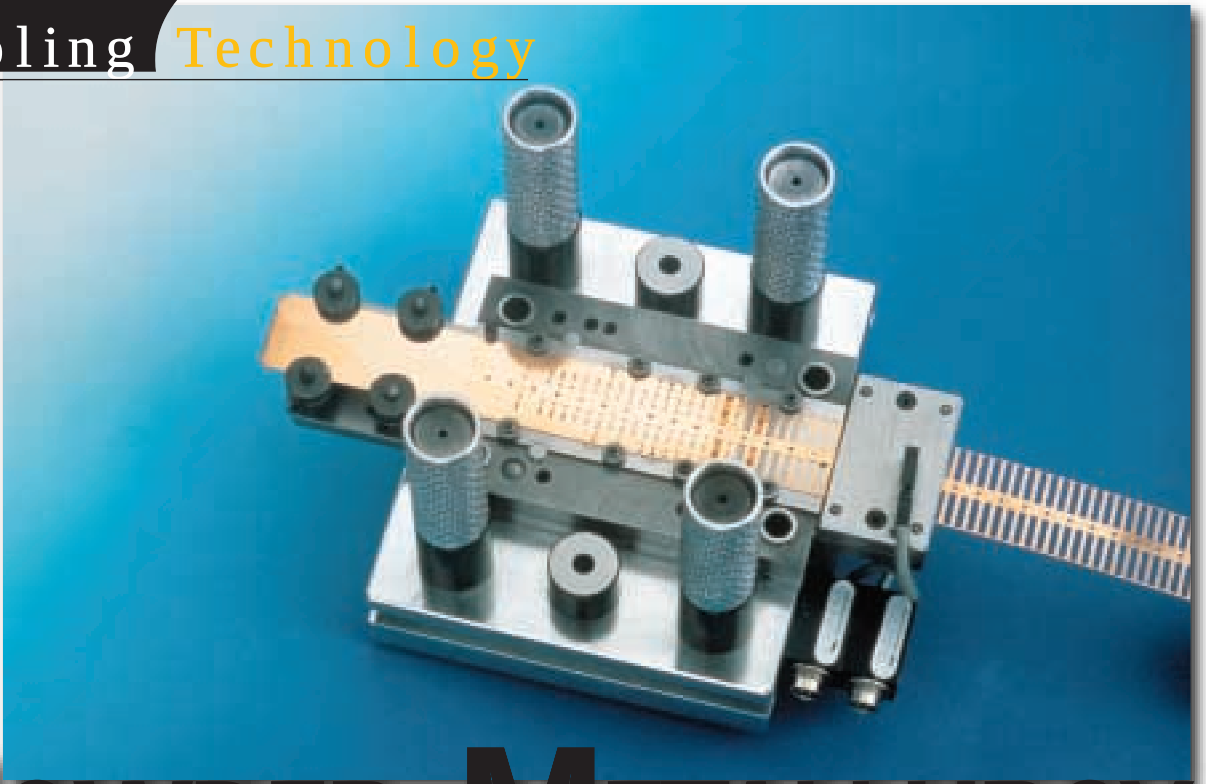

POWDER-METALLURGY TOOL STEELS

AN OVERVIEW

Powder-metallurgy-produced tool steels have been in use for some 30 years, improving tool life in a multitude of applications. This overview explains how and why this processing technique was developed, and its benefits to the tooling industry.

BY THOMAS HILLSKOG

Traditional tool-steel grades have several limitations that can prove difficult to overcome with conventional steelmaking techniques. When trying to improve wear resistance of the steels by increasing alloying content, problems can occur during manufacturing at the mill and when trying to use the alloyed steels in applications where the poor cracking resistance of the alloys limits their effectiveness. These limitations led to the development of the powder-metallurgy (PM) technique for producing high-alloyed tool steels.

Some may be familiar with sintered PM parts, which have a lower strength than corresponding parts made via forging and machining, due to a residual porosity. Therefore it is beneficial to describe the differences between sintered parts and the production methods used to make PM tool steels and high-speed steels (HSS).

Traditionally, to produce PM tool steels and HSS, manufacturers follow these steps:

1) Powder manufacture by nitrogen-gas atomization of a prealloyed melt;

2) Encapsulation of the produced spherical powder in metal containers;

3) Consolidation of the packed powder by hot isostatic pressing (HIP) at 2100 F and at a very high pressure, which compresses the powder into a fully dense billet; and

4) In most cases, the billet then is

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The Making of PM Tool Steels

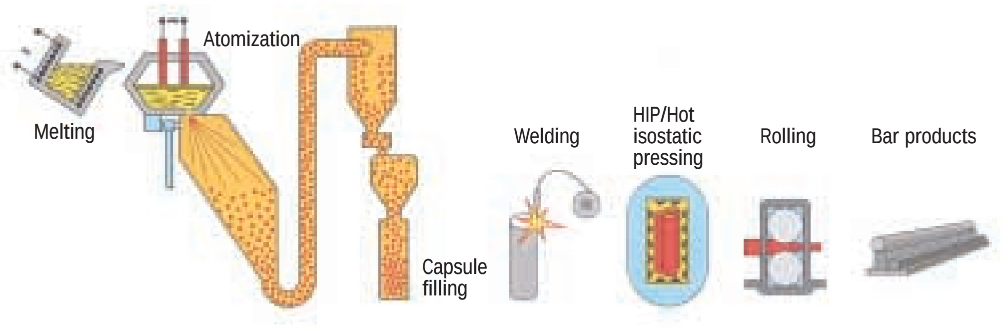


Fig. 1—Hot isostatic processing of packed powder, at 2100 F and at high pressures, compresses the powder into a dense billet, which then is rolled or forged to the desired bar size.

rolled or forged to various bar sizes.

This process (Fig. 1) yields a 100-percent dense steel with a higher mechanical strength than if produced conventionally.

What are the Benefits?

The primary benefits realized by users of PM steels include:

- Improved cracking and fatigue resistance. The PM process creates a refined carbide structure when compared with conventionally produced high-alloy grades such as D2 or D3. The more uniform microstructure leads to a significant improvement in ductility. This improves cracking and fatigue resistance while at the same time maintains or improves wear resistance. The PM process also allows the steelmaker more freedom in choosing the alloy content of the steel so it can increase alloying content and also select carbide-forming elements other than chromium, such as vanadium. By doing so, steelmakers can increase wear resistance while maintaining a similar or even better cracking resistance.
- Better dimensional stability during heattreatment. The more uniform microstructure of PM steels, without the carbide bands in the rolling direction typical with D2 steel, will minimize any dimensional changes during heattreatment. Any dimensional changes that do occur will be more predictable and consistent from bar to bar, and not as sensitive to rolling direction.
- A small and uniform carbide structure that makes PM steels easier to grind, and yields ground surfaces with smoother edges when compared with D2 or D3. Also, because grinding wheels will wear more uniformly when working on PM steels, their redressing depth can be reduced.
- The potential increase in tool life. PM steels will reduce maintenance and downtime costs. They best fit applications where a large number of parts must be produced or where chipping causes major problems. As a rule of thumb, any time more than one tool will be needed to produce the required number of parts, the stamper can justify investment in a PM grade (Fig.2).

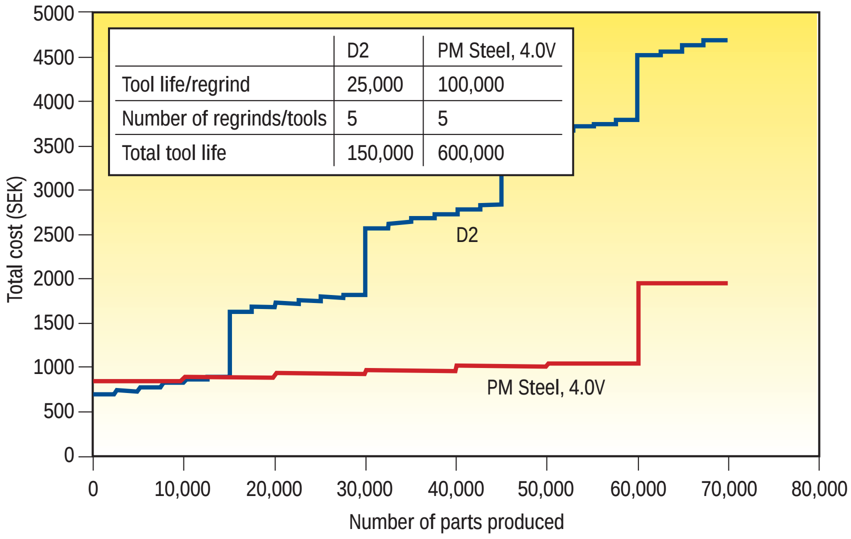
Recent Developments

Although an improvement over conventionally produced tool steels, the first generation of PM steels still showed a noticeable variation in performance, mainly due to rather high nonmetallic inclusion content. This occurred because, with the carbides, the nonmetallic inclusions become the largest defects that limit tool life. The inclusion content causes a more pronounced effect in low-alloyed PM steels, specifically aimed at providing high cracking resistance because they contain fewer carbides. Contrary to popular belief, low-alloy PM steels can be quite anisotropic, their properties different depending on their grain orientation during testing.

Their cracking resistance would depend on the amount of inclusions in a particular bar.

High inclusion content also can cause occasional problems, such as wire skipping or breakage during wire-EDM processing.

Tool Cost as a Function of Number of Parts Produced



	D2	PM Steel, 4.0V
Tool life/regrind	25,000	100,000
Number of regrinds/tools	5	5
Total tool life	150,000	600,000

Fig. 2—The small increases in tool costs shown in the graphs represent regrinding costs; the larger increases represent the cost of a new tool.

Process Perfected: Inclusion Content Minimized, Tool Life Increased

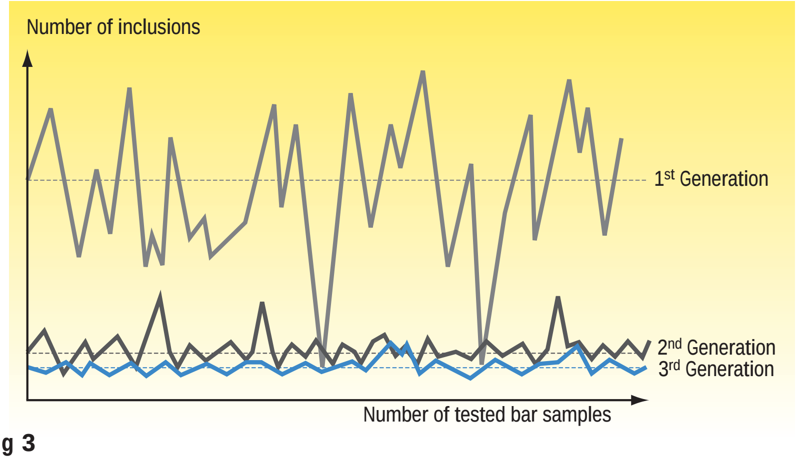


Fig 3

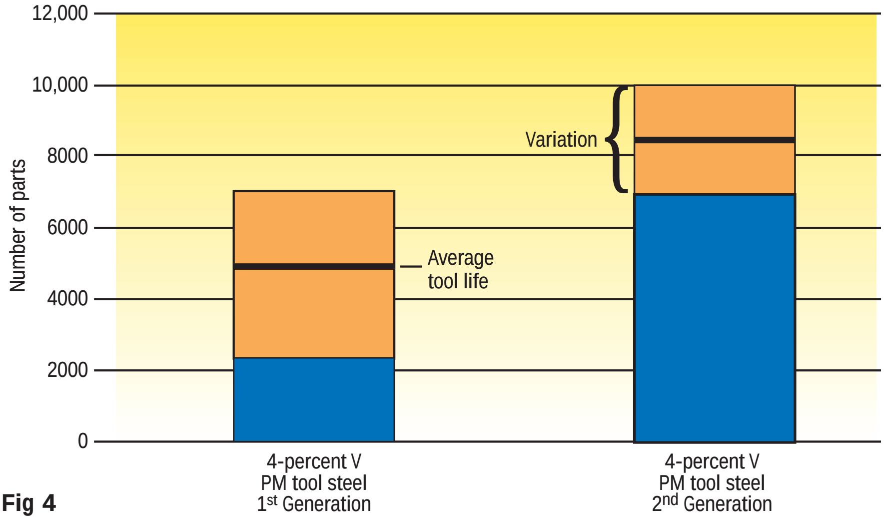


Fig 4

Second- and third-generation PM tool steels contain significantly fewer inclusions than earlier alloys (top graph). Increased cleanliness yields improved cracking and chipping resistance and increased tool life. The example above shows how improved PM grades increase tool life when blanking stainless-steel strip.

For these reasons, manufacturers of PM tool steels have focused on reducing nonmetallic inclusion content in the alloys. A series of process developments led to the introduction of a second generation of PM steels. Today's second- and third-generation PM steels contain less than 10 percent of the inclusions found in earlier PM alloys, with improved consistency from heat to heat (Fig. 3).

The increased cleanliness of the PM steels has yielded significant improvements in cracking and chipping resistance, especially in the transverse direction. For example, as shown in Fig. 4, the effect on four-percent-vanadium PM tool steel in a blanking operation of 18Cr - 9Ni stainless steel, the improved cleanliness of the tool steel significantly increased average tool life and reduced variation in punch life.

New Grades Meet Specific Needs

Another area of development has been the introduction of new PM grades to cover more specialized tooling needs. In the early years the grades were based mostly on standard alloys. Steelmakers produced grades of PM steels to improve properties, such as HSS grades M3:2, M4 and T15. On the cold-work side, manufacturers used standard compositions as starting points and then added up to 10-percent vanadium with a balanced amount of carbon to increase carbide volume and hardness. This greatly improved wear resistance while maintaining good cracking resistance compared with conventional grades.

Those early PM grades covered most tooling requirements for many years, but as application requirements evolved, industry needed PM grades with more specific property profiles. Over the last decade this has led to the development of new grades, mainly in two directions. First, manufacturers offer low-alloyed grades containing one- to five-percent vanadium, with optimized compositions that further improve ductility. These grades offer significantly higher cracking and fatigue resistance, in some cases approaching or even surpassing mold-quality S7, while offering better wear resistance.

The second development: wear-resistant grades trying to span the gap between steels and cemented carbides. These grades have vanadium content to 18 percent, giving them extremely high wear resistance while maintaining a cracking resistance better than conventionally produced D2 and D3 steels. And, tool-steel providers have developed new super-HSS alloy for the cutting-tool market that can achieve hardness of 70 HRC or slightly above.

Steel Selection

The higher the carbon and vanadium content in a PM grade, the higher the alloy's wear resistance and the lower its resistance to cracking and chipping. Selecting the appropriate PM grade, the following discussion assumes that other factors that can cause failures have been looked at and corrected. This would include obvious design features that can initiate cracks, and surface-finish issues with special considerations for remaining EDM layers and heattreatment.

• A stamper using conventional cold-work grades such as D2 or D3 without experiencing cracking or chipping problems can benefit from using almost any

Case Study

To summarize the benefits of changing from traditional grades to PM tool steels, the following case serves as a good example.

Tool type: Blanking tool
Hardness: Punch and die both 57-58 HRC
Work material strength: 78 ksi
Thickness: 0.39 in.
Surface condition: Hot rolled
Die clearance: 5 percent
Details for toolmaking:
  Machinability: The PM grade is a little worse than A2. Grindability: Same as for D2.

Results:
Steel grade: A2
Tool life/regrind: 15,000 parts
Steel grade: 4.0V PM grade
Tool life/regrind: 58,000 parts
The tool life/regrind is almost four times better with the PM grade.
D2 cannot be used for this application because the tool chips almost immediately after entering service.

PM grade with a vanadium content above five or six percent, to improve tool life. In these applications, PM grades will offer at least the same cracking resistance while improving wear resistance with correspondingly increasing alloy content. The right choice of PM alloys then depends on factors such as how many parts have to be produced, steel price, ease of machining and heat-treatment. Because machinability decreases with increasing alloying content, the metalformer must balance the choice of grade against the cost of machining and total number of parts produced. This way, the stamper can minimize overall tooling costs, including the steel price, by not selecting a grade with higher alloying content and price than necessary.

• When a stamper experiences chipping or cracking with grades such as D2 or A2, the job of selecting the appropriate PM tool steels becomes more difficult. Factors in play include hardness and thickness of the workpiece material, tool-design complexity, and the severity of the chipping and cracking. Here, the experience of similar-type tools can be of great help when determining which grade and hardness level to select. Typically, stampers find that selecting a lower-alloyed PM grade, with vanadium content of one to six percent, works best. Here's where the second- and third-generation PM steels, with their improved cracking resistance, can offer the advantage of allowing the customer to use a somewhat higher-alloyed grade. This will improve tool life by not sacrificing more wear resistance than necessary.

This case illustrates the low cracking resistance of traditional high wear-resistant grades and how it can force the tool user toward grades with very low wear resistance. A PM grade can solve both problems. **MF**