Technical Datasheet

CARPENTER TECHNOLOGY

CarTech® Micro-Melt® DuoSorb® 316NU Alloys

Identification

U.S. Patent Number

- 9,267,192

Type Analysis

Single figures are nominal except where noted.

Carbon (Maximum)	0.08 %	**Manganese (Maximum)**	3.00 %
Phosphorus (Maximum)	0.050 %	**Sulfur (Maximum)**	0.030 %
Silicon (Maximum)	2.00 %	**Chromium**	17.00 to 27.00 %
Nickel	11.00 to 20.00 %	**Molybdenum (Maximum)**	5.20 %
Cobalt (Maximum)	0.20 %	**Boron**	0.250 to 2.000 %
Nitrogen (Maximum)	0.20 %	**Iron**	Balance
Gadolinium	0.05 to 2.60 %		

Bequivalent = B+(4.35 x Gd): 0.78-13.00%

General Information

Description

CarTech Micro-Melt DuoSorb 316NU alloys are powder metallurgy 316 type stainless steels containing varying amounts of two thermal neutron absorbing elements, boron and gadolinium. Despite its much higher atomic weight, gadolinium has more than four times the thermal neutron absorbing capabilities of boron. By restricting the boron content to less than 1%, and using gadolinium to attain an equivalent boron content (Beq), the new alloys exhibit superior ductility, toughness, bendability and corrosion resistance compared to borated stainless steels.

The alloys exhibit a substantially higher thermal neutron absorbing cross section than borated stainless steels and approach that of Boral® and other boron-containing composites, such as Metamic®. While boron remains the traditional thermal neutron absorber for containment of spent nuclear fuel materials, gadolinium has a higher thermal neutron cross section than boron.

The production of the CarTech Micro-Melt DuoSorb alloys is enhanced by the use of powder metal technology. PM processing yields a fine-grained, uniform microstructure, which improves hot and cold fabricability and facilitates consistent thermal neutron absorption capabilities throughout the product.

Applications

These alloys can be considered for use in the nuclear industry for spent fuel storage racks and transportation casks, control rods, burnable poison, and shielding.

Boron Isotopes

Neutron Absorption

The boron equivalent (Beq) equation calculates the barns number, i.e. the 0.023 eV thermal neutron absorption cross section number, for the total weight percent of naturally occurring boron and gadolinium in a given CarTech Micro-Melt DuoSorb alloy. The calculation is performed by dividing the barns numbers for boron and gadolinium by their respective atomic weights and then dividing the ratio of the gadolinium barns/gram number by the gadolinium barns/gram number. The result of this calculation is 1 wt.% Gd = 4.35 wt.% B, and the resultant boron equivalent equation is Beq = wt.% B + 4.35 wt.% Gd. This equation provides a relative measure of the theoretical ability of a DuoSorb alloy to capture thermal neutrons. The higher the boron equivalent number, the greater the potential to capture thermal neutrons.

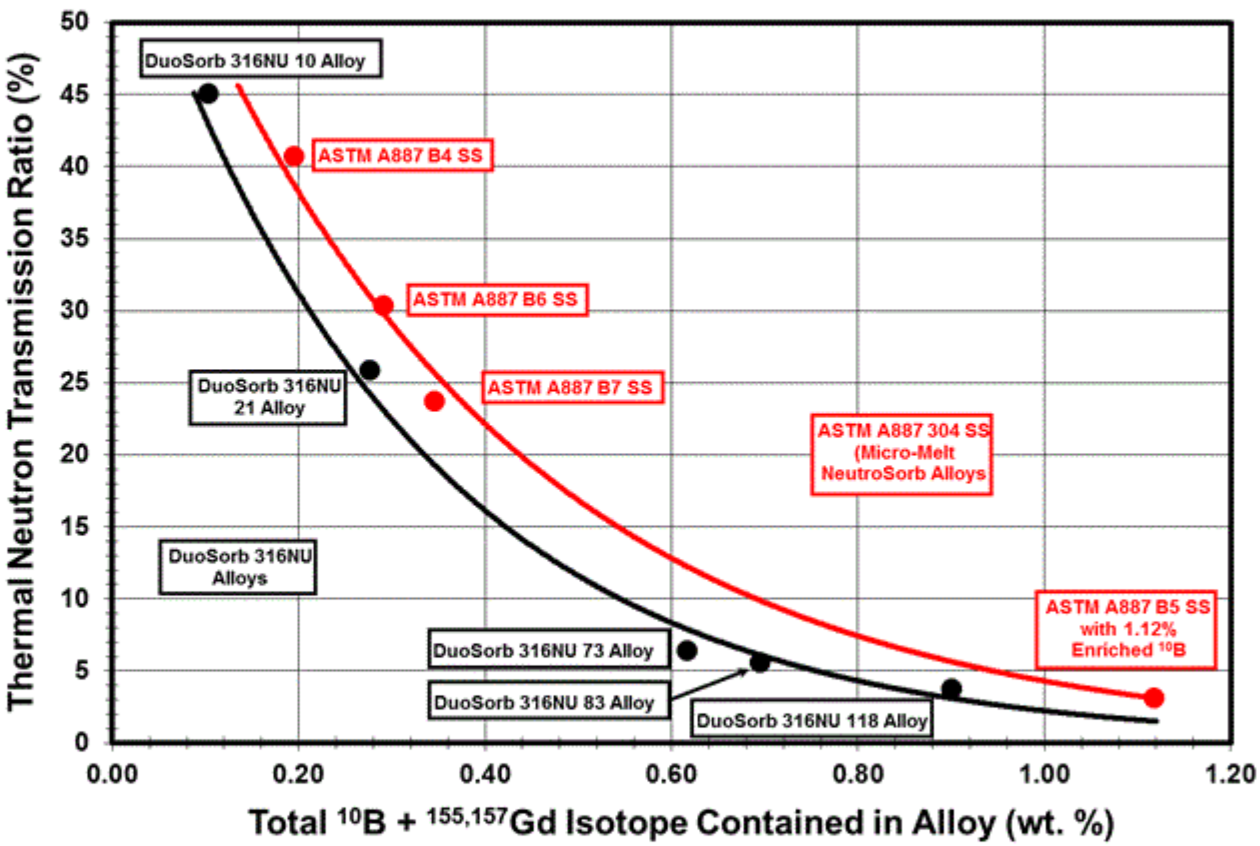
The actual ability of a particular CarTech Micro-Melt DuoSorb alloy to capture thermal neutrons is measured empirically by testing metallurgical samples in a reactor window and determining the thermal transmission ratio of the material, i.e. the ratio of the number of thermal neutrons passing through and leaving the sample divided by the thermal neutrons entering the sample. The lower the transmission level, the higher the thermal neutron absorption capability of the sample.

Figure 1 shows the relationship between the thermal neutron transmission ratio and the total 10B+155Gd +157Gd isotopic content of several CarTech Micro-Melt DuoSorb 316NU alloys. As can be seen, using natural Gd in Cartech Micro-Melt 316NU alloys to enhance thermal neutron absorption, produces cost effective performance compared to CarTech Micro-Melt NeutroSorb enriched with costly 10B, and performance approaching that of existing metal matrix composite materials such as pressed B4C, Metamic® and Boral® (Figure 2).

Product Information Images

Figure 1

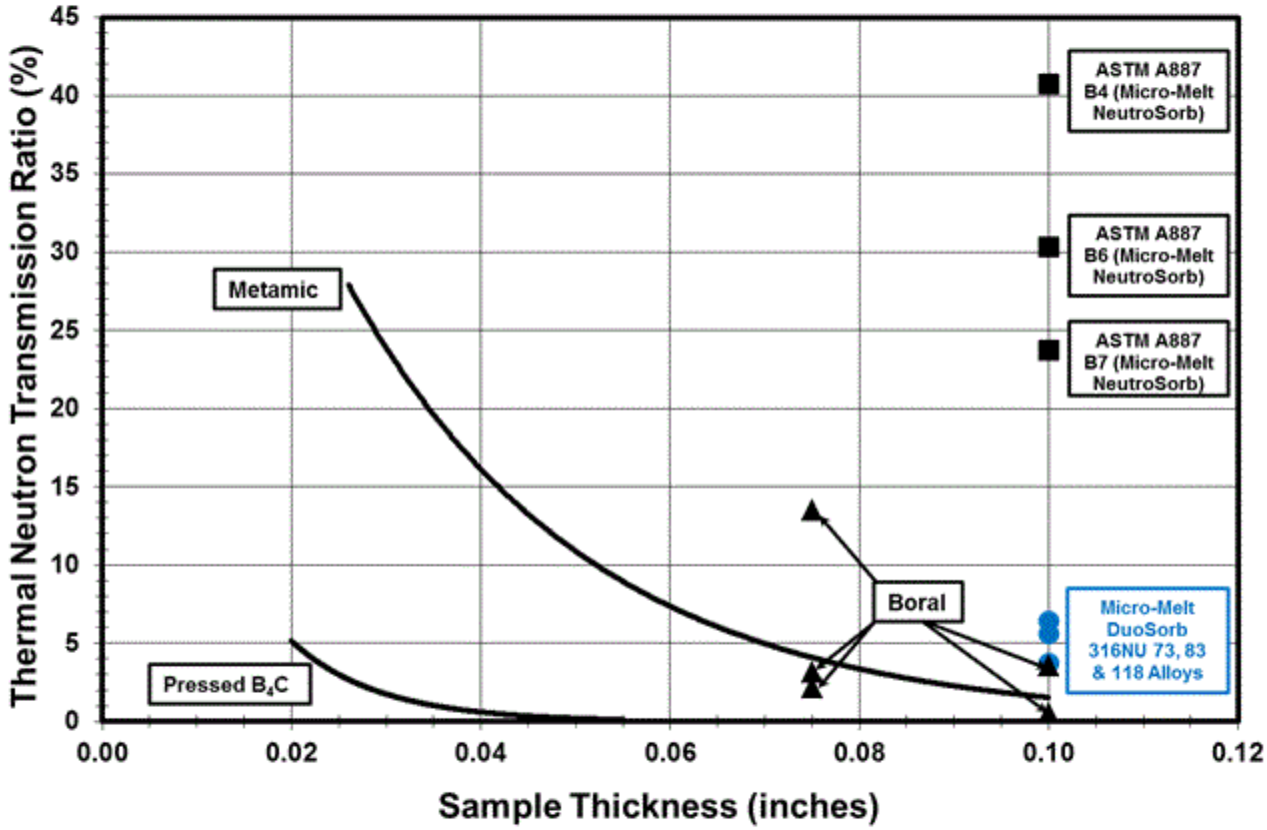
Thermal neutron transmission ratio versus total ^{10}B + $^{155,157}Gd$ isotopic content – CarTech® Micro-Melt® DuoSorb® Alloys and ASTM A887 (Micro-Melt® NeutroSorb® Alloys)



Data obtained from a NETCO-Carpenter testing program

Figure 2

Thermal neutron transmission ratio versus total sample thickness of several CarTech® Micro-Melt® DuoSorb® 316NU Alloys compared to CarTech® Micro-Melt® NeutroSorb® borated stainless steels, pressed B_4C, Metamic® and Boral® NETCO standards



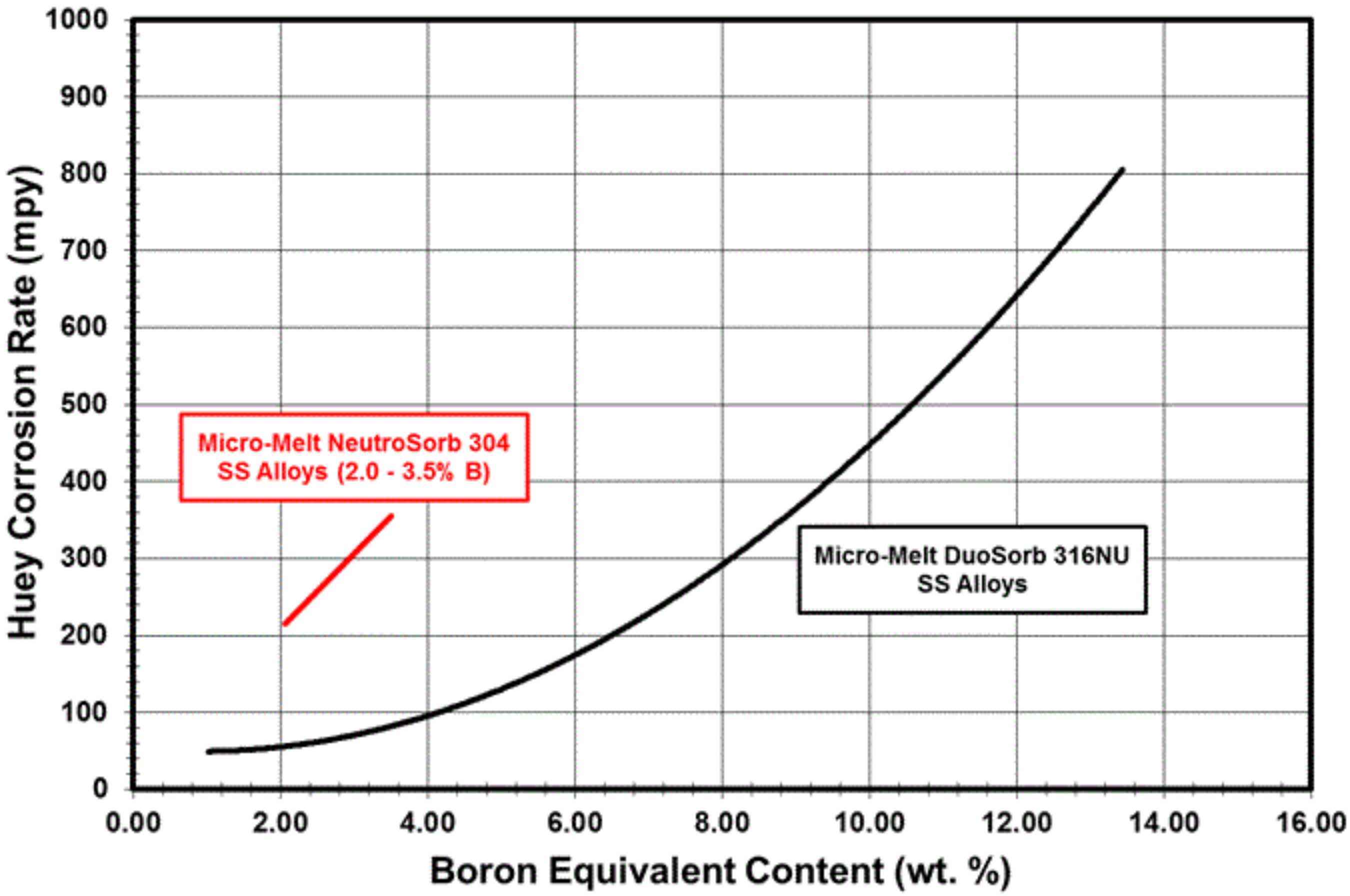
Data obtained from a NETCO-Carpenter testing program
Boral® is a registered trademark of Ceradyne Inc.
Metamic® is a registered trademark of Metamic LLC.

Corrosion Resistance

CarTech Micro-Melt DuoSorb 316NU alloys containing boron and gadolinium exhibit superior corrosion resistance compared to straight boron containing 304 alloys. CarTech Micro-Melt DuoSorb 316NU alloys have been laboratory tested in simulated spent fuel pool water containing 13,000 ppm boric acid and 10 PPM Cl- and show no corrosion.

Figure 3

Huey Corrosion Rate (ASTM A262-C) – Cartech® Micro-Melt® NeutroSorb® Borated 304 Stainless Steel Alloys and Cartech® Micro-Melt® DuoSorb® 316NU Alloys



Condition: Annealed at 1950°F – 1h, WQ

Properties

Physical Properties

Specific Gravity	7.89

Figure 4

Specific Gravity and Density – CarTech® Micro-Melt® DuoSorb® Alloys

CarTech® Micro-Melt® DuoSorb® Alloys	Specific Gravity	Density	
		lb/in³	kg/m³
316NU-30 Alloy (B=0.82%; Gd=0.50%; Beq=2.99%)	7.89	0.285	7886
316NU-70 Alloy (B=0.86%; Gd=1.42%; Beq=7.04%)	7.89	0.285	7788
316NU-94 Alloy (B=0.87%; Gd=1.96%; Beq=9.40%)	7.88	0.285	7878

Figure 5

Mean Specific Heat – CarTech® Micro-Melt® DuoSorb® Alloys

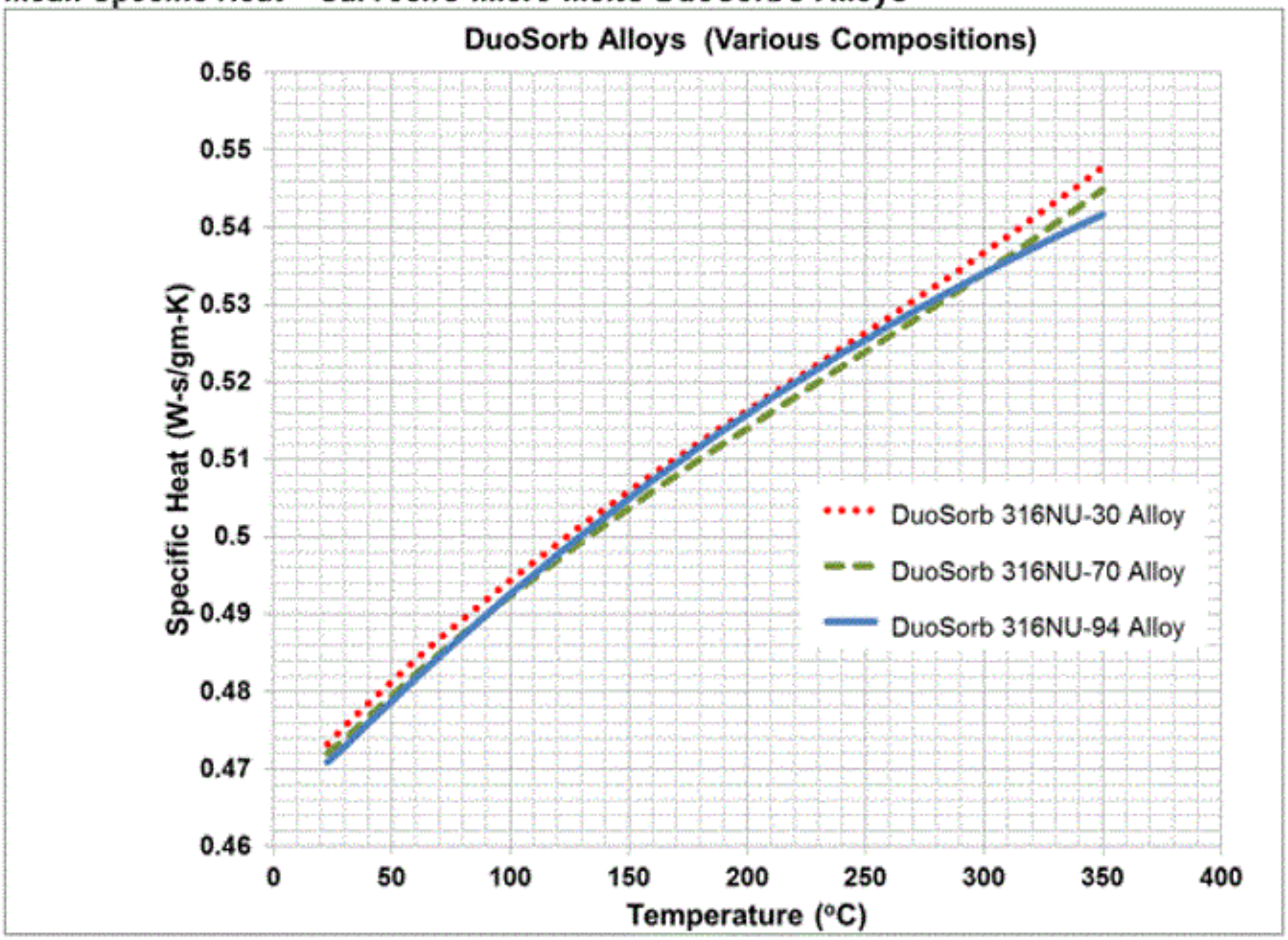


Figure 6

Mean Coefficient of Thermal Expansion – CarTech® Micro-Melt® DuoSorb® 316NU-30 Alloy

Temperature		10^6/°F	10^6/°C
77°F to	25°C to		
212	100	8.53	15.36
392	200	8.86	15.95
572	300	9.11	16.39
752	400	9.30	16.74
932	500	9.47	17.04
1202	650	9.73	17.51

Mean Coefficient of Thermal Expansion - CarTech® Micro-Melt® DuoSorb® 316NU-70 Alloy

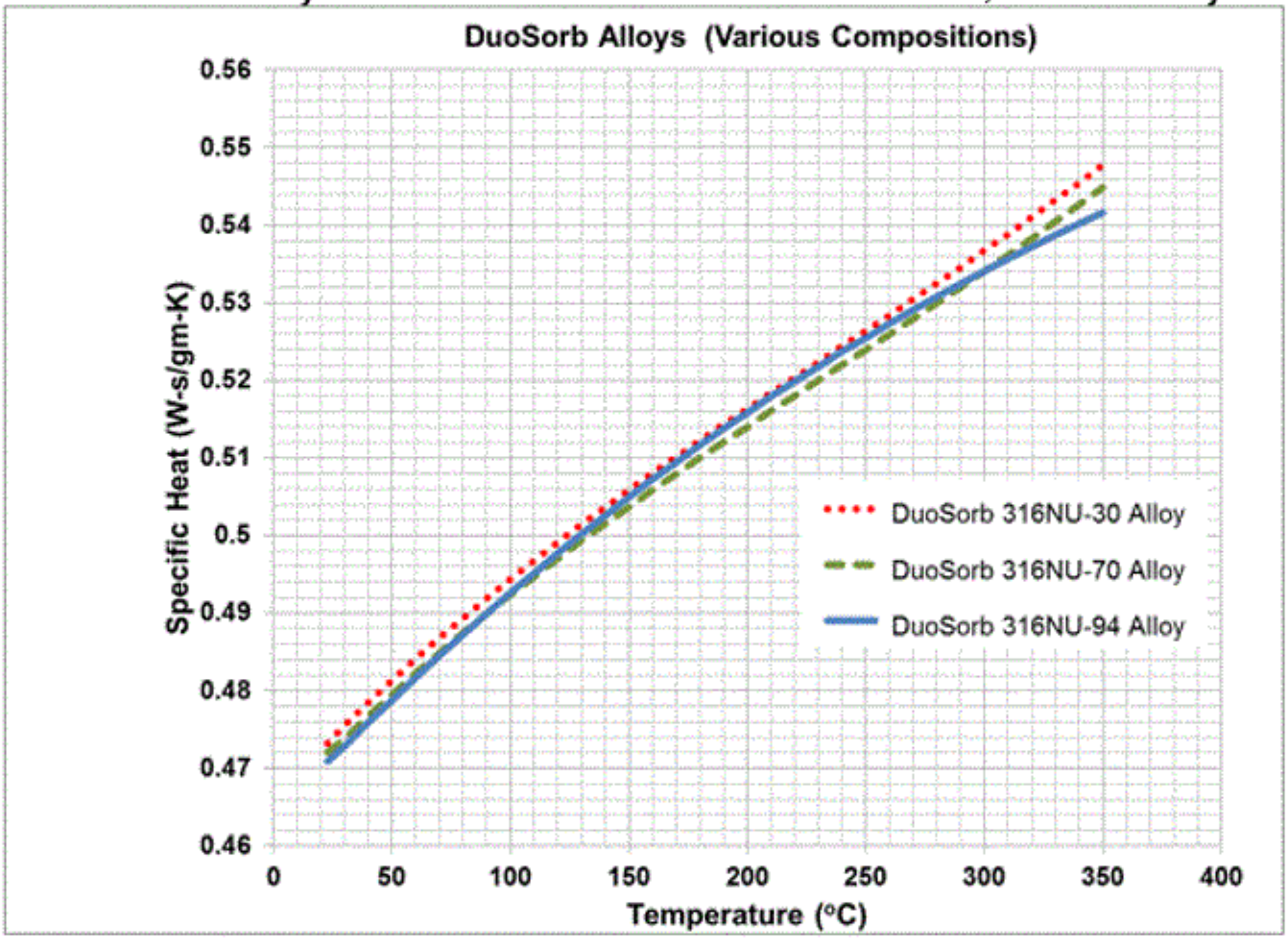
Temperature		10^6/°F	10^6/°C
77°F to	25°C to		
212	100	8.60	15.48
392	200	8.86	15.94
572	300	9.07	16.32
752	400	9.26	16.66
932	500	9.41	16.93
1202	650	9.65	17.37

Mean Coefficient of Thermal Expansion - CarTech® Micro-Melt® DuoSorb® 316NU-94 Alloy

Temperature		10^6/°F	10^6/°C
77°F to	25°C to		
212	100	8.36	15.05
392	200	8.65	15.57
572	300	8.87	15.96
752	400	9.04	16.27
932	500	9.18	16.52
1202	650	9.42	16.96

Figure 7

Thermal Conductivity - CarTech® Micro-Melt® DuoSorb® 316NU-30, 70 and 94 Alloys



Modulus of Elasticity – CarTech® Micro-Melt® DuoSorb® Alloys

Temperature	Micro-Melt DuoSorb 316NU-30	Micro-Melt DuoSorb 316NU-70	Micro-Melt DuoSorb 316NU-94
70°F -320°F 662°F	28.0×10^6 ksi 30.8×10^6 ksi 22.7×10^6 ksi	29.0×10^6 ksi 29.1×10^6 ksi 22.7×10^6 ksi	28.1×10^6 ksi 29.2×10^6 ksi 22.1×10^6 ksi
21.1°C -195.6°C 350°C	193.1×10^6 MPa 212.6×10^6 MPa 156.5×10^6 MPa	199.7×10^6 MPa 200.9×10^6 MPa 156.3×10^6 MPa	194.0×10^6 MPa 201.1×10^6 MPa 152.1×10^6 MPa

Figure 9

Electrical Resistivity – CarTech® Micro-Melt® DuoSorb® Alloys

Temperature	Micro-Melt DuoSorb 316NU-30	Micro-Melt DuoSorb 316NU-70	Micro-Melt DuoSorb 316NU-94
70ºF	32.03 micro-ohm in	32.43 micro-ohm in	32.38 micro-ohm in
21.1ºC	813.56 micro-ohm mm	823.72 micro-ohm mm	822.45 micro-ohm mm

Typical Mechanical Properties

Typical Room Temperature Mechanical Properties – CarTech® Micro-Melt® DuoSorb® Alloys

CarTech® Micro-Melt® DuoSorb® 316NU Alloy	Temperature °F (°C)	0.2% Yield Strength		Ultimate Tensile strength		% Elongation in 4D	% Reduction of Area	Charpy V-notch		Fracture Toughness		BHN
		ksi	MPa	ksi	MPa			Ft.-lbs.	J	ksi√in	MPa√M	
316NU-30	-320 (-196)	113	779	189	1303	14	15	7	9.5	----	----	---
	R.T.	57	393	114	784	30	28	20	27.1	----	----	234
	662 (350)	42	290	89	614	25	23	---	---	----	----	---
316NU-70	-320 (-196)	94	648	172	1186	10	10	7	9.5	----	----	---
	R.T.	56	386	112	772	26	29	20	27.1	----	----	232
	662 (350)	46	317	88	607	22	23	---	---	----	----	---
316NU-94	-320 (-196)	80	552	161	1110	10	10	7	9.5	----	----	---
	R.T.	51	352	106	731	22	28	17	23.0	----	----	224
	662 (350)	41	283	85	586	20	22	---	---	----	----	---

Heat Treatment

Annealing

Heat to 1900/2050°F (1038/1093°C), hold 30-60 minutes and quench in water or rapid gas quench.

Workability

Hot Working

Heat uniformly to 2050/2125°F (1121/1163°C). Do not overheat these alloys. Do not hot work below 1700°F (927°C). Because of the presence of borides and gadolinides in the microstructure of these alloys, more power for a given reduction is required than for regular 316 stainless steels. Hot worked products can be air-cooled without danger of cracking. For full corrosion resistance, hot worked products must be solution annealed.

Cold Working

CarTech Micro-Melt DuoSorb alloys have higher cold working rates than 316 stainless steels, but have improved cold working capabilities over borated stainless steels. Micro-Melt DuoSorb alloys containing less than 1wt% B have significantly higher cold workability than ASTM A887 Grade B7 alloys while having significantly higher thermal neutron absorption capability than ASTM A887 Grade B7. This cold working behavior as measure by bend angle is shown in Figure 11. The cross hatching in Figure 11 indicates that bend performance for alloys containing B >1% and <2% would be expected to lie within the area bounded by the two lines defining Micro-Melt® DuoSorb® 316NU Alloys.

Machinability

Compared with AISI B1112, the machinability ratings of these alloys vary from 20% (2% boron) to 50% (boron less than 1%). The higher boron contents cause faster tool wear.

Weldability

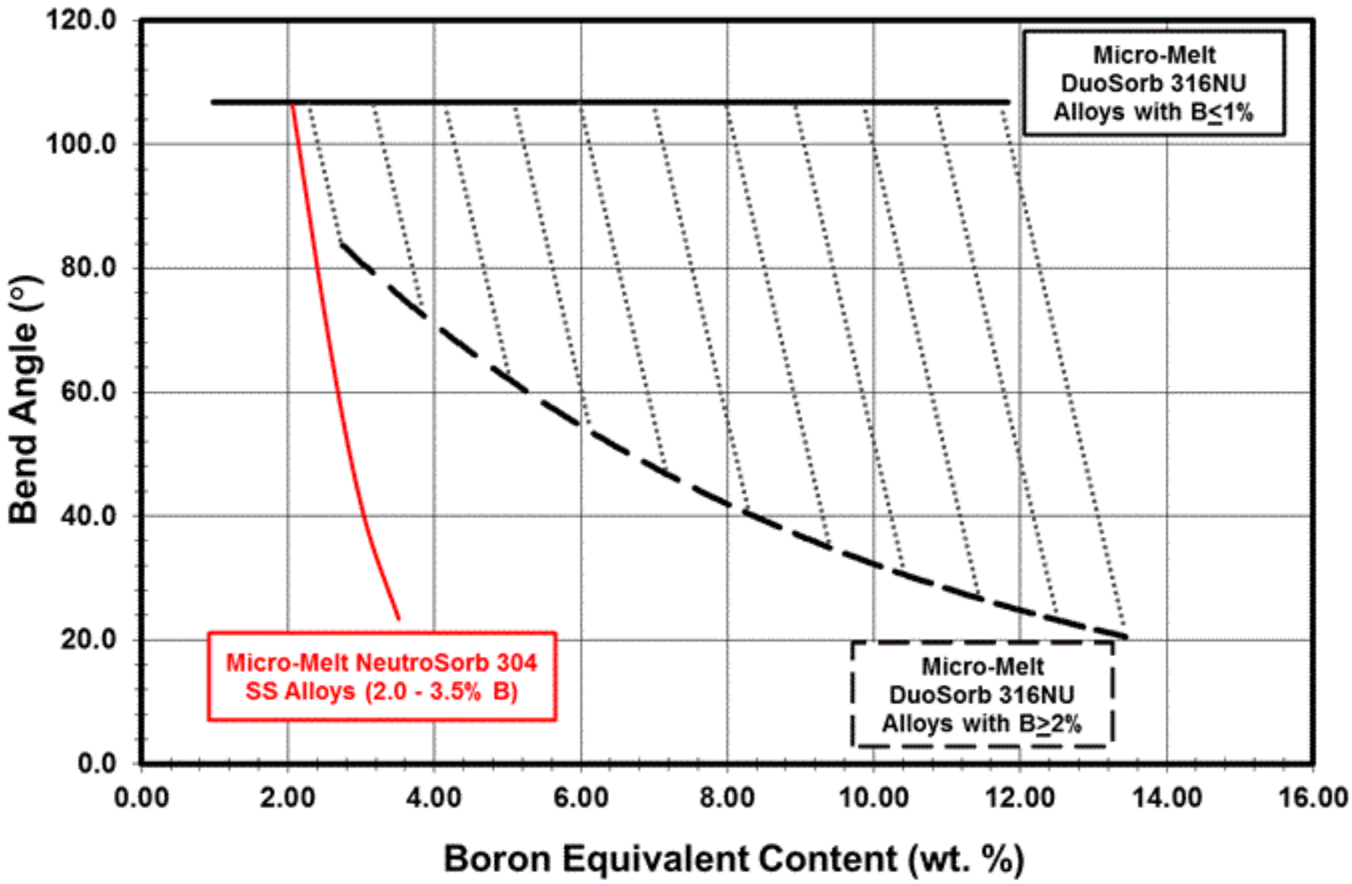
CarTech Micro-Melt DuoSorb alloys can we welded; however, the welds will possess limited ductility. If these alloys must be welded, consider using AWS E/ER308 or 309 welding consumables. Use minimum heat inputs and limit the base metal dilution. Full annealing of welded sections restores the weld area to the baseline properties of the alloy.

Other Information

Metallurgical Requirements

Figure 11

Bend angle versus B_{Eq} content for Cartech® Micro-Melt® NeutroSorb® Borated 304 Stainless Steel Alloys and Cartech® Micro-Melt® DuoSorb® 316NU Alloys with Boron contents ≤1% and ≥2%



Condition: Annealed at 1950°F – 1h, WQ

Forms Manufactured

- Bar-Flats
- Bar-Rounds
- HIP'd Shapes
- Plate
- Powder
- Sheet
- Strip

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Edition Date: 1/20/2016

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