# EFFECT OF PROCESSING PARAMETERS ON THE KINETICS OF

# GRAIN COARSENING IN P/M 718

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## Abstract

Forging billets were produced from P/M 718 by extrusion. Initial powder particle size and extrusion parameters were varied, followed by the same schedule for upset forging of each of the extruded billets. Pieces from the extrusions and forgings were exposed to 1785°F-1825°F and 1825°F-1875°F, respectively. It was found that no grain coarsening occurred in any of the extrusions even after 12 hours at 1825°F. A small amount of coarsening was observed in forgings after 2 hours at 1850°F and 4 and 6 hours at 1875°F. The onset of observable coarsening in forgings coincided with a substantial decrease in the amount of $Ni_3Nb$(δ). Prior particle boundary(PPB)network was seen in all forgings. It is believed that this network restrained grain coarsening after the δ phase had dissolved and that the uniformity of the grain coarsened structure reflected the uniformity of the PPB network. It was observed in one case that an exposure to 2175°F prior to extrusion produced a more uniform PPB network compared to other extruded material. This study indicated that (a)large billets of P/M 718 can be preheated without undue coarsening prior to forging, (b) forgings can be made at slow press speeds and subsequently cooled slowly without undue coarsening and (c) solution temperatures higher than 1875°F would be needed to obtain intermediate and coarse grain sizes in forgings made from P/M extrusions.

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## Introduction

A powder metallurgy(P/M) version of any cast and wrought(C/W) alloy has a potential for significant reduction in the scale of compositional segregation since conceivably, the latter can only be as large as the size of a powder particle. Accordingly, limitations on the size of a segregation-free primary ingot might be circumvented during production of large final products if P/M approach can be economically employed. A particularly relevant case in point is that of assessing the potential of P/M 718 to be used for large land-based gas turbines(LBGT). These components are at present forged from ingots of IN-706, an alloy that was specifically developed to exhibit very low propensity for segregation and improved forgeability compared to IN-718. As a result of the compositional differences, listed in Table I, the elevated temperature tensile and creep properties of IN-706 are in general lower compared to those of IN-718.

Table I. Nominal Composition(w%) of IN-718 and IN-706

| Alloy | Ni | Fe | Cr | Ti | Al | Mo | Nb+Ta | C | Mn | Si |
|---|---|---|---|---|---|---|---|---|---|---|
| IN-718 | 52.5 | 18.5 | 19.0 | 0.9 | 0.5 | 3.0 | 5.1 | 0.04 | 0.2 | 0.2 |
| IN-706 | 41.5 | 40.0 | 16.0 | 1.8 | 0.2 | - | 2.9 | 0.03 | 0.2 | 0.2 |

An attractive possibility would be to use P/M 718 to get around the constraints of the maximum diameter of a primary ingot and thus utilize its superior high temperature properties in a LBGT application.

It was in this vein that a number of argon-atomized heats of Alloy 718 were produced at WG-Brighton and extruded. It would be recognized that for a successful use of P/M 718 in a LBGT application, the following requirements, among others, should be met.

(a) Large billets can be heated to a uniform temperature prior to forging without incurring unacceptable grain coarsening.

(b) The forged components are amenable to a control of grain size for the desired elevated temperature properties.

It was therefore planned to determine the effect of the extrusion parameters on the kinetics of grain coarsening in extrusions and forgings made from these extrusions.

## Experimental Procedures

Argon atomization was employed to produce a number of powder heats that were blended and sieved into - 150 mesh and - 80 mesh fractions. These fractions were used to make 6 extrusions, as described below.

### Extrusion

Either -150 mesh or -80 mesh powder was canned, compacted at 60 ksi for 30 seconds minimum and used to make each of six extrusions, 3" in diameter, at a ratio of 6:1. The parameters used for canning, compaction and extrusion are listed in Table II, where it should be noted that an 8 hour hold at 2175°F prior to compaction for extrusion # 6 was intended to determine its effect on the PPB's.

Table II. Parameters Used in Making the Extrusions

| Extrusion No. | Powder Size, Mesh | Can Dimensions, inch | | Compaction Temperature °F | Extrusion Temperature, °F |
|---|---|---|---|---|---|
| | | Diameter | Length | | |
| 1 | -150 | 7.0 | 9.0 | 1900 | 1900 |
| 2 | -150 | 7.0 | 9.0 | 2000 | 2000 |
| 3 | -80 | 7.0 | 9.0 | 1900 | 1900 |
| 4 | -80 | 7.0 | 9.0 | 2000 | 2000 |
| 5 | -80 | 5.0 | 9.0 | 1900 | 1900 |
| 6 | -80 | 5.0 | 9.0 | 2175(8 hr hold) | 2000 |

### Forging

Since the aim was to simulate the final forging operations for large components, the scheme given in Table III was planned to obtain comparable reductions and slow cooling rates during and after hot die forging. Parameters obtained during forging are listed in Table IV.

Table III. Scheme Used for Forging(die heated to 1600°F)

| Step No. | Temperature °F | $H_i$ , inch | $H_f$, inch | Reduction % | Comments |
|---|---|---|---|---|---|
| 1 | 1800 | 6.0 | 3.9 | 35.0 | Return to the furnace, set the furnace to 1750°F |
| 2 | 1750 | 3.9 | 2.6 | 33.0 | Return to the furnace |
| 3 | 1750 | 2.6 | 2.0 | 22.0 | Return to the furnace, hold for 20 minutes, remove and cool in vermiculite |

Table IV. Parameters Obtained during Forging

| Extrusion No. | Step 1(at 1800°F) | | Step 2(at 1750°F) | | Step 3(at 1750°F) | |
|---|---|---|---|---|---|---|
| | Strain Rate, $sec^{-1}$ | Load Ton | Strain Rate, $sec^{-1}$ | Load Ton | Strain Rate, $sec^{-1}$ | Load Ton |
| 1 | 0.06 | 221 | 0.10 | 283 | 0.14 | 461 |
| 2 | 0.06 | 226 | 0.10 | 292 | 0.14 | 436 |
| 3 | 0.06 | 206 | 0.10 | 282 | 0.14 | 441 |
| 4 | 0.06 | 237 | 0.10 | 292 | 0.14 | 476 |
| 5 | 0.06 | 221 | 0.10 | 296 | 0.14 | 452 |
| 6 | 0.06 | 229 | 0.10 | 310 | 0.14 | 445 |

Coarsening Studies

Slices from the extrusions and forgings, about 0.5" in thickness, were obtained and used to ascertain that the initial grain size of either did not vary from the edge, mid-radius and center. Details of the coarsening studies are described below.

Coarsening in extrusions. Cubical pieces from the extrusion slices, about 0.5" on an edge, were subjected to 4 and 12 hours at 1785, 1800 and 1825°F, the conditions relevant to forging of large billets of Alloy 718, and cooled in air. These were sectioned, mounted, polished and etched with Kalling's Reagent. Standard analytical techniques were used to determine the ASTM grain size numbers.

Coarsening in forgings. Since it was intended to obtain controllable coarsening, 0.5" cubical pieces were subjected to 2, 4 and 6 hours at 1825, 1850 and 1875°F. These were analyzed in the manner described above.

## Results and Discussion

It would be timely at this juncture to review the elemental levels in Alloy 718 powder, before discussing the activities outlined in the previous section. Chemical analysis of the powder blend is given in Table V, where carbon content is seen to exceed the desired value of 0.015 w%. The effect of higher carbon might be reflected in more pronounced PPB's.

Table V. Chemical Analysis of the Powder Blend

| Element | Ni | Cr | Ti | Al | Nb | Ta | Mo | C | Si | Mn |
|---|---|---|---|---|---|---|---|---|---|---|
| Content, w% | 53.5 | 17.84 | 0.98 | 0.53 | 5.37 | 0.03 | 2.98 | 0.024 | 0.09 | 0.065 |

The grain size of extrusions and forgings after thermal exposure will be discussed in this section, where comparison will be made with the coarsening behavior of C/W 718 presented in a number of other investigations.

Grain Coarsening in Extrusions

Values of the ASTM grain size numbers are listed in Table VI, where it can be seen that in light of an expected experimental scatter of ± 0.5, essentially no coarsening was observed in any of the extrusions even after 12 hours at temperatures up to 1825°F. As illustrated in Figure 1 for the case of extrusion # 5 after 12 hours at 1825°F, the presence of δ phase at the grain boundaries was seen in each case. It is thus believed that the grain boundary motion was restricted by the δ phase.

Furthermore, no effect of the initial powder particle size and extrusion temperature was seen. The absence of coarsening would be helpful in uniformly heating large billets to temperatures up to 1825°F, without unacceptable grain coarsening. In contrast, a number of investigations of C/W 718 material have indicated grain sizes of ASTM 6 after 4 hours at 1800°F[1], ASTM 3 to 4 after 1750°F/1 hour/ slowly cooled to 1550°F/air cooled[2] and ASTM 6 after 1 hour at 1800°F[3].

Table VI. Grain Size(ASTM No.) of Extrusions after Thermal Exposure

| Extrusion No. | 1785°F | | 1800°F | | 1825°F | |
|---|---|---|---|---|---|---|
| | 4 hours | 12 hours | 4 hours | 12 hours | 4 hours | 12 hours |
| 1 | 10.0 | 9.5 | 9.5 | 9.5 | 10.0 | 10.5 |
| 2 | 8.5 | 9.0 | 9.5 | 9.0 | 10.0 | 10.0 |
| 3 | 9.0 | 9.0 | 10.5 | 10.0 | 9.5 | 10.0 |
| 4 | 9.0 | 9.0 | 10.0 | 9.5 | 9.0 | 10.0 |
| 5 | 9.5 | 9.0 | 9.5 | 9.5 | 10.0 | 9.5 |
| 6 | 9.0 | 9.0 | 9.5 | 9.5 | 9.0 | 9.0 |

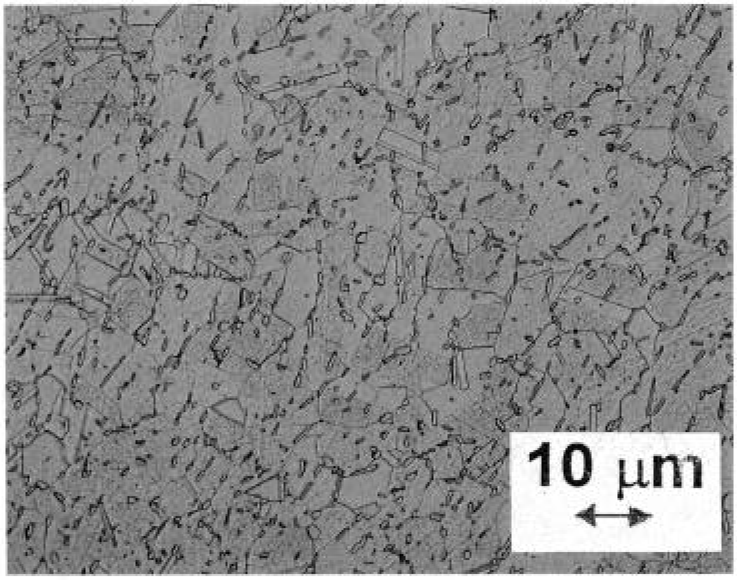


Figure 1. Microstructure of extrusion # 5 after 12 hours at 1825°F.

Grain Coarsening in Forgings

Values of the ASTM grain size numbers are listed in Table VII, where ALA indicates the largest grain size observed. No coarsening was obtained after 6 hours at 1825°F. Raising the temperature to 1850°F led to a small amount of coarsening after 6 hours. At 1875°F, although coarsening was seen after 2 hours, it proceeded very slowly for periods up to 6 hours. No δ phase was observed in the cases where coarsening was seen, indicating its retarding effect on the grain boundary motion. Prior particle boundaries(PPB) could be seen in all the cases, as illustrated in Figures 2 and 3 for forging # 2 and forging # 6, respectively, after 6 hours at 1875°F. It is thus believed that even after the dissolution of the δ phase, the PPB network restrained grain coarsening. It is also put forth that the absence of a duplex structure and ALA in forging # 6 reflected a more uniform PPB network compared to those in other forgings (e. g. # 2, Figure 2), due to an 8 hour hold at 2175°F prior to the compaction step. No effect of the initial powder particle size and extrusion temperature was seen. These grain coarsening data on forgings made from P/M 718 are in contrast to those obtained by other researchers on forgings made from C/W 718, which exhibited grain sizes of ASTM 4.5 after 1 hour at 1895°F[4], ASTM 3.5 after 5 hours at 1850°F[5] and ASTM 5 to 6 after 1 hour at 1896°F[6].

Restrained grain coarsening in P/M 718 forgings at temperatures up to 1875°F seen in this study would be conducive to either slow forging speeds at these temperatures or slow subsequent cooling rates that would not lead to unacceptable coarsening. The present study has also indicated a need for temperatures higher than 1875°F in order to obtain intermediate and coarse grain sizes.

Table VII. Grain Size(ASTM No.) of Forgings after Thermal Exposure

| Forging No. | 1825°F | | | 1850°F | | | 1875°F | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2 hr | 4 hr | 6 hr | 2 hr | 4 hr | 6 hr | 2 hr | 4 hr | 6 hr |
| 1 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 10.5 | 9.5 ALA 4 | 9.5/4.0 ALA 1 | 9.0/5.0 ALA 1 |
| 2 | 10.5 | 10.5 | 10.5 | 10.0 | 10.0 | 10.0 | 8.5 ALA 4 | 9.5 | 9.0/5.0 ALA 2 |
| 3 | 10.5 | 10.0 | 11.0 | 10.5 | 10.0 | 10.0 ALA 4 | 8.5 ALA 4 | 9.5/4.0 ALA 2 | 9.0/4.0 ALA 1 |
| 4 | 10.0 | 11.0 | 10.0 | 10.0 | 10.5 | 9.5 | 9.5 | 9.0/4.0 ALA 0 | 8.5 |
| 5 | 11.0 | 10.5 | 10.0 | 10.5 | 10.5 | 9.0 ALA 3 | 9.0 ALA 3 | 9.5/5.0 | 9.0/5.0 ALA 2 |
| 6 | 10.5 | 11.0 | 11.0 | 10.0 | 10.0 | 9.0 | 9.0 | 8.0 | 8.5 |

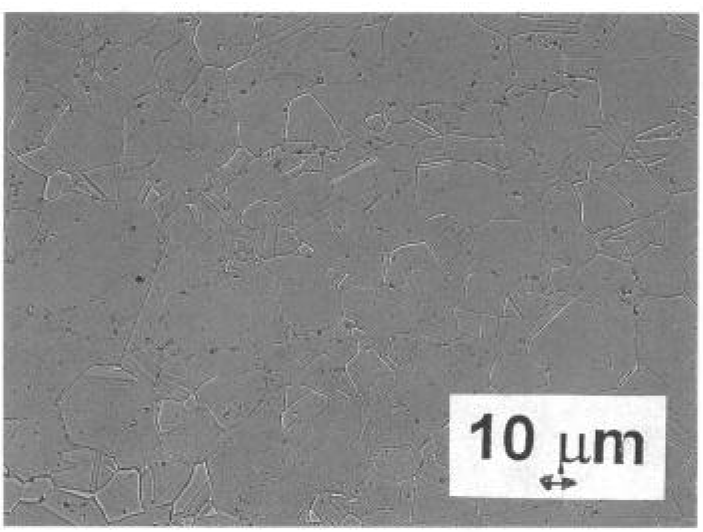


Figure 2. Microstructure of forging # 2 after 6 hours at 1875°F.

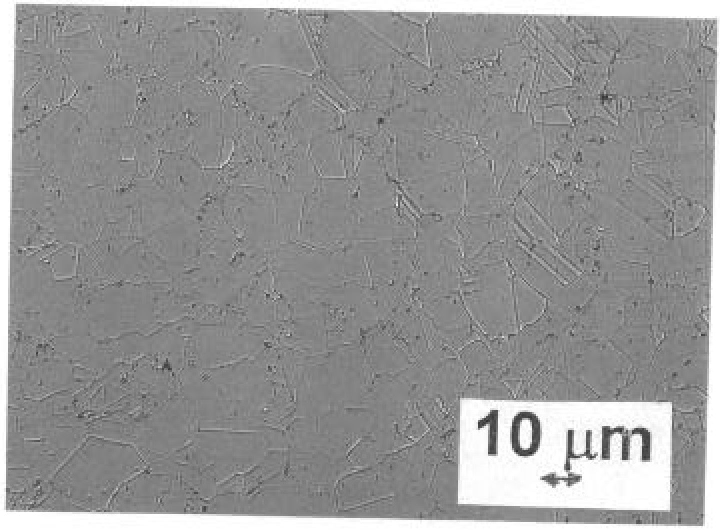


Figure 3. Microstructure of forging # 6 after 6 hours at 1875°F.

## Conclusions

(1) No grain coarsening was seen in any of the extruded material, indicating a marginal sensitivity to the initial powder particle size and extrusion temperature and slow kinetics of coarsening at 1785°F to 1825°F. It is believed that the δ phase in extrusions was responsible for the lack of coarsening,

(2) Due to slow kinetics of coarsening, large billets of P/M 718 can be uniformly heated to temperatures in the 1785 to 1825°F range without unacceptable coarsening before forging.

(3) A small amount of coarsening was seen in forged material after 6 hours at 1850°F and 2 , 4 and 6 hours at 1875°F. It is thus indicated that large P/M 718 billets can be forged at 1850°F at slow speeds and can be subsequently allowed to cool slowly without incurring unacceptable coarsening.

(4) Absence of the δ phase in coarsened microstructures is believed to indicate that its dissolution was necessary before coarsening could take place.

(5) PPB network was believed to be responsible for limited coarsening even after 6 hours at 1875°F.

(6) It is believed that the forging with an uniformly coarsened structure reflected its uniform PPB network, the latter due to an extended hold at 2175°F prior to the compaction step.

(7) Solution temperatures higher than 1875°F would be needed to obtain intermediate and coarse grain sizes in forgings.

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