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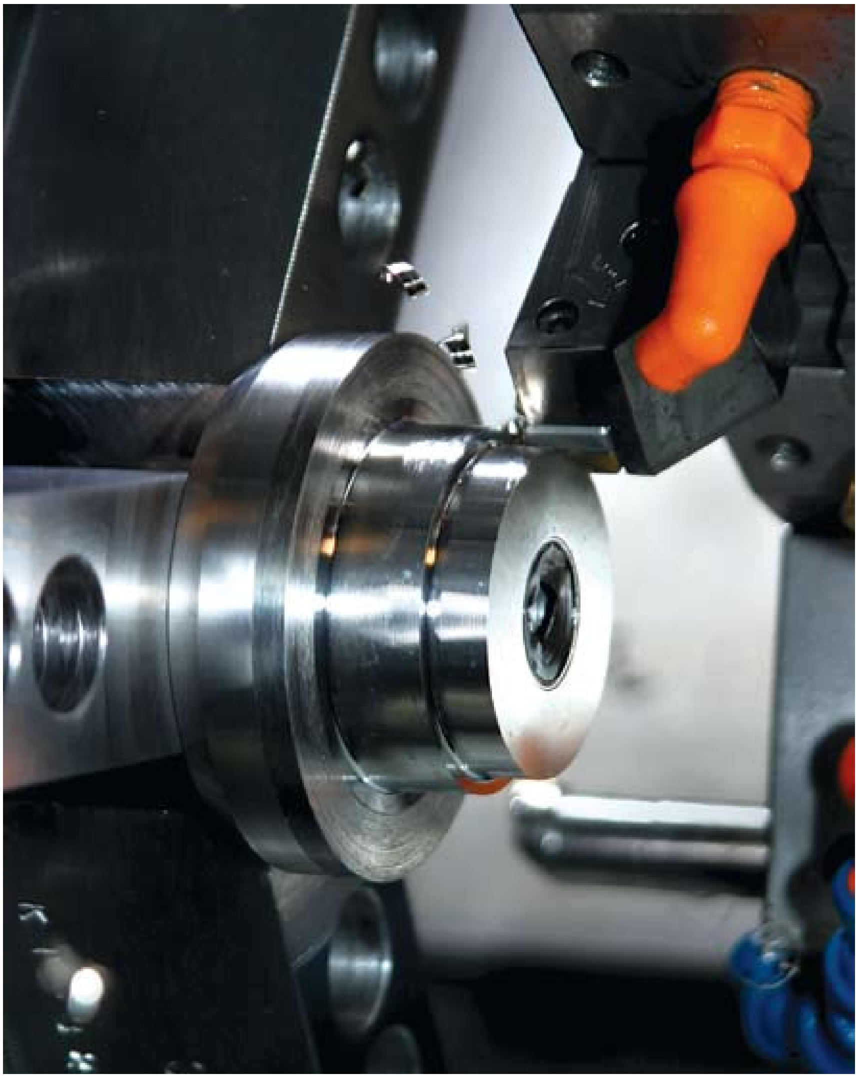
Alloys for Demanding Parts

BY EDMUND ISAKOV, PH.D.

Guidelines for turning of alloy steels.


Bill Kennedy

Alloy steels are not as common as carbon steels, but when hardness, strength and wear resistance of the machined parts are a necessity, alloy steels are the right choice. And when turning alloy steels, shop personnel should know the workpiece grade to boost productivity. Also, they need to know from which material their tools should be made to choose the correct machining parameters for turning alloy steels.

According to AMS International's *Metals Handbook*: "Alloy steels constitute a category of ferrous materials that exhibit mechanical properties superior to carbon steels as the result of additions of such alloying elements as nickel, chromium and molybdenum. Total alloy content can range from 2.0 percent up to levels just below that of stainless steels. For many alloy steels, the primary function of the alloying elements is to increase hardenability in order to optimize mechanical properties and toughness after heat treatment."

Engineering Properties of Steel, published by the American Society for Metals, further defines the material. "Steel is considered an alloy steel when the maximum content range of alloying elements exceeds one or more of the following limits: 1.65 percent manganese, 0.60 percent silicon or 0.60 percent copper. Also included in the recognized field of alloy steels are steels with a specified or required range or minimum quantity of the following elements: aluminum, boron, chromium, cobalt, niobium, molybdenum, nickel, titanium, tungsten, vanadium, zirconium or any other element added to obtain a desired alloying effect."

Designation System

The AISI–SAE system of designations for alloy steels is similar to that for carbon steels. With four digits in the designation, the last two digits indicate carbon content in hundredths of a percent. For chromium steels with five digits in the designation (high-carbon, electric-furnace, E50100, E51100 and E52100 grades), the last three digits indicate carbon content, which is a minimum of 1.00 percent. A letter B between the second and third digits denotes boron steel to which a minimum of 0.0005 percent boron has been added. The letter H after the four digits indicates a grade produced to prescribed hardenability limits. H-steels require a slight modification in the chemical composition of the conventional grade with the same AISI numerical designation. (See sidebar.)

Machining data for turning alloy steels depend on the carbon content. These steels are divided into four classes: one for low-carbon (0.07 to 0.30 percent), two for medium-carbon (0.27 to 0.41 percent) and (0.37 to 0.49 percent); and one for high-carbon content (0.47 to 0.65 percent).

According to current classification, there are 66 standard grades and more than 90 nonstandard grades of alloy steels. Because of space limitations, machining data is only provided for the most common category—nickel-chromium-molybdenum alloy steels.

This versatile category includes 10 groups. The groups differ from each other by the content of the principal alloying elements. There are 22 standard and 37 nonstandard grades of nickel-chromium-molybdenum alloy steels. Machining data for this category is based on carbon content.

Low-Carbon Grades

There are 27 low-carbon grades, but detailed technical information is available for only six: AISI 4320, 4320H, 8620, 8620H, E9310 and E9310H. 4320 and 4320H are carburizing steels with the same range of molybdenum (0.20 to 0.30 percent). The 4320 grade contains 1.65 to 2.00 percent nickel and 0.40 to 0.60 percent chromium. The 4320H grade contains 1.55 to 2.00 percent nickel and 0.35 to 0.65 percent chromium. These grades are used to make automotive gears, piston pins, ball studs, universal crosses and roller bearings.

Hardness of these steels depends on the heat treatment. When 4320 and 4320H are annealed, their hardness is 163 HB. When normalized, it is 201 to 248 HB, and like other alloy steels, hardness increases as normalized workpiece diameter decreases.

The hardness is 241 to 415 HB when carburized, quenched in oil and tempered. A lower tempering temperature and a smaller workpiece diameter result in a higher hardness for this heat-treatment process.

Surface hardness of a round workpiece quenched in oil decreases when the workpiece diameter increases. For example, at a 0.5" diameter, the hardness is 45.5 HRC, which is equivalent to 425 HB, and at a 4.0" diameter, the hardness is 25.0 HRC, which is equivalent to 253 HB.

Average machinability rating of 4320 and 4320H is 60 percent at 187 to 229 HB.

The relationship between tensile strength and Brinell hardness for the 4320 and 4320H grades is expressed by the formula: $\sigma = 496 \times HB$.

Where 496 is a multiplier and HB is a Brinell hardness number. For example, if the workpiece hardness is 200 HB, then tensile strength of the workpiece is 99,200 psi (496 × 200).

AISI 8620 and 8620H are carburizing steels produced to the same range of molybdenum (0.15 to 0.25 percent). The 8620 grade contains 0.40 to 0.70 percent nickel and 0.40 to 0.60 percent chromium. The 8620H grade contains 0.35 to 0.75 percent nickel and 0.35 to 0.65 percent chromium.

Heat treatment depends on required hardness in the case and core for specific applications. These grades are used to make differential ring gears, camshafts, piston pins, transmission gears, steering worm gears, spline shafts, high-strength fasteners and applications requiring medium-strength, tough core properties and hard wear-resistant case properties.

When annealed, the hardness of 8620 and 8620H is 149 HB, and 163 to 197 HB when normalized. The hardness is 201 to 388 HB when carburized, quenched in oil and tempered.

Average machinability rating of 8620 and 8620H is 65 percent at 179 to 235 HB.

The relationship between tensile strength and Brinell hardness for the 8620 and 8620H grades is expressed by the formula: $\sigma = 495 \times HB$.

AISI E9310 and E9310H grades are carburizing steels with high case and core hardenability. They are produced to the same range of molybdenum (0.08 to 0.15 percent). E9310 contains 3.00 to 3.50 percent nickel and 1.00 to 1.40 percent chromium. E9310H contains 2.95 to 3.55 percent nickel and 1.00 to 1.45 percent chromium. Typical applications of these grades include aircraft and heavy-duty truck gears.

When these steels are annealed, the hardness is 241 HB, and when normalized, it is 255 to 285 HB. The hardness is 269 to 363 HB when carburized, quenched in oil and tempered.

Average machinability rating of E9310 and E9310H grades is 50 percent at 184 to 229 HB.

The relationship between tensile strength and Brinell hardness for the E9310 and E9310H is expressed by the formula: $\sigma = 490 \times HB$.

Medium-Carbon Grades

There are seven medium-carbon grades containing 0.27 to 0.41 percent carbon, but detailed technical information is available for just three: AISI 8630, 8630H and 86B30H.

These grades are produced to the same range of molybdenum (0.15 to 0.25 percent) but to different ranges for the other two alloying elements: 0.40 to 0.70 percent nickel and 0.40 to 0.60 percent chromium for 8630 and 0.35 to 0.75 percent nickel and 0.35 to 0.65 percent chromium for 8630H and 86B30H.

These steels are characterized by low hardenability, but the addition of 0.0005 to 0.003 percent boron enhances hardenability of 86B30H. When normalized, they provide good mechanical properties. These grades are used to make connecting rods, engine bolts and studs.

When these grades are annealed, the hardness is 156 HB. When normalized, it is 187 to 201 HB. The hardness is 197 to 302 HB when quenched in water and tempered. Because these steels are directly hardenable, they are not carburized.

Average machinability rating of 8630, 8630H and 86B30H grades is 70 percent at 179 to 229 HB.

The relationship between tensile strength and Brinell hardness for the 8630, 8630H and 86B30H grades is expressed by the formula: $\sigma = 495 \times HB$.

There are 18 medium-carbon grades containing 0.37 to 0.49 percent carbon, but detailed technical information is available for eight: AISI 4340, 4340H, E4340, E4340H, 8640, 8640H, 8740 and 8740H.

4340 (E4340) steel is produced to a range of 1.65 to 2.00 percent nickel and 0.70 to 0.90 percent chromium. 4340H (E4340H) steel is produced to a range of 1.55 to 2.00 percent nickel and 0.65 to 0.95 percent chromium. Both grades have the same range of molybdenum, 0.20 to 0.30 percent. The letter E as a prefix indicates the steel is made by the electric furnace process. These steels are used to make piston pins, bearings, gears, machine tool arbors, die blocks and cutting tool shanks.

When annealed, the hardness is 217 HB, and 321 to 363 HB when normalized. The hardness is 255 to 363 HB when oil quenched and tempered. Average machinability rating of these steels is 50 percent at 187 to 241 HB.

The relationship between tensile strength and Brinell hardness for the 4340 (E4340) and 4340H (E4340H) grades are expressed by the following formula: $\sigma = 501 \times HB$.

The 8640 and 8640H grades are produced to the same range of molybdenum, 0.15 to 0.25 percent, but to different ranges for the other two alloying elements: 0.40 to 0.70 percent nickel and 0.40 to 0.60 percent chromium for 8640 and 0.35 to 0.75 percent nickel and 0.35 to 0.65 percent chromium for 8640H.

These grades have medium hardenability. They are used for parts requiring a high degree of strength and toughness, such as automotive steering knuckles, axle shafts and propeller shafts. Electric furnace grade E8640 is produced as aircraft quality, fine-grain steels, which are used in manufacturing cap, socket and recessed-head aircraft screws.

With cold drawn processing, 8640 and 8640H grades attain a hardness of 277 HB. The hardness is 219 to 342 HB when these grades are quenched in oil and tempered.

Average machinability rating of these grades is 65 percent at 184 to 229 HB.

The relationship between tensile strength and Brinell hardness for the 8640 and 8640H grades is expressed by the formula: $\sigma = 494 \times HB$.

The 8740 and 8740H grades are produced to the same range of molybdenum, 0.20 to 0.30 percent, and exactly the same range for the other two alloying elements, similar to 8640 and 8640H grades.

The 8740 and 8740H grades are used for making camshafts, wrist pins and clutch fingers. Other applications include torsion bars, springs, and other cold-headed parts.

When annealed, the hardness of these steels is 201 HB. When normalized, the hardness is 255 to 269 HB, and the hardness is 229 to 352 HB when quenched in oil and tempered.

Average machinability rating of 8740 and 8740H is 65 percent at 184

Designating an alloy steel

The first two digits of a designation number define the principal alloying element or elements, which identify the following 12 categories of alloy steels.

1. Manganese steels are designated as 13XX series. There are four standard grades having 1.60 to 1.90 percent Mn.

2. Nickel steels are designated as 23XX and 25XX series. Two nonstandard grades are available: AISI A2317 (3.25 to 3.75 percent Ni) and AISI A2515 (4.75 to 5.25 percent Ni).

3. Nickel-chromium steels are designated as 31XX, 32XX, 33XX and 34XX series.

4. Molybdenum steels are designated as 40XX series, which include six standard grades (AISI 4023 to 4047) produced with 0.20 to 0.30 percent Mo, and 44XX series with three nonstandard grades (AISI 4419 to 4427) having 0.35 to 0.60 percent Mo.

5. Chromium-molybdenum steels are designated as 41XX series. There are nine standard grades (AISI 4118 to 4161) and seven of them have 0.80 to 1.10 percent Cr and 0.15 to 0.25 percent Mo.

6. Nickel-molybdenum steels are designated as 46XX series (AISI 4615, 4620 and 4626 standard grades) and 48XX series (AISI 4815, 4817 and 4820 standard grades). AISI 4615 and 4620 grades have 1.65 to 2.00 percent Ni and 0.20 to 0.30 percent Mo. All grades of 48XX series have 3.25 to 3.75 percent Ni and 0.20 to 0.30 percent Mo.

7. Chromium steels are designated as 50XX series, which include four standard boron grades (AISI 50B44 to 50B60) with 0.20 to 0.60 percent Cr; 51XX series, which include nine standard grades (AISI 5117 to 5160) and one standard boron grade (AISI 51B60) with 0.70 to 1.10 percent Cr. Also in this category are two standard grades: AISI E51100 (0.90 to 1.15 percent Cr) and E52100 (1.30 to 1.60 percent Cr), which are characterized as high-carbon grades (0.98 to 1.10 percent C).

8. Chromium-vanadium steels are designated as 61XX series, which include two standard grades: AISI 6118 (0.50 to 0.70 percent Cr and 0.10 to 0.15 percent V) and 6150 (0.80 to 1.10 percent Cr and at least 0.15 percent V).

9. Nickel-chromium-molybdenum steels include 10 groups:

- 43XX series—six grades, three of which are standard: AISI 4320, 4340 and E4340;
- 47XX series—four grades, one of which is standard: AISI 4720;
- 81XX series—two boron grades, one of which is standard: AISI 81B45;
- 86XX series—31 grades, 12 of which are standard: AISI 8615 to 8655;
- 87XX series—four grades, two of which are standard: AISI 8720 and 8740;
- 88XX series—two grades, one of which is standard: AISI 8822;
- 93XX series—two nonstandard grades: AISI E9310 and E9310H;
- 94XX series—seven boron grades, two of which are standard: AISI 94B17 and 94B30;
- 97XX series—the number of grades are currently unknown; and
- 98XX series—one nonstandard grade: AISI 9840.

10. Chromium-molybdenum-aluminum steels include the 71XX series.

11. Tungsten-chromium steels include the 72XX series.

12. Silicon steels are designated as 92XX series, which include one standard (AISI 9260) and one nonstandard (AISI 9255) grade, both of which have 1.80 to 2.20 percent Si.

—*E. Isakov*

to 235 HB.

The relationship between tensile strength and Brinell hardness for the 8740 and 8740H grades is expressed by the formula: σ = 502 × HB.

High-Carbon Grades

There are seven high-carbon grades containing 0.47 to 0.65 percent carbon, but detailed technical information is available for three: 8650, 8650H and 86B50.

These three grades are produced to a range of 0.15 to 0.25 percent molybdenum but to different ranges of the other two alloying elements: 0.40 to 0.70 percent nickel and 0.40 to 0.60 percent chromium for 8650 and 0.35 to 0.75 percent nickel and 0.35 to 0.65 percent chromium for 8650H and 86B50.

These steels have medium hardenability. The addition of 0.0005 to 0.003 percent boron enhances hardenability of the 86B50 grade. Primary applications include springs, hand tools and automotive axle shafts.

When these steels are annealed, their hardness is 212 HB. When normalized, the hardness is 285 to 363 HB. The hardness is 241 to 363 HB when quenched in oil and tempered.

Average machinability rating of the three grades is 60 percent at 187 to 248 HB.

The relationship between tensile strength and Brinell hardness for the 8650, 8650H and 86B50 grades is expressed by the formula: σ = 494 × HB.

The eight formulas for tensile strength relationship are based on statistical treatment of Brinell hardness and tensile strength data performed by the author. The multipliers vary from 490 to 502, and each is an arithmetic average obtained by dividing the cumulative tensile strength value by the cumulative Brinell hardness value. The tensile strength value of the workpiece material is used for calculating cutting force, torque and required machining power.

Tool Materials

Cutting tool material specification is based on ANSI (American National Standards Institute) and ISO (International Organization for Standardization) codes. ANSI adapted the industry code, which designates uncoated carbide grades as C-1 to C-8.

The C-1 through C-4 grades are straight tungsten carbide bonded with cobalt and usually vary in cobalt content and grain size. Hardness of these grades increases and toughness decreases from C-1 to C-4.

The C-5 through C-8 grades contain various combinations of tungsten carbide, titanium carbide, tantalum carbide and niobium carbide bonded with cobalt. The majority of these carbide grades are coated and coded as CC-5 through CC-8. Hardness of these grades increases and toughness decreases from CC-5 to CC-8. Grades CC-6 and CC-7 are typical for machining carbon and alloy steels. CC-6

Table 1. Machining data for low-carbon nickel-chromium-molybdenum grades.

Brinell hardness, HB	DOC, in.	Feed rate, ipr	Cutting speed, sfm	Cutting tool material specification, ANSI/ISO
175 to 225	0.300	0.020	450	CC-6/CP30
	0.150	0.015	575	CC-6/CP20
	0.040	0.007	725	CC-7/CP10
225 to 275	0.300	0.020	400	CC-6/CP30
	0.150	0.015	500	CC-6/CP20
	0.040	0.007	650	CC-7/CP10
275 to 325	0.300	0.020	350	CC-6/CP30
	0.150	0.015	450	CC-6/CP20
	0.040	0.007	575	CC-7/CP10
325 to 375	0.300	0.020	300	CC-6/CP30
	0.150	0.015	375	CC-6/CP20
	0.040	0.007	475	CC-7/CP10
375 to 425	0.300	0.020	225	CC-6/CP30
	0.150	0.015	300	CC-6/CP20
	0.040	0.007	375	CC-7/CP10

All tables: Machining Data Handbook

Table 2. Machining data for high-carbon nickel-chromium-molybdenum grades.

Brinell hardness,HB	DOC, in.	Feed rate, ipr	Cutting speed, sfm	Cutting tool material specification, ANSI/ISO
175 to 225	0.300	0.020	400	CC-6/CP30
	0.150	0.015	500	CC-6/CP20
	0.040	0.007	650	CC-7/CP10
225 to 275	0.300	0.020	350	CC-6/CP30
	0.150	0.015	450	CC-6/CP20
	0.040	0.007	575	CC-7/CP10
275 to 325	0.300	0.020	325	CC-6/CP30
	0.150	0.015	425	CC-6/CP20
	0.040	0.007	550	CC-7/CP10
325 to 375	0.300	0.020	275	CC-6/CP30
	0.150	0.015	350	CC-6/CP20
	0.040	0.007	450	CC-7/CP10
375 to 425	0.300	0.020	225	CC-6/CP30
	0.150	0.015	275	CC-6/CP20
	0.040	0.007	350	CC-7/CP10

grades have a medium to high shock resistance and medium wear resistance. Such grades are recommended for roughing and semifinishing. CC-7 grades have medium shock and wear resistance. CC-7 grades are typically used for finishing.

ISO code consists of letters and two-digit numbers. The letter C denotes coated carbides, and the letter P indicates that these carbide grades are suitable for machining alloy steels. CP10 grades indicate they are for high cutting speeds when producing small to medium chip cross sections, CP20 grades are for medium speeds and medium chip cross sections, and CP30 grades indicate medium to low cutting speeds and medium to large chip cross sections.

The higher the numbers, the higher the toughness and the lower the hardness of the carbides. Increased cutting speeds and wear resistance are attainable with lower-numbered carbides. Increased feed rates and carbide toughness are attainable with higher-numbered carbides.

Carbide grades listed under the ANSI and ISO codes and the corresponding grades listed by various manufacturers are not equivalent.

The cutting speed data shown in Tables 1 and 2 are starting recommendations. Tables 3 and 4 show medium-carbon grades. Because of modern machine tools and coated carbide tools, the cutting speeds can be increased 15 to 30 percent to achieve higher productivity. However, the machine tools' power availability should always be considered.

Coated carbide cutting tools not only last longer, they also cut faster, which increases machining effectiveness. Increasing cutting speeds by 30 percent reduces manufacturing costs by as much as 15 percent.

Among the varieties of coated materials, a PVD titanium-aluminum-nitride coating is the most popular for dry or near-dry high-speed finishing to general machining. A CVD multilayer coating containing an outer layer of titanium-nitride, a medium layer of aluminum oxide and an inner layer of titanium-carbon-nitride is commonly used for roughing and semifinishing.

With the preceding information—along with the appropriate cutters, lathe or turning center and workholders—maximum machining efficiency can be achieved. △

Table 3. Machining data for medium-carbon (0.27 to 0.41 percent) nickel-chromium-molybdenum grades.

Brinell hardness, HB	DOC, in.	Feed rate, ipr	Cutting speed, sfm	Cutting tool material specification, ANSI/ISO
175 to 225	0.300	0.020	400	CC-6/CP30
	0.150	0.015	525	CC-6/CP20
	0.040	0.007	650	CC-7/CP10
225 to 275	0.300	0.020	375	CC-6/CP30
	0.150	0.015	450	CC-6/CP20
	0.040	0.007	600	CC-7/CP10
275 to 325	0.300	0.020	350	CC-6/CP30
	0.150	0.015	425	CC-6/CP20
	0.040	0.007	550	CC-7/CP10
325 to 375	0.300	0.020	300	CC-6/CP30
	0.150	0.015	350	CC-6/CP20
	0.040	0.007	500	CC-7/CP10
375 to 425	0.300	0.020	225	CC-6/CP30
	0.150	0.015	300	CC-6/CP20
	0.040	0.007	375	CC-7/CP10

Table 4. Machining data for medium-carbon (0.37 to 0.49 percent) nickel-chromium-molybdenum grades.

Brinell hardness, HB	DOC, in.	Feed rate, ipr	Cutting speed, sfm	Cutting tool material specification, ANSI/ISO
175 to 225	0.300	0.020	400	CC-6/CP30
	0.150	0.015	525	CC-6/CP20
	0.040	0.007	650	CC-7/CP10
225 to 275	0.300	0.020	375	CC-6/CP30
	0.150	0.015	475	CC-6/CP20
	0.040	0.007	600	CC-7/CP10
275 to 325	0.300	0.020	350	CC-6/CP30
	0.150	0.015	450	CC-6/CP20
	0.040	0.007	575	CC-7/CP10
325 to 375	0.300	0.020	300	CC-6/CP30
	0.150	0.015	400	CC-6/CP20
	0.040	0.007	500	CC-7/CP10
375 to 425	0.300	0.020	250	CC-6/CP30
	0.150	0.015	300	CC-6/CP20
	0.040	0.007	400	CC-7/CP10

About the Author

Edmund Isakov, Ph.D., is a consultant and writer. He is the author of several books, including Engineering Formulas for Metalcutting *(Industrial Press, 2004) and* Advanced Metalcutting Calculators *(Industrial Press, 2005).*