ATI

Technical Data Sheet

ATI 334Mo® Alloy

Stainless Steel: Austenitic

(UNS S33425)

GENERAL INFORMATION

ATI 334Mo® alloy is a proprietary austenitic Fe-Ni-Cr-Mo stainless steel intended primarily as a high performance and economical material for use in automotive flexible couplings. It is a relatively lean alloy that achieves performance similar to ATI 332Mo™ alloy (UNS S35125) by providing resistance to both aqueous corrosion and elevated temperature degradation while possessing excellent weldability and formability.

This alloy is currently available as a Precision Rolled Strip® product. Customers interested in other product forms (sheet, plate, etc.) should inquire.

ATI 334Mo® alloy has relatively high chromium content for corrosion and oxidation resistance. The alloy contains molybdenum for resistance to aqueous corrosion and manganese for resistance to oxidation in air containing water vapor. A small amount of titanium is added for resistance to sensitization and resultant susceptibility to intergranular corrosion. ATI 334Mo™ alloy contains significantly less nickel than ATI 332Mo™ alloy, making the alloy less expensive and moderating the volatility in its raw materials surcharge.

Chemical Composition of ATI 334Mo® Alloy (ASTM A240 Limits for S33425)	
Element	**Weight Percent**
Carbon	0.08 max
Manganese	1.50 max
Phosphorus	0.045 max
Sulfur	0.020 max
Silicon	1.00 max
Chromium	21.0 - 23.0
Nickel	20.0 - 23.0
Molybdenum	2.00 - 3.00
Aluminum	0.15 - 0.60
Titanium	0.15 - 0.60
Iron	Balance

SPECIFICATIONS

ATI 334Mo® (UNS S33425) alloy is included in ASTM standards A240 and A480.

Allegheny Technologies Incorporated
1000 Six PPG Place
Pittsburgh, PA 15222-5479 U.S.A.
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PHYSICAL PROPERTIES

Density	0.286 lb/in^3 (7.93 g/cm^3)
Elastic Modulus	29 × 10^6 psi (200 GPa)

Linear Coefficient of Thermal Expansion (mean coefficient over range)			
Temperature Range		in/in / °F × 10^{-6}	mm/mm / °C × 10^{-6}
°F	°C		
70 to 212	20 to 100	8.2	14.6
70 to 392	20 to 200	8.6	15.3
70 to 572	20 to 300	8.8	15.8
70 to 752	20 to 400	9.0	16.2
70 to 932	20 to 500	9.2	16.6
70 to 1112	20 to 600	9.4	16.8
70 to 1292	20 to 700	9.6	17.2
70 to 1472	20 to 800	9.8	17.5
70 to 1652	20 to 900	9.9	17.9

MECHANICAL PROPERTIES

Room Temperature Mechanical Properties

Typical room temperature mechanical property data for ATI 334Mo® alloy was generated using Precision Rolled Strip® products and is shown in the table below. For reference, ASTM A240 specification limits for annealed ATI 334Mo® alloy are also listed. ATI 334Mo® alloy has higher elongation than ATI 332Mo™ alloy.

Room Temperature Tensile Properties					
Product	Tensile Strength		0.2% Yield Strength		Elongation in 2 in. or 50 mm
	ksi	MPa	ksi	MPa	%
ASTM A240 Limits (Min.)	75	515	30	205	40
Typical	82	565	38	260	50

Elevated Temperature Mechanical Properties

The following chart shows the short-term elevated temperature tensile properties of ATI 334Mo® alloy after a 30-minute hold at temperatures up to 1200°F (649°C). This data was generated using material at a thickness of 0.021” (0.53 mm).

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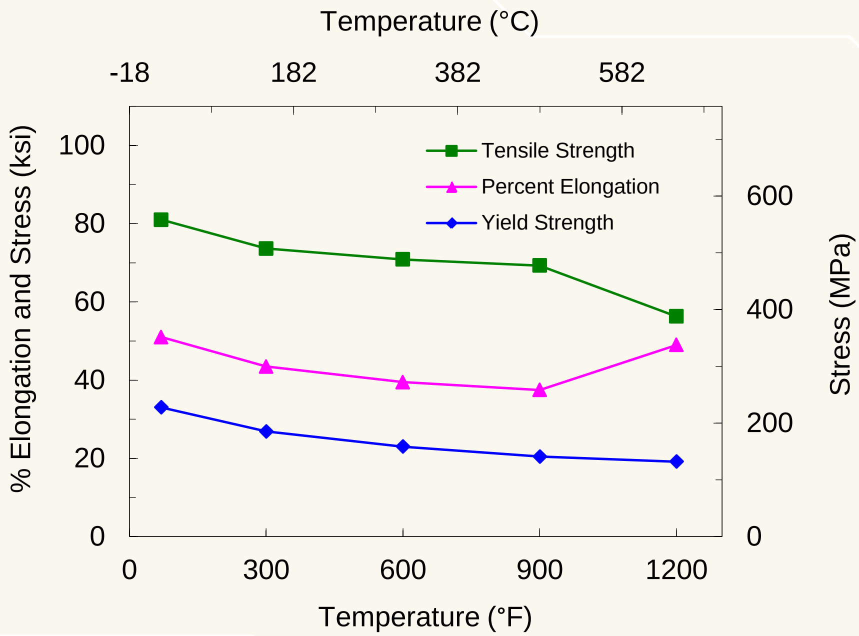
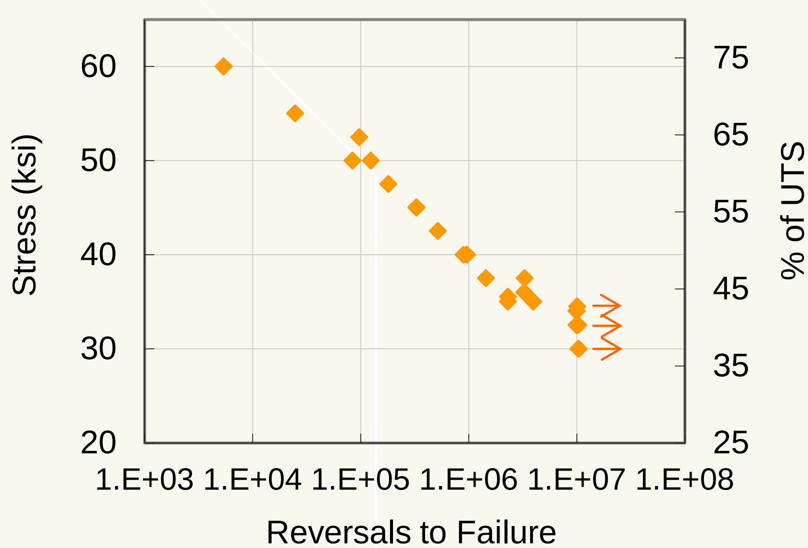


Elevated temperature tensile properties of ATI 334Mo® alloy

Room Temperature High Cycle Fatigue

Fatigue resistance is critical for applications such as exhaust bellows, which are subjected to a high-vibration environment. The fatigue limit of 0.040 in. (1.0 mm) thick ATI 334Mo® alloy at room temperature under reverse bending conditions was determined to be approximately 35-40% of the ultimate strength, which is considered nominal performance for an austenitic stainless steel. This is similar to that reported for ATI 332Mo™ alloy. Arrows next to data points in the figure below denote test run-out beyond 10 million cycles.



Room Temperature S/N curve (reverse bending) for ATI 334Mo® alloy

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Pittsburgh, PA 15222-5479 U.S.A.
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FORMABILITY

A ball punch deformation test, which subjects a sample to biaxial stretching, is widely used to evaluate and compare the formability of metallic sheet materials. A comparison of Olsen cup test results and Erickson test results for ATI 334Mo® and ATI 332Mo™ alloys are listed in the following table. There are no essential differences in cup heights between the two alloys.

Formability			
Alloy	**Test Gauge, in. (mm)**	**Olsen Cup Height, in. (mm)**	**Erichsen Cup Height, in. (mm)**
ATI 334Mo®	0.021 (0.5)	0.52 (13.2)	-
	0.008 (0.2)	0.39 (9.9)	0.38 (9.8)
ATI 332Mo™	0.021 (0.5)	0.52 (13.2)	-
	0.008 (0.2)	0.37 (9.4)	0.39 (10.0)

CORROSION RESISTANCE

Thin flexible connector components must resist degradation and corrosion in order to provide extended lifetimes, which are required to meet extended warranty and pollution control requirements. Extensive corrosion testing was performed on ATI 334Mo® alloy. Corrosion rates in several solutions are shown in the tables below, along with comparative data for other common flexible connector alloys.

General Corrosion Resistance

The sensitization resistance of ATI 334Mo® alloy was tested using the ASTM A262 oxalic acid etch test (Practice A). A pre-test heat treatment was first performed on the ATI 334Mo® material for one hour at 1200°F (649°C). The observation of a step structure showed resistance of ATI 334Mo® alloy to sensitization as any susceptibility to intergranular attack would have been readily marked by the observation of pronounced grain boundary ditches. The alloy in this condition passed with a resulting step structure. To determine the susceptibility of welded ATI 334Mo® alloy to intergranular attack associated with chromium carbide precipitation, bead-on-plate welded samples were subjected to Practices B and E of ASTM A262. Following Practice E, after subjection to a 180° bend, there was no observed cracking of the samples, indicating that the welded samples were resistant to sensitization. The following table summarizes ASTM A262 test results.

Sensitization Resistance (ASTM A262 Testing) of ATI 334Mo® Alloy		
Test Practice	**Base Metal**	**Weld Metal**
Practice A: Electrolytic Oxalic Acid Etch - Samples heat treated 1 hr at 1200°F	Step structure	---
Practice B: Ferric Sulfate-Sulfuric Acid - One period of 120 hrs	---	5.59 mpy (0.142 mm/y)
Practice E: Copper-Cupric Sulfate-Sulfuric Acid - One period of 120 hrs	---	No cracking – 180° bend 1.18 mpy (0.030 mm/y)

The corrosion resistance of ATI 334Mo® alloy was tested in 10% sulfuric acid and 1% hydrochloric acid solutions. In both test solutions, samples were activated at the start of each test period. There is little difference between the corrosion resistance of ATI 334Mo® base metal and welded metal. For comparison, ATI 625™ nickel alloy and ATI 316Ti™ stainless are presented.

Corrosion Resistance in Dilute Reducing Acids				
Test Solution (Boiling)	**Corrosion Rate in Mils per Year (mm/y)[1]**			
	ATI 334Mo®	**ATI 332Mo™**	**ATI 625™**	**ATI 316Ti™**
10% Sulfuric Acid	151 (3.8)	26 (0.7)	25 (0.6)	636 (16.2)
1% Hydrochloric Acid	243 (6.2)	140 (3.6)	59 (1.5)	194 (4.9)

(1) Results are the average of five 48-hour test periods

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Chloride Corrosion Resistance

Attack by chlorides is a common form of corrosion encountered in environments where austenitic stainless steels are used. The pitting resistance equivalent number (PRE_N) is a theoretical way of comparing the relative resistance of stainless steels to localized corrosion based on their chemical compositions. A higher PRE_N value signifies that an alloy is likely to be more resistant to localized corrosion in a chloride-containing environment. A common equation used to calculate the PRE_N is:

$$PRE_N = \%Cr + 3.3(\%Mo) + 30(\%N)$$

The PRE_N values calculated for some automotive bellows alloys are listed in the following table along with experimental results for the critical pitting temperatures (CPT) and critical crevice temperatures (CCT). The CPT and CCT are defined as the lowest temperatures at which measureable corrosion occurs and tend to follow the same trend among a group of alloys. ATI 334Mo® and ATI 332Mo™ alloys have similar performance with a CCT of 50°F (10°C). In comparison, ATI 625 alloy has better performance with a CCT of 110°F (43°C), while ATI 316Ti has worse performance with lower CPT and CCT values.

Pitting and Crevice Corrosion Resistance			
Alloy	PRE_N for Nominal Alloy Composition	ASTM G150 Critical Pitting Temperature	ASTM G48, Practice D Critical Crevice Temperature
ATI 316Ti™	25	59°F (15°C)	<32°F (<0°C)
ATI 332Mo™	29	101°F (38.5°C)	50°F (10°C)
ATI 334Mo®	32	103°F (39.5°C)	50°F (10°C)
ATI 625™	52	Not tested	110°F (43°C)

Stress Corrosion Cracking Resistance

Stress corrosion cracking resistance of Fe-Ni-Cr-Mo austenitic stainless steels to chloride stress-corrosion cracking depends on the nickel content of the alloy. Duplicate U-bend samples of ATI 334Mo® and ATI 332Mo™ alloys were immersed in a boiling solution of acidified 25% sodium chloride according to ASTM G123. None of the samples had any apparent cracking at the top of the U-bend after 1008 hours of testing, the preselected test duration. Though ATI 332Mo™ alloy is expected to have more resistance to SCC than ATI 334Mo® alloy based on its higher nickel content, these results show a similar level of SCC resistance.

OXIDATION RESISTANCE

ATI 334Mo® alloy is resistant to oxidation at elevated temperature (i.e. scaling) due primarily to its high chromium and nickel contents. Exposure to high temperature air results in a slow-growing protective chromium oxide scale. While elevated temperature testing in ambient air showed some differentiation between ATI 334Mo® alloy and other alloys used to manufacture flexible connectors, oxidation testing in humidified air indicated more significant differentiation between alloys.

Water vapor is present in many environments and has been noted to result in accelerated attack on lower alloyed stainless steels (e.g. 18Cr-8Ni alloys such as Types 304, 347, and 316). Oxidation testing in humidified air has shown that water vapor has essentially no detrimental effect on ATI 334Mo® alloy due to its high chromium and nickel contents, along with a deliberate addition of manganese, which reduces the likelihood of oxide scale evaporation. Isothermal testing at 1400°F (760°C) shows the resistance of ATI 625™, ATI 332Mo™, and ATI 334Mo® alloys to this form of attack, where the weight gains were small and positive, indicating that the corrosion products were adherent and relatively protective. ATI 316Ti™ alloy showed rapid attack and weight loss due to scale spallation under the same conditions, indicating that the corrosion products were loose and non-protective in humidified air.

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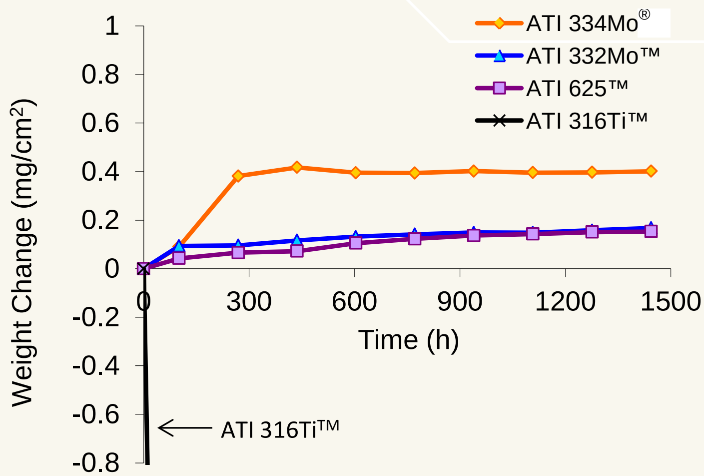
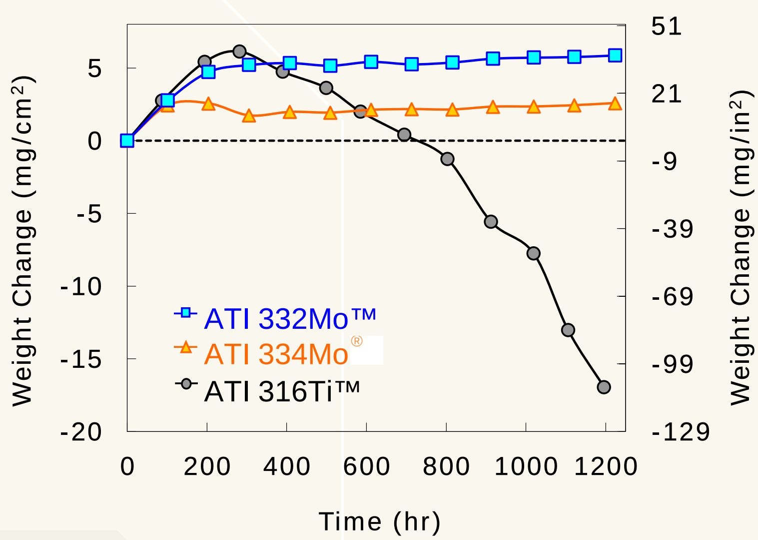


Oxidation weight change at 1400°F (760°C) in air containing 10% water vapor by volume

RESISTANCE TO HIGH TEMPERATURE HOT SALT ATTACK

Automotive flexible connectors operate under difficult conditions. Deposited alkali salts are severely corrosive at elevated temperature and can degrade a protective oxide layer, leaving the underlying metal open to attack. Testing was developed to take into account factors such as thermal cycling, residual stress, and the presence of autogenous weldments. Cyclic hot salt testing was performed to evaluate resistance to hot salt corrosion. The thermal cycles were 1 hour (45 minutes at temperature and 15 minutes of cooling to or holding at room temperature), and an exposure interval was nominally 100 hours, which consisted of 133 thermal cycles. Sheet samples were bent around a mandrel into a teardrop shape and welded shut. They were suspended from a wire tree in a vertical tube furnace. Prior to each exposure interval, samples were weighed to monitor the extent of attack, and then sprayed with a fresh coating of NaCl salt.

Results from testing at 1200°F (649°C) are shown below. The weight gains for ATI 332Mo™ and ATI 334Mo® alloys were small and positive, indicating that the corrosion products were adherent and relatively protective. ATI 334Mo™ and ATI 332Mo™ alloys show long-term stability and resistance to cyclic hot salt testing, while ATI 316Ti alloy has initial weight gain followed by rapid weight loss due to oxide spallation after short exposure times of a few hundred hours.



Weight change of salt-coated, welded teardrop samples exposed at 1200°F (649°C) in air under thermal cycling conditions

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FABRICATION

Welding/Joining

The austenitic grades are generally considered to be the most weldable of the stainless steels, and can be joined using all of the common processes. The austenitic alloys exhibit a relatively high coefficient of thermal expansion, low thermal conductivity, and form low levels of ferrite in the solidifying weld metal. These factors can lead to hot cracking. The problem can be more severe for restrained and/or wide joints. The weldability of ATI 334Mo® Precision Rolled Strip® product less than 0.015 in. (0.38 mm) thick has been evaluated by end users and has been found to be readily welded. Most austenitic stainless steels are amenable to other forms of joining, including cladding, brazing, mechanical fastening, and explosive bonding. Specific processes will require testing and qualification.

Forming

The austenitic stainless steels are readily cold formable by standard methods such as bending, stretch forming, roll forming, hammer forming, flaring/flanging, spinning, and drawing. They work harden, which is manifested by steadily increasing amounts of force needed to continue deformation. This results in the need to use stronger forming machines and eventually limits the amount of deformation possible without cracking.

ATI 334Mo® Precision Rolled Strip® product, at light gauges less than 0.015 in. (0.38 mm) thick, exhibits excellent ductility and formability. It has performed well in manufacturing trials and has been found to be readily formed into complex shapes using hydroforming.

Cutting

Cutting and machining the austenitic stainless steels is readily accomplished using standard techniques typically employed for common mild steel, with some modifications. Their cutting behavior can be quite different – they are tougher and tend to harden rapidly during working. The chips produced are stringy and tough and retain considerable ductility. Tooling should be kept sharp and be rigidly held. Deeper cuts and slower speeds are generally used to cut below work hardened zones. Due to the low thermal conductivity and high coefficient of thermal expansion inherent to the austenitic stainless steels, heat removal and dimensional tolerances must be considered during cutting and machining operations.

Heat Treatment

Primary reasons for annealing are to produce a recrystallized microstructure with a uniform grain size and to dissolve detrimental precipitates. ATI 334Mo® alloy should be annealed between 2000 and 2150°F (1093- 1179°C) for at least 30 minutes (time at temperature) per inch of section thickness. This is a general recommendation only – specific cases may require further investigation.

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