

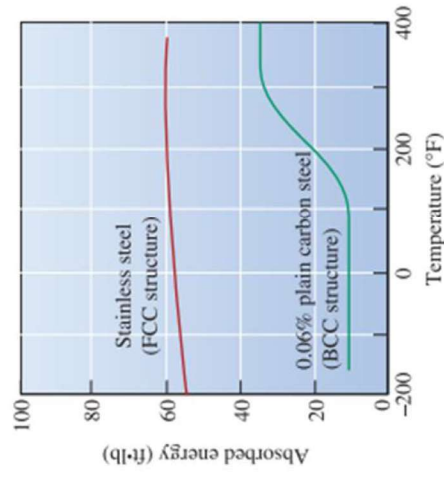
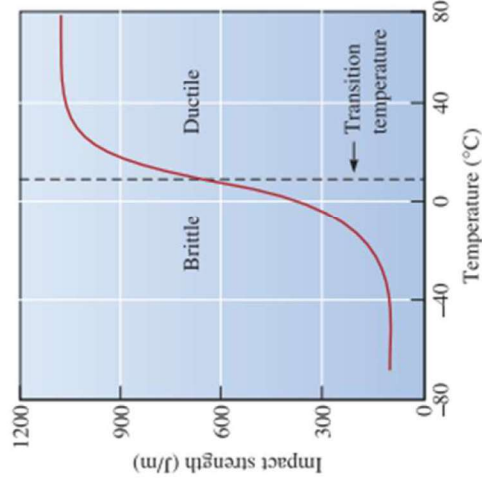
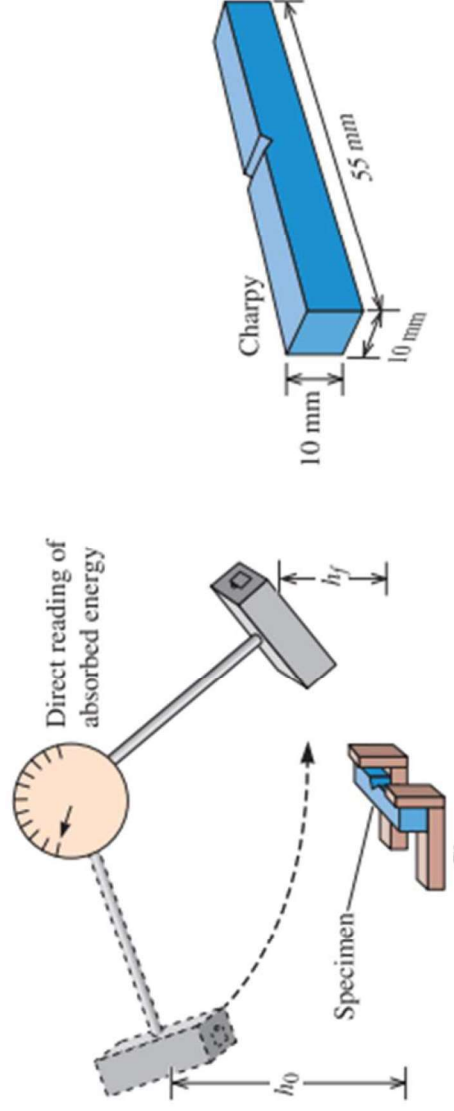


Cryogenic applications – Charpy, lateral expansion & standards

TOMISLAV BUZANCIC – FILLER METAL EUROPE

CRYOGENIC APPLICATIONS – CHARPY, LATERAL EXPANSION & STANDARDS – CHARPY TESTING

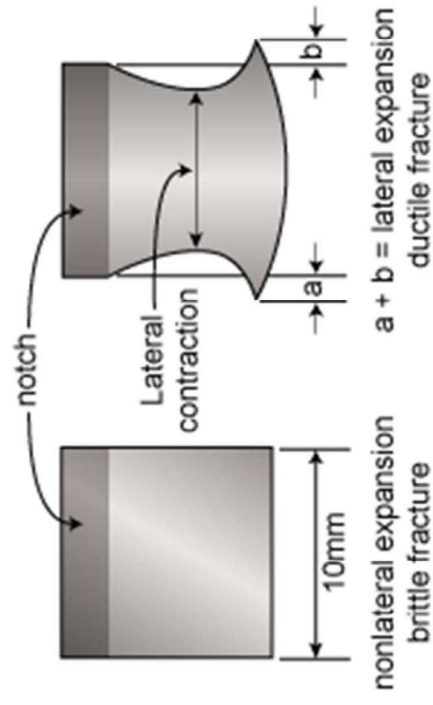
- Brittle/ductile transition
- Transition temperature – 27J, 42J



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CRYOGENIC APPLICATIONS – CHARPY, LATERAL EXPANSION & STANDARDS – LATERAL EXPANSION

Lateral expansion is a measure of the ductility of the specimen



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CRYOGENIC APPLICATIONS – CHARPY, LATERAL EXPANSION & STANDARDS – LATERAL EXPANSION

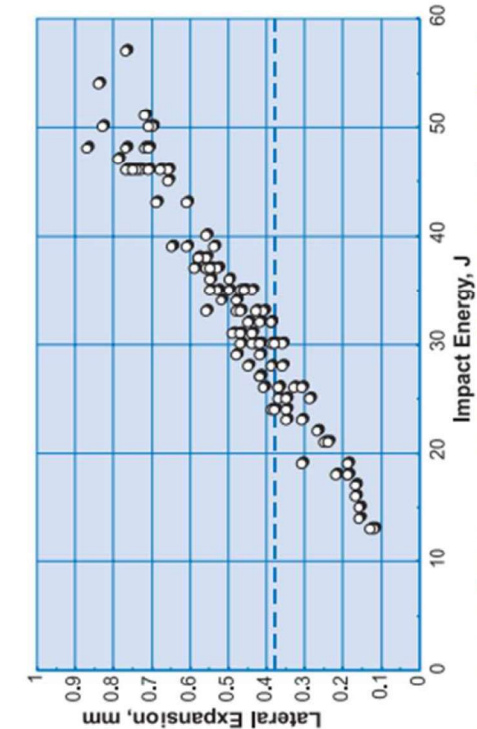
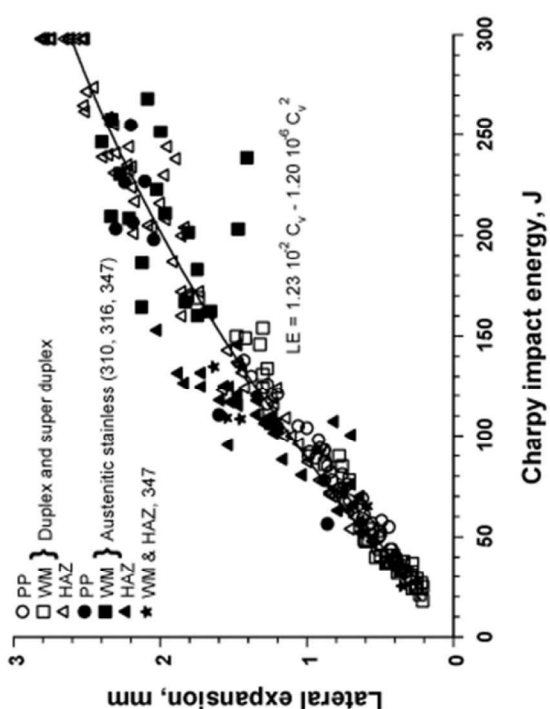


Figure 1: Correlation between impact energy and lateral expansion for E316L-16 MMA electrodes impact tested at -196°C. Data plotted is from individual Charpy specimens.



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CRYOGENIC APPLICATIONS – CHARPY, LATERAL EXPANSION & STANDARDS – LATERAL EXPANSION

- Charpy V-notch impact test becomes invalid at temperatures much below -196°C . It is valid for liquid nitrogen testing **but not for liquid hydrogen** testing since liquid hydrogen temperature at atmospheric pressure is about -253°C .
- The problem with Charpy impact testing at these very low temperatures is that the thermal capacitance of the metal approaches zero, so as plastic deformation begins in the root of the notch during the impact test, **adiabatic heating occurs**, which raises the temperature of the metal. The only valid tests at these very low temperatures are slow strain rate fracture toughness tests, where liquid hydrogen or liquid helium can extract heat fast enough to overcome adiabatic heating.

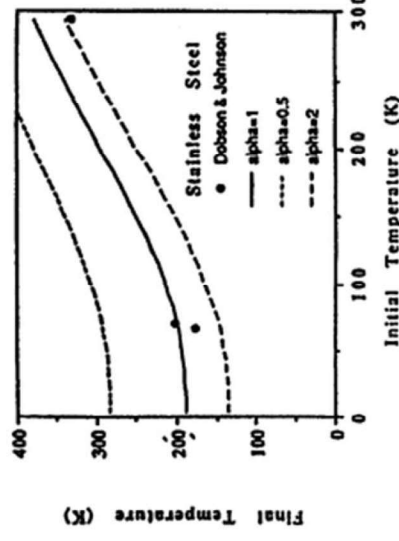
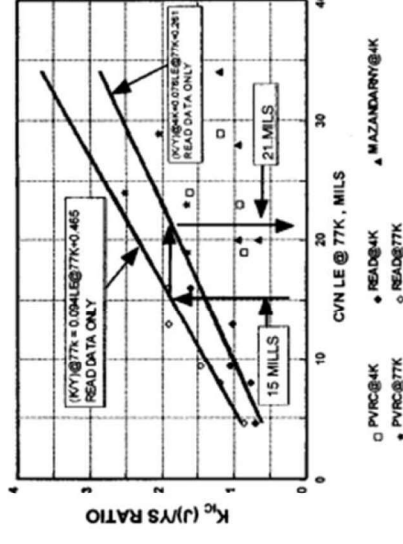


Fig. 1 Predicted temperature rise during a Charpy test as a function of initial temperature for austenitic stainless steel (re-produced from Tobler et al.)

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CRYOGENIC APPLICATIONS – CHARPY, LATERAL EXPANSION & STANDARDS – LATERAL EXPANSION

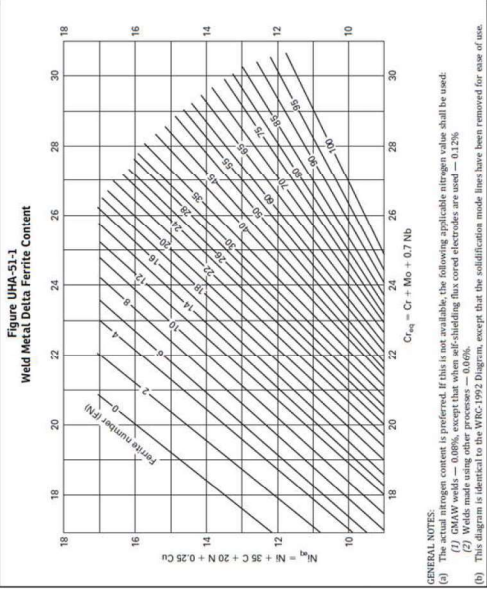
- The ASME Code Committee, after examining correlations between fracture toughness tests at liquid helium temperature and Charpy V-notch results at liquid nitrogen temperature, proposes to require 0.53-mm lateral expansion, not 0.38-mm lateral expansion as specified in ASME B31.3, at liquid nitrogen temperature to qualify a welding procedure for service at liquid helium temperature.
- The yield strength of austenitic stainless steels increases markedly at cryogenic temperatures, therefore, the ASME Code uses the lateral expansion criterion instead.



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UHA-51

ASME BPVC.VIII.1-2023



UHA-44 - UHA-51

ASME BPVC.VIII.1-2023

specimens may be made, each of which must equal or exceed 0.015 in. (0.38 mm). Such a retest shall be permitted only when the average value of the three specimens tested is less than 0.015 in. (0.38 mm). The retest specimens are not obtained in the retest or if the values in the initial test are less than minimum required for retest, the material may be reheat treated. After reheat treatment, new sets of specimens shall be made and retested; the retested specimens must meet the lateral expansion value of 0.015 in. minimum.

(3) When the MDMT is colder than -320°F (-196°C), production welding processes shall be limited to shielded metal arc welding (SMAW), flux cored arc welding (FCAW), gas metal arc welding (GMAW), submerged arc welding (SAW), plasma arc welding (PAW), and gas tungsten arc welding (GTAW). The filler metal and flux combination shall be pre-qualified as required by (1)(4)(a) through (1)(4)(c). Exemption from pre-use testing as allowed by (1)(4)(d) and (1)(4)(e) is not applicable. Toughness testing shall be performed as specified in (c) or (b) below, as appropriate.

(a) If using Type 316L weld filler metal, or Type 308L filler metal welded with the GTAW, FCAW, or GMAW process

INSPECTION AND TESTS

UHA-50 GENERAL

The rules in the following paragraphs apply specifically to the inspection and testing of pressure vessels and vessel parts that are constructed of high alloy steel and shall be used in conjunction with the general requirements for inspection and testing of pressure vessels in Subsection I that pertain to the method of fabrication used.

UHA-51 IMPACT TESTS

Impact tests, as prescribed in (a), shall be performed on materials listed in Table UHA-25 for all combinations of materials and minimum thicknesses. The impact tests (MDMT's) shall be required in (a), (b), (c), (d), (e), (f), (g), (h), (i), (j), (k), (l), (m), (n), (o), (p), (q), (r), (s), (t), (u), (v), (w), (x), (y), (z), (aa), (ab), (ac), (ad), (ae), (af), (ag), (ah), (ai), (aj), (ak), (al), (am), (an), (ao), (ap), (aq), (ar), (as), (at), (au), (av), (aw), (ax), (ay), (az), (ba), (bb), (bc), (bd), (be), (bf), (bg), (bh), (bi), (bj), (bk), (bl), (bm), (bn), (bo), (bp), (bq), (br), (bs), (bt), (bu), (bv), (bw), (bx), (by), (bz), (ca), (cb), (cc), (cd), (ce), (cf), (cg), (ch), (ci), (cj), (ck), (cl), (cm), (cn), (co), (cp), (cq), (cr), (cs), (ct), (cu), (cv), (cw), (cx), (cy), (cz), (da), (db), (dc), (dd), (de), (df), (dg), (dh), (di), (dj), (dk), (dl), (dm), (dn), (do), (dp), (dq), (dr), (ds), (dt), (du), (dv), (dw), (dx), (dy), (dz), (ea), (eb), (ec), (ed), (ee), (ef), (eg), (eh), (ei), (ej), (ek), (el), (em), (en), (eo), (ep), (eq), (er), (es), (et), (eu), (ev), (ew), (ex), (ey), (ez), (fa), (fb), (fc), (fd), (fe), (ff), (fg), (fh), (fi), (fj), (fk), (fl), (fm), (fn), (fo), (fp), (fq), (fr), (fs), (ft), (fu), (fv), (fw), (fx), (fy), (fz), (ga), (gb), (gc), (gd), (ge), (gf), (gg), (gh), (gi), (gj), (gk), (gl), (gm), (gn), (go), (gp), (gq), (gr), (gs), (gt), (gu), (gv), (gw), (gx), (gy), (gz), (ha), (hb), (hc), (hd), (he), (hf), (hg), (hi), (hj), (hk), (hl), (hm), (hn), (ho), (hp), (hq), (hr), (hs), (ht), (hu), (hv), (hw), (hx), (hy), (hz), (ia), (ib), (ic), (id), (ie), (if), (ig), (ih), (ii), (ij), (ik), (il), (im), (in), (io), (ip), (iq), (ir), (is), (it), (iu), (iv), (iw), (ix), (iy), (iz), (ja), (jb), (jc), (jd), (je), (jf), (jg), (jh), (ji), (jj), (jk), (jl), (jm), (jn), (jo), (jp), (jq), (jr), (js), (jt), (ju), (jv), (jw), (jx), (jy), (jz), (ka), (kb), (kc), (kd), (ke), (kf), (kg), (kh), (ki), (kj), (kk), (kl), (km), (kn), (ko), (kp), (kq), (kr), (ks), (kt), (ku), (kv), (kw), (kx), (ky), (kz), (la), (lb), (lc), (ld), (le), (lf), (lg), (lh), (li), (lj), (lk), (ll), (lm), (ln), (lo), (lp), (lq), (lr), (ls), (lt), (lu), (lv), (lw), (lx), (ly), (lz), (ma), (mb), (mc), (md), (me), (mf), (mg), (mh), (mi), (mj), (mk), (ml), (mn), (mo), (mp), (mq), (mr), (ms), (mt), (mu), (mv), (mw), (mx), (my), (mz), (na), (nb), (nc), (nd), (ne), (nf), (ng), (nh), (ni), (nj), (nk), (nl), (nm), (nn), (no), (np), (nq), (nr), (ns), (nt), (nu), (nv), (nw), (nx), (ny), (nz), (oa), (ob), (oc), (od), (oe), (of), (og), (oh), (oi), (oj), (ok), (ol), (om), (on), (oo), (op), (oq), (or), (os), (ot), (ou), (ov), (ow), (ox), (oy), (oz), (pa), (pb), (pc), (pd), (pe), (pf), (pg), (ph), (pi), (pj), (pk), (pl), (pm), (pn), (po), (pp), (pq), (pr), (ps), (pt), (pu), (pv), (pw), (px), (py), (pz), (qa), (qb), (qc), (qd), (qe), (qf), (qg), (qh), (qi), (qj), (qk), (ql), (qm), (qn), (qo), (qp), (qq), (qr), (qs), (qt), (qu), (qv), (qw), (qx), (qy), (qz), (ra), (rb), (rc), (rd), (re), (rf), (rg), (rh), (ri), (rj), (rk), (rl), (rm), (rn), (ro), (rp), (rq), (rr), (rs), (rt), (ru), (rv), (rw), (rx), (ry), (rz), (sa), (sb), (sc), (sd), (se), (sf), (sg), (sh), (si), (sj), (sk), (sl), (sm), (sn), (so), (sp), (sq), (sr), (ss), (st), (su), (sv), (sw), (sx), (sy), (sz), (ta), (tb), (tc), (td), (te), (tf), (tg), (th), (ti), (tj), (tk), (tl), (tm), (tn), (to), (tp), (tq), (tr), (ts), (tt), (tu), (tv), (tw), (tx), (ty), (tz), (ua), (ub), (uc), (ud), (ue), (uf), (ug), (uh), (ui), (uj), (uk), (ul), (um), (un), (uo), (up), (uq), (ur), (us), (ut), (uu), (uv), (uw), (ux), (uy), (uz), (va), (vb), (vc), (vd), (ve), (vf), (vg), (vh), (vi), (vj), (vk), (vl), (vm), (vn), (vo), (vp), (vq), (vr), (vs), (vt), (vu), (vv), (vw), (vx), (vy), (vz), (wa), (wb), (wc), (wd), (we), (wf), (wg), (wh), (wi), (wj), (wk), (wl), (wm), (wn), (wo), (wp), (wq), (wr), (ws), (wt), (wu), (wv), (ww), (wx), (wy), (wz), (xa), (xb), (xc), (xd), (xe), (xf), (xg), (xh), (xi), (xj), (xk), (xl), (xm), (xn), (xo), (xp), (xq), (xr), (xs), (xt), (xu), (xv), (xw), (xx), (xy), (xz), (ya), (yb), (yc), (yd), (ye), (yf), (yg), (yh), (yi), (yj), (yk), (yl), (ym), (yn), (yo), (yp), (yq), (yr), (ys), (yt), (yu), (yv), (yw), (yx), (yy), (yz), (za), (zb), (zc), (zd), (ze), (zf), (zg), (zh), (zi), (zj), (zk), (zl), (zm), (zn), (zo), (zp), (zq), (zr), (zs), (zt), (zu), (zv), (zw), (zx), (zy), (zz).

(c) When the required Charpy impact test specimens do not meet the lateral expansion requirements in (a)(1)(3) or (a)(1)(2), ASTM E1820 J_{IC} tests shall be conducted on an additional set of two specimens representing the failed set of impact test specimens at a test temperature no warmer than MDMT. The specimen orientation for the base metal and HAZ shall be T-L. A $K_{IC}(J)$ value of not less than 120 ksi $\sqrt{\text{in}}$ (132 MPa $\sqrt{\text{m}}$) is required for all specimens tested.

(b) Required Impact Testing for Welding Procedure Qualification. For welded construction, the Welding Procedure Qualification shall include impact tests of welds in accordance with (1)(4)(b) and with the requirements of (a), when any of the components of the welded joint are required to be impact tested by the rules of this Division.

(c) Required Impact Testing When Thermal Treatments Are Performed. Impact tests are required at the test temperature in accordance with (a) but not warmer than 70 $^{\circ}\text{F}$ (20 $^{\circ}\text{C}$) whenever thermal treatments²⁷ within the temperature ranges listed for the following materials are applied:

(1) austenitic stainless steels thermally treated at temperatures between 900 $^{\circ}\text{F}$ (480 $^{\circ}\text{C}$) and 1650 $^{\circ}\text{F}$ (900 $^{\circ}\text{C}$); however, Types 304, 304L, 316, and 316L that are thermally treated at temperatures between 900 $^{\circ}\text{F}$ (480 $^{\circ}\text{C}$) and 1650 $^{\circ}\text{F}$ (900 $^{\circ}\text{C}$) are exempt from impact testing provided the MDMT is -20°F (-29°C) or warmer

(2) austenitic-ferritic duplex stainless steels thermally treated weld metal are performed for Category A and B joints;

(3) austenitic-ferritic duplex stainless steels thermally treated at temperatures between 600 $^{\circ}\text{F}$ (315 $^{\circ}\text{C}$) and 1650 $^{\circ}\text{F}$ (900 $^{\circ}\text{C}$);

(4) for chromium stainless steels thermally treated at temperatures between 800 $^{\circ}\text{F}$ (425 $^{\circ}\text{C}$) and 1350 $^{\circ}\text{F}$ (730 $^{\circ}\text{C}$);

INTERNATIONAL
STANDARD

ISO
21028-1

Second edition
2016-09-15

4.2 Steels

4.2.1 The materials used for the manufacture of the vessels, the welds and the heat-affected zone shall meet either the minimum impact energy or lateral expansion values.

- a) Ferritic steels: Minimum impact energy value: 34 J/cm².

NOTE 1 34 J/cm² corresponds to a 27 J energy for a full-size specimen.

- b) Austenitic steels: Minimum impact energy value: 40 J/cm².

NOTE 2 40 J/cm² corresponds to a 32 J energy for a full-size specimen.

- c) Minimum lateral expansion value: 0,38 mm.

**Cryogenic vessels — Toughness
requirements for materials at
cryogenic temperature —**

Part 1:

Temperatures below -80 °C

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INTERNATIONAL STANDARD

ISO 19881

First edition
2018-10

Gaseous hydrogen — Land vehicle fuel containers

6.3.2 Impact test for steel

The impact properties of the steel in the finished container or liner shall be determined in general accordance with ISO 148-1 or ASTM E23. The impact test pieces shall be taken from the wall of the container in the transverse direction. The notch plane orientation shall be in the C-L direction (i.e., perpendicular to the circumference and along the length). Test pieces with a width of less than 5 mm shall be taken from the longitudinal direction. If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the container wall. All impact tests shall be conducted at -40 °C. Impact values shall not be less than that indicated as follows:

Width of the test piece	(mm)	5,0 ≤ width < 7,5	7,5 ≤ width < 10,0
Impact strength	(J/cm ²)	35	40

- a) Impact values for test pieces of width less than 5 mm shall be based on special studies of particular materials and particular specimens.
- b) Required average results of three specimens.
- c) Not more than one specimen shall break at less than the average value required and no single specimen shall break at less than 80 % of the average value.

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CRYOGENIC APPLICATIONS – CHARPY, LATERAL EXPANSION & STANDARDS – LATERAL EXPANSION

ASME B31.12-2011

Table A-2-1 Materials Compatible With Hydrogen Service

Material	Form of Hydrogen		Notes
	Gas	Liquid	
Aluminum and aluminum alloys	Acceptable	Acceptable	...
Austenitic stainless steels with greater than 7% nickel (e.g., 304, 304L, 308, 316, 321, 347)	Acceptable	Acceptable	Beware of martensitic conversion at low temperature if stressed above yield point
Carbon steels	Acceptable	Not acceptable	Too brittle for cryogenic service
Copper and copper alloys (e.g., brass, bronze, and copper-nickel)	Acceptable	Acceptable	...
Gray, ductile, or cast iron	Not acceptable	Not acceptable	Not permitted for hydrogen service
Low-alloy steels	Acceptable	Not acceptable	Too brittle for cryogenic service
Nickel and nickel alloys (e.g., Inconel and Monel)	Not acceptable	Acceptable	Beware of susceptibility to hydrogen embrittlement
Nickel steels (e.g., 2.25%, 3.5%, 5%, and 9% Ni)	Not acceptable	Not acceptable	Beware of ductility loss
Titanium and titanium alloys	Acceptable	Acceptable	...

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