HAYNES® HR-235® Alloy

Principal Features

HAYNES® HR-235® alloy is a nickel-chromium-molybdenum-copper material with outstanding resistance to metal dusting. It has no deliberate addition of iron, an element which is detrimental to the performance of alloys under metal dusting conditions. It is resistant to creep-rupture at temperatures under which metal dusting is normally encountered. Having a low silicon and aluminum content, HR-235® alloy is resistant to weld solidification and strain-age cracking. This is an improvement over other alloys intended for metal dusting resistance. It is also available as a filler wire with matching composition.

Applications:

- Petrochemical Plants
- Syngas production
- Synthesis of ammonia, methanol, LNG, H_2
- Microchannel High Temperature Reactors
- High carbon containing gases
- Direct reduction of iron ores
- Carbon fiber production
- Gas-to-liquids (GTL) plants
- Steam-methane-reforming process

Nominal Composition

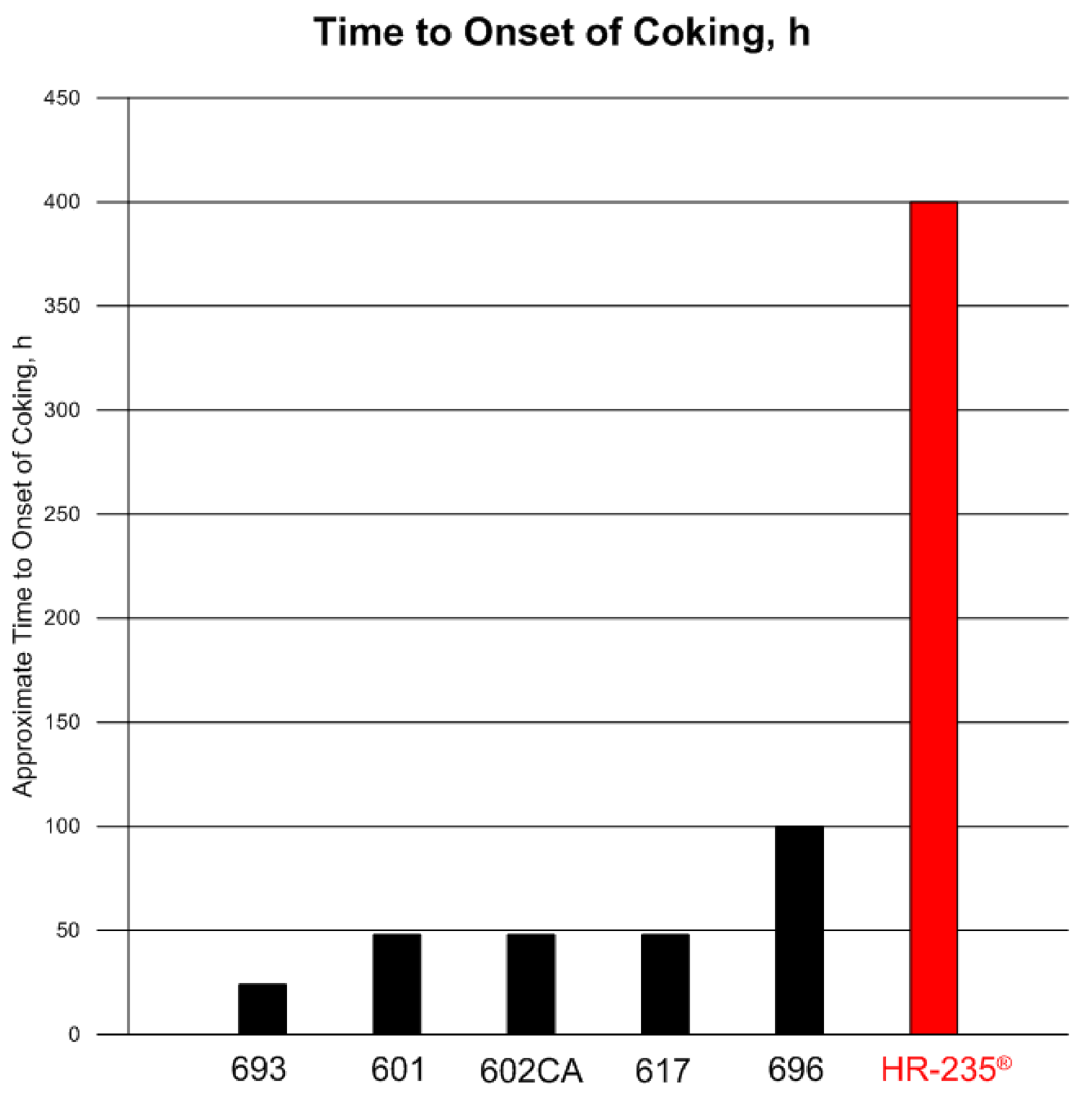
Weight %

Nickel:	Balance
Chromium:	31
Molybdenum:	5.6
Copper:	3.8
Iron:	1.5 max
Niobium:	1.0 max
Aluminum:	0.4 max
Manganese:	0.65 max
Silicon:	0.6 max
Titanium:	0.5 max
Carbon:	0.06 max

Meltal Dusting

HAYNES® HR-235® alloy has been tested alongside competitive materials in a controlled atmosphere, thermal cycling rig. The reaction gas was H_2 + 68% CO + 6% H_2O, the carbon activity of which was 2.9 at the reaction temperature. The cycling operation, which was controlled automatically, comprised 45 minutes at the reaction temperature of 1256°F (680°C), followed by a cooling period of 15 minutes, during which the samples rapidly reached a temperature of about 194°F (90°C). The samples were tested for 1,200 (one hour) cycles, with the following results. The formation of filamentary carbon deposits with metallic nanoparticles (coking) is an indicator of the onset of surface damage (pitting).

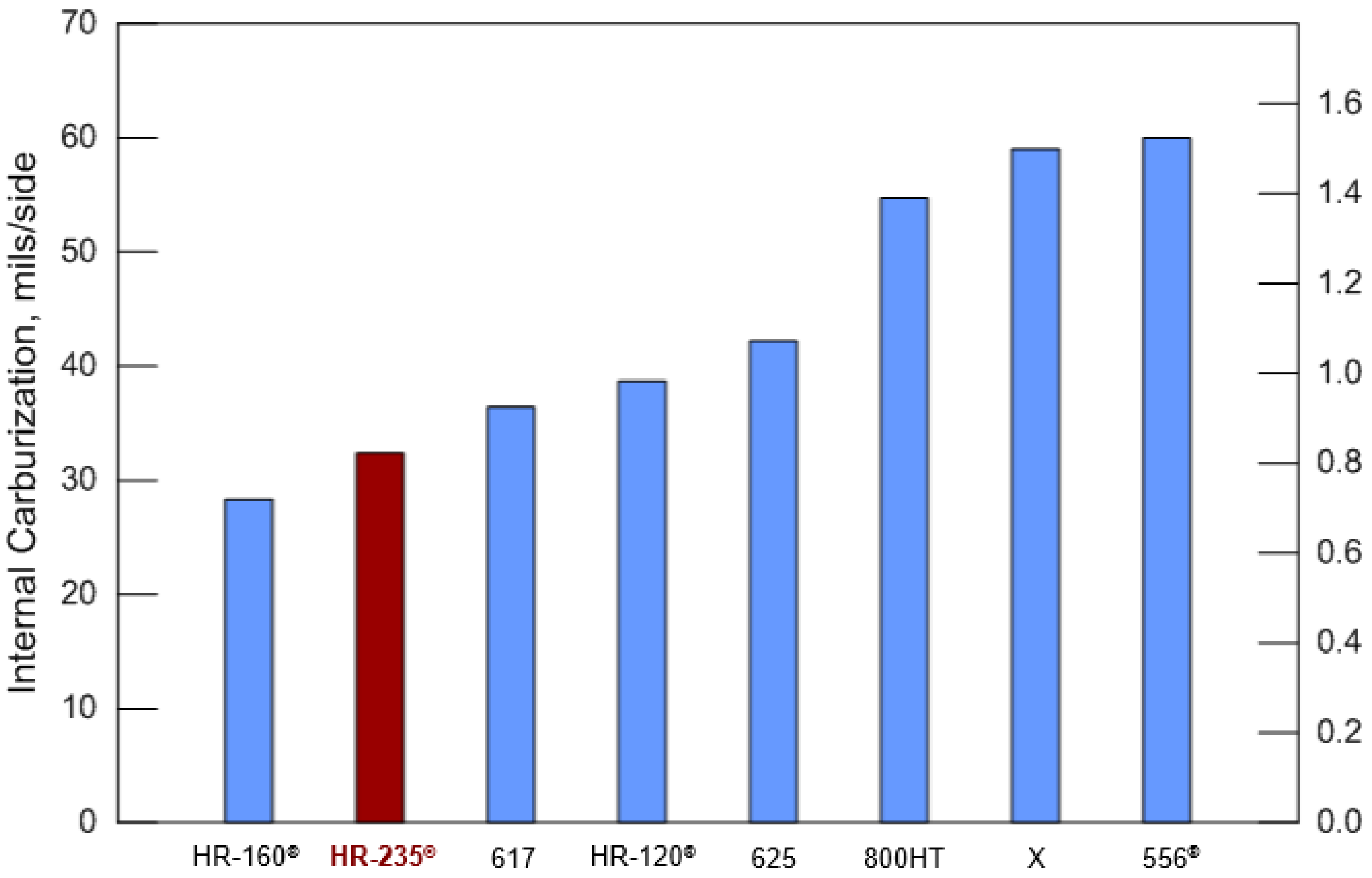
Alloy	Approximate Number of Cycles to Coking	Form of Coke
601	48	Grain boundary deposits, pits
602CA	48	Adherent coke, no metal visible
617	48	Numerous small pits, grain boundary deposits
693	24	Numerous small pits
696	100	Attack on grain boundaries
HR-235®	**400**	**Grain boundary deposits, minor pits**



Carburization Resistance

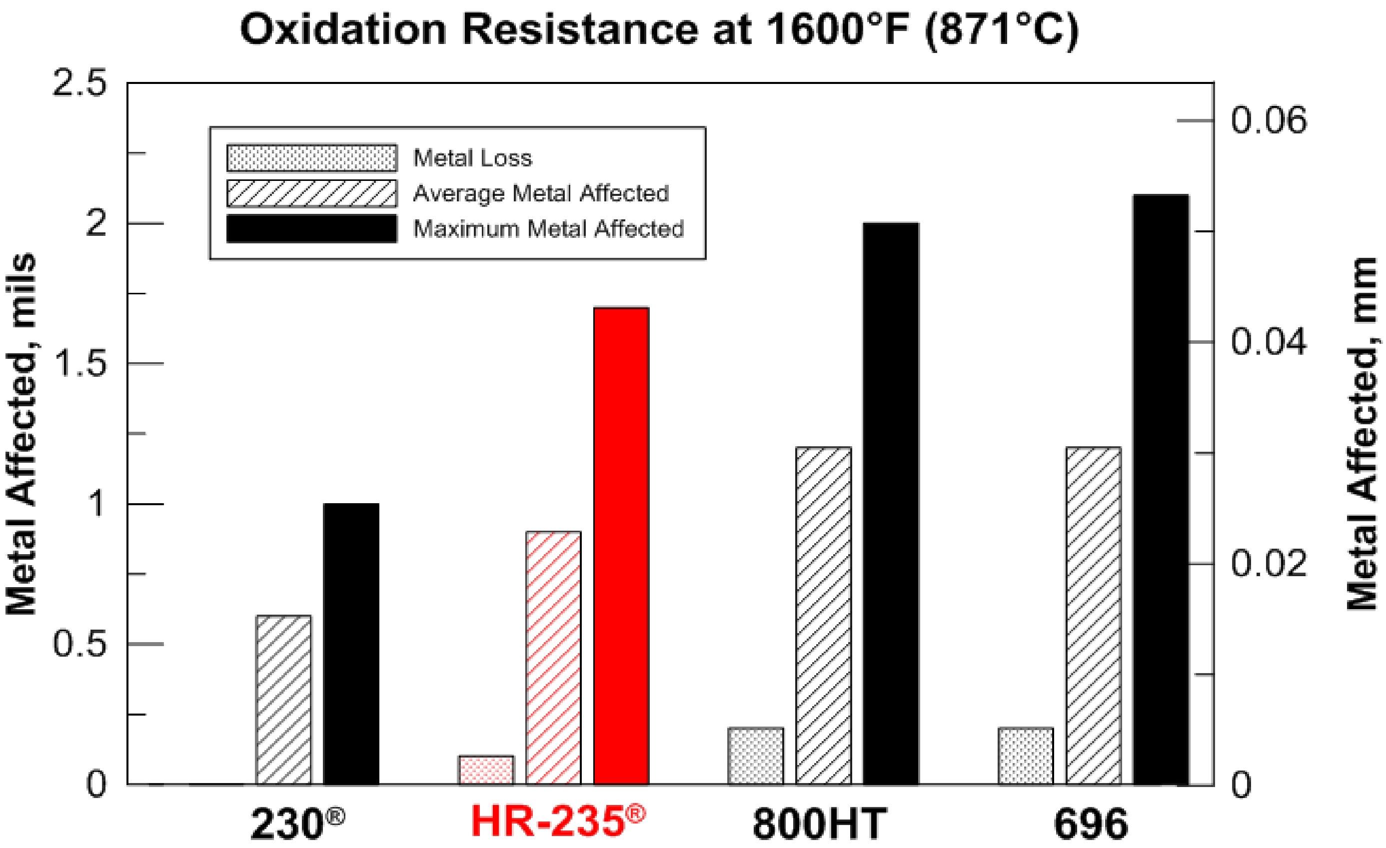
In addition to its high resistance to metal dusting, HAYNES® HR-235® alloy also withstands carburization, a degradation process which occurs at lower carbon activities and which negatively affects many metallic materials, as shown in the following chart. The test involved a gas mixture of Ar – 5% H_2 – 2% C_3H_6 at 1800°F (982°C), with a carbon activity of 1; the test duration was 215 h.

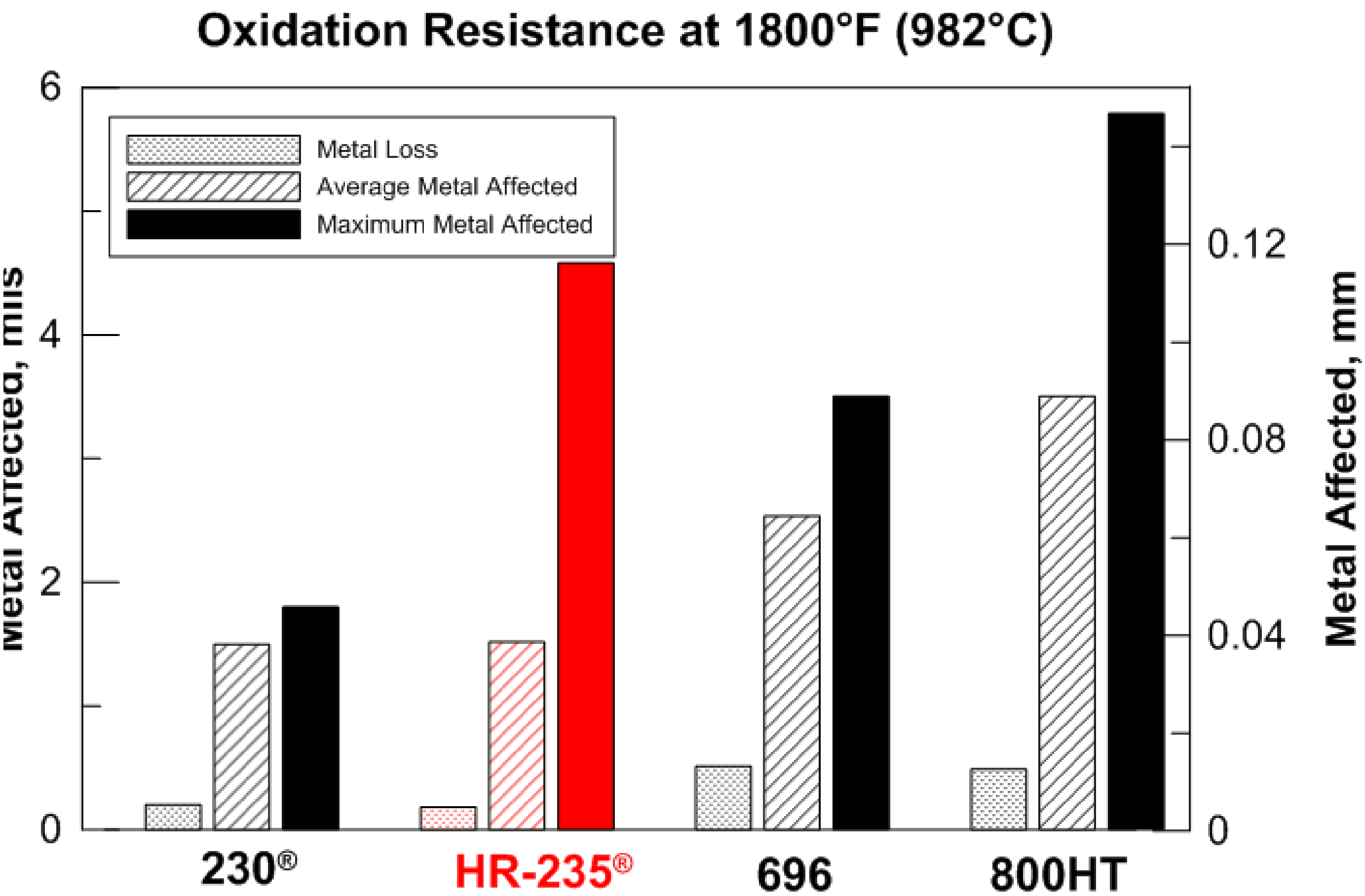
Internal Carburization in Ar– 5% H_2 – 2% C_3H_6 at 1800°F (982ºC)



Oxidation Resistance

HAYNES® HR-235® alloy also exhibits good oxidation resistance, as indicated in the following chart. The test was performed in flowing air (55.5 cm³/s) for 1,008 h, with an air cool to room temperature every 168 h.

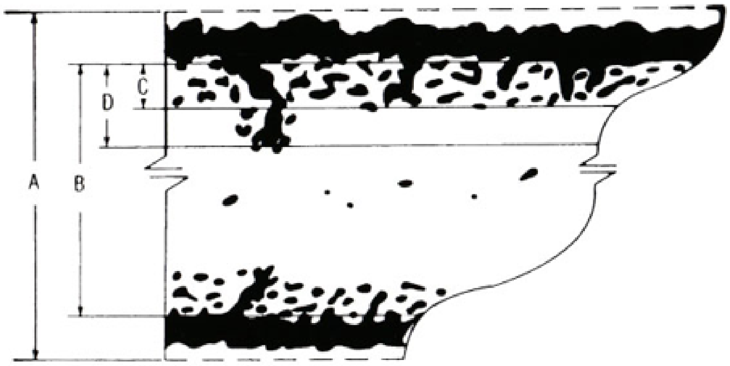




Oxidation Resistance Continued

Measurement of High Temperature Corrosion Attack

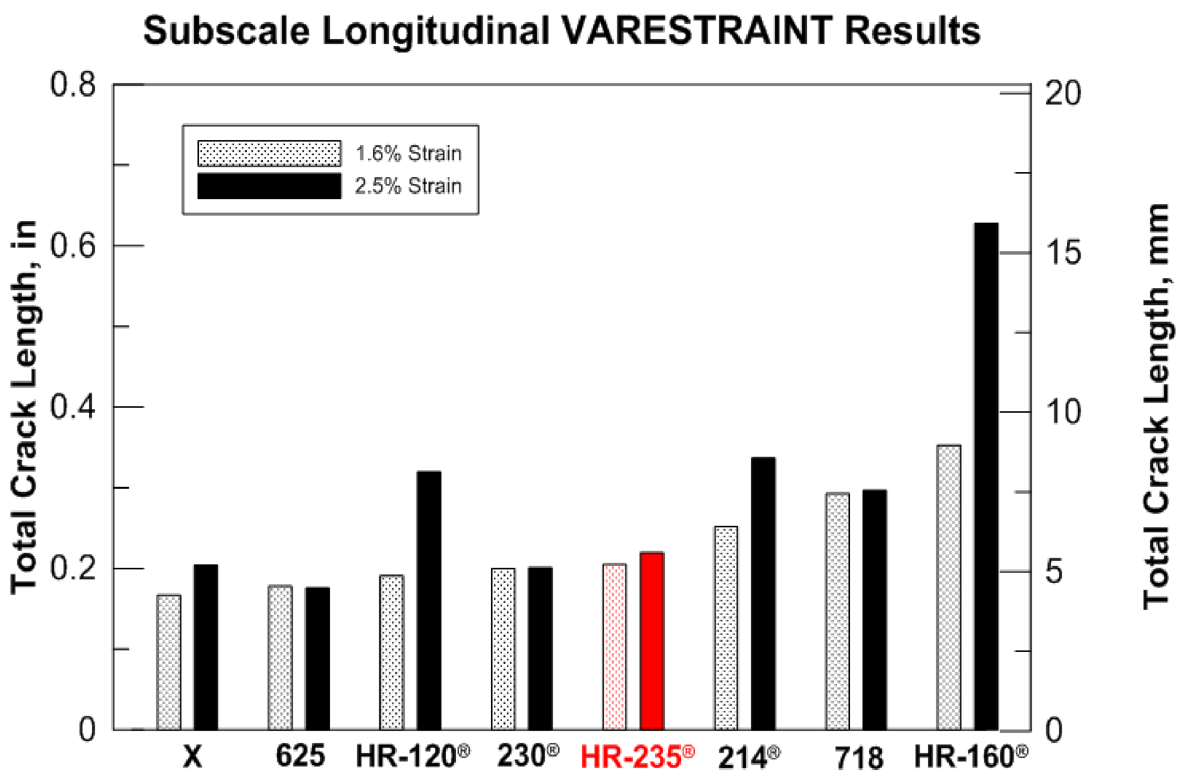
To assess the extent of attack (internal and external) of materials caused by oxidation, the following measurements are taken, using metallographic techniques, where A is the original thickness of the sample.



1. Metal Loss = (A-B)/2
2. Average Internal Penetration = C
3. Maximum Internal Penetration = D
4. Average Metal Affected = [(A-B)/2] + C
5. Maximum Metal Affected = [(A-B)/2] + D

Weld Solidification Cracking Resistance

HAYNES® HR-235® alloy is resistant to weld solidification cracking, as measured by the VARESTRAINT weldability test. Materials with significant silicon contents, such as HR-160® alloy, are prone to this form of cracking, as a result of their wider melting ranges. Having a low silicon and aluminum content, HR-235® alloy is resistant to weld solidification and strain-age cracking. This is an improvement over other alloys intended for metal dusting resistance. It is also available as a filler wire with matching composition. For more information, visit our Welding and Fabrication Brochure.



Physical Properties

Physical Property	British Units		Metric Units	
Density	RT	0.295 lb/in³	RT	8.16 g/cm³
Melting Range	2401-2437ºF		1316-1356ºC	
Electrical Resistivity	RT	48.4 µohm-in	RT	1.23 µohm-m
	200°F	48.8 µohm-in	100°C	1.24 µohm-m
	400°F	49.2 µohm-in	200°C	1.25 µohm-m
	600°F	49.6 µohm-in	300°C	1.26 µohm-m
	800°F	50.4 µohm-in	400°C	1.27 µohm-m
	1000°F	50.8 µohm-in	500°C	1.29 µohm-m
	1200°F	50.4 µohm-in	600°C	1.29 µohm-m
	1400°F	50.4 µohm-in	700°C	1.28 µohm-m
	1600°F	50.4 µohm-in	800°C	1.28 µohm-m
	1800°F	50.4 µohm-in	900°C	1.28 µohm-m
	2000°F	51.2 µohm-in	1000°C	1.28 µohm-m
Thermal Conductivity	RT	70 BTU.in/h.ft².°F	RT	10.0 W/m.°C
	200°F	77 BTU.in/h.ft².°F	100°C	11.0 W/m.°C
	400°F	89 BTU.in/h.ft².°F	200°C	12.5 W/m.°C
	600°F	101 BTU.in/h.ft².°F	300°C	14.2 W/m.°C
	800°F	114 BTU.in/h.ft².°F	400°C	15.8 W/m.°C
	1000°F	125 BTU.in/h.ft².°F	500°C	17.3 W/m.°C
	1200°F	137 BTU.in/h.ft².°F	600°C	18.9 W/m.°C
	1400°F	150 BTU.in/h.ft².°F	700°C	20.6 W/m.°C
	1600°F	153 BTU.in/h.ft².°F	800°C	21.6 W/m.°C
	1800°F	164 BTU.in/h.ft².°F	900°C	22.3 W/m.°C
	2000°F	174BTU.in/h.ft².°F	1000°C	23.5 W/m.°C
Mean Coefficient of Thermal Expansion	70-200°F	6.8 µin/in.°F	25-100°C	12.3 µm/m.°C
	70-400°F	7.1 µin/in.°F	25-200°C	12.8 µm/m.°C
	70-600°F	7.4 µin/in.°F	25-300°C	13.2 µm/m.°C
	70-800°F	7.5 µin/in.°F	25-400°C	13.5 µm/m.°C
	70-1000°F	7.7 µin/in.°F	25-500°C	13.8 µm/m.°C
	70-1200°F	8.1 µin/in.°F	25-600°C	14.2 µm/m.°C
	70-1400°F	8.4 µin/in.°F	25-700°C	14.7 µm/m.°C
	70-1600°F	8.7 µin/in.°F	25-800°C	15.2 µm/m.°C
	70-1800°F	9.0 µin/in.°F	25-900°C	15.7 µm/m.°C
	70-2000°F	9.3 µin/in.°F	25-1000°C	16.2 µm/m.°C

Physical Properties Continued

Physical Property	British Units		Metric Units	
Thermal Diffusivity	RT	0.108 ft^2/h	RT	0.0279 cm^2/s
	200°F	0.116 ft^2/h	100°C	0.0299 cm^2/s
	400°F	0.127 ft^2/h	200°C	0.0328 cm^2/s
	600°F	0.139 ft^2/h	300°C	0.0356 cm^2/s
	800°F	0.151 ft^2/h	400°C	0.0382 cm^2/s
	1000°F	0.162 ft^2/h	500°C	0.0408 cm^2/s
	1200°F	0.173 ft^2/h	600°C	0.0434 cm^2/s
	1400°F	0.183 ft^2/h	700°C	0.0459 cm^2/s
	1600°F	0.182 ft^2/h	800°C	0.0470 cm^2/s
	1800°F	0.191 ft^2/h	900°C	0.0475 cm^2/s
	2000°F	0.200 ft^2/h	1000°C	0.0495 cm^2/s
Specific Heat	RT	0.105 BTU/lb.°F	RT	440 J/kg.°C
	200°F	0.109 BTU/lb.°F	100°C	456 J/kg.°C
	400°F	0.114 BTU/lb.°F	200°C	477 J/kg.°C
	600°F	0.119 BTU/lb.°F	300°C	494 J/kg.°C
	800°F	0.124 BTU/lb.°F	400°C	511 J/kg.°C
	1000°F	0.133 BTU/lb.°F	500°C	532 J/kg.°C
	1200°F	0.148 BTU/lb.°F	600°C	611 J/kg.°C
	1400°F	0.146 BTU/lb.°F	700°C	620 J/kg.°C
	1600°F	0.152 BTU/lb.°F	800°C	615 J/kg.°C
	1800°F	0.152 BTU/lb.°F	900°C	641 J/kg.°C
	2000°F	0.153 BTU/lb.°F	1000°C	624 J/kg.°C
Dynamic Modulus of Elasticity	RT	29.0 x 10^6psi	RT	200 GPa
	200°F	28.5 x 10^6psi	100°C	196 GPa
	400°F	27.6 x 10^6psi	200°C	191 GPa
	600°F	26.7 x 10^6psi	300°C	184 GPa
	800°F	25.9 x 10^6psi	400°C	180 GPa
	1000°F	25.0 x 10^6psi	500°C	174 GPa
	1200°F	23.9 x 10^6psi	600°C	168 GPa
	1400°F	23.0 x 10^6psi	700°C	162 GPa
	1600°F	21.3 x 10^6psi	800°C	154 GPa
	-	-	900°C	144 GPa

Tensile Properties

HAYNES® HR-235® Solution Annealed Plate

Temperature		Yield Strength 0.2% Offset		Ultimate Tensile Strength		Elonga-tion
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	48.8	337	106.9	737	58
1000	538	29.5	203	81.6	562	63
1200	649	28.7	198	72.7	501	61
1400	760	27.7	191	56.5	389	67
1600	871	22.4	154	31.3	216	72
1800	982	11.3	78	16.4	113	72

Creep and Stress Rupture Strength

HR-235® Solution Annealed Plate*

Temperature		Creep	Approximate Initial Stress to Produce Specified Creep in:			
			100 h		1000 h	
°F	°C	%	ksi	MPa	ksi	MPa
1000	538	1	57	393	45	310
		Rupture	81	558	58	400
1100	593	1	40	276	30	207
		Rupture	56	386	38	262
1200	649	1	27	186	19	131
		Rupture	38	262	24	165
1300	704	1	17	117	11	76
		Rupture	25	172	15	103
1400	760	1	10	69	6	41
		Rupture	16	110	9	62
1500	816	1	6	41	4	28
		Rupture	10	69	6	41
1600	871	1	4	28	2	14
		Rupture	6	41	4	28
1700	927	1	2	14	1	7
		Rupture	4	28	2	14

*Preliminary data

Hardness and Grain Size

HAYNES® HR-235® Alloy

Form	Solution Annealed Room Temperature Hardness	Typical ASTM Grain Size
Sheet	87 HRBW	2-4
Plate	85 HRBW	2-4

HRBW = Hardness Rockwell "B", Tungsten Indentor.

Heat Treatment

Wrought HAYNES® HR-235® alloy is furnished in the solution heat treated condition, unless otherwise specified. The alloy is normally solution heat-treated at 2050-2150°F (1121-1177°C) at a time to commensurate with thickness and rapidly cooled or water quenched for optimal properties.

Welding

HAYNES® HR-235® alloy is readily weldable by Gas Tungsten Arc (GTAW) and Gas Metal Arc (GMAW) welding processes. For sheet welds and plate root passes, GTAW is suggested. For plate welds, GMAW is preferred. For GMAW, the pulsed spray transfer mode (GMAW-P) is highly suggested. The GMAW-P transfer mode is a stable, low spatter spray transfer at average current levels significantly below that for conventional spray transfer. This results in low-to-moderate weld heat input, which is important to maintain the material properties of Ni-base alloys. Submerged arc welding (SAW) is not recommended as this process is characterized by high heat input to the base metal and slow cooling of the weld. The welding characteristics of HR-235® alloy are comparable to the highly weldable “C-type” alloys and the same general welding guidelines apply. Compared to other metal dusting resistant Ni-base alloys, HR-235® alloy exhibits excellent weldability. For further welding details, please refer to the the Welding and Fabrication guide, which contains general welding guidelines applicable to HR-235® alloy.

Heat Treatment

Wrought forms of HR-235® alloy are furnished in the solution annealed condition, unless otherwise specified, and should be welded in this condition. Welding of cold-worked materials is strongly discouraged, since it accelerates precipitation of secondary phases and induces residual stresses. As such, a full solution anneal in the range of 2100-2150°F (1149-1177°C), depending on specific requirements, followed by rapid air cool or water quench is suggested. Water quenching is recommended when annealing heavy section components and cold-worked structures prior to welding.

Base Metal Preparation

The joint surface and adjacent area should be thoroughly cleaned before welding. All grease, oil, crayon marks, sulfur compounds, and other foreign matter should be removed. Contact with copper or copper-bearing materials in the joint area should be avoided. It is preferable, but not necessary, that the alloy be in the solution-annealed condition when welded.

Filler Metal Selection

For GTAW and GMAW, HR-235® bare filler wire is suggested. For dissimilar metal welds involving HR-235® alloy, please consult with Haynes International for suggested filler metals.

Welding Continued

Preheating, Interpass Temperatures, and Postweld Heat Treatment

Preheat is not required and is generally specified as room temperature. Preheat should not be used if the base metal to be welded is above 32°F (0°C). To minimize the precipitation of second phases in regions affected by the heat of welding, a maximum interpass temperature of 200°F (93°C) is recommended for HR-235® alloy. Auxiliary cooling methods may be used between weld passes, as needed, providing that such methods do not introduce contaminants. Post-weld heat treatment is not normally required or suggested for HR-235® alloy. Heat treatment of welded fabrications may be required for other reasons, such as stress relief.

Tensile Properties of Welded Material

Transverse Tensile – GTAW Welded Sheet

Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	88.1	607	105.3	726	30
200	93	43.6	300	94.0	648	43
400	204	43.1	297	99.5	686	42
600	316	38.8	268	82.6	570	26
800	427	35.3	243	76.5	527	27
1000	538	37.6	259	86.1	594	38
1200	649	32.8	226	65.1	449	25
1400	760	28.2	194	54.3	374	22
1600	871	22.1	152	29.6	204	31
1800	982	11.0	76	15.9	110	34
2000	1093	5.3	37	7.7	53	37

Transverse Tensile – GTAW Welded Plate

Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation
°F	°C	ksi	MPa	ksi	MPa	%
RT	RT	65.3	450	112.3	774	51
200	93	56.2	387	89.8	619	19
400	204	48.2	332	96.4	665	41
600	316	45.6	314	90.0	621	40
800	427	42.3	292	89.1	614	44
1000	538	44.1	304	74.2	512	23
1200	649	38.1	263	73.5	507	30
1400	760	37.1	256	60.8	419	13
1600	871	23.9	165	33.1	228	25
1800	982	12.3	85	17.9	123	17
2000	1093	7.2	50	9.8	68	19

Welding Continued

AWM (All Weld Metal) Tensile – GTAW

Temperature		0.2% Yield Strength		Ultimate Tensile Strength		Elongation	Reduction of Area
°F	°C	ksi	MPa	ksi	MPa	%	%
RT	RT	80.0	552	115.3	795	26	30
200	93	69.2	477	101.2	698	31	32
400	204	66.7	460	98.3	678	27	27
600	316	67.0	462	94.4	651	26	35
800	427	63.0	434	89.9	620	30	30
1000	538	58.9	406	82.5	569	29	37
1200	649	52.0	359	71.6	494	22	31
1400	760	48.3	333	64.8	447	16	24
1600	871	26.3	181	36.3	250	21	23
1800	982	15.3	105	20.7	143	15	10
2000	1093	9.1	63	12.0	83	20	15

Specifications and Codes

Specifications

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(N06235)</th></tr>
<tr><td>Sheet, Plate & Strip</td><td>ASTM B168</td></tr>
<tr><td>Billet, Rod & Bar</td><td>ASTM B166</td></tr>
<tr><td>Coated Electrodes</td><td>-</td></tr>
<tr><td>Bare Welding Rods & Wire</td><td>-</td></tr>
<tr><td>Seamless Pipe & Tube</td><td>ASTM B167</td></tr>
<tr><td>Welded Pipe & Tube</td><td>ASTM B619
ASTM B626</td></tr>
<tr><td>Fittings</td><td>-</td></tr>
<tr><td>Forgings</td><td>-</td></tr>
<tr><td>DIN</td><td>-</td></tr>
<tr><td>TÜV</td><td>-</td></tr>
<tr><td>Others</td><td>-</td></tr>
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Codes

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(N06235)</th></tr>
<tr><td rowspan="11">ASME</td><td>Section I</td><td>-</td><td>-</td></tr>
<tr><td rowspan="3">Section III</td><td>Class 1</td><td>-</td></tr>
<tr><td>Class 2</td><td>-</td></tr>
<tr><td>Class 3</td><td>-</td></tr>
<tr><td rowspan="2">Section VIII</td><td>Div. 1</td><td>1600°F
(870°C)[1]</td></tr>
<tr><td>Div. 2</td><td>-</td></tr>
<tr><td>Section XII</td><td>-</td><td>-</td></tr>
<tr><td>B16.5</td><td>-</td><td>-</td></tr>
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