ATI C-200™/C-250™/C-300™/C-350™ Alloys

GENERAL

ATI C-200™, ATI C-250™, and ATI C-350™ 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 1960s, depend on cobalt (7-12% cobalt depending on grade) as their strengthening agent; they are cobalt strengthened 18% nickel maraging steels. In the early 1980s, ATI 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: ATI C-250). Titanium-strengthened grades, or "T-type 18Ni maraging", are designated by the letter "T" in the grade identification (example: ATI T-250).

This data sheet covers the C-type 18Ni maraging steels manufactured by ATI: ATI C-200, ATI C-250, ATI C-300, and ATI C-350. Information on the T-type grades is available in a separate Technical Data Sheet. ATI continues to be a leading producer of the titanium-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, ATI employs double vacuum melting – under strictest quality control – for all maraging steel grades.

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, ATI C-350 has a nominal ultimate tensile strength of 350 ksi (350,000 psi). This variety in property levels among the four grades allows flexibility in selecting the property combination which best suits a given application. Mechanical properties of the four ATI C-grades are reported in Table 1 on page 3 illustrating briefly their properties and highlighting their outstanding values.

An additional benefit of the maraging steel 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 Rc), 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.

APPLICATIONS

ATI produces the maraging steel 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 ATI C-250, 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 1960s. ATI was instrumental in assisting INCO in this development and pioneered these alloys in the specialty steel industry.

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RECOMMENDED HEAT TREATMENT

All maraging 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 achieve 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 than time.

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

The maraging 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 ATI C-steels should be aged at 900° to 950°F (480° to 510°C) for three to six hours. Air cool. Very large cross sections should be aged for longer periods.

RECOMMENDED PROCEDURES FOR PROCESSING/FABRICATION

The ATI C-steels are processed essentially the same as the titanium-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 ATI C Recommended Procedures for Processing and Fabrication Data Sheet.

ADVANTAGES OF ATI C-200/C-250/C-300/C-350 ALLOYS

ATI prepared this technical data sheet to assist both the engineer and the less technically oriented individual in understanding the tremendous benefits of maraging steel 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

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ATI C-200™/ C-250™/ C-300™ C-350™

Technical Data Sheet

Nominal Mechanical Properties of Small Diameter Bars Following Aging Heat Treatment — Figure 1

	ATI C-200	ATI C-250	ATI C-300	ATI C-350
Ultimate Tensile Strength, 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 (K_t= 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

Nominal Analyses — Figure 2

	ATI C-200	ATI C-250	ATI C-300	ATI C-350	ATI T-200	ATI T-250	ATI 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
Molybdenum	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	–	–	–

ATI C-200 ALLOY

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 Annealed Properties

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

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	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

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ATI C-200™/ C-250™/ C-300™ C-350™

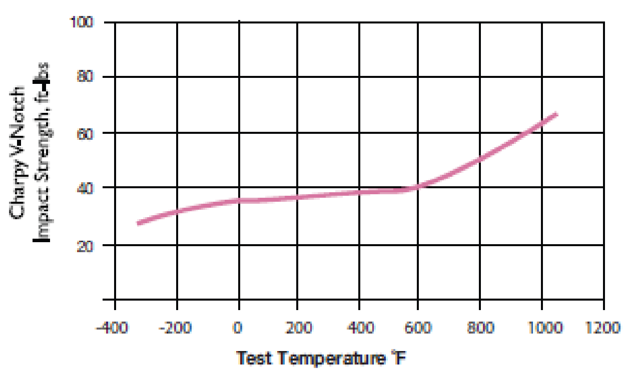
Technical Data Sheet

Effect of Stress Concentration Factor, Kt, on Tensile Properties

Kt	Notch Tensile Strength Average ksi	Notch Tensile Strength Range ksi	Notch-To-Smooth Tensile Strength Ratio*
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

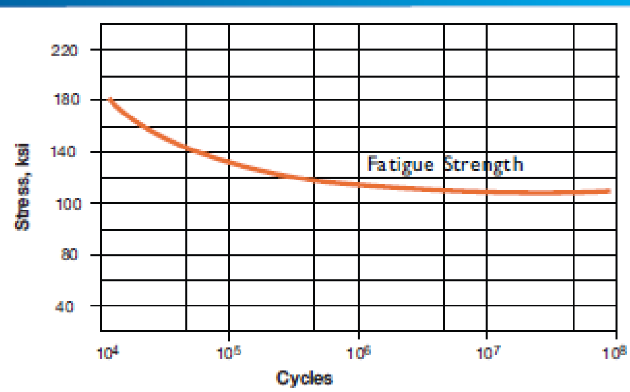
* Based on smooth bar tensile strength of 212.0 ksi
All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

Effect of Test Temperature on Charpy V-Notch Impact Strength



All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

R. R. Moore Rotating Beam Fatigue Tests



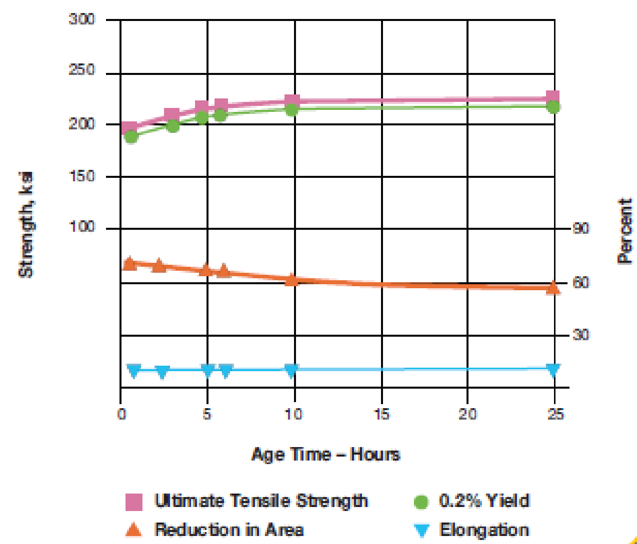
All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

Effect of Test Temperature on Tensile Properties

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

All samples solution annealed for one hour at 1,500°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 1,500°F, air cooled and aged at 900°F for the times indicated.

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

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ATI C-250 ALLOY

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 Annealed Properties	
Hardness	30 Rc
Yield Strength	95 ksi
Ultimate Strength	140 ksi
Elongation	17%
Reduction of Area	75%

Nominal Room Temperature Properties after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation %	Reduction of Area %
5/8" 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

Effect of Stress Concentration Factor, Kt, on Tensile Properties

Kt	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

All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

Effect of Test Temperature on Tensile Properties

Test Temp °F	0.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation % in 4.5√A %	Reduction of Area %
600°F	224.5	233.4	11.5	56.0
800°F	210.8	221.0	12.0	56.1
900°F	185.1	200.0	16.5	64.6
1000°F	129.1	149.2	23.0	72.9

All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

Condition	Compressive Strength		Rockwell Hardness "C"
	Proportional Limit ksi	0.2% Offset Yield Strength ksi	
Solution Annealed	105.0	149.0	29.0
Aged	241.3	280.0	51.0

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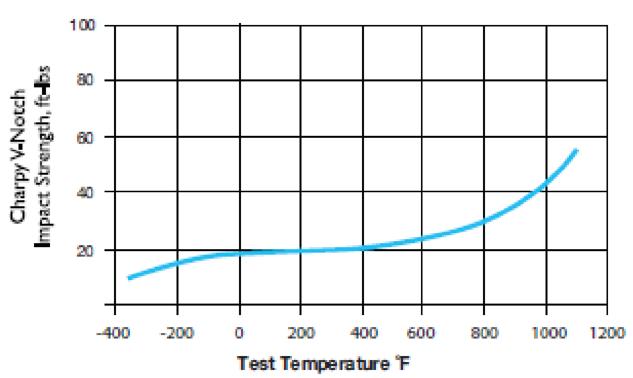
Effect of Various Aging Treatments on Tensile Properties of 0.125 Sheet*

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	48.7
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

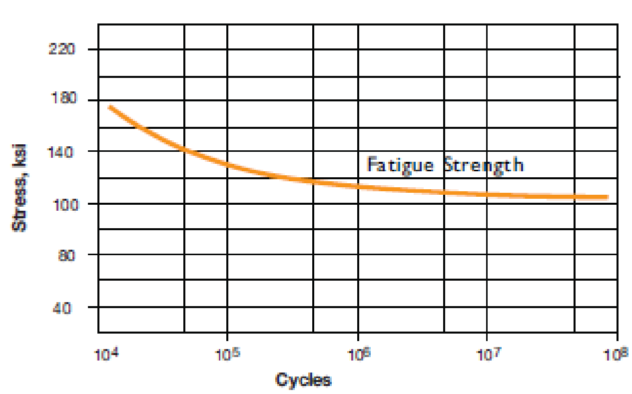
*Standard ASTM sheet tensiles solution annealed for 30 minutes at the indicated temperatures, air cooled and aged as shown.

Effect of Test Temperature on Charpy V-Notch Impact Strength



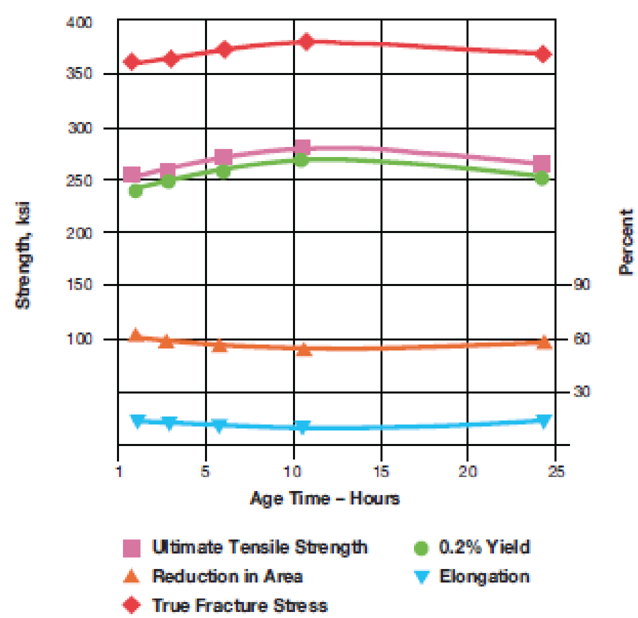
All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

R. R. Moore Rotating Beam Fatigue Tests



All samples solution annealed for one hour at 1,500°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 1,500°F, air cooled and aged at 900°F for the times indicated.

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Technical Data Sheet

ATI C-300 ALLOY

Physical Properties

Average Coefficient of Thermal Expansion (70-900°F)	5.6 x 10^{-6} in/in/°F
Modulus of Elasticity	27.5 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 Annealed Properties

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

Nominal Room Temperature Properties after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation in 4.5√A %	Reduction of Area %
5/8" 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

Effect of Stress Concentration Factor, Kt, on Tensile Properties

Kt	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 270.1 ksi
All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

Effect of Test Temperature on Tensile Properties

Test Temp °F	0.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation % in 4.5√A %	Reduction of Area %
600°F	245.6	256.8	12.0	61.8
800°F	227.7	240.1	14.0	61.3
900°F	194.8	210.9	17.3	68.4
950°F	172.9	189.1	22.0	76.5
1000 °F	153.2	168.0	24.0	77.2

All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

Effect of Various Aging Treatments on Tensile Properties of 0.125 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.

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Effect of Sheet Thickness on Tensile Properties*

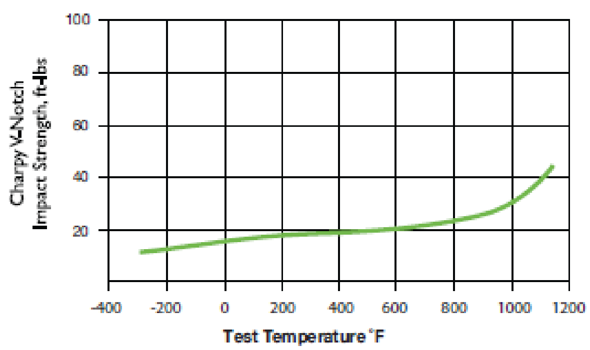
Sheet Thickness inches	.2% Offset Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation, % in. **	
			1"	2"
.250	315.1	320.8	9.0	5.0
.125	313.9	316.8	6.8	3.4
.090	308.2	312.7	6.0	3.2
.065	301.4	307.2	5.0	3.0
.045	291.9	295.0	4.0	2.0
.025	294.0	296.0	2.0	1.0

* Standard ASTM sheet tensiles solution annealed for 15 minutes at 1,500°F, air cooled and aged at 900°F for three hours.
** 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 in $4.5\sqrt{A}$ should be used, not a fixed 1" or 2" gage length.

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

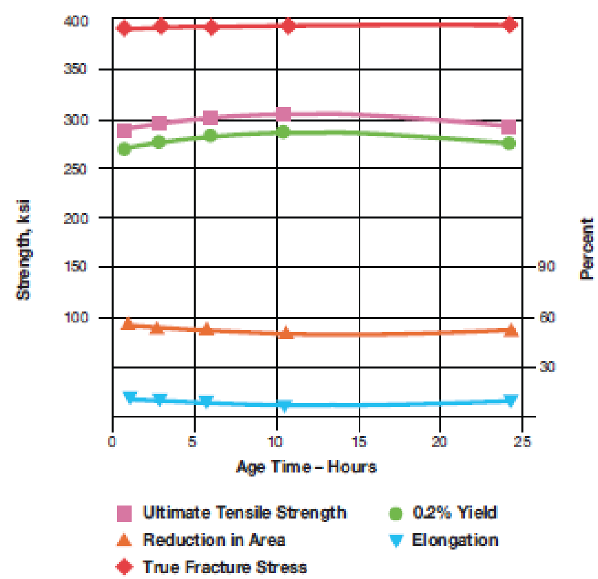
Samples solution annealed for 30 minutes at 1,500°F, air cooled and aged 3 hours at 900°F as indicated. Average of 3 tests per condition.

Effect of Test Temperature on Charpy V-Notch Impact Strength



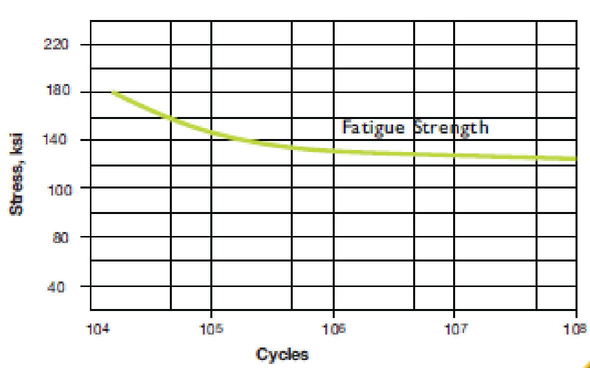
All specimens solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for the times indicated.

Effect of Aging Time on Tensile Properties



All specimens solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for the times indicated.

R. R. Moore Rotating Beam Fatigue Tests



All specimens solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for the times indicated.

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ATI C-350 ALLOY

Physical Properties	
Average Coefficient of Thermal Expansion (70-900°F)	6.3 x 10^{-6} in/in/°F
Modulus of Elasticity	29 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 Annealed Properties	
Hardness	35 Rc
Yield Strength	120 ksi
Ultimate Strength	165 ksi
Elongation	18%
Reduction of Area	70%

Nominal Room Temperature Properties after Aging

Size	Direction	Hardness Rockwell "C"	Tensile Strength ksi	0.2% Yield Strength ksi	Elongation %	Reduction of Area %
5/8" 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

Effect of Stress Concentration Factor, Kt, on Tensile Properties

	Notch Tensile Strength		Notch-To-Smooth Tensile Strength Ratio*
	Average ksi	Range ksi	
2.0	433.7	427.4 - 437.3	1.20
6.25	334.3	331.7 - 337.6	0.93
9.0	333.0	326.7 - 338.6	0.92

* Based on smooth bar tensile strength of 362.8 ksi
All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for three hours.

Effect of Test Temperature on Tensile Properties

Test Temp °F	0.2% Yield Strength ksi	Ultimate Tensile Strength ksi	Elongation in 4.5√A %	Reduction of Area %
600°F	295.4	310.2	12.3	54.9
800°F	277.3	288.4	15.6	57.6
900°F	251.9	270.4	17.4	60.3
1000°F	233.6	251.8	20.0	70.9

All samples solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for six hours.

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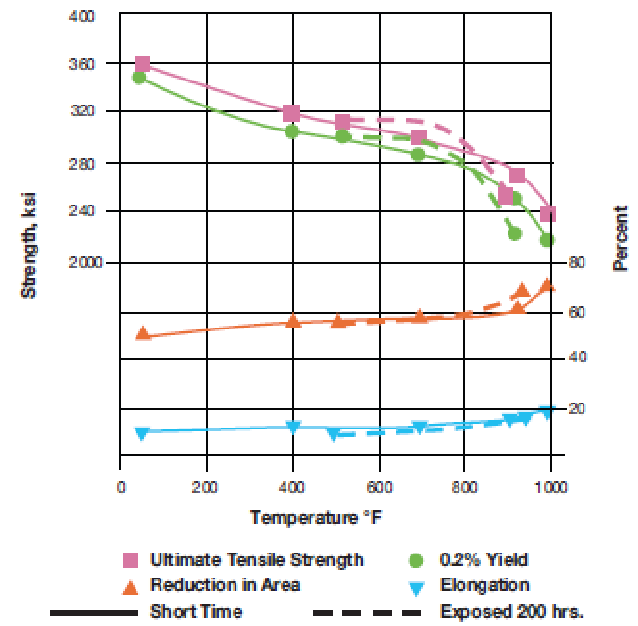
ATI C-200™/ C-250™/ C-300™ C-350™

Technical Data Sheet

Condition	Compressive Strength Proportional Limit ksi	Compressive Strength 0.2% Offset Yield Strength ksi	Rockwel Hardness "C"
Solution Annealed	108.0	160.5	34.3
Aged	349.3	388.1	59.6

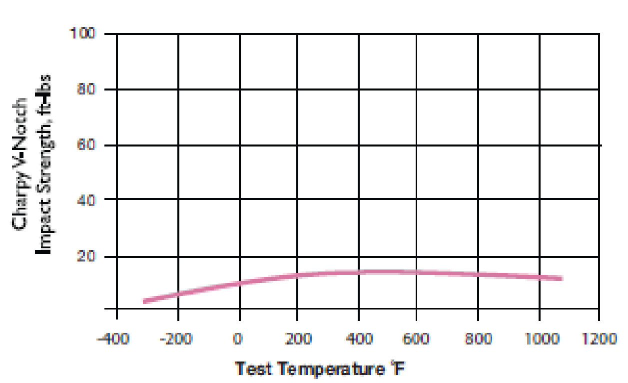
Samples solution annealed for 30 minutes at 1,500°F, air cooled and aged 3 hours at 900°F as indicated. Average of 3 tests per condition.

Tensile Properties as a Function of Test and Exposure Temperatures



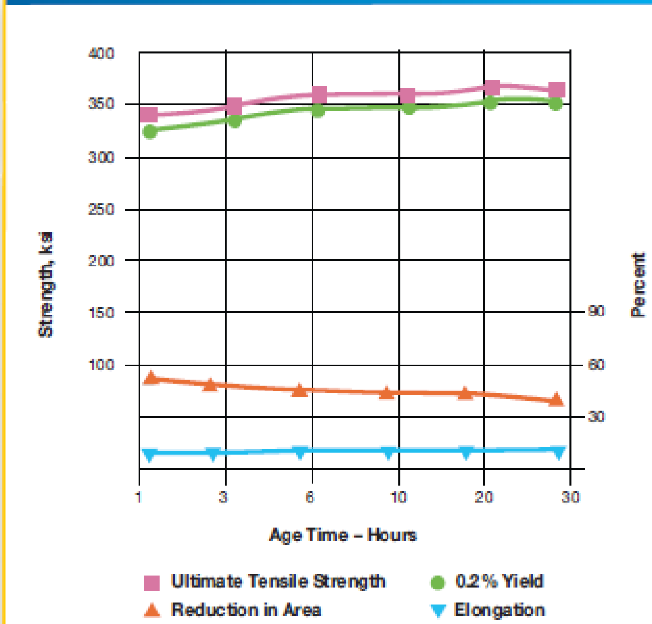
All specimens solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for the times indicated.

Effect of Test Temperature on Charpy V-Notch Impact Strength



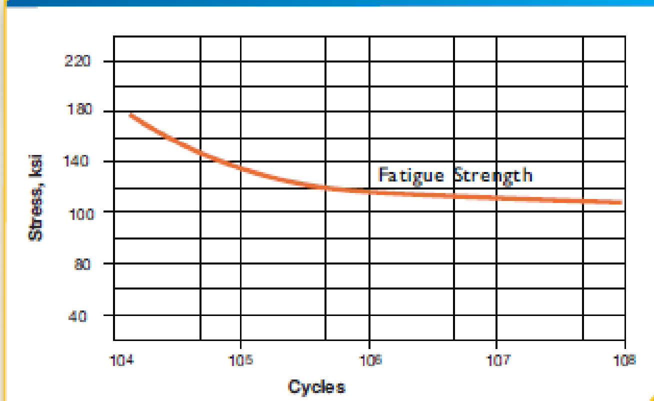
All specimens solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for the times indicated.

Effect of Aging Time on Tensile Properties



All specimens solution annealed for one hour at 1,500°F, air cooled and aged at 900°F for the times indicated.

R. R. Moore Rotating Beam Fatigue Tests



All specimens solution annealed for one hour at 1,500°F, air cooled and aged at 900° F for the times indicated.

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