
Grinding at high speed needs cooling (1: 50 ~ 100) soluble oil. For finish grinding of metals and alloys low viscosity neat oil is also used.

(vi) Methods of application of cutting fluid

The effectiveness and expense of cutting fluid application significantly depend also on how it is applied in respect of flow rate and direction of application.
In machining, depending upon the requirement and facilities available, cutting fluids are generally employed in the following ways (flow) :

- Drop-by-drop under gravity
- Flood under gravity
- In the form of liquid jet(s)
- Mist (atomised oil) with compressed air
- Z-Z method – centrifugal through the grinding wheels (pores) as indicated in Fig. 2.8.3.

The direction of application also significantly governs the effectiveness of the cutting fluid in respect of reaching at or near the chip-tool and work-tool interfaces. Depending upon the requirement and accessibility the cutting fluid is applied from top or side(s). in operations like deep hole drilling the pressurised fluid is often sent through the axial or inner spiral hole(s) of the drill. For effective cooling and lubrication in high speed machining of ductile metals having wide and plastic chip-tool contact, cutting fluid may be pushed at high pressure to the chip-tool interface through hole(s) in the cutting tool, as schematically shown in Fig. 2.8.4.

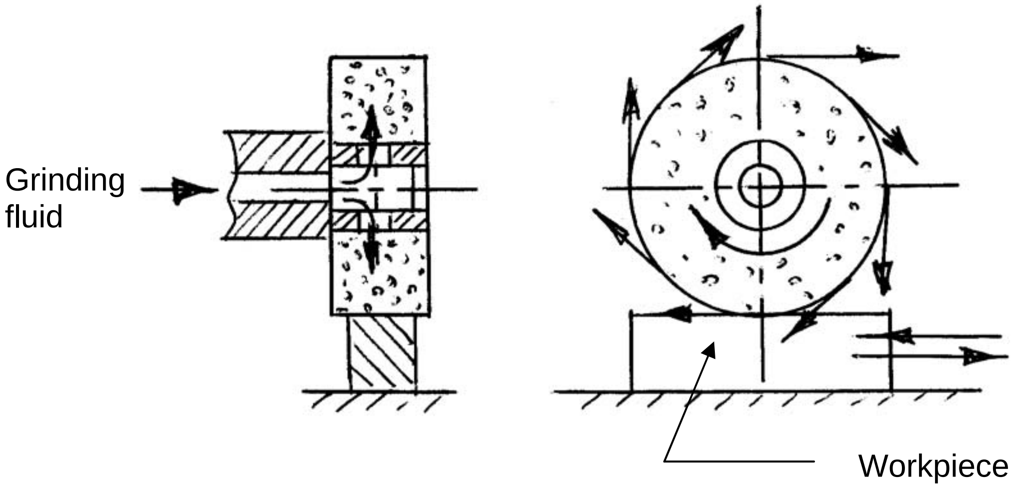

Fig. 2.8.3 *Z-Z method of cutting fluid application in grinding.*

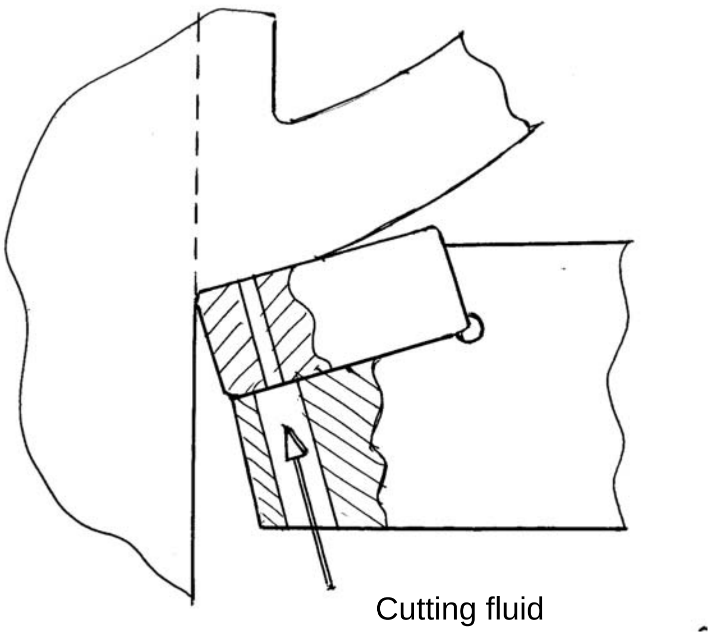

Fig. 2.8.4 *Application of cutting fluid at high pressure through the hole in the tool.*

Exercise – 2.8

Identify the correct answer from the given four options:

1. Cutting fluid is employed in machining for
   (a) cooling the tool and the job
   (b) lubricate at the rubbing surfaces
   (c) cleaning the machining zone
   (d) all of the above

2. For same tool-work materials and speed, feed and depth of cut, the average cutting temperature will decrease
   (a) with the increase in principal cutting edge angle (ϕ)
   (b) with the decrease in principal cutting edge angle (ϕ)
   (c) with the increase in auxiliary cutting edge angle (ϕ_1)
   (d) with the decrease in the auxiliary cutting edge angle (ϕ_1)

3. The work material, which is machined by HSS tool generally in dry condition, is
   (a) grey cast iron
   (b) mild steel
   (c) stainless steel
   (d) low alloy steel

4. Extreme pressure additive (EPA) is mixed with cutting fluid for improving its power of
   (a) cooling
   (b) lubrication
   (c) cleaning of the cutting zone
   (d) protection of the machined surface

5. More lubricating type cutting fluid should be used while machining
   (a) easily machinable material at high speed
   (b) grey cast iron at low speed
   (c) high alloy steels at low speed
   (d) aluminium at high speed

6. In Z-Z method of cooling in surface grinding, the cutting fluid is employed
   (a) in the form of flood under gravity
   (b) in the form of jet at the grinding zone
   (c) drop by drop
   (d) none of the above

7. In machining copper under heavy cut one should use
   (a) light soluble oil
   (b) active type chemical fluid

(c) inactive type chemical fluid
(d) compound oil

Answers

1 – (d)
2 – (b)
3 – (a)
4 – (b)
5 – (c)
6 – (d)
7 – (b)