Module
3
Machinability

Lesson
15
Cutting Tool Materials of common use

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) Stellite
  (c) Sintered carbides
  (d) Plain ceramics

(i) 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. 3.3.1

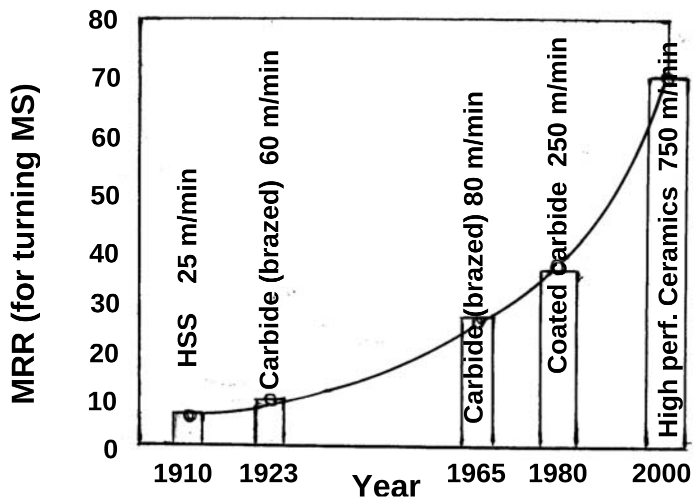

***Fig. 3.3.1** Productivity raised by cutting tool materials.*

The chronological development of cutting tool materials is briefly indicated in Fig. 3.3.2

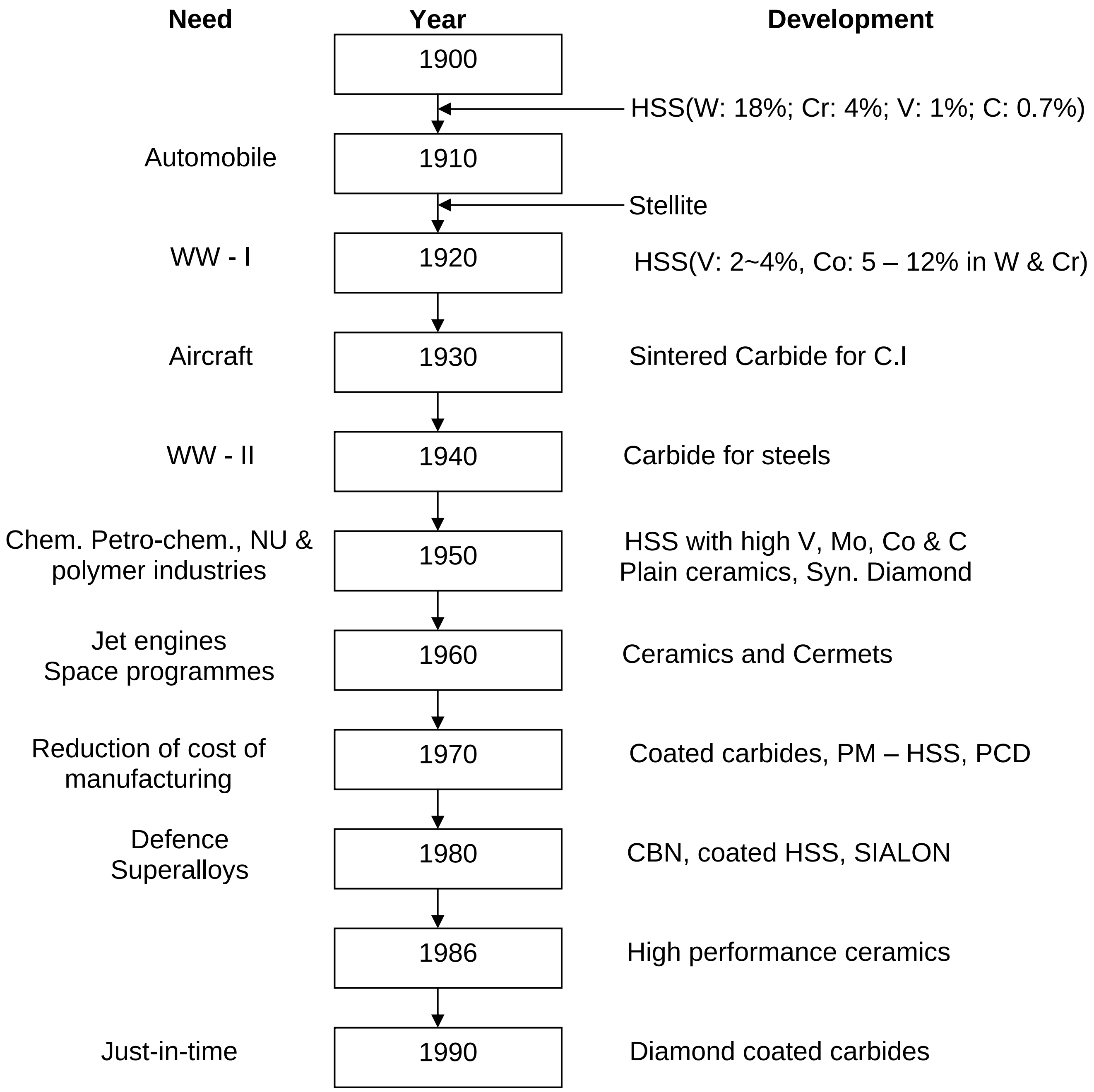

Fig. 3.3.2 *Chronological development of cutting tool materials.*

(ii) 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of HSS in around 1905 made a break through at that time in the history of cutting tool materials though got later superseded by many other novel tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools.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)
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 3.3.1.

Table 3.3.1 Compositions and types of popular high speed steels

Type	C	W	Mo	Cr	V	Co	R_C
T – 1	0.70	18		4	1		
T – 4	0.75	18		4	1	5	
T – 6	0.80	20		4	2	12	
M – 2	0.80	6	5	4	2		64.7
M – 4	1.30	6	5	4	4		
M – 15	1.55	6	3	5	5	5	
M – 42	1.08	1.5	9.5	4	1.1	8	62.4

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.

- **Composite carbides**

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.
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 3.3.2.

Table 3.3.2 Broad classification of carbide tools.

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

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 3.3.3 depending upon their properties and applications.

Table 3.3.3 Detail grouping of cemented carbide tools

ISO Application group	Material	Process
P01	Steel, Steel castings	Precision and finish machining, high speed
P10	Steel, steel castings	Turning, threading and milling high speed, small chips
P20	Steel, steel castings, malleable cast iron	Turning, milling, medium speed with small chip section
P30	Steel, steel castings, malleable cast iron forming long chips	Turning, milling, low cutting speed, large chip section
P40	Steel and steel casting with sand inclusions	Turning, planning, low cutting speed, large chip section
P50	Steel and steel castings of medium or low tensile strength	Operations requiring high toughness turning, planning, shaping at low cutting speeds
K01	Hard grey C.I., chilled casting, Al. alloys with high silicon	Turning, precision turning and boring, milling, scraping
K10	Grey C.I. hardness > 220 HB. Malleable C.I., Al. alloys containing Si	Turning, milling, boring, reaming, broaching, scraping
K20	Grey C.I. hardness up to 220 HB	Turning, milling, broaching, requiring high toughness
K30	Soft grey C.I. Low tensile strength steel	Turning, reaming under favourable conditions
K40	Soft non-ferrous metals	Turning milling etc.
M10	Steel, steel castings, manganese steel, grey C.I.	Turning at medium or high cutting speed, medium chip section
M20	Steel casting, austentic steel, manganese steel, spherodized C.I., Malleable C.I.	Turning, milling, medium cutting speed and medium chip section
M30	Steel, austenitic steel, spherodized C.I. heat resisting alloys	Turning, milling, planning, medium cutting speed, medium or large chip section
M40	Free cutting steel, low tensile strength steel, brass and light alloy	Turning, profile turning, specially in automatic machines.

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 3.3.4 shows the advantages and limitations of alumina ceramics in contrast to sintered carbide. Alumina (Al_2O_3) is preferred to silicon nitride (Si_3N_4) for higher hardness and chemical stability. Si_3N_4 is tougher but again more difficult to process. The plain ceramic tools are brittle in nature and hence had limited applications.

Table 3.3.4 Cutting tool properties of alumina ceramics.

Advantages	**Shortcoming**
very high hardness	poor toughness
very high hot hardness	poor tensile strength
chemical stability	poor TRS
antiwelding	low thermal conductivity
less diffusivity	less density
high abrasion resistance	
high melting point	
very low thermal conductivity*	
very low thermal expansion coefficient	

* 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 (Al_2O_3 + 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. 3.3.3

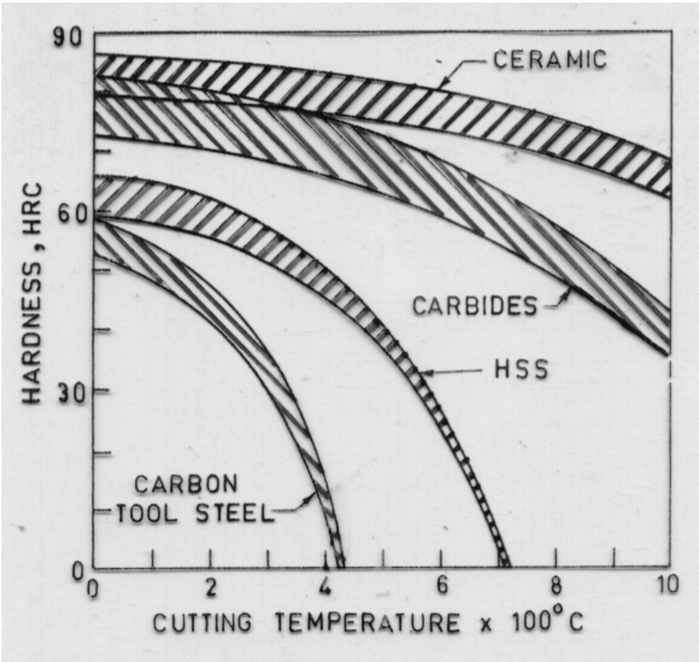

Fig. 3.3.3 *Hot hardness of the different commonly used tool materials.*
(Ref. Book by A.Bhattacharya)

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.