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Hardmetal STEEL

Powder metallurgy can allow harder, tougher HSS tools to replace solid-carbide cutters in high-shock and high-stock-removal applications.

Since the 1970s, carbide has eroded the market share for cutting tools made from high-speed steel. However, HSS tools made via powder metallurgy (P/M) are harder, tougher and more wear resistant than conventional HSS. This has allowed HSS to hold its own against—and even take back some market share from—hard, but brittle, tungsten carbide in certain applications.

Developed in Söderfors, Sweden, in the late 1960s and introduced to the market in the early 1970s, the P/M steelmaking process allows for increased alloy content without any detrimental loss in toughness or grindability. The result is a hard, wear-resistant tool that can absorb the shocks associated with high metal-removal rates and intermittent cutting—shocks that would shatter a solid-carbide tool.

P/M steel is also known as powder-metal and particle-metal steel and is sold under many trade names.

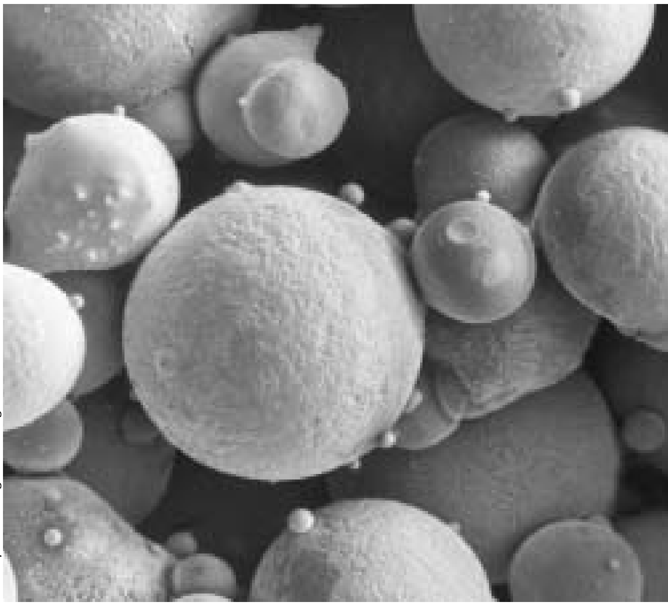
Making HSS, P/M Steel

Before you can understand P/M steel, you must comprehend conventional HSS. HSS is composed of two primary components: carbides and the surrounding steel matrix. Carbides—carbon combined with tungsten, molybdenum or vanadium—give the cutting tool its wear resistance. The surrounding steel matrix gives the tool its toughness, or ability to absorb shock without fracturing.

When producing conventional HSS, molten steel is poured from a ladle into ingot molds, where it slowly cools and solidifies. During this time, carbides precipitate out of solution and form large carbide clusters. The greater the alloy content of the steel, the larger the carbide clusters (Figure 1). At a certain point, large, and even monster-sized carbides can form (upwards of 40mm in diameter). The threshold varies by ingot size and other factors, but is typically at about 4 percent vanadium-carbide. Subsequent forging and rolling of the ingot breaks up these clusters somewhat, but not completely.

It's unfortunate that as the number of carbide particles is increased, to improve wear resistance, they increase in size and cluster together. This has a catastrophic effect on toughness, because the large, clustered carbides act as initiation points for fractures.

P/M steel begins the same way as conventional HSS: with a molten bath of steel. But, instead of being poured into an ingot mold, the molten steel is blasted through a small nozzle into a



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P/M steel is produced by compressing steel powder (less than 1mm in diameter) in a vacuum under high pressures and temperatures. Shown is a micrograph of P/M steel particles.

stream of nitrogen. The steel rapidly solidifies, or "atomizes," into small particles. The carbides don't have time to precipitate out of solution and form clusters, resulting in much smaller, uniformly distributed carbides.

The resultant powder is then poured through a screen and placed in a steel container. The air between the powder globules is sucked out, creating a vacuum. The container's contents are then compacted at high temperature and pressure to achieve 100 percent density. This process is called hot isostatic pressing, or HIPing (Figure 2). The steel is then forged and rolled.

The final product is a HSS with very small carbide particles that are homogeneously dispersed throughout the steel matrix, regardless of the alloy content.

Although the details may differ slightly, producers all use the same basic process to make their steel: nitrogen atomization and HIPing. Most importantly, P/M steel processing should never be confused with the pressing and sintering of parts using steel powder heated to its melting temperature. Although both processes are often referred to by the same names, they are completely different. Sintering is typically done on a part-by-part basis in a die, and often the raw material contains a binder, which results in a porous structure.

Using the P/M process, steel producers can substantially increase the number of carbides in the steel without a detrimental effect on toughness or grindability. P/M steel enthusiasts like to tout it as a hybrid between conventional HSS and solid carbide. In reality, it's simply HSS with much smaller carbides and a somewhat smaller steel-matrix grain structure (Figure 3). But it does combine the best of both worlds: The excellent toughness of HSS and the high wear resistance of cemented tungsten carbide.

Pros and Cons of P/M Steel

Smaller, more uniformly distributed carbides mean that, for any given carbide content, P/M steel is much tougher than conventional HSS. This is advantageous in high-shock and high-mrr applications, such as hogging or interrupted cutting. In addition, because P/M HSS can hold far more carbides by volume and remain tough, steel producers can pack a lot more carbides into the steel.

For example, tapping, with its constant engaging and disengaging of the cutting edge, requires a tough grade of fracture-resistant steel. The tap also needs carbides for wear resistance. A common conventional-to-P/M switch is from M-2 to powder M-4. They both contain approximately the same num-

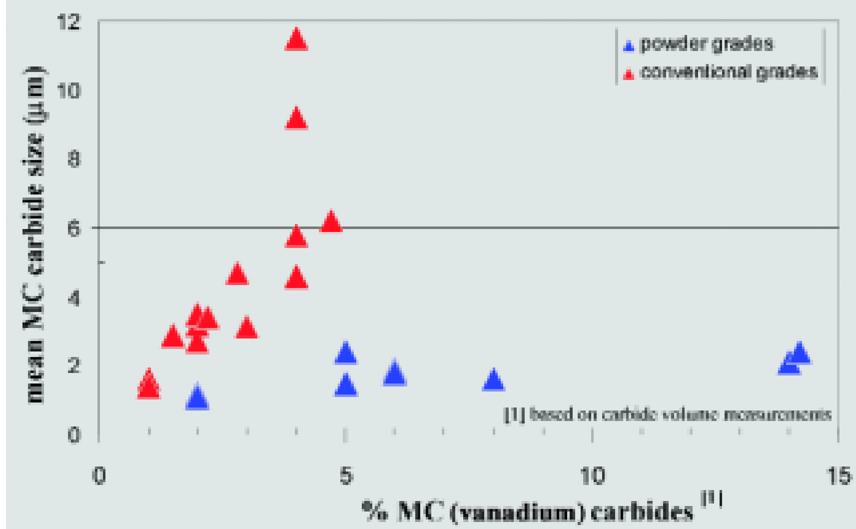

Figure 1: In P/M steel, carbide size is virtually independent of the amount of carbide in the steel. In conventional HSS, however, the carbide size increases drastically when the carbide content increases.

The grindability of P/M steel

The dominant factor affecting steel's grindability—the ease of grinding a given metal—is the percentage of vanadium carbides in the steel. Because vanadium carbides are harder than the aluminum-oxide grits in the grinding wheel, they cause the wheel to dull quickly, resulting in excessive heat generation and wheel wear. Therefore, longer grinding times are needed for vanadium-rich, conventional high-speed steels.

Because the carbides are smaller and evenly dispersed in P/M steel, they tend not to damage the wheel as much. Therefore, for a given alloy content, P/M HSS will be much easier to grind than conventional HSS.

A powder grade is more expensive than an equivalent conventional grade, but it makes a far better tool.

All is not lost, though. Because P/M steel is easier to grind, this extra cost can be recouped—either in part or in whole—by taking advantage of its enhanced grindability. This is accomplished through reduced wheel wear, less scrap and, most importantly, shorter cycle times.

How much you can recoup depends on the relative fraction of grinding-to-material costs. Smaller tools that require numerous precision grinding operations usually have a higher grinding-to-material-cost ratio. In these cases, it is easier to recoup all additional material costs—or even save money. Larger tools that require fewer grinding operations usually have a smaller ratio of grinding-to-material costs. In such cases, only part of the additional cost can be recouped. The economics will depend on the specifics of your process. But a general guideline is that a grindabilty factor of three can drop your cycle time by about 30 percent.

In the end, a powder grade will give you a better tool, and, if the extra cost of switching to powder can be recovered, a better tool for the same price.

—J. Badger

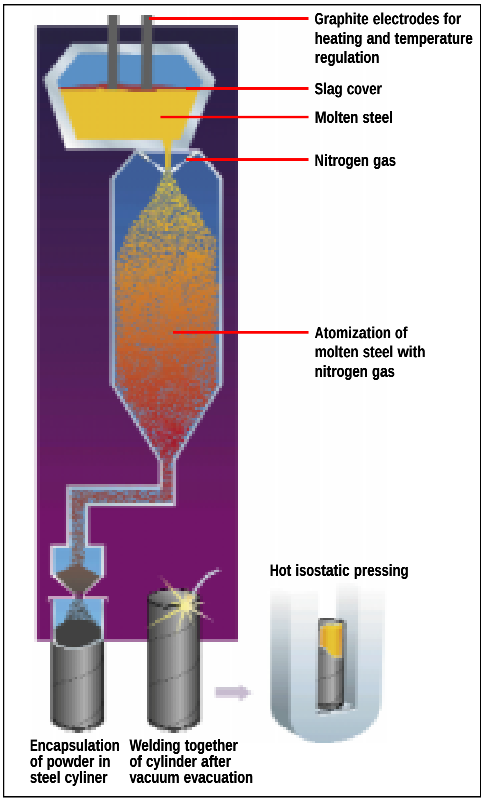

Figure 2: Outlined here, the equipment and steps involved in hot isostatic pressing (HIPing).

ber of medium-hard carbides: 8 percent for P/M M-4 and 7 percent for M-2. However, the P/M steel has significantly more hard carbides, which give the tool its wear resistance: 6 percent for P/M M-4 vs. only 2 percent for M-2. In spite of this, it's a lot tougher than M-2. The result is a tool that, in addition to having enhanced wear resistance, can "take the hits" when tapping, without fracturing.

There is a disadvantage to P/M steel: The metal is more expensive than conventional HSS—two to five times more, depending on the grade. Tool producers must weigh the superior performance of P/M steel against the extra cost.

For smaller, more intricate tools, the material represents a small fraction of the total cost. In these cases, it's easier to justify the cost increases. For larger, simpler tools, it's a harder sell. However, P/M steel's improved grindability (see sidebar, previous page) often allows some, or all, of the material's extra cost to be recouped.

P/M vs. WC

P/M steel's competitor is solid carbide, which has been steadily whittling away at the HSS market. Solid-carbide tools may be super hard, but they're also super brittle. Thus, carbide is used more for turning than high-shock and roughing applications.

Because P/M steel can pack in so many hard carbides, its wear resistance can approach that of solid carbide. However, its toughness allows the material to outperform solid carbide in applications that require tough, wear-resistant tools, such as tapping and endmilling.

The latest push in P/M steel has been the development of new processes to make it cleaner. One significant milestone was electro-slag heating (ESH), a refinement process that removes almost all the impurities in the steel, resulting in higher toughness and improved resistance to chipping.

In addition, because of the reduction in impurities, P/M steel producers can now produce grades that have extremely large alloy contents. One grade, for example, contains 14 percent vanadium carbides, compared to a maximum of about 4 percent for the most highly alloyed conventional grade. Despite its composition, the material is still tough and reasonably easy to grind**.**

Beware: Many low-cost P/M producers haven't implemented purity improvements. Their steel may contain large inclusions, which can cause microchipping. There's no way to know from their data sheets. Ask them what measures they've taken to remove inclusions—or better yet, request specifics on inclusion size.

The P/M process has changed the nature of HSS. The basic technology, coupled with recent developments in improving purity, enables it to achieve a very high alloy content while maintaining toughness. Consequently, it outperforms conventional HSS in almost all applications and outperforms solid carbide in high-mrr and high-shock applications. Its higher cost, compared with HSS, is offset by superior performance, extended life and enhanced grindability.

About the Author

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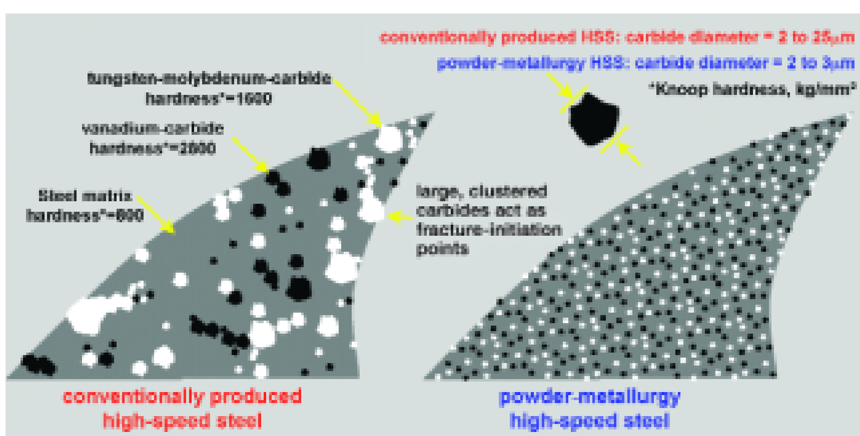

Figure 3: HSS (left) is composed of large, abrasion-resistant carbide clusters surrounded by a tough steel matrix. In contrast, the P/M process results in a material (right) with smaller, homogeneously distributed carbides.