VASCOMAX® NICKEL MARAGING ALLOYS

GENERAL

VascoMax® alloys (18% nickel maraging steels) are divided into two broad classes depending on the primary strengthening element in the chemical analysis. The original maraging steels, introduced in the early 1960's, depend on cobalt (7-12% cobalt depending on grade) as their strengthening agent; they are **cobalt strengthened** 18% nickel maraging steels. In the early 1980's, Allvac 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 18 Ni maraging", are designated by the letter "C" in the grade identification (example: VascoMax® C-250 alloy). Titanium-strengthened grades, or "T-type 18Ni maraging", are designated by the letter "T" in the grade identification (example: VascoMax® T-250 alloy).

This data sheet covers the T-type 18Ni maraging steels manufactured by Allvac: VascoMax T-200®, VascoMax T-250®, and VascoMax T-300® alloys. Information on the C-type VascoMax grades is available in a separate Technical Data Sheet. Allvac continues to be a leading producer of the cobalt-strengthened alloys. 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. Since high purity melting is essential to assure optimum mechanical properties, Allvac employs double vacuum melting - under strictest quality control - for all VascoMax grades.

Numerical designations for each grade, while not direct correlations in all cases, are generally representative of the nominal ultimate tensile strength of that grade, expressed in "ksi units". This variety in property levels among the three grades allows flexibility in selecting the property combination which best suits a given application. Mechanical properties of the three VascoMax T-grades are reported in Table 1 on page 3 illustrating briefly their properties and highlighting their outstanding values.

COBALT-FREE (Free-Co)

VascoMax T-200, VascoMax T-250, and VascoMax T-300 alloys contain no cobalt and are often referred to as "Free-Co" alloys. Chemical analyses of the three VascMax T-grades are compared with the four cobalt-bearing VascoMax C-grades in Table 2 on page 3.

APPLICATIONS

Allvac produces the VascoMax alloys in a full range of "long" mill product forms including billet, bar, rod, rod coil, and wire.

Extensive laboratory and field testing, plus numerous production applications of VascoMax T-250 alloy, have proven that this family of maraging steels is equivalent to, or slightly better than, the cobalt-bearing grades. Typical applications for the maraging steels are missile and rocket motor cases, wind tunnel models, recoil springs, flexures, actuators, landing gear components, high performance shafting, gears, and fasteners. The alloys are used in extrusion tooling, and in the die casting industry for long-run dies and also as core pins.

DEVELOPMENT

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

VascoMax T-250 alloy was a joint project of VASCO and INCO's Research and Development Center which held the patent rights for the material at that time. VascoMax T-200 and VascoMax T-300 alloys were developed by VASCO research as part of a continuing effort in 18% nickel maraging steel development.

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VASCOMAX® NICKEL MARAGING ALLOYS

RECOMMENDED HEAT TREATMENT

All VascoMax steels are furnished in the solution annealed condition. They are very tough, relatively soft (28 to 32 Rc) and, therefore, readily machined and formed. They acheive full properties through martensitic precipitation aging (hence the name maraging steels) - a relatively simple, low temperature heat treatment. As is true of other heat treating procedures, aging is a time/temperature dependent reaction. Of these two factors, temperature is more important.

Because the VascoMax steels are essentially carbon-free, protective atmospheres are not required during annealing or aging. This is one of several VascoMax advantages over carbon-strengthened high-strength steels which are subject to carburization and decarburization, and require a protected or neutral environment.

The VascoMax steels are also exceptionally stable during annealing and aging, offering predictable, uniform shrinkage on all dimensions. This distortion-free (nonwarping) characteristic is a significant advantage over many other high-strength steels.

The VascoMax T grades should be aged at 900° to 925°F (480° to 495°C) for three to six hours. Air cool. Very large cross sections should be aged for longer periods.

RECOMMENDED PROCEDURES FOR PROCESSING/FABRICATION

The VascoMax T grades are processed essentially the same as the cobalt-bearing 18% nickel maraging steels. Detailed procedures for machining, cold working, warm working, hot working, welding, nitriding, plating, forging, rolling, solution annealing, as well as recommendations for die casting applications, can be found in the C-type VascoMax Grades Technical Data Sheet from Allvac.

ADVANTAGES OF VASCOMAX

Allvac prepared this technical data sheet to assist both the engineer and the less technically oriented individual in understanding the tremendous benefits of VascoMax alloys as both structural and a tooling material. Here is a summary of those advantages

- **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
- **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

VASCOMAX® NICKEL MARAGING ALLOYS

Nominal Mechanical Properties of Small Diameter Bars Following Aging Heat Treatment
Table I

	VascoMax T-200 ®	VascoMax T-250 ®	VascoMax T-300 ®
Ultimate Tensile, psi (kPa)	210,000 (1447896)	260,000 (1792634)	290,000 (1999476)
0.2% Yield, psi (kPa)	205,000 (1413423)	255,000 (1758160)	285,000 (1965002)
Elongation, %	14	11	10
Reduction of Area, %	68	58	51
Notch Tensile (Kt=9.0), psi (kPa)	344,000 (2371792)	377,000 (2599319)	375,000 (2585529)
Charpy V-Notch, ft - lb (Nm)	81 (110)	25 (34)	15 (20)
Fatigue Endurance Limit (10^8 Cycles), psi (kPa)	110,000 (758422)	110,000 (758422)	120,000 (827369)
Rockwell "C" Hardness	43/47	49/52	52/55

Nominal Analyses
Table 2

	VascoMax ® C-200	VascoMax ® C-250	VascoMax ® C-300	VascoMax ® C-350	VascoMax T-200 ®	VascoMax T-250 ®	VascoMax T-300 ®
Nickel	18.50%	18.50%	18.50%	18.50%	18.50%	18.50%	18.50%
Cobalt	8.50	7.50	9.00	12.00	None	None	None
Molybenum	3.25	4.80	4.80	4.80	3.00	3.00	4.00
Titanium	.20	.40	.60	1.40	.70	1.40	1.85
Aluminum	.10	.10	.10	.10	.10	.10	.10
Silicon	.10 max	.10 max	.10 max	.10 max	.10 max	.10 max	.10 max
Manganese	.10 max	.10 max	.10 max	.10 max	.10 max	.10 max	.10 max
Carbon	.03 max	.03 max	.03 max	.03 max	.03 max	.03 max	.03 max
Sulfur	.01 max	.01 max	.01 max	.01 max	.01 max	.01 max	.01 max
Phosphorus	.01 max	.01 max	.01 max	.01 max	.01 max	.01 max	.01 max
Zirconium	.01	.01	.01	.01	-	-	-
Boron	.003	.003	.003	.003	-	-	-
Iron	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.

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VASCOMAX® T-200

Physical Properties

Average Coefficient of Thermal Expansion (70-900° F)	7.1 x 10^{-6} in/in/°F
Modulus of Elasticity	27.2 x 10^{6} psi
Density	.288 lbs/cu. in. (7.98 g/cc)
Critical Transformation Temperatures	
A_S	1175° F
A_F	1255° F
M_S	436° F

Nominal Analysis

Nickel	18.50
Molybenum	3.00
Titanium	.70
Aluminum	.10
Silicon	.10 max
Manganese	.10 max
Carbon	.03 max
Sulfur	.010 max
Phosphorus	.010 max

Nominal Annealed Properties

Hardness	27-29 Rc
Yield Strength	100 ksi
Ultimate Strength	140 ksi
Elongation	21%
Reduction of Area	92%

Nominal Room Temperature Properties after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %
9/16" Round	Longitudinal	43.9	213.3	207.7	13.0	69.0
2-1/2" Round	Longitudinal	44.3	211.6	205.9	13.1	68.3
6" Square	Longitudinal	45.5	213.8	208.4	13.7	69.8
6" Square	Transverse	45.3	214.7	209.0	12.3	62.0
.155" Sheet	Transverse	44.2	211.0	205.4	8.0	62.2
.300" Sheet	Transverse	46.2	212.7	206.1	9.0	66.7

Effect of Stress Concentration Factor, K_t, on Tensile Properties

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	317.6	316.9 - 319.1	1.49
3.0	336.0	335.4 - 336.5	1.58
5.0	340.1	339.5 - 340.5	1.60
7.0	342.7	342.1 - 342.9	1.61
9.0	343.8	341.7 - 345.9	1.62

* Based on smooth bar tensile strength of 212.2 ksi

All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Test Temperature on Tensile Properties

Test Temp °F	Ultimate Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %
400 °F	188.8	183.7	13.0	68.0
600 °F	180.6	174.7	12.5	68.0
800 °F	168.9	159.4	13.0	69.0
900 °F	152.0	148.5	15.5	72.0
950 °F	145.4	141.6	17.5	74.0
1000 °F	129.6	127.6	19.5	78.0

All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

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VASCOMAX® T-200

Effect of Aging Temperature on Tensile Properties

Aging Temperature	Ultimate Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %	Hardness Rockwell "C"
600° F	143.4	136.2	19.0	80.0	30.0
700° F	164.3	157.1	18.0	74.0	36.5
800° F	204.1	197.4	16.0	69.0	42.6
850° F	215.1	209.4	14.0	68.0	44.2
900° F	214.3	209.2	14.0	70.0	43.9
950° F	205.9	202.8	13.0	69.0	42.7
1000° F	194.9	189.3	15.0	69.0	42.3

All samples solution annealed for one hour at 1500° F, air cooled and aged for six hours at the temperatures indicated.

Fracture Toughness

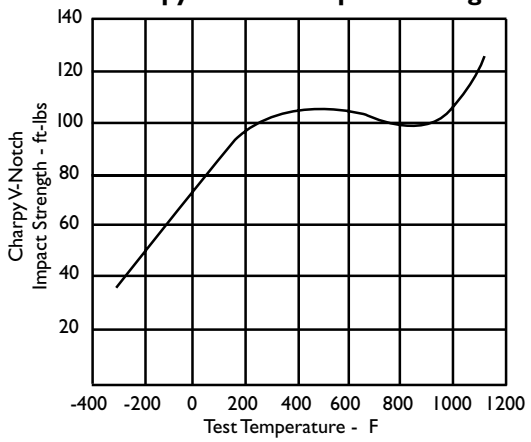
Compact Tension Specimens*	
Product	**K_{IC}**
6" Square	116.6 ksi $\sqrt{in}$
6" Square	112.6 ksi $\sqrt{in}$
6" Square	124.6 ksi $\sqrt{in}$
6" Square	117.6 ksi $\sqrt{in}$

*Specimens were 1T-type and were machined, precracked and tested per ASTM E-399-83

NOTE: Product was taken from two different production heats of material

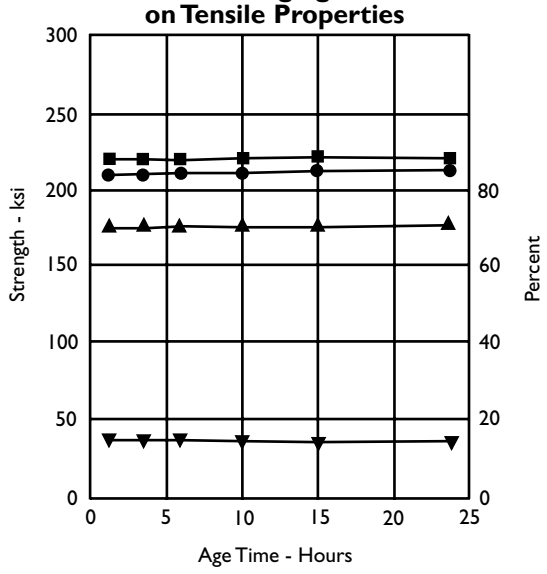
All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Test Temperature on Charpy V-Notch Impact Strength



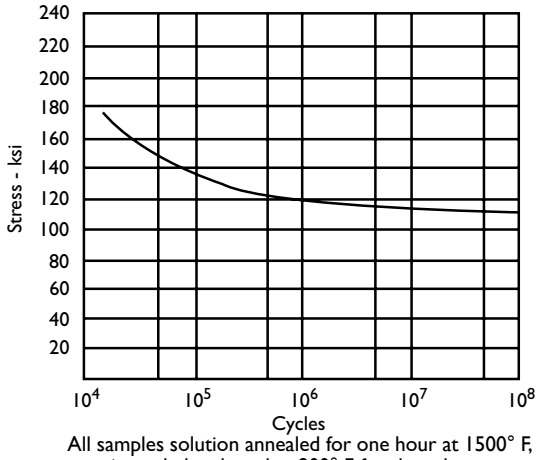
All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Aging Time on Tensile Properties



All specimens solution annealed for one hour at 1500° F, air cooled and aged at 900° F for the times indicated.

R.R. Moore Rotating Beam Fatigue Tests



All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

VASCOMAX® T-250

Physical Properties

Average Coefficient of Thermal Expansion (70-900° F)	6.2 x 10^{-6} in/in/°F
Modulus of Elasticity	27.0 x 10^{6} psi
Density	.288 lbs/cu. in. (7.98 g/cc)
Critical Transformation Temperatures	
A_S	1225° F
A_F	1311° F
M_S	310° F

Nominal Analysis

Nickel	18.50
Molybenum	3.00
Titanium	1.40
Aluminum	.10
Silicon	.10 max
Manganese	.10 max
Carbon	.03 max
Sulfur	.010 max
Phosphorus	.010 max

Nominal Annealed Properties

Hardness	30/32 Rc
Yield Strength	95 ksi
Ultimate Strength	140 ksi
Elongation	16%
Reduction of Area	70%

Nominal Room Temperature Properties after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %
5/8" Round	Longitudinal	51.4	264.3	257.7	12.1	59.4
2" Round	Longitudinal	50.8	258.7	252.6	11.0	58.1
3" Round	Longitudinal	50.3	266.3	259.6	10.0	52.4
6" Square	Longitudinal	50.8	259.6	253.6	10.5	56.1
6" Square	Transverse	50.1	259.6	253.5	8.9	45.8
.200" Sheet	Transverse	50.0	259.9	254.3	7.0	54.0
.250" Sheet	Longitudinal	51.4	262.0	252.0	8.0	62.0

Effect of Stress Concentration Factor, K_t, on Tensile Properties

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	398.3	397.0 - 400.0	1.49
2.2	401.7	397.0 - 405.0	1.50
2.5	404.7	403.0 - 406.0	1.51
3.0	409.0	409.0 - 409.0	1.53
4.0	399.0	399.0 - 399.0	1.49
4.9	384.2	379.0 - 390.0	1.44
7.0	382.4	378.7 - 386.1	1.43
9.0	377.2	376.0 - 378.4	1.41

* Based on smooth bar tensile strength of 267.5 ksi

All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Test Temperature on Tensile Properties

Test Temp °F	Ultimate Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %
400 °F	242.1	233.6	11.0	61.0
600 °F	230.6	222.9	11.0	58.5
800 °F	215.3	207.9	12.2	62.0
900 °F	193.3	185.2	15.0	66.0
950 °F	180.6	175.5	15.2	69.5
1000 °F	136.1	128.9	23.0	80.0

All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

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VASCOMAX® T-250

Effect of Aging Temperature on Tensile Properties

Aging Temperature	Ultimate Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %	Hardness Rockwell "C"
600° F	174.6	163.2	14.2	59.1	33.0
700° F	207.3	196.8	12.8	56.2	39.7
800° F	242.5	227.0	11.0	53.8	44.6
850° F	251.9	237.5	10.6	47.8	50.6
900° F	265.1	254.6	11.0	55.8	51.4
950° F	252.8	242.5	12.0	60.6	51.1
1000° F	236.9	224.9	12.4	61.2	50.0

All samples solution annealed for one hour at 1500° F, air cooled and aged for six hours at the temperatures indicated.

Fracture Toughness

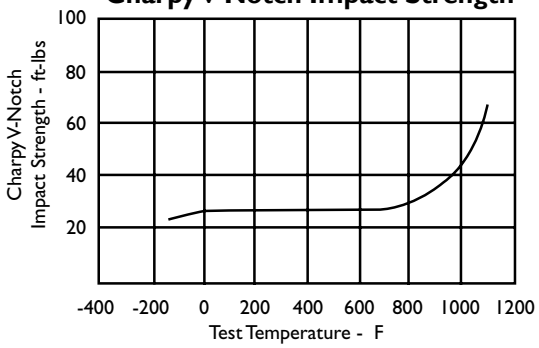
Bend-Type Specimens	
Product	**K_{max}***
4" x 250"	89.3 ksi $\sqrt{in}$
6" x 500"	99.1 ksi $\sqrt{in}$
2" Round	111.9 ksi $\sqrt{in}$
3" Round	98.3 ksi $\sqrt{in}$
8" Square	94.7 ksi $\sqrt{in}$

*Because of the relatively high strength level of this material, plane strain conditions exist and $K_{max}=K_Q$. As such, K_{max} is comparable to the the K_{IC} values that would be obtained per ASTM E-399-83.

NOTE: Product was taken from two different production heats of material

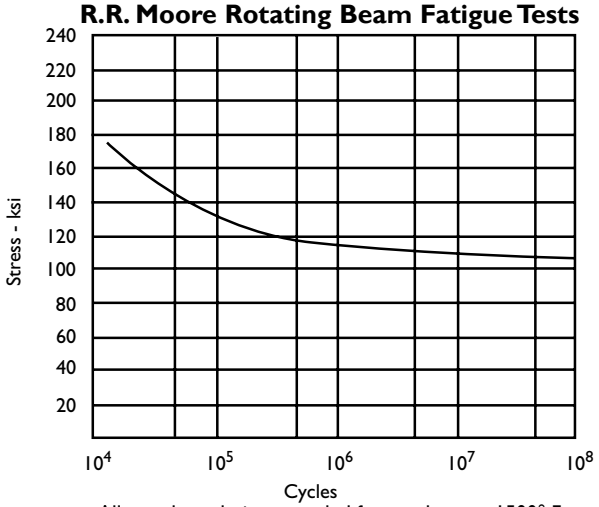
All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Test Temperature on Charpy V-Notch Impact Strength



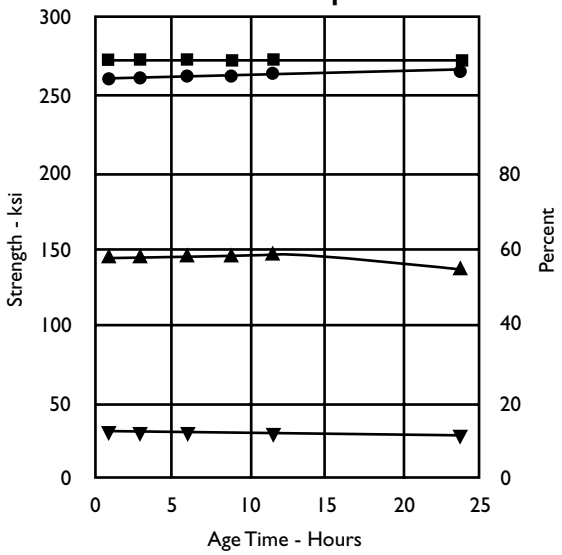
All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

R.R. Moore Rotating Beam Fatigue Tests



All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Aging Time on Tensile Properties



All specimens solution annealed for one hour at 1500° F, air cooled and aged at 900° F for the times indicated.

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VASCOMAX® T-300

Physical Properties

Average Coefficient of Thermal Expansion (70-900° F)	7.4 x 10^{-6} in/in/°F
Modulus of Elasticity	27.8 x 10^{6} psi
Density	.288 lbs/cu. in. (7.98 g/cc)
Critical Transformation Temperatures	
A_S	1238° F
A_F	1329° F
M_S	347° F

Nominal Analysis

Nickel	18.50
Molybenum	4.00
Titanium	1.85
Aluminum	.10
Silicon	.10 max
Manganese	.10 max
Carbon	.03 max
Sulfur	.010 max
Phosphorus	.010 max

Nominal Annealed Properties

Hardness	30/32 Rc
Yield Strength	110 ksi
Ultimate Strength	150 ksi
Elongation	16%
Reduction of Area	69%

Nominal Room Temperature Properties after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %
9/16" Round	Longitudinal	53.6	299.5	291.3	11.0	56.1
3" Round	Longitudinal	54.0	292.3	283.7	10.6	49.0
6" Square	Longitudinal	55.3	297.2	287.8	8.8	45.3
6" Square	Transverse	55.1	296.8	289.6	7.5	38.2
.155" Sheet	Transverse	54.2	298.9	289.8	6.0	45.0
.300" Sheet	Transverse	55.0	300.5	295.7	6.6	50.7

Effect of Stress Concentration Factor, K_t, on Tensile Properties

K_t	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	436.8	436.2 - 437.5	1.46
3.0	427.7	420.8 - 434.6	1.43
5.0	391.4	383.7 - 396.1	1.31
7.0	376.8	376.5 - 377.1	1.28
9.0	375.1	367.9 - 384.8	1.26

* Based on smooth bar tensile strength of 299.0 ksi

All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Test Temperature on Tensile Properties

Test Temp °F	Ultimate Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %
400 °F	270.4	265.3	11.0	58.0
600 °F	254.6	247.4	10.0	58.0
800 °F	236.1	229.5	13.0	62.0
900 °F	220.4	216.8	13.0	65.0
950 °F	203.8	200.2	16.0	70.0
1000 °F	185.7	181.1	18.0	75.0

All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

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VASCOMAX® T-300

Effect of Aging Temperature on Tensile Properties

Aging Temperature	Ultimate Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5 $\sqrt{A}$ %	Reduction of Area %	Hardness Rockwell "C"
600° F	169.9	158.7	18.0	74.0	36.8
700° F	194.9	181.1	12.0	48.0	41.6
800° F	265.8	255.1	10.0	33.0	50.7
850° F	291.3	283.2	11.0	52.0	53.5
900° F	300.0	292.9	10.0	54.0	53.6
950° F	288.3	281.6	11.0	57.0	52.5
1000° F	272.4	265.3	11.0	53.0	52.0

All samples solution annealed for one hour at 1500° F, air cooled and aged for six hours at the temperatures indicated.

Fracture Toughness

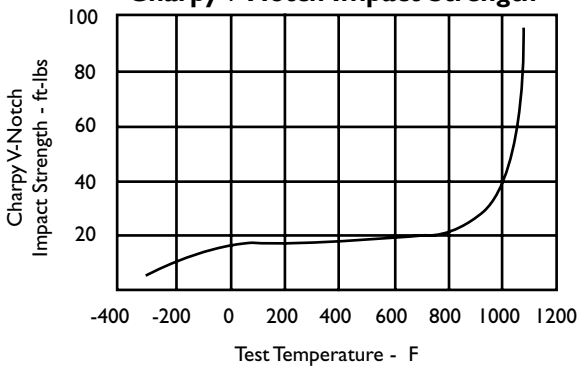
Bend-Type Specimens	
Product	**K_{max}***
6" Square	63.4 ksi $\sqrt{in}$
6" Square	63.7 ksi $\sqrt{in}$
6" Square	65.2 ksi $\sqrt{in}$
6" Square	67.3 ksi $\sqrt{in}$

*Because of the relatively high strength level of this material, plane strain conditions exist and $K_{max}=K_Q$. As such, K_{max} is comparable to the the K_{IC} values that would be obtained per ASTM E-399-83.

NOTE: Product was taken from two different production heats of material

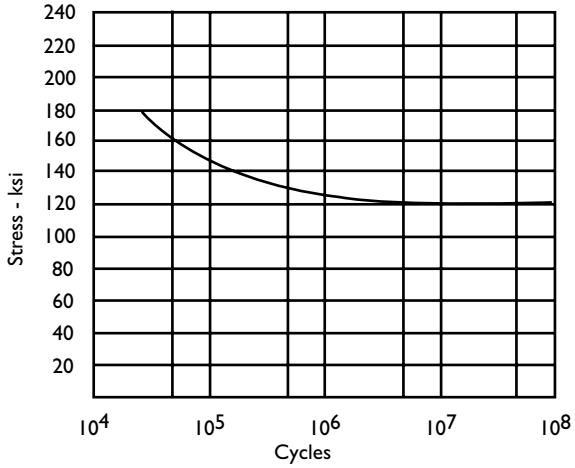
All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Test Temperature on Charpy V-Notch Impact Strength



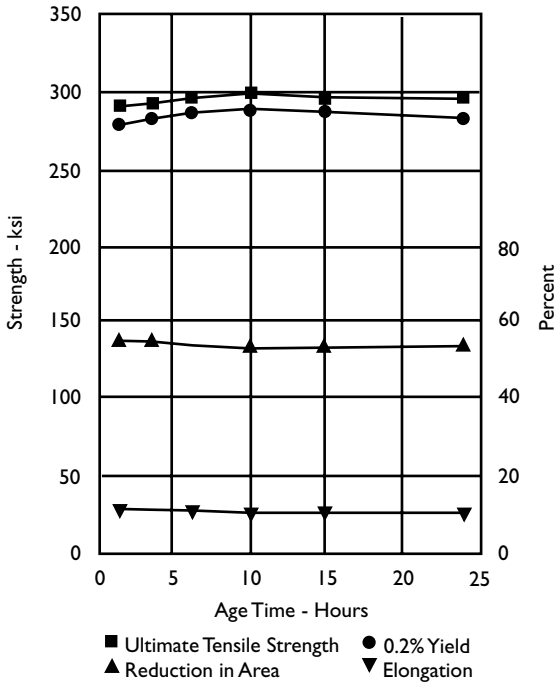
All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

R.R. Moore Rotating Beam Fatigue Tests



All samples solution annealed for one hour at 1500° F, air cooled and aged at 900° F for three hours.

Effect of Aging Time on Tensile Properties



All specimens solution annealed for one hour at 1500° F, air cooled and aged at 900° F for the times indicated.

Data are typical and should not be construed as maximum or minimum values for specification or for final design. Data on any particular piece of material may vary from those shown herein. Allvac® and VascoMax® T-200, VascoMax® T-250, and VascoMax® T-300 are registered trademarks of ATI Properties, Inc.

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