UNIT 2:


Instructional objectives:

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

(i) Identify the needs and cite the chronological development of cutting tool materials.
(ii) Describe the characteristics and state the applications of the commonly used cutting tool materials;
   (a) High speed steel
   (b) Sintered carbides
   (c) Plain ceramics

Needs and Chronological Development of Cutting Tool Materials:

With the progress of the industrial world it has been needed to continuously develop and improve the cutting tool materials and geometry;

➢ To meet the growing demands for high productivity, quality and economy of machining
➢ To enable effective and efficient machining of the exotic materials that are coming up with the rapid and vast progress of science and technology
➢ For precision and ultra-precision machining
➢ For micro and even nano machining demanded by the day and future.

It is already stated that the capability and overall performance of the cutting tools depend upon,

➢ The cutting tool materials
➢ The cutting tool geometry
➢ Proper selection and use of those tools
➢ The machining conditions and the environments
Out of which the tool material plays the most vital role.

The relative contribution of the cutting tool materials on productivity, for instance, can be roughly assessed from Fig. 2.1

![Graph showing productivity raised by cutting tool materials.](image)

**Fig. 2.1** Productivity raised by cutting tool materials.

The chronological development of cutting tool materials is briefly indicated in Fig. 2.2

**Characteristics and Applications of the Primary Cutting Tool Materials:**

(a) **High Speed Steel (HSS)**

Advent of HSS in around 1905 made a break through at that time in the history of cutting tool materials though got later superseded by many other novel tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools.

The basic composition of HSS is 18% W, 4% Cr, 1% V, 0.7% C and rest Fe. Such HSS tool could machine (turn) mild steel jobs at speed only upto 20 ~ 30 m/min (which was quite substantial those days)
Fig. 2.2 Chronological Development of cutting tool materials

However, HSS is still used as cutting tool material where;

- The tool geometry and mechanics of chip formation are complex, such as helical twist drills, reamers, gear shaping cutters, hobs, form tools, broaches etc.
- Brittle tools like carbides, ceramics etc. are not suitable under shock loading
- The small scale industries cannot afford costlier tools
- The old or low powered small machine tools cannot accept high speed and feed.
- The tool is to be used number of times by resharpening.
With time the effectiveness and efficiency of HSS (tools) and their application range were gradually enhanced by improving its properties and surface condition through -

- Refinement of microstructure
- Addition of large amount of cobalt and Vanadium to increase hot hardness and wear resistance respectively
- Manufacture by powder metallurgical process
- Surface coating with heat and wear resistive materials like TiC, TiN, etc by Chemical Vapour Deposition (CVD) or Physical Vapour Deposition (PVD)

The commonly used grades of HSS are given in Table 2.1.

Table 2.1 Compositions and types of popular high speed steels

<table>
<thead>
<tr>
<th>Type</th>
<th>C</th>
<th>W</th>
<th>Mo</th>
<th>Cr</th>
<th>V</th>
<th>Co</th>
<th>R_C</th>
</tr>
</thead>
<tbody>
<tr>
<td>T – 1</td>
<td>0.70</td>
<td>18</td>
<td></td>
<td>4</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>T – 4</td>
<td>0.75</td>
<td>18</td>
<td></td>
<td>4</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>T – 6</td>
<td>0.80</td>
<td>20</td>
<td></td>
<td>4</td>
<td>2</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>M – 2</td>
<td>0.80</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td></td>
<td>64.7</td>
</tr>
<tr>
<td>M – 4</td>
<td>1.30</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M – 15</td>
<td>1.55</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>M – 42</td>
<td>1.08</td>
<td>1.5</td>
<td>9.5</td>
<td>4</td>
<td>1.1</td>
<td>8</td>
<td>62.4</td>
</tr>
</tbody>
</table>

Addition of large amount of Co and V, refinement of microstructure and coating increased strength and wear resistance and thus enhanced productivity and life of the HSS tools remarkably.

(b) Stellite

This is a cast alloy of Co (40 to 50%), Cr (27 to 32%), W (14 to 19%) and C (2%). Stellite is quite tough and more heat and wear resistive than the basic HSS (18 – 4 – 1) But such stellite as cutting tool material became obsolete for its poor grindability and specially after the arrival of cemented carbides.

(c) Sintered Tungsten carbides

The advent of sintered carbides made another breakthrough in the history of cutting tool materials.
**Straight or single carbide:**

First the straight or single carbide tools or inserts were powder metallurgically produced by mixing, compacting and sintering 90 to 95% WC powder with cobalt. The hot, hard and wear resistant WC grains are held by the binder Co which provides the necessary strength and toughness. Such tools are suitable for machining grey cast iron, brass, bronze etc. which produce short discontinuous chips and at cutting velocities two to three times of that possible for HSS tools.

Dis-Advantages: The single carbide is not suitable for machining steels because of rapid growth of wear, particularly crater wear, by diffusion of Co and carbon from the tool to the chip under the high stress and temperature bulk (plastic) contact between the continuous chip and the tool surfaces.

**Composite carbides:**

For machining steels successfully, another type called composite carbide have been developed by adding (8 to 20%) a gamma phase to WC and Co mix. The gamma phase is a mix of TiC, TiN, TaC, NiC etc. which are more diffusion resistant than WC due to their more stability and less wettability by steel.

**Mixed carbides:**

Titanium carbide (TiC) is not only more stable but also much harder than WC. So for machining ferritic steels causing intensive diffusion and adhesion wear a large quantity (5 to 25%) of TiC is added with WC and Co to produce another grade called Mixed carbide. But increase in TiC content reduces the toughness of the tools. Therefore, for finishing with light cut but high speed, the harder grades containing upto 25% TiC are used and for heavy roughing work at lower speeds lesser amount (5 to 10%) of TiC is suitable.
Gradation of cemented carbides and their applications:

The standards developed by ISO for grouping of carbide tools and their application ranges are given in Table 2.2.

### Table 2.2 Broad classification of carbide tools.

<table>
<thead>
<tr>
<th>ISO Code</th>
<th>Colour Code</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td></td>
<td>For machining long chip forming common materials like plain carbon and low alloy steels</td>
</tr>
<tr>
<td>M</td>
<td></td>
<td>For machining long or short chip forming ferrous materials like Stainless steel</td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>For machining short chipping, ferrous and non-ferrous material and non-metals like Cast Iron, Brass etc.</td>
</tr>
</tbody>
</table>

- **K-group** is suitable for machining short chip producing ferrous and non-ferrous metals and also some non-metals.

- **P-group** is suitably used for machining long chipping ferrous metals i.e. plain carbon and low alloy steels

- **M-group** is generally recommended for machining more difficult-to-machine materials like strain hardening austenitic steel and manganese steel etc.

Each group again is divided into some subgroups like $P_{10}$, $P_{20}$, etc., as shown in Table 2.3 depending upon their properties and applications.
Table 2.3: Detail grouping of cemented carbide tools

<table>
<thead>
<tr>
<th>ISO Application group</th>
<th>Material</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>P01</td>
<td>Steel, Steel castings</td>
<td>Precision and finish machining, high speed</td>
</tr>
<tr>
<td>P10</td>
<td>Steel, steel castings</td>
<td>Turning, threading and milling high speed, small chips</td>
</tr>
<tr>
<td>P20</td>
<td>Steel, steel castings, malleable cast iron</td>
<td>Turning, milling, medium speed with small chip section</td>
</tr>
<tr>
<td>P30</td>
<td>Steel, steel castings, malleable cast iron forming long chips</td>
<td>Turning, milling, low cutting speed, large chip section</td>
</tr>
<tr>
<td>P40</td>
<td>Steel and steel casting with sand inclusions</td>
<td>Turning, planning, low cutting speed, large chip section</td>
</tr>
<tr>
<td>P50</td>
<td>Steel and steel castings of medium or low tensile strength</td>
<td>Operations requiring high toughness turning, planning, shaping at low cutting speeds</td>
</tr>
<tr>
<td>K01</td>
<td>Hard grey C.I., chilled casting, Al. alloys with high silicon</td>
<td>Turning, precision turning and boring, milling, scraping</td>
</tr>
<tr>
<td>K10</td>
<td>Grey C.I. hardness &gt; 220 HB. Malleable C.I., Al. alloys containing Si</td>
<td>Turning, milling, boring, reaming, broaching, scraping</td>
</tr>
<tr>
<td>K20</td>
<td>Grey C.I. hardness up to 220 HB</td>
<td>Turning, milling, broaching, requiring high toughness</td>
</tr>
<tr>
<td>K30</td>
<td>Soft grey C.I. Low tensile strength steel</td>
<td>Turning, reaming under favourable conditions</td>
</tr>
<tr>
<td>K40</td>
<td>Soft non-ferrous metals</td>
<td>Turning milling etc.</td>
</tr>
<tr>
<td>M10</td>
<td>Steel, steel castings, manganese steel, grey C.I.</td>
<td>Turning at medium or high cutting speed, medium chip section</td>
</tr>
<tr>
<td>M20</td>
<td>Steel casting, austenitic steel, manganese steel, spherodized C.I., Malleable C.I.</td>
<td>Turning, milling, medium cutting speed and medium chip section</td>
</tr>
<tr>
<td>M30</td>
<td>Steel, austenitic steel, spherodized C.I. heat resisting alloys</td>
<td>Turning, milling, planning, medium cutting speed, medium or large chip section</td>
</tr>
<tr>
<td>M40</td>
<td>Free cutting steel, low tensile strength steel, brass and light alloy</td>
<td>Turning, profile turning, specially in automatic machines.</td>
</tr>
</tbody>
</table>
The smaller number refers to the operations which need more wear resistance and the larger numbers to those requiring higher toughness for the tool.

(d) Plain ceramics

Inherently high compressive strength, chemical stability and hot hardness of the ceramics led to powder metallurgical production of indexable ceramic tool inserts since 1950. Table 2.4 shows the advantages and limitations of alumina ceramics in contrast to sintered carbide. Alumina ($\text{Al}_2\text{O}_3$) is preferred to silicon nitride ($\text{Si}_3\text{N}_4$) for higher hardness and chemical stability. $\text{Si}_3\text{N}_4$ is tougher but again more difficult to process. The plain ceramic tools are brittle in nature and hence had limited applications.

Table 2.4 Cutting tool properties of alumina ceramics.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Shortcoming</th>
</tr>
</thead>
<tbody>
<tr>
<td>very high hardness</td>
<td>poor toughness</td>
</tr>
<tr>
<td>very high hot hardness</td>
<td>poor tensile strength</td>
</tr>
<tr>
<td>chemical stability</td>
<td>poor TRS</td>
</tr>
<tr>
<td>antiwelding</td>
<td>low thermal conductivity</td>
</tr>
<tr>
<td>less diffusivity</td>
<td>less density</td>
</tr>
<tr>
<td>high abrasion resistance</td>
<td></td>
</tr>
<tr>
<td>high melting point</td>
<td></td>
</tr>
<tr>
<td>very low thermal conductivity*</td>
<td></td>
</tr>
<tr>
<td>very low thermal expansion coefficient</td>
<td></td>
</tr>
</tbody>
</table>

* Cutting tool should resist penetration of heat but should disperse the heat throughout the core.

Basically three types of ceramic tool bits are available in the market;

- Plain alumina with traces of additives – these white or pink sintered inserts are cold pressed and are used mainly for machining cast iron and similar materials at speeds 200 to 250 m/min

- Alumina; with or without additives – hot pressed, black colour, hard and strong – used for machining steels and cast iron at $V_c = 150$ to 250 m/min
Carbide ceramic (Al₂O₃ + 30% TiC) cold or hot pressed, black colour, quite strong and enough tough – used for machining hard cast irons and plain and alloy steels at 150 to 200 m/min.

The plain ceramic outperformed the then existing tool materials in some application areas like high speed machining of softer steels mainly for higher hot hardness as indicated in Fig. 2.3

![Fig. 2.3 Hot hardness of the different commonly used tool materials.](Ref. Book by A.Bhattacharya)

However, the use of those brittle plain ceramic tools, until their strength and toughness could be substantially improved since 1970, gradually decreased for being restricted to

- Uninterrupted machining of soft cast irons and steels only
- Relatively high cutting velocity but only in a narrow range (200 ~ 300 m/min)
- Requiring very rigid machine tools

Advent of coated carbide capable of machining cast iron and steels at high velocity made the then ceramics almost obsolete.
Coated carbides:

The properties and performance of carbide tools could be substantially improved by

- Refining microstructure
- Manufacturing by casting – expensive and uncommon
- Surface coating – made remarkable contribution.

Thin but hard coating of single or multilayers of more stable and heat and wear resistive materials like TiC, TiCN, TiOCN, TiN, Al₂O₃ etc on the tough carbide inserts (substrate) (Fig. 2.4) by processes like chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD) etc at controlled pressure and temperature enhanced MRR and overall machining economy remarkably enabling,

- Reduction of cutting forces and power consumption
- Increase in tool life (by 200 to 500%) for same Vₐ or increase in Vₐ (by 50 to 150%) for same tool life
- Improvement in product quality
- Effective and efficient machining of wide range of work materials
- Pollution control by less or no use of cutting fluid through
  - Reduction of abrasion, adhesion and diffusion wear
  - Reduction of friction and BUE (Built up edge) formation
  - Heat resistance and reduction of thermal cracking and plastic deformation
Fig. 2.4 Machining by coated carbide insert.

The contributions of the coating continues even after rupture of the coating as indicated in Fig. 2.5.

Fig. 2.5 Role of coating even after its wear and rupture
The cutting velocity range in machining mild steel could be enhanced from $120 \sim 150$ m/min to $300 \sim 350$ m/min by properly coating the suitable carbide inserts.

About 50% of the carbide tools being used at present are coated carbides which are obviously to some extent costlier than the uncoated tools.

Different varieties of coated tools are available. The appropriate one is selected depending upon the type of the cutting tool, work material and the desired productivity and product quality.

The properties and performances of coated inserts and tools are getting further improved by:

- Refining the microstructure of the coating
- Multilayering (already up to 13 layers within $12 \sim 16$ μm)
- Direct coating by TiN instead of TiC, if feasible
- Using better coating materials.

**Cutting Fluid:**

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 $SO_2$, $O_2$, $H_2S$, $N_2O_y$ 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.

**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.
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 benefit 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
  - Soluble oil for cooling and flushing chips in high speed machining and grinding

- Steels:
  - 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 straight 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 only 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.

**Sources and causes of heat generation and development of temperature in machining:**

During machining heat is generated at the cutting point from three sources, as indicated in Fig. 2.6. Those sources and causes of development of cutting temperature are:

- Primary shear zone (1) where the major part of the energy is converted into heat
- Secondary deformation zone (2) at the chip – tool interface where further heat is generated due to rubbing and / or shear
- At the worn out flanks (3) due to rubbing between the tool and the finished surfaces.
The heat generated is shared by the chip, cutting tool and the blank. The apportionment of sharing that heat depends upon the configuration, size and thermal conductivity of the tool – work material and the cutting condition. Fig. 2.7 visualises that maximum amount of heat is carried away by the flowing chip. From 10 to 20% of the total heat goes into the tool and some heat is absorbed in the blank. With the increase in cutting velocity, the chip shares heat increasingly.
Determination of cutting temperature:

The magnitude of the cutting temperature need to be known or evaluated to facilitate

- Assessment of machinability which is judged mainly by cutting forces and temperature and tool life
- Design and selection of cutting tools
- Evaluate the role of variation of the different machining parameters on cutting temperature
- Proper selection and application of cutting fluid
- Analysis of temperature distribution in the chip, tool and job.

The temperatures which are of major interests are:

- $\theta_s$: Average shear zone temperature
- $\theta_i$: Average (and maximum) temperature at the chip-tool interface
- $\theta_f$: Temperature at the work-tool interface (tool flanks)
- $\theta_{avg}$: Average cutting temperature

Cutting temperature can be determined by two ways:

- Analytically – using mathematical models (equations) if available or can be developed. This method is simple, quick and inexpensive but less accurate and precise.
- Experimentally – this method is more accurate, precise and reliable.

Experimental methods of determination of cutting temperature:

Amongst $\theta_s$, $\theta_i$, and $\theta_f$, $\theta_i$ is obviously the highest one and its value is maximum almost at the middle of the chip – tool contact length. Experimental methods generally provide the average or maximum value of $\theta_i$. Some techniques also enable get even distribution of temperature in the chip, tool and job at the cutting zone.
The feasible experimental methods are:

- Calorimetric method – quite simple and low cost but inaccurate and gives only grand average value

- Decolourising agent – some paint or tape, which change in colour with variation of temperature, is pasted on the tool or job near the cutting point; the as such colour of the chip (steels) may also often indicate cutting temperature

- Tool-work thermocouple – simple and inexpensive but gives only average or maximum value

- Moving thermocouple technique

- Embedded thermocouple technique

- Using compound tool

- Indirectly from Hardness and structural transformation

- Photo-cell technique

- Infra ray detection method

The aforesaid methods are all feasible but vary w.r.t. accuracy, preciseness and reliability as well as complexity or difficulties and expensiveness.

Some of the methods commonly used are briefly presented here.

**Tool work thermocouple technique:**

Fig. 2.8 shows the principle of this method.

In a thermocouple two dissimilar but electrically conductive metals are connected at two junctions. Whenever, one of the junctions is heated, the difference in temperature at the hot and cold junctions produce a proportional current. This is detected and measured by a milli-voltmeter. In machining like turning, the tool and the job constitute the two dissimilar metals and the cutting zone functions as the hot junction. Then the average cutting temperature is evaluated from the mV after thorough calibration for establishing the exact relation between mV and the cutting temperature.
Fig. 2.9 typically shows a method of calibration for measuring average cutting temperature, $\theta_{avg}$, in turning steel rod by uncoated carbide tool.

Fig. 2.8 Tool-work thermocouple technique of measuring cutting temperature.

Fig. 2.9 Calibration for tool – work thermocouple.
Moving thermocouple technique:

This simple method, schematically shown in Fig. 2.10, enables measure the gradual variation in the temperature of the flowing chip before, during and immediately after its formation. A bead of standard thermocouple like chrome-alumel is brazed on the side surface of the layer to be removed from the work surface and the temperature is attained in terms of mV.

![Fig. 2.10 Moving thermocouple technique](image)

Embedded thermocouple technique:

In operations like milling, grinding etc. where the previous methods are not applicable, embedded thermocouple can serve the purpose. Fig. 2.7.6 shows the principle. The standard thermocouple monitors the job temperature at a certain depth, \( h \), from the cutting zone. The temperature recorded in oscilloscope or strip chart recorder becomes maximum when the thermocouple bead comes nearest (slightly offset) to the grinding zone. With the progress of grinding the depth, \( h \), gradually decreases after each grinding pass and the value of temperature, \( \theta_m \), also rises as has been indicated in Fig. 2.7.6. For getting the temperature exactly at the
surface i.e., grinding zone, $h_i$ has to be zero, which is not possible. So the $\theta_m$ vs $h_i$ curve has to be extrapolated upto $h_i = 0$ to get the actual grinding zone temperature. Log – log plot helps such extrapolation more easily and accurately.

*Fig. 2.11 Embedded thermocouple technique*

**Measurement of chip-tool interface temperature by Compound Tool:**

In this method a conducting tool piece (carbide) is embedded in a non conducting tool (ceramic). The conducting piece and the job form the tool-work thermocouple as shown in Fig. 2.12 which detects temperature $\theta_i$ at the location ($L_i$) of the carbide strip. Thus $\theta_i$ can be measured along the entire chip-tool contact length by gradually reducing $L_i$ by grinding the tool flank. Before that calibration has to be done as usual.
Photo-cell technique:

This unique technique enables accurate measurement of the temperature along the shear zone and tool flank as can be seen in Fig. 2.13. The electrical resistance of the cell, like PbS cell, changes when it is exposed to any heat radiation. The amount of change in the resistance depends upon the temperature of the heat radiating source and is measured in terms of voltage, which is calibrated with the source temperature. It is evident from Fig. 2.13 that the cell starts receiving radiation through the small hole only when it enters the shear zone where the hole at the upper end faces a hot surface. Receiving radiation and measurement of temperature continues until the hole passes through the entire shear zone and then the tool flank.

Infra-red photographic technique:

This modern and powerful method is based on taking infra-red photograph of the hot surfaces of the tool, chip, and/or job and get temperature distribution at those surfaces. Proper calibration is to be done before that. This way the temperature profiles can be recorded in PC as indicated in Fig. 2.14. The fringe pattern readily changes with the change in any machining parameter which affect cutting temperature.
Fig. 2.13 Measuring temperature at shear plane and tool flank by photocell technique

Fig. 2.7.9 Temperature distribution at the tool tip detected by Infra ray technique
Role of variation of the various machining parameters on cutting temperature:

The magnitude of cutting temperature is more or less governed or influenced by all the machining parameters like:

- Work material: - specific energy requirement, - ductility - thermal properties ($\lambda$, $c_v$)
- Process parameters: - cutting velocity ($V_C$) - feed ($s_o$) - depth of cut ($t$)
- Cutting tool material: - thermal properties - wear resistance - chemical stability
- Tool geometry: - rake angle ($\gamma$) - cutting edge angle ($\phi$) - clearance angle ($\alpha$)
  - nose radius ($r$)
- Cutting fluid: - thermal and lubricating properties - method of application

Control of cutting temperature:

It is already seen that high cutting temperature is mostly detrimental in several respects. Therefore, it is necessary to control or reduce the cutting temperature as far as possible.

Cutting temperature can be controlled in varying extent by the following general methods:

- Proper selection of material and geometry of the cutting tool(s)
- Optimum selection of $V_C - \text{ s}_o$ combination without sacrificing MRR
- Proper selection and application of cutting fluid
- Application of special technique, if required and feasible.