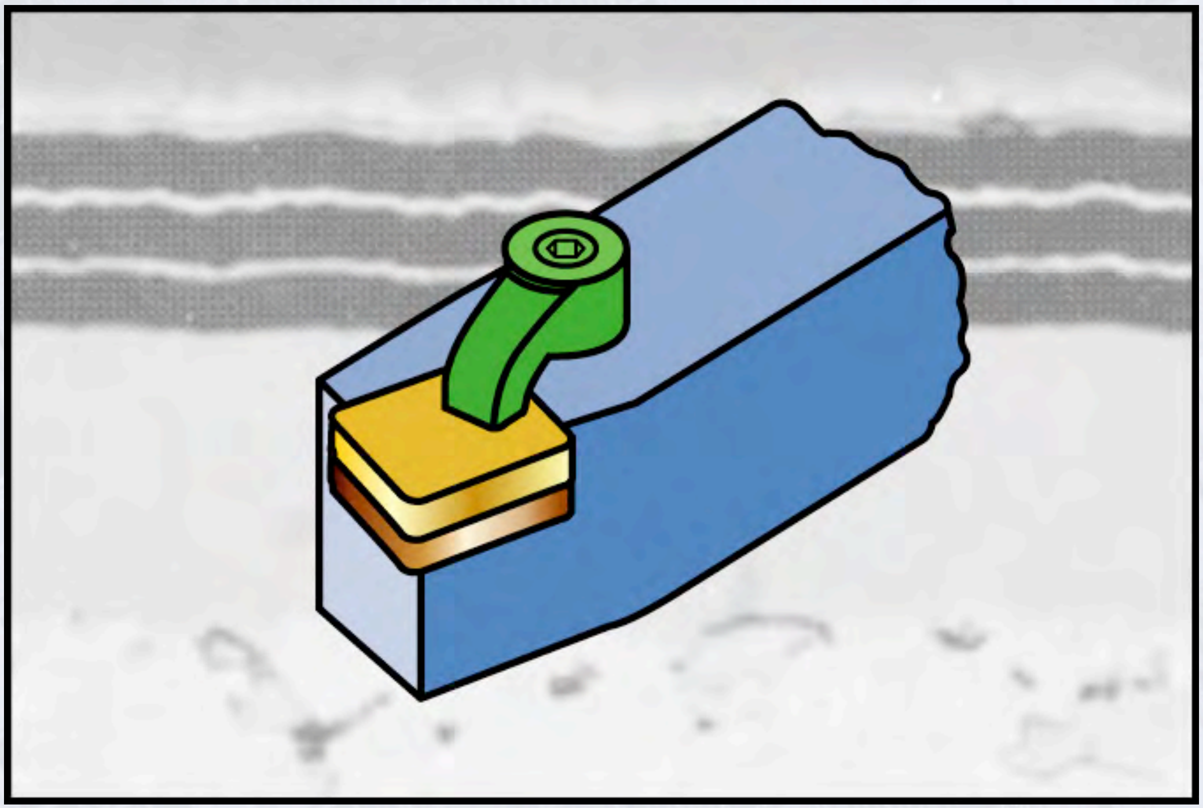
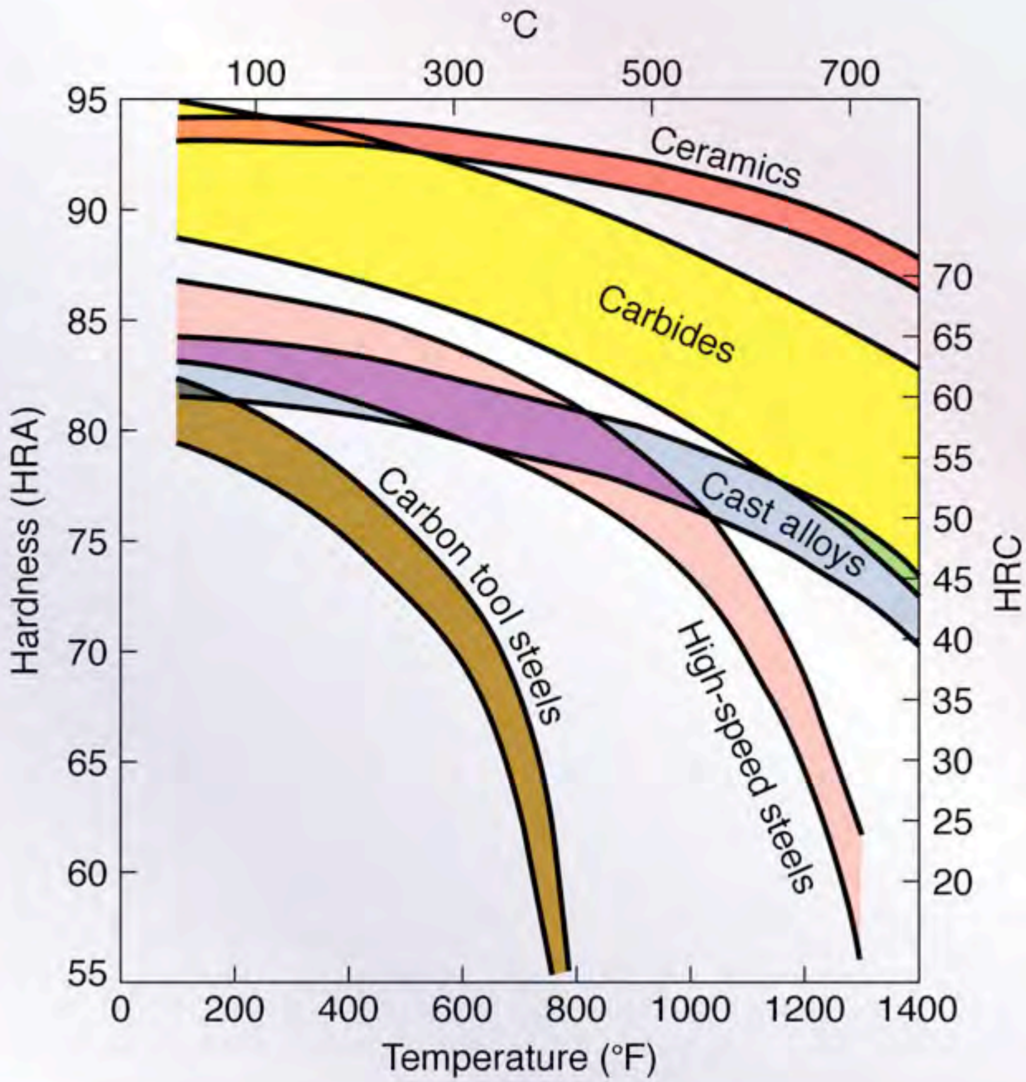
Chapter 21

Cutting-Tool Materials and Cutting Fluids



Manufacturing, Engineering & Technology, Fifth Edition, by Serope Kalpakjian and Steven R. Schmid.
ISBN 0-13-148965-8.



Hardness of Cutting Tool Materials as a Function of Temperature

Figure 22.1 The hardness of various cutting-tool materials as a function of temperature (hot hardness). The wide range in each group of materials is due to the variety of tool compositions and treatments available for that group.

Manufacturing, Engineering & Technology, Fifth Edition, by Serope Kalpakjian and Steven R. Schmid.
ISBN 0-13-148965-8.

General Properties of Tool Materials

TABLE 22.1

General Properties of Tool Materials

Property	High-speed steels	Cast-cobalt alloys	Carbides WC	Carbides TiC	Ceramics	Cubic boron nitride	Single-crystal diamond *
Hardness	83–86 HRA	82–84 HRA 46–62 HRC	90–95 HRA 1800–2400 HK	91–93 HRA 1800–3200 HK	91–95 HRA 2000–3000 HK	4000–5000 HK	7000–8000 HK
Compressive strength,							
MPa	4100–4500	1500–2300	4100–5850	3100–3850	2750–4500	6900	6900
psi * 10^3	600–650	220–335	600–850	450–560	400–650	1000	1000
Transverse rupture strength,							
MPa	2400–4800	1380–2050	1050–2600	1380–1900	345–950	700	1350
psi * 10^3	350–700	200–300	150–375	200–275	50–135	105	200
Impact strength,							
J	1.35–8	0.34–1.25	0.34–1.35	0.79–1.24	6 0.1	6 0.5	6 0.2
in.-lb	12–70	3–11	3–12	7–11	6 1	6 5	6 2
Modulus of elasticity,							
GPa	200	–	520–690	310–450	310–410	850	820–1050
psi * 10^6	30	–	75–100	45–65	45–60	125	120–150
Density,							
kg/m^3	8600	8000–8700	10,000–15,000	5500–5800	4000–4500	3500	3500
lb/in^3	0.31	0.29–0.31	0.36–0.54	0.2–0.22	0.14–0.16	0.13	0.13
Volume of hard phase, %	7–15	10–20	70–90	–	100	95	95
Melting or decomposition temperature,							
°C	1300	–	1400	1400	2000	1300	700
°F	2370	–	2550	2550	3600	2400	1300
Thermal conductivity, W/m K	30–50	–	42–125	17	29	13	500–2000
Coefficient of thermal expansion, * 10^{-6}/°C	12	–	4–6.5	7.5–9	6–8.5	4.8	1.5–4.8

*The values for polycrystalline diamond are generally lower, except impact strength, which is higher.

General Characteristics of Cutting-Tool Materials

TABLE 22.2

General Characteristics of Cutting-Tool Materials (These Tool Materials Have a Wide Range of Compositions and Properties. Overlapping Characteristics Exist in Many Categories of Tool Materials.)

	High-speed steels	Cast-cobalt alloys	Uncoated carbides	Coated carbides	Ceramics	Polycrystalline cubic boron nitride	Diamond
Hot hardness	→						
Toughness	←						
Impact strength	←						
Wear resistance	→						
Chipping resistance	←						
Cutting speed	→						
Thermal-shock resistance	←						
Tool material cost	→						
Depth of cut	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Light to heavy	Very light for siingle-crystal diamond
Processing method	Wrought, cast, HIP* sintering	Cast and HIP sintering	Cold pressing and sintering	CVD or PVD†	Cold pressing and sintering or HIP sintering	High-pressure, high-temperature sintering	High-pressure, high-temperature sintering

Source: After R. Komanduri .
*Hot-isostatic pressing.
† Chemical-vapor deposition, physical-vapor deposition.

Operating Characteristics of Cutting-Tool Materials

TABLE 22.3

General Operating Characteristics of Cutting-Tool Materials

Tool materials	General characteristics	Modes of tool wear or failure	Limitations
High-speed steels	High toughness, resistance to fracture, wide range of roughening and finishing cuts, good for interrupted cuts	Flank wear, crater wear	Low hot hardness, limited hardenability, and limited wear resistance
Uncoated carbides	High hardness over a wide range of temperatures, toughness, wear resistance, versatile and wide range of applications	Flank wear, crater wear	Cannot use at low speeds because of cold welding of chips and microchipping
Coated carbides	Improved wear resistance over uncoated carbides, better frictional and thermal properties	Flank wear, crater wear	Cannot use at low speeds because of cold welding of chips and microchipping
Ceramics	High hardness at elevated temperatures, high abrasive wear resistance	Depth-of-cut line notching, microchipping, gross fracture	Low strength, and low thermo-mechanical fatigue strength
Polycrystalline cubic boron nitride (cBN)	High hot hardness, toughness, cutting-edge strength	Depth-of-cut line notching, chipping, oxidation, graphitization	Low strength, and low chemical stability at higher temperature
Diamond	High hardness and toughness, abrasive wear resistance	Chipping, oxidation, graphitization	Low strength, and low chemical stability at higher temperatures

Source: After R. Komanduri and other sources.

Inserts and Toolholders

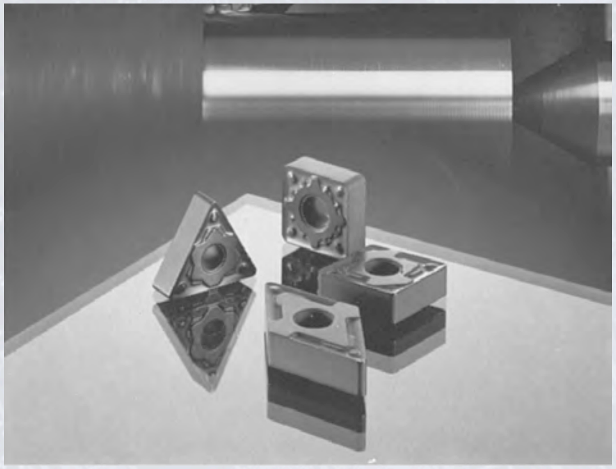


Figure 22.2 Typical carbide inserts with various shapes and chip-breaker features: Round inserts are also available, as can be seen in Figs. 22.3c and 22.4. The holes in the inserts are standardized for interchangeability in toolholders. *Source*: Courtesy of Kyocera Engineered Ceramics, Inc.

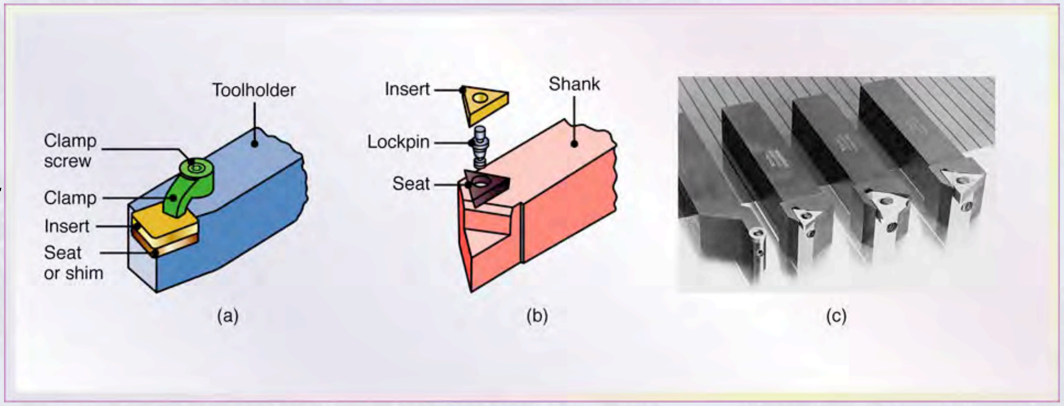


Figure 22.3 Methods of mounting inserts on toolholders: (a) clamping and (b) wing lockpins. (c) Examples of inserts mounted with threadless lockpins, which are secured with side screws. *Source*: Courtesy of Valenite.

Insert Edge Properties

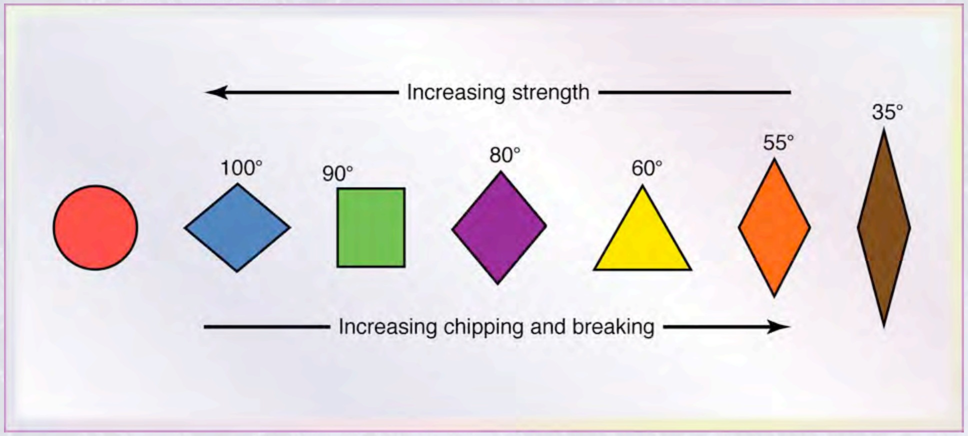


Figure 22.4 Relative edge strength and tendency for chipping of inserts with various shapes. Strength refers to the cutting edge indicated by the included angles. *Source*: Courtesy of Kennametal, Inc.

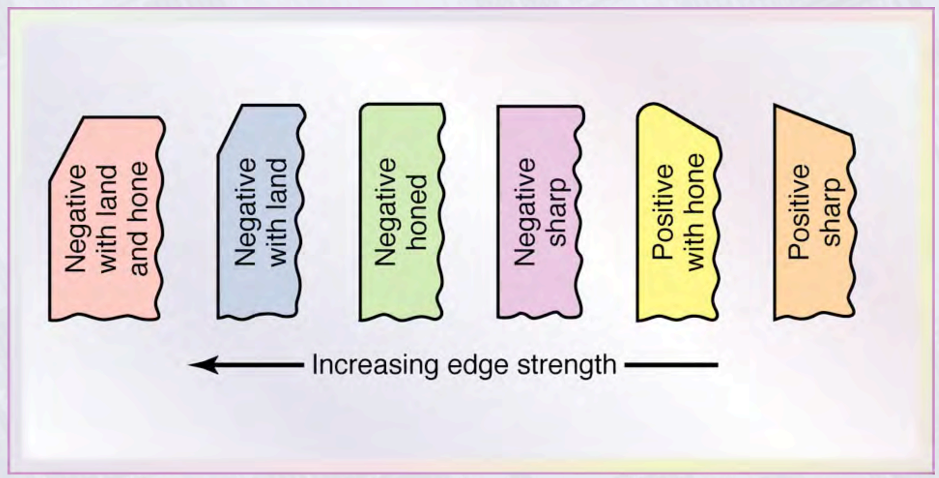


Figure 22.5 Edge preparation for inserts to improve edge strength. *Source*: Courtesy of Kennametal, Inc.

Manufacturing, Engineering & Technology, Fifth Edition, by Serope Kalpakjian and Steven R. Schmid.
ISBN 0-13-148965-8.

ISO Classification of Carbide Cutting Tools

TABLE 22.4

ISO Classification of Carbide Cutting Tools According to Use

Symbol	Workpiece material	Color code	Designation in increasing order of wear resistance and decreasing order of toughness in each category (in increments of 5)
P	Ferrous metals with long chips	Blue	P01, P05–P50
M	Ferrous metals with long or short chips, nonferrous metals	Yellow	M10–M40
K	Ferrous metals with short chips, nonferrous metals, nonmetallic materials	Red	K01, K10–K40

Classification of Tungsten Carbides According to Machining Applications

TABLE 22.5

Classification of Tungsten Carbides According to Machining Applications

ISO standard	ANSI Classification number (Grade)	Materials to be machined	Machining operation	Type of carbide	Characteristics of Cut	Characteristics of Carbide
K30–K40	C1	Cast iron, nonferrous metals, and nonmetallic materials requiring abrasion resistance	Roughing	Wear-resistant grades; generally straight WC-Co with varying grain sizes	Increasing cutting speed ↓ ↑ Increasing feed rate	Increasing hardness and wear resistance ↓ ↑ Increasing strength and binder content
K20	C2		General purpose			
K10	C3		Light finishing			
K01	C4		Precision finishing			
P30–P50	C5	Steels and steel alloys requiring crater and deformation resistance	Roughing	Crater-resistant grades; various WC-Co compositions with TiC and/or TaC alloys	Increasing cutting speed ↓ ↑ Increasing feed rate	Increasing hardness and wear resistance ↓ ↑ Increasing strength and binder content
P20	C6		General purpose			
P10	C7		Light finishing			
P01	C8		Precision finishing			

Note: The ISO and ANSI comparisons are approximate.

Manufacturing, Engineering & Technology, Fifth Edition, by Serope Kalpakjian and Steven R. Schmid.
ISBN 0-13-148965-8.

Relative Time Required to Machine with Various Cutting-Tool Materials

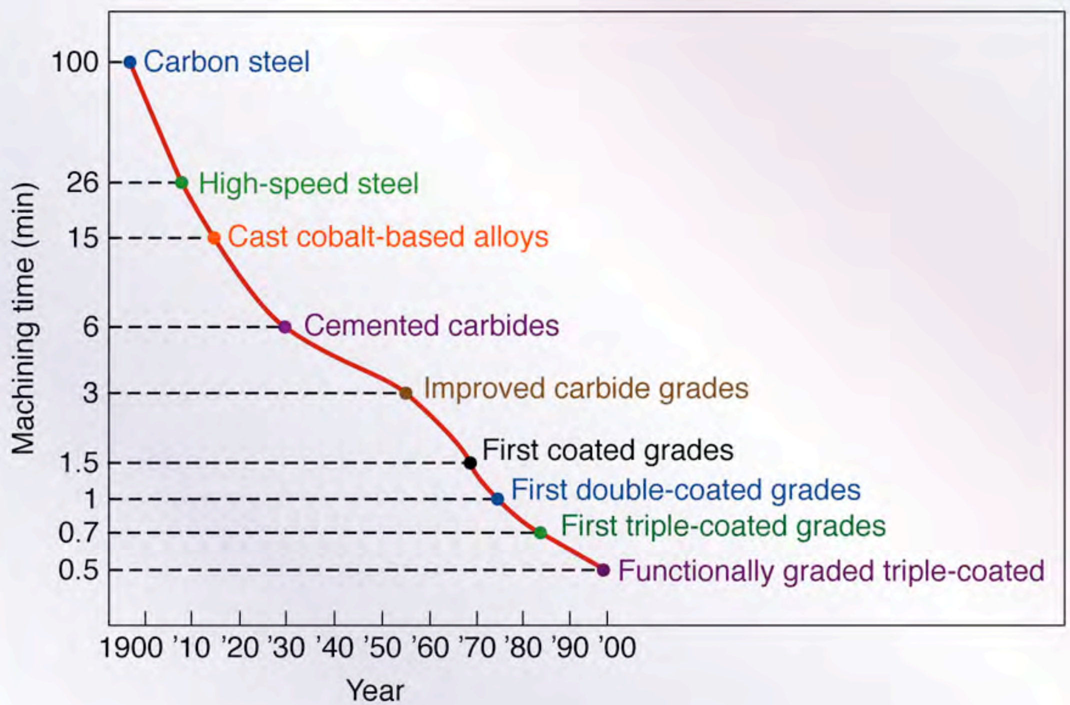


Figure 22.6 Relative time required to machine with various cutting-tool materials, indicating the year the tool materials were first introduced. Note that machining time has been reduced by two orders of magnitude with a hundred years. *Source*: Courtesy of Sandvik.

Typical Wear Patterns on High-Speed-Steel Uncoated and Titanium-Nitride Coated Tools

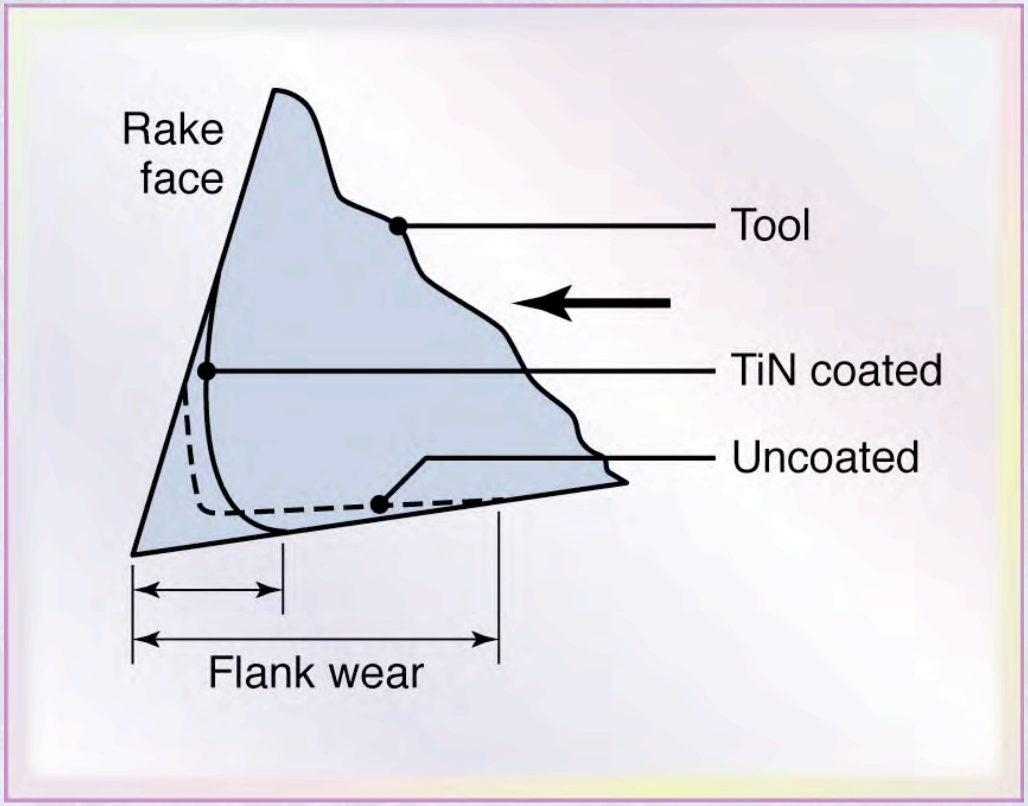


Figure 22.7 Schematic illustration of typical wear patterns of high-speed-steel uncoated and titanium-nitride coated tools. Note that flank wear is significantly lower for the coated tool.

Manufacturing, Engineering & Technology, Fifth Edition, by Serope Kalpakjian and Steven R. Schmid.
ISBN 0-13-148965-8.

Multiphase Coatings on a Tungsten-Carbide Substrate

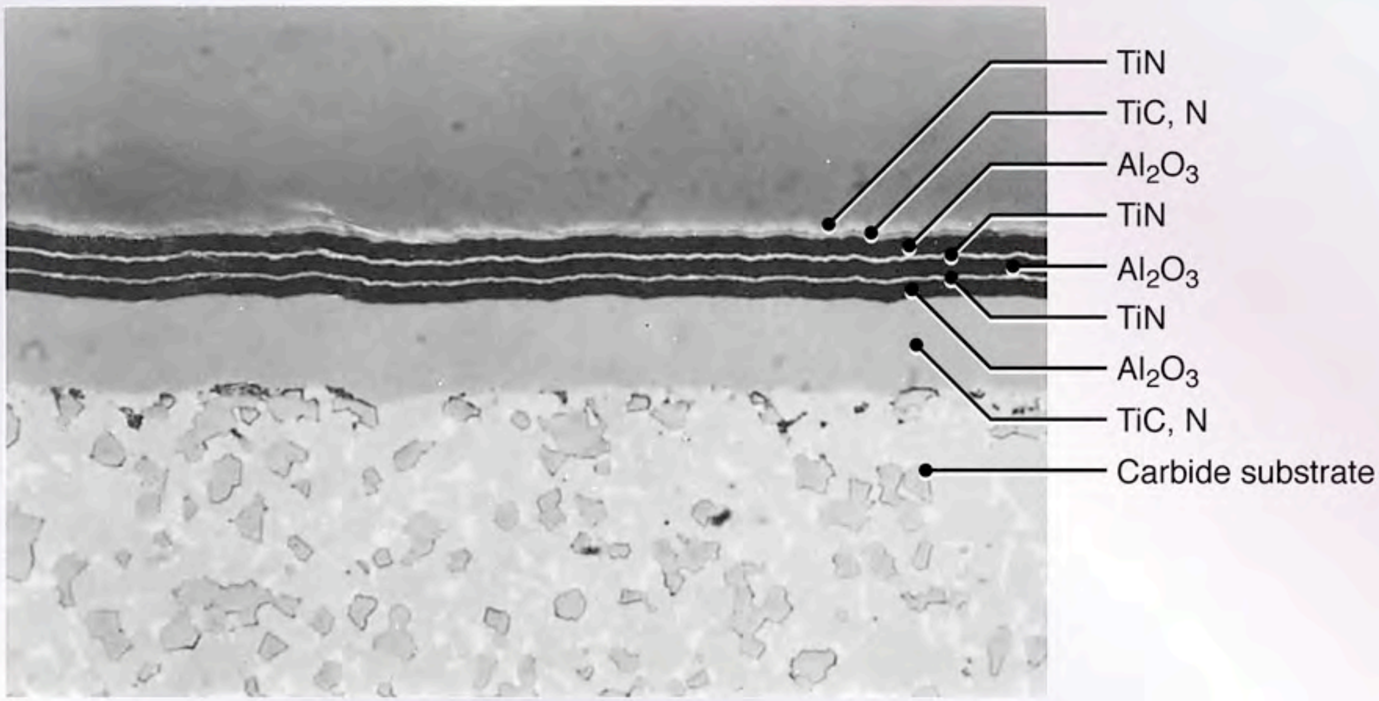


Figure 22.8 Multiphase coatings on a tungsten-carbide substrate. Three alternating layers of aluminum oxide are separated by very thin layers of titanium nitride. Inserts with as many as thirteen layers of coatings have been made. Coating thicknesses are typically in the range of 2 to 10 μm. *Source*: Courtesy of Kennametal, Inc.

Ranges of Mechanical Properties for Groups of Tool Materials

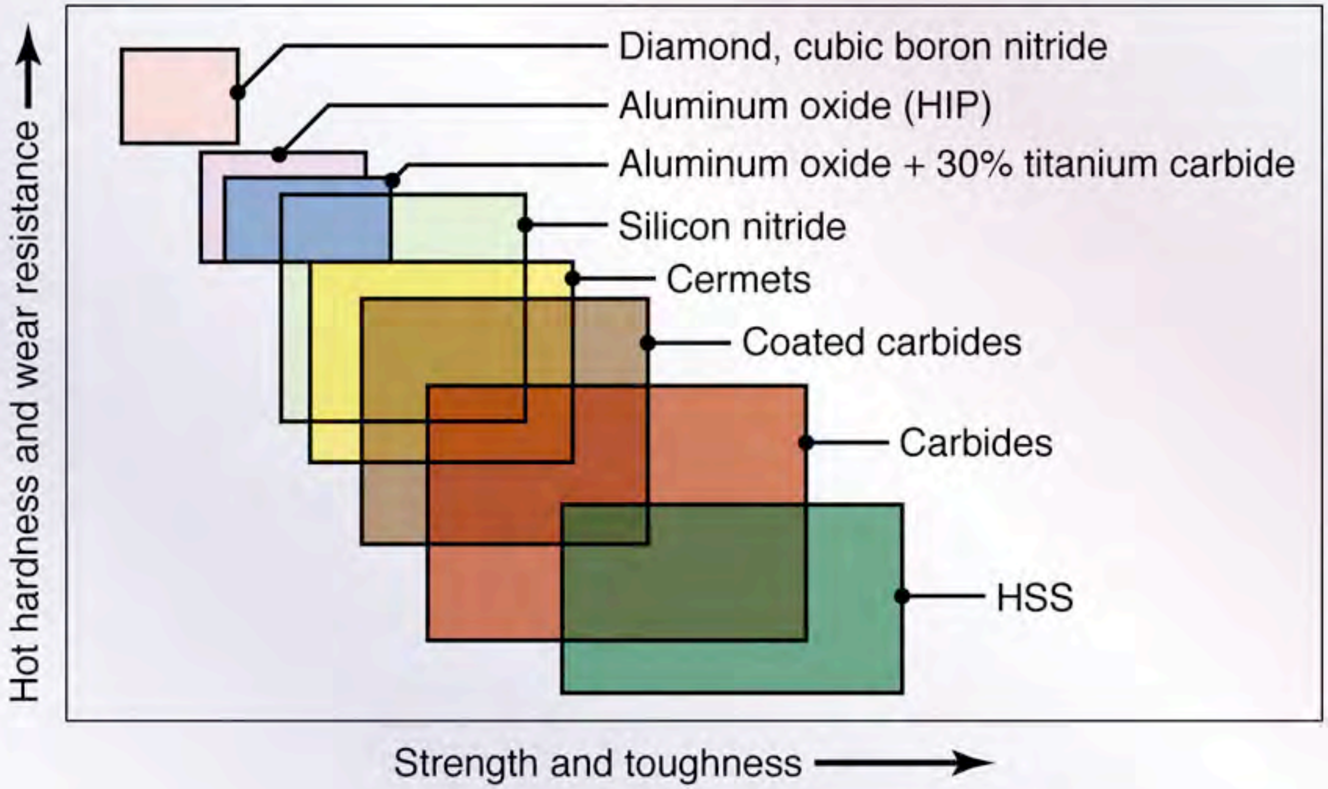


Figure 22.9 Ranges of mechanical properties for various groups of tool materials. See also Tables 22.1 through 22.5.

Cubic Boron Nitride Inserts

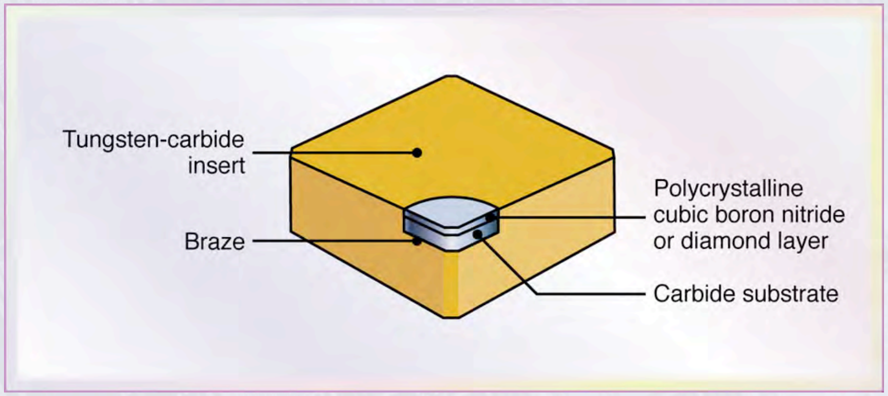


Figure 22.10 An insert of polycrystalline cubic boron nitride or a diamond layer on tungsten carbide.

Figure 22.11 Inserts with polycrystalline cubic boron nitride tips (top row), and solid-polycrystalline cBN inserts (bottom row). *Source*: Courtesy of Valenite.

Proper Methods of Applying Cutting Fluids

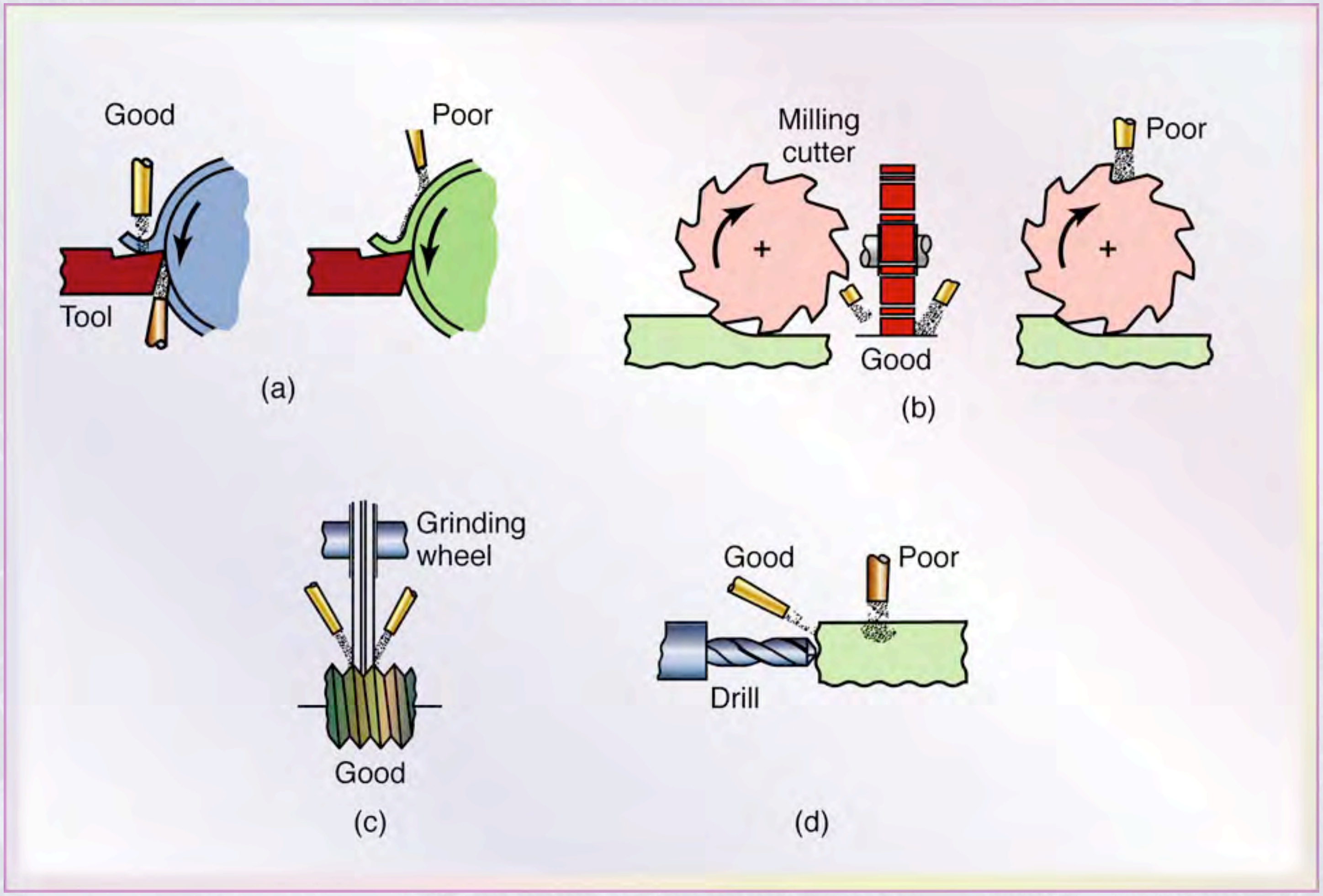


Figure 22.12 Schematic illustration of the proper methods of applying cutting fluids (flooding) in various machining operations: (a) turning, (b) milling, (c) thread grinding, and (d) drilling.