

Tool Steel Tempering Chart

Tool steel tempering temperatures and the hardness each one produces, with the oxide colors used to judge temperature on the shop floor. Reference summary of published tempering practice, not a heat treatment specification and not an Aobo Steel standard.

Reference only. Aobo Steel supplies tool steel in the annealed condition and does not provide heat treatment services. Verify the values below against the applicable standard, the mill data sheet and the heat treater's own procedure.

Tempering temperature and working hardness

Six grades that cover most die and tool work, with the hardness each is normally put into service at.

Grade	Type	As-quenched HRC ^(a)	Working HRC	Recommended tempering, °F	°C
A2	Cold work, air-hardening	64	58–60	400–450	204–232
D2	Cold work, high-chromium	64	58–60	900–960	482–516
H13	Hot work, chromium	54	40–48	1050–1150	566–621
M2	High speed, molybdenum	65	62–64	1000–1050	538–566
O1	Cold work, oil-hardening	64	58–60	400–450	204–232
S7	Shock-resisting	60	56–58	400–450	204–232

Source: Tool and Die Making Troubleshooter (R. M. Leed), Table 8-7, from Bethlehem Steel data.

Tempering windows by grade

Hardening and tempering data for the tool steels most often quoted and stocked. Grouped by family, with the approximate hardness span across the window.

Grade	Type	Tempering temperature, °F	°C	Approx. tempered hardness, HRC ^(c)
High-speed tool steels				
M2	Molybdenum high speed	1000–1160	538–627	65–60
M4	Molybdenum high speed, vanadium	1000–1100	538–593	66–61
M7	Molybdenum high speed	1000–1100	538–593	66–61
M10	Molybdenum high speed	1000–1100	538–593	65–60
M42	Cobalt high speed	950–1100	510–593	70–65
Hot-work tool steels				
H10	Chromium hot work	1000–1200	538–649	56–39
H11	Chromium hot work	1000–1200	538–649	54–38
H12	Chromium-tungsten hot work	1000–1200	538–649	55–38
H13	Chromium hot work	1000–1200	538–649	53–38
H19	Chromium-cobalt hot work	1000–1300	538–704	59–40
H21	Tungsten hot work	1100–1250	593–677	54–36
H23	Tungsten hot work	1200–1500	649–816	47–30
Cold-work tool steels				
D2	High-chromium cold work	400–1000	204–538	61–54
D3	High-chromium cold work	400–1000	204–538	61–54
D4	High-chromium cold work	400–1000	204–538	61–54
D5	High-chromium cold work	400–1000	204–538	61–54
D7	High-chromium cold work	300–1000	149–538	65–58
A2	Medium-alloy air-hardening	350–1000	177–538	62–57
A6	Medium-alloy air-hardening	300–800	149–427	60–54
A7	Medium-alloy air-hardening	300–1000	149–538	67–57
A8	Medium-alloy air-hardening	350–1100	177–593	60–50
O1	Oil-hardening cold work	350–500	177–260	62–57
O2	Oil-hardening cold work	350–500	177–260	62–57
O6	Oil-hardening cold work	350–600	177–316	63–58
O7	Oil-hardening cold work	350–550	177–288	64–58

Tempering windows by grade, continued

Grade	Type	Tempering temperature, °F	°C	Approx. tempered hardness, HRC (c)
Shock-resisting tool steels				
S1	Shock-resisting	400–1200	204–649	58–40
S5	Shock-resisting	350–800	177–427	60–50
S7	Shock-resisting	400–1150	204–621	57–45

Source: Machinery's Handbook, 28th ed., tool steel tables 6, 8, 9 and 10 (high-speed, hot-work, cold-work and shock-resisting groups).

H13 at each tempering temperature

Hardness, tensile properties and impact energy of H13 after double tempering. Same austenitizing temperature, two different quench routes.

Tempering °C	°F	Hardness HRC	Tensile MPa (ksi)	Yield MPa (ksi)	Elongation %	Charpy V-notch at 21 °C, J (ft-lbf)
Oil quenched from 1010 °C (1850 °F), double tempered 2 + 2 h						
527	980	52	1960 (284)	1570 (228)	13.0	16 (12)
555	1030	50	1835 (266)	1530 (222)	13.1	24 (18)
575	1065	48	1730 (251)	1470 (213)	13.5	27 (20)
593	1100	46	1580 (229)	1365 (198)	14.4	28.5 (21)
Air cooled from 1010 °C (1850 °F), double tempered 2 + 2 h						
524	975	54	—	—	—	14 (10)
565	1050	52	—	—	—	14 (10)
607	1125	47	—	—	—	24 (18)

Source: ASM Handbook, Volume 1 (10th ed.), Ultrahigh-Strength Steels, Tables 31 and 33 (H13 round bar). The air-cooled series is reported with hardness and impact energy only.

M2 hardness against tempering temperature

The dip and recovery between 700 and 1050 °F is secondary hardening, which is why high-speed steel is tempered hot instead of just hard.

Tempering °F	°C	Hardness after oil quench, HRC	Hardness after air quench, HRC
300	150	66	66.5
400	205	65	65
500	260	64	63.5
600	315	63	62.5
700	370	62.5	62.5
800	425	63	62.5
900	480	65	63.5
1000	540	66	63.5
1050	565	66	63.5
1100	595	64.5	61.5
1150	620	62	60
1200	650	53.5	53

Source: Heat Treatment, Selection and Application of Tool Steels (W. E. Bryson, 2nd ed.), Table 10.1, austenitized at 2250 °F (1230 °C).

Table notes

Different references publish different tempering windows for the same grade because the outcome depends on how the part was austenitized, how fast it cooled, how thick it is and how many tempers it receives. D2, for example, is tempered at 900 to 960 °F (482 to 516 °C) to hold 58 to 60 HRC in shop practice, while Machinery's Handbook prints a wider 400 to 1000 °F window with an approximate hardness span of 61 to 54 HRC. Treat both tables as starting windows, then confirm on your own furnace with a test piece.

Temper twice, and three times on high-speed steel. Air-hardening cold-work grades and molybdenum high-speed grades are normally tempered twice to convert retained austenite and stabilise the dimensions. A third temper is added for parts with a lot of detail or for hard-service tooling.

Never heat a tempered part above its tempering temperature. Stress relieving, straightening or weld repair above that temperature softens the tool, so the tempering temperature sets a ceiling for every later operation.

Tempering colors are an indication only. The oxide colors in the last table were measured on plain carbon steel. Alloy content shifts them, so use a thermocouple or pyrometer for control and the colors as a cross-check on the shop floor.

Tempering colors

Oxide colors on plain carbon steel, used as a shop-floor cross-check when a pyrometer is not at hand.

°F	°C	Color of steel
430	221	Very pale yellow
440	227	Light yellow
450	232	Pale straw-yellow
460	238	Straw-yellow
470	243	Deep straw-yellow
480	249	Dark yellow
490	254	Yellow-brown
500	260	Brown-yellow
510	266	Spotted red-brown
520	271	Brown-purple
530	277	Light purple
540	282	Full purple
550	288	Dark purple
560	293	Full blue
570	299	Dark blue
640	338	Light blue

Source: Machinery's Handbook, 28th ed., Table 1, temperatures indicated by the color of plain carbon steel. Other shop references list the same colors over slightly different ranges, for example straw at 460 °F (238 °C) and blue at 580 °F (304 °C).

Notes on the tables

- (a) As-quenched hardness, measured before tempering.
- (b) Temperatures are printed here as published in each source. Celsius values in the tempered-hardness tables are converted from Fahrenheit and rounded to the nearest degree.
- (c) Approximate tempered hardness is the span from the low end of the tempering window to the high end. The exact value depends on austenitizing temperature, quench, section size and the number of tempers.

Temper within the hour

The part should be at 125 to 150 °F (50 to 65 °C) when it enters the tempering furnace. Waiting until it is cold adds cracking risk on air-hardening grades.

One hour per inch

Hold at temperature for one hour per inch of section, two hours per inch on heavy or complex blocks. Short soak times leave retained austenite and unstable dimensions.

Hardness costs toughness

Every point of hardness above the working range removes toughness. Some tempering bands lower toughness for a different reason, and the temperatures that trigger each one are listed on the steel embrittlement types page. Choose the range the die needs and stay inside it rather than hardening to the maximum the steel can take.

Ask for the mill data sheet

Tempering windows are grade and mill specific. Aobo Steel supplies heat treatment guidance with each order, and the mill certificate travels with the steel.

Aobo Steel, tool steel supplier

Aobo Steel supplies forged tool steel from Huangshi, Hubei, China, where the local supply chain covers ESR melting, vacuum degassing and LF refining, forging, hot rolling, turned and peeled bar, heat treatment and third party inspection. We have worked in tool steel since 2003 and supply to order in cold work grades such as D2, D3 and O1, hot work grades such as H10 and H13, and stainless grades 420, 440C and 4Cr13. Mill test certificates to EN 10204 3.1 travel with every shipment and every order is checked against its working hardness range before it leaves the works.

Reference data compiled from published tool steel tempering sources and the Aobo Steel tool steel heat treatment guide.

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