High Speed Steel Properties: Different Grades for Different Requirements

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Hobs, broaches, shaper cutters, shaver cutters, milling cutters, and bevel cutters used in the manufacture of gears are commonly made of high speed steel. These specialized gear cutting tools often require properties, such as toughness or manufacturability, that are difficult to achieve with carbide, despite the developments in carbide cutting tools for end mills, milling cutters, and tool inserts.

High performance tools for gear-manufacturing markets have been served primarily by developments in particle metallurgy (P/M) high speed steels. Given the wide assortment of grades of high speed steels available, and the separation between the tool users and the raw material manufacturers, it is not surprising that many gear manufacturers are not intimately familiar with the details of selecting a raw material.

However, some relatively easy general guidelines may be used to guide tool users, whenever operating experience does create some interest in the makeup of a tool.

All high speed steels have the ability to reach a high hardness, often exceeding the mid-60s on the Rockwell C hardness (HRC) scale. This characteristic is the result of the high carbon content, combined with tungsten and/or molybdenum in the appropriate proportions. Most high speed steels feature a characteristic amount of tungsten and molybdenum, where tungsten may be replaced by about one-half as much molybdenum to achieve the same result. In traditional high speed steels, this amount may be approximated by a "tungsten equivalency" (%tungsten + 2x%molybdenum) of about 16%–20%.

As an example, one of the first high speed steels invented, T1, contained 18% tungsten, but no molybdenum. M2 (HS 6-5-2)*, one of the most common high speed steels used today, contains 6% tungsten and 5% molybdenum, or a tungsten equivalent of about 16%.

Subsequent development has produced variations on the tungsten and molybdenum balance. Other major elements added to high speed steels to enhance specific properties include vanadium and cobalt.

Vanadium is added primarily to enhance wear resistance, through the formation of particularly hard carbide particles in the microstructure. Cobalt is added to retard softening of the steel when exposed to elevated temperature—for example, to improve temper resistance or "red hardness" properties. Thus, it is often possible to judge whether a high speed steel is suited more for high cutting speed (temper

** This is a standard European format for designating high speed steels. The numbers signify the nominal tungsten, molybdenum, vanadium, and cobalt percentages, in that order. (M2 contains no cobalt.)*

resistance) or tool wear life (abrasion resistance) by observing the relative vanadium and/or cobalt contents.

In considering which high speed steel may be best suited for an application, consider the cutting conditions the tool will encounter.

For general purpose, low-demand or short-run tools, a simple grade such as M2 may suffice. It offers the basic high hardness and wear resistance common to all high speed steels. Prior to the development of P/M-manufactured high speed steels, M2 was the basic entry-level grade for gear tooling.

For the next step up in tool performance, especially where improved toughness is required to handle interrupted cutting, machining under less than ideal rigidity, or other environments tending to chip or break tools, P/M-manufactured M3 (HS 6-5-3) and M4 (HS 6-5-4) are available. In many cases, M3 has gradually been supplanted by M4 over the years.

Because of the combination of improved wear resistance over M2 (from higher vanadium) and the improved toughness (from the P/M process), M4 has become the common base grade for many general-purpose gear cutting tools. In addition, its improved wear properties over M2 have made it popular for improved broaching performance. Because cutting speeds are not extreme, the tempering resistance of cobalt grades is not usually required, and the longer wear life of the higher vanadium M4 is beneficial.

Where faster cutting speeds or more difficult cooling conditions may place a higher thermal load on the cutting tools, cobalt-bearing high speed steels are called for. Cobalt adds heat resistance, but not significant abrasion resistance. At one time, M35 (HS 6-5-2-5), similar to M2, but with 5% cobalt, was popular.

As the base grade changed from M2 to P/M M3 and ultimately to M4, the cobalt-bearing counterpart also changed to M3 or M4 types with 5%–8% cobalt added (HS 6-5-3-8, HS 6-5-4-5) to help retain hardness during high temperature exposure. They are commonly specified

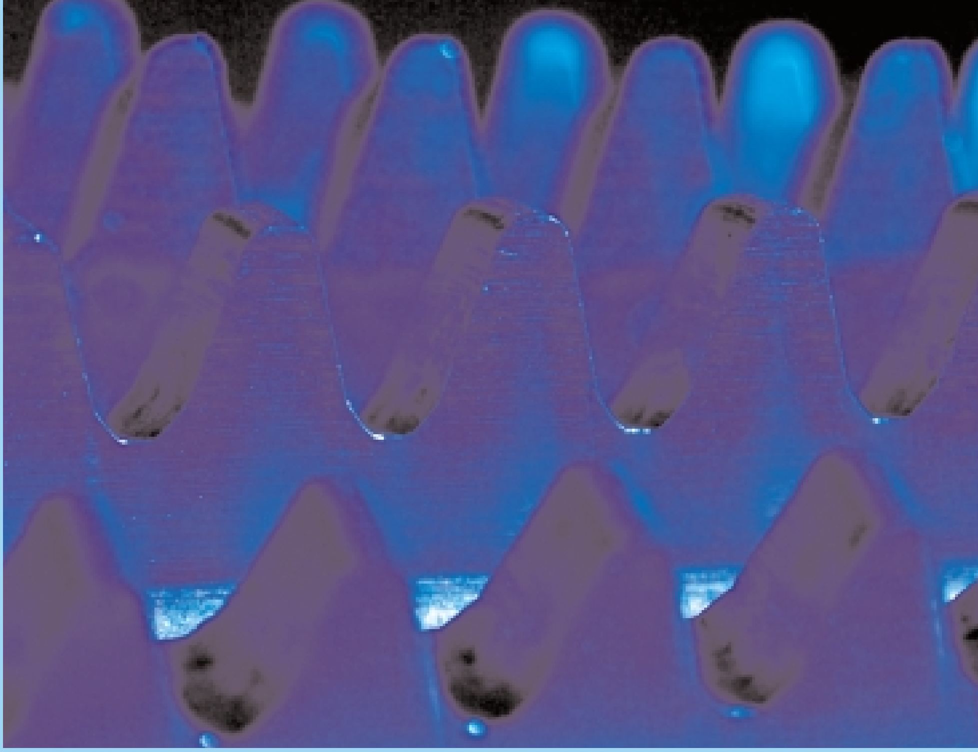

Table 1—Grades, Uses and Properties of Steels for Gear Cutting Tools.

Grade*	Gear Cutting Characteristics	Gear Cutting Tool Properties	Typical Hardness	Wear Resistance	Red Hardness	Toughness
M2 * (HS 6-5-2)	General purpose, low-demand or short-run tools	basic high speed steel				
M4 (HS 6-5-4)	Longer wear life than M2 under similar cutting conditions	improved toughness, improved wear resistance				
M3+Co (HS 6-5-3-8) M4+Co (HS 6-5-4-5)	Higher temperature exposure, faster cutting speeds	improved temper resistance, slightly higher hardness				
T15 (HS 12-1-5-5)	Machining of cast iron, cutting abrasive materials at slower speeds	high abrasion resistance, moderate temper resistance				
M48 (~HS 10-5-3-9) T15 Mod (~HS 10-2-5-8)	High cutting speeds, dry or semi-dry cutting, high productivity & tool life	high hardness, wear resistance & temper resistance				
Advanced grades	Highest cutting speeds, dry & semi-dry cutting	maximum hardness & temper resistance				

*All grades are given using standard industry (AISI or ASTM) designations. All grades, except M2, are manufactured by P/M steelmaking technology; M2 is manufactured by traditional ingot cast steelmaking.

at slightly higher hardness than the non-cobalt-bearing grades. The higher initial heat-treated hardness contributes to higher retained hardness at elevated temperature as well.

Because they feature improved tempering resistance over M3 or M4, but not higher vanadium content, cobalt-bearing high speed steels are best suited for applications involving higher cutting speeds in similar materials. In slower cutting operations, such as broaching, where abrasion is a more common failure mode, they may offer somewhat improved performance over M3 or M4, but may not be as effective as higher vanadium grades.

T15 (HS 12-1-5-5), with 5% vanadium and 5% cobalt, is sometimes used where moderate temper resistance but high abrasion resistance is needed, such as in machining of cast iron, or in broaching of difficult machining materials. The high vanadium content provides improved wear life, and the attainable hardness—higher than M2 or M4—can improve cutting edge integrity.

For highest productivity, or for particularly abrasive cutting conditions, various highly alloyed "super-high speed steel" grades, such as M48 (~HS 10-5-3-9), have been developed. These steels combine very high attainable hardness (usually over 67/68 HRC) with either very high wear resistance, improved tempering resistance, or both. These steels are used for high cutting speeds, dry or semi-dry cutting, or simply to provide the maximum in tool life.

Because of their high hardness and wear resistance, some of these grades are considered to provide a bridge between high speed steels and carbides. In particular, developments in P/M high speed steels in recent years have produced several advanced specialty grades, often capable of hardnesses reaching—or in some cases exceeding—70 HRC, further extending the reach of high speed steels into high performance applications.

Of course, there is also a firm market for solid carbide cutting tools of various types. Despite the advances in alloy composition of high speed steels, the wear resistance of carbide remains superior. In applications where machine rigidity and tool design permit their use, and cost can be rationalized, carbide

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tools can offer certain performance benefits over any high speed steel, such as high hardness at elevated temperature and long term abrasion resistance.

The cost of the raw material and the difficulty of fabricating the cutting tool both tend to increase with the more highly alloyed steels. However, in most cases, improvements in productivity or tool life would pay for the additional tool cost many times over.

Heat treatment, surface finish and coatings can have a major impact on tool performance. In some cases, these factors may be more inportant than the choice of substrate material. The great majority of gear cutting tools are PVD-coated, with coatings such as TiN, TiAlN or other ceramic-type coatings that offer reduced coefficients of friction and enhanced wear resistance.

These factors are integral in the manufacture of any cutting tool. Savvy gear manufacturers will discuss operating conditions, common modes of tool failure, and desired performance results with their tool manufacturers to find the best material for a given operation. ⚙

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