Ignorance is not always bliss

What you don't know about P/M tool steel production that can affect productivity

By Brett Krause

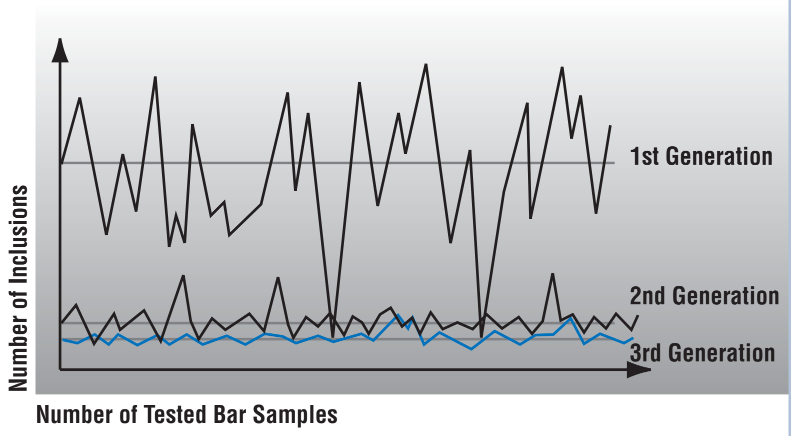

Figure 1

This graph shows how the number of nonmetallic inclusions varies during processing for each generation of P/M tool steel.

If you want to improve die life, you need to strengthen the weakest link. In many dies, the weakest link often is the ductility of the tool steel used. Wear resistance also is important, but the critical property for stamping stainless steels and high-strength steels is resistance to chipping, which is related to the tool steel's impact energy.

The current powder metallurgy (P/M) process for manufacturing has been around since the 1900s. The P/M process was developed for production processing of high-melting-temperature alloys. It was an alternative to conventional steel castings or weldments and offered tight dimensional tolerances (near net shape). However, it produced parts that were not 100 percent dense because of sintering, a process that fuses the particles together by diffusion at elevated temperatures.

During the 1970s P/M processes were developed for manufacturing tool steels. Tool steel producers were looking for a better way to produce highly alloyed tool steels, much the same way P/M was used for production parts.

A major difference for tool steels is that the process produces 100 percent dense material through hot isostatic pressing (HIP). HIP is a process that heats the powder in a welded capsule to forging temperatures and then applies pressure to produce an ingot (billet) that is 100 percent dense. After the ingot is formed by HIP, it is processed the same way as conventional tool steels. With their larger volumes of smaller carbides (size 2 to 4 µm/ 0.0001 inch to 0.0002 in.), P/M tool steels have increased wear resistance, toughness and ductility, and fatigue life.

Since the 1970s P/M has developed even further to meet the needs of today's manufacturers.

Generations of P/M Tool Steel Production

The basic principle of P/M is melting metal and turning the molten metal into powder through the atomization process. The molten metal passes through a high-pressure stream of inert gas, which separates the metal into small particles. The particles fall through a cooling tower, making the small particles solidify.

The resulting powder is collected and transferred into a capsule, which then is sealed by welding. The capsule then is heated to forging temperatures, and HIP is performed. The ingot then can be rolled or forged (hot-worked).

Even though the basic principle of atomization for P/M tool steels has remained unchanged, the process has gone through numerous enhancements over the years to keep up with demands placed on the products during application.

The first-generation P/M tool steel

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production process employed a ladle and tundish, both of which were subjected to open air. Since the tundish was small, it had to be refilled constantly during atomization. When the tundish was refilled, the molten metal penetrated the slag layer, which is a layer of organic material that protects the molten steel from the atmosphere and acts as insulation.

The disruption of the slag layer and the open tundish process caused a large number of nonmetallic inclusions to be introduced into the molten metal, leading to a wide distribution in the size of nonmetallic inclusions. This distribution gave the materials inconsistent mechanical properties.

In the second-generation P/M tool steel production process, the tundish size was increased to require less refilling. The tundish was electroslag-heated; inert gas was used to keep the alloying elements evenly distributed throughout the atomization process, giving a homogenous microstructure.

Even though major strides were made in increasing the cleanness in the second generation, the inert gas passing through the slag layer still introduced slag (nonmetallic inclusions) into the molten metal, so researchers developed the third-generation P/M tool steel production process.

In the third generation, electromagnetic stirring keeps the alloys evenly distributed without disturbing the slag layer, thereby reducing the number of nonmetallic inclusions in the atomized powder. **Figure 1** shows the reduction of nonmetallic inclusions and variation over the three generations of development.

Effects of Nonmetallic Inclusions

During the rolling or forging (hot working) of P/M tool steel ingots, the nonmetallic inclusions align in the hot-working direction similarly to the way that carbides align in conventional tool steel during the hot-working process.

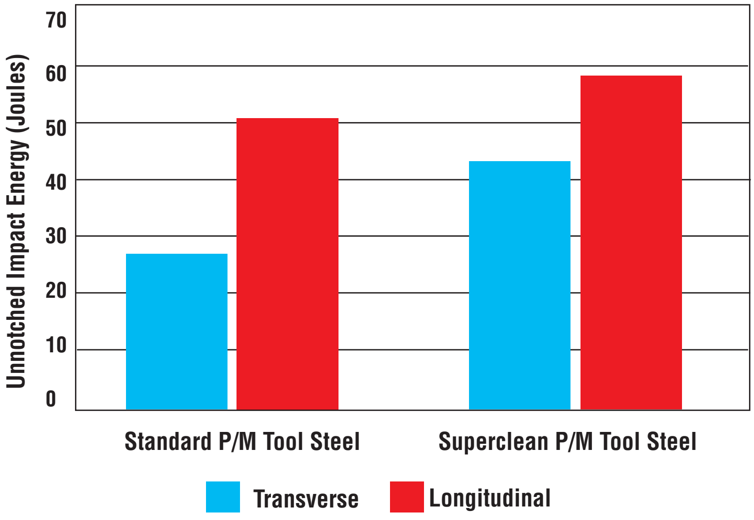

Figure 2

Unnotched impact energy improved when nonmetallic inclusion content was reduced in the atomized P/M tool steel. This can help increase chipping resistance.

These inclusions can have an adverse effect on tool steel performance in P/M tool steels. In conventional tool steels such as D2, the carbide size can be 35 to 50 µm (0.0014 in. to 0.002 in.), with nonmetallic inclusions in the same size range. Since the carbides and nonmetallic inclusions are about the same size, neither one acts more like a defect than the other, so, in essence, cleanness in conventional tool steel is not as important as in P/M tool steel.

In P/M tool steels the carbide size is usually 2 to 4 µm, while the nonmetallic inclusion size can be 5 to 15 µm (0.0002 in. to 0.0006 in.). This difference in size means that the inclusion acts as the primary defect in the microstructure of the P/M tool steel. Therefore, the cleanness of the P/M tool steel becomes a critical factor in tool performance.

Figure 2 shows how reducing nonmetallic inclusions in the P/M powder increases the P/M's impact energy.

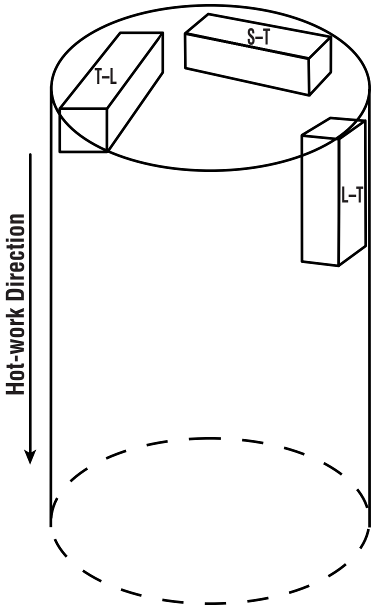

Figure 3

Different orientations of impact samples can be tested with regard to the hot-working direction.

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Orientations for Impact Testing

For performing impact testing, many different testing orientations are available in both the longitudinal and transverse directions (see **Figure 3**). The longitudinal direction is parallel to the length of a bar or round; the transverse direction is parallel to the width or radius. Depending on the orientation chosen, significantly different values of unnotched impact energy can be reported.

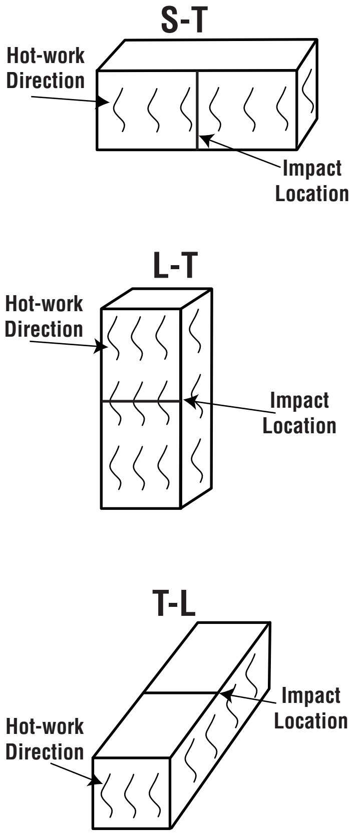

Figure 4

Schematics for each of the impact specimens for both hot-working direction and impact location for the L-T, T-L, and S-T orientations give a general idea of how impact location and hot-working direction relate. The relationship then can be correlated with best and worst impact energy values.

Also, the hot-worked cross section of the material is important. The larger the cross section, the lower the unnotched impact energy will be compared to a smaller cross section. In smaller cross sections, more hot working (reduction of area) has been performed on the ingot, making a more homogenous microstructure and better mechanical properties. In larger cross sections, less hot working has been performed on the ingot, resulting in a less homogenous microstructure and weaker mechanical properties.

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The different orientations for unnotched impact energy are as follows, in order of best case to worst case (see Figure 3):

- **L-T** – The length of the specimen is in the direction of hot-working (longitudinal), and the impact is performed perpendicular to the hot-working direction (transverse) (see **Figure 4**). This orientation results in the best test results or mechanical properties.
- **T-L** – The length of the specimen is perpendicular to the hot-working direction (transverse), and the impact is performed in the direction of hot working (longitudinal) (see Figure 4). If the P/M tool steel has an increased number of nonmetallic inclusions, this orientation will have decreased impact toughness, therefore increasing the likelihood of chipping and cracking.
- **S-T** - The length of the specimen runs the thickness of the cross section, and the impact is performed transverse to the hot-working direction (see Figure 4). This impact test has the lowest unnotched impact energy. If the material has a lot of nonmetallic inclusions, they act like stress risers that easily open up during impact testing, giving the lowest unnotched impact energy of the test results.

Strengthening the Weak Link

For a die to perform well when stamping stainless and high-strength steels, it must have a high resistance to chipping. Increased ductility is one way to reduce chipping in P/M tool steels, and this is achieved by reducing nonmetallic inclusions during the tool steel's manufacture. Tool steels manufactured with enhanced mechanical properties can help improve a traditionally weak link in the production chain.

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