ATI

Technical Data Sheet

ATI 441 HP™

Stainless Steel: Ferritic

(UNS S44100)

INTRODUCTION

ATI 441 HP™ alloy is a heat resisting ferritic grade that provides good oxidation and corrosion resistance for applications like automotive exhaust system components. Ferritic steels are not inherently strong at elevated temperatures, but columbium additions coupled with appropriate solution annealing markedly improve long-time creep rupture strength properties. ATI 441 HP alloy is dual stabilized with columbium and titanium to provide good weld ductility and resistance to intergranular corrosion in the weld heat affected zone.

ATI 441 HP alloy has been developed for the severe tube bending and forming operations typical in automotive exhaust manifold fabrication. Tight control on carbon and nitrogen levels plus improved mill processing result in enhanced formability in terms of higher tube bending speeds and lower breakage or scrap rate.

STRUCTURE

ATI 441 HP ferritic alloy matrix has a body-centered cubic crystal structure. Angular carbo-nitrides of titanium and columbium are randomly dispersed throughout the structure.

Excess columbium is taken into solid solution during high temperature annealing and precipitates as very fine particles of Laves phase (Fe_2Cb) upon either slow cooling or upon holding at intermediate temperatures (1500-1700°F, 816-927°C). Strengthening by this dispersion is responsible for improved elevated temperature strength.

TYPICAL COMPOSITION

Element	UNS S44100	Typical ATI 441 HP™
Carbon	0.03 max	0.009
Manganese	1.00 max	0.35
Phosphorus	0.04 max	0.023
Sulfur	0.03 max	0.002
Silicon	1.00 max	0.34
Chromium	17.5-19.5	18.0
Nickel	1.00 max	0.30
Titanium	0.10 - 0.50	0.22
Columbium	0.3 + (9 x C) min 0.9 max	0.45
Nitrogen	0.03 max	0.014
Aluminum	-	0.05
Iron	Balance	Balance

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SPECIFICATIONS

The ATI 441 alloy is designated as UNS S44100 in ASTM specifications A240, and A554.

PHYSICAL PROPERTIES

Coefficient of Linear Thermal Expansion

Coefficient of Linear Thermal Expansion			
Temperature Range		ATI 441 HP™	ATI 441 HP™
°C	°F	10^{-6}cm/cm•°C	10^{-6}in/in•°F
20-100	68-212	10.2	5.7
20-300	68-572	10.8	6.0
20-500	68-932	11.5	6.4
20-700	68-1292	12.1	6.7
20-800	68-1472	12.4	6.9
20-900	68-1652	12.8	7.1

Density	ATI 441 HP™
lb/in³ (g/cm³)	0.278 (7.711)
Electrical Resistivity microhm-cm at 68°F (20°C)	58.7

MECHANICAL PROPERTIES

Typical Annealed Tensile Properties	
	ATI 441 HP™
Yield Strength ksi MPa	 45.0 310
Tensile Strength ksi MPa	 72.0 496
Elongation % in 2" (51 cm)	31.0
Hardness R_B	82.0

Short Time Tensile Properties.

Elevated temperature tensile properties are shown in the following table on the next page and compared with ATI 409HP™ and ATI 439HP™ alloys. At 1300°F (704°C) and above, the yield and tensile strengths of ATI 441 HP and ATI 439HP alloys are about double those of ATI 409HP alloy. It is assumed that the solid solution strengthening effects of chromium in ATI 441 HP and ATI 439HP alloys provide the improved short time tensile properties above 1200°F (649°C).

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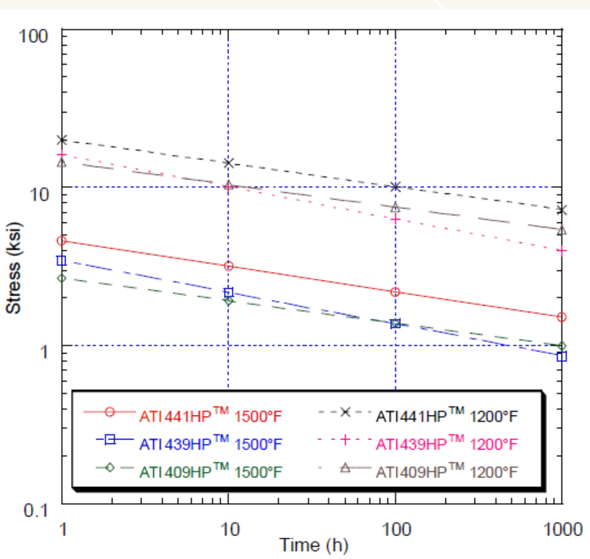
Elevated Temperature Tensile Properties Yield Strength and Tensile Strength (ksi)						
	ATI 409 HP™		ATI 439 HP™		ATI 441 HP™	
Temp.	Y.S.	T.S.	Y.S.	T.S.	Y.S.	T.S.
RT	35.5	62.0	40.3	65.6	43.7	68.5
200	31.3	56.7	37.0	64.2	40.3	65.0
400	27.0	51.7	33.4	60.3	36.4	60.0
600	26.5	50.2	27.5	57.6	35.6	58.7
800	24.1	43.1	26.7	51.7	32.5	56.5
100	22.0	34.0	24.1	43.5	28.2	54.1
1100	21.0	29.6	22.8	36.7	24.0	53.1
1200	14.5	20.4	17.2	25.3	24.8	48.8
1300	8.5	11.7	12.0	15.0	19.0	25.4
1400	6.3	8.3	6.7	9.3	12.1	18.9
1500	5.0	6.3	5.0	6.1	9.8	11.0
1600	3.2	4.2	4.0	5.2	6.4	7.3
1700					4.7	5.9

Stress Rupture Properties

The long duration of stress rupture and creep testing enables the Fe_2Cb Laves phase to precipitate, and 100 and 1,000 hour stress rupture properties reveal the beneficial strengthening effects due to columbium additions to ATI 441 HP alloy.

Stress Rupture Properties



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CORROSION RESISTANCE

ATI 441 alloy has generally good overall corrosion resistance typical for 18% chromium stainless steels. Like all ferritic stainless alloys, it is highly resistant to stress corrosion cracking. The following tables and figures show the relative corrosion resistance compared to ATI 409, ATI 439 and ATI 304 alloys in a variety of laboratory tests.

General Corrosion Properties

	Corrosion Rate in Inches Per Month and (Millimeters Per Annum)			
Medium	**ATI 441HP™**	**ATI 439HP™**	**ATI 409HP™**	**ATI 304™**
20% Acetic Acid Boiling	0.000 (0.000)	0.0003 (0.09)	0.010 (3.10)	0.00001 (0.003)
65% Nitric Acid Boiling	0.013 (3.96)	0.0020 (0.61)	0.027 (8.3)	0.0007 (0.22)
20% Phosphoric Acid Boiling	0.00005 (0.015)	0.00002 (0.006)	0.0017 (0.52)	0.00002 (0.006)
10% Sodium Bisulfate Boiling	0.0010 (0.31)	0.00001 (0.003)	0.21 (64.0)	0.005 (1.53)
10% Sulfamic Acid Boiling	0.0012 (0.037)	0.00008 (0.025)	0.27 (82.3)	0.013 (4.0)
10% Oxalic Acid Boiling	0.14 (42.7)	0.18 (55.0)	0.15 (46.0)	0.004 (1.22)

5% Neutral Salt Spray Test - ASTM B117		
Alloy	**Time of Exposure Hours**	**% Surface Attack**
ATI 441HP™	100	0
ATI 409HP™	100	1%
ATI 304™	100	0

Typical Stress Corrosion Cracking Test Results In Boiling Solutions			
Alloy	**42% MgCl**	**33% LiCl**	**26% NaCl**
ATI 441HP™	R (216 hrs.)	R (501 hrs.)	R (1,005 hrs.)
ATI 439HP™	R (200 hrs.)	R (200 hrs.)	R (200 hrs.)
ATI 409HP™	R (1,000 hrs.)	F (500 hrs.)	R (1,000 hrs.)
ATI 304L™	F (20 hrs.)	F (96 hrs.)	F (744 hrs.)

Key: F=Fails; R=Resistant; ( ) test discontinued at indicated hours.

OXIDATION RESISTANCE

Laboratory cyclic and continuous oxidation data are useful for preliminary screening or ranking of candidate alloys for potential consideration in various applications. Tests are conducted in still air and the environment is oxidizing.

ATI 441 alloy has very good resistance to progressive scaling in both continuous and cyclic oxidizing laboratory test environments. Continuous 100 hour tests are conducted in still air and total weight gain measurements are used to determine oxidation and progressive scaling resistance in the temperature range of 1500°F (816°C) to 1900°F (1038°C). These results are plotted in the following graph and compared with ATI 304 stainless and the ATI 409HP and ATI 439HP alloys.

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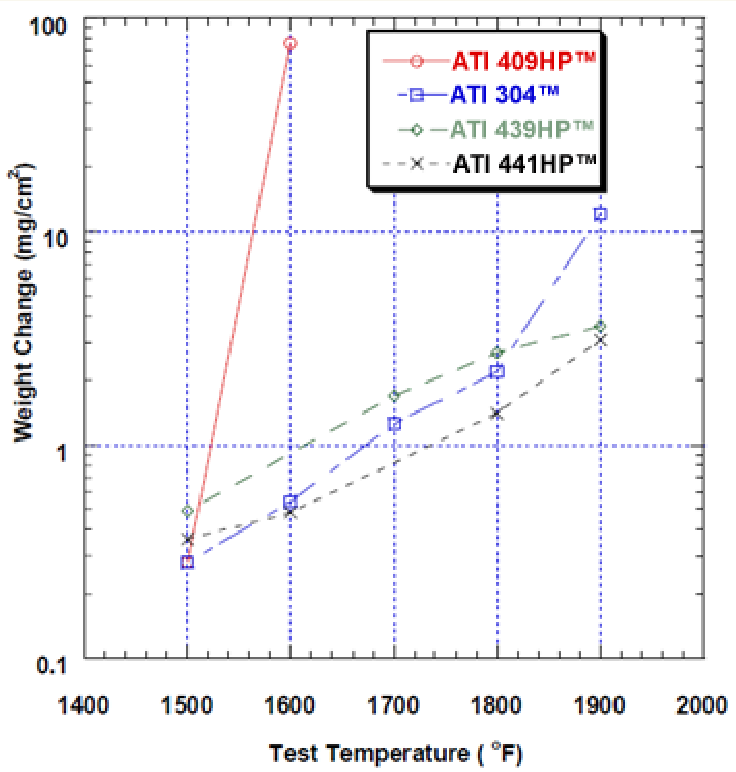
100 Hour Oxidation in Still Air



Very few service environments are continuous operations and more often temperatures are cycling. Thermal cycling induces differential thermal expansion and contraction of the developing oxide and metal substrate causing the scale to flake or spall. Ferritic stainless steels have relatively low coefficients of thermal expansion compared to the austenitic stainless alloys like Types 304, 309 and 310. The ferritic stainless steels are, therefore, more resistant to progressive scaling at higher temperatures under cyclic conditions than the austenitic grades.

Cyclic oxidation data has been developed over a temperature range of 1400°F (760°C) to 2200°F (1204°C). These results are shown in the following figure. Testing is conducted in still air where the procedure is to repetitively resistance heat 0.002 in. (0.05 mm) thick x 0.250 in. (6.35 mm) wide strip samples to temperature for two minutes and subsequently cool to room temperature for two minutes. Failure occurs when the 0.002 in. (0.05 mm) thick strip oxidizes through and breaks.

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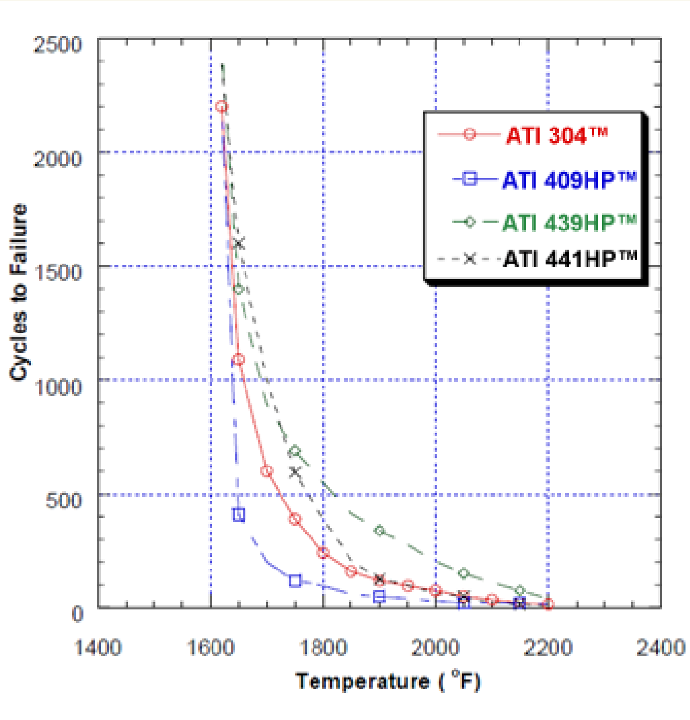
Cyclic Oxidation in Still Air



Projecting service temperature limits for a stainless alloy from either continuous or cyclic oxidation test modes requires arbitrarily selected failure criteria. In the continuous test mode, 1.5 mg/cm2 weight gain or more is considered the point above which spalling and progressing scaling is occurring. Under the pure cyclic test conditions, 2,000 cycles has been selected to project maximum temperature limits. Results of these rating systems are shown in the following bar graph. The bar graph indicates a range of useful temperature limits for each alloy where the actual limit would depend on the number of thermal cycles during the life cycle and how rapidly the metal parts are heated and cooled. This interpretation projects a useful temperature range limit of approximately 1650°F (899°C) to 1850°F (1010°C) for ATI 441 alloys. This compares to a useful temperature range projection of 1475°F (801°C) to 1550°F (843 °C) for ATI 409.

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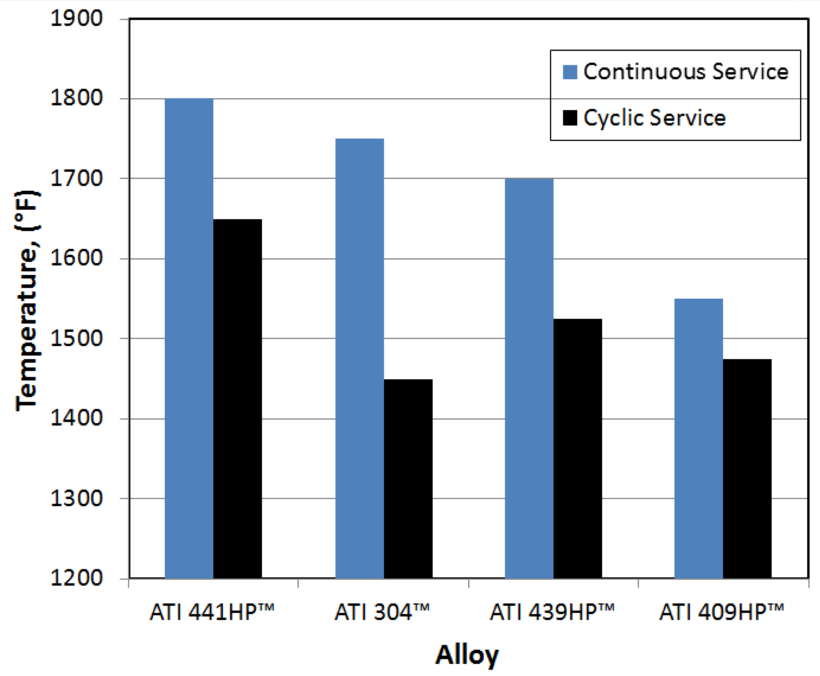
Projected Maximum Use Temperature in Still Air Oxidizing Atmospheres



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