

PM Alloy 625M for High Strength Corrosion Resistant Applications

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INTRODUCTION

For years the nuclear power industry has had a need for a high strength corrosion resistant material for applications such as bolting, support pins, etc. The alloys most often used in this service have been X-750, 718, and A-286 (References 1-3). However, these alloys have shown a tendency to fail by stress corrosion cracking. In recent years, Crucible has developed a powder metal alloy PM 625M (UNS N06626) which is a high strength age-hardenable version of Alloy 625. The PM alloy was designed to have the strength of conventional cast and wrought Alloy 718 with the corrosion resistance of Alloy 625.

PM625M relies on the precipitation of γ'' (Ni_3Nb) for strengthening. The modification from Alloy 625 is primarily niobium (1.25% higher) which helps to boost the strength by making more niobium available for precipitation. The property of interest is the yield strength which can be selected to be between 827 MPa (120 ksi) and 965 MPa (140 ksi) depending on the aging treatment used. Corrosion resistance in many of the standard tests (e.g., pitting, crevice, or intergranular corrosion) is better than that of Alloy 718 and approaches that of Alloy 625 (Reference 4). This paper deals with the stress corrosion cracking behavior of PM 625M and how it compares to some of the other conventional alloys used in these environments.

PREPARATION OF MATERIALS

Powder for this investigation was produced in the Crucible Pilot Gas Atomizer. Portions of several 800 pound heats were screened to -250μ (i.e., -60 mesh) particle size and blended together to make a single master powder blend, 88IM375, for the program. The particle size is plotted in Figure 1 and shows that the powder was relatively fine. The apparent density and the tap density per ASTM standards B-212 and B-527 are given in Table I and are typical of this type of powder. The chemical analyses of blend 88IM375 is given in Table II. All of the values are within the specified ranges for this alloy. The niobium level is 5.01%, which is the only element outside the range for conventional cast and wrought Alloy 625 (UNS N06625).

Three compacts were produced from this blend of powder; two were consolidated by hot isostatic pressing (HIP) and one was consolidated by extrusion. The HIP bars (M1479 and M1480) were loaded, out gassed, and sealed and HIPed at 1130°C (2065°F) and 103 MPa (15 ksi). The extrusion compact (M1481) was extruded in a 23.5 cm (9.25 in) liner to approximately 4.8 cm (1.9 in) in diameter. The temperature of extrusion was 1120°C (2050°F) and the compact was held for 8 hours at temperature prior to the push.

After consolidation, all of the bars were evaluated for density and microstructure. The density results are given in Table III and are considered typical for this alloy. A thermally induced porosity (TIP) test was also conducted on each compact to check for container leaks during consolidation with no adverse findings. The microstructure was fine grain equiaxed and the extruded bar exhibited some slight gain elongation in the longitudinal direction.

MECHANICAL PROPERTY EVALUATION

Material from each identification condition was sectioned, prepared, and room temperature tensile tested in the as-consolidated state. These data appear in Table IV. The bars were room temperature tensile tested in the fully heat-treated condition and after further thermal exposure at 427°C (800°F) for 500 hours. The extruded material had slightly higher 0.2% yield strength and slightly higher ductility than the HIP material. However, these differences are not considered significant. The thermally exposed material had virtually the same tensile properties as the fully heat-treated material.

Charpy "V"-notch impact tests were also conducted on material consolidated by both methods in the heat-treated and heat-treated plus thermally exposed conditions. Table IV contains these data also. Extruded material exhibited about an 11 J (8 ft-lb) advantage over the HIP material. However, the thermal exposure appeared to have no significant effect on impact values.

MICROSTRUCTURAL CHARACTERISTICS

Examination of PM 625M by scanning electron microscopy (SEM) shows that in the fully heat-treated condition, the matrix contains Nb-rich MC and Mo-rich M₆C carbides and considerable γ'' (Ni₃Nb). Figure 2 shows a photomicrograph of PM 625M in the fully heat-treated condition. The carbides are present in the as-consolidated condition and the γ'' precipitates during the heat-treatment cycle. This aging response of the PM 625 and 625M alloys was reported previously (References 5-6).

STRESS CORROSION TEST RESULTS

Test samples were taken from 38 mm (1.5 in) diameter bar stock lengths that had been consolidated by either extrusion or HIP and subsequently double aged at 718°C (1325°F)/8 hrs/furnace cool 55°C (100°F)/hr to 621°C (1150°F)/8hrs/air cool. A number of 10 mm (0.4 in) compact tension fracture toughness specimens were machined from the bar stock with precracks oriented in the transverse direction (i.e., running across the bar). In addition, a set of fracture toughness specimens were machined from extruded material in the longitudinal direction with precracks running down the bar length to determine the effect of orientation on stress corrosion cracking behavior.

The majority of the specimens were tested in the fully heat-treated condition. In addition, portions of both materials were given a thermal exposure at 427°C (800°F) for 500 hours before specimen machining. This thermal exposure was intended as a screening test to see if the alloy was susceptible to changes in corrosion properties during long-time service at lower temperatures.

The compact tension specimens were fatigue precracked and bolt loaded to nominal stress intensities of either 50 or 65 MPa \sqrt{m} (45.5 or 59.1 ksi \sqrt{in}). These samples were tested in deaerated (1 to 2 ppb oxygen) pH 10 water at either 288°C or 360°C (550°F or 680°F). The samples were periodically removed from test and inspected for signs of stress corrosion crack growth. No crack growth could be detected on the sides of the samples during exposures. After various exposure times, the samples were removed from test and broken open at room temperature. The fracture surfaces were then examined by optical and SEM for signs of intergranular crack growth.

These results are summarized in Table V. Many of the specimens showed no stress corrosion crack growth after exposure times up to 841 days. In some samples, localized small thumb nail shaped regions of stress corrosion crack growth were detected. These regions were typically about 0.5 mm (0.020 in) wide and about 0.1 mm (0.004 in) deep. This type of cracking was more noticeable in the HIP material than in the extruded stock. In the extruded materials crack growth was only detected in the longitudinal orientation. The 427°C (800°F) thermal exposure did not promote crack growth, indicating that long-time service exposures would not degrade the stress corrosion resistance of PM 625M.

CONCLUSIONS

The overall results indicate that Alloy PM 625M has excellent resistance to stress corrosion in a high purity water environment. In comparison, other commonly used precipitation hardened nickel base alloys such as Alloy X-750 and Alloy 718 have generally shown about an order of magnitude greater crack growth after exposure times on the order of 100 days in tests of this kind (References 1 through 3). Thus Alloy PM 625M would appear to be worthy of consideration for light water reactor applications requiring high strength and good corrosion resistance.

REFERENCES

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3. W. L. Kimmerle, M. T. Miglin and J. L. Nelson, "Stress Corrosion Cracking of Alloy 718 in Pressurized-Water-Reactor Primary Water" (Superalloy 718 - Metallurgy and Applications), TMS, Warrendale, Pennsylvania, 1989, pp 417.

4. F. J. Rizzo and S. B. Justus, "PM Alloy 625M - A High Strength Modification of Alloy 625" (Superalloys 718, 625, 706 and Various Derivatives), TMS, Warrendale, Pennsylvania, 1994, pp 903.
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TABLE I Apparent Density and Tap Density of PM 625M Blend 88IM375	
Apparent Density	5.14 g/cm ³ (0.185 lb/in ³)
Tap Density	5.68 g/cm ³ (0.205 lb/in ³)

TABLE II Chemical Analysis (wt%) of PM 625M Blend 88IM375			
C = 0.028	Cr = 20.67	Co = 0.020	O = 0.006
Mn = 0.070	Mo = 8.62	Cu = <0.01	N = 0.012
Si = 0.140	Nb = 5.01	W = <0.02	
S = 0.005	Ti = 0.07	Fe = 4.93	
P = 0.010	Al = 0.40	Ni = Balance	

TABLE III Density of Consolidated PM 625M Blend 88IM375		
Compact Code	Consolidation Process	Density g/cm ³ (lb/in ³)
M1479	Hot Isostatic Press	8.42 (0.304)
M1480	Hot Isostatic Press	8.42 (0.304)
M1481	Extrusion	8.40 (0.303)

TABLE IV: Room Temperature Tensile and Charpy Impact Properties of PM 625M

Compact Code	Consolidation Process	Thermal Condition ⁽¹⁾	Ultimate Tensile Strength MPa (ksi)	0.2% Yield Strength MPa (ksi)	Elongation (%)	Reduction In Area (%)	Charpy "V" Notch Impact Energy (J) (ft-lbs)
M1479	HIP	As-HIP	945 (137.0)	536 (77.8)	50.0	47.3	--
M1479	HIP	A	1256 (182.2)	908 (131.8)	25.5	29.6	--
M1480	HIP	A	1248 (181.0)	910 (137.0)	28.0	30.0	32.5 (24.0)
M1480	HIP	B	1227 (178.0)	917 (133.0)	25.0	41.0	36.9 (27.2)
M1481	Extrude	A	1234 (179.0)	903 (131.0)	33.0	31.0	46.3 (34.2)
M1481	Extrude	B	1234 (179.0)	896 (130.0)	36.0	39.0	45.8 (33.8)

(1) A = 718°C (1325°F) 8 hrs/furnace cool 55°C (100°F)/hr to 621°C (1150°F)/h hrs/air cool
 B = A plus 427°C (800°F)/500 hrs/air cool

TABLE V Stress Corrosion Cracking Results of PM 625M in Deaerated Water

Compact Code	Consolidation Process	Thermal Condition ⁽¹⁾	Test Temperature °C (°F)		Test Duration (Days)	Initial Stress Intensity MPa√m (ksi√m)		Max SCC Depth mm (in)	
1480	HIP	A	360	(680)	448	49.5	(45.1)	0.05	(0.002)
1480	"	A	360	(680)	711	65.9	(60.0)	0.14	(0.006)
1480	"	B	360	(680)	448	49.5	(45.1)	0	
1480	"	B	360	(680)	711	66.1	(60.2)	0	
1480	HIP	A	288	(550)	841	65.9	(60.0)	0.08	(0.003)
1480	"	A	288	(550)	841	64.7	(58.9)	0.13	(0.005)
1480	"	B	288	(550)	841	65.5	(59.6)	0.10	(0.004)
1480	"	B	288	(550)	841	65.6	(59.7)	0.13	(0.005)
1481	Extrusion	A	360	(680)	448	49.7	(45.2)	0	
1481	"	A	360	(680)	711	65.9	(60.0)	0	
1481 ⁽²⁾	"	A	360	(680)	448	50.0	(45.5)	0.05	(0.002)
1481 ⁽²⁾	"	A	360	(680)	711	66.1	(60.2)	0.14	(0.006)
1481	"	B	360	(680)	448	49.3	(44.9)	0	
1481	"	B	360	(680)	711	65.0	(44.9)	0	
1481	Extrusion	A	288	(550)	841	66.4	(60.4)	0	
1481	"	A	288	(550)	841	65.2	(59.3)	0	
1481 ⁽²⁾	"	A	288	(550)	841	66.4	(60.4)	0.14	(0.006)
1481 ⁽²⁾	"	A	288	(550)	841	65.6	(59.7)	0	
1481	"	B	288	(550)	841	65.8	(59.9)	0	
1481	"	B	288	(550)	841	65.5	(59.6)	0	

(1) A = 718°C (1325°F)8hrs/Furnace Cool 55°C(100°F)/hr to 621°C(1150°F)/8 hrs/Air Cool
 B = A plus 427°C (800°F)/500 hrs/Air Cool
 (2) Specimen Precracked with a Longitudinal Orientation

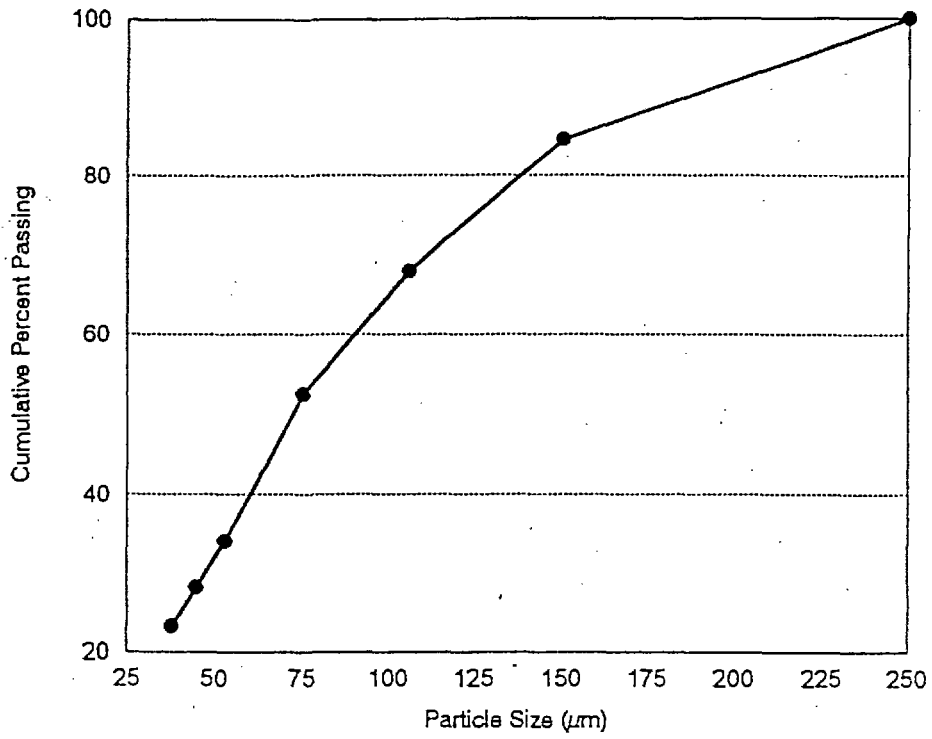


Figure 1. Powder Particle Size Distribution for PM 625M Blend 88IM375.

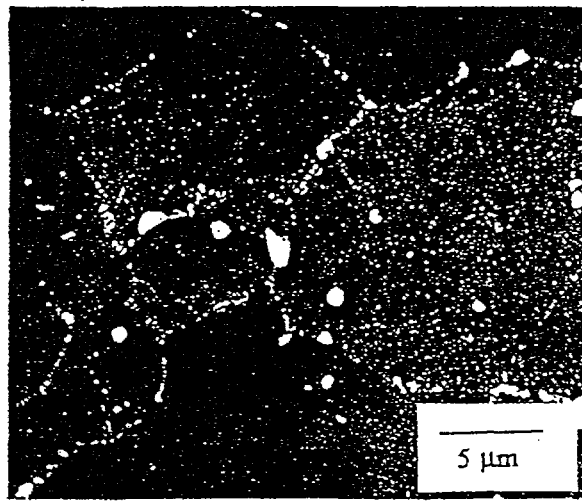


Figure 2. SEM Photograph of PM 625M in the Fully Heat-Treated Condition. Etchant: 10% HCl in Methanol Electrolytic. Heat Treatment = 718°C (1325°F)/8 hrs/FC 55°C (100°F)/hr to 621°C (1150°F)/8 hrs/AC