

Case Hardening Compared

Carburizing and carbonitriding harden by diffusing carbon into the surface and quenching, which is where distortion enters. Nitriding, nitrocarburizing and the pack diffusion coatings run without a quench. The tables below put the process temperature, case depth, case hardness and base metals of each process side by side, and list the tool steels that are nitrided.

Reference only. This is a reference summary of published practice and it is not a specification of ours. The values are reproduced from the source tables, and what a particular tool reaches depends on the grade, the section, the equipment and the cycle that follows. Final selection is confirmed on the job.

Carburizing, nitriding, carbonitriding and nitrocarburizing side by side

Process	Name of case	Process temperature	Typical case depth	Case hardness, HRC	Typical base metals	Process characteristics
Carburizing						
Pack	Diffused carbon	815-1090 °C (1500-2000 °F)	125 µm to 1.5 mm (5-60 mils)	50-63(a)	Low carbon steels, low carbon alloy steels	Low equipment cost, difficult to control case depth accurately
Gas	Diffused carbon	815-980 °C (1500-1800 °F)	75 µm to 1.5 mm (3-60 mils)	50-63(a)	Low carbon steels, low carbon alloy steels	Good control of case depth, suitable for continuous operation, good gas controls required, can be dangerous
Liquid	Diffused carbon and possibly nitrogen	815-980 °C (1500-1800 °F)	50 µm to 1.5 mm (2-60 mils)	50-65(a)	Low carbon steels, low carbon alloy steels	Faster than pack and gas, salt disposal problem, salt baths need frequent maintenance
Vacuum	Diffused carbon	815-1090 °C (1500-2000 °F)	75 µm to 1.5 mm (3-60 mils)	50-63(a)	Low carbon steels, low carbon alloy steels	Excellent process control, bright parts, faster than gas carburizing, high equipment cost
Nitriding						
Gas	Diffused nitrogen, nitrogen compounds	480-590 °C (900-1100 °F)	125 µm to 0.75 mm (5-30 mils)	50-70	Alloy steels, nitriding steels, stainless steels	Hardest cases from nitriding steels, no quench required, low distortion, slow, usually a batch process
Salt	Diffused nitrogen, nitrogen compounds	510-565 °C (950-1050 °F)	2.5 µm to 0.75 mm (0.1-30 mils)	50-70	Most ferrous metals including cast iron	Usually used for thin hard cases under 25 µm (1 mil), no white layer, most are proprietary processes
Ion	Diffused nitrogen, nitrogen compounds	340-565 °C (650-1050 °F)	75 µm to 0.75 mm (3-30 mils)	50-70	Alloy steels, nitriding steels, stainless steels	Faster than gas nitriding, no white layer, high equipment cost, close case control
Carbonitriding						
Gas	Diffused carbon and nitrogen	760-870 °C (1400-1600 °F)	75 µm to 0.75 mm (3-30 mils)	50-65(a)	Low carbon steels, low carbon alloy steels, stainless steels	Lower temperature than carburizing so less distortion, slightly harder case than carburizing, gas control critical
Liquid (cyaniding)	Diffused carbon and nitrogen	760-870 °C (1400-1600 °F)	2.5 to 125 µm (0.1-5 mils)	50-65(a)	Low carbon steels	Good for thin cases on noncritical parts, batch process, salt disposal problems
Ferritic nitrocarburizing	Diffused carbon and nitrogen	480-590 °C (900-1090 °F)	2.5 to 25 µm (0.1-1 mil)	40-60(a)	Low carbon steels	Low distortion process for a thin case on low carbon steel, most processes are proprietary

Typical characteristics of carburizing, nitriding, carbonitriding and nitrocarburizing treatments, reproduced from the source table. (a) Requires a quench from the austenitizing temperature. The rows without that marker, which are all the nitriding and nitrocarburizing rows, need no quench and are the low distortion processes.

The quench is what separates the families

Which tool steels are nitrided

Grade family	Grades the source lists
Aluminium containing low alloy steels	Nitr alloy grades
Medium carbon chromium low alloy steels	4100, 4300, 5100, 6100, 8600, 8700 and 9800 series
Low carbon chromium low alloy steels	3300, 8600 and 9300 series
Hot work die steels with 5% Cr	H11, H12 and H13
Air hardening tool steels	A2, A6, D2, D3 and S7

Grade family	Grades the source lists
High speed tool steels	M2 and M4
Nitronic stainless steels	30, 40, 50 and 60
Ferritic and martensitic stainless steels	400 and 500 series

The steels named in the source as nitridable for specific applications. All hardenable steels must be quenched and tempered before nitriding, and the process is carried out below the temperature at which the previous heat treatment set the core properties.

- Effective case depth is measured at 50 HRC
- Pack diffusion coatings, where tool steel is the main customer

Case Hardening Compared

Process	Nature of case	Process temperature	Typical case depth	Case hardness, HRC	Typical base metals	Process characteristics
Aluminizing (pack)	Diffused aluminum	870-980 °C (1600-1800 °F)	25 µm to 1 mm (1-40 mils)	<20	Low carbon steels	Diffused coating for oxidation resistance at elevated temperature
Siliconizing by CVD	Diffused silicon	925-1040 °C (1700-1900 °F)	25 µm to 1 mm (1-40 mils)	30-50	Low carbon steels	For corrosion and wear resistance, atmosphere control is critical
Chromizing by CVD	Diffused chromium	980-1090 °C (1800-2000 °F)	25 to 50 µm (1-2 mils)	Low carbon steel <30, high carbon steel 50-60	High and low carbon steels	Chromized low carbon steels yield a low cost stainless steel, high carbon steels develop a hard corrosion resistant case
Titanium carbide (TiC)	Diffused carbon and titanium, TiC	900-1010 °C (1650-1850 °F)	2.5 to 12.5 µm (0.1-0.5 mil)	>70(a)	Alloy steels, tool steels	Produces a thin TiC case for high wear resistance, compound temperature may cause distortion
Boriding	Diffused boron, boron compounds	400-1150 °C (750-2100 °F)	12.5 to 50 µm (0.5-2 mils)	40-70	Alloy steels, tool steels, cobalt and nickel alloys	Produces a hard compound layer, mostly applied over hardened tool steels, high process temperature can cause distortion

Typical characteristics of the pack cementation processes, reproduced from the source table. (a) Requires a quench from the austenitizing temperature. The boronized and TiC coated cases do not need a quench to reach their hardness, but a tool steel processed in the austenitizing temperature range still has to be quenched to harden the substrate.

Choosing between a quenched case and a diffused case

Aobo Steel, tool steel supplier

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Source, ASM Handbook, Volume 20, Materials Selection and Design, ASM International, 1997.

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