The Spectrum of Investment Casting Possibilities: PMI Alloy and Engineering Guide

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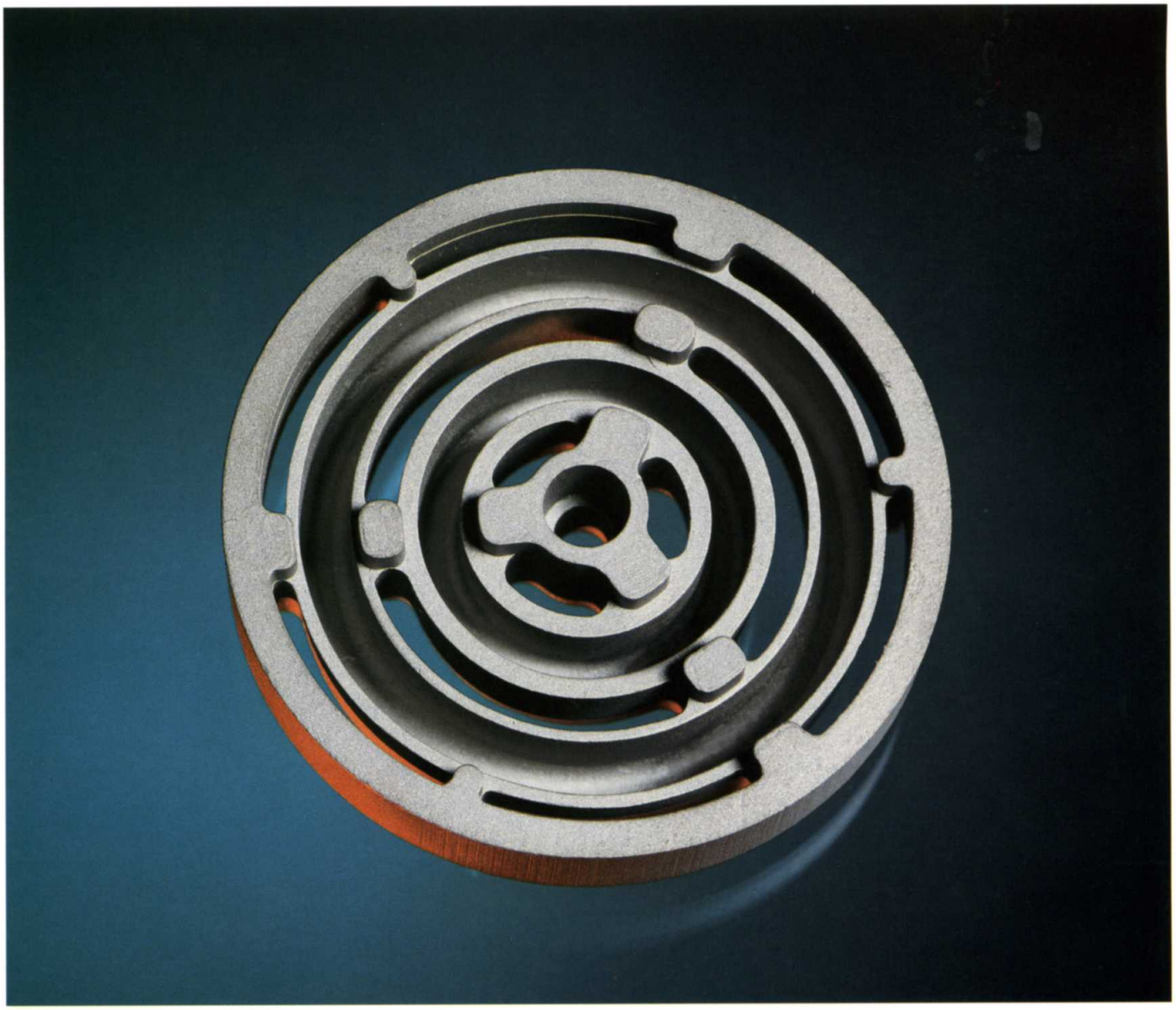

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***PMI's** investment casting process is ideal for the holes and radial slots and grooves found in this circular seat used in air and gas compressors. Alloy: 17-4-PH precipitation hardened steel, 0.523 lbs., shown 1.5 times actual size.*

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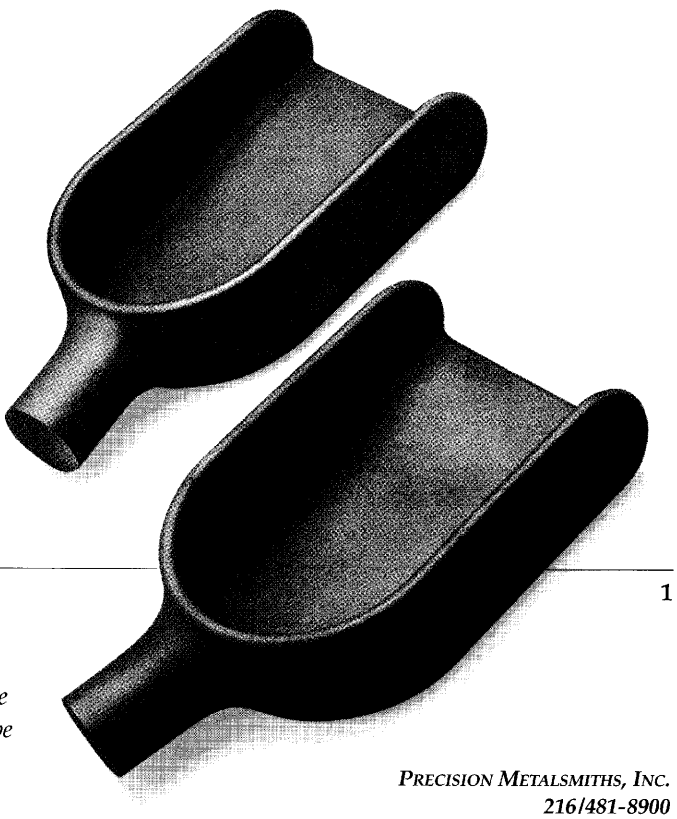
Introduction

Investment casting accommodates the widest alloy range of any casting process. By manipulating process variables, we can offer ferrous and non-ferrous castings in almost any air-meltable alloy. PMI has poured over 200 different alloy variations during its more than 50 years of casting experience. In this guide, we list only the most common alloys and alloy groups we currently use even though our expertise includes virtually all air-meltable alloys. If you need alloys that are not listed, our metallurgists will work with you either to develop the alloy you need or to offer suitable alternatives.



These medical examining table stirrups with a fine surface finish and smoothly rounded corners are a good example of a near net shape investment casting application. Alloy: 356 aluminum, 1.076 lbs., shown 1/3 actual size.

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How Does Investment Casting Compare with Other Processes?

Investment casting—the lost wax process—produces precise, close-tolerance parts, a factor to consider when evaluating the costs of parts-making processes. Choosing the best method to meet your requirements should be based on more than part price alone. Because the investment process yields a net shape or near net shape part, you will likely spend less for machining, fabrication, or other secondary operations necessary to make the part ready to use. Considering what you can save on those processes plus the benefits of design and alloy flexibility, investment casting can compare favorably to other manufacturing methods.

When a part originally made by another process is redesigned as an investment casting, the result is often a part that requires less metal, weighs less, and has a more streamlined appearance. While we actively encourage you to consider converting parts to investment castings, our engineering staff will gladly help you select the most cost-effective solution.

Alloy Suitability for Various Processes

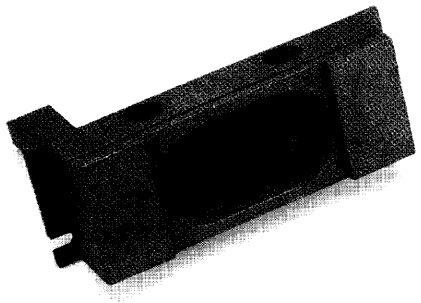
Process	Ductile Iron	Tool Steel	Steel	Stainless Steel	Aluminum/ Magnesium	Copper Bronze Brass	*Titanium	*Super Alloys
Investment Casting	•	•	•	•	•	•	•	•
Die Casting					•	•		
Forging		•	•	•	•	•	•	•
Permanent Mold			•	•	•	•	•	
P/M High Density		•	•	•			•	
Sand Casting	•	•	•	•	•	•		•
Stamping			•	•	•	•		
Weldments			•	•	•	•	•	•
Extrusion			•		•	•	•	
Roll Forming			•	•	•	•	•	

** Includes titanium, nickel, and cobalt, which are vacuum-melt alloys. This group is included for comparison only; **PMI** casts only air-meltable alloys.*

Comparative Processes

Process	Investment Casting	Die Casting	Forging	Permanent Mold	Plaster Mold	Powdered Metal	Resin Shell Mold	Sand Casting
Tooling Cost	Average	High	High	Average	Low	Average	Average	Low
Unit Cost	High	Low	Average	Average	High	Low	Average	Average
Metal Options	Most	Few	Average	Average	Few	Average	Average	Average
Design Freedom	Most	Least	Least	Average	Average	Least	Average	Average
Volume Capability	All	High	High	All	Low	High	All	All
Draft Required	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Tolerance Control	Average	Average	Poor	Average	Average	Best	Average	Poor
Size Range	Average	Average	Average	Average	Average	Small	Average	Poor
Surface Finish	Average	Best	Poor	Average	Average	Best	Poor	Poor
Wall Minimum	Average	Average	Large	Large	Large	Large	Large	Large
Normal Delivery	Average	Long	Long	Average	Short	Average	Average	Short

Chart reprinted from the Investment Casting Handbook, (American Foundrymen's Society, 1993), p. 26



*Close-tolerance computer peripheral parts like this junction block demand the precision attained by **PMI's** investment casting. Alloy: 356 aluminum, 0.323 lbs., shown 1/2 actual size.*

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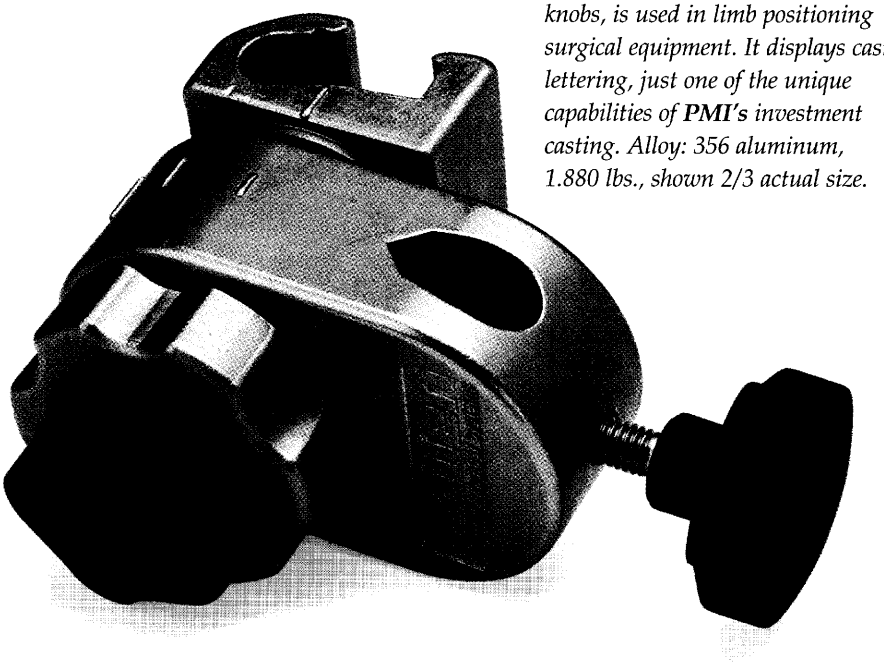
Investment Casting–Ferrous and Non-Ferrous Alloys from PMI

The alloys listed on the following pages represent the many metals we routinely pour at ***PMI***. We have experience in working not only with the more common grades of steel and aluminum, but also with a full spectrum of tool, plain carbon, and low alloy steels; alloyed aluminums; stainless steels; as-cast and austempered ductile iron; and beryllium copper and other copper-based metals. As mentioned earlier, the charts presented do not include all variations of the metals we can offer you.

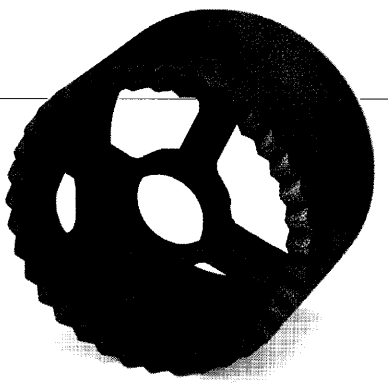
Castability ratings are based on fluidity, resistance to hot tearing, the anticipated shrinkage, and the extent of the precautions required during the pour. The castability of an alloy can impact unit price.

All values shown are for comparison purposes only, as determined from separately cast test bars. Properties for design purposes must be obtained from appropriate material specifications and design standards, or by negotiation.

Contact our metallurgical department for any additional information regarding heat treatment or other characteristics of these or other alloys.



This part, assembled from three castings and customer-supplied knobs, is used in limb positioning surgical equipment. It displays cast lettering, just one of the unique capabilities of ***PMI's*** *investment casting. Alloy: 356 aluminum, 1.880 lbs., shown 2/3 actual size.*



The perfectly formed teeth and internal supports featured in this cup used in the manufacture of lab furniture demonstrate the functional detail achievable by ***PMI*** *investment casting.*
Alloy: 356 aluminum,
0.221 lbs.. shown 1/2 actual size.

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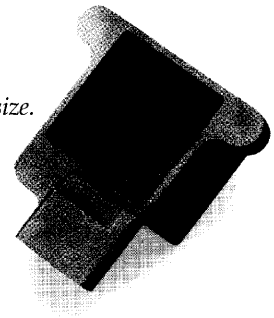

Cover for aircraft fuel control valve. Alloy: 356 aluminum, 0.209 lbs., shown 1/2 actual size.

Aluminum Alloys

ALLOY	Similar Designations	Usual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength
A 201 (A02010)	AMS 4223 MIL A 21180 MIL C 19494	T6	5	1	4	4	Yes	2.8		
354 (A03540)	MIL A 21180	T6	1	3	3	1	Yes	2.7		
355 (A03550)	ASTM B26 ASTM B618	T6	2	3	3	2	Yes	2.7	23,000	12,000
C 355 (A33550)	AMS 4215 MIL A 21180 ASTM B615	T6	2	3	3	2	Yes	2.7		
356 (A13560)	AMS 4260 ASTM B26	T6	1	4	2	2	Yes	2.7	24,000	18,000
A 356 (A13560)	AMS 4218	T6	1	4	2	2	Yes	2.7	23,000	12,000
A 357 (A13570)	AMS 4219	T6	2	3	2	1	Yes	2.7	25,000	13,000
514 (A05140)	214, ASTM 0618 ASTM B26	As-Cast	5	1	1	2	No	2.7	25,000	12,000
535 (A05350)	Almag 35 AMS 4239	As-Cast	4	1	1	5	No	2.6	40,000	20,000
712 (A07120)	ASTM B26 40E	As-Cast 3 wks. Aging	4	1	3	4	Yes	2.8	35,000	25,000
713 (A07130)	ASTM B26 Tenzalloy	As-Cast 3 wks. Aging	4	1	3	4	Yes	2.8	32,000	22,000

Key: 1= Excellent 2 = Very Good 3 = Good 4 = Fair 5 = Poor

No data available; metal not usually used in this condition

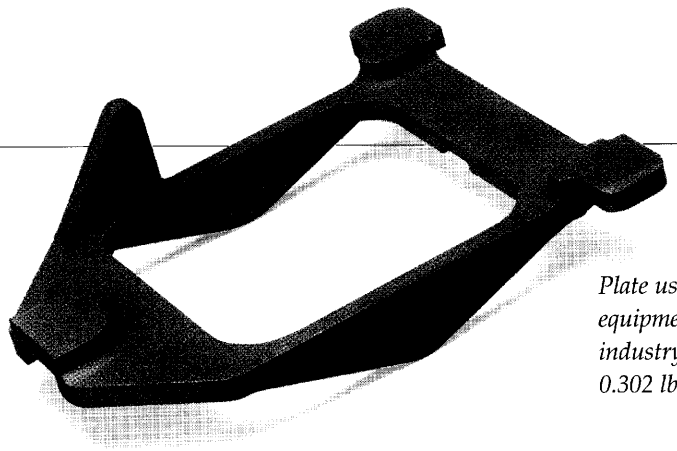

Plate used in laser measurement equipment for the construction industry. Alloy: 356 aluminum, 0.302 lbs., shown 1/2 actual size.

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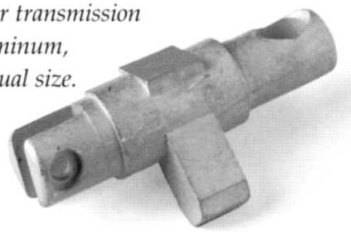
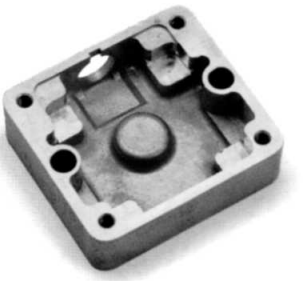
Padlock bolt for the power transmission industry. Alloy: 356 aluminum, 0.049 lbs., shown 3/4 actual size.



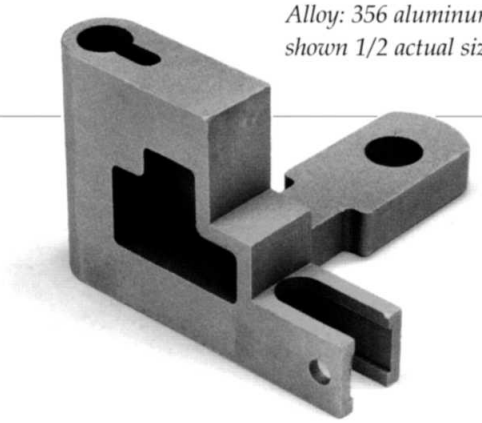
Case for sonar unit used to detect underground pipes. Alloy: 356 aluminum, 0.302 lbs., shown 2/3 actual size.



As-Cast Elongation (%)	As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (psi)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS
						67,000	59,000	7	HRB 80	Highest strength alloy. Excellent machinability.
						50,000	38,000	4	HRE 75/95	High strength.
3	HRE 55/70					35,000	25,000	3	HRE 73/98	Good strength and corrosion resistance. Leak proof and pressure-tight.
						38,000	25,000	5	HRE 80/100	Premium quality 355 alloy.
6	HRE 50/65					33,000	24,000	3	HRE 73/93	Most popular aluminum alloy. Good strength, corrosion resistance, and stability. Pressure-tight.
6	HRE 50/65					38,000	28,000	5	HRE 73/93	Premium quality 356 alloy. Poor brazability. Good weldability.
5	HRE 50/65					45,000	35,000	3	HRE 75/95	Premium quality alloy. Higher strength than A 356.
9	HRE 60									Excellent for anodizing.
13	HRE 80									Maximum properties in the as-cast condition. Good for marine and other highly corrosive applications.
5	HRE 80									Good brazing alloy. Self aging.
3	HRE 80									Excellent machinability.

Hardness Scales: HRB – Rockwell Hardness, B Scale HRC – Rockwell Hardness, C Scale
HRE – Rockwell Hardness, E Scale BHN – Brinell Hardness Scale

Slider used in dental chairs. Alloy: 356 aluminum, 0.156 lbs., shown 1/2 actual size.



Housing for rifle scope prism. Alloy: 356 aluminum, 0.083 lbs., shown 3/4 actual size.

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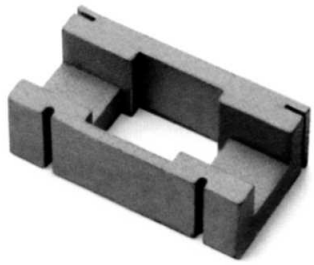
Copper-Based Alloys

ALLOY	Similar Designations	Usual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength (psi)	As-Ca
Silicon Brass (C87500)	ASTM B584 MIL C 22087	As-Cast	2	2	2	2	No	8.3	60,000	35,000	16
Silicon Bronze (C87300)	ASTM B763 MIL C 11866	As-Cast	3	3	3	3	No	8.3	45,000	28,000	12
Phosphor Bronze (C90700)	ASTM B427	As-Cast	4	2	2	3	No	8.8	45,000	25,000	30
Navy "G" (C90300)	ASTM B584 MIL C 22087	As-Cast	4	2	2	3	No	8.7	40,000	20,000	30
Manganese Bronze A (C86500)	ASTM B584 AMS 4860 MIL C 22087	As-Cast	4	2	1	4	No	8.3	71,000	28,000	30

Key: 1= Excellent 2 = Very Good 3 = Good 4 = Fair 5 = Poor

No data available; metal not usually used in this condition

Block brush used in motion control system actuators. Alloy: leaded red brass, 0.023 lbs., shown 1.75 times actual size.



Cylinder disc for door openi closing device. Alloy: silicon 0.063 lbs., shown 1.25 actu

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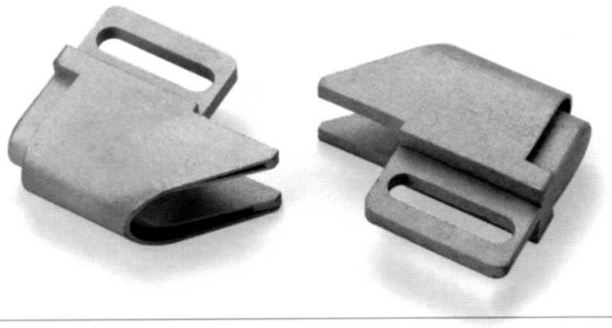


Binders used in mattress manufacturing. Alloy: silicon brass, 0.117 lbs., shown actual size.

As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (psi)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS
HRB 55									Very good castability and toughness. High strength at high temperatures; good resistance to corrosion and pressure-tightness.
HRB 50									Highest strength at elevated temperatures. Used in place of pure copper where strength is required.
HRB 45									Cast gears and gear blanks. Good wear and corrosion resistance. Retains ductility, tensile, and impact strengths at low temperatures.
HRB 40									Bearings and bushings. General utility bronze for high pressure applications and severe conditions.
HRB 80									Good for salt and fresh water environments.

Hardness Scales: HRB – Rockwell Hardness, B Scale HRC – Rockwell Hardness, C Scale
HRE – Rockwell Hardness, E Scale BHN – Brinell Hardness Scale

Tape binder used in mattress manufacturing. Alloy: silicon brass, 0.117 lbs., shown actual size.

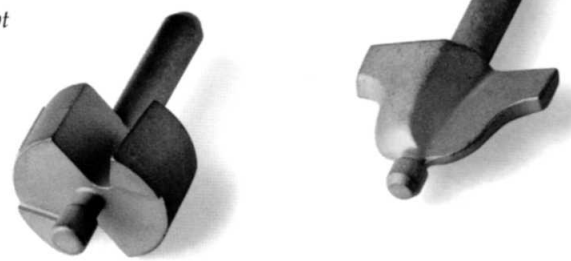
Tool Steel Alloys

ALLOY	Similar Designations	Unusual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength (psi)	As-Cast
A-2 (T90102)	ASTM A597	Annealed, Quenched, and Tempered	3	3	5	3	Yes	7.8			
D-2 (T90402)	ASTM A597	Annealed, Quenched, and Tempered	4	4	4	5	Yes	7.8			
D-3 (T30493)		Annealed, Quenched, and Tempered	4	4	4	5	Yes	7.8			
H-11 (T20811)		Annealed, Quenched, and Tempered	4	4	4	5	Yes	7.8			
H-13 (T90813)	ASTM A597	Annealed, Quenched, and Tempered	4	4	4	5	Yes	7.8			
L-6 (T61206)		Annealed, Quenched, and Tempered	4	3	5	4	Yes	7.8			
M-2 (T11302)	ASTM A597	Annealed, Quenched, and Tempered	4	4	5	4	Yes	7.8			
M-52 (T11352)		Annealed, Quenched, and Tempered	3	3	5	3	Yes	7.8			
O-1 (T91501)	ASTM A597	Annealed, Quenched, and Tempered	3	3	5	4	Yes	7.8			
O-6 (T31506)		Annealed, Quenched, and Tempered	3	3	5	4	Yes	7.8			
S-1 (T49101)		Annealed, Quenched, and Tempered	2	3	5	4	Yes	7.9			
S-2 (T41902)		Annealed, Quenched, and Tempered	2	3	5	4	Yes	7.8			
S-5 (T41905)		Annealed, Quenched, and Tempered	2	3	5	4	Yes	7.8			
S-7 (T41907)	ASTM A597	Annealed, Quenched, and Tempered	2	3	5	4	Yes	7.8			

Key: 1= Excellent 2 = Very Good 3 = Good 4 = Fair 5 = Poor

No data available; metal not usually used in this condition

These router bits for hand tools are cast from hard, wear-resistant M-52 tool steel alloy except the leftmost bit, which is cast from a D-2 tool steel alloy with similar properties. The bits weigh from 0.020 to 0.79 lbs. and are shown actual size.



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As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (%)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS
				HRC 20				HRC 57	Good hardness retention at high heat. Good wear resistance. Fair toughness. Often used for forming gauges, punches, and bushings.
				HRC 30				HRC 60	Good hardness retention at high heat. Very good wear resistance. Poor toughness. Often used for shear blades, cutters, broaches, and forming dies.
				HRC 30				HRC 61	Good hardness retention at high heat. Good wear resistance. Poor toughness. Often used for shear blades, cutters, broaches, and forming dies.
				HRC 25				HRC 52	Good hardness retention at high heat. Fair wear resistance. Poor toughness. Often used for piercing tools, high strength structural components, and extrusion tooling.
				HRC 25				HRC 50/55	Good hardness retention at high heat. Fair wear resistance. Poor toughness. Often used for die inserts, piercing tools, high strength structural components, and extrusion tooling.
				HRC 20				HRC 59	Poor hardness retention at high heat. Poor wear resistance. Fair toughness. Often used for shear blades, press brake dies, clutch parts, gears, and ratchets.
				HRC 30				HRC 62	Very good hardness retention at high heat. Good wear resistance. Poor toughness. Often used for drills, taps, end mills, cutters, and woodworking tools.
				HRC 30				HRC 62	Very good hardness retention at high heat. Very good wear resistance. Poor toughness. Often used for drills, taps, end mills, cutters, and woodworking tools.
				HRC 20				HRC 61	Very good hardness retention at high heat. Very good wear resistance. Poor toughness. Often used for dies, shear blades, reamers, gauges, bushings, and punches.
				HRC 26				HRC 63	Often used for cold-forming dies, wear plates, arbors, guides, and tool shanks.
				HRC 20				HRC 55	Fair hardness retention at high heat. Poor wear resistance. Good toughness. Often used for chisels, punches, concrete drills, and grippers.
				HRC 20				HRC 59	Poor hardness retention at high heat. Poor wear resistance. Good toughness. Often used for nail sets, forming tools, screw driver bits, and stamps.
				HRC 20				HRC 59	Poor hardness retention at high heat. Poor wear resistance. Good toughness. Often used for drift pins, collets, bending dies, and shears.
				HRC 25				HRC 55	Fair hardness retention at high heat. Poor wear resistance. Good toughness. Often used for engraving dies, clutches, shears, chuck jaws, and gripper dies.

Hardness Scales: HRB – Rockwell Hardness, B Scale HRC – Rockwell Hardness, C Scale
HRE – Rockwell Hardness, E Scale BHN – Brinell Hardness Scale

Carbon Steel Alloys

ALLOY	Similar Designations	Usual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength (psi)	As-Cast E (%/
1010 (G10100)		As-Cast	4	3	5	3	Yes	7.9	50,000	30,000	30
1020 (G10200)	ASTM A372 MIL S 22141	As-Cast or Annealed	4	3	5	3	Yes	7.9	60,000	45,000	20
1040 (G10400)	ASTM A372 MIL S 22141	Annealed and/or Quenched and Tempered	3	3	5	3	Yes	7.8			
1050 (G10500)	ASTM A732 MIL S 22141	Annealed and/or Quenched and Tempered	3	3	5	3	Yes	7.8			
1095 (G10950)		Annealed and/or Quenched and Tempered	2	4	5	4	Yes	7.8			
4130 (G41300)	AMS 5336 ASTM A732 MIL S 22141	Annealed and/or Quenched and Tempered	2	2	5	3	Yes	7.8			
4140 (G41400)	AMS 5338 ASTM A732	Annealed and/or Quenched and Tempered	2	4	5	2	Yes	7.8			
4340 (G43400)	AMS 5338 ASTM A732	Annealed and/or Quenched and Tempered	2	2	5	2	Yes	7.8			
6150 (G61500)	ASTM A732	Annealed and/or Quenched and Tempered	2	4	5	3	Yes	7.8			
8620 (G86200)	ASTM A732 MIL S 22141	Annealed and/or Quenched and Tempered	3	3	5	3	Yes	7.8			
8640 (G86400)	ASTM A732 MIL S 22141	Annealed and/or Quenched and Tempered	3	3	5	3	Yes	7.8			
52100 (G51986)	MIL S 22141	Annealed and/or Quenched and Tempered	3	3	5	3	Yes	7.8			

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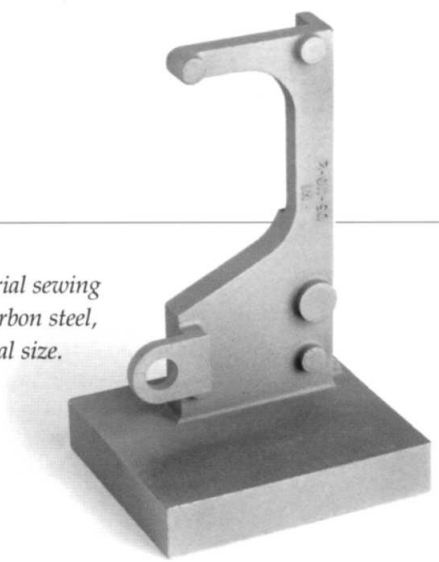
No data available; metal not usually used in this condition



Needle carrier for industrial sewing machines. Alloy: 8620 carbon steel, 0.04 lbs., shown 1/2 actual size.

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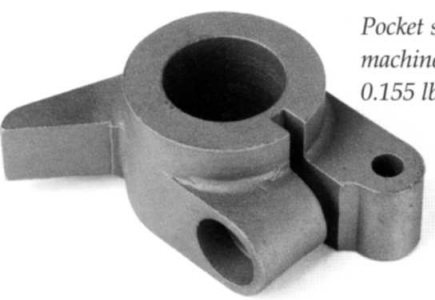
Spindle for industrial power tools. Alloy: 8620 carbon steel, 0.21 lbs., shown 3/4 actual size.

Extractor for small firearms. Alloy: 4140 carbon steel, 0.007 lbs., shown 2/3 actual size.

As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (psi)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS
HRB 50									Electrical components.
HRB 60	57,500	37,500	28	HRB 60					High impact, carburizing.
	70,000	40,000	33	HRB 70	100,000	90,000	10	HRC 24	Medium strength.
	90,000	45,000	14	HRB 85	125,000	100,000	5	HRC 35	Medium strength.
	95,000	55,000	13	HRB 90	216,000	152,000	10	HRB 59	High strength.
	80,000	60,000	18	HRB 100 max	105,000	85,000	18	HRC 42	Structural parts requiring welding. High fatigue resistance and strength.
	90,000	60,000	17	HRB 100 max	175,000	160,000	3	HRC 38	High hardenability, good fatigue, abrasion, and impact resistance.
	90,000	70,000	15	HRB 100 max	200,000	180,000	5	HRC 44	Better hardenability than 4140.
	100,000	60,000	23	HRB 100 max	280,000	245,000	8	HRC 50	High strength and hardness. Highly resistant to shock and adaptable for highly-stressed machinery parts which are heat treated after machining.
	70,000	50,000	22	HRB 85	100,000	80,000	2	HRC 28	Carburizing alloy steel for stressed parts.
	100,000	55,000	22	HRB 95	270,000	242,000	10	HRC 50	Often used for small machine parts and shafts.
	94,000	62,000	27	HRC 20	180,000	170,000	6	HRC 58	High hardness and abrasion resistance.

Hardness Scales: HRB – Rockwell Hardness, B Scale HRC – Rockwell Hardness, C Scale
HRE – Rockwell Hardness, E Scale BHN – Brinell Hardness Scale

Arched magazine guide for small firearms. Alloy: 4140 carbon steel, 0.282 lbs., shown actual size.



Pocket stop lever for printing machinery. Alloy: 4140 carbon steel, 0.155 lbs., shown actual size.

Precision Metalsmiths, Inc.
216/481-8900

Stainless Steel 300/400 Series Alloys

ALLOY	Similar Designations	Usual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength (psi)	As-Cast El (%)
302 CF-20 (JJ92501)	AMS 5358, ASTM A743 MIL S 81591	Solution Annealed	1	4	2	4	No	8.0			
303 CF-16F (J92511)	AMS 5341, ASTM A743 MIL S 81591	Solution Annealed	3	3	2	5	No	8.0			
304 CF-8 (J92600)	ASTM A743 MIL S 867 MIL S 8159	Solution Annealed	1	4	1	2	No	8.0			
304L CF-3 (J92700)	AMS 5370, ASTM A351 MIL S 22216	Solution Annealed	1	4	1	1	No	8.0			
310 CK-20 (S31000)	AMS 5366, ASTM A351 MIL S 22216	Solution Annealed	3	3	3	3	No	8.0			
316 CF-8M (J92900)	AMS 5360, ASTM A351 MIL S 867	Solution Annealed	1	4	1	3	No	8.0			
347 CF-8C (J92710)	AMS 5362, ASTM A 351 MIL S 867	Solution Annealed	2	3	1	1	No	8.0			
CN-7M (J95150)	ASTM A351 ASTM A743	Solution Annealed	3	3	1	1	No	8.0			
410 CA-15 (J91150)	AMS 5350, ASTM A217 MIL S 81591	Annealed, Quenched, and Tempered	2	2	3	3	Yes	7.75			
416 (S41600)	AMS 5349	Annealed, Quenched, and Tempered	4	2	3	5	Yes	7.73			
420 CA-40 (J91153)	ASTM A743 MIL S 81591	Annealed, Quenched, and Tempered	2	3	2	3	Yes	7.75			
431 CB-30 (J91803)	AMS 5353, ASTM A743 MIL S 8159	Annealed, Quenched, and Tempered	3	3	2	3	Yes	7.74			
436 Greek Ascoloy (J91631)	AMS 5354	Normalized and Tempered	2	3	1	2	Yes	7.75			
440A (S44002)	MIL A 22216 MIL S 91591	Annealed, Quenched, and Tempered	2	4	4	5	Yes	7.68			
440C (S44004)	AMS 5352 MIL S 22216 MIL S 81591	Annealed, Quenched, and Tempered	3	4	4	5	Yes	7.65			
440F (S44020)		Annealed, Quenched, and Tempered	4	2	4	5	Yes	7.7			

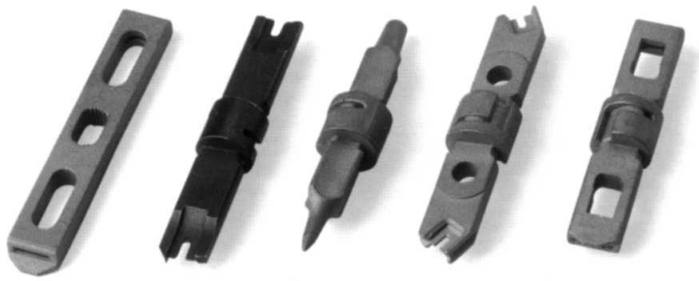
Key: 1= Excellent 2 = Very Good 3 = Good 4 = Fair 5 = Poor

No data available; metal not usually used in this condition

Grinding wheel used in vending machines. Alloy: 440C stainless steel, 0.055 lbs., shown 3/4 actual size.

Precision Metalsmiths, Inc.
216/481-8900

Interchangeable blades and center punch for hand tools used by telephone installers. Various alloys: 440C stainless steel, 6150 carbon steel, 17-4-PH precipitation hardened steel, and SAE A-2; 0.035 lbs. to 0.041 lbs.; shown 3/4 actual size.



As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (psi)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS
	65,000	30,000	35	HRB 80					Best combination castability and corrosion resistance.
	65,000	30,000	35	HRB 80					Free matching stainless. Not easily welded.
	65,000	30,000	35	HRB 80					Better corrosion resistance than 302 or 303.
	63,000	30,000	35	HRB 80					304 low carbon cryogenic applications. Good weldability.
	60,000	30,000	35	HRB 80					Oxidation resistance to 2000°F (1000°C). Moderate high temperature strength. Very good for thin sections, fine detail, and smooth surface finish.
	65,000	30,000	35	HRB 80					Excellent corrosion resistance and oxidation to 1600°F (870°C). Often used for food and paper processing equipment and ship hardware.
	70,000	32,000	30	HRB 80					Excellent for welding application. Excellent corrosion resistance. Will work harden.
	65,000	25,000	35	HRB 80					Sulfuric acid resistant.
HRC 25	70,000	45,000	20	HRB 95	180,000	140,000	8	HRC 44	Best combination of hardness and corrosion resistance.
HRC 26	70,000	40,000	15	HRB 95 max	160,000	130,000	5	HRC 30	Less tough but a more machinable grade of 410.
HRC 27	90,000	60,000	12	HRC 30	180,000	150,000	3	HRC 40/44	Higher hardness but less toughness than 410.
HRC 20	130,000	80,000	15	HRC 17/25	208,000	165,000	13	HRC 40/45	Most resistant to corrosion of any 400 Series Stainless. Used in products requiring high strength and maximum corrosion resistance.
	128,000	80,000	13	HRC 20/33	209,000	152,000	11	HRC 45/53	Heat resistance to 1000°F (540°C) but has excellent oxidation resistance to 1500°F (825°C). Often substituted for more costly high alloy steels.
	100,000	60,000	10	HRC 28	260,000	240,000	2	HRC 50/58	Cutlery and molds. High hardness and ductility.
HRC 35	90,000	60,000	8	HRC 30	270,000	280,000	2	HRC 58/62	Best cutlery grade.
HRC 35	105,000	60,000	8	HRC 24				HRC 56/62	More machinable grade of 440C.

Hardness Scales: HRB – Rockwell Hardness, B Scale HRC – Rockwell Hardness, C Scale
HRE – Rockwell Hardness, E Scale BHN – Brinell Hardness Scale

Piston used in aircraft equipment. Alloy: 316 stainless steel, 0.109 lbs., shown actual size.

Precision Metalsmiths, Inc.
216/481-8900

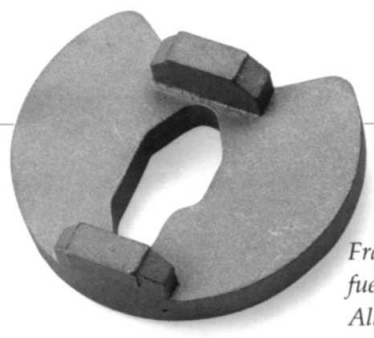
Cobalt / High Nickel / Magnetic Steels Alloys

ALLOY	Similar Designations	Usual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength (psi)	As-Cast Elong (%)
Cobalt 6 (R30006)	AMS 5387	As-Cast	3	5	2	4	No	8.4	115,000	46,000	2
Cobalt 12 (R30012)	MIL C 24248	As-Cast	3	5	1	4	No	8.7	107,000	107,000	Nil
Nickel B (N10001)	AMS 5396 ASTM A494	Solution Annealed	3	4	2	3	No	8.5	75,000	50,000	10
Nickel C (N10002)	AMS 5388 ASTM A494	Solution Annealed	4	4	2	3	No	8.5	50,000		10
Nickel X (N06002)	AMS 5390	As-Cast	5	4	2	3	No	8.5	60,000	40,000	10
"S" Monel (N04019)	AMS 4892 ASTM A494	Solution Annealed and Aged	5	4	2	5	Yes	8.4			
Inconel 600 (N06600)		As-Cast	5	3	1	4	No	8.4	75,000	35,000	20
Beryllium Nickel 41 C		Solution Annealed	2	3	1	2	Yes	8.2	115,000	60,000	5
1.0% Si Fe		As-Cast	3	3	5	5	No	7.8			
2.5% Si Fe		As-Cast	3	3	5	5	No	7.8	49,000		
47-50		As-Cast	3	3	5	1	No	8.2	60,000	20,000	30

Key: 1= Excellent 2 = Very Good 3 = Good 4 = Fair 5 = Poor

No data available; metal not usually used in this condition

Armature used in aircraft fuel control valves. Alloy: 47-50 magnetic steel, 0.006 lbs., shown actual size.



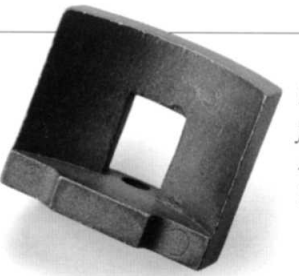
Frame used in aircraft fuel control valves. Alloy: 47-50 magnetic steel, 0.157 lbs., shown actual size.

PRECISION METALSMITHS, INC.
216/481-8900

As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (psi)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS
HRC 37									Best impact. Oxidation resistant to 1600°F (870°C).
HRC 42									High hot corrosion resistance and excellent wear characteristics.
HRB 90	75,000	50,000	8	HRB 90	53,000 at elevated temp		10		Resistant to hydrochloric acid. Good strength at high temperature applications under oxidizing conditions up to 1400°F (760°C).
HRB 85	75,000	45,000	8	HRB 90					Resistant to wet chlorine gas and oxidation. Resistant to 1800°F (980°C).
HRB 85									Oxidation resistant to 2200°F (1200°C).
	120,000	85,000	10	HRC 26	140,000	125,000	3	HRC 32/41	At room or elevated temperatures offers good gall and corrosion resistance.
									Highly resistant to corrosion up to 1500°F (825°C) in a sulfurous atmosphere.
HRC 24	120,000	55,000	25	HRB 95	220,000	200,000	1	HRC 52	Age hardenable. Excellent wear resistance.
HRB 60									Solenoid switches, relays, pole pieces, and electromagnets. Large grain size. Low hysteresis loss and poor wear resistance. 1.0% Si Fe 16,850 Br (Gauss) Hc = 0.3 (Oersteds).
HRB 70									Solenoid switches, relays, pole pieces, and electromagnets. Large grain size. Low hyteresis loss and poor wear resistance. 2.0% Si Fe 16,375 Br (Gauss), Hc = 0.18 (Oersteds).
HRB 60									Solenoid switches, relays, pole pieces, and electromagnets. 15,800 Br (Gauss) Hc = 0.21 (Oersteds). High physical strength combined with good density and magnetic permeability.

Hardness Scales: HRB – Rockwell Hardness, B Scale HRC – Rockwell Hardness, C Scale
HRE – Rockwell Hardness, E Scale BHN – Brinell Hardness Scale

Frame used in aircraft fuel control valves. Alloy: 47-50 magnetic steel, 0.033 lbs., shown two times actual size.



Frame used in aircraft fuel control valves. Alloy: 47-50 magnetic steel, 1.86 lbs., shown actual size.

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Hinge used in airline seats.
Alloy: precipitation hardened steel,
0.023 lbs., shown 2/3 actual size.

Precipitation Hardened Steel Alloys

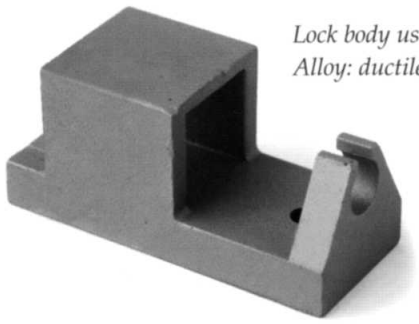
ALLOY	Similar Designations	Usual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength (psi)	As-Cast Elong (%)
15-5 PH (J92110)	AMS 5357 ASTM A747	Homogenized, Solution Treated, and Aged	3	3	2	3	Yes	7.8			
17-4 PH (J92180)	AMS 5355, ASTM A747 MIL S 81591	Homogenized, Solution Treated, and Aged	2	3	2	2	Yes	7.8			
25-5 PH (J933370)	ASTM A351 ASTM A743	Solution Treated and Aged	3	3	2	2	Yes	7.8			

Ductile Iron Alloys

ALLOY	Similar Designations	Usual Condition	Castability	Machinability	Corrosion Resistance	Weldability	Hardenable	Density (g/cm³)	As-Cast Tensile Strength (psi)	As-Cast Yield Strength (psi)	As-Cast Elong (%)
60-40-18 (F32800)	ASTM A536	As-Cast	1	2	5	4	Yes	7.1	60,000	40,000	18
65-45-12 (F33100)	ASTM A536	As-Cast	1	2	5	4	Yes	7.1	65,000	45,000	12
80-55-06 (F33800)	ASTM A536	As-Cast	1	3	5	4	Yes	7.1	80,000	55,000	6
100-70-03 (F34800)	ASTM A536	As-Cast	1	3	5	4	Yes	7.1	100,000	70,000	3
ADI 1	ASTM A897	Austempered	1	2	5	4	Yes	7.1			
ADI 2	ASTM A897	Austempered	1	2	5	4	Yes	7.1			
ADI 3	ASTM A897	Austempered	1	2	5	4	Yes	7.1			
ADI 4	ASTM A897	Austempered	1	2	5	4	Yes	7.1			
ADI 5	ASTM A897	Austempered	1	2	5	4	Yes	7.1			

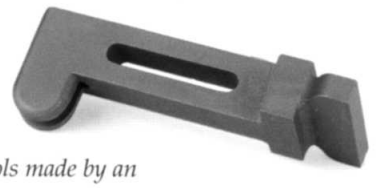
Key: 1= Excellent 2 = Very Good 3 = Good 4 = Fair 5 = Poor

No data available; metal not usually used in this condition



Lock body used in medical examining tables.
Alloy: ductile iron, 0.136 lbs., shown actual size.

Operating handle for firearm.
Alloy: precipitation hardened steel,
0.028 lbs., shown 1.25 times actual size.

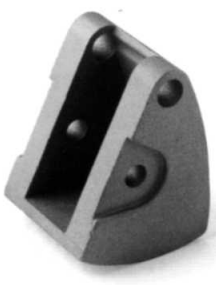


Anvil used in tools made by an
electronics connector manufacturer.
Alloy: precipitation hardened steel,
0.109 lbs., shown 3/4 actual size.

As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (psi)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS
	160,000	130,000	8	HRC 36 max	200,000	185,000	14	HRC 40/45	Same as 17-4 except greater ductility.
	180,000	160,000	6	HRC 36 max	200,000	185,000	12	HRC 40/45	Very good corrosion resistance and hardness. Easily machined. Very popular alloy.
	100,000	70,000	12	HRC 30				HRB 55	Best combination of strength and corrosion resistance.

As-Cast Hardness	Annealed Tensile Strength (psi)	Annealed Yield Strength (psi)	Annealed Elongation (%)	Annealed Hardness	Heat Treated Tensile Strength (psi)	Heat Treated Yield Strength (%)	Heat Treated Elongation (%)	Heat Treated Hardness	COMMENTS	
BHN 140/190									May substitute for 1010, 1020, 1030 and above.	
BHN 149/229									May substitute for 4620, 8620, and above.	
BHN 199/255									May substitute for 1040, 4130, 4140, 8630, 8640, and above.	
BHN 220/302									May substitute for 4330, 4340, 8730, 4620, and above.	
					125,000	80,000	10	BHN 269/321	Impact 75 Ft. Lb.	High strength, elongation, and damping characteristics, combined with a lower density than steel make ADI an excellent candidate for suspension components, camshafts, gears, teeth, plow points, housings, wear plates, and high-wear components.
					150,000	100,000	7	BHN 302/363	Impact 60 Ft. Lb.	
					175,000	125,000	4	BHN 341/444	Impact 45 Ft. Lb.	
					200,000	155,000	1	BHN 388/477	Impact 25 Ft. Lb.	
					230,000	195,000		BHN 444/555	Impact N/S	

Hardness Scales: HRB – Rockwell Hardness, B Scale HRC – Rockwell Hardness, C Scale
HRE – Rockwell Hardness, E Scale BHN – Brinell Hardness Scale



Rim latch bolt for door
opening and closing device.
Alloy: ductile iron, 0.156 lbs.,
shown 3/4 actual size.

Latch guide used in medical examining table.
Alloy: ductile iron, 0.079 lbs.,
shown 1.5 times actual size.

PRECISION METALSMITHS, INC.
216/481-8900

Our Promise To You. . .

When you come to PMI with your casting needs, we will work with you to help you determine whether investment casting is the best process to meet your objectives. The first step to keeping costs in line is finding the right fit between your parts needs and the process for making them. If you choose investment casting, we are committed to offering you the best value for your money.

We offer our half-century of engineering expertise with every quality part we sell. Our sales engineers and field sales agents are always willing to demonstrate how we can offer top quality parts at total lower cost.

Designing for castability– that's what we do best

Investment casting promises net or near net shape cast-in detail (including lettering, holes, and complex internal geometry) and consistency between lots. Like any process that depends on the proper resolidification of metal after melting, investment casting is subject to porosity, non-fill, and other inherent defects if not controlled through good design and careful process control. When you bring us your part, our job is to improve castability and capture the many benefits of investment casting. Often, we can remove unnecessary metal from the part to improve castability, reduce weight, streamline appearance, and lower materials cost.

Whether we convert your existing part from another casting process or work with you to create your part as an investment casting, we strive to eliminate potential problems through design and pre-production planning. You tell our engineers what is essential for the function of your part, and we give you an honest appraisal of what to expect from the process. We can often suggest a change in your design that will improve castability without compromising performance. Since we can provide you with parts in either an as-cast or finished state, we can deliver what you need.

This design guide will show you what to expect from ***PMI*** investment casting, as well as recommendations we might make for best results.

Net or Near Net Shape

In its as-cast state, a net or near net shape part closely resembles the finished product. On the average, our process provides you with a part that incorporates 90% or more of your finished product's requirements into the die. To build the final 10% of your requirement into the die may add significant and unnecessary cost to the part. Our policy is to tell you honestly what can be economically cast and what should be machined.

Our quotes list in detail what operations are included in the part price as well as the costs for any after-cast operations necessary to bring the part to print. We may even quote in multiple suitable alloys to offer you a cost comparison. Before proceeding with production, we submit a casting drawing to you that demonstrates exactly what you will receive in the as-cast state. Approval of this casting drawing is necessary before we begin production.

Cap back used in industrial power tools. Alloy: 356 aluminum, 0.346 lbs., shown 1/2 actual size.

Precision Metalsmiths, Inc.
216/481-8900

Tolerances

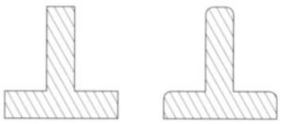
Maintaining specific tolerances can have a direct bearing on both the tooling and the unit costs. Typically, investment casting can hold a tolerance of .005 inch per inch. If you need a closer tolerance on a section of a part, we may be able to provide premium tolerance in a small area either by die design or additional after-cast operations. The actual tolerances we can hold may vary due to the alloy; the mass and configuration of the part; tool parting lines; wax, die, and mold temperatures; gate locations; and a host of other factors. However, to control costs that may add little value to your part, we urge you to specify premium tolerances only when necessary for functionality.

- Cast edges sharp to 0.010 R
- Cast fillets 1/32 R
- Flatness ±.005 in./in. (Feeler Gage)
- Minimum 0.015 stock on all surfaces to be machined.
- Surface finish 125 RMS max.
- Angles ±1°

Radii *Fillet (internal) and Edge (external) Radii*

Metal does not flow easily into sharp corners. To reduce or eliminate non-fill, we discourage knife-like edges on the inside or outside of parts by adding radii in the die. We may also add radii to support cores that create internal details or cast holes. To maximize opportunities for economical tool construction and good foundry practices, we ask you to note non-functional edges and fillet radii as "maximum unless otherwise specified." We can then add radii where appropriate.

Even when you specify sharp internal corners, you will still notice a minimum fillet on the casting of 0.008 for most non-ferrous alloys and 0.012 for most ferrous alloys. Additional fillet radii of 0.030 or more will discourage metal build-up in the corners, assist the flow of metal, and reduce cracking tendencies and hot tearing. Internal or fillet radii have more of a positive impact on the casting process (and tooling cost) than corner radii.



Original Design **Redesign**

In the redesign shown at the above right, the rigid 90° angles of the original design have been replaced with radii.

In addition to using radii, we can also incorporate flats and end beads into the design. A simple sharpening operation after casting will restore the desired point where a knife-edge is desirable.

Original Design **Redesign** **Redesign**

Both of the redesigned parts shown above use radii to eliminate sharp corners; the design at the far right also removes weight from the midsection of the part.

PMI Standard Tolerances

INCHES		MILLIMETERS	
Dimension	Tolerance	Dimension	Tolerance
Up to 1.000	0.005	Up to 25.40	0.127
Up to 2.000	0.010	Up to 50.80	0.254
Up to 3.000	0.015	Up to 76.20	0.538
Up to 4.000	0.020	Up to 101.60	0.508
Up to 5.000	0.022	Up to 127.00	0.559
Up to 6.000	0.025	Up to 152.40	0.635
Up to 7.000	0.028	Up to 177.80	0.711
Up to 8.000	0.031	Up to 203.10	0.787

Parting Lines

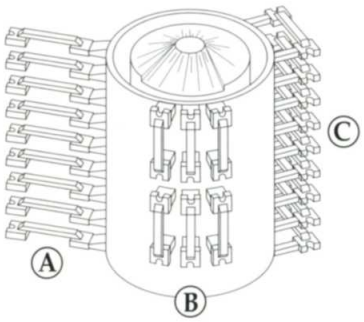
Parting lines are evidence of the meeting of two or more pattern tool components. They are visible on the casting. Though they are unavoidable, their placement must be carefully planned by our engineers. To avoid process problems or distortion of tolerances, we try to locate a complete dimension in one portion of the die rather than splitting it between the two die halves.

Housing for valves used in aerospace. Alloy: 356 aluminum, 0.652 lbs., shown 1/2 actual size.

Precision Metalsmiths, Inc.
216/481-8900

Gating

Gates are the conduit that directs the wax and later the metal to the individual part in the mold. Gating also supports the castings throughout the process. We strive to fill every part completely while getting as many parts on the set-up as practical. To ensure proper solidification of the metal and acceptable metallurgical quality, we must introduce metal into the heaviest section of the part. We may vary our gating method to create a balance between quality and acceptable quantity.



A. End gating – By feeding the part from one end, we can get many parts on a single set-up which reduces costs. This method works effectively with more fluid alloys or when we can add a rib down the center of the part to allow metal to flow to the end.

B. Flat gating – This method feeds from the top of the part to ensure the best metal filling. Since we can put fewer parts in an assembly, it is the most expensive method.

C. Edge gating – By adding gates on both sides of the part, we can ensure even filling while providing good stability to the part. The major cost disadvantage lies in the extra cutting operations necessary to remove the part from the assembly and to finish it.

Cast Holes

We can form cast holes using one of several options depending on configuration, diameter, length, alloy, process (solid mold or ceramic shell), and production rate. Ideally, we will build the core into the die. We might also inject a "soluble wax core" and place it into the main wax pattern die prior to injection. The soluble wax is removed from the wax pattern prior to assembling the patterns to the drum set-up.

When the diameter and length are too small to permit ample shell layers to be applied, a "pre-formed ceramic core" is used. The ceramic core is removed after the metal has been poured.

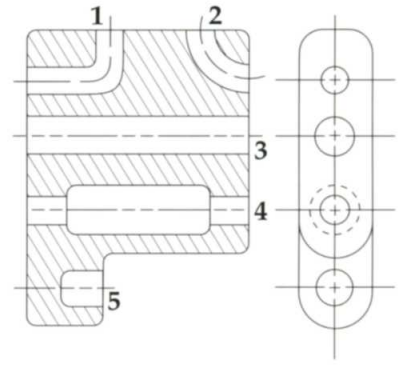
The process enables you to cast through holes and blind holes, as noted in the chart below. The maximum permissible hole length increases as the diameter increases.

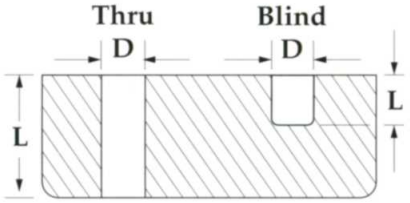
In cases where we need to strengthen sections of your part or prevent shell buckle on large flat surfaces, we may add through holes, ribs, or bosses. These features will add to the stability of the shell and make it less likely to flex after the wax is evacuated or during the metal pour.

PMI Cast Hole Forming Methods

Hole	Die Core	Soluble Wax Core	Ceramic Core
1		x	x
2	x	x	x
3	x		
4		x	x
5	x		

The holes shown in the drawings below use the methods for hole forming demonstrated in the chart above.





Cast Hole Sizing Guide

	Minimum Diameter (D)		Maximum Length (L)		
	Ferrous	Non-Ferrous	Ferrous	Non-Ferrous	
				Shell	Solid Mold
Thru	.060	.040	3D	4D	6D
Blind	.070	.050	1D	2D	3D

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*Castings with intricate internal shapes achieved by proper coring, like the right angle tube bend required in this body float used in aircraft equipment, are well within the capabilities of **PMI's** investment casting.*
Alloy: 356 aluminum, 0.108 lbs., shown 2/3 actual size.

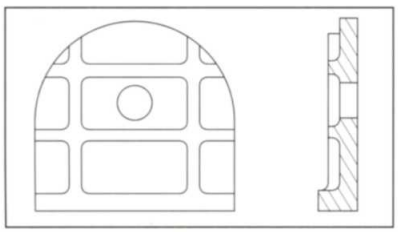
***PMI's** investment casting provides the accurate control needed to create the precisely curved surfaces of this pump impeller for the aircraft industr*
Alloy: 355 aluminum, 0.069 lbs shown 3/4 actual size.

Wall Thickness

The wall thickness we can offer depends on the fluidity of the alloy. For aluminum, copper-based, or ductile iron, we can pour walls as thin as .060 in. compared to a wall thickness of only .080 in. or .090 in. for steel. We can create a much thinner wall thickness for a small area, e.g., around a slot or counter bore, than over a large area.

PMI Minimum Wall Thickness Guidelines (inches)

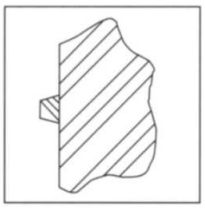
Metal	Small Area (.25 x .25)	Normal
Be Copper	0.035	0.050
Ductile	0.035	0.050
Aluminum	0.040	0.060
Cobalt	0.040	0.060
300 Series Stainless Steel	0.040	0.060
400 Series Stainless Steel	0.045	0.070
Carbon Steel	0.050	0.080



All wall thickness tolerances shown in the above chart should be applied to the "plus" side, i.e., +.015 - .000.

Cast Lettering

Cast lettering is one of the unique capabilities of investment casting. It enables ***PMI*** to cast your company name or logo, your part number, or gradations and indicator lines right into the part. We offer raised lettering, raised lettering on a depressed pad, and depressed lettering. To avoid possible washing away of the lettering, we recommend raising the lettering on a depressed pad to produce a "stamped-in" look.



Raised letters

Raised letters on a depressed pad

Depressed letters

Surface Finish

Among metal casting processes, investment casting is known for its fine as-cast finish. The actual finish depends upon the alloy, with non-ferrous alloys yielding a finer finish than ferrous materials.

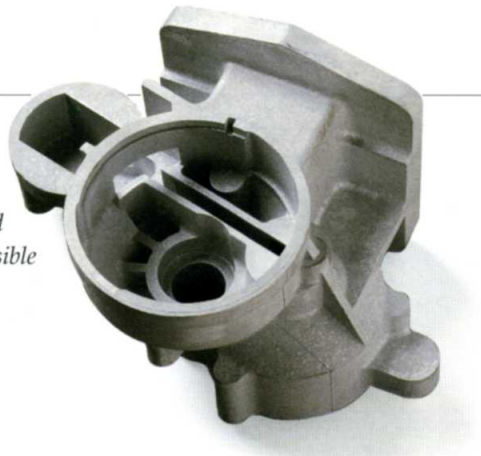
Surface Finish by Alloy

Alloy	RMS Range
Aluminum Alloys	60–100
Copper Alloys	60–100
Cobalt Chrome	80–100
300 Series Stainless	90–125
Carbon Steel	90–125
400 Series Stainless	100–125

Surface Finish by Casting Process

Casting Process	RMS Range
Die	20–120
Investment	60–200*
Steel Mold	120–300
Centrifugal-Permanent Mold	30–300
Static Permanent Mold	200–420
Normal Non-Ferrous Sand	300–560
Normal Ferrous Sand	560–900

*The typical finish offered by the ***PMI*** investment casting process for ferrous alloys is 125 RMS.

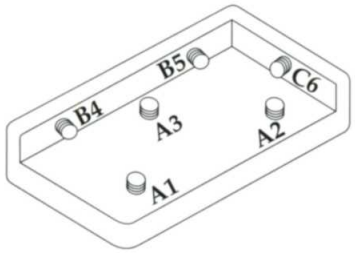


*This end bell starter, used in small aircraft or helicopter engines, shows the type of detailed internal design configuration possible with **PMI's** investment casting. Alloy: 356 aluminum, 1.695 lbs., shown 1/2 actual size.*

Tooling Points

Tooling points are specified locations of a casting that serve as points of fixture contact for inspection and machining operations. These points define at least three datum points on the casting.

All features of the casting are dimensioned from the datum planes. Tooling points should be as far apart as part size and shape will permit. Every attempt should be made to locate all tooling points on surfaces that are not subsequently machined.



A – Primary tooling points
B – Secondary tooling points
C – Tertiary tooling points

PROTO-CAST®

PMI offers a unique prototyping service that allows you to see your part in metal before we construct permanent tooling. Using our patented Proto-Cast® process, we create the component parts of your design in wax using conventional machining techniques. We then cast the handmade pattern in your desired alloy. Proto-Cast® gives you a metal part incorporating the design freedom only investment casting can offer while closely resembling the output of tooling. Intended mainly for parts for which you anticipate placing a production order, the Proto-Cast® system is an excellent means of obtaining a limited number of functional samples. With Proto-Cast®, you can visualize a new design, update an old one, verify alloy selection, and establish heat treat and finishing requirements.

If you order a Proto-Cast® that later becomes a production part, your Proto-Cast® charges may be applied towards the cost of your permanent tooling.

Ask your ***PMI*** Sales Engineer for details about how our unique system can benefit your design process.

Getting the Most Accurate Quote

To provide you with an accurate quote, we need as much information as possible from you when you send in your request for quote (RFQ). Our ability to develop a price and translate your requirements into the part that you need depends on our having a thorough understanding of what you expect. For the best response to your RFQ, please submit a clear part drawing—accurate to your latest revision—that includes the following information:

- Your part name and number
- Your alloy preference
- Tolerances
- Critical dimensions
- Finish requirements
- Machining reference points, if applicable
- Inspection requirements
- Heat treat requirements

If the part will need after-cast machining, please submit a machining drawing.

We also need your projected volume requirements and preferred date of delivery along with any other special requirements.

Our estimating staff will provide you with a quote in a timely manner. On the face of the quote we will list exactly what is included in the as-cast price for the raw castings, plus any heat treating or other after-cast operations.

We can accommodate your inquiry via mail, fax, disk, e-mail, or modem. Please contact us to discuss software compatibility.

This valve cap used in aircraft equipment includes multiple wall thicknesses and cast-in holes. Alloy: 356 aluminum, 0.515 lbs., shown 1/2 actual size.

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Achieving the design requirements of this spool used in flow, pressure, and motion control valves demonstrates the capabilities of ***PMI's*** *investment casting. Alloy: 356 aluminum, 0.283 lbs., shown 1/2 actual size.*

Furnished Tooling

Because we pride ourselves on our ability to produce quality made-to-print parts, we prefer to construct new tooling for you. However, if you supply us with investment casting tooling, we will try to adapt it to our system. In assessing whether we can adapt your die, we will examine the general condition of the die in light of your projected volume. We will advise you of any adaptation charges and offer you a choice of either adapting or replacing the tool.

After running sample patterns and castings from your die, we will examine the product of the mold to determine whether the die can perform adequately. With furnished dies, we can offer you tolerances only as close as the tool can produce.

Finished Products

Investment casting is known for its capacity to yield parts that need little if any finishing work. For some features (holes, angle surfaces, critical dimensions, or surface finish requirements), it may be more economical to cast a part with additional stock material and then perform secondary or finishing operations like drilling, facing, tapping, etc. ***PMI*** not only wants to be your casting supplier but also your full-service vendor for small metal parts.

When your investment castings need after-cast services to make them ready to use, ***PMI*** can perform these services. Our services include heat treating, machining, anodizing, coating, plating, painting, and simple assembly. What we can't do in-house, we contract out to carefully selected and audited vendors who meet our rigid standards for quality and on-time delivery.

When you submit a quote for a part that will require finishing from an outside vendor, you will receive your pricing information for the casting and the finishing on separate quotes. To get the most accurate pricing, please include all company specifications and a machining drawing or marked-up print.

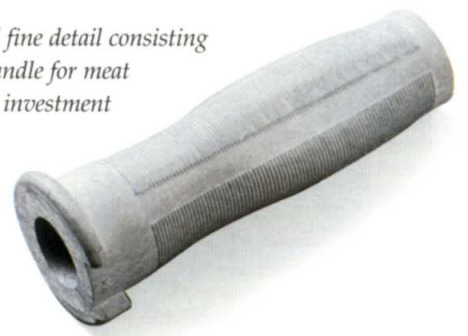
Summary of *PMI* Capabilities

Investment casting is an excellent way to produce metal parts. As a customer, there are two ways for you to get the best the process has to offer. First, choose a foundry that offers you the best combination of price, quality, and service. For over 50 years, ***PMI*** has been the foundry of choice for small parts. Second, communicate your product specifications to our engineers, metallurgists, and sales and service representatives. We are interested in working with you to create the best castings for the best price.

PMI is dedicated to promoting casting design awareness in your design engineers by hosting engineering seminars, either at ***PMI*** or at your facility. These seminars are aimed at helping your engineering staff help us by considering tolerances, surface finish, roundness, material grade, gating, and other variables before submitting a print. Contact your ***PMI*** sales agent or customer service representative if you are interested in having us put on a seminar for your group.

If you have any questions about alloy choice or casting design, call us at (216) 481-8900. Our staff of metallurgists, engineers, and sales professionals is available to help you bring your design from prototype to ready-to-use part.

The near net shape, as-cast finish, and fine detail consisting of ribbing and cast lettering on this handle for meat trimming tools illustrates how ***PMI's*** *investment casting process can eliminate the need for many costly secondary operations. Alloy: 356 aluminum, 0.216 lbs., shown 1/2 actual size.*



Hardness Comparison–Rockwell B to Other Hardness Numbers

B 100 KG. 1/16" BALL	F 60 KG. 1/16" BALL	30-T 30 KG. 1/16" BALL	E 100 KG. 1/8" BALL	VICKERS HARDNESS NUMBER	KNOOP 50 GR. and over	BRINELL 3,000 kg. D.P.H. 10 kg.	TENSILE STRENGTH
ROCKWELL	ROCKWELL	ROCKWELL SUPERFICIAL	ROCKWELL	VICKERS	ROCKWELL	ROCKWELL	Thousand lbs. per sq. in.
100	-	83.1	-	240	251	240	116
99	-	82.5	-	234	246	234	112
98	-	81.8	-	228	241	228	109
97	-	81.1	-	222	236	222	106
96	-	80.4	-	216	231	216	103
95	-	79.8	-	210	226	210	101
94	-	79.1	-	205	221	205	98
93	-	78.4	-	200	216	200	96
92	-	77.8	-	195	211	195	93
91	-	77.1	-	190	206	190	91
90	-	76.4	-	185	201	185	89
89	-	75.8	-	180	196	180	87
88	-	75.1	-	176	182	176	85
87	-	74.4	-	172	188	172	83
86	-	73.8	-	169	184	169	81
85	-	73.1	-	165	180	165	80
84	-	72.4	-	162	176	162	78
83	-	71.8	-	159	173	159	77
82	-	71.1	-	156	170	156	75
81	-	70.4	-	153	167	153	74
80	-	69.7	-	150	164	150	72
79	-	69.1	-	147	161	147	EVEN FOR STEEL, TENSILE STRENGTH RELATION TO HARDNESS IS INEXACT UNLESS DETERMINED FOR SPECIFIC MATERIALS.
78	-	68.4	-	144	158	144	
77	-	67.7	-	141	155	141	
76	-	67.1	-	139	152	139	
75	99.6	66.4	-	137	150	137	
74	99.1	65.7	-	135	147	135	
72	98.0	64.4	-	130	143	130	
70	96.8	63.1	99.5	125	139	125	
68	95.6	61.7	98.0	121	135	121	
66	94.5	60.4	97.0	117	131	117	
64	93.4	59.0	95.5	114	127	114	
62	92.2	57.7	94.5	110	124	110	
60	91.1	56.4	93.0	107	120	107	
58	90.0	55.0	92.0	104	117	104	
56	88.8	53.7	90.5	101	114	101	
54	87.1	52.4	89.5	87	111	*87	
52	86.5	51.0	88.0	85	109	*85	
50	85.4	49.7	87.0	83	107	*83	
48	84.3	48.3	85.5	81	48	*81	
46	83.1	47.0	84.5	79	103	*79	
44	82.0	45.7	83.5	78	101	*78	
42	80.8	44.3	82.0	76	99	*76	
40	79.7	43.0	81.0	74	97	*74	
38	78.6	41.6	79.5	73	95	*73	
36	77.4	40.3	78.5	71	93	*71	
34	76.3	39.0	77.0	70	91	*70	
32	75.2	37.6	76.0	68	89	*68	
30	74.0	36.3	75.0	67	87	*67	
28	73.0	34.5	73.5	66	85	*66	
24	70.5	32.0	71.0	64	82	*64	
20	68.5	29.0	68.5	62	79	*62	
16	66.0	26.0	66.5	60	76	*60	
12	64.0	23.5	64.0	58	73	*58	
8	61.5	20.5	61.5	56	71	*56	
4	59.5	18.0	59.0	55	69	*55	
0	57.0	15.0	57.0	53	67	*53	

Hardness Comparison–Rockwell C to Other Hardness Numbers

C 150 KG. BRALE®	A 60 KG. BRALE®	15-N 15 KG. N BRALE®	30N 30 KG. N BRALE®	VICKERS HARDNESS NUMBER	KNOOP 50 GR. and over	BRINELL 3,000 kg. 10 mm. Ball	TENSILE STRENGTH
ROCKWELL	ROCKWELL	ROCKWELL SUPERFICIAL	ROCKWELL	VICKERS	ROCKWELL	ROCKWELL	Thousand lbs. per sq. in.
70	86.5	94.0	86.0	1076	972	-	INEXACT AND ONLY FOR STEEL
69	86.0	93.5	85.0	1004	946	-	
68	85.6	93.2	84.4	940	920	-	
67	85.0	92.9	83.6	900	895	-	
66	84.5	92.5	82.8	865	870	-	
65	83.9	92.2	81.9	832	846	-	
64	83.4	91.8	81.1	800	822	-	
63	82.8	91.4	80.1	772	799	-	
62	82.3	91.1	79.3	746	776	-	
61	81.8	90.7	78.4	720	754	-	
60	81.2	90.2	77.5	697	732	-	
59	80.7	89.8	76.6	674	710	634	351
58	80.1	89.3	75.7	653	690	615	338
57	79.6	88.9	74.8	633	670	595	325
56	79.0	88.3	73.9	613	650	577	313
55	78.5	87.9	73.0	595	630	560	301
54	78.0	87.4	72.0	577	612	543	292
53	77.4	86.9	71.2	560	594	525	283
52	76.8	86.4	70.2	544	576	512	273
51	76.3	85.9	69.4	528	558	496	264
50	75.9	85.5	68.5	513	542	481	255
49	75.2	85.0	67.6	498	526	469	246
48	74.7	84.5	66.7	484	510	451	238
47	74.1	83.9	65.8	471	495	442	228
46	73.6	83.5	64.8	458	480	432	221
45	73.1	83.0	64.0	446	466	421	215
44	72.5	82.5	63.1	434	452	409	208
42	71.5	81.5	61.3	412	426	390	194
40	70.4	80.4	59.5	392	402	371	182
38	69.4	79.4	57.7	372	380	353	171
36	68.4	78.3	55.9	354	360	336	161
34	67.4	77.2	54.2	336	342	319	152
32	66.3	76.1	52.1	318	326	301	146
30	65.3	75.0	50.4	302	311	286	138
28	64.3	73.9	48.6	286	297	271	131
26	63.3	72.8	46.8	272	284	258	125
24	62.4	71.6	45.0	260	272	247	119
22	61.5	70.5	43.2	248	261	237	115
20	60.5	69.4	41.5	238	251	226	110

Metric Conversion Factors

TO CONVERT FROM	TO	MULTIPLY BY	TO CONVERT FROM	TO	MULTIPLY BY
angstrom	m	1.0000×10^{-10}(a)	hp(e)	W	7.4570×10^{2}
atm	Pa	1.0133×10^{5}	hp(f)	W	7.4600×10^{2}
Btu(b)	J	1.054×10^{3}	in.	m	2.5400×10^{-2}
Btu(b)/ft².h	W/m²	3.1525	in.2	m²	6.4516×10^{-4}
Btu(b)/ft².h.°F	W/m².K	5.6745	in.3	m³	1.6387×10^{-5}
Btu(b).ft/ʰ.ft².°F	W/m.K	1.7296	in. of Hg(g)	Pa	3.3864×10^{3}
Btu(b)/ft².s	W/m²	1.135×10^{4}	in. Of water(c)	Pa	2.4908×10^{2}
Btu(b).in./ft².h.°F	W/m.K	1.4413×10^{-1}	K	°C	$t_C - t_K - 273.15$
Btu(b).in./s.ft².°F	W/m.K	5.1887×10^{2}	kgf	N	9.80665(a)
Btu(b)/lbm.°F	J/kg.K	4.1840×10^{3}	kgf/mm²	Pa	9.80665×10^{6}(a)
cal(b)	J	4.1840 (a)	ksi	MPa	6.8948
cal(b)/cm.s.°C	W/m.K	4.1840×10^{2}(a)	ksi	Pa	6.8948×10^{6}
cal(b)/g	J/kg	4.1840×10^{3}(a)	ksi√in.	MPa√m	1.089
cal(b)/g.°C	J/kg.K	4.1840×10^{3}(a)	lb(h)	kg	4.5359×10^{-1}
circ mil	m²	5.0671×10^{-10}	lb/in.³	kg/m³	2.7680×10^{4}
°C	K	$t_K = t_C + 273.15$	lbf	N	4.4482
degree	rad	1.7453×10^{-2}	lbf.in.	N.m	1.1298×10^{-1}
dyne/cm²	Pa	1.0000×10^{-1}(a)	lbf.ft	N.m	1.3558
°F	°C	$t_C = (t_F - 32)/1.8$	MPa√m	$MNm^{-3/2}$	1.0000(a)
°F	K	$t_K = (t_F + 459.67)/1.8$	µin.	m	2.5400×10^{6}(a)
ft	m	3.0480×10^{-1}	mil	m	2.5400×10^{-5}(a)
ft²	m²	9.2903×10^{-2}	N/M²	Pa	1.0000(a)
ft³	m³	2.8317×10^{-2}	oersted	A/m	79.578
ft of water(c)	Pa	2.9890×10^{3}	oz/ft²	kg/m²	3.0515×10^{-1}
ft²/h (thermal diffusivity)	m²/s	2.58064×10^{-5}(a)	psi	Pa	6.8948×10^{3}
ft.lbf	J	1.3558	°R	K	$t_K = t_F/1.8$
ft.lbf/s	W	1.3558	ton(j)	kg	9.0718×10^{2}
ft/s	m/s	3.0480×10^{-1}	ton(k)	kg	1.0160×10^{3}
gauss	T	1.0000×10^{-4}(a)	ton/in.²	Pa	1.3786×10^{4}
gallon(d)	m³	3.7854×10^{3}1	tonne	kg	1.0000×10^{3}(a)
g/cm³	kg/m³	1.0000×10^{3}(a)	torr	Pa	1.3332×10^{2}
g/cm³	Mg/m³	1.0000(a)	Ω/circ mil.ft	Ω.m	1.6624×10^{-9}

Key:
(a) Exactly.
(b) Thermochemical
(c) At 4°C (39.2°F)
(d) U.S. liquid.
(e) Mechanical (1 hp=550 ft lbf/s)
(f) Electrical
(g) At 0°C(32°F)
(g) Avoirdupois
(j) Short; equal to 2000 lbm
(k) Long; 2240 lbm

For more than 50 years, PRECISION METALSMITHS, INC. has satisfied customers in a wide range of industries. We would welcome the opportunity to show you how our experience and skill can provide the exceptional value and quality that only our investment casting processes can deliver.

The Benefits of ***PMI*** Investment Casting:

- Near Net Shape — uses metal economically and reduces after-cast machining.
- Close Tolerances — casts at an average tolerance of ±.005-inch or better, which decreases the need for after-cast straightening.
- Excellent Surface Finish — yields an average, as-cast microfinish of 125 RMS; lessens or eliminates after-cast finishing requirements.
- Cast-in Detail — capable of including holes and lettering, lowers the need for costly machining.
- Design Freedom — allows simple or complex design, including intricate internal configuration.
- Wide Alloy Choice — offers a broad range of nearly 200 ferrous and non-ferrous air-meltable alloys.
- Size Range — ideal for small parts with weights from fractions of an ounce to 10 pounds.
- Tooling Economy — requires lower-cost tooling to cast high-quality parts.

Please contact us to receive any of our other brochures:

- The Strength of Ferrous Alloys
- The Benefits of Ductile Iron
- The Versatility of Aluminum and Non-Ferrous Castings
- Investment Casting Systems

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PRECISION METALSMITHS, INC.

1081 East 200th Street
Cleveland, OH 44117
Telephone: 216/481-8900
Fax: 216/481-8903
www.precisionmetalsmiths.com