Technical Datasheet CARPENTER TECHNOLOGY

CarTech® BioDur® CCM Plus® Alloy

Identification

U.S. Patent Number

• 5,462,575

Type Analysis

Single figures are nominal except where noted.

Carbon	0.20 to 0.30 %	**Chromium**	26.00 to 30.00 %
Molybdenum	5.00 to 7.00 %	**Cobalt**	Balance
Nitrogen	0.15 to 0.20 %		

General Information

Description

CarTech BioDur CCM Plus alloy is a non-magnetic, cobalt-chromium-molybdenum alloy exhibiting high strength, corrosion resistance, and wear resistance.

This alloy is a high carbon version of CarTech BioDur CCM alloy and meets the requirements of ASTM F1537, ASTM F799, ISO 5832-12 and ISO 5832-4.

CarTech BioDur CCM Plus alloy is a wrought powder metallurgy product produced by vacuum induction melting (VIM) followed by gas atomization and hot isostatic pressing to produce 100% dense billets. These billets are then processed by conventional steel-making practices to produce finished products.

CarTech BioDur CCM Plus alloy possesses the following product attributes:

* homogeneous chemistry and microstructure;

* small, uniformly distributed carbides, typically less than 10 microns in length as measured on longitudinal sections;

* fine austenitic grain size, typically ASTM E112 grain size number 12 and finer for hot rolled material and 10-11 and finer for material annealed at 2050/2100°F (1121/1149°C) for 1 hour and water quenched;

* improved forgeability over CarTech BioDur CCM alloy;

* meets ASTM F799 requirements without requiring thermomechanical processing;

* retains a high strength level after high temperature annealing;

* improved machinability over CarTech BioDur CCM alloy.

Because CarTech BioDur CCM Plus alloy does not require thermomechanical processing in order to meet ASTM F799 mechanical property requirements, normally supplies the finished product in the hot worked condition.

Applications

CarTech BioDur CCM Plus alloy should be considered as a candidate for use in the orthopedic industry for joint replacement and fracture fixation devices such as total hip, knee, and shoulder replacements, especially when wear or fatigue properties are of major importance or where intricate high strength forgings are required.

CarTech BioDur CCM Plus alloy should be considered for use in producing large forgings where it is difficult to attain ASTM F799 properties throughout the forging's cross section due to a lack of sufficient thermomechanical processing. Applications have included hip and knee forgings and machined modular femoral heads for metal-metal and metal-HDPE wear couples.

Corrosion Resistance

Important Note: *The following 4-level rating scale is intended for comparative purposes only. Corrosion testing is recommended; factors which affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish and dissimilar metal contact.*

Nitric Acid	Excellent	Sulfuric Acid	Good
Phosphoric Acid	Good	Acetic Acid	Excellent
Sodium Hydroxide	Moderate	Salt Spray (NaCl)	Excellent
Sea Water	Good	Humidity	Excellent

Properties

Physical Properties

Specific Gravity	8.28	
Density	0.2990	lb/in³
Mean Specific Heat		
73°F	0.1080	Btu/lb/°F
212°F	0.1120	Btu/lb/°F
572°F	0.1230	Btu/lb/°F
1112°F	0.1410	Btu/lb/°F
1652°F	0.1550	Btu/lb/°F
1832°F	0.1570	Btu/lb/°F
2012°F	0.1610	Btu/lb/°F

Specific heat

The specific heat of BioDur CCM Plus alloy is equivalent to that of BioDur Carpenter CCM alloy.

Temperature		Specific Heat	
°F	°C	Btu/(lb•°F)	(W•S)/(Kg•K)
73	23	0.108	452
212	100	0.112	470
572	300	0.123	516
1112	600	0.141	590
1652	900	0.155	647
1832	1000	0.157	660
2012	1100	0.161	673

Mean CTE		
68 to 212°F	7.11	x 10^{-6} in/in/°F
68 to 392°F	7.16	x 10^{-6} in/in/°F
68 to 572°F	7.30	x 10^{-6} in/in/°F
68 to 752°F	7.49	x 10^{-6} in/in/°F
68 to 932°F	7.68	x 10^{-6} in/in/°F
68 to 1112°F	7.90	x 10^{-6} in/in/°F
68 to 1292°F	8.18	x 10^{-6} in/in/°F
68 to 1472°F	8.33	x 10^{-6} in/in/°F
68 to 1652°F	8.52	x 10^{-6} in/in/°F
68 to 1832°F	8.79	x 10^{-6} in/in/°F
68 to 2048°F	9.11	x 10^{-6} in/in/°F
68 to 2102°F	9.24	x 10^{-6} in/in/°F
68 to 2156°F	9.40	x 10^{-6} in/in/°F

Mean coefficient of thermal expansion

Microinches/inch/°C from 20°C to the indicated temperature or microinches/inch/°F from 68°F to the indicated temperature.

The mean coefficient of thermal expansion of BioDur CCM Plus alloy is similar to that of BioDur Carpenter CCM alloy.

Workpiece Temperature		Mean Coefficient Thermal of Expansion	
°F	°C	per °F	per °C
212	100	7.11	12.791
392	200	7.16	12.886
572	300	7.30	13.133
752	400	7.49	13.473
932	500	7.68	13.825
1112	600	7.90	14.213
1292	700	8.18	14.721
1472	800	8.33	15.000
1652	900	8.52	15.331
1832	1000	8.79	15.826
2048	1120	9.11	16.403
2102	1150	9.24	16.638
2156	1180	9.40	16.916

Thermal Conductivity		
73°F	88.57	BTU-in/hr/ft²/°F
212°F	100.5	BTU-in/hr/ft²/°F
572°F	127.2	BTU-in/hr/ft²/°F
1112°F	175.3	BTU-in/hr/ft²/°F
1652°F	202.3	BTU-in/hr/ft²/°F
1832°F	219.2	BTU-in/hr/ft²/°F
2012°F	229.3	BTU-in/hr/ft²/°F
2150°F	243.0	BTU-in/hr/ft²/°F

Thermal conductivity

The thermal conductivity of BioDur CCM Plus alloy is similar to that of BioDur Carpenter CCM alloy.

Temperature		Thermal Conductivity	
°F	°C	(Btu•in)/(hr•ft²•°F)	W/(m•K)
73	23	88.57	12.766
212	100	100.47	14.481
572	300	127.21	18.334
1112	600	175.28	25.264
1652	900	202.26	29.152
1832	1000	219.22	31.596
2012	1100	229.34	33.055
2150	1177	242.98	35.022

Poisson's Ratio	0.300	
Modulus of Elasticity (E)	35.0	x 10^3 ksi
Modulus of Rigidity (G)	13.4	x 10^3 ksi

Typical Mechanical Properties

Typical Mechanical Properties—BioDur Carpenter CCM Alloy

The following data are provided for comparison to BioDur CCM Plus Alloy.

Condition	0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 4D	% Reduction of Area	HRC Hardness
	ksi	MPa	ksi	MPa			
Annealed	85	585	150	1035	25	23	30
Warm Worked	135	930	190	1310	26	23	40
Hot Worked	110	760	160	1100	25	23	33

Typical Mechanical Properties—BioDur CCM Plus Alloy

Tensile specimens were low stress ground prior to testing.

Condition		0.2% Yield Strength		Ultimate Tensile Strength		% Elongation in 4D	% Reduction of Area	HRC Hardness
		ksi	MPa	ksi	MPa			
Hot Worked		135	930	198	1365	22	17	43
Annealed	2000°F/1hr+WQ	128	882	196	1351	22	18	42
	2050°F/1hr+WQ	123	848	203	1399	28	24	41
	2100°F/1hr+WQ	117	806	202	1392	29	25	40
	2200°F/2hr+WQ	104	717	190	1310	32	27	36
ASTM F799 Requirements		120	827	170	1172	12	12	35

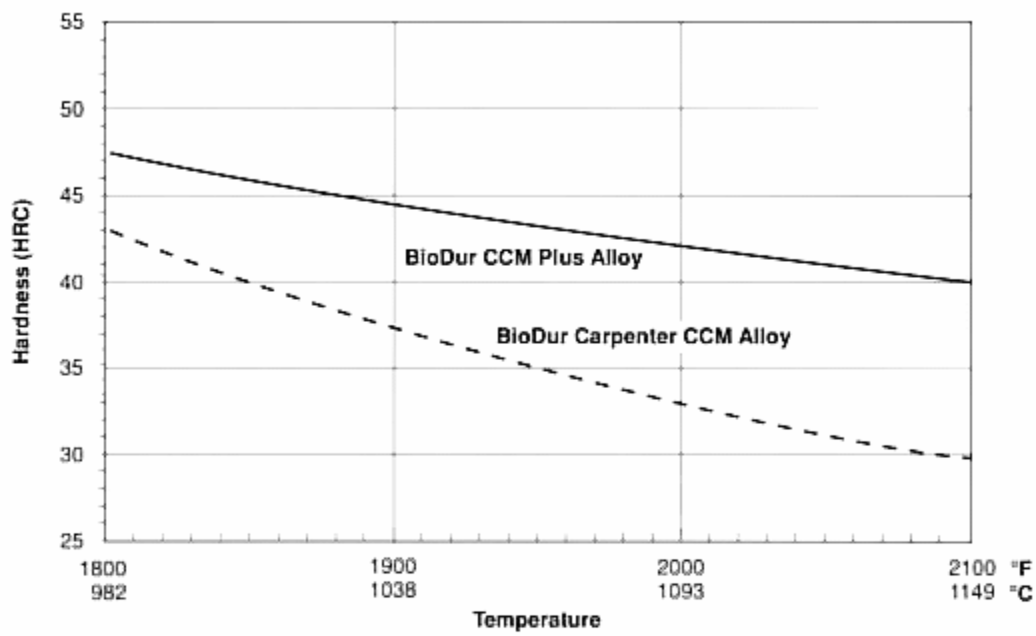
Heat Treatment

Annealing

BioDur CCM Plus alloy is not normally supplied in the annealed condition. If annealing is desired the alloy can be annealed at 2000°F/2100°F (1093°C/1149°C) for 1 hour followed by water quenching. Finer grain size can be maintained through the use of lower annealing temperatures with corresponding increases in annealed hardness.

Hardness vs. Temperature—BioDur CCM Plus Alloy vs. BioDur Carpenter CCM Alloy

1 hour, air cooled.



Workability

Hot Working

BioDur CCM Plus alloy should be hot worked from a furnace temperature of 2050/2100°F (1121/1149°C). BioDur CCM Plus alloy produces a forging that meets ASTM F799 requirements without using thermomechanical processing.

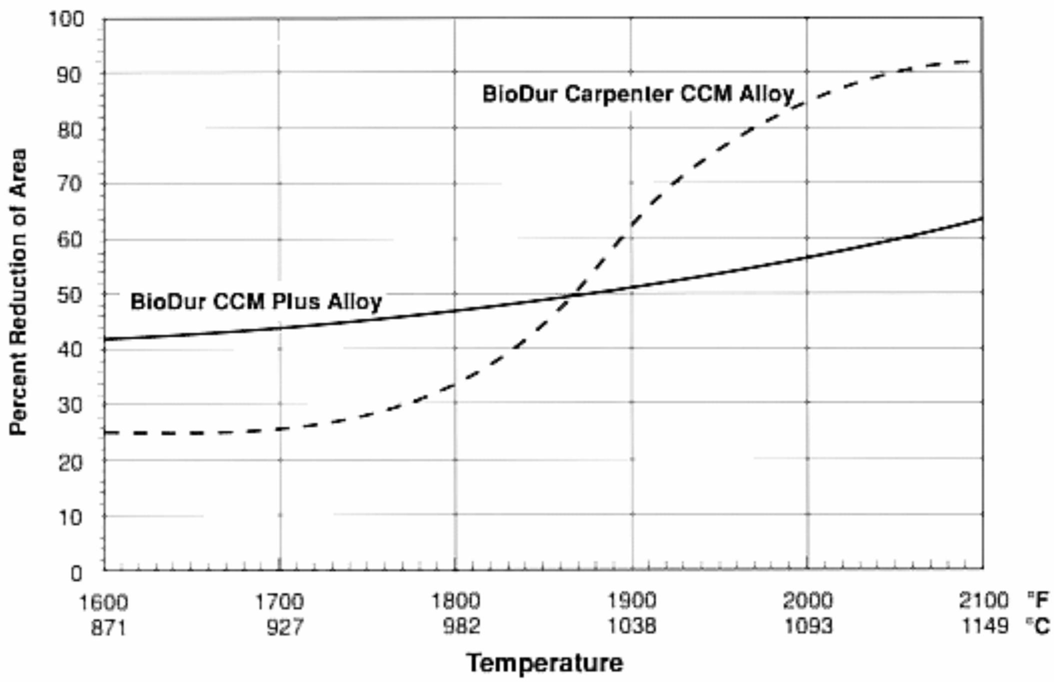
Gleeble Testing for Hot Workability

Gleeble* testing is used by Carpenter Technology as a measure of a material's hot workability. On-heating Gleeble data show the general temperature range over which an alloy can be hot worked at a given strain rate, as well as the temperature where the ductility falls to zero (hot shortness).

The temperature corresponding to the peak ductility of the on-heating curve is recommended to be used as the heating temperature for the material, see the figure entitled "Comparative On-Heating Gleeble Curves." Using this temperature, the Gleeble on-cooling curve is generated, see the figure entitled "Comparative On-Cooling Gleeble Curves." This curve shows relative ductility as a function of temperature and reduction of area. Forty to fifty percent reduction of area is considered acceptable. Fifty to sixty percent is good, sixty to seventy percent is excellent and higher than seventy percent is superior.

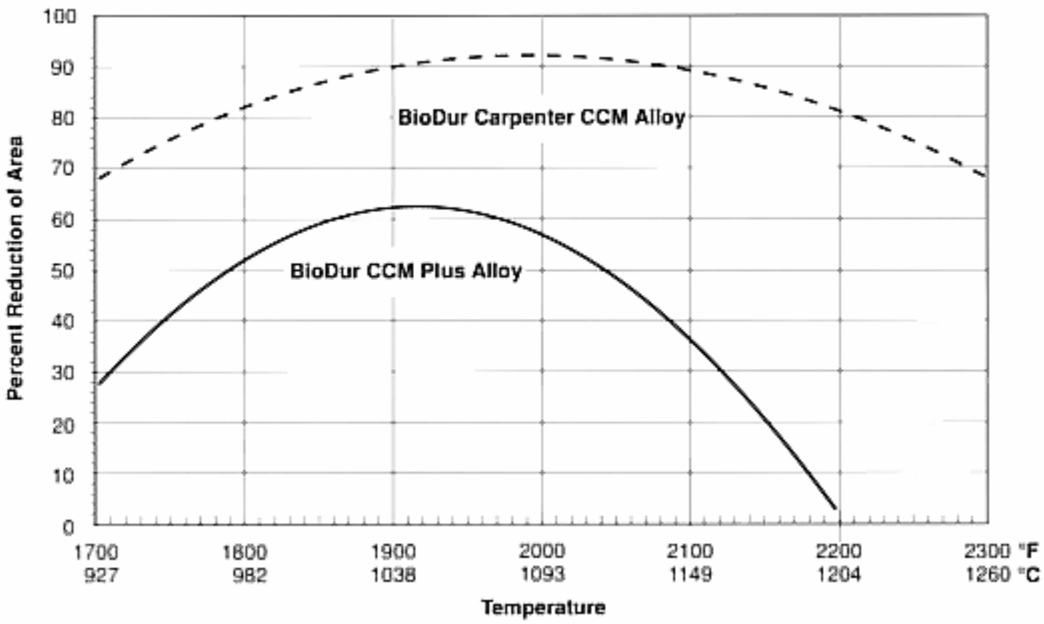
*Gleeble is a registered trademark of Dynamic Systems Inc.

Comparative On-Cooling Gleeble Curves from 2100°F (1149°C)—BioDur CCM Plus Alloy vs. BioDur Carpenter CCM Alloy
Strain Rate-20/sec.



Gleeble is a registered trademark of Dynamic Systems Inc.

Comparative On-Heating Gleeble Curves—BioDur CCM Plus Alloy vs. BioDur Carpenter CCM Alloy
Strain Rate-20/sec.



Gleeble is a registered trademark of Dynamic Systems Inc.

Gleeble Testing for Flow Stress

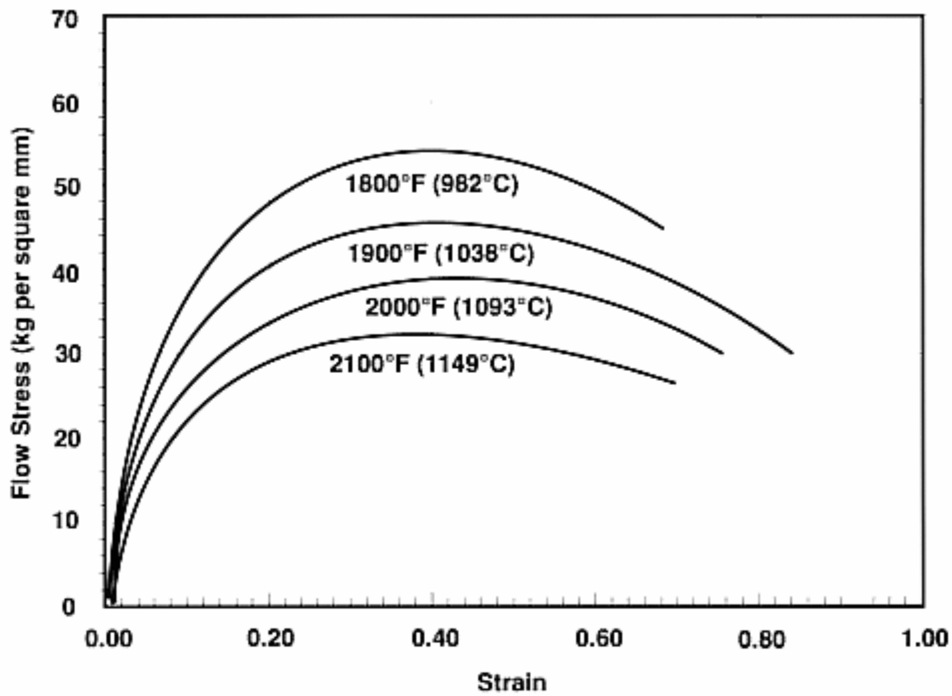
Gleeble* testing is also used by Carpenter to determine a material's flow stress as a function of temperature and strain rate. Using the Gleeble, compression testing is performed and true stress (flow stress) - true strain curves are generated.

The graphs within the hyperlinks below entitled "Flow Stress Curves" show how the flow stress and strain are related in the range of forging temperatures. The graph for BioDur Carpenter CCM alloy is included for reference. Both alloys have similar maximum flow stress values for a given forging temperature. Each true stress, true strain curve is composed of two different regions: work hardening, where the curve increases to a maximum, and dynamic recrystallization, where the curve decreases.

BioDur CCM Plus alloy work hardens to its maximum flow stress at a strain between 0.20 and 0.30 while the BioDur Carpenter CCM alloy has a maximum flow stress at a strain of 0.40 BioDur CCM Plus alloy begins dynamic recrystallization earlier than BioDur Carpenter CCM alloy, making it easier to forge.

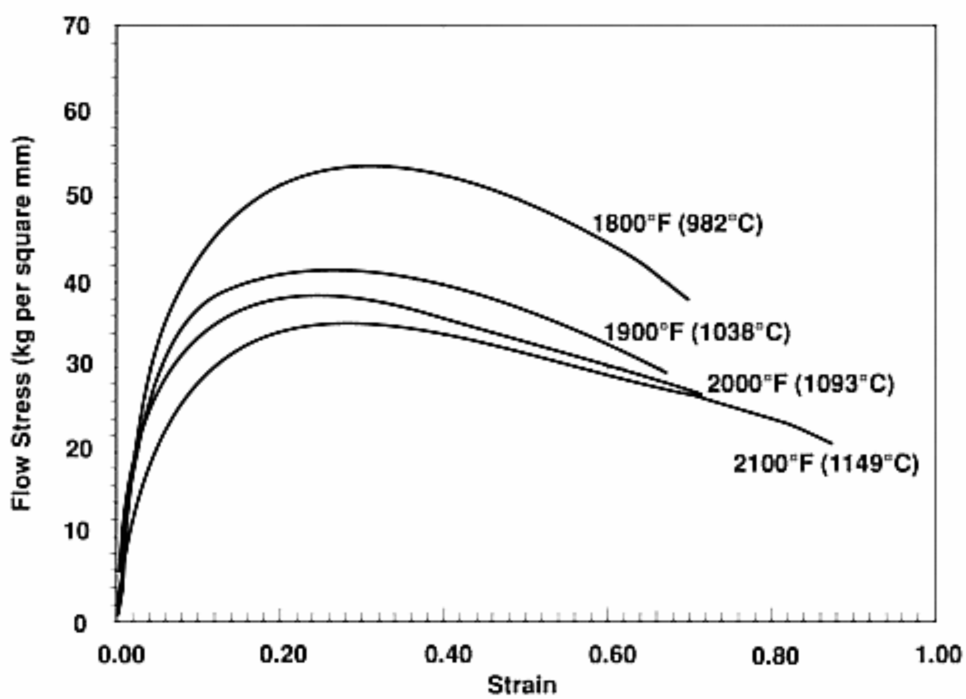
*Gleeble is a registered trademark of Dynamic Systems Inc.

Flow Stress Curves—BioDur Carpenter CCM Alloy
Strain Rate-20/sec. Included for comparison to BioDur CCM Plus alloy.



1 kg per square mm = 1.422 ksi

Flow Stress Curves—BioDur CCM Plus Alloy
Strain Rate-20/sec.



1 kg per square mm = 1.422 ksi

Cold Working

High strength levels can be achieved in BioDur CCM Plus alloy through either hot/cold work or cold-work only processes. Significant loss of ductility results from even small amounts of cold work.

Machinability

BioDur CCM Plus alloy is difficult to machine in any heat treated condition due to its extremely high work-hardening rate, low thermal conductivity, and the presence of hard, abrasive carbides in the microstructure. Tool geometry, rigidity, and adequate machine power are all extremely important considerations. As a starting point, machinability parameters for other cobalt-based alloys such as Carpenter L-605 alloy may be used as a guideline. BioDur CCM Plus alloy has better machinability than BioDur Carpenter CCM alloy.

The following are typical feeds and speeds for BioDur CCM Plus Alloy.

The following tables summarize suggested machining conditions for BioDur CCM Plus alloy and BioDur Carpenter CCM alloy:

Turning—Single point and box tools

Condition	Depth of Cut In.	High Speed Tool			Carbide Tool			
		Speed fpm	Feed ipr	Tool Mtl.	Speed fpm		Feed ipr	Tool Mtl.
					Brazed	Throw away		
BHN less than 260	.100	20	.010	M-42	70	80	.010	C-2
	.025	25	.007		90	100	.007	C-3
BHN 260 to 340	.100	15	.010	M-47	65	75	.010	C-2
	.025	25	.007		80	95	.007	C-3
BHN greater than 340	.100	12	.010	M-42	60	70	.010	C-2
	.025	15	.005	M-47	70	80	.007	C-3

Turning—Cutoff and form tools

Condition	Speed fpm	Feed ipr							Tool Mtl.
		Cutoff Tool Width, Inches			Form Tool Width, Inches				
		1/16	1/8	1/4	1/2	1	1 1/2	2	
BHN less than 300	15	.002	.004	.005	.004	.002	.002	.001	M-42
	45	.003	.0045	.006	.004	.003	.0025	.0015	C-2
BHN greater than 300	15	.002	.003	.004	.003	.002	.002	.001	M-42
	45	.003	.003	.0045	.003	.0025	.002	.001	C-2

Drilling

Condition	Speed fpm	Feed ipr								Tool Mtl.
		Nominal Hole Diameter, Inches								
		1/16	1/8	1/4	1/2	3/4	1	1 1/2	2	
BHN less than 300	20	—	.002	.003	.003	.004	—	—	—	M-42
BHN greater than 300	15	—	.002	.003	.003	.004	—	—	—	

Tapping

Condition	Speed fpm	Tool Mtl.
BHN less than 300	10	M-1; M-7; M-10
BHN greater than 300	7	M-1; M-7; M-10; Nitrided

Threading, Die

Condition	Speed fpm				Tool Mtl.
	7 or less	8 to 15	16 to 24	25 and up T.P.I.	
BHN less than 300	4-6	5-8	6-10	8-12	M-2; M-7; M-10
BHN greater than 300	3-4	3-5	4-8	5-10	M-42

Milling, End—Peripheral

Condition	Depth of Cut In.	High Speed Tool						Carbide Tool					
		Speed fpm	Feed—Inches per tooth, Cutter Diam. Inches				Tool Mtl.	Speed fpm	Feed—Inches per tooth, Cutter Diam. Inches				Tool Mtl.
			1/4	1/2	3/4	1-2			1/4	1/2	3/4	1-2	
BHN less than 300	.050	15	.002	.002	.003	.004	M-42	60	.001	.002	.003	.004	C-2
BHN greater than 300		12	.0015	.0015	.002	.003		50	.0015	.0015	.002	.003	

Broaching

Condition	Speed fpm	Chip Load Inches per Tooth	Tool Mtl.
BHN less than 300	8	.002	M-42
BHN greater than 300	6	.002	

Reaming

Condition	High Speed Tool								Carbide Tool	
	Speed fpm	Feed Inches Per Rev, Reamer Diam. Inches						Tool Mtl.	Speed fpm	Tool Mtl.
		1/8	1/4	1/2	1	1 1/2	2			
BHN less than 300	20	.002	.006	.008	.010	.012	.014	M-42	60	C-2
BHN greater than 300	15	.002	.006	.008	.010	.012	.014	M-42	50	C-2

Sawing, Power Hack Saw

Condition	Pitch—Teeth Per Inch, Material Thickness, Inches				Speed	Feed
	Under 1/4	1/4 to 3/4	3/4 to 2	Over 2	Strokes/ Minute	Inches/ Stroke
All Conditions	10	6	6	4	30-60	.003-.006

Other Information

Applicable Specifications

- ASTM F1537
- ASTM F799
- ISO 5832-12
- ASTM F75
- BS 7252
- ISO 5832-4

Forms Manufactured

- Bar-Rounds
- HIP'd Shapes
- Billet
- Powder

Technical Articles

- A Guide to Etching Specialty Alloys for Microstructural Evaluation
- Effect of Cold Drawing and Heat Treating on Powder Metallurgy Processed ASTM F 1537 Alloy 1 & Alloy 2 Barstock
- Higher Performance Material Solutions for a Dynamic Spine Market
- Specialty Alloys And Titanium Shapes To Consider For Latest Medical Materials Requirements
- Unique Properties Required of Alloys for the Medical and Dental Products Industry

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