Modified & Proprietary Heat Resistant: Nickel-, Chromium-, & Iron- Base Alloys

High temperature degradation of heat resistant nickel-, cobalt-, and iron-base alloys (commonly referred as Super Alloys), as well as stainless steels, is typically caused by oxidation, carburization, nitridation, sulphidation and or halogenation and one / or more phenomenon mentioned can be influential in causing high temperature of the part. Apparently, each type of high-temperature corrosion is caused by a specific corrosive media and can be successfully mitigated by addition, alloying, or micro-alloying of an element summarized in the Table # 1. Most heat resistant alloys have sufficient amounts of chromium (with or without additions of Aluminium and Silicon) to form **chromia** (Cr_2O_3), **alumina** (Al_2O_3) and/ or **silica** (SiO_2) protective oxide scales, which provide resistance to environmental degradation. Nickel-Aluminides and other inter-metallics are not discussed here.

Table # 1

Element	**Effect on alloy**
Chromium	Improves oxidation resistance provided temperature does not exceed 950°C (1740°F) for long periods; decreases carbon ingress-helps carburization resistance; Detrimental to fluorine (alike halogens) containing environment at high temperatures; detrimental to nitridation resistance; high chromium is beneficial to oil-ash corrosion and attack by molten glass; improves sulphidation resistance.
Silicon	Improves resistance to oxidation, nitridation, sulphidation, and carburization; mitigates oxide film grain growth; synergistically acts with chromium to improve scale resilience; detrimental to non-oxidizing chlorination process.
Aluminium	Independently and synergistically with chromium raises oxidation resistance, improves sulphidation and carburizing resistance; detrimental in nitridation resistance.
Titanium	Detrimental to nitridation resistance.
Niobium/ Columbium	Increases short-term creep strength, improves resistance to thermal cycling; may be beneficial in carburization resistance; detrimental in nitridation resistance.
Molybdenum Tungsten	Improves high temperature strength, good in reducing chlorination resistance, improves creep strength, detrimental in oxidation resistance at high temperatures.
Nickel	Improves carburization, nitridation and chlorination resistance; detrimental to sulphidation resistance.
Carbon	Improves strength; helps nitridation resistance; beneficial for carburization resistance; oxidation resistance adversely affected.
Rare Earth Metals (REM)- Yttrium Cerium & alike	Improves adherence and spalling resistance of oxide layer with the substrate; checks grain growth rate; hence improves oxidation, sulphidation and carburization resistance.
Manganese	Slight positive effect on high-temperature strength and creep; detrimental to oxidation resistance, increases solubility of nitrogen.
Cobalt	Reduces rate of sulphur diffusion, hence helps with sulphidation resistance; improves solid-solution strength
Non-metallic inclusions -S, P, N, O, H	Keep at lowest levels below 300 ppm (parts per million) in alloys; otherwise they result in degrading mechanical and high temperature properties of an alloy.

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The Ni-Cr-Fe group of heat resistant alloys, prominently nickel base, are not generally covered in standard specifications and hence are proprietary modifications. ACMECAST offers not only proprietary alloys for area specific end application to combat high temperature corrosion, but also offers modified ASTM 297 Standard Specification grades of heat resistant austenitic stainless-steel cast grades. Rare Earth Metals (REM) heat resistant cast alloys are newer generations compositions with cerium rare earth used as micro-alloying element. Some of the alloys and its typical room temperature properties are listed in Table 2.

Table # 2: ACME Proprietary and Modified Alloy; Iron-Chromium-Nickel (Fe-Cr-Ni) and Iron-Nickel-Chromium (Fe-Ni-Cr) including 45Ni-35Cr Group alloys For Heat Resistant Applications Room Temperature Properties

Alloy	C	Mn	Si	P (max)	S (max)	Cr	Ni	Others	Tensile Strength Ksi (min)	Tensile Strength MPa (min)	Yield Strength Ksi (min)	Yield Strength MPa (min)	Elong -ation %	Hardness BHN
HK-Nb-Ti	0.35-045	1	1	0.03	0.03	25	22	Nb 0.30; Ti 0.10	74	510	-	-	18	176
HK-Nb	0.30-0.45	1	1	0.03	0.03	24	25	Nb 1.50	76	524	37	255	20	176
HK-Co-W	0.40-0.50	1	1	0.03	0.03	23	25	Co 1.5; W 2	84	579	50	344	15	195
HK-REM	0.25-0.45	1	1.5	0.03	0.03	24	25	Ce 1.2-2.8	-	-	-	-	-	-
HP-Nb	0.35-0.45	1	1	0.03	0.03	25	35	Nb 1.25-1.30	75	517	40	276	12	181
HP-Nb-Si	0.45	1	1.7-2.2	0.03	0.03	25	35	Nb 1.25	-	-	-	-	-	-
HP-Nb-LC	0.15	1	1	0.03	0.03	25	35	Nb 1.30	88	606	41	283	44	-
HP-Nb-Ti	0.50	1	1	0.03	0.03	26	35	Nb 0.50; Ti additional	77	531	37	255	12	185
HP-Nb-W	0.40	1	1.5	0.03	0.03	25	37	Nb 1.5; W 1.5	78	538	43	296	13	-
HP-Nb-W-Mo	0.45	1	1.6	0.03	0.03	25	35	Nb 1.3; W 1.3; Mo 0.50	76	525	36	250	11	181
HP-Mo	0.45	1.5	1.5	0.03	0.03	25	36	Mo 1.3	86	592	46	317	13	181
HP-W	0.45	1	1.5	0.03	0.03	26	36	W 4	76	524	45	310	13	185
HP-W-Co	0.50	0.5	1.3	0.03	0.03	26	35	W 5; Co 15	74	510	44	303	8	185
HP-REM	0.40-0.50	1	1.5	0.03	0.03	25	35	Ce 1.6-2.8	-	-	-	-	-	-
30-45-Nb-W	0.40	1	1	0.03	0.03	34	44	Nb 0.50; W 0.50	-	-	-	-	-	-
30-45-Nb-Ti	0.42	1	1	0.03	0.03	34	45	Nb 1; Ti additional	85	586	42	290	8	195
30-45-W	0.50	1	1	0.03	0.03	28	47	W 5	75	517	42	290	10	171
30-45-W-Co	0.45	1	1	0.03	0.03	28	47	W 5; Co 3	77	531	44	303	10	-
30-45-W-Al	0.20	0.4	0.2	0.03	0.03	26	47	W 1.6; Al additional	103	710	-	-	-	256
30-45-REM	0.30-0.50	1	1	0.03	0.03	26	467	Ce 1.2-3.1	-	-	-	-	-	-