Technical Data Sheet

ATI 436S™

Stainless Steel: Ferritic

INTRODUCTION

ATI 436S™ alloy is a single phase ferritic stainless steel in the same family of alloys as Type 409 and Type 439. The ATI 436S alloy typically contains 17.3% chromium and 1.2% molybdenum which provide improved general corrosion and pitting resistance compared to Type 409 (11% Cr), Type 430 (16% Cr) and Type 439 (18% Cr) ferritic alloys. The ATI 436S™ alloy is less resistant to pitting and crevice corrosion than Type 444 alloy (18% Cr - 2% Mo). Like all ferritic stainless steels the ATI 436S alloy provides excellent resistance to stress corrosion cracking in the presence of chlorides. It is stabilized with titanium for resistance to intergranular corrosion. Formability and weldability of the ATI 436S alloy are very good in common with ATI 409™ and ATI 439™ alloys. These characteristics make the ATI 436S™ alloy an excellent candidate for use in automotive exhaust systems as well as other applications where resistance to chlorides and mild corrosives, combined with fabricability, are needed.

TYPICAL COMPOSITION

Typical composition of the ATI 436S™ alloy is:

Element	Weight Percent
Carbon	0.01
Manganese	0.20
Phosphorus	0.020
Sulfur	0.001
Silicon	0.37
Chromium	17.3
Nickel	0.30
Molybdenum	1.20
Titanium	0.20
Nitrogen	0.015
Ti/(C+N) ≥	8.0

PHYSICAL PROPERTIES

The ATI 436S™ alloy has a ferritic, body-centered cubic crystal structure at all temperatures below the melting point. Angular titanium carbo-nitride particles occur randomly in the ferrite matrix microstructure. Representative physical properties of the ATI 436S™ alloy are compared with similar data for Type 409 below.

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Pittsburgh, PA 15222-5479 U.S.A.
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	ATI 409™	ATI 436S™
Density (lb./in3)		
	0.28	0.28
Mean Coefficient of Thermal Expansion (in/in/°F)		
68 - 212°F	6.0 x 10^{6}	5.5 x 10^{6}
68 - 500°F	6.1 x 10^{6}	5.6 x 10^{6}
68 - 900°F	6.3 x 10^{6}	5.9 x 10^{6}
68 - 1200°F	6.4 x 10^{6}	6.1 x 10^{6}
Specific Heat, 68°F: (Btu/lb°F)		
68°F	0.114	0.109
Thermal Conductivity (Btu/hr•ft•°F)		
68- 212°F	14.4	13.0
Elastic Modulus (Psi)		
	29 x 10^{6}	29 x 10^{6}

MECHANICAL PROPERTIES

Representative room temperature tensile properties for the ATI 436S™ alloy in the annealed condition are as follows:

0.2% Yield Strength (Psi)	Ultimate Tensile Strength (Psi)	Elongation (% in 2")	Hardness Rb
43,000	66,000	30.5	77

ATI 409™ and the ATI 436S™ alloy elevated temperature mechanical properties are compared below.

Elevated Temperature Tensile Properties						
	ATI 409™			ATI 433™		
Temperature °F	0.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (% in 2")	0.2% Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (% in 2")
RT	34.5	62.0	33	42.3	67.3	33
200	29.9	53.9	31	37.5	64.0	32
400	23.3	49.9	27	33.9	60.1	24
600	21.2	48.3	23	30.6	58.6	23
800	20.3	44.4	21	27.6	52.8	19
1000	17.7	39.4	18	28.2	49.4	18
1200	16.6	30.0	15	20.0	36.0	30
1400	8.0	16.5	23	8.2	20.0	35
1600	3.0	3.3	59	4.8	5.9	50

While elongation values for ATI 409 and the ATI 436S™ alloy are similar across the temperature range (75 - 1600°F), both tensile and yield strength of the ATI 436S™ alloy are higher at all temperatures. This is attributable to the higher chromium content of the ATI 436S™ alloy and, particularly, its molybdenum addition.

Stress rupture plots for Type 409 and the ATI 436S™ alloy at 1200 and 1500°F are shown on page 3. The higher alloy content of the ATI 436S™ alloy results in somewhat higher stress rupture properties than the ATI 409™ alloy. This is particularly evident from comparison of the 1500°F data.

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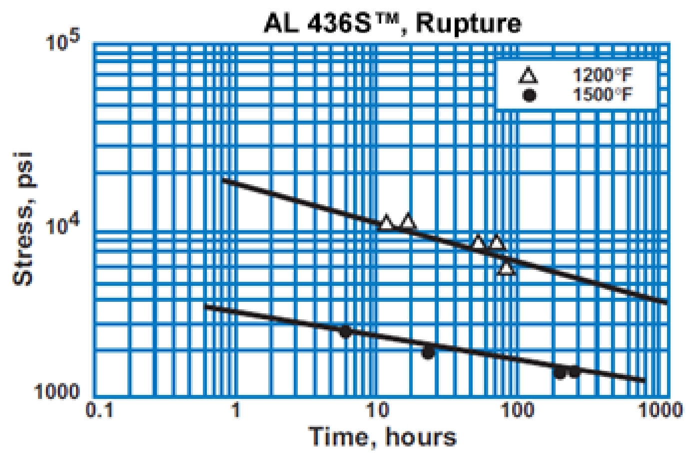

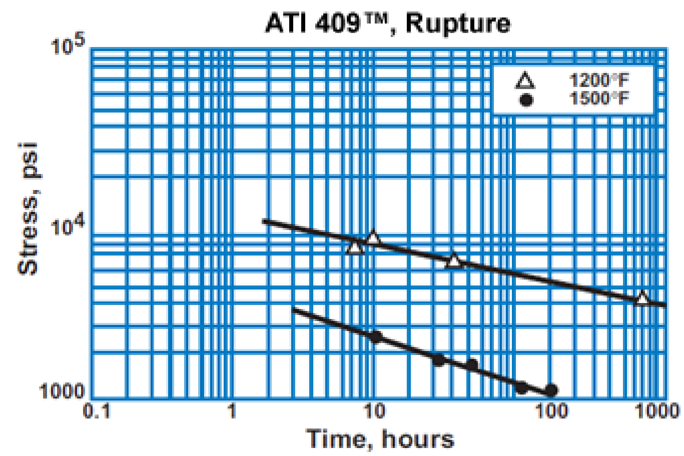

OXIDATION RESISTANCE

A comparison of results from exposure of ATI 409 and the ATI 436S™ alloy in still air at various elevated temperature for 100 hours is given below:

100-Hour Oxidation in Still Air Weight Gain, mg/cm²		
Temperature °F	ATI 409™	ATI 436S™
1400	0.167	0.193
1500	0.372	0.243
1600	3.45	0.424
1700	88.95	0.580
1800	-	0.836
1900	-	40.023

Additional tests at 1600°F for various lengths of time yielded the following results:

Oxidation in Still Air at 1600°F Weight Gain, mg/cm²		
Time, Hours °F	ATI 409™	ATI 436S™
5	0.217	0.181
18	0.384	0.256
24	1.146	0.312
150	5.805	0.505

The ATI 436S™ alloy provides a clear improvement in resistance to oxidation when compared to the ATI 409 alloy. This improvement is to be expected because of the higher chromium content of the ATI 436S™ alloy (17.3% Cr) as compared to the ATI 409 alloy (11% Cr).

CORROSION RESISTANCE

With 17.3% chromium and 1.2% molybdenum, the ATI 436S™ alloy provides better general corrosion resistance and pitting or crevice corrosion resistance than Type 409 which has lower chromium and no molybdenum. The ferritic structure of ATI 436S™ alloy provides excellent resistance to chloride stress corrosion cracking. Stabilization with titanium provides resistance to sensitization and intergranular corrosion. No fissures were observed on 180° bends of annealed ATI 436S™ alloy samples following exposure to the ASTM A763 Practice Z test (Cu-$CuSO_4$-16%H_2SO_4, boiling, 24 hours). Similar results are obtained on ATI 436S™ alloy samples with autogenous welds, following the Practice Z test.

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The potential (Volts vs SCE) required to cause pitting on ATI 436S™ alloy and ATI 409 stainless steel was determined in a 1000 ppm chloride (as NaCl) solution at 75°F and pH 5:

Alloy	Pitting Potential (Volts vs SCE)
ATI 409™ ATI 436S™	0.21, 0.23 0.53, 0.47

The data illustrate a significant improvement in resistance to pitting provided by the higher chromium, molybdenum-bearing ATI 436S™ alloy.

Two corrosion tests which simulate automotive exhaust system conditions were used to compare the performance of Type 409 and ATI 436S™ ferritic alloys, as follows:

Exhaust System Cyclic Condensate Corrosion Test
ATI 409 and ATI 436S™ alloy samples were placed in a one liter tall form beaker containing 100 ml of a simulated exhaust system condensate test solution consisting of:

Chloride ion - 1000 or 2000 ppm

Carbonate ion - 2000 ppm
Ammonium ion - 3740 ppm
Sulfate ion - 5000 ppm
Nitrate ion - 100 ppm
pH 8.7 - 8.9

This beaker of solution with alloy samples was then exposed to repeated controlled cycles consisting of:

1. heating to 482°F in one hour,
2. hold for two hours,
3. cool down to ambient temperature in three hours.

Since only a solid residue remained of the original test solution after the six-hour cycle, another 100 ml of test solution was added to the beaker and the cycle was repeated. Samples exposed to 10, 20, 30, 40, 50, etc., cycles were cleaned to bare metal and weight loss (corrosion) was determined. Data are plotted on page 5.

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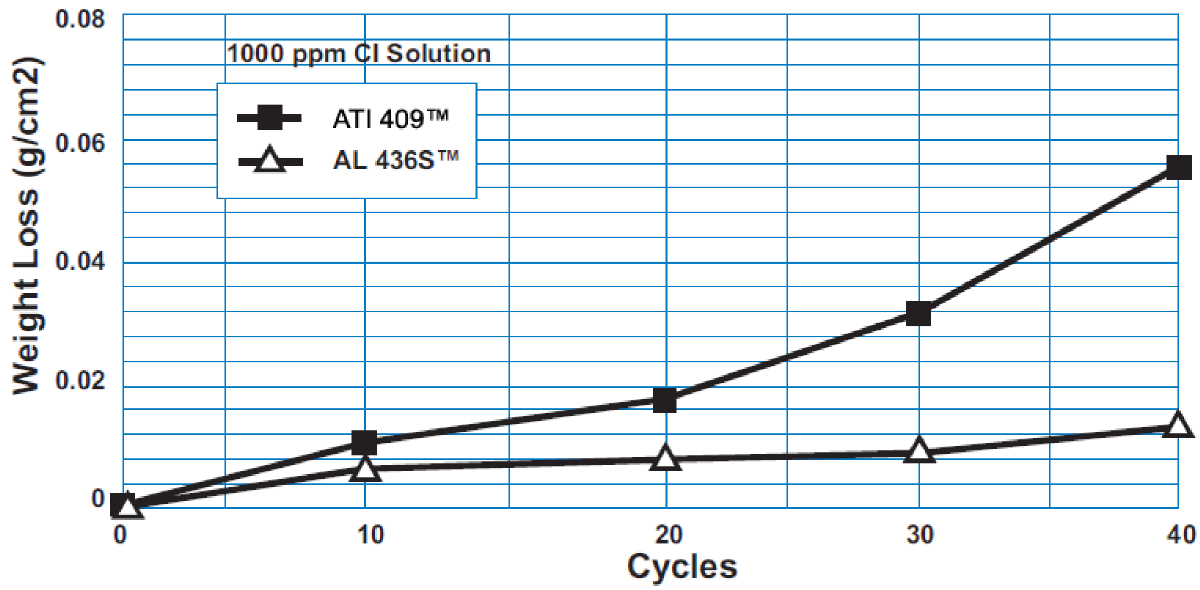

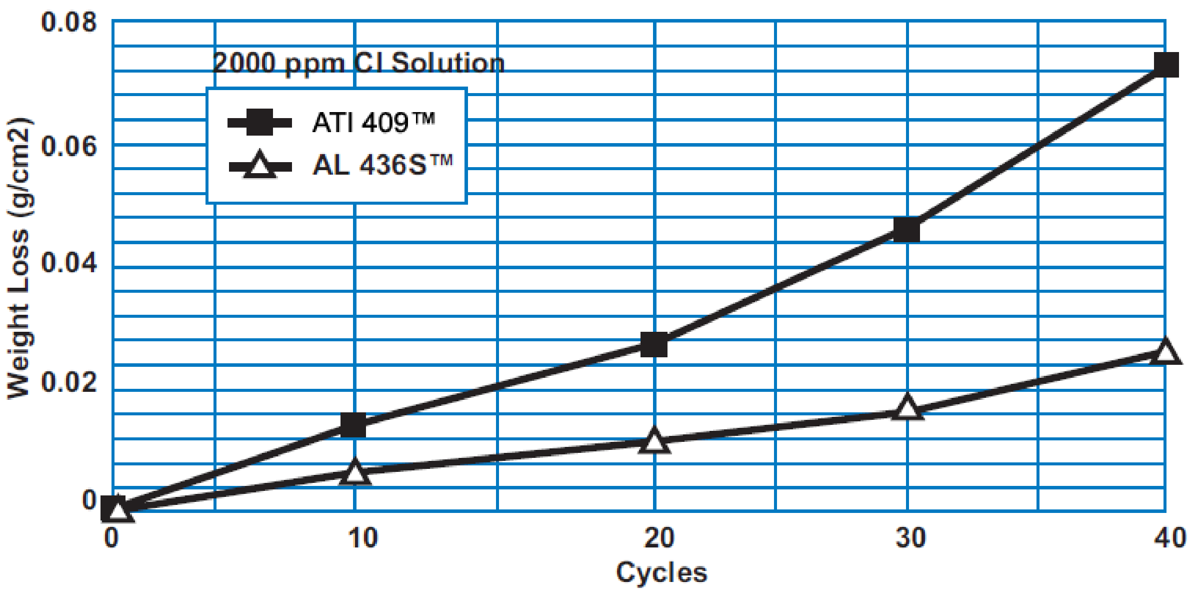

The superior corrosion resistance of the ATI 436S™ alloy in both the 1000 ppm chloride solution (top plot) and the 2000 ppm chloride solution (bottom plot) is evident through significantly lower weight loss. Comparison of the two plots shows the detrimental effect of increasing chloride content from 1000 ppm to 2000 ppm. Corrosion, as illustrated by weight loss, is significantly increased by the increase in chloride content. Although the test solution is slightly alkaline when introduced into the beaker (pH about 8.8), conditions become more and more acidic with increasing numbers of cycles, eventually reaching pH 3 with 10 or more cycles. These conditions are believed to simulate conditions on the inside of an exhaust system where condensation occurs.

Exhaust System Cyclic Oxidation/Corrosion Test

The hot outside of an automotive system is exposed to air. Therefore, resistance to oxidation is important for an exhaust system alloy. These alloys may also be exposed to road de-icing salts requiring resistance to pitting and/or crevice corrosion from the salts.

Cyclic oxidation/corrosion tests were conducted on ATI 409 alloy and the ATI 436™ alloy for comparison purposes. In this test, alloy samples are heated in air at 1200°F for one hour, cooled to ambient temperature, and then exposed 24 hours in a salt spray cabinet

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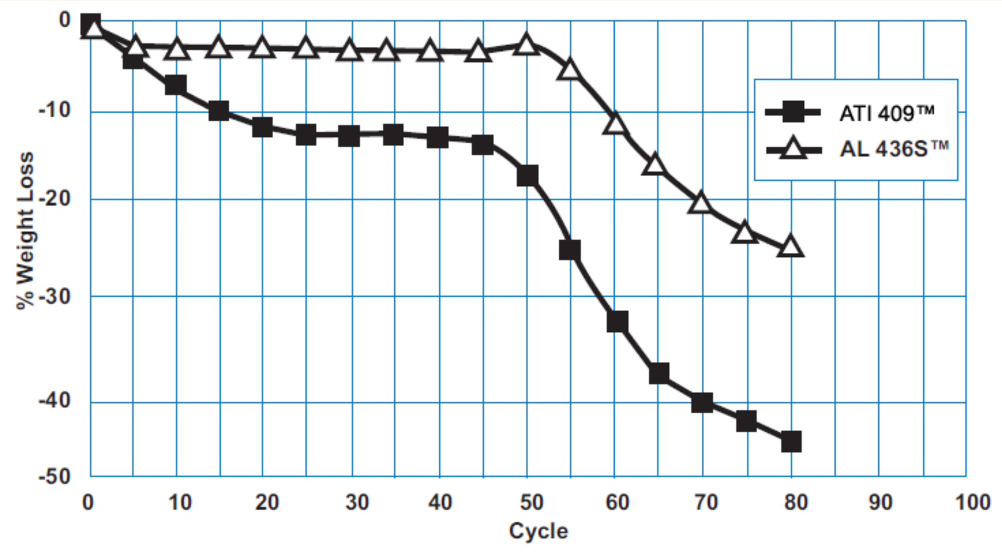
for each cycle. Weight loss is determined at five cycle intervals. Results from ATI 409 alloy and the ATI 436S™ alloy in the oxidation/corrosion test are shown below. Again, the superior performance of the ATI 436S™ alloy is evident.



Whereas corrosion was evident on the ATI 409 alloy sample after the first cycle, the ATI 436S™ alloy does not show any significant weight loss until the samples have experienced more than 50 oxidation/corrosion cycles. The higher chromium of the ATI 436S™ alloy provides better oxidation resistance and, the higher chromium plus molybdenum provide better resistance to chlorides, resulting in much less weight loss for the ATI 436S™ alloy than the ATI 409 alloy in this severe test.

MACHINEABILITY

The ATI 436S™ alloy exhibits machining, welding and forming characteristics similar to those of other stabilized, ferritic stainless steels.

Machining ATI 436S™ alloy compares more closely with carbon steel than with 300 series stainless steels. In this regard, the ATI 436S™ alloy is similar to other ferritic stainless steels such as ATI 409 and ATI 439 alloys. The presence of hard carbo-nitride particles in the microstructure may lead to more rapid tool wear than experienced with carbon steels.

WELDABILITY

Weldability of the ATI 436S™ alloy also is similar to that of other stabilized ferritic alloys. GTAW (TIG), GMAW (MIG), high frequency and spot welding procedures are applicable. Conventional inert gas shielding is required for tungsten or metal arc processes. Properly welded, the ATI 436S alloy retains corrosion resistance and most of the mechanical properties of the base metal in the weld deposit and heat-affected zone. Weld deposits are fully ferritic and free of martensite.

FORMABILITY

Formability of the ATI 436S™ alloy is similar to that of other ferritic stainless steels such as ATI 409™ and ATI 439™ alloys. The ferritic structure of the ATI 436S™ alloy leads to strain hardening exponent “n”- values of 0.22, similar to low carbon steels. This translates into similar stretch formability for ATI 436S™ alloy as that of carbon steel. Average strain ratio, R, value of 1.3 and Limiting Draw Ratio (LDR) value of 2.18 for ATI 436S™ alloy strip indicate that drawability of the ATI 436S™ alloy is excellent, in common with ATI 409 and ATI 439 ferritic alloys and drawing quality carbon steels.

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