VascoMax®
C-200
C-250
C-300
C-350

TELEDYNE VASCO

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Initial Cost per Pound of the Material Is Always Only Part of the Story

Most often, the cost of machining, forming, and heat treatment will exceed the cost of the alloy selected for a given application. VascoMax, with a simple aging heat treatment, good machinability, uniform, predictable shrinkage during heat treatment, and other fabrication advantages, has cost advantages over many other alloys.

Life of the part manufactured is of course also critical to the overall cost picture. What is the cost per unit cast, punched, extruded, or formed? Here again, VascoMax has proven, long-standing records of success over more traditional tool and die steels in a wide variety of applications.

This visualization illustrates how drastic the cost reductions can be by switching to one of the VascoMax alloys. It is based on an actual cost study done for one die casting application, comparing VascoMax C-250 and H-13. Die cost for both materials are visualized in terms of cost per unit cast.

Introduction

C-type VascoMax Steels

Unique combinations of vital mechanical properties, plus cost-saving processing advantages, lead to the continued success of the VascoMax alloys in a growing number of structural and tooling applications.

VascoMax alloys (18% nickel maraging steels) are divided into two broad classes depending upon the primary strengthening element in the chemical analysis. The original maraging steels, introduced in the early 1960s, depend on cobalt (7-12% cobalt depending on the grade) as their strengthening agent; they are **cobalt-strengthened** 18% nickel maraging steels. In the early 1980s, Teledyne Vasco introduced a new type of maraging steel which contains no cobalt and has titanium as a primary strengthening agent; they are **titanium-strengthened** 18% nickel maraging steels.

Cobalt-strengthened grades, or "C-type 18Ni maraging," are designated by the letter "C" in the grade identification. Example: VascoMax C-250. Titanium-strengthened grades, or "T-type 18Ni maraging," sometimes referred to as Free-Co (cobalt-free), are designated by the letter "T" in the grade identification. Example: VascoMax T-200, T-250, and T-300. It should be noted that the "T" grades are less expensive than the "C" grades.

This booklet covers the C-type 18Ni maraging steels manufactured by Teledyne Vasco — VascoMax C-200, VascoMax C-250, VascoMax C-300, and VascoMax C-350. Information on the T-type VascoMax grades is available in separate publications. It should be emphasized that the essential difference between C-type and T-type maraging steels is the chemical analysis. In terms of mechanical properties and recommended processing, there are few, if any, significant differences.

Nickel, rather than carbon, is the principal alloying element in the VascoMax steels, which are essentially carbon-free. Other major alloying elements in C-type 18Ni maraging are cobalt, molybdenum, aluminum, and titanium (See figure 2).

Since high purity melting is essential to assure optimum mechanical properties, Teledyne Vasco employs double vacuum melting, under strictest quality control, for all VascoMax grades.

	VascoMax C-200	VascoMax C-250	VascoMax C-300	VascoMax C-350
Ultimate Tensile, psi	210,000	260,000	294,000	350,000
0.2% Yield, psi	206,000	255,000	290,000	340,000
Elongation, %	12	11	11	7
Reduction of Area, %	62	58	57	35
Notch Tensile (Kt=9.0), psi	325,000	380,000	420,000	330,000
Charpy V-Notch Ft. Lb.	36	20	17	10
Fatigue Endurance Limit (10^8 Cycles), psi	110,000	110,000	125,000	110,000
Rockwell "C" Hardness	43/48	48/52	50/55	55/60
Compressive Yield Strength, psi	213,000	280,000	317,000	388,000

FIGURE 1 — Nominal Mechanical Properties of Small Diameter Bars following "Aging" Heat Treatment

NOMINAL ANALYSIS	VascoMax C-200	VascoMax C-250	VascoMax C-300	VascoMax C-350
Nickel	18.50%	18.50%	18.50%	18.50%
Cobalt	8.50	7.50	9.00	12.00
Molybdenum	3.25	4.80	4.80	4.80
Titanium	.20	.40	.60	1.40
Aluminum	.10	.10	.10	.10
Silicon	.10 max.	.10 max.	.10 max.	.10 max.
Manganese	.10 max.	.10 max.	.10 max.	.10 max.
Carbon	.03 max.	.03 max.	.03 max.	.03 max.
Sulfur	.01 max.	.01 max.	.01 max.	.01 max.
Phosphorus	.01 max.	.01 max.	.01 max.	.01 max.
Zirconium	.01	.01	.01	.01
Boron	.003	.003	.003	.003

FIGURE 2 — Nominal Analyses, VascoMax Alloys

Numerical designations for each grade, while not direct correlations in all cases, are generally representative of the ultimate tensile strength of that grade, expressed in ksi. For example, VascoMax C-350 has a nominal ultimate tensile strength of 350 ksi (350,000 psi). Variety in property levels among these four grades allows flexibility in selecting the property combination which best suits a given application. Detailed analyses of mechanical properties are offered beginning on page 10. Figure 1, offered here, illustrates briefly the properties of the various VascoMax grades, highlighting the outstanding values for all grades.

An additional benefit of the VascoMax alloys is the age hardening reaction of these nickel maraging steels. In the solution annealed condition (as supplied to the customer), they are very tough, relatively soft (30/35 R_C), and therefore, readily machined and formed. After machining or forming, a precipitation hardening (aging) process, which requires no protective atmosphere and relatively low furnace temperatures, raises the hardness to a level sufficient for many tooling applications.

Development and Early Applications

Aerospace demands for ultra-high-strength materials led to the development of C-type 18% nickel maraging steels by the International Nickel Company in the early 1960s. Teledyne Vasco was instrumental in assisting INCO in the development, and pioneered these alloys in the specialty steel industry.

Initial VascoMax applications in the aerospace industry included solid propellant rocket motor cases, load cells (used to measure the thrust of large rockets), flexures (used in the guidance mechanism of missiles), helicopter drive shafts, and aircraft wing components. C-type 18Ni 250-grade helped write space history. It was used for torsion bars on the Apollo 15 Lunar Roving Vehicle — the first wheeled vehicle on the moon; and was later used for a critical component on the Space Shuttle Columbia — the first reusable space craft.

Shortly after development, the great potential for VascoMax in tooling applications was realized. Initial tooling applications included aluminum die casting dies and core pins, plastic molding dies, extrusion tooling, punches, trim knives, blanking dies, and cold forming dies.

Today, the C-type VascoMax grades continue as a cost-effective material in aerospace, structural, component, and tooling applications. Success of these four steels is not due solely to high strength and excellent ductility inherent in these alloys, but to unique combinations of outstanding mechanical properties and fabrication characteristics.

Advantages of VascoMax

Teledyne Vasco prepared this brochure to assist both the engineer, and the less technically oriented individual in understanding the tremendous benefits of VascoMax as both a structural and tooling material. Contained in this brochure is information on mechanical properties; recommended procedures for heat treating, machining, forming, welding, and finishing; and highlights of a variety of applications. Each of the advantages of VascoMax, outlined to the right, is described in greater detail in this brochure.

Excellent Mechanical Properties

- High yield and ultimate tensile strengths
- High toughness, ductility, and impact strengths
- High fatigue strength
- High compressive strength
- Hardness and wear resistance sufficient for many tooling applications

Excellent Workability

- Easily machined
- Readily formed — cold, warm, or hot (without in-process anneals)
- High resistance to crack propagation
- Excellent polishability
- Good weldability without preheating or post heating

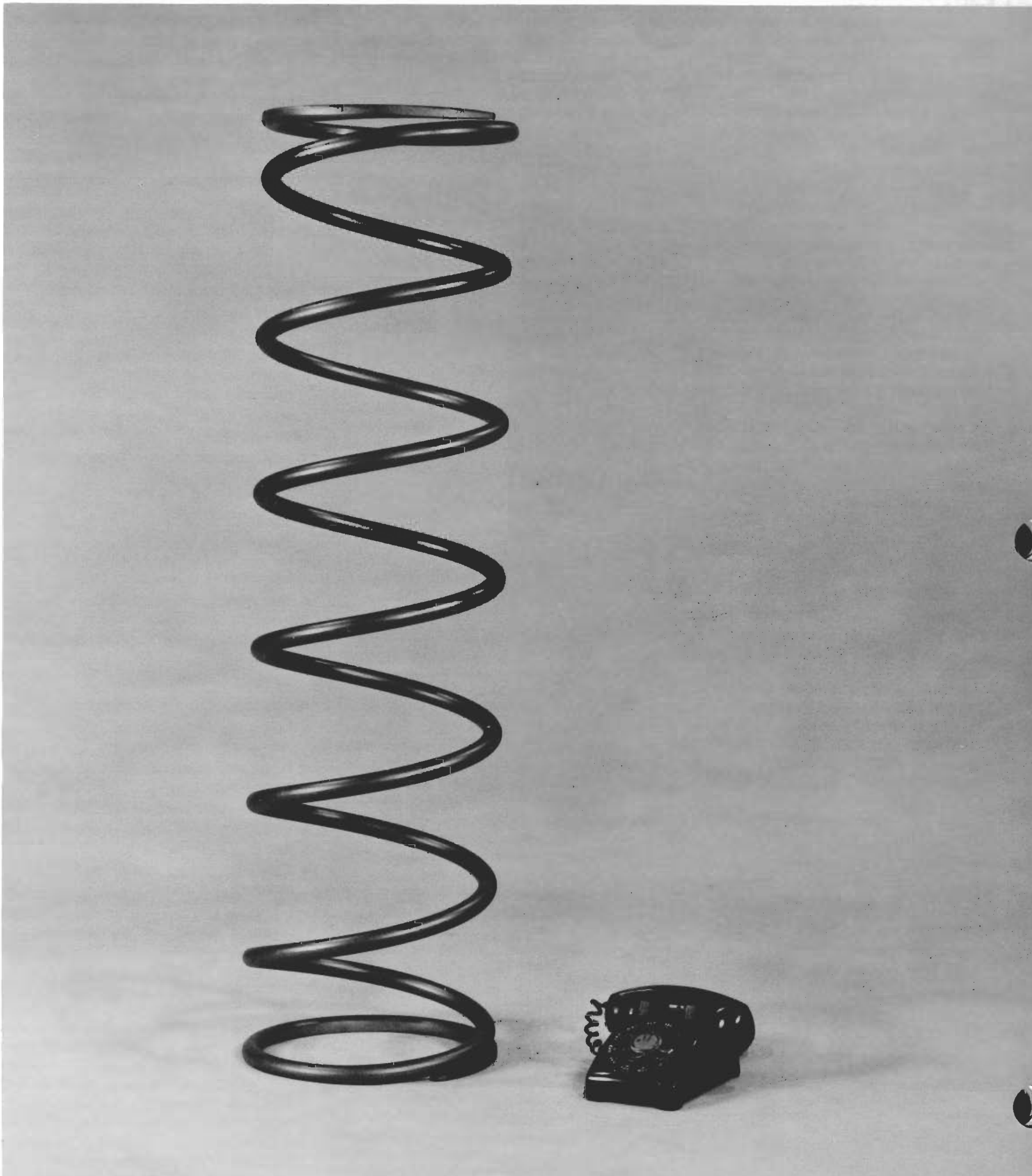
Excellent Heat Treatment Characteristics

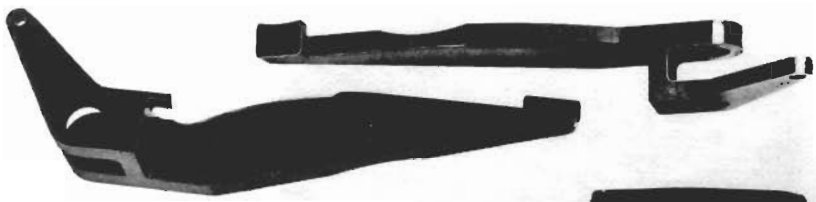
- Low furnace temperatures required
- Precipitation hardening, aging heat treatment
- Uniform, predictable shrinkage during heat treatment
- Minimal distortion during heat treatment
- Through hardening without quenching
- No protective atmosphere required
- Freedom from carburization or decarburization

Advantages During Application

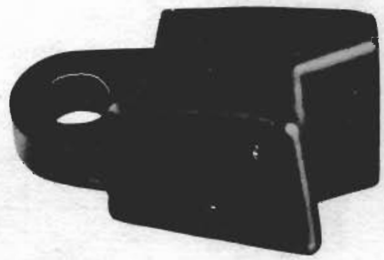
- Low coefficient of expansion minimizes heat checking
- Pitting and corrosion resistance superior to common tool steel
- Good repair weldability
- Excellent mechanical properties have led to longer tool life
- Easily reworked and retreated for secondary tool life

Applications





VASCOMAX C-250
Empty Case Extractor



VASCOMAX C-250
Powder Can Latch

VASCOMAX C-250
Shouldered Splined Shaft

VASCOMAX C-250
Huge (16" x 30" x 55") high quality forging as furnished by Teledyne Vasco for a die casting customer.

VASCOMAX C-200
Buffer Arm (Welded segments)

VASCOMAX C-350
Piston Hoist Gear Rack

VASCOMAX C-350
Cold forming die for plow bolt heads. Best previous die material was D-2 — yielding an average of 3000 pieces. VascoMax gave 8000 pieces before cracking occurred.

Gun Recoil Spring for the 105mm Cannon of the M-60 Combat Tank

The spring manufacturer hot winds these huge springs (Note size comparison with common desk telephone) from a single, high quality bar of VascoMax C-250, 1.030" diameter. *Photo compliments of: Union Spring & Mfg. Co., Division of the Union Corporation.*

Flexures for Rocket Motor Testing

High strength VascoMax C-300 has been used in rocket motor testing, as well as for construction of rocket motor cases. The flexure shown was manufactured from an 18" diameter by 18" long forging. Flexures such as the one illustrated are the largest of several designs produced from VascoMax C-300, and are rated at 1,000,000 pound capacity. High proportional limits, good toughness, machinability, and ease of heat treatment were major considerations in material selection. A proportional limit over 60% higher than other steels permitted the 1,000,000 pound flexures to be made sufficiently smaller (using VascoMax) so that they could be manufactured for a lower total unit cost than comparably rated units made of either low alloy or precipitation hardening stainless steel. *Photo: Teledyne Vasco*

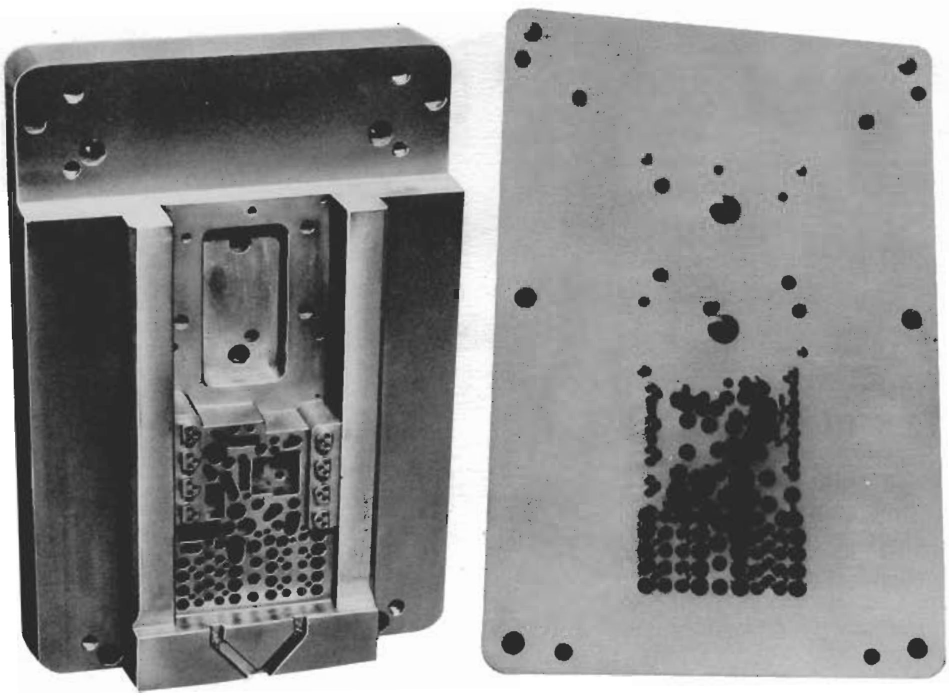
Aircraft Quill Shaft

This application won the 1962 Materials Award competition sponsored by the American Society for Metals as the "outstanding ferrous application of the year." This aircraft quill shaft was made from VascoMax C-250. *Photo compliments of Bendix Utica Division, The Bendix Corporation.*

Complex Plastic Mold Manufactured from VascoMax C-250

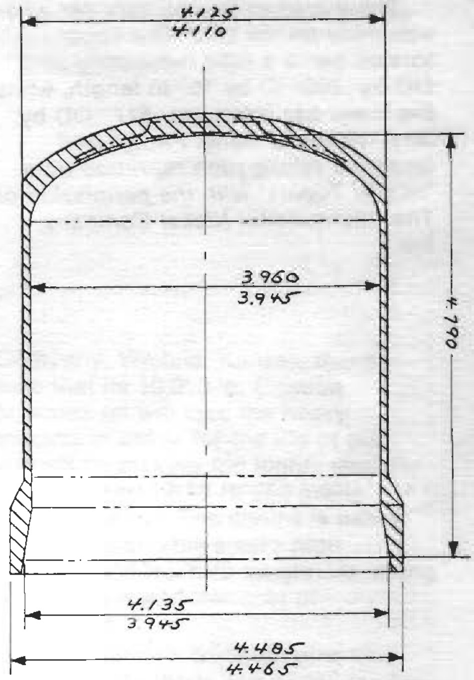
These are the front and back views of a very complex plastic mold which measures 3⅜" by 8" by 12" long. It contains round holes ranging in diameter from ¼" to 1½", as well as square, oblong, and irregularly shaped holes concentrated in one area of the die.

Major considerations which led to the selection of VascoMax for this application were the need for a material which would not distort during heat treatment, would not require excessive rework after heat treatment, would produce a fine surface finish, and would have sufficient hardness and strength to withstand the pressures of compression molding VascoMax C-250 was the ideal material. Aged at 900°F for 4 hours, it shrank uniformly (in this case .0008 in./in.) on all dimensions, showed no distortion or cracking, and had a resulting hardness of 50 R_C. Because of the predictable, uniform shrinkage of VascoMax, it was possible to keep post-aging rework to a minimum. *Photo: Teledyne Vasco.*



Gas Generator Case for Dragon Anti-Tank Missile

The Dragon missile is one of today's "smart" missiles. It is a shoulder-fired, anti-tank "wired" missile with a range of 1000 meters (well over a half-mile). The gas generator case (on left) is cold formed from circles 7.25" diameter which Teledyne Vasco blanks from .250" thick VascoMax C-250 sheet. The case is finished with single lathe cuts on diameters (to a wall thickness of .082") and internal threading. Holes are added in subsequent operations. *Photo and diagram compliments of : Floturn, Inc.*



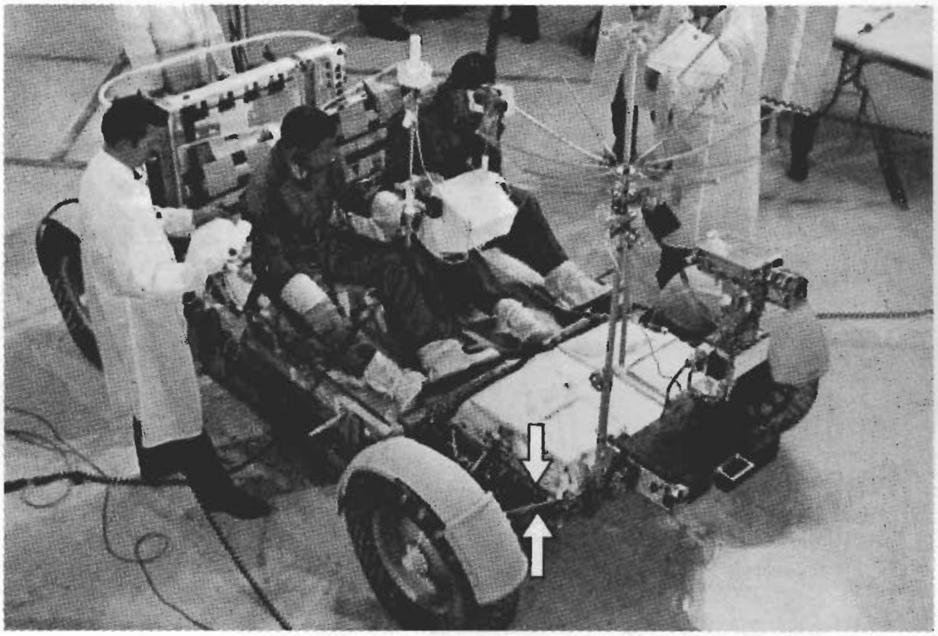
VascoMax C-300 Load Cell

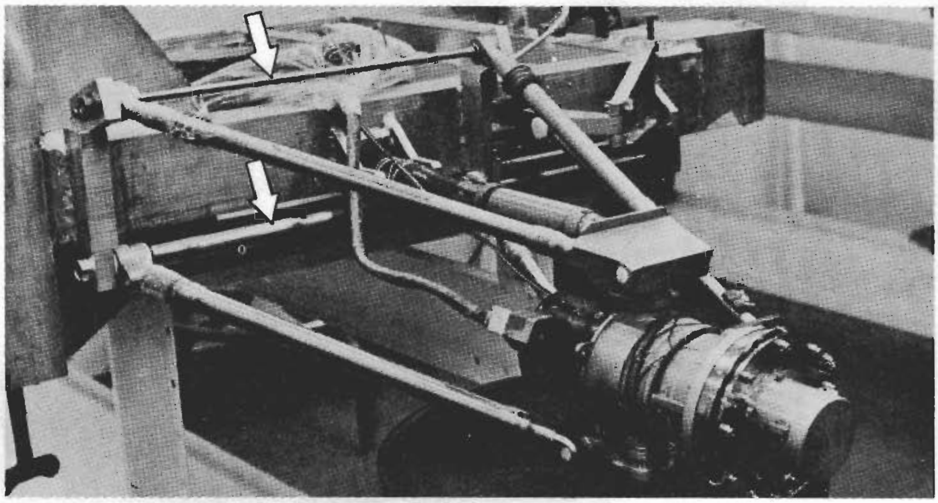
Modern rockets generate thrusts amounting to millions of pounds. These awesome totals are measured by load cells capable of sustained operation under pressure. One such load cell, developed for NASA's Marshall Space Flight Center, is capable of measuring sustained forces of 5,000,000 pounds. A major constituent of this cell is VascoMax C-300, aged to a yield strength of 270,000 psi. Its design stress level is nearly 80,000 psi, with an allowable overstress limit of nearly twice that value. The cell measures approximately 10" in diameter. *Photo: Teledyne Vasco.*

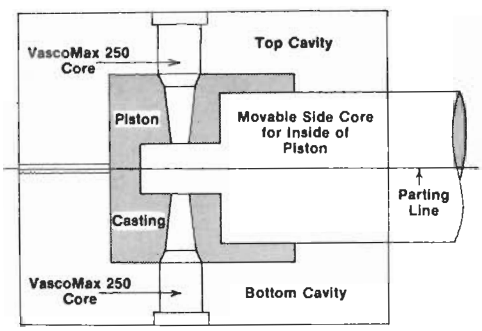
Torsion bars for the Apollo 15 Lunar Roving Vehicle

18 Ni 250 grade maraging steel was used for torsion bars on the Apollo 15 Lunar Roving Vehicle (LRV). To be stored on the Lunar Module, the LRV had to be folded, and the four, wheel suspension systems cocked at 57 degree angles. In the 57 degree position, the torsional shearing stress developed in the bars was 110,000 psi. Further, the torsion bars acted as springs for the LRV once it was deployed, and had to be capable of withstanding the lunar temperature extremes (from -250°F to +250°F) without any possibility of loss of mechanical properties.

There are two torsion bars per wheel assembly on the LRV. The upper torsion bar is a tube measuring .290" OD by .200" ID by 15" in length, while the lower bar measures .517" OD by .417" ID by 25" long. *Photos and technical information reprinted from "Nickel Topics" with the permission of The International Nickel Company, Inc.*



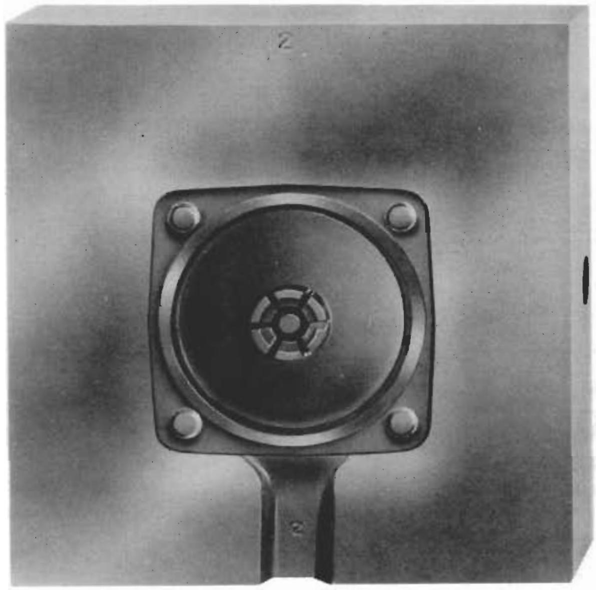




Aluminum Die Casting Die Core Pins

A major die casting company has reported that they have been using VascoMax C-250 for aluminum die casting die core pins with outstanding results.

To determine the advantage of VascoMax in this application a test was conducted, matching VascoMax C-250 against traditional die casting steel, H-13. A six cavity die casting mold employing six H-13 core pins and six VascoMax C-250 core pins was used for the test. After 32,000 shots of all the H-13 pins were cracked. The VascoMax pins were in perfect condition. The H-13 pins were replaced and after an additional 51,000 shots the second set of H-13 pins failed — the VascoMax pins still in very good condition. These same VascoMax pins were run another 70,000 shots — a total of 153,000 shots — before one of the six developed a fine crack. Test results: VascoMax C-250 proven superior to H-13 by a factor greater than 3.5 to 1.



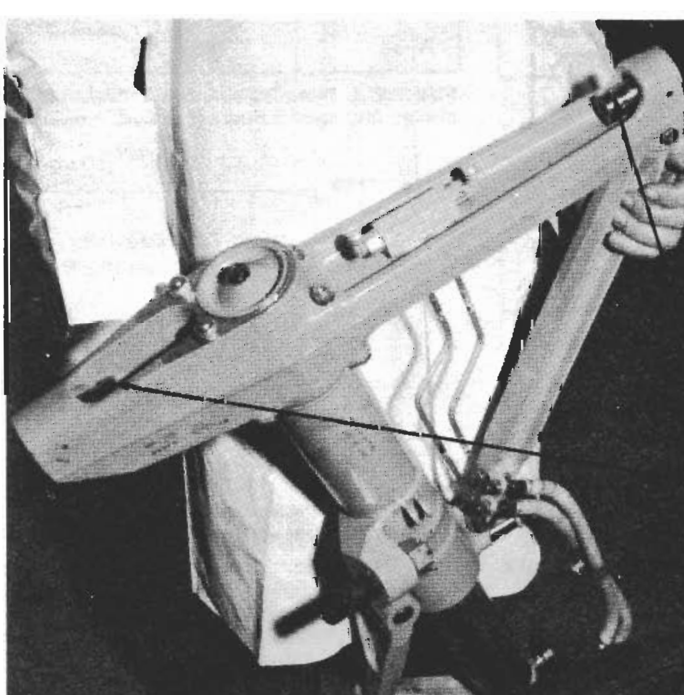
VascoMax C-300
Aluminum Die Casting Die

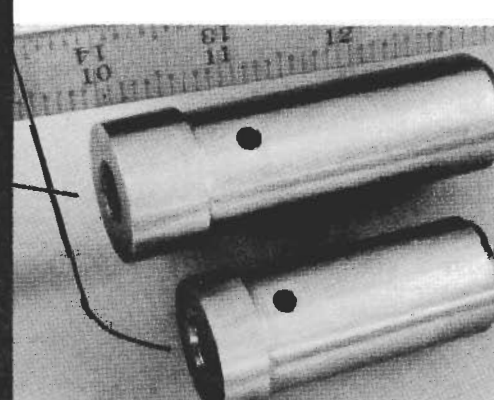
This die casting die makes an aluminum cover for a quick release valve automotive air brake system. The die castings produced by this 5" by 5" by 2" die must have a perfect finish on the flat section in the center of the die because a rubber seal is in contact with this area. One of the reasons for using VascoMax C-300 for this die was the excellent finish that can be obtained on this material. The other principal reason was that the initial die made of VascoMax C-300 outlasted the previous die material, H-13, by a factor of three-to-one. *Photo compliments of: Latrobe Die Casting Company.*

Trunnion Pins
for Aircraft Landing Gear

Landing jolts produce the greatest stresses an aircraft will ever get in normal operation — so landing gear components must be tough enough to take it, yet light enough not to pay any weight penalty. Cessna Aircraft Company, Wichita, Kansas, makes sure that its 10,000 lb. Citation business jet will take the heavy impacts in stride for the life of the aircraft by making the highly stressed trunnion pins of 18 Ni 250 grade maraging steel. The choice is based on this remarkable steel's high strength and fracture toughness, along with its ease and low cost of fabrication.

The Citation's trunnion pins take the full shock loads put on the landing gear, as much as 100,000 ft.-lbs., and transfer them to the main wing spar structure. *Photos and caption reprinted from "Nickel Topics" with the permission of The International Nickel Company, Inc.*





Properties

VascoMax C-200

Physical Properties

Average Coefficient of Thermal Expansion (70° - 900°F)	5.6 x 10^{-6}in./in./°F
Modulus of Elasticity	26.2 x 10^6 psi
Density	.289 lbs./cu. in. (8.0 g/cc)
Thermal Conductivity at 68°F	11.3 BTU/(ft)(hr)(°F)
at 122°F	11.6 BTU/(ft)(hr)(°F)
at 212°F	12.1 BTU/(ft)(hr)(°F)

Nominal Analysis

Nickel	18.50%
Cobalt	8.50
Molybdenum	3.25
Titanium	.20
Aluminum	.10
Silicon	.10 max.
Manganese	.10 max.
Carbon	.03 max.
Sulfur	.01 max.
Phosphorus	.01 max.
Zirconium	.01
Boron	.003

Nominal Annealed Properties

Hardness	30 Rc
Yield Strength	100 ksi
Ultimate Strength	140 ksi
Elongation	18%
Reduction of Area	72%

Nominal Room Temperature Properties of VascoMax C-200 after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5√A %	Reduction of Area %
⅝" Round	Longitudinal	43.4	212.0	207.7	12.5	61.7
1¼" Round	Longitudinal	43.0	214.3	208.5	12.0	60.6
3" Round	Longitudinal	42.8	210.0	204.2	11.9	60.4
6" Square	Longitudinal	43.5	208.4	202.6	11.6	58.8
	Transverse	43.9	206.9	200.1	8.9	41.7
.250" Sheet	Transverse	42.9	218.1	213.0	11.0	45.0

Test Temp. °F	0.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation in 4.5√A %	Reduction of Area %
600	165.5	176.5	12.5	60.0
800	153.6	167.4	14.0	61.0
900	141.7	151.4	18.0	66.3
950	127.1	138.2	18.5	69.6
1000	107.7	121.9	24.0	73.2

FIGURE 1. Effect of test temperature on the tensile properties of VascoMax C-200 solution annealed for one hour at 1500° F., air cooled and aged three hours at 900° F.

Condition	Compressive Strength		Rockwell "C" Hardness
	Proportional Limit ksi	0.2% Offset Yield Strength ksi	
Solution Annealed	105.0	145.0	28
Aged	183.4	213.0	43

FIGURE 3. Samples solution annealed for 30 minutes at 1500°F., air cooled and aged 3 hours at 900°F. Average of four tests per condition.

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	322.9	316.0 - 333.3	1.52
3.0	327.2	323.6 - 334.5	1.54
5.0	325.8	320.3 - 328.5	1.54
6.25	329.1	324.4 - 340.7	1.55
7.0	329.7	319.7 - 339.1	1.55
9.0	328.6	325.5 - 333.6	1.55

*Based on smooth bar tensile strength of 212.0 ksi.

FIGURE 2. Effect of stress concentration factor, K_t, on the tensile properties of VascoMax C-200 solution annealed for one hour at 1500° F., air cooled and aged three hours at 900° F.

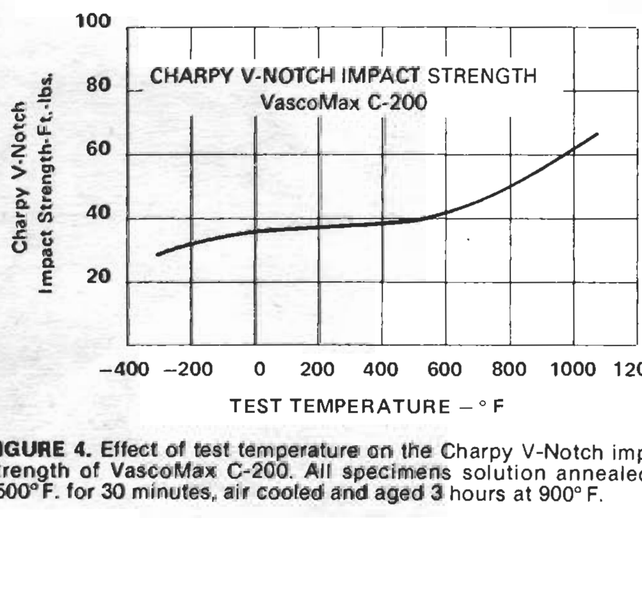


FIGURE 4. Effect of test temperature on the Charpy V-Notch impact strength of VascoMax C-200. All specimens solution annealed at 1500°F. for 30 minutes, air cooled and aged 3 hours at 900° F.

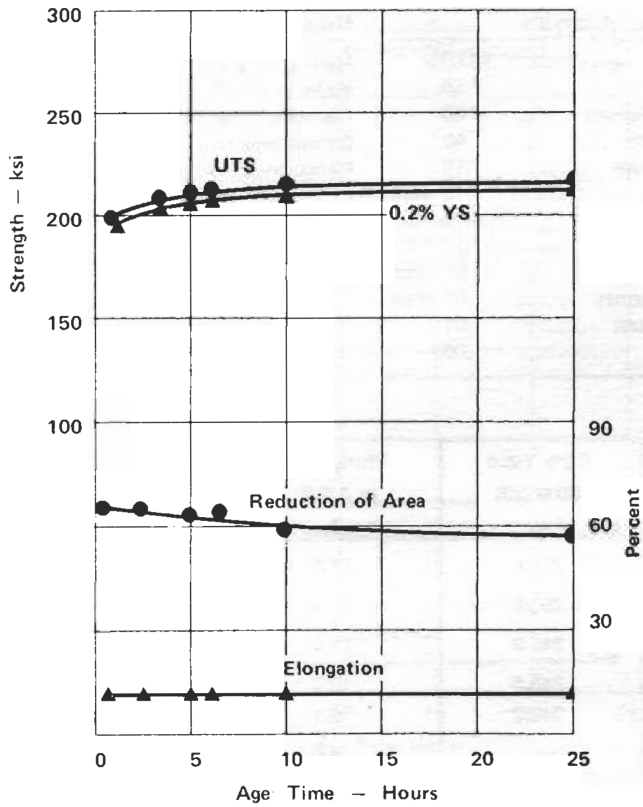


FIGURE 5. Effect of aging time at 900° F. on the tensile properties of VascoMax C-200. Specimens were solution annealed for one hour at 1500° F., air cooled and aged at 900° F. for the times indicated.

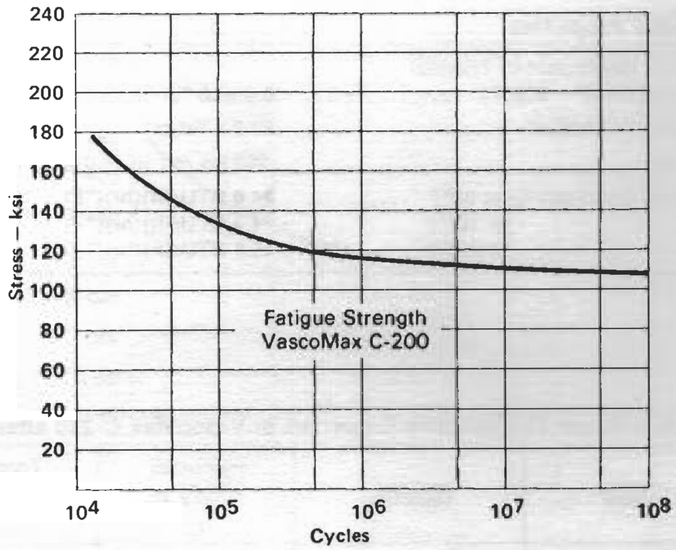


FIGURE 6. R.R. Moore rotating beam fatigue tests on production bar stock of VascoMax C-200. All samples solution annealed at 1500° F. for 30 minutes, air cooled and aged at 900° F. for 3 hours.

All data pertains to bars of small cross section unless stated otherwise.

VascoMax C-250

Physical Properties

Average Coefficient of Thermal Expansion (70° - 900°F)	5.6 x 10^{-6}in./in./°F
Modulus of Elasticity	27.0 x 10^6 psi
Density	.289 lbs./cu. in. (8.0 g/cc)
Thermal Conductivity at 68°F	14.6 BTU/(ft)(hr)(°F)
at 122°F	14.9 BTU/(ft)(hr)(°F)
at 212°F	15.6 BTU/(ft)(hr)(°F)

Nominal Analysis

Nickel	18.50%
Cobalt	7.50
Molybdenum	4.80
Titanium	.40
Aluminum	.10
Silicon	.10 max.
Manganese	.10 max.
Carbon	.03 max.
Sulfur	.01 max.
Phosphorus	.01 max.
Zirconium	.01
Boron	.003

Nominal Annealed Properties

Hardness	30 R_C
Yield Strength	95 ksi
Ultimate Strength	140 ksi
Elongation	17%
Reduction of Area	75%

Nominal Room Temperature Properties of VascoMax C-250 after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5√A %	Reduction of Area %
⅝" Round	Longitudinal	51.3	264.5	255.8	11.5	57.9
1¼" Round	Longitudinal	51.8	268.5	258.8	11.0	56.5
3" Round	Longitudinal	50.4	253.8	248.3	11.0	53.4
6" Square	Longitudinal	50.8	251.0	245.8	10.0	46.7
	Transverse	50.3	249.9	245.2	8.1	30.3
.250" Sheet	Transverse	50.6	271.9	265.7	8.0	40.8

Test Temp. °F	.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation In 4.5√A %	Reduction of Area %
600	224.5	233.4	11.5	56.0
800	210.8	221.0	12.0	56.1
900	185.1	200.0	16.5	64.6
1000	129.1	149.2	23.0	72.9

FIGURE 1. Effect of test temperatue on the tensile properties of VascoMax C-250 solution annealed for one hour at 1500°F. Air cooled and aged three hours at 900°F.

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	403.8	401.6 - 406.4	1.49
3.0	399.0	393.6 - 402.4	1.48
5.0	381.3	376.7 - 386.3	1.41
6.25	385.7	383.9 - 392.0	1.43
7.0	377.5	375.9 - 382.3	1.40
9.0	380.7	377.5 - 383.9	1.41

*Based on smooth bar tensile strength of 270.1 ksi.

FIGURE 2. Effect of stress concentration Factor, K_t, on the tensile properties of VascoMax C-250 solution annealed for one hour at 1500°F., air cooled and aged three hours at 900°F.

Condition	Compressive Strength		Rockwell "C" Hardness
	Proportional Limit ksi	.2% Offset Yield ksi	
Solution Annealed	105.0	149.0	29.0
Aged	241.3	280.0	51.0

FIGURE 3. Samples solution annealed for 30 minutes at 1500°F., air cooled and aged 3 hours at 900°F. as indicated. Average of 3 tests per condition.

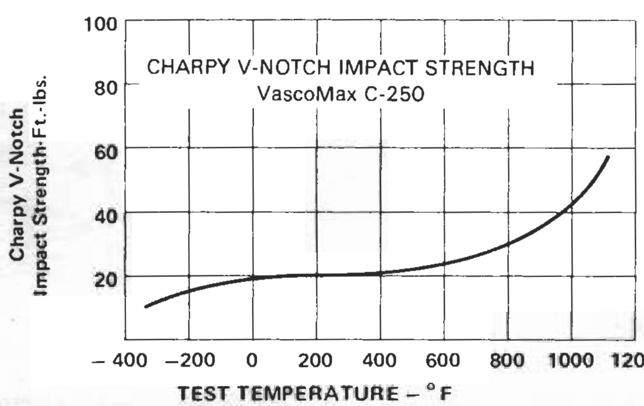


FIGURE 4. Effect of test temperature on the Charpy V-Notch impact strength of VascoMax C-250. All specimens solution annealed at 1500°F. for 30 minutes, air cooled and aged at 900°F. for 3 hours.

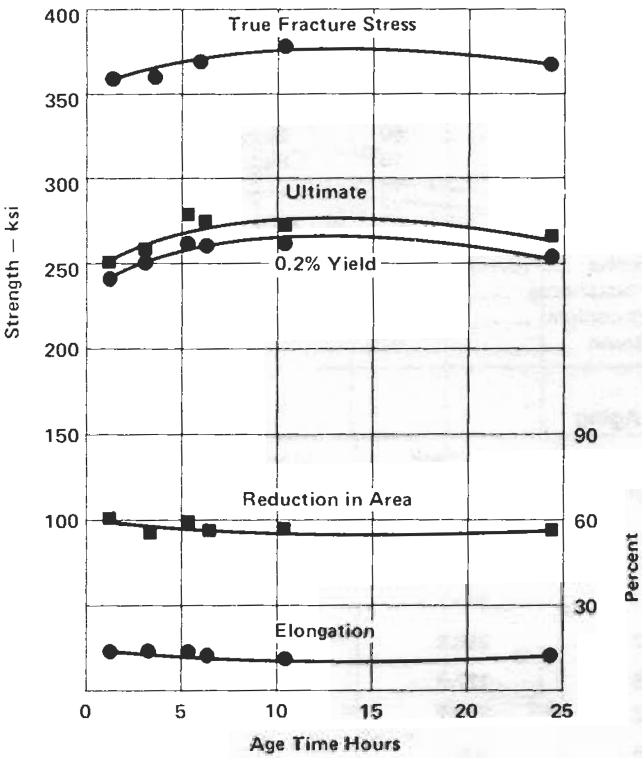


FIGURE 5. Effect of Aging Time at 900° F. on the Tensile Properties of VascoMax C-250. Specimens solution annealed for 1 hour at 1500° F., air cooled and aged at 900° F. for the time indicated.

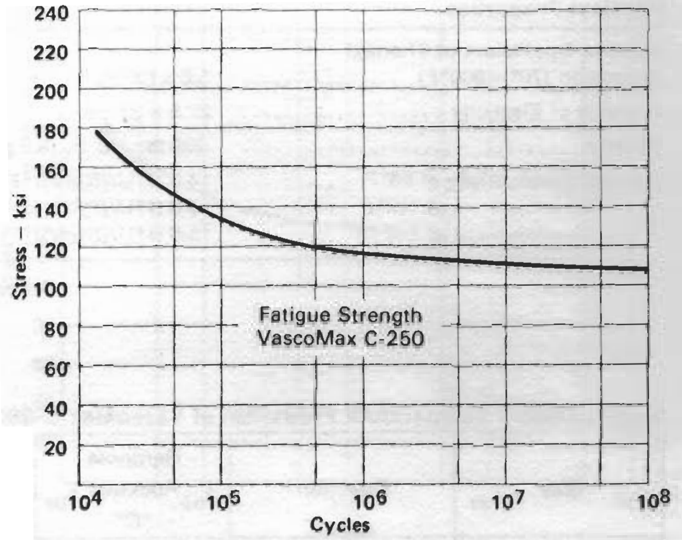


FIGURE 6. R.R. Moore rotating beam fatigue tests on production bar stock of VascoMax C-250. All samples annealed at 1500°F. for 30 minutes, air cooled and aged at 900°F. for 3 hours.

All data pertains to bars of small cross section unless stated otherwise.

Effect of Various Aging Treatments on the Tensile Properties of .125" Thick VascoMax C-250 Sheet*

Solution Annealing Temperature °F	Aging Temperature °F	Aging Time Hours	.2% Offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation, % in.		Reduction of Area %
					1"	2"	
1500	850	3	256.7	262.5	9.7	4.7	47.6
1500	900	1	256.6	264.5	9.4	4.8	48.7
1500	900	3	280.2	287.0	8.8	4.5	44.9
1500	900	6	267.5	280.1	8.5	4.2	44.7
1500	950	3	262.3	270.5	9.7	4.5	47.2

*Standard ASTM sheet tensiles solution annealed for 30 minutes at the indicated temperatures, air cooled and aged as shown.

FIGURE 7.

VascoMax C-300

Physical Properties

Average Coefficient of Thermal Expansion (70° - 900° F)	5.6×10^{-6} in./in./° F
Modulus of Elasticity	27.5×10^{6} psi
Density	.289 lbs./cu. in. (8.0 g/cc)
Thermal Conductivity at 68° F	14.6 BTU/(ft)(hr)(°F)
at 122° F	14.9 BTU/(ft)(hr)(°F)
at 212 °F	15.6 BTU/(ft)(hr)(°F)

Nominal Analysis

Nickel	18.50%	
Cobalt	9.00	
Molybdenum	4.80	
Titanium	.60	
Aluminum	.10	
Silicon	.10	max.
Manganese	.10	max.
Carbon	.03	max.
Sulfur	.01	max.
Phosphorus	.01	max.
Zirconium	.01	
Boron	.003	

Nominal Annealed Properties

Hardness	32 R_C
Yield Strength	110 ksi
Ultimate Strength	150 ksi
Elongation	18%
Reduction of Area	72%

Nominal Room Temperature Properties of VascoMax C-300 after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5√A %	Reduction of Area %
⅝" Round	Longitudinal	54.3	294.0	290.0	11.8	56.6
1¼" Round	Longitudinal	54.7	296.0	293.0	11.6	55.8
3" Round	Longitudinal	54.0	293.7	286.8	10.3	46.6
6" Square	Longitudinal	53.9	284.6	277.8	9.8	43.9
	Transverse	54.3	283.2	277.1	6.6	28.4
.250" Sheet	Transverse	55.1	314.6	309.7	7.7	35.0

Test Temp. °F	.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation In 4.5√A %	Reduction of Area %
600	245.6	256.8	12.0	61.8
800	227.7	240.1	14.0	61.3
900	194.8	210.9	17.3	68.4
950	172.9	189.1	22.0	76.5
1000	153.2	168.0	24.0	77.2

FIGURE 1. Effect of test temperature on the tensile properties of VascoMax C-300 solution annealed for one hour at 1500° F., air cooled and aged three hours at 900° F.

Condition	Compressive Strength		Rockwell "C" Hardness
	Proportional Limit ksi	0.2% Offset Yield Strength ksi	
Solution Annealed	105.0	150.0	31.0
Aged	272.0	317.5	53.5

FIGURE 3. Samples solution annealed for 30 minutes at 1500°F., air cooled and aged 3 hours at 900° F. as indicated. Average of 3 tests per condition.

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	426.0	422.6 - 432.3	1.45
3.0	420.5	419.4 - 421.8	1.43
5.0	417.9	411.3 - 427.4	1.42
6.25	418.4	412.9 - 423.4	1.42
7.0	414.0	403.9 - 425.8	1.41
9.0	420.3	411.3 - 423.4	1.43

*Based on smooth bar tensile strength of 293.5 ksi.

FIGURE 2. Effect of stress concentration factor, K_t, on the tensile properties of VascoMax C-300 solution annealed for one hour at 1500° F., air cooled and aged three hours at 900° F.

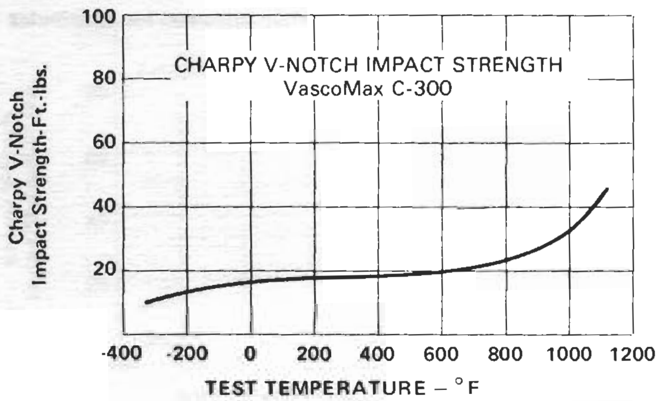


FIGURE 4. Effect of test temperature on the Charpy V-Notch impact strength of VascoMax C-300. All specimens solution annealed at 1500° F. for 30 minutes, air cooled and aged at 900° F. for 3 hours.

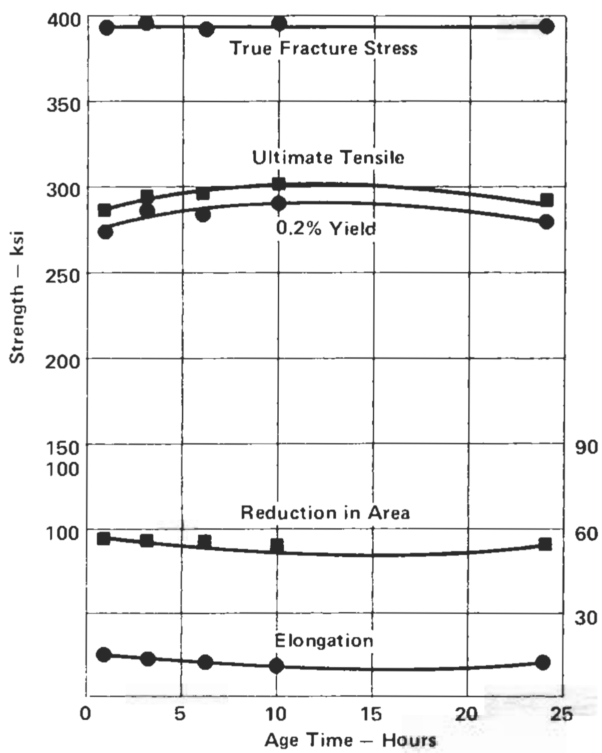


FIGURE 5. Effect of aging time at 900° F. on the tensile properties of VascoMax C-300. Specimens were solution annealed for 30 minutes at 1500° F., air cooled and aged at 900° F. for the times indicated.

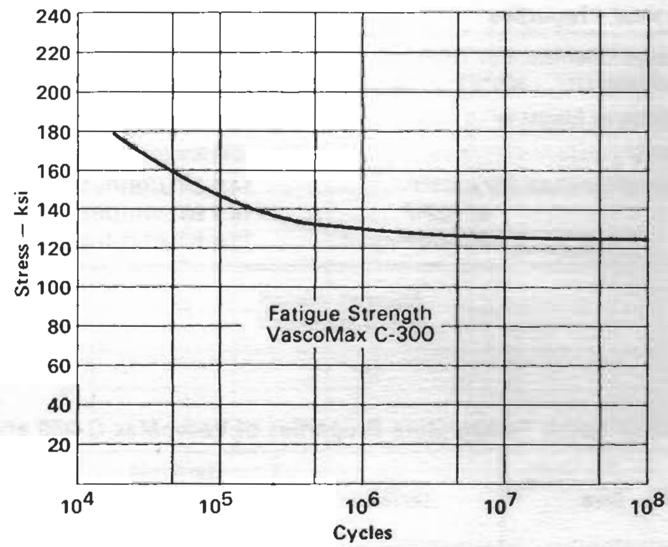


FIGURE 6. R.R. Moore rotating beam fatigue tests on production bar stock of VascoMax C-300. All samples solution annealed at 1500° F. for 30 minutes, air cooled and aged at 900° F. for 3 hours.

All data pertains to bars of small cross section unless stated otherwise.

Effect of Various Aging Treatments on the Tensile Properties of .125″ Thick VascoMax C-300 Sheet*

Solution Annealing Temperature °F	Aging Temperature °F	Aging Time Hours	.2% Offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation, % in.		Reduction of Area %
					1″	2″	
1500	850	3	294.8	309.5	7.0	3.5	34.2
1500	900	1	296.9	306.7	8.2	4.2	38.6
1500	900	3	313.9	316.8	6.8	3.4	32.5
1500	900	6	314.2	321.2	7.5	3.7	33.2
1500	950	3	305.6	308.1	8.0	4.0	33.6

*Standard ASTM sheet tensiles solution annealed for 30 minutes at the indicated temperatures, air cooled and aged as shown.
FIGURE 7.

Effect of Sheet Thickness on the Tensile Properties *

Sheet Thickness Inches	.2% Offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation, % in.**	
			1″	2″
.250	315.1	320.8	9.0	5.0
.125	313.9	316.8	6.8	3.4
.090	308.2	312.7	6.0	3.2
.065	301.4	307.2	5.0	3.0
.045	291.9	295.0	4.0	2.0
.025	294.0	296.0	2.0	1.0

*Standard ASTM sheet tensiles solution annealed at 1500°F. for 15 minutes, air cooled and aged 3 hours at 900° F.

**The change in elongation with thickness is not caused by a change in material ductility, but is due to changing the geometry of the test specimen. For correct elongation measurements a gage length of $4.5\sqrt{A}$ should be used; not a fixed 1″ or 2″ gage length.

FIGURE 8.

VascoMax C-350

Physical Properties

Average Coefficient of Thermal Expansion (70° - 900° F)	6.3 x 10^{-6} in./in./° F
Modulus of Elasticity	29.0 x 10^6 psi
Density	.292 lbs./cu. in. (8.1 g/cc)
Thermal Conductivity at 68° F	14.6 BTU/(ft)(hr)(° F)
at 122° F	14.9 BTU/(ft)(hr)(° F)
at 212° F	15.6 BTU/(ft)(hr)(° F)

Nominal Analysis

Nickel	18.50%
Cobalt	12.00
Molybdenum	4.80
Titanium	1.40
Aluminum	.10
Silicon	.10 max.
Manganese	.10 max.
Carbon	.03 max.
Sulfur	.01 max.
Phosphorus	.01 max.
Zirconium	.01
Boron	.003

Nominal Annealed Properties

Hardness	35 R_C
Yield Strength	120 ksi
Ultimate Strength	165 ksi
Elongation	18%
Reduction of Area	70%

Nominal Room Temperature Properties of VascoMax C-350 after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5$\sqrt{A}$ %	Reduction of Area %
⅝" Round	Longitudinal	57.8	350.2	342.7	7.5	35.4
1¼" Round	Longitudinal	58.4	346.8	340.6	7.6	33.8
3" Round	Longitudinal	58.2	342.2	336.5	6.2	28.6
.250" Sheet	Transverse	57.7	355.5	347.3	3.0	15.4

Test Temp. °F	.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation in 4.5$\sqrt{A}$ %	Reduction of Area %
600	295.4	310.2	12.3	54.9
800	277.3	288.4	15.6	57.6
900	251.9	270.4	17.4	60.3
1000	233.6	251.8	20.0	70.9

FIGURE 1. Effect of test temperature on the tensile properties of VascoMax C-350 solution annealed for one hour at 1500° F, air cooled and aged six hours at 900° F.

Condition	Compressive Strength		
	Proportional Limit ksi	.2% Offset Yield ksi	Rockwell "C" Hardness
Solution Annealed	108.0	160.5	34.3
Aged	349.3	388.1	59.6

FIGURE 3. Samples solution annealed for 30 minutes at 1500° F., air cooled and aged 3 hours at 900° F. as indicated. Average of 3 tests per condition.

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	433.7	427.4 - 437.3	1.2
6.25	334.3	331.7 - 337.6	.93
9.0	333.0	326.7 - 338.6	.92

*Based on smooth bar tensile strength of 362.8 ksi.

FIGURE 2. Effect of stress concentration factor, K_t on the tensile of VascoMax C-350 solution annealed for one hour at 1500° F., air cooled and aged three hours at 900° F.

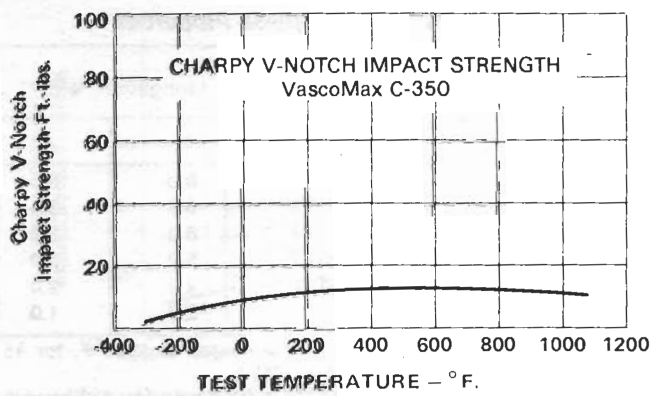


FIGURE 4. Effect of test temperature on the Charpy V-notch impact strength of VascoMax C-350. All specimens solution annealed at 1500° F for 30 minutes, air cooled and aged at 900° F. for 3 hours.

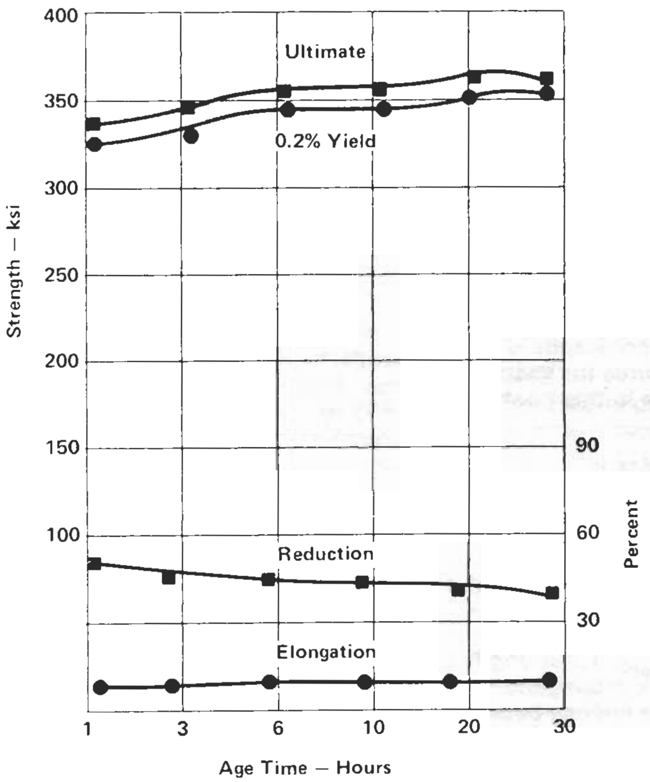


FIGURE 5. Effect of aging at 900° F. on the tensile properties of VascoMax C-350. Specimens solution annealed for 1 hour at 1500° F., air cooled and aged at 900° F. for the times indicated.

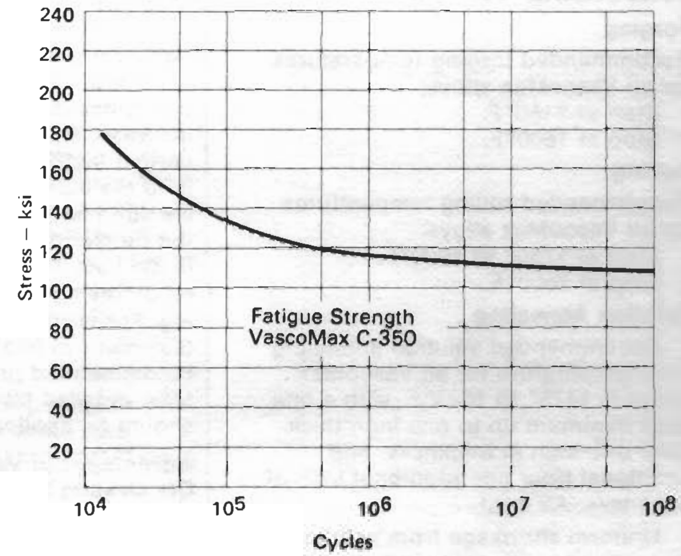


FIGURE 6. R.R. Moore rotating beam fatigue tests on production bar stock of VascoMax C-350. All samples solution annealed at 1500° F. for 30 minutes, air cooled and aged at 900° F. for 3 hours.

All data pertains to bars of small cross section unless stated otherwise.

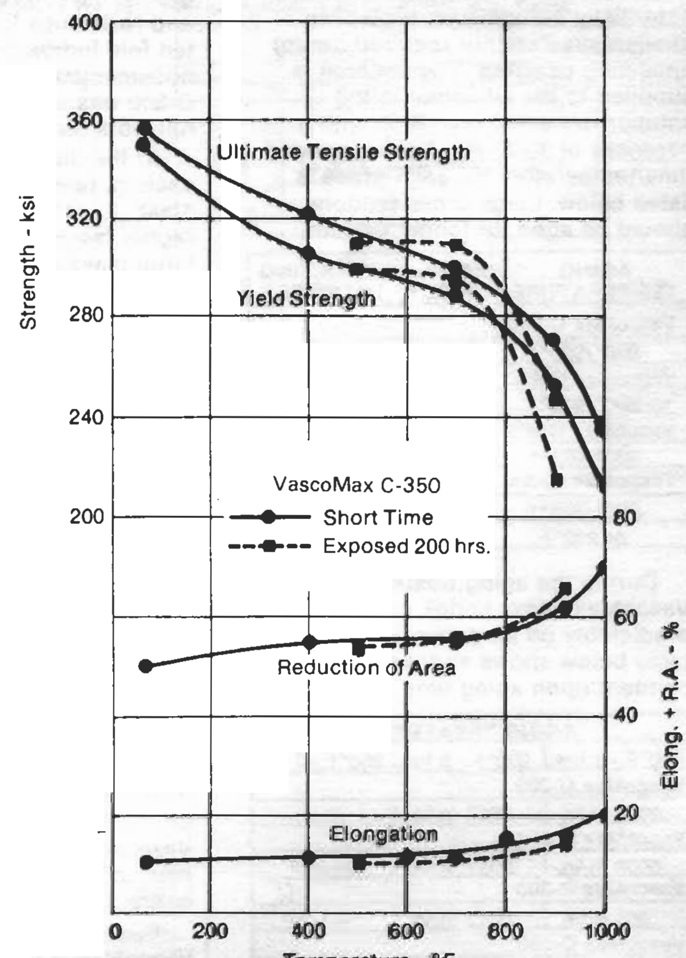


FIGURE 7. Tensile properties as a function of test and exposure temperature. All samples annealed one hour at 1475°F., air cooled, aged 3 hours at 950°F.

Recommended Procedures for Processing / Fabrication

Processing Temperatures

Forging

Recommended forging temperatures for all VascoMax alloys:
Start at 2150° F.
Stop at 1600° F.

Rolling

Recommended rolling temperatures for all VascoMax alloys:
Start at 1750° to 1900° F.
Stop at 1500° F.

Solution Annealing

Recommended solution annealing time/temperature for all VascoMax alloys is 1475° to 1525° F. with a one hour minimum up to one inch thick. Over one inch in thickness, one additional hour per additional inch of thickness. Air cool.

Uniform shrinkage from solution annealing for all grades is approximately .001 in./in.

Aging (Heat Treatment)

Because the VascoMax alloys are essentially carbon-free, protective atmospheres are not required during annealing or aging. The material is supplied to the customer in the solution annealed condition with a hardness of 30/35 R_C. Recommended time/temperature for each grade is listed below. Large cross sections should be aged for longer periods.

AGING TEMPERATURE	AGING TIME	RESULTING HARDNESS
VascoMax C-200		
900°/925° F.	6 hrs.	44/48 R_C
VascoMax C-250		
900°/925° F.	6 hrs.	48/52 R_C
VascoMax C-300		
900°/925° F.	6 hrs.	50/55 R_C
VascoMax C-350		
900°/925° F.	6 hrs.	55/60 R_C
or 950° F.	3 hrs.	56/60 R_C

During the aging treatment, the VascoMax alloys shrink uniformly and predictably on all dimensions. The table below shows shrinkage is dependent upon aging time.

AGING TREATMENT		
900° F.-6 hrs.	900° F.-9 hrs.	950° F.-3 hrs
VascoMax C-200		
.0006 in/in.	.0007 in/in.	———
VascoMax C-250		
.0009 in/in.	.0011 in/in.	———
VascoMax C-300		
.001 in/in.	.0012 in/in.	———
VascoMax C-350		
.001 in/in.	.0013 in/in.	.001 in/in.

NOTE: A modified aging process for die casting application of VascoMax C-250 and C-300 is offered in the section entitled "Die Casting Application".

Die Casting

Use of VascoMax C-250 and C-300 has increased steadily in the die casting industry since their introduction. Because of this continued increase, and because there are certain factors which relate specifically to die casting applications, this section has been set aside to examine the outstanding benefits of VascoMax in die casting, and to offer special recommended procedures for processing. For fabrication processes not discussed in this section, standard recommended procedures for VascoMax, detailed elswhere in this booklet, should be applied.

Advantages of VascoMax in Die Casting Applications

Because of their low co-efficient of expansion, VascoMax C-250 and C-300 have essentially eliminated heat checking as a problem in applications where they are used. Both of these grades have excellent impact strength and resistance to crack propagation. A ten fold increase in die life has been documented when VascoMax C-250 or C-300 was used in place of traditional hot work die steels H-11 and H-13.

At the die surface during aluminum casting, temperatures may reach 1000° to 1100° F. Occassionally, even higher temperatures are reached if a large mass of aluminum is involved. VascoMax alloys exhibit remarkable resistance to softening up to 1200° F. Figure 1 illustrates the results of tests conducted on VascoMax C-250 and C-300, and H-11. Room temperature hardnesses of the three steels were recorded following 200 hour exposures at each of the elevated temperatures indicated. This is approximately equivalent to 360,000 shots of two seconds duration each. After 1100° and 1200° F. exposures, both VascoMax C-250 and C-300 were 10 to 12 Rockwell "C" points harder than H-11. This data is particularly significant in demonstrating the superior resistance to washing and heat checking of the VascoMax grades.

Figure 2 shows the results of tensile tests conducted at various elevated temperatures. These tests show VascoMax to be both stronger and more ductile than H-11 through the entire die operating range.

Superior oxidation resistance of VascoMax is illustrated in Figure 3. Again, comparison is made with the traditional hot work die steel, H-11. A tight, adherent scale, associated with VascoMax, greatly reduces die deterioration due to oxidation.

Coefficient of expansion for VascoMax C-250 and C-300 is approximately 12% lower than for H-11, thus reducing the fatigue effects of thermal cycling, and contributing to improved heat check resistance. Thermal conductivity of VascoMax is within 2% of that for H-11.

Aside from the superior mechanical properties just described, VascoMax also possesses superior weldability to H-11 or H-13. VascoMax requires no preheating or post heating, and high efficiency joints are achieved by following the relatively simple procedures recommended in this booklet's section on welding.

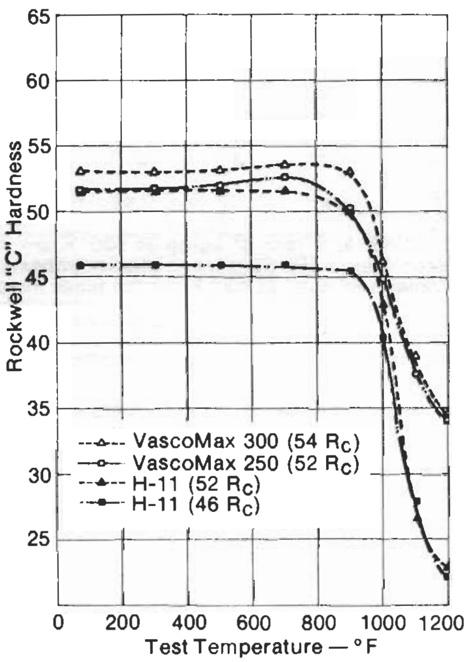


FIGURE 1. Effect of 200-hour exposure at temperature on the room temperature hardness of VascoMax C-300 and VascoMax C-250 compared with H-11. All maraging samples solution annealed at 1500° F. for 30 minutes, then air cooled and aged at 900° F. for 3 hours before exposing for 200 hours at indicated temperature.

Annealing and Aging for Die Casting Applications

Initially, VascoMax die casting dies were aged using the same procedures as those employed for other applications. However, increased die life has been obtained by modifying the aging cycle.

Following rough machining, an anneal at 1500°/1525° F. for one hour per inch of thickness is recommended to relieve stresses which could cause gross cracking problems. The die may then be finish machined.

After finish machining, an aging treatment of 980°/1000°F. for six hours is recommended (as opposed to the standard 900°/925°F.). This higher aging temperature more closely approximates the operating temperature of the die, thus eliminating stresses and enhancing die life.

SPECIAL NOTE: Under no circumstances should a VascoMax die be tested for dimensions in the soft (annealed) condition. The die should be fully aged using the recommended procedures before the first shot.

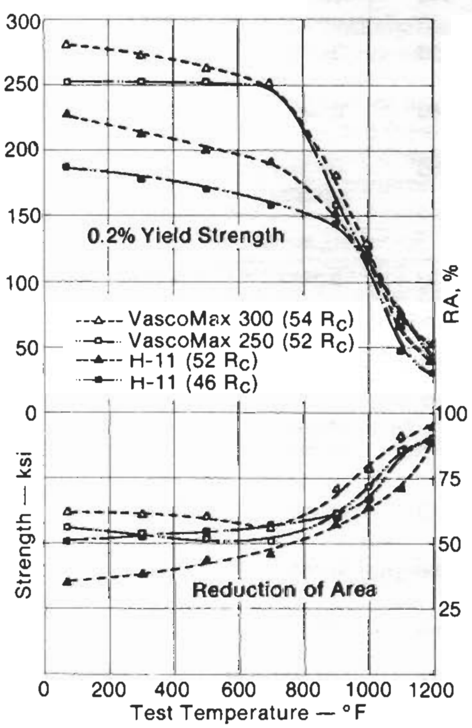


FIGURE 2. Effect of 200-hour exposure at temperature on the elevated temperature tensile properties of VascoMax C-300 and VascoMax C-250 compared with H-11. All maraging samples solution annealed at 1500°F. for 30 minutes, then air cooled and aged at 900°F. for 3 hours before exposing for 200 hours at indicated temperatures. Tensile tests run at same temperature of exposure.

Weight Gain Per Surface Area (mg/cm²)

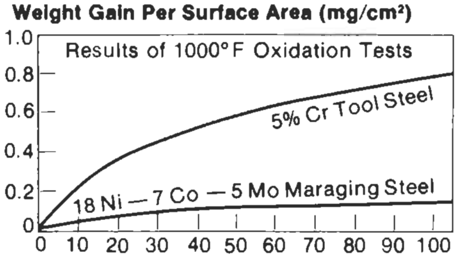


FIGURE 3. Comparative oxidation weight loss of H-11 and maraging steel.

Machining

Machinability of the VascoMax grades in the annealed condition is approximately comparable to steels such as 4340 at the same hardness level (30/35 R_C). However, when the material is aged (heat treated), the choice of cutting tools and machining conditions become very important. Rigid equipment, firm tool supports, very sharp tools, and an abundance of coolant are essential. Suggested conditions for most machining operations are offered in this section.

Planing

The results of planing tests employing Vasco M-2 and Vasco Supreme (T-15) high speed steel tools are shown in Table 1. The alloys machine best using tools that cut with a positive shearing action, and it follows that tools should accordingly be designed to positive rakes.

Table 1

Planing Speeds for 18% Nickel Maraging Steel With H.S.S. Tools

Condition of Material	Hardness of Material R_C	Sfpm.	FEED (inch)			DEPTH CUT (inch)	
			Roughing	Finishing*	Parting	Roughing	Finishing
Annealed	30 - 33	40 - 50	.015	to 3/16	.008 Max.	3/16	.010
Aged	50	25	.015	to 3/16	.004 Max.	3/16	.010

*Broad Face Finishing Tool

Circular Sawing

Circular sawing has been performed on annealed VascoMax alloys on a conventional saw having high and low insert teeth. The saw operated at 68 fpm at .0011" feed per tooth. Cutting lubricant was chlorinated, sulfurized, fatty mineral oil. Chip control was no problem. Circular sawing under these conditions is practical and can be recommended for production.

Power Hacksawing

Annealed VascoMax is easily cut by power hacksawing at 90-100 strokes per minute using high speed steel saw blades. On heavy sawing operations cutting 6" square billets, a saw blade having four teeth per inch withstands .006" feed per stroke. Recommended cutting lubricant is a rich solution of soluble oil and water.

ANNEALED								
Operation	Tool Material	Tool Geometry*	Depth of Cut	Width of Cut	Feed	Cutting Speed	Wearland	Cutting Fluid
Turning	M2 or T-15	BR: 0°; SR: 10°; SCEA: 15°; ECEA: 5°; Relief: 5°; NR: 0.030 in.	0.060 in.	—	0.009 in./rev	80 ft/ min.	0.060 in.	Soluble oil (1:20)
Turning	C3	BR: -5°; SR: -5°; SCEA: 15°; ECEA: 15°; Relief: 5°; NR: 0.030 in.	0.060	—	0.009 in./rev	475	0.010	Soluble oil (1:20)
Face milling	M2 or M-7	AR: 5°; RR: 5°; CA: 45°; ECEA: 10°; Cl: 8°	0.060	2 in.	0.005 in./tooth	140	0.060	Highly chlorinated oil
Face milling	C2	AR: 10°; RR: 0°; CA: 45°; ECEA: 10°; Cl: 8°	0.060	2	0.005 in./tooth	330	0.015	Dry
Peripheral end milling	M2	Helix angle: 30°; RR: 10°; CA: 45° x 0.060 in; Cl: 7°	0.250	0.750	0.004 in./tooth	225	0.012	Soluble oil (1:20)
End mill slotting	M2	Helix angle: 30°; RR: 10°; CA: 45° x 0.060 in.; Cl: 7°	0.250	0.750	0.002 in./tooth	140	0.012	Highly chlorinated oil
Drilling	M1	118° plain point; Cl: 7°	0.500 (through hole)	—	0.005 in./rev	100	0.015	Highly sulfurized oil
Reaming	M2	Helix angle: 0°; CA: 45°; Cl: 7°	0.500 (through hole)	—	0.009 in./rev	60	0.006	Highly sulfurized oil
Tapping	M1	2 flute plug; 75% thread	0.500 (through hole)	—	—	150	Undersize threads	Highly sulfurized oil
HARDENED								
Turning	T-15 M-42	BR: 0°; SR: 10°; SCEA: 15°; ECEA: 5°; Relief: 5°; NR: 0.030 in.	0.062	—	0.005 in./rev	60	0.016	Soluble oil (1:20)
Turning	C3	BR: -5°; SR: -5°; SCEA: 15°; ECEA: 15°; Relief: 5°; NR: 0.030 in.	0.062	—	0.009 in./rev	275	0.015	Soluble oil (1:20)
Face milling	T-15 or M-33	AR: 5°; RR: 5°; CA: 45°; ECEA: 10°; Cl: 8°	0.060	2	0.005 in./tooth	75	0.060	Highly chlorinated oil
Face milling	C2	AR: -15°; RR: -7°; CA: 45°; ECEA: 10°; Cl: 8°	0.060	2	0.004 in./tooth	180	0.015	Dry
Peripheral end milling	T-15 or M-42	Helix angle: 30 °; RR: 10°; CA: 45° x 0.060 in.; Cl: 7°	0.250	0.750	0.001 in./tooth	80	0.012	Highly chlorinated oil
End mill slotting	T-15 or M-42	Helix angle: 30°; RR: 10°; CA: 45° x 0.060 in.; Cl: 7°	0.250	0.750	0.001 in./tooth	40	0.012	Highly chlorinated oil
End mill slotting	C2	AR: -7°; RR: -7°; NR: 0.045 in.; CA: 45°; ECEA: 45°; Cl: 7°	0.125	1.0	0.002 in./tooth	312	0.015	Dry
Drilling	T-15 or M-33	118° split point; Cl: 7°	0.500 (through hole)	—	0.002 in./rev	50	0.015	Highly sulfurized oil
Reaming	M33	Helix angle: 0°; CA: 45°; Cl: 7°	0.500 (through hole)	—	0.005 in./rev	100	0.006	Highly sulfurized oil
Tapping	M1 nitrided	2 flute plug; spiral point; 75% thread	0.500 (tnrough hole)	—	—	7	Undersize threads	Highly chlorinated oil

SURFACE GRINDING							
Operation	Wheel Grade	Grinding Fluid	Wheel Speed	Table Speed	Down Feed	Crossfeed	G Ratio
Finishing	32A46H8V8E	Highly sulfurized oil	400 ft/min	60 ft/min	0.0005 in./pass	0.050 in./pass	7
Roughing	32A46K8V8E	Highly sulfurized oil or soluble oil (1:20)	6000	60	0.001	0.100	30

*BR, back rake; SR, side rake; SCEA, side cutting edge angle; ECEA, end cutting edge angle; NR, nose radius; AR, axial rake; RR, radia rake; CA, corner angle; Cl, clearance.

Cold Working

Because of the relative softness of the nickel martensite, VascoMax alloys can be readily formed, spun, drawn, or hydroformed cold with minimal work hardening. Table 2 shows the effect of cold reduction on the ultimate tensile strength, yield strength, elongation, and hardness of VascoMax C-250. With as much as 80% cold reduction, ultimate strength increased only 55,000 psi, and hardness only 10 points Rockwell "C." Adequate ductility remains should still further cold work be required.

When necessary, stress relieving is best accomplished by heating to 1500°F, holding for one hour, and air cooling to room temperature.

The excellent cold forming characteristics of the VascoMax alloys are exemplified by the mechanical properties shown in Figure 4 for a deep drawn cylinder produced from annealed sheet. The shell was drawn in stages with intermediate solution treat anneals.*

Figure 5 shows the sequence of operations used for cold heading screws made from .368" diameter cold drawn, annealed, and copper flashed VascoMax C-250. The annealed hardness of the wire was 30 R_C. After cold heading, the hardness of the cold worked portion of the screws was 40/44 R_C.**

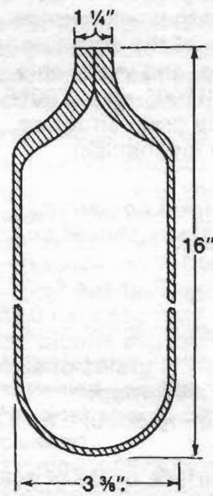
*Pressed Steel Tank Company, Milwaukee, Wisconsin.

**The Allen Manufacturing Company, Hartford, Conn.

TABLE 2 — Effect of Cold Reduction

VascoMax C-250	Percentage of Reduction				
Mechanical Property	0%	20%	40%	60%	80%
Ultimate Tensile Strength (ksi)	160	170	180	200	215
Yield Strength (ksi)	110	145	170	180	200
Hardness (Rc)	32	34	35	38	42
Elongation (%)	10	8	7	6	4

Deep Drawn and Hot Spun



Mechanical Properties of Annealed Material From Which The Shells Were Drawn

Material	Tensile psi	Yield Strength 0.2% Offset	Elongation in 2" (%)	Hardness Rc
18% Nickel Maraging Steel	162,000	115,000	8	32

FIGURE 4. Deep Drawn and Hot Spun Cylinder Produced from Cold Rolled Annealed Maraging Steel of the Mechanical Properties Shown.

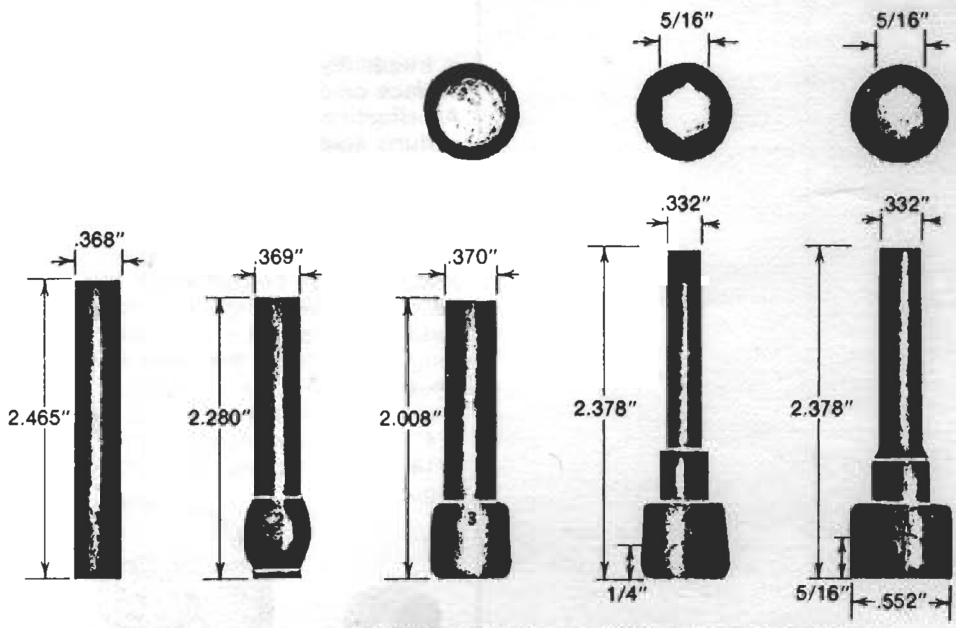


FIGURE 5. Screw Blanks Made by Cold Heading Annealed 18% Nickel Maraging Steel.

Warm Working

Warm working may be done at temperatures up to 600° F. Above this temperature, maraging may occur. Consideration should be given to the amount of heat generated by the working operation itself. A warming temperature for the material should be selected which allows for the additional heat input from working operations without raising the temperature above 600° F.

Hot Working

VascoMax alloys are readily hot formed by conventional forging, forming or rolling operations at temperatures from 2150° to 1500° F. Although plasticity is highest at 2150° F, lower hot work temperatures are permissible providing the equipment has sufficient capacity to handle the work. Preheating is generally not required for cross-sections up to 6" square. Larger cross sections should be preheated at 1700° to 1800° F. A starting temperature should be selected that will provide adequate break up of the structure during hot working, and yet enable finishing between 1500° and 1700° F. This will insure fine grain structure, and thus optimum mechanical properties.

As with other nickel containing alloys, VascoMax steels should be free from oil, grease, and other contaminants before heating. Furnace fuel oil should contain no more than 0.75% sulfur by weight. Fuel gas should not contain more than 100 grains of sulfur per 0.1 mcf of gas. A furnace atmosphere containing about 5% CO_2 is suggested.

Formation of surface oxide or scale is heavier and more rapid on these steels than on Type 304 stainless, but less extensive than on carbon or low alloy steels. During hot pressing or forging, the scale sluffs off readily during initial reduction. Sand blasting is frequently employed for removal of surface oxide from finished material. An effective pickling solution is 18% sulfuric acid at 150°-160° F. Sodium hydride and other high temperature (above 700° F) descaling treatments should not be employed.

Hot forming and bending of VascoMax can be performed from 1800° to 1500° F. Figure 6 shows a VascoMax blank, 1.4" diameter, 1.23 " long. In one blow, the blank was hot upset at 2000° F. on a Model 10 Convair Dynapak machine to the 3-3/4" diameter diaphragm (3/16" and 7/16" maximum thickness) shown in Figure 7.

FIGURE 6.
Blank for Upset Forging.

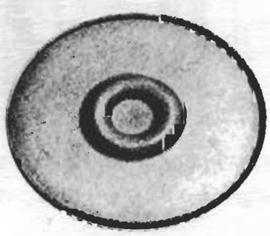


FIGURE 7.
Diaphragm forged from blank shown in Figure 6.

Welding

VascoMax alloys have high weldability in both the solution annealed and the fully heat treated conditions. Most conventional welding procedures achieve sound, crack-free welds.

Structrual Welding

Best results for structural welding have been obtained by using either TIG (Tungsten-Inert-Gas) or electron beam welding. Although the MIG (Metal-Inert-Gas) process may be employed, it can produce a reduction in the material's ductility.

Preheating is not only unnecessary, but should not be employed because of the hardening mechanism of these grades. Gas shielding with pure argon is recommended for TIG and MIG welding. Thorough cleaning of the prior deposit, and a maximum interpass temperature of 250° F are essential. Post heating should not be employed.

To obtain the best possible weld microstructure, and thus the highest joint efficiency, the material should be re-solution annealed after welding, and prior to re-aging. However, joint efficiencies of better than 90% have been obtained with VascoMax C-200, C-250 and C-300 by merely re-aging after welding.

Weld Repairing with VascoMax Weld Wire

In tool and die applications, VascoMax weld wire is used extensively to repair both VascoMax alloys and 5% chromium hot work die steels. Typical applications for successful weld repair include aluminum and zinc die casting dies, cores, and pins, as well as plastic molds, forging dies, and extrusion tooling.

TIG welding is generally employed with the greatest success for the weld repair of VascoMax alloys. Oil, grease, and other contaminants should be removed prior to weld repair. As is true for structural welding, the material should not be preheated, and a pure argon shield is preferential.

When the tooling material to be repaired is one of the 5% chromium hot work die steels, such as H-11 or H-13, the same welding method may be used, and the same cleaning procedures applied. However, preheating to 300°F. prior to welding is recommended. After welding with VascoMax weld wire, the entire tool should be tempered (aged) at 900°F. for three hours. This will harden the VascoMax weldment, and will also stress relieve the tool.

VascoMax C-250W
VascoMax C-300W

VascoMax C-250W and C-300W are alloys specifically manufactured for use as filler wire in the TIG or MIG welding of VascoMax C-250 and C-300, respectively. These alloys are vacuum melted to insure excellent internal cleanliness of the wire. Surface cleanliness and finish are obtained through the use of special dies and lubricants in the drawing operation, and meticulous cleaning during processing and after finishing. This processing produces a bright, smooth surface, free from foreign materials, which is essential for sound welding. The surgically clean wire is level layer wound on standard spools to provide trouble-free feeding in automatic welding operations. Additional protection from corrosion and other surface damage is insured by final packaging with a desiccant, in argon purged and sealed metal cans.

Both VascoMax C-250W and C-300W are available in cut lengths or 25 pound spools, in wire sizes ranging from .020" to .125" diameter. Information concerning larger or smaller diameter wire is available upon request.

Nitriding

VascoMax steels may be nitrided to increase both the surface hardness and wear resistance of the material.

One method of determining a material's resistance to wear or "galling" is the Hohman Wear Test, in which a flat shoe is pressed against a rotating disc of test material under varying degrees of pressure. The "galling stress" is then expressed in pounds per linear inch, based upon the line contact of the shoe with the disc. Nitrided VascoMax did not gall even at the maximum applied stress of 2240 pounds per linear inch. Specimens which were not nitrided failed at 400 pounds per linear inch.

Data developed on nitrided and non-nitrided, smooth and notched fatigue specimens show that nitriding increases the endurance limit by as much as 20%. While impact properties are lowered, they remain at acceptable levels for the majority of applications.

Standard Nitriding Procedure

1. Material should be in the solution annealed condition
2. Material should be thoroughly cleaned
3. Employ a 25/30% dissociated ammonia atmosphere
4. Simultaneously age and nitride at 825°/850°F.
5. Hold at temperature for 40 to 48 hours.

This procedure will produce a case with an effective depth of .005/.007", as illustrated in Figure 8. Core hardness resulting from nitriding is generally from 2 to 4 Rockwell "C" points higher than normally achieved by conventional aging.

Nitriding in Liquid Salt Bath

Nitriding in liquid salt baths for 90 minutes at 1000°F. has successfully produced a case hardness of 64/66 R_C, with .003" case depth. Because of the controlled driving force for nitrogen in the liquid bath, the slightly higher nitriding temperature is practical. When utilizing this method, aging may be performed prior to, or simultaneously with the nitriding.

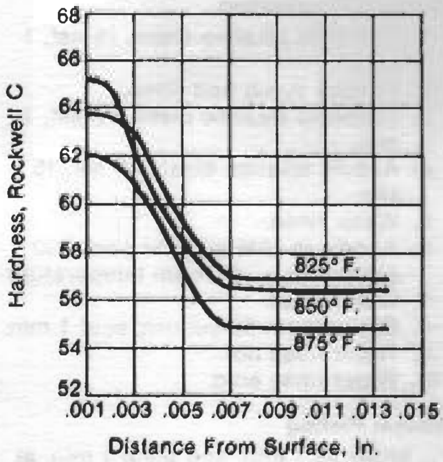


FIGURE 8. Simultaneous aging and nitriding in dissociated ammonia at the indicated temperatures for 48 hr develops cases of varying hardness in VascoMax C-250.

Plating

Recommended procedures for nickel, cadmium, and chromium plating for VascoMax alloys are contained in this section. Plating should be considered for (1) applications in which the material will be exposed to a severe environment, or (2) applications in which even slight corrosion would be harmful to a critical part, or (3) applications in which increased wear resistance is required.

Surface Preparation

1. Cathodic alkaline clean, 75 asf, 1 min.
2. Pumice scrub and rinse.
3. Cathodic alkaline clean, 75 asf, 1 min.
4. Anodic alkaline clean, 75 asf, 15 sec.
5. Water rinse.
6. Anodic in 25% sulfuric acid, 200 asf, 2 min. — at room temperature
7. Water rinse.
8. Dip in chromic-sulfuric acid 1 min.
9. Water rinse hot.
10. Water rinse cold.

Nickel Plating

Immerse 1 min. and plate 1 min. at 30 asf in acid nickel chloride bath at room temperature. Transfer without rinsing to regular nickel plating bath.

Cadmium Plating

Operate Cadmium bath at 90°F and at a current density of 25 asf.

Chromium Plating

Operate at current density of 200 asf.

Composition of Solutions

Alkaline Baths: 60 gpl sodium carbonate, 180°F.
Sulfuric Acid Etch: 25% by weight of concentrated sulfuric acid or 146 ml/1.
Chromic-Sulfuric Acid Solution: 45 gpl chromic acid, 20 ml/1 of sulfuric acid.
Acid Nickel Chloride Bath: 240 gpl nickel chloride hexahydrate, 38 gpl hydrochloric acid, pH = 0, room temperature.
Regular Nickel Bath (Watts-type): 80 gpl nickel (metal); 18 gpl chloride; 30 gpl boric acid, operated at pH 4.0, 140°F and at 20 to 40 asf.
Cadmium Plating Bath Composition: 30 gpl cadmium oxide, 121.5 gpl sodium cyanide.
Chromium Plating Bath Composition: 250 gpl chromic acid, 2.5 gpl sulfuric acid.

Comments:

- Steps 1,2 and 4 might possibly be omitted on oil-free and rust-free shot-peened steel.
- Anodic treatment in alkaline cleaning solutions should not be excessive to avoid possible oxidation of molybdenum.
- The details for Step 6 are as follows: The work is placed in the bath with the current off. The leads are then attached. As the current is increased from 0 to 200 asf, the work will form a black film. As the film grows the current drawn at the maintained voltage will decrease to a low value (about 75 asf), gas evolution occurs, and the black film disappears. Adjust the current to 25 asf. After this treatment the work should be clean and slightly etched.
- After the chromic-sulfuric acid dip, the specimen should be rinsed thoroughly but not allowed to dry.
- When nickel plating, the specimen enters the acid nickel chloride strike bath without current and is allowed to soak for 1 minute.
- Hydrogen which forms during the cleaning and plating procedure may be absorbed and baking after plating is recommended. Heating in the temperature range 400° to 600°F. for 24 hours should permit removal of the hydrogen.