Hardness Conversion

Approximate equivalents for steel — read the caution below

HRC	HRB	Brinell	Vickers	Tensile ksi
68	—	—	940	—
65	—	739	832	—
62	—	690	746	—
60	—	654	697	329
58	—	615	653	306
55	—	560	595	276
52	—	512	544	252
50	—	481	513	238
48	—	455	484	225
45	—	421	446	208
42	—	390	412	193
40	—	371	392	182
38	—	353	372	173
35	—	327	345	159
32	—	301	317	146
30	—	286	302	138
28	—	271	285	131
25	—	253	266	121
22	—	237	248	112
20	98	226	238	107

HRB	Brinell	Vickers	Tensile ksi
100	240	240	116
98	228	228	110
95	210	210	101
92	197	197	95
90	185	190	90
87	176	180	86
85	170	175	83
80	150	155	74
75	137	142	68
70	125	130	62
65	115	120	57
60	105	110	52

These conversions are approximate and they are for steel. Hardness scales measure different things with different indenters and loads, so there is no exact mathematical relationship between them — only empirical tables built from testing carbon and alloy steels. Applying them to aluminium, brass, cast iron or nickel alloys will give you a number that is simply wrong.

Which scale to use. HRC for hardened steel above roughly 20 HRC. HRB for softer steel, brass and aluminium. Brinell for castings, forgings and coarse-grained material where a large indenter averages out the structure. Vickers or microhardness for thin sections, case depths and small features.

Tensile strength from hardness is a rule of thumb. For steel, tensile in ksi is roughly Brinell × 0.5. It is useful for a sanity check and useless as a specification — if the print calls a tensile value, it has to be tested, not inferred.

Case-hardened parts read the case, not the core. A carburised part can show 60 HRC on the surface and 25 HRC a few thousandths down. If case depth matters, it needs a sectioned microhardness traverse, not a surface reading.

Temper Designations — Aluminium

What the letters and numbers after the alloy actually mean

Thermal Tempers (T) — heat-treatable alloys

Temper	Meaning	Where you see it
F	As fabricated	No special control over thermal or work-hardening conditions
O	Annealed	Softest, most formable state
T3	Solution treated, cold worked, naturally aged	2024-T3 sheet — aerospace
T4	Solution treated, naturally aged	Formable, ages at room temperature
T5	Cooled from forming, artificially aged	Extrusions
T6	Solution treated, artificially aged	**The common one.** 6061-T6, 7075-T6
T7	Solution treated, overaged	Better stress-corrosion resistance, slightly lower strength
T351 / T651	As T3 / T6, stress relieved by stretching	Plate — stays flat when machined

Strain Hardened (H) — non-heat-treatable alloys

Temper	Meaning	Note
H1x	Strain hardened only	Work hardened by cold rolling
H2x	Strain hardened, partially annealed	Softened back for formability
H3x	Strain hardened, stabilised	Low-temperature treatment to prevent age softening
x2 / x4 / x6 / x8	Quarter / half / three-quarter / full hard	Second digit = degree of hardening

The temper is part of the material spec. 6061-T6 and 6061-O are the same alloy and completely different materials — one is roughly three times the strength of the other. If the print says T6, annealed stock is not a substitute, and neither is T4.

Welding destroys the temper locally. Weld 6061-T6 and the heat-affected zone drops back toward T4 or softer. If the joint has to carry the design load, the part needs re-heat-treating after welding, or the joint needs designing around the weakened zone.

Stress-relieved plate is worth the money. T651 and similar designations mean the plate was stretched to relieve residual stress. Machine a large pocket out of non-stress-relieved plate and it will bow — sometimes visibly, on the table, while you watch.

Reading the H designation. The second digit is the degree of hardening: 2 is quarter hard, 4 is half, 6 is three-quarter, 8 is full hard. So 5052-H32 is strain hardened, stabilised, and quarter hard.

Heat Treat — Steel & Stainless

The processes, what they do, and why you would ask for them

Process	What happens	Why you do it
Annealing	Heat, hold, slow furnace cool	Softest condition. Relieves stress, improves machinability
Normalising	Heat above critical, cool in still air	Refines grain, more uniform structure than annealed
Hardening	Heat to austenitising temp, rapid quench	Maximum hardness — and maximum brittleness
Tempering	Reheat after quench, controlled cool	Trades hardness for toughness. **Always follows hardening**
Stress relieving	Heat below critical, slow cool	Removes residual stress without changing hardness
Carburising	Add carbon at surface, then harden	Hard case, tough core. Case depth is specified
Nitriding	Diffuse nitrogen at low temperature	Very hard thin case, minimal distortion
Through hardening	Hardened all the way through	Section size limits what is achievable

17-4 PH Stainless — Aged Conditions

Condition	Meaning	Note
Condition A	Solution annealed	As supplied. Machine in this condition
H900	Aged at 900°F	Highest strength, lowest toughness
H1025	Aged at 1025°F	Good balance — common choice
H1150	Aged at 1150°F	Lower strength, best toughness and corrosion resistance

Machine before hardening wherever you can. Cutting 60 HRC steel is slow, expensive and hard on tooling. Rough the part, heat treat, then grind or finish to size. Leave stock for it — parts grow and move in the furnace, and thin sections move most.

Hardening without tempering gives you a part that shatters. As-quenched steel is at maximum hardness and close to zero toughness. Tempering is not optional, and the tempering temperature is what sets the final hardness — higher temperature, lower hardness, more toughness.

Case depth is specified for a reason. On a carburised or nitrided part, the surface hardness tells you almost nothing on its own. What matters is how deep the hard layer runs, and that is measured on a sectioned sample, not with a surface tester.

17-4 is machined in Condition A, then aged. Ageing changes dimensions slightly, so allow for it on close-tolerance features — or grind after.

Weld Defects — What Caused It

The common discontinuities and where they come from

Defect	What you see	Usual causes
Porosity	Rounded voids in or on the weld; sometimes wormholes	Contaminated or damp base metal · wrong or low gas flow · drafts blowing shielding away · wet electrodes · arc length too long
Undercut	Groove melted into the base metal at the toe, left unfilled	Current too high · travel speed too fast · wrong work angle · arc length too long
Lack of fusion	Weld metal sitting against base metal without bonding	Insufficient heat input · travel too fast · wrong torch angle · dirty or oxidised surfaces · poor bead placement
Incomplete penetration	Root of the joint not fully filled	Root opening too tight · bevel angle too small · current too low · electrode too large · travel too fast
Slag inclusion	Non-metallic material trapped in the weld	Inadequate cleaning between passes · wrong electrode angle · travel too slow letting slag run ahead
Hot cracking	Cracks forming as the weld solidifies, often centreline	High sulphur or phosphorus in base metal · excessive restraint · deep narrow bead profile · crater cracking at stops
Cold cracking	Cracks appearing hours after welding — hydrogen induced	Moisture in electrodes or on the joint · high-strength or hardenable steel · no preheat · rapid cooling
Overlap / cold lap	Weld metal rolled over the base without fusing	Travel too slow · current too low · wrong technique or angle
Burn-through	Hole melted through thin material	Current too high · travel too slow · root opening too wide · no backing
Excessive spatter	Metal droplets thrown around the weld	Voltage or current out of balance · dirty wire or contact tip · wrong gas mix · damp electrodes
Arc strike	Hard spot outside the weld zone	Striking the arc off the joint. Creates an untempered martensite spot and a crack initiation site
Distortion	Part pulled out of shape	Excessive heat input · poor weld sequence · inadequate fixturing · welding one side only

Preheat is the answer more often than people expect. Cold cracking in higher-carbon or thicker material is a hydrogen and cooling-rate problem, and preheat addresses both. If the WPS specifies preheat and interpass temperature, they are not suggestions — check with a temperature stick or an IR gun, not with your hand.

Most of these start before the arc. Cleanliness, fit-up and joint prep account for a large share of weld defects. Mill scale, oil, paint, moisture and a sloppy root gap will beat good technique every time.

Grinding a defect out does not always fix it. A crack usually runs deeper than it looks. Remove it, verify it is gone — dye penetrant if you have it — then re-weld. Blending the surface so it looks acceptable leaves the crack in the part.

Filler Metal Selection

Matching filler to base material — common combinations

Carbon & Alloy Steel

Base material	MIG (GMAW)	Stick (SMAW)	TIG (GTAW)
Mild steel (A36, 1018, 1020)	ER70S-6	E7018 / E6011	ER70S-2
Medium carbon (1045)	ER70S-6	E7018	ER70S-2 (preheat)
Low alloy (4130, 4140)	ER80S-D2	E8018-B2	ER80S-D2 (preheat & PWHT)
Structural, higher strength	ER80S-D2	E8018 / E9018	—
Cast iron	—	ENi-CI / ENiFe-CI	—
Galvanised steel	ER70S-6	E6011 / E6013	—

Stainless Steel

Base material	Filler	Note
304 / 304L	ER308L	General purpose austenitic
316 / 316L	ER316L	Marine, chemical — keeps the molybdenum
321 / 347	ER347	Stabilised grades, high temperature
Stainless to carbon steel	ER309L	**The dissimilar-metal bridge.** Also for cladding
17-4 PH	ER630	Matches the PH chemistry
410 / 416 martensitic	ER410 / ER309L	Preheat and PWHT usually required

Aluminium

Base material	Filler	Note
6061, 6063	ER4043	General purpose. Easier to weld, less crack sensitive
6061 (higher strength)	ER5356	Stronger joint, better colour match if anodised
5052, 5083, 5086	ER5356	Magnesium alloys — use 5356, not 4043
3003, 1100	ER4043 or ER1100	Formable, low strength
356 / A356 castings	ER4043	Casting alloy
2024, 7075	Not recommended	**Generally not weldable** — crack sensitive. Mechanically fasten

Reading the designation. ER means a bare rod or wire that can be used as either electrode or rod — MIG and TIG. **E** alone is a covered stick electrode. In E70XX, the 70 is 70,000 psi tensile; the last two digits describe position and coating. The **L** in 308L or 316L means low carbon, which resists carbide precipitation and keeps corrosion resistance in the heat-affected zone.

Match or over-match, do not under-match. The filler should be at least as strong as the weaker base metal. Over-matching slightly is normal; under-matching puts the failure in your weld.

309L is the one to remember. When joining stainless to carbon steel, neither a 308 nor a 70S filler works properly — 309L has the extra alloy content to handle the dilution.

A WPS overrides this card. On any coded, structural or customer-specified work, the procedure specifies the filler, and that is the one you use.