pending on cutting conditions, coolants used, and other operational factors."

Qualities of HSS

The *Crucible Tool Steel and Specialty Alloy Selector* handbook outlines HSS characteristics for good cutting-tool performance:

- **High attainable hardness**, usually a minimum hardness of HRC 63. Typical metal-cutting tools may be HRC 64–68, depending on grade and application. High carbon content, along with elements to promote a more thorough hardening process, are common to all HSS for this purpose.
- **High wear resistance** to promote edge retention during cutting. Constant abrasion wears away tool surfaces. The high volumes of wear-resistant carbides in HSS micro-structures aids in resisting this abrasion.
- **Sufficient impact toughness** to handle interrupted cutting applications, to avoid chipping during cutting, and to avoid breakage in fragile tools. HSS are notably tougher than carbide or ceramic materials.
- **High hardness at elevated temperatures** involves both red hardness (the ability to stay hard at elevated temperature during cutting) and temper resistance (the ability to resist permanent softening over time due to high temperature exposure). The tungsten and/or molybdenum contents promote these properties. When needed, cobalt further enhances red hardness.

Heat-treating HSS

The heat treating of HSS is an involved process. The *Crucible Tool Steel* handbook referenced *above* also outlines the recommended process for M2 HSS (the most common steel used in English-made tools):

- Preheat to 1,500–1,550˚F.
- High-heat to 2,100–2,225˚F for 2 to 5 minutes.
- Quench in salt bath or oil to 1,000–1,100˚F, then air-cool to hand warm (150˚F). Temper immediately.
- Temper at 1,000˚F or higher two times for at least two hours. Tempering at 1,025˚F yields a 63.5 HRC, while tempering at 1,050˚F yields a 62.6 HRC. Both are optimum for maximum toughness and effective stress-relieving.
- Air-cool to room temperature between tempers.

The experts I spoke to believe that the lower-than-normal levels of hardness in some of the samples in the test may have been due to errors in the heat-treating process rather than a conscious choice to make a softer tool. The heat treating of HSS is a most critical part of the toolmaking process—one that must be done precisely and with great care.

Confusing terms

There are two terms related to turning tools that confuse many turners.

First is the use of **powdered** or **particle metals (PM)**. This is a process in steel making that yields

WOODTURNING TOOL-STEEL ANALYSIS

BRAND	COUNTRY OF ORIGIN	CARBON BY %	MANGANESE BY %	PHOSPHORUS BY %	SULFUR BY %	COBALT BY %	SILICON BY %	CHROMIUM BY %	NICKEL BY %	MOLYBDENUM BY %	COPPER BY %	VANADIUM BY %	TUNGSTEN BY %	IRON	HARDNESS (HRC)	PROBABLE STEEL[4]
Packard (Hamlet)	UK	2.30	0.00	0.00	0.00	10.70	0.77	4.00	0.00	7.10	0.00	6.60	6.50	B[1]	68.0	2060[5]
Sorby	UK	0.91	0.27	0.02	0.00	0.00	0.24	4.03	0.00	4.79	0.00	1.75	5.96	B[1]	65.0	M2[6]
Apprentice (Craft Supplies)	CHINA	0.87	0.40	0.03	0.02	0.00	0.30	3.95	0.00	4.55	0.00	1.83	5.99	B[1]	64.0	M2[6]
Benjamin's Best (eBay[2])	CHINA	0.85	0.35	0.02	0.02	0.02	1.18	4.50	0.07	0.29	0.11	0.12	2.41	B[1]	65.0	UN[7]
Benjamin's Best (Penn State)	CHINA	0.86	0.62	0.03	0.02	0.05	0.36	3.91	0.11	4.73	0.15	1.93	6.34	B[1]	58.0	M2[6]
Bodger (Highland Hardware)	CHINA	1.05	0.39	0.03	0.01	0.02	0.50	4.11	0.05	0.45	0.12	0.40	2.46	B[1]	57.0	UN[7]
Grizzly	CHINA	0.85	0.37	0.02	0.01	0.23	0.61	4.13	0.15	2.18	0.15	0.97	4.37	B[1]	62.0	HSS[8]
Harbor Freight	CHINA	0.74	0.17	0.02	0.01	0.00	0.27	4.11	0.00	0.00	0.00	1.04	17.61	B[1]	62.2	T1[6]
Pinnacle (Woodcraft)	CHINA	0.87	0.70	0.03	0.02	0.00	0.36	4.21	0.00	4.81	0.00	2.03	6.23	B[1]	61.7	M2[6]
Sears Craftsman	CHINA	0.82	0.26	0.0	0.00	0.03	0.56	4.10	0.11	3.97	0.09	0.97	0.05	B[1]	61.0	M50[9]
Shopsmith[3]	CHINA	0.94	0.11	0.02	0.01	0.09	0.22	4.02	0.11	4.50	0.14	1.68	5.84	B[1]	64.0	M2[6]

1. Balance of tool composition is iron.
2. Purchased new via eBay auction.
3. Part of a 4-piece bowl-turning set (not the standard 5-piece Shopsmith turning set).
4. Interpretations contributed by Stork laboratory technicians, Dr. Jeryl Wright, and Jerry Glaser.
5. 2060 is a particle or powdered metal (PM) HSS with extremely high wear-resistance properties.
6. M2 and T1 are long-established HSS compositions with good track records.
7. Unknown steel. Failed high-speed steel (HSS) test as defined by the American Society for Testing Materials (ASTM). HSS must contain specified amounts of carbon, chromium, vanadium, tungsten, and molybdenum.
8. Meets the minimum amounts to be called an intermediate HSS.
9. M50 is a HSS, primarily used for bearings, but with low-wear resistance.