EVALUATION OF AN L-SHAPED EXTRUSION OF P/M ALLOY 718

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Abstract

A unique advantage of P/M processing is in producing near-net shape or even final shape products. This survey of a channel extrusion produced directly from a consolidated billet of P/M 718 reveals that excellent mechanical properties and uniform grain size are obtained. Tensile properties at ambient and at 650°C and stress rupture at 650°C exceed the internal specification for a rolled profile as well as the AMS specifications for cast and wrought 718. From a property and cost standpoint, the P/M near-net shape is superior to the rolled profile from conventional cast-wrought operations. Also, properties are compared with other special products of P/M 718 that were studied previously, and an SEM analysis of a stringer aggregate in the P/M 718 extrusion is provided.

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Introduction

The advantages cited for the use of powder metallurgy include the ability to make complex alloys not possible with conventional techniques, freedom from segregation, finer grain size, superplastic forming and hot consolidation processes to produce near-net shapes. Developed initially for advanced materials that could only be made this way, the technology can be applied equally well to high volume superalloys. The structure and properties of P/M Alloy 718 have been shown to be at least comparable and in some instances superior to the conventionally produced wrought counterpart.¹ Although the replacement has been slow because of the extensive experience built up for the latter, the P/M approach is being explored for specific products. Heavy wall tubing has been produced from P/M 718 tube hollows via successive cold reductions on a Pilger mill and lighter wall tubing has been produced by radial cold forging of P/M 718 tube hollows in a Grotnes machine.² Even cross rolled plate has been examined from solid P/M 718 billet. Also, P/M 625 billet has been extruded and then hot and cold rolled to coil product for redraw-stock welding wire.³ In all cases, the powders were consolidated by atmospheric pressure in glass molds, the CAP process.¹ To add to these exploratory studies, this paper provides results obtained on an L-shaped channel produced by extrusion of P/M 718 which could be a replacement of a rolled profile that is fabricated into an aircraft turbine component.

Figure 1. End views and flow line contours produced during extrusion of P/M 718 billet into an L-shaped channel.

Experimental Procedure

The extruded shape was produced from a 5 in. round by 30 in. long P/M CAP718 billet derived from a heat whose principal composition was 53.2Ni, 18.3Cr, 18.6Fe, 5.4Nb, 3.0Mo, 0.94Ti and 0.55Al in wt.pct. The remaining residual elements were 0.10Mn, 0.11Si, 0.005P, 0.002S and 0.058C. The L-shaped channel was extruded at 1100°C by a proprietary process employing optimum extrusion flow stress for P/M 718 derived from the billet section, the optimum extrusion ratio and the alloy's high temperature flow stress. The dimensions of the extruded profile were 2 1/8 in. height with 13/16 in. thickness and 1 3/4 in. base with 5/8 in. thickness,

per Figure 1. The macrostructure appeared uniform both visually and under binoculars. Metal flow lines in various parts of the extrusion are seen in Figure 1 and the clean contours are important aspects of the successful processing of this very stiff alloy. Longitudinal specimens were cut from the base and vertical of the extruded channel and subjected to metallography, tensile and stress rupture testing after the specified heat treatments.

Results

The grain size of the extruded channel was uniform ASTM7 as seen in the longitudinal views of Figure 2. The presence of stringers, dispersed throughout the microstructure, would not be of any concern to mechanical properties which

Figure 2. Microstructure in longitudinal direction of P/M Alloy 718 extruded shape. (a) X100. (b) X200.

would only be requisite in the longitudinal direction for the component fabricated from the channel. Room temperature tensile test results for the two specific heat treatments listed in Table I exceed the specification for rolled profiles from cast-wrought practice. The 995°C or 990°C solution treatments provided higher values than as extruded or as extruded plus direct aged product. It is somewhat surprising that the latter did not maximize tensile strength which is the usual case. Also, the values obtained for the two solution treatments exceed the specified 185 ksi ultimate, 150 ksi yield, 12 pct elongation and 15 pct reduction of area in AMS5662B and 5663B for bars, forgings and rings and AMS5589 for seamless tubing produced by conventional CW processing.

The tensile test results at 650°C, per Table II, reveal that either heat treatment on the extruded channel provided values that exceed the internal specification established for a rolled profile. Again, the results are well above the requirements of the above AMS specs for other CW products which are 145 ksi ultimate, 125 ksi yield with 12 pct elongation and 15 pct reduction of area. Finally, the stress rupture results at 650°C under a stress of 100 ksi, listed in Table III, exceed the requirements of the internal specification as well as the above AMS spec requirements of 23 hours and 4 pct elongation for a stress of 100 ksi at 650°C.

Table I Tensile Test Results at 20°C on P/M CAP 718 Extruded Shape

Metallurgical State		Ultimate Stress		0.2% Yield Stress		Elong. %	Red. of Area, %
		ksi	MPa	ksi	MPa		
Required values in Spec DND 424 and DNF90420-01 on products		≥180	≥1240	≥149	≥1030	12	15
As-extruded L-shape, Profile 2466A	{ Vertical Base	130	898	66	454	53	48
		132	909	67	463	51	43
Extruded and heat treated at 995°C/1 hr, air + aging	{ Vertical Base	197	1359	174	1199	22	34
		199	1372	169	1164	19	31
Extruded and heat treated at 990°C/2 hr, air + aging		196	1357	173	1190	22	34
As extruded + direct aging		195	1343	167	1152	22	35

Aging Treatment = 720°C for 8 hrs, cooled at 50°C/hr to 620°C, hold 8 hrs at 620°C and then air cooled.

Table II Tensile Test Results at 650°C on P/M CAP 718 Extruded Shape

Metallurgical State	Ultimate Stress		0.2% Yield Stress		Elong. %	Red. of Area, %
	ksi	MPa	ksi	MPa		
Required values in Spec DND 424-22 and DNF90420-01	≥145	≥1000	≥125	≥860	10	15
Extruded and heat treated at 955°C/1 hr, air + aging	153	1055	138	952	11	16
Extruded and heat treated at 990°C/2 hrs, air + aging	158	1088	143	987	10	19.5

Aging Treatment = 720°C for 8 hrs, cooled at 50°C/hr to 620°C, hold 8 hrs at 620°C and then air cooled.

Table III Stress Rupture Results at 650°C in P/M CAP 718 Extruded Shape

Metallurgical State	Test Conditions			Time Hrs.	Elong. %
	Temp., °C	Stress			
		ksi	MPa		
Required values in Spec. DND 424.22 and DNF90420-01	650	100	690	23	5
Extruded and heat treated at 955°C/1 hr, air + aging	650	100	690	103	7.7
Extruded and heat treated at 990°C/1 hr, air + aging	650	100	690	83	11.2

Aging Treatment = 720°C for 8 hrs, cooled at 50°C/hr to 620°C, hold 8 hrs at 620°C and then air cooled.

Figure 3. Comparison of tensile properties of various P/M Alloy 718 products.

Figure 3 is presented as a summary of the tensile test results obtained on the earlier end-products derived from P/M 718. Although there are finite differences between them which can be explained on the basis of the different mechanical working procedures and heat treatments, the properties for all three products greatly exceed the specification requirements for cast and wrought 718. Adding the present results on the L-shaped extrusion of P/M 718 to our prior work, it is evident that somewhat lower values for ultimate and yield strength were obtained but still significantly higher than the CW spec requirement. Again, a strict

Figure 4. Optical photomicrographs of stringers in extruded shape of P/M Alloy 718. (a) X400. (b) X1000.

Figure 5. Secondary electron images of stringer aggregate in extruded shape of P/M Alloy 718. (a) X1000. (b) X3000. Numbered particles subjected to EDAX.

Figure 6. EDAX of numbered particles in Figure 5. (a) Particle 1, with particles 5 and 6 identical to this EDAX. (b) Particle 2, with particles 3 and 4 identical to this EDAX. (c) Particle 1 in the range to detect the presence of secondary peaks for Nb and Mo. (d) Particle 6 in the range to detect the presence of secondary peaks for Nb and Mo.

comparison between this product and the earlier ones is really not justified for the above reasons. However, it can be noted that the ultimate tensile strength of Standard Process 718 is 185 ksi for ASTM4-6 grain size. Also, it has been reported that the P/M 718 extruded channel has better properties than those obtained on the rolled profile, and there would be a cost advantage for this near-net shape compared to the extensive rolling operations when starting with CW material.

While it is not possible to make perfect material, the industry has made great strides in powder production in order to provide a cleaner, more structural uniform material. In this regard, an inclusion stringer distributed in the extrusion direction was examined via the scanning electron microscope. Optical photomicrographs are shown in Figure 4 and the secondary electron images of the aggregate via the SEM are seen in Figure 5, with the individual particles that were specifically analyzed enumerated as 1 to 6.

The energy dispersive x-ray analysis (EDAX) of large particle 1, per Figure 6a, revealed a strong Nb-Mo peak and a nearly equivalent Ti peak at the expected positions and the analyses made on smaller particles 5 and 6 were identical to particle 1. The analysis of small particle 2, shown in Figure 6b, revealed a strong Nb-Mo peak and a smaller Ti peak, in a ratio of 3 to 1, and the analyses of particles 3 and 4 were identical to particle 2. With this ratio, past experience indicates these particles can be identified as carbide. With the nearly equal x-ray counts (peak heights) for Ti and the Nb-Mo, the large angular particle 1 and the smaller, separate rod-shaped particle 6 appear similar to known sulfides in high temperature alloys and could possibly be titanium carbosulfides. However, when the EDAX scale was expanded to distinguish secondary peaks which were seen, per Figure 6c and 6d, this possibility was discarded since sulfur has no secondary peaks.

It is known that primary carbides in Alloy 718 are Nb-rich carbides. Hence, an EDAX was made on a primary carbide located away from the stringer aggregate, per Figure 7a. As seen in the expanded scale, Figure 7b, the carbide particles exhibit the

Figure 7. Secondary electron image of area showing typical primary carbides located away from stringer segregate at X3000 and EDAX of carbide particle to show similarity between its Nb and Mo secondary peaks with those obtained on rod-shaped Particle 6 which appears as tiny dots on top of the peaks obtained from the primary carbide particle.

characteristic secondary Nb peaks. Recalled from the memory were the secondary Nb peaks for the rod shaped particle 6 which superimposed directly on this scale. Since the two sets of secondary peaks are identical and from spectra with primary Nb-Mo peaks of the same intensity, the only logical conclusion is that the rod-shaped particles do not contain sulfur.

It is recognized that the complete composition of the stringer aggregate is still not known and possibly more information on it could be obtained by bulk extraction of the stringers and x-ray diffraction analysis of the extracted residue. However, this would be an analysis of a bulk residue and it would still not be possible to separate and obtain an analysis of the individual particles provided by EDAX via SEM.

References

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3. E.A. Loria, Paper in this volume.