Balancing wear, strength, and toughness

Tips for choosing tool steels, heat treatment, and surface treatments

By Nick Tarkany

Selecting the proper tool steels, heat treatment, and surface treatments for stamping of coated materials can be a complex and confusing process. To simplify this process, you first must understand a few basic facts about the available choices.

Tool Steel Analysis and Characteristics

Tool steels are vastly different from steel used in consumer goods. They are made on a much smaller scale with strict quality procedures and possess qualities necessary to perform a specific task, such as machining or perforating.

Many different qualities in tool steels are sought based on a particular application need. These needs can be met by adding a particular alloy along with the appropriate amount of carbon. The alloy combines with carbon to enhance the steel's wear, strength, or toughness characteristics. These alloys also contribute to the steel's ability to resist thermal and mechanical stress.

The chart in **Figure 1** contains some of the commonly used tool steels and their alloy content. While each alloy element listed in the table contributes to a specific characteristic in the finished steel, it also can create an undesirable side effect, particularly when used in excessive amounts. Additionally, alloy elements can react with each other, which either can enhance or, in some cases, detract from the final result.

Figure 2 compares the three tool steel characteristics necessary for stamping applications: toughness, wear resistance, and compressive strength. While some

steels possess exceptional values for one characteristic, they tend to have low values for one or both of the other two characterists.

High-load stamping applications such as stainless steel; spring steel; and high-strength, low-alloy steel call for tool steels that have a combination of shock resistance and high compressive strength. M2 or PM-M4 tend to work the best in these applications.

Toughness. If toughness were the only factor to consider in choosing a tool steel, S7 would be the obvious choice (see Figure 2). Unfortunately, this is not the case. Tool steel toughness tends to decrease as alloy content increases. This increase in alloy content also demands a higher price.

Toughness also is affected by the manufacturing process of the steel. The particle metallurgy (PM) process can enhance the toughness of a given grade of tool steel over its conventional counterpart. Note the difference in toughness between M4 and PM-M4 in Figure 2.

Wear Resistance. Increased alloy content typically means increased wear resistance, as illustrated in Figure 2. Perforating coated materials places a high demand on abrasive resistance. High-speed steels such as M2 and PM-M4, as well as high-alloy grades such as CPM-10V, can provide the necessary wear resistance. These steels also serve as a good substrate for wear-resistant coatings.

Carbides are hard particles that provide wear resistance. They are suspended in the matrix structure of alloy tool steels. The majority of carbides are formed when alloy additives such as vanadium, molybdenum, and chrome combine with carbon as the molten steel begins to solidify. Greater amounts of carbide improve wear resistance but reduce toughness.

Compressive Strength. Two factors affect compressive strength: alloy content and punch material hardness. Alloy elements such as molybdenum and tungsten contribute a great deal to the compressive strength. Additionally, the higher the hardness of a given grade of steel, the higher that steel's compressive strength.

Steel Type	C	Mn	Si	Cr	W	Mo	V
A2	1.0	0.9	0.3	5.25	0	1.15	0.3
D2	1.5	0.5	0.3	12.0	0	0.9	0.9
M2	0.85	0.3	0.3	4.15	6.4	5.0	1.9
M4	1.4	0.3	0.3	4.0	5.75	4.5	4.0
CPM 10V	2.45	0.5	0.9	5.25	0	1.3	9.75

Figure 1

Alloys are combined with carbon to produce characteristics in common tool steels. This table lists the percentages of alloy content for some commonly used tool steels.

Heat-Treat Considerations

Each grade of tool steel has specific heat-treat guidelines to acquire optimum results for a given application. Stamping operations place a higher demand on toughness than do cutting operations. This means that a given grade of tool steel should be heat-treated differently if it is to be used as a stamping tool versus a cutting tool.

Tool steels are only as good as the heat treat they receive. The keys to achieving optimum results in heat treat include:

1. Segregating by size and material type.
2. Fixturing.
3. Preheating.
4. Soaking (austenitizing).
5. Quenching (martensite transformation).
6. Tempering.
7. Freezing (cryogenics).

Segregation by size is extremely important, because items of different sizes require adjustments in preheat, soak, and quench rates. Fixturing ensures even support and uniform exposure to heating and
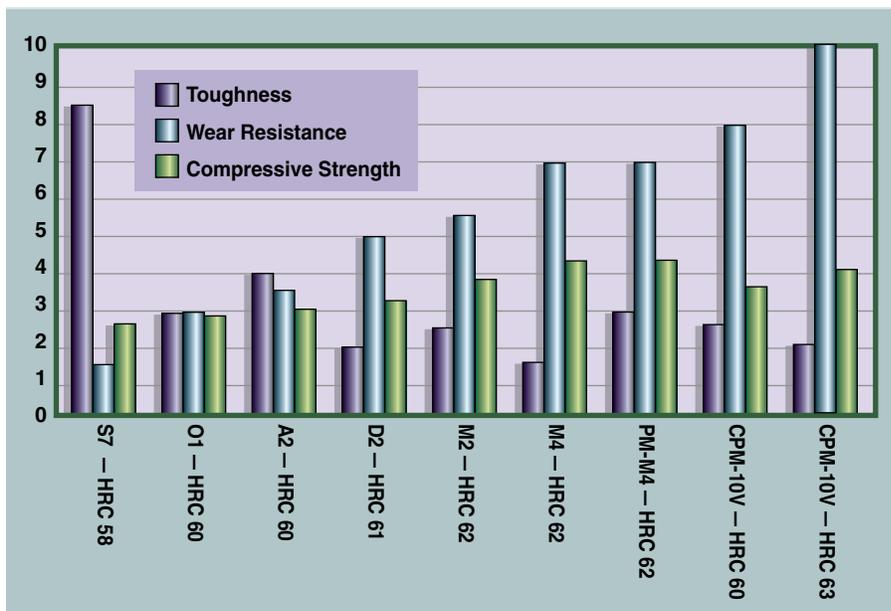

Figure 2

Choosing the proper tool steel for a particular application involves balancing toughness, wear resistance, and compressive strength. This chart compares these properties on a conceptual scale of 1 to 10.

cooling during the heat-treat process.

Cold-work Tool Steel. During preheating of cold-work tool steels (A2, D2, etc.), parts are heated to just below the critical austenitizing temperature of about 800 degrees C (1,450 degrees F) long enough to allow the part to be heated evenly. This is necessary because when the part enters the austenitizing temperature range, the steel is restructured on an atomic level, creating a volume expansion. If this volume expansion does not occur uniformly, the part will distort and possibly crack.

Soaking (austenitizing) is heating the part into the carbide phase region for a specified period of time. The intention is to force some of the alloy elements into the matrix. Soaking cold-work steels such as A2 or D2 at temperatures in the high end of their austenitizing range (overheating) or higher produces excessive levels of retained austenite and generates a coarse grain structure. This results in inferior toughness in the finished product.

Quenching is the sudden cooling of parts from the austenitizing temperature through the martensite transfer range. This transforms the steel from austenite to martensite, hardening the parts. Unfortunately, tool steels have a transformation range that is well below room temperature. This is one reason why cold-work steels benefit from freezing (cryogenics).

Tempering is necessary to remove stress associated with the hardening process. Cold-work tool steels generally are tempered at 200 degrees C (400 degrees F) or less. Because of the low tempering temperature involved, one temper generally is adequate for cold-work tool steels.

High-speed Tool Steel. High-speed and high-alloy steels such as M2, PM-M4, and CPM-10V require a somewhat different approach to heat treating. Although the process initially appears similar to cold working of tool steels, the temperatures and number of tempers differ.

Preheat temperatures begin at about 830 degrees C (1,525 degrees F), and soak temperatures can be higher than 1,100 degrees C (2,000 degrees F).

Because the soak temperature approaches the melting point, control of both time and temperature is critical. Oversoaking a part can result in incipient melting—the alloys with lower melting points begin to melt within the structure, damaging the steel's grain structure.

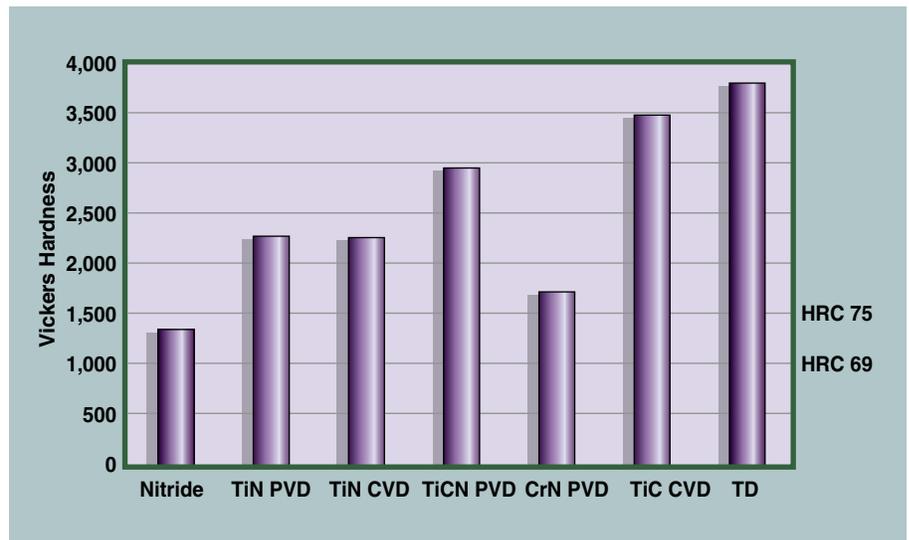High-speed and high-alloy tool steels

Figure 3
Common surface treatments add extra amounts of hardness to a tool steel

have good temper resistance, which allows them to be tempered at higher temperatures. After quenching, the steels contain a majority of untempered martensite and about 30 percent retained austenite. Retained austenite and untempered martensite contain a great deal of stress that must be relieved or the tool will fail.

Tempering at 550 degrees C (1,000 degrees F) or higher tempers the untempered martensite and converts about half of the retained austenite into untempered martensite without reducing the part hardness below HRC 60. Because the higher tempering temperatures are enough to convert retained austenite to martensite, the need for cryogenic treatment is reduced significantly.

Standard heat-treat practice for high-speed tool steels calls for at least two tempers; however, three tempers are needed to bring the amounts of retained austenite and untempered martensite to acceptable levels for stamping operations.

Surface Treatment Considerations

Surface treatments often are used to prolong tool life. These treatments increase surface hardness and wear resistance while reducing the coefficient of friction.

Common Surface Treatments. There are many surface treatments and treatment processes from which to choose.

Nitride is a treatment that case-hardens the surface of the substrate material. This treatment can be applied by numerous processes. Fluidized bed, salt bath, and gas are the most common and economical processes to apply nitride. Ion nitride is a good process, but it tends to be more expensive. Nitride surface treatments work in a broad range of applications. Salt bath nitride is the best from an application point of view but has lost favor because of environmental concerns.

Titanium nitride, titanium carbonitride, and chrome nitride applied using the physical vapor deposition (PVD) work well on precision tooling when it is used in specific applications. Titanium nitride offers better wear resistance than does nitride; however, it will encounter some difficulties when working with copper and stainless steel applications. Titanium carbonitride provides greater wear resistance in a narrower range of applications.

Titanium nitride and titanium carbide, applied using the chemical vapor deposition (CVD) process and thermal diffusion (TD), work best in forming applications that do not require high levels of precision. Because of the high processing temperatures involved, distortion and size changes occur that limit the precision with which these tools perform.

Surface Treatment Process Temperatures. Surface treatments can be applied to a variety of substrate materials (tool steels) with varying results.

Cold-work tool steels such as A2 and D2 have tempering temperatures below PVD and nitride processing temperatures. Exposure to these temperatures will draw down the hardness of cold-work tool

steels to below HRC 58, which leaves the substrate steel vulnerable to deformation beneath the coating, creating adhesion problems for coating. Part growth and distortion also become factors that affect assembly of the tooling and precision of the finished product.

CVD process coatings are applied at the high end of the austenitizing range for cold-work tool steels. Coarse grain structure and size changes should be expected in these circumstances, which will affect precision and toughness adversely.

TD is a unique process that uses the carbon content within the substrate material to form the coating and quenches the tool as part of its coating cycle. It can be applied to D2 steel. However, the substrate hardness typically falls below HRC 58, potentially reducing the strength of the part.

PVD process coatings and nitride work well with high-speed and high-alloy tool steels such as M2, M4, and CPM-10V. The PVD process temperatures fall more than 30 degrees C (50 degrees F) below the tempering temperature of high-speed and high-alloy tool steels, nearly eliminating distortion and growth in the part.

Because of the high processing temperature of CVD coatings and TD, post heat treat commonly is required to achieve acceptable hardness of the substrate material. Distortion and growth are to be expected.

Because it uses carbon that is already present in the substrate material, TD works well for steels with high carbon content, such as M4 and CPM-10V, in low- to moderate-precision applications. TD is not recommended on M2 because of that tool steel's relatively low carbon content.

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Coating Thickness. Coating thickness becomes an issue in high-precision applications.

Nitride is a process of case hardening the existing surface of the part. Although nitride does not build up on the surface, the heat involved may cause slight growth in the part as a result of the matrix accommodating the diffusion of nitrogen.

PVD coatings are relatively thin and cover only areas within the line of sight of the coating source. Precision of the coated area generally is maintained, and the fit at tool assembly typically is not affected by this process.

CVD and TD coatings are thicker and cover an entire part, affecting the precision of the working end and its fit in a retainer. Portions of punches may need to be stripped and reworked to assemble the tooling.

Surface Treatment Hardness. Hardness provides an indication of wear resistance and lubricity for a given coating. PVD process coatings and nitride enhance the life of precision high-speed and high-alloy tool steels but will not cure wear problems caused by tight die clearances or prevent punches from bending under high loads.

Coatings with higher hardness values, such as titanium carbide and TD, tend to be thicker and must be applied with a great deal of heat, which prevents their use in many applications.

Figure 3 lists hardness values for a number of coatings. Because these coatings are extremely thin and nearly undetectable on the HRC scale, their values cannot be measured with a Rockwell hardness tester.

Conclusion

Creating the best tool for a stamping operation involves analyzing tool steels to find one that provides the proper balance of wear, strength, and toughness characteristics for a particular application. Whatever grade of tool steel is selected must be heat-treated properly to capitalize on those qualities and provide optimal results in production.

A variety of surface treatments also are available to increase surface hardness and wear resistance while reducing the coefficient of friction of tool steels, helping to prolong tool life. Understanding the available tool steel options is the first step in achieving quality results.

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