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;

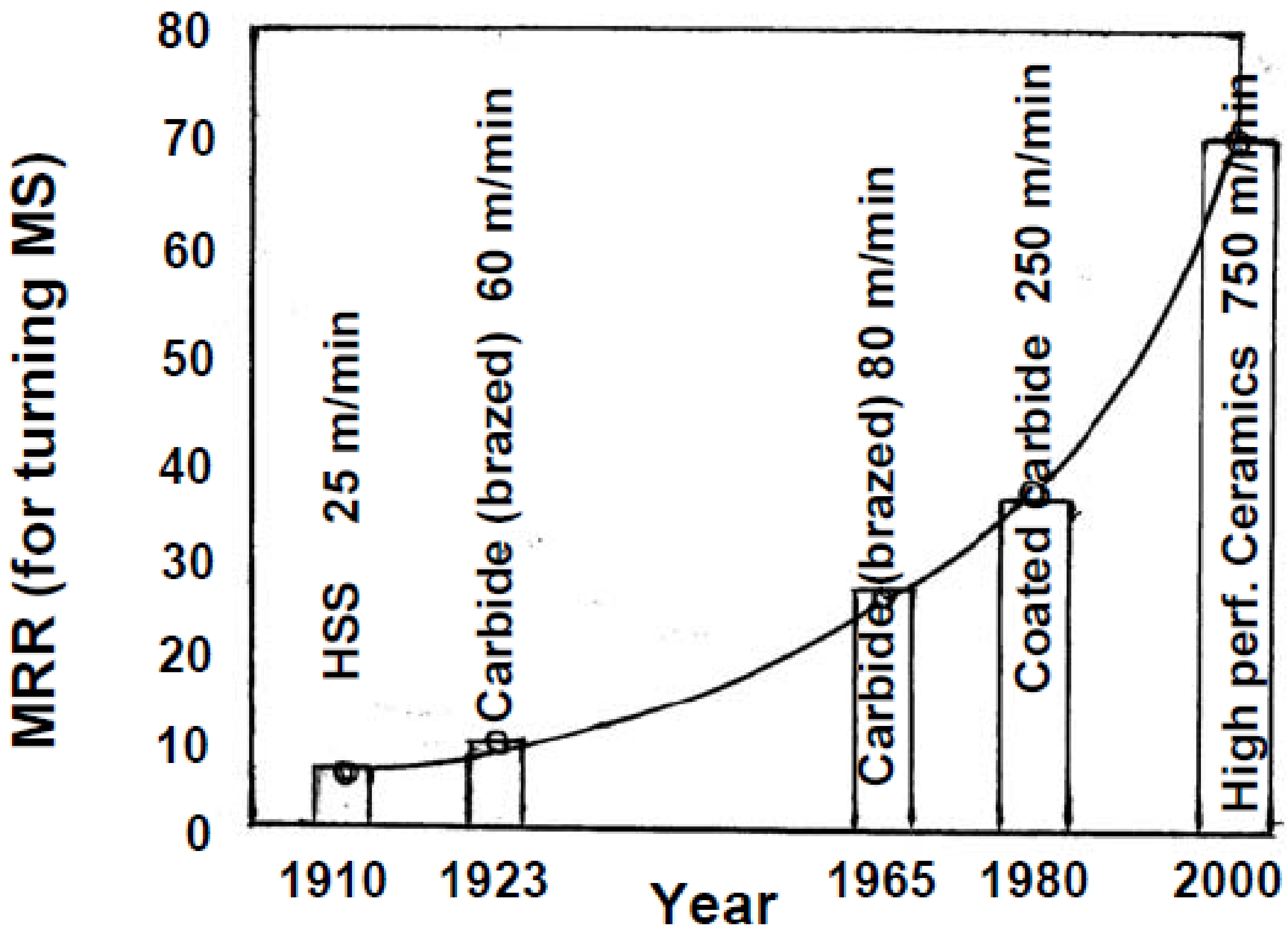
- to meet the growing demands for high productivity, quality and economy of machining
- to enable effective and efficient machining of the exotic materials that are coming up with the rapid and vast progress of science and technology
- for precision and ultra-precision machining
- for micro and even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

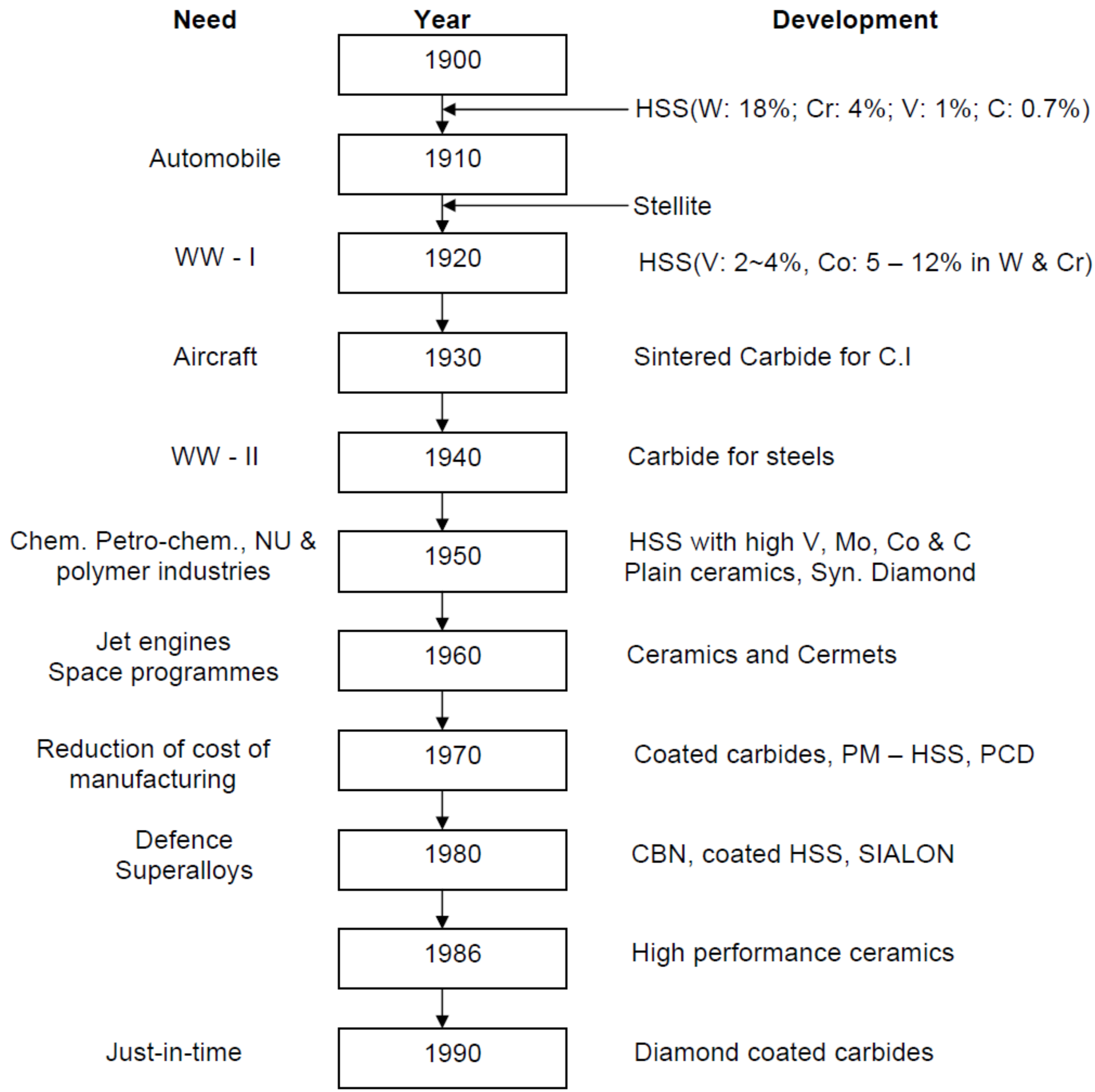
It is already stated that the capability and overall performance of the cutting tools depend upon,

- 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.




Need
Year
Development
1900
HSS(W: 18%; Cr: 4%; V: 1%; C: 0.7%)
Automobile
1910
Stellite
WW - I
1920
HSS(V: 2~4%, Co: 5 – 12% in W & Cr)
Aircraft
1930
Sintered Carbide for C.I
WW - II
1940
Carbide for steels
Chem. Petro-chem., NU & polymer industries
1950
HSS with high V, Mo, Co & C
Plain ceramics, Syn. Diamond
Jet engines
Space programmes
1960
Ceramics and Cermets
Reduction of cost of manufacturing
1970
Coated carbides, PM – HSS, PCD
Defence
Superalloys
1980
CBN, coated HSS, SIALON
1986
High performance ceramics
Just-in-time
1990
Diamond coated carbides

Common Tool Materials

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of HSS in around 1905 made a break through at that time in the history of cutting tool materials though got later superseded by many other novel tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools.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

(2) 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.

(3) 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.

(4) 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. 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.

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.

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.

Advanced Tool Material

1. 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, Al_2O_3 etc on the tough carbide inserts (substrate) 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

(b) Cermets

These sintered hard inserts are made by combining ‘cer’ from ceramics like TiC, TiN or TiCN and ‘met’ from metal (binder) like Ni, Ni-Co, Fe etc. Since around 1980, the modern cermets providing much better performance are being made by TiCN which is consistently more wear resistant, less porous and easier to make.

Application wise, the modern TiCN based cermets with bevelled or slightly rounded cutting edges are suitable for finishing and semi-finishing of steels at higher speeds, stainless steels but are not suitable for jerky interrupted machining and machining of aluminium and similar materials. Research and development are still going on for further improvement in the properties and performance of cermets.

(c) Coronite

It is already mentioned earlier that the properties and performance of HSS tools could have been sizeably improved by refinement of microstructure, powder metallurgical process of making and surface coating. Recently a unique tool material, namely Coronite has been developed for making the tools like small and medium size drills and milling cutters etc. which were earlier essentially made of HSS. Coronite is made basically by combining HSS for strength and toughness and tungsten carbides for heat and wear resistance. Microfine TiCN particles are uniformly dispersed into the matrix.

Unlike a solid carbide, the coronite based tool is made of three layers;

- the central HSS or spring steel core
- a layer of coronite of thickness around 15% of the tool diameter
- a thin (2 to 5 µm) PVD coating of TiCN.

Such tools are not only more productive but also provides better product quality.

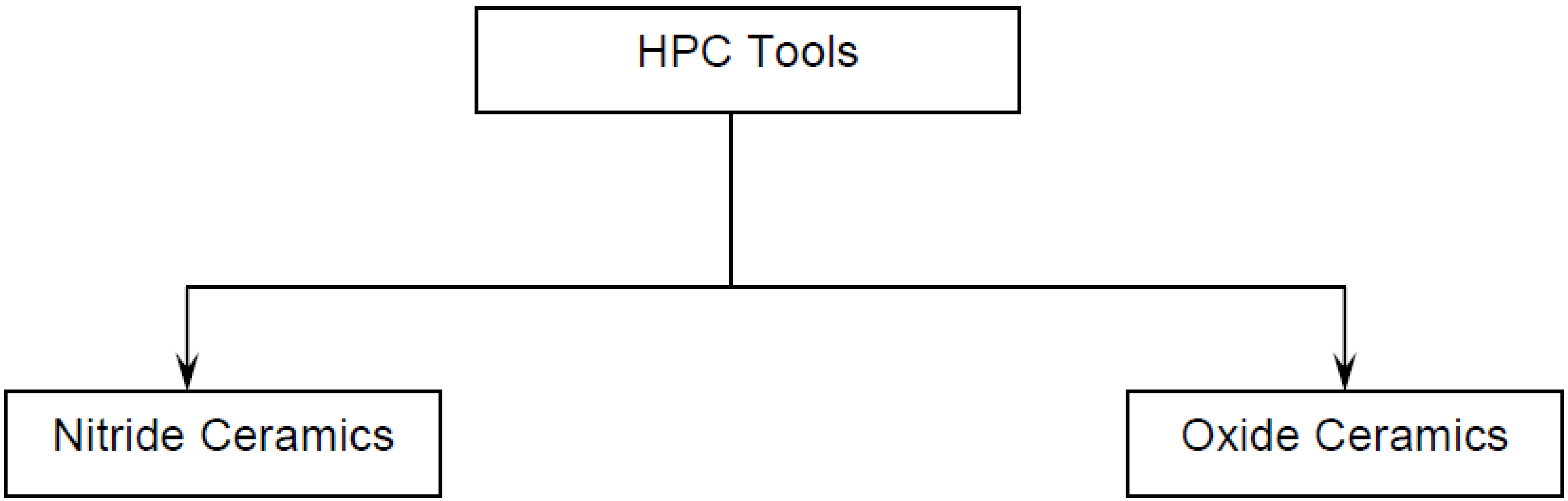
(4) High Performance ceramics (HPC)

Ceramic tools as such are much superior to sintered carbides in respect of hot hardness, chemical stability and resistance to heat and wear but lack in fracture toughness and strength

Through last few years remarkable improvements in strength and toughness and hence overall performance of ceramic tools could have been possible by several means which include;

- Sinterability, microstructure, strength and toughness of Al^2O^3 ceramics were improved to some extent by adding TiO^2 and MgO
- Transformation toughening by adding appropriate amount of partially or fully stabilised zirconia in Al^2O^3 powder
- Isostatic and hot isostatic pressing (HIP) – these are very effective but expensive route

The HPC tools can be broadly classified into two groups as :



Silicon Nitride

(i) Plain
(ii) SIALON
(iii) Whisker toughened

Alumina toughned by

(i) Zirconia
(ii) SiC whiskers
(iii) Metal (Silver etc)

SIALON tools

Hot pressing and sintering of an appropriate mix of Al^2O^3 and Si^3N^4 powders yielded an excellent composite ceramic tool called SIALON which are very hot hard, quite tough and wear resistant. These tools can machine steel and cast irons at high speeds (250 – 300 m/min). But machining of steels by such tools at too high speeds reduces the tool life by rapid diffusion.

(5) Cubic Boron Nitride

Such unique tools effectively and beneficially used in machining wide range of work materials covering high carbon and alloy steels, non-ferrous metals and alloys, exotic metals like Ni-hard, Inconel, Nimonic etc and many non-metallic materials which are as such difficult to machine by conventional tools.

(6) Diamond Tools

Single stone, natural or synthetic, diamond crystals are used as tips/edge of cutting tools. Owing to the extreme hardness and sharp edges, natural single crystal is used for many applications, particularly where high accuracy and precision are required.

Polycrystalline Diamond (PCD)

The polycrystalline diamond (PCD) tools consist of a layer (0.5 to 1.5 mm) of fine grain size, randomly oriented diamond particles sintered with a suitable binder (ususally cobalt) and then metallurgically bonded to a suitable substrate like cemented carbide or Si^3N^4 inserts. PCD exhibits excellent wear resistance, hold sharp edge, generates little friction in the cut, provide high fracture strength, and had good thermal conductivity. These properties contribute to PCD tooling's long life in conventional and high speed machining of soft, non-ferrous materials (aluminium, magnesium, copper etc), advanced composites and metal-matrix composites, superalloys, and non-metallic materials.

Diamond coated carbide tools

Since the invention of low pressure synthesis of diamond from gaseous phase, continuous effort has been made to use thin film diamond in cutting tool field. These are normally used as thin (<50 μm) or thick (> 200 μm) films of diamond synthesised by CVD method for cutting tools, dies, wear surfaces and even abrasives for Abrasive Jet Machining (AJM) and grinding. Thin film is directly deposited on the tool surface. Thick film (> 500 μm) is grown on an easy substrate and later brazed to the actual tool substrate and the primary substrate is removed by dissolving it or by other means. Thick film diamond finds application in making inserts, drills, reamers, end mills, routers.