JANUARY 2007 / VOLUME 59 / NUMBER 1

➤ BY EDMUND ISAKOV, PH.D.

Bill Kennedy

Carbon Content

Guidelines for turning carbon steels.

Carbon steel is the "workhorse" of the metalworking industry. Carbon steels are—by far—the most frequently machined steel. Carbon steels represent about 87 percent of the steel produced in the U.S.

The feasibility of using carbon steels depends on whether or not their properties (tensile, yield and fatigue strengths; impact resistance; and need for heat treating) are suitable for the parts. If the required characteristics can be obtained with carbon steel, most users select this steel, which is less costly than other steel.

The objective of this article is to help producers of carbon steel parts understand the composition of the various grades to increase turning productivity. The article also provides cutting speed data in relation to the DOC, feed rate, cutting tool material and the Brinell hardness of carbon steels.

Sixty-six years ago, metalcutting pioneers Dr. M. Eugene Merchant and Hans Ernst described chip formation, friction between the chip and tool, surface quality and metal-removal efficiency.

In the study, Dr. Merchant used a variety of metals, and among them were 1020 low-carbon steel and 1112 free-machining carbon steel. Based on the experiments, he developed a mathematical model of the metalcutting process that is still in use and can be applied to design chipbreakers.

Machinability ratings of ferrous and nonferrous alloys are expressed in percentages based on AISI 1212 free-machining carbon steel as 100 percent average machinability.

The turning test to determine tool life of various grades of indexable inserts is conducted under specified cutting conditions using AISI 1045 medium-carbon steel as the standard workpiece material.

Carbon steels are divided into six categories:

- low-carbon;
- medium-carbon;
- high-carbon;
- free-machining resulfurized;
- free-machining resulfurized and rephosphorized; and
- nonresulfurized high-manganese (containing more than 1.00 percent

manganese).

Low Carbon

Low-carbon steels (AISI 1005 to 1026) are produced with 0.06 to 0.28 percent carbon and 0.25 to 1.00 percent manganese. Low-carbon steels are limited to 0.040 percent phosphorus and 0.050 percent sulfur. Currently, there are 16 standard grades of low-carbon steels.

When turned, low-carbon steels produce long chips, which will form built-up edge on an indexable insert if a chipbreaker doesn't create a sufficient shear angle to curl the chip away from the insert's rake face. Low cutting speed is another cause of BUE, which acts as an extension of the cutting tool, changing part dimensions and imparting rough surface finishes. When that's the case, the cutting speed should be increased 15 to 20 percent or more until the surface finish improves.

The appropriate cutting speed depends on the DOC, feed rate, cutting tool material and hardness of the workpiece. Selecting the cutting speed is always a challenge. Usually, the DOC and feed rate are conservative parameters predetermined by whether it's a roughing, semifinishing or finishing operation.

Low-carbon steels are subjected to slightly different cutting speeds and, therefore, are divided in two groups. Typical roughing, semifinishing and finishing parameters are shown in Tables 1 and 2.

The tables indicate that cutting speed decreases when the DOC and feed rates increase. If DOC, feed rate or both are different than those presented in the tables, the cutting speed should be adjusted so that the metal-removal rate remains the same as it is for the machining parameters shown in the tables. The following calculation explains the concept.

Let's take the machining parameters shown in the first row of Table 1 and calculate the mrr.

mrr = 12" × sfm × DOC × ipr =
12 × 550 × 0.300 × 0.020 =
39.6 in.³⁄min.

Changing the DOC to 0.200" and keeping the mrr the same, the cutting speed must be equal to 825 sfm.

sfm = mrr ÷ DOC ÷ ipr ÷ 12 =
39.6 ÷ 0.200 ÷ 0.020 ÷ 12 = 825 sfm.

In this example, the cutting speed was increased proportionally to the decrease of the DOC (0.300 ÷ 0.200 = 1.5, and 550 × 1.5 = 825 sfm).

Table 1. Parameters for AISI 1015, 1020, 1023, 1025 and 1026 grades.

Brinell hardness (HB)	DOC (in.)	Feed rate (ipr)	Cutting speed (sfm)	Cutting tool material specification (ANSI*/ISO**)
85 to 125	0.300	0.020	550	CC-6/CP30
	0.150	0.015	700	CC-6/CP20
	0.040	0.007	1,050	CC-7/CP10
125 to 175	0.300	0.020	500	CC-6/CP30
	0.150	0.015	625	CC-6/CP20
	0.040	0.007	950	CC-7/CP10
175 to 225	0.300	0.020	450	CC-6/CP30
	0.150	0.015	550	CC-6/CP20
	0.040	0.007	850	CC-7/CP10

* ANSI (American National Standards Institute) is used with customary U.S. units.
** ISO (International Organization for Standardization) is used with metric units.

Tables 1 through 6 adopted from Machining Data Handbook, 3rd Edition, Volume 1, and Engineering Properties of Steel. Cutting tool material specifications in Tables 1 through 6 are for coated carbides.

Table 2. Parameters for AISI 1016, 1017, 1018, 1019, 1021 and 1022 grades.

Brinell hardness (HB)	DOC (in.)	Feed rate (ipr)	Cutting speed (sfm)	Cutting tool material specification (ANSI/ISO)
85 to 125	0.300	0.020	525	CC-6/CP30
	0.150	0.015	675	CC-6/CP20
	0.040	0.007	1,025	CC-7/CP10
125 to 175	0.300	0.020	500	CC-6/CP30
	0.150	0.015	625	CC-6/CP20
	0.040	0.007	950	CC-7/CP10
175 to 225	0.300	0.020	450	CC-6/CP30
	0.150	0.015	550	CC-6/CP20
	0.040	0.007	850	CC-7/CP10

Table 3.Parameters for medium-carbon steels.

Brinell hardness (HB)	DOC (in.)	Feed rate (ipr)	Cutting speed (sfm)	Cutting tool material specification (ANSI/ISO)
125 to 175	0.300	0.020	475	CC-6/CP30
	0.150	0.015	600	CC-6/CP20
	0.040	0.007	925	CC-7/CP10
175 to 225	0.300	0.020	415	CC-6/CP30
	0.150	0.015	525	CC-6/CP20
	0.040	0.007	785	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	750	CC-7/CP10

Medium Carbon

Medium-carbon steels (AISI 1029 to 1053) are produced with 0.25 to 0.55 percent carbon and 0.30 to 1.00 percent manganese. Medium-carbon steels are limited to 0.040 percent phosphorus and 0.050 percent sulfur. There are 16 standard grades of medium-carbon steels (See Table 3).

When turned, medium-carbon steels produce discontinuous chips resulting in a finer surface finish compared to low-carbon steels. Cutting forces and tool wear increase as the carbon content and hardness increase. With increased hardness, cutting speeds should be reduced.

High Carbon

High-carbon steels (AISI 1055 to 1095) are produced with 0.60 to 1.03 percent carbon and 0.30 to 0.90 percent manganese. These steels are limited to 0.040 percent phosphorus and 0.050 percent sulfur. There are 14 standard grades of high-carbon steels (See Table 4).

Cutting forces and tool wear are higher when turning high-carbon steels than they are when turning medium-carbon steels, because of higher carbon content. Therefore, lower cutting speeds are necessary to minimize tool wear. The effect of hardness on the cutting speed is similar to that for low- and medium-carbon steels.

Table 4. Parameters for high-carbon steels.

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	750	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	700	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	675	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	550	CC-7/CP10

Table 5. Parameters for AISI 12L13, 12L14 and 12L15 leaded steels.

Brinell hardness (HB)	DOC (in.)	Feed rate (ipr)	Cutting speed (sfm)	Cutting tool material specification (ANSI/ISO)
100 to 150	0.300	0.020	825	CC-6/CP30
	0.150	0.015	1,025	CC-6/CP20
	0.040	0.007	1,550	CC-7/CP10
150 to 200	0.300	0.020	800	CC-6/CP30
	0.150	0.015	1,000	CC-6/CP20
	0.040	0.007	1,500	CC-7/CP10
200 to 250	0.300	0.020	750	CC-6/CP30
	0.150	0.015	925	CC-6/CP20
	0.040	0.007	1,400	CC-7/CP10

Free-Machining Grades

Free-machining steels are divided into resulfurized grades (11XX series) and both resulfurized and rephosphorized grades (12XX series).

The resulfurized steels (AISI 1108 to 1151) include 14 standard grades, which improve machinability with increased sulfur content up to 0.33 percent (AISI 1119 and AISI 1144).

Most of the 11XX series grades are produced with increased manganese content from 1.30 to 1.65 percent, which is enough to react with sulfur and form manganese sulfide particles. The presence of these MnS particles results in a finer surface finish because they create microvoids and microcracks during chip formation. These microdefects propagate into a removable layer of a workpiece, increasing the chip's shear angle and enhancing the chip-breaking process.

The resulfurized and rephosphorized steels include four unleaded standard grades (AISI 1211, 1212, 1213 and 1215) and three standard grades containing lead in the amount of 0.15 to 0.35 percent (AISI 12L13, 12L14 and 12L15). The 12XX series grades are produced with increased sulfur content (0.10 to 0.35 percent) and increased phosphorus content (0.04 to 0.12 percent). The effect of increased amounts of sulfur in 12XX grades is similar to that for AISI 11XX grades.

The increased amount of phosphorus, which is soluble in iron, promotes chip breaking, helps to avoid formation of long, stringy chips and may result in a finer surface finish.

Lead in the 12XX series grades works as an internal lubricant during turning, reducing friction and the buildup of heat at the tool/workpiece interface. Leaded steels are most commonly used for high-volume production. An increase of 25 percent or more in machining productivity results from the use of leaded steels because of the ability to increase the cutting speed while imparting a finer finish.

Free-machining resulfurized and rephosphorized steels are widely used in screw machine operations. Economic reasons, however, limit leaded steels to use for high-speed screw machining, where the steel's superior machining characteristics can be fully utilized.

Of all free-machining steels, the 12LXX grades can be turned at the highest cutting speed (See Table 5). Turning free-machining steels produces discontinuous chips, so chip control is not a problem.

High Manganese

High-manganese steels (AISI 1513 to 1566) are produced with 0.75 to 1.65 percent manganese and 0.10 to 0.71 percent carbon. The amount of phosphorus and sulfur is the same as in low-, medium- and high-carbon steels.

There are 12 standard grades of manganese steels. Most grades have 0.0005 to 0.030 percent boron, which is added to increase the depth of hardening when quenched.

The low-carbon steels of the 15XX series (AISI 1513 to 1527) are used for carburizing applications, which require greater case hardenability than regular carbon steels provide.

The medium-carbon steels (0.30 to 0.35 percent carbon) are used for parts machined from bar stock. Depending on the application and the level of strength required, the parts could be used with or without heat treatment.

The high-carbon steels (AISI 1547 to 1566) are used where greater strength levels and higher wear resistance are required than those attainable with regular carbon grades.

The boron-treated manganese steels, such as AISI 15B48H, are used in the production of rods. These steels substitute for alloy and high-carbon steels when manufacturing heat-treated bolts (See Table 6).

Turning of high-manganese steels is similar to that for medium-carbon 10XX series grades.

Table 6. Parameters for AISI 1524, 1541, 1547, 1548, 1551 and 1552.

Brinell hardness (HB)	DOC (in.)	Feed rate (ipr)	Cutting speed (sfm)	Cutting tool material specification (ANSI/ISO)
125 to 175	0.300	0.020	450	CC-6/CP30
	0.150	0.015	550	CC-6/CP20
	0.040	0.007	850	CC-7/CP10
175 to 225	0.300	0.020	400	CC-6/CP30
	0.150	0.015	500	CC-6/CP20
	0.040	0.007	750	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	725	CC-7/CP10

Cracking the Code

Cutting tool material specification is based on ANSI (American National Standards Institute) and ISO (International Organization for Standardization) codes. ANSI adopted the industry code, which designates uncoated carbide grades (C-1, C-2, etc.) and coated carbide grades (CC-5, CC-6, etc.). The numeric portion of the code gives only basic information on carbides, their toughness and hardness. The C-1 through C-4 grades are straight tungsten carbide bonded with cobalt. However, the cobalt content and tungsten-carbide grain size vary.

The CC-5 to CC-8 grades include those that contain various combinations of tungsten carbide, tantalum carbide, titanium carbide and niobium carbide bonded with cobalt. These grades are recommended for machining steels because they provide better crater resistance than the C-1 to C-4 grades.

Hardness of the carbide grades increases and toughness decreases from CC-5 to CC-8.

CC-6 grades are general-purpose carbides having a medium to high shock resistance and medium wear resistance. Such grades are recommended for roughing and semifinishing operations. CC-7 is for finishing. CC-7 grades have medium shock resistance and medium wear resistance. Increased cutting speeds and increased wear resistance are attainable with carbides denoted by higher numbers. Increased feeds and increased carbide toughness are indicated by lower numbers.

ISO code consists of letters and two-digit numbers. The letter C denotes coated carbides, and the following letter P indicates that these carbide grades are suitable for machining carbon steels. CP-10 grades indicate high cutting speeds and small to medium chip cross sections, CP-20 grades are for medium speeds and medium chip cross sections, and CP-30 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 carbides.

Increased cutting speeds and increased wear resistance are attainable with lower-numbered carbides. Increased feeds and increased carbide toughness are designated by higher numbers.

It is important to know that carbide grades listed under the ANSI and ISO codes do not imply that the various manufacturers' grades under specific designations are equivalent.

The cutting speed data shown in these tables are starting recommendations. 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 tool's power availability should always be considered.

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

Among the varieties of coated materials, a PVD TiAlN coating is the most popular for dry high-speed finishing, as well as general machining. A CVD three-layer coating containing an outer layer of TiN, a medium layer of Al_2O_3 and the inner layer of TiCN is commonly used for roughing and semifinishing.

Turning of carbon steel is relatively common, but parts manufacturers need to know the steel grade to boost productivity. Having that information, along with the appropriate cutting tools, lathe or turning center and workholding devices, maximum machining efficiency can be achieved. △

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). The author can be e-mailed at edmund isakov@aol.com.*