CARPENTER ELECTRIFICATION®

DATASHEET

HYPOCORE®

U.S. Patent Pending

Type analysis

Single figures are nominal except where noted.

Iron	Balance	**Cobalt**	5.00 %	**Silicon**	2.30 %
Manganese	1.00 %	**Chromium**	0.30 %	**Carbon**	0.01 %

Forms manufactured

Bar*	**Strip** Supplied in the as cold-rolled/unannealed condition or cold-rolled with a mill anneal for stampability Sizes available are 0.002-0.200 in gauge (0.051-5.08 mm) and widths between 0.250-15.0 in (6.4 – 380 mm)
Wire*	

** Product forms are available upon special inquiry*

Description

Hypocore is a low cobalt alternative to traditional thin-gage silicon steels. As compared to standard silicon steels, Hypocore exhibits superior properties, specifically high DC induction, low AC core loss, and low coercivity while exhibiting a magnetic saturation of 21 kilogauss. The alloy contains a researched and optimized combination of elements and processing parameters to increase electrical resistivity while maintaining high induction.

Hypocore's high resistivity has been shown to increase efficiency due to limiting core losses at medium to high frequencies and higher induction results in smaller, more efficient EM machines.

Laminations stamped from cold-rolled strip are recommended to be either stress relieved or fully annealed in a protective atmosphere or vacuum environment to promote peak operational performance.

Key Properties:

- High resistivity
- High DC induction
- Low AC core loss
- Low coercivity

Markets:

- Aerospace
- Automotive
- Consumer
- Industrial

Applications:

- Electromagnetic generators
- Motors
- Transformers
- Other EM laminated-core components

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Corrosion resistance

Hypocore is an essentially chromium-free iron-base alloy not intended for most corrosion-resistant applications.

Physical properties

PROPERTY	At or From	English Units	Metric Units
SPECIFIC GRAVITY	—	7.83	7830.65 kg/m^3
DENSITY	—	0.2829 lb/in^3	460.13 J/kg·K
MEAN SPECIFIC HEAT	77°F	0.1099 Btu/lb/°F	480.23 J/kg·K
	212°F	0.1147 Btu/lb/°F	520.42 J/kg·K
	392°F	0.1243 Btu/lb/°F	550.56 J/kg·K
	572°F	0.1315 Btu/lb/°F	590.34 J/kg·K
	752°F	0.1410 Btu/lb/°F	660.26 J/kg·K
	932°F	0.1577 Btu/lb/°F	730.6 J/kg·K
	1112°F	0.1745 Btu/lb/°F	25.5 W/m·K
THERMAL CONDUCTIVITY	77°F	176.9 Btu-in/hr/ft^2/°F	—
ELASTIC MODULUS	—	23.1 x 10^3 ksi	—
ELECTRICAL RESISTIVITY	—	312.9 ohm-cir-mil/ft	52 microohm·cm
CURIE TEMPERATURE	—	1450°F	788°C

Magnetic properties

Typical DC induction values	Typical DC induction values in kilogauss from varying magnetizing forces in oersteds are shown below for different strip thicknesses heat treated using two specific heat treating cycles. A stress relief anneal at 1562°F (850°C) and a full magnetic anneal at 2150°F (1180°C) for 4 hours each, cooled at 200°F (111°C)/hr. The magnetic data was determined on ring laminations 1.50 in. OD x 1.25 in. ID per ASTM A596. All values are typical results.
Typical AC core loss values	Typical AC core loss values at multiple frequencies are shown for common lamination strip thicknesses of 0.005 in. (0.127 mm), 0.007 in. (0.178 mm), 0.010 in. (0.25 mm), 0.014 in. (0.35 mm), and 0.019 in. (0.483 mm) heat treated using two specific heat treating cycles. A stress relief anneal at 1562°F (850°C) and a full anneal at 2150°F (1180°C) for 4 hours each, cooled at 200°F (111°C)/hr. Typical core loss values cover the induction range of 5 kilogauss (0.5 T) to 20 kilogauss (2.0 T).[1]
Lower temperature stress relief cycle	The lower temperature stress relief cycle (1562°F) results in lower DC induction, which is directly related to the higher core losses vs. fully annealed product (2150°F) at lower frequencies and lower induction levels. At higher frequencies and higher levels of induction, the properties converge between the two heat treatments. At 1800 Hz, the treatments behave similarly in performance, and at lower frequencies, the 20 kG test point shows a much smaller gap between the two conditions as compared to lower levels of induction.

** Magnetic data was determined on ring laminations 1.50 in O.D. x 1.25in I.D. x thickness per ASTM A-697 taking special precautions to ensure the retention of a sinusoidal flux wave form.Typical direct current magnetic properties.*

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TYPICAL DC MAGNETIC PROPERTIES

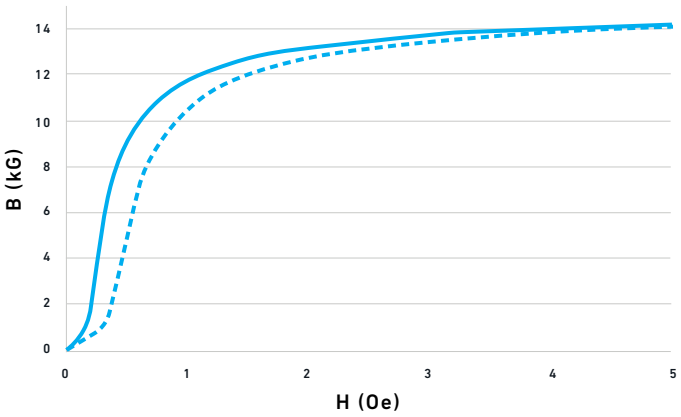
BY HEAT TREATMENT AND SIZE

H (Oe)	STRESS RELIEVED AT 1562°F (850°C), 4 HRS		ANNEALED AT 2150°F (1177°C), 4 HRS	
	B (GAUSS)		B (GAUSS)	
	GAUGE < = 0.007 IN	*GAUGE > 0.007 IN*	*GAUGE < = 0.007 IN*	*GAUGE > 0.007 IN*
5	13700	14000	14200	14400
10	14300	14700	14700	15100
20	15000	15300	15400	15700
50	16100	16400	16600	16800
100	17400	17500	18200	18200
150	18300	18400	19000	19000
200	19000	19000	19500	19500

LOW FIELD BH CURVES

——— 2150°F (1180°C) full anneal

— — — 1562°F (850°C) stress relieved



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TYPICAL AC CORE LOSS

STRESS RELIEVED 1562°F (850°C), 4 HRS

FREQUENCY	GAUSS	SIZE, IN				
		0.005	*0.007*	*0.010*	*0.014*	*0.019*
60	5000	0.136	0.141	0.144	0.165	0.232
	10000	0.452	0.455	0.461	0.525	0.745
	15000	.0833	0.850	0.853	0.992	1.42
	20000	1.07	1.11	1.16	1.39	2.06
400	5000	1.37	1.50	1.74	2.10	2.91
	10000	4.75	5.20	6.01	7.60	11.1
	15000	9.63	10.9	13.0	18.2	28.5
	20000	13.0	15.5	20.4	31.1	49.9
900	5000	3.78	4.48	5.59	6.92	9.43
	10000	13.4	15.9	19.8	26.9	41.3
	15000	29.0	35.3	47.3	74.3	119
	20000	41.3	54.3	81.6	136	218
1800	5000	9.62	12.0	15.5	19.6	27.2
	10000	34.7	43.8	58.0	85.8	139
	15000	77.6	103	154	261	435
	20000	117	170	280	483	—

ANNEALED 2150°F (1180°C), 4 HRS

FREQUENCY	GAUSS	SIZE, IN				
		0.005	*0.007*	*0.010*	*0.014*	*0.019*
60	5000	0.102	0.106	0.112	0.132	0.154
	10000	0.362	0.367	0.372	0.446	0.522
	15000	0.619	0.673	0.723	0.866	1.06
	20000	0.877	0.942	0.996	1.27	1.63
400	5000	1.20	1.37	1.62	2.01	2.45
	10000	4.19	4.72	5.58	7.18	9.27
	15000	8.54	9.90	12.2	17.8	26.1
	20000	12.2	14.9	19.8	32.1	49.9
900	5000	3.63	4.43	5.38	6.72	8.37
	10000	12.9	15.3	19.0	25.9	36.8
	15000	28.5	33.9	45.7	73.6	117
	20000	41.3	54.5	80.6	141	230
1800	5000	9.94	12.4	15.4	19.4	24.7
	10000	35.1	42.8	56.5	84.7	130
	15000	76.7	101	153	268	418
	20000	120	175	283	483	—

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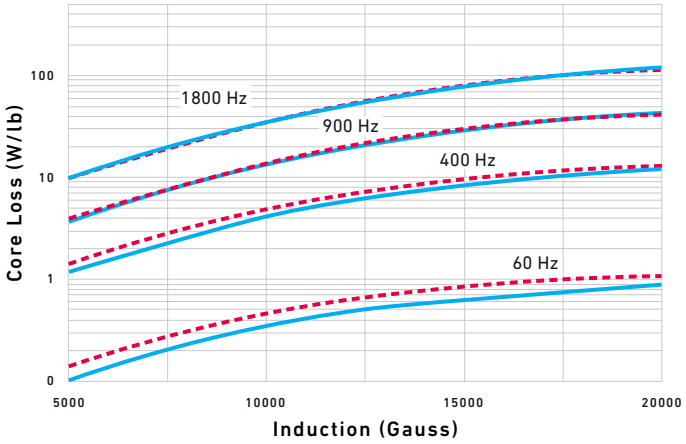
TYPICAL CORE LOSS VALUES

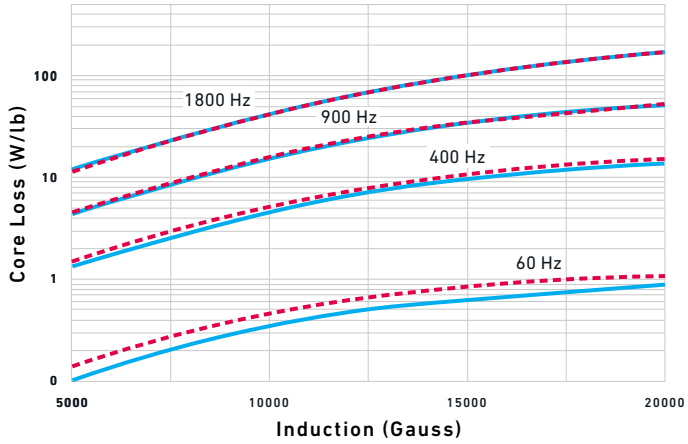
0.005 IN THICK

2150°F (1180°C) full anneal
1562°F (850°C) stress relieved



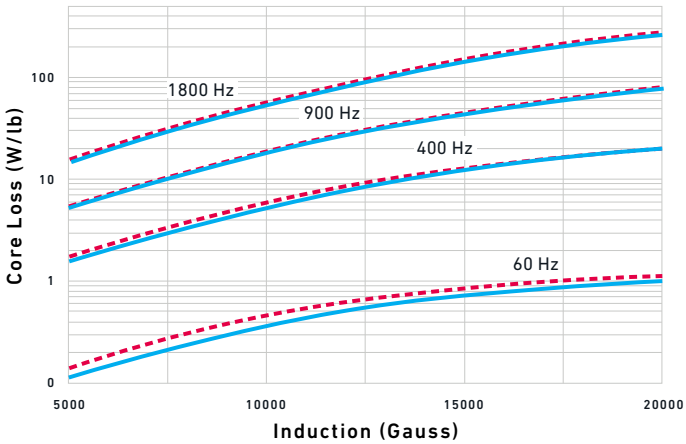
0.007 IN THICK

2150°F (1180°C) full anneal
1562°F (850°C) stress relieved



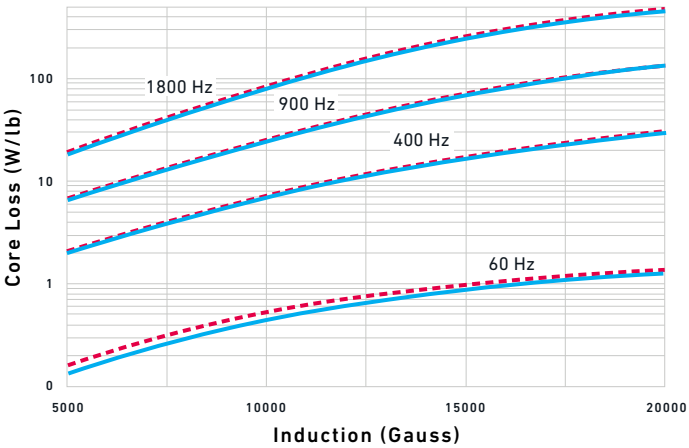
0.010 IN THICK

2150°F (1180°C) full anneal
1562°F (850°C) stress relieved



0.014 IN THICK

2150°F (1180°C) full anneal
1562°F (850°C) stress relieved



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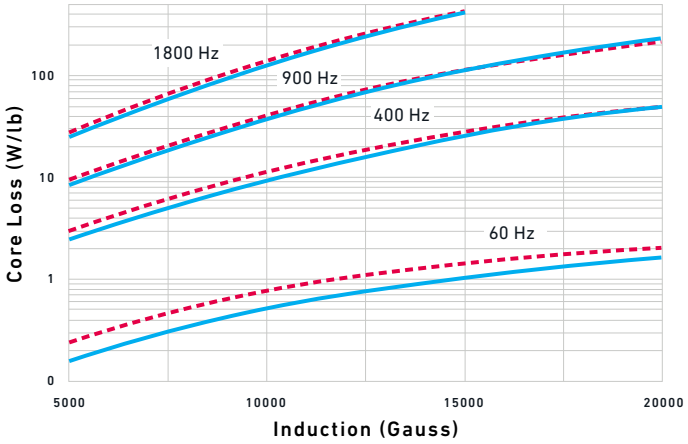
TYPICAL CORE LOSS VALUES (CONTINUED)

0.019 IN THICK

——— 2150°F (1180°C) Full Anneal

— — — 1562°F (850°C) Stress Relieved



Typical mechanical properties

STRESS RELIEVED 1562°F (850°C), 4 HRS					
GAUGE	UTS		YS		ELONGATION
	ksi	MPa	ksi	MPa	%
< = 0.007 IN	63.5	437.8	47.5	327.5	13.5
> 0.007 IN	67.0	461.9	50.0	344.7	17

FULLY ANNEALED 2150°F (1177°C), 4 HRS					
GAUGE	UTS		YS		ELONGATION
	ksi	MPa	ksi	MPa	%
< = 0.007 IN	50.0	344.7	40.0	275.8	8
> 0.007 IN	50.0	344.7	42.0	289.6	10

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Heat treatment

Coating	Hypocore is available with an Inlac coating that prevents the laminations from sticking during heat treatment and acts as interlaminar insulation.
Annealing	It is important to avoid any contamination of the finished parts going into and during the heat treatment. All parts must be cleaned thoroughly to remove any surface contaminants prior to annealing. A dry hydrogen atmosphere or a high vacuum is recommended to minimize oxide contamination of the parts during annealing. When hydrogen is employed, the entry dew point should be dryer than -60°F (-51°C) and the exit dew point dryer than about -40°F (-40°C) when the inside retort temperature is above 900°F (482°C). A full magnetic anneal should be carried out at 2150°F (1180°C) for 2 to 4 hours in an inert atmosphere or vacuum. Cooling rates should be between 150°F (83°C)/hr and 400°F (222°C)/hr. This heat treatment will lead to exceptional AC and DC magnetic properties and lower strength. A full magnetic anneal should be used when maximum magnetic performance is the most critical attribute for the lamination.
Stress relieving	It is important to avoid any contamination of the finished parts going into and during the heat treatment. All parts must be cleaned thoroughly to remove any surface contaminants prior to stress relieving. Stress relief annealing should be carried out at 1562°F (850°C) for 1 to 4 hours in an inert atmosphere or vacuum. Cooling rates should be between 150°F (83°C)/hr and 400°F (222°C)/hr. This heat treatment will lead to the ascribed AC and DC magnetic properties and result in the documented strength. Stress relieving should be used when cost/capability restrict employing a full anneal or when elevated strength is desired.

For additional information, please contact your nearest sales office:
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