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Crucible Materials Corp.

Fast Times in HSS

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New alloys improve the performance of HSS cutting tools.

Although the overall market share of high-speed steel tools is declining vis-à-vis solid-carbide ones, HSS remains a cost-effective alternative for applications where tool toughness is paramount.

The continued viability of HSS is largely attributable to the single greatest advancement in the technology of HSS: the advent of powder, or particle, metallurgy (P/M). Introduced by the specialty steel industry in 1970, this method for processing HSS significantly boosts the material's properties and enables it to retain its inherent wear-resistance, as well as approach the hardness levels of carbides.

Basically, the process entails induction melting of a pre-alloyed tool steel. While still in a liquid state, the metal is processed through a gas atomizer, like perfume sprayed from a bottle. Unlike perfume, though, the metal quickly solidifies into uniform particles, which, after encapsulation in a large, compressible cylinder, undergo what's known as hot isostatic pressing (HIP). Afterwards, the steel is forged or hot-rolled.

The distinctive feature of this method of metallurgy is the uniformity with which the alloying elements are distributed throughout the steel. The process eliminates one of the endemic problems with ingot-style forging of HSS: segregation of the alloy elements in the steel, creating a nonhomogenous product that can impede the material's performance.

In addition, the P/M process can significantly boost the percentage of alloying elements a steelmaker can add to the product, which would otherwise be impossible with traditional ingot-style metallurgy.

According to Bud Carnes, manager of technical services for Carpenter Powder Products, Wyomissing, Pa., it would be impossible to produce his company's more heavily alloyed HSS without the P/M process. He cited Carpenter's Mico-Melt Maxamet alloy as an example. It contains 13.0 percent tungsten, 10.0 percent cobalt, 6.0 percent vanadium, 4.75 percent chromium and 2.15 percent carbon.

"If we were to put that much alloy content into a cast ingot, and if it withstood the process of cooling and solidification without cracking, it would later face a problem because of its nonhomogenous structure," he said. The steel would segregate into very large carbide particles.

Jerry Wright, vice president of technology for Crucible Materials Corp., Syracuse, N.Y., concurred with the limits on alloying steel via the standard ingot process. "P/M HSS rapidly solidifies during atomization and has extremely fine carbides. These carbides will be a maximum of about 3µm and average around 1µm in diameter," he said. With the ingot approach, carbides would measure up to 40µm in diameter.

The typical alloying elements in HSS are carbon, chromium, molybdenum, tungsten, vanadium and cobalt. Tungsten, molybdenum and cobalt improve the "red hardness" of the material—its ability to withstand the friction-gener-

Heat Treat Response (HRC), Oil or Salt Quench*						
Tempering temp. °F	°C	1,875° F 1,025° C (HRC)	2,050° F 1,120° C (HRC)	2,150° F 1,175° C (HRC)	2,200° F 1,205° C (HRC)	2,240° F 1,225° C (HRC)
As quenched		71.0	69.0	67.0	65.0	63.0
1,000	540	68.5	70.0	70.5	70.5	70.5
Optimum for maximum toughness and effective stress relieving						
1,025	550	67.5	69.5	70.5	70.5	70.0
1,050	565	66.5	68.5	70.0	69.0	69.5
1,100	595	63.0	66.0	67.5	68.0	68.5
1,200	650	55.0	56.0	58.0	59.0	60.0
Min. time at aust. temp. (mins.)		**30**	**20**	**15**	**10**	**5**
Min. number of tempers		**2**	**3**	**3**	**4**	**4**

*Results may vary with hardening method and section size. Salt or oil quenching will give maximum response. Vacuum or atmosphere cooling may result in approximately 1 point lower HRC.

Table 1: Hardening results for Rex 121

Oil quenched from austenizing temperature.
Vacuum hardening may result in slightly lower hardness values.

Tempering temperature	Hardening temperature 2,225° F (1,218° C) (HRC)	Hardening temperature 2,250° F (1,232° C) (HRC)
As quenched	59.0	56.5
1,000° F (538°C)	70.0	70.0
1,025° F (552°C)	69.0	69.5
1,050° F (566°C)	68.5	68.5
Tempering practice	2+2+2	2+2+2

Each temper should be 2 hours at temperature, with parts cooled to room temperature between tempers.

Table 2: Hardening results for Micro-Melt Maxamet

ated heat found at the tool/workpiece interface, according to the *ASM Materials Handbook*. Vanadium forms the hardest carbides, offering increased high-temperature wear-resistance. It is generally acknowledged that the higher the content of vanadium in P/M HSS, the better the wear-resistance.

Tweaking Steel

The specific advancements being made in P/M HSS center on tweaking the alloys that go into the tool steel, according to Mark Mullen, vice president and general manager of Griggs Steel Co., Oak Park, Mich. "As the manufacturing process continues to improve, steelmakers are able to produce higher and higher alloyed material. And with these different alloy components, they're able to get different characteristics, depending on the application," he said.

Carpenter's new high-alloy Micro-Melt Maxamet alloy has a hot hardness of 63.0 HRC at a test temperature of 1,000° F (538° C) after being austenitized at 2,250° F (1,232° C) and tempered at 1,025° F (552° C). By contrast, the company's T-15 HSS alloy measured 58.0 HRC under similar conditions.

To demonstrate the Maxamet's improved wear-resistance, the company ran a comparison of the Maxamet to M-4 HSS using a standard dry sand and rubber wheel test, whereby a flow of loose sand was introduced between the sample and a rotating rubber wheel for a specified period of time. In the test, the Maxamet alloy lost only 9mm^3 of volume compared to the 12mm^3 loss experienced by the M-4.

For its part, Crucible recently introduced the Rex 121 high-alloy HSS. The alloy content of the steel is 10.0 percent tungsten, 9.5 percent vanadium, 9.0 percent cobalt, 5.0 percent molybdenum, 4.0 percent chromium and 3.4 percent carbon. In terms of wear-resistance, the company reports Rex 121 is 50 to 100 percent more resistant than its comparable P/M HSS grades, such as Rex T15, Rex 76 and 10-V.

In addition, Crucible said the hot hardness of Rex 121 is higher than that of Rex 76, and it retains a room-temperature hardness of 60.0 HRC even after tempering at 1,200° F (650° C). Cutting speeds have reportedly increased 25 to 50 percent when Rex 121 replaced conventional, cobalt-bearing HSS tools.

Optimizing Toughness and Hardness

Of the P/M HSS compositions that optimize the inherent toughness of the material, or high-speed steel's ability to withstand stresses and wear far beyond the tolerances of carbide, alloys with the least amount of carbon seem to work best. Compared to carbides, HSS is a material that possesses a much greater degree of flexibility in terms of overall bend strength. According to data from the International High Speed Steel Research Forum, the bend, or universal tensile, strength of P/M HSS is rated from approximately 2,500 to almost 6,000 MPa. Carbide tools, on the other hand, have a bend strength which is much lower, between approximately 1,250 and 2,250 MPa.

As Henry Wisell, director of research and development for Erasteel, Paris, puts it, "The toughest steel is a HSS with a low carbon content."

Carnes agreed. He also said that when common grades of HSS, such as M-3 and M-4, are processed using powder metallurgy, they are significantly tougher than the same compositions manufactured from ingots.

To optimize tool life, however, steelmakers work at the other end of the spectrum and increase the alloy content. Enriching the composition also may boost the hot hardness of the material so that it can withstand elevated temperatures and not soften significantly over time.

"With the development of new alloys, we have the ability to provide material that is starting to approach the properties of cemented tungsten-carbide cutting tools," said Carnes. This allows heavily alloyed HSS to be used in applications where conventional tool steels often fail, such as dry machining.

Achieving the needed hardness of P/M HSS is also cost-effective compared to working with carbide, because it's less expensive, said Carnes. He pointed out the differences between these two materials when grinding them: "The toolmaker has lower costs when fabricating a cutting tool from HSS, especially P/M HSS, because it's easier to machine than carbide. Carbides are hard, and they need to be ground entirely. You don't have the ability to work with carbide in the soft condition. You can machine tool steel in the annealed or soft condition, and heat-treat it to harden it or temper it, and then finish grind the tool. With carbide, it's grind all the way."

Tools of the Trade

Most cutting tools can be made from either HSS or solid carbide, including hobs, punches, form tools, taps, endmills, milling cutters and thread roll dies. However, this has not meant that the competition between HSS and carbide has been a one-way street.

Wright mentioned the advent of carbide hobs just 4 years ago. "People thought they couldn't make that tool out of carbide due to its complicated shape," he said. This, in turn, he said, has prompted steelmakers to further develop grades that would be able to run on machining centers used with carbide hobs.

He added, "While carbide has pushed its way into traditional areas of HSS, we have pushed back and developed more wear-resistant, higher red-hardness, high-speed grades to try to take some of that market back."

To compete for this market, Carpenter ran a comparison test in which SAE 2060 steel gears were produced using hobs made of Maxamet HSS and carbide. Because the HSS tool is able to cut metal at a higher feed rate, the company said the Maxamet tool cut 105 gears per hour compared to 85 gears per hour for the carbide tools.

Furthermore, in the area of form tools, such as the ones for machining stainless steel parts on a screw machine, the Maxamet tool could run 12 hours before resharpening was necessary, and even then only 0.020" was removed. The T-15 HSS alloy, on the other hand, ran for 8 hours between resharpening and 0.040" of steel was removed.

All in all, Wright takes pains to emphasize that the competition between carbide and HSS, in the end, ultimately benefits not only end users, but toolmakers and the carbide producers as well. "That's the way advances are made," he said. "Where there's a need and competition, people start thinking very hard and develop another approach. And that's the way we all make progress."