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Slow Cooling and Grain Boundary Carbide Embrittlement in Tool Steel

A tool steel reaches its working hardness easily, and a slow quench then takes the toughness away. Alloy carbides dissolve during austenitizing and precipitate again as a film on the prior austenite grain boundaries during cooling, while the product of the transformation changes from martensite to bainite. The tables below give the effect of section size and austenitizing temperature, the impact toughness measured on H13 under three hardening conditions, and the practice that avoids it.

Reference only. This is a reference summary of published practice and it is not a specification of ours. The mechanism and the figures are reproduced from the source, which describes one class of damage on hardened tool steels. Final judgement is made on the job.

Section size works against the quench

Simulated condition	Cooling rate	Toughness against a small air cooled specimen	What it means for a real part
25 mm, air cooled	The fastest of the three	The highest of the three	The condition a small tool can be quenched into.
Core of a 150 mm round	Slower	Lower, and lower again as the austenitizing temperature rises	A medium block is already at risk in the core.
Core of a 300 mm round	The slowest of the three	The lowest	Even a strong quench medium cannot protect the core of a large block.

Charpy V-notch toughness of H13 cooled at rates that simulate the core of round bars, at room temperature and at 425 °C. The fall in toughness at the largest section is the reason heavy tools are sensitive to embrittlement in the core.

What a controlled heat treatment study measured on H13

Condition	Hardening	Tempering	Toughness against the recommended treatment	What else changed
Recommended	1020 °C	610 °C, twice for 2 h	The reference condition	The structure the grade is specified for.
Low austenitizing	890 °C	250 °C	Down by about 40 percent	Incomplete austenite transformation leaves a heterogeneous structure, and the softening rate in service is about six times the expected one.
High austenitizing	1150 °C	640 °C	Down by about 90 percent	Coarse austenite grains, ASTM 3 to 4 against the 7 to 10 the grade should show, with proeutectoid carbide on the grain boundaries.

Impact toughness measured on H13 tempered to 45 HRC under three hardening conditions. Both of the alternatives lose toughness without any gain in the hardness that was the target.

Practice that avoids the embrittlement

Practice	What it controls	What goes wrong without it
Quench rate control in a vacuum furnace	Gas pressure and gas circulation	Too strong and too uneven, distortion or cracking. Too slow, a carbide film on the grain boundaries and bainite in the core.
Heat treatment after rough machining	Where the embrittled core ends up	Heat treating the finished tool leaves the embrittled material in the working region.
Coupon testing after hardening	Whether the treatment actually produced the properties	Hardness alone passes a treatment that has no toughness left in it.

The three practices the source gives for heavy tooling. Each one is aimed at the same risk, that the hardness is on specification while the toughness is gone.

Aobo Steel, tool steel supplier

Aobo Steel supplies tool steel to distributors and mold, tool and die shops, including D2, D3, DC53, A2, O1, H13, H11, H10, H21, S7, M2, M42, L6, P20 and 420 and 440C stainless. Forged or hot rolled, annealed or pre-hardened, cut to your sizes, with test certificates.

Source, Failure Analysis of Heat Treated Steel Components (L. C. F. Canale, R. A. Mesquita and G. E. Totten), ASM International, 2008.

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