THE INFLUENCE OF REDUCED CARBON

ON ALLOY 718

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Abstract

Ingots 20 inches in diameter with carbon ranging from .008 to .027 wt. % were processed to billet 8 inches in diameter. Two processing methods were used; standard forging above the delta solvus and mini-grain forging well below the delta solvus. Also, both aerospace and oil patch heat treatments were used. Tensile stress rupture, and creep testing did not reveal any deleterious effects with reduced carbon. Also, increased grain growth was not observed over the temperature range investigated (to 1900°F). Carbide stringers and clusters were eliminated at .008% carbon. Therefore, reducing carbon has the potential for improving LCF life. Toughness, as measured by Charpy and Fracture Toughness testing, improved substantially with decreasing carbon.

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Introduction

Advances in jet engine design continue to subject rotating parts made from alloys like 718 to increased temperatures and stresses. Consequently, there is much emphasis on improving low cycle fatigue (LCF) where crack initiation can occur at oxide, nitride, and carbide particles. Since oxides and nitrides are the most detrimental particles to LCF, improved melt practices are being developed and implemented to reduce the frequency, size, and clustering of these particles. As these improved practices become more effective, it is anticipated that increased attention will be directed towards reducing carbides. The most direct approach to eliminate carbides as LCF initiation sites in alloy 718 is to lower the carbon content. However, there is concern in the superalloy community that very low carbon would result in higher creep rates and less stable grain size control. Also, Stroup and Pugliese (1,2) reported lower stress rupture life and elongation as carbon was reduced.

Another motivation for evaluating reduced carbon content in 718 is the stringent toughness requirement for oil patch applications. It is conceivable that improved toughness could be achieved by reducing the size of carbide stringers and clusters. This study was conducted to determine if reduced carbon would improve toughness for oil patch applications; also, it was directed toward establishing if detrimental effects would result from lowering the carbon for rotating 718 parts in jet engines in order to improve LCF life.

Procedure

Chemistry and Processing

Billets 8 inches in diameter were processed from 20 inch diameter ingots that were vacuum induction melted and vacuum arc remelted. Chemistries for low (.008), medium (.018), and standard (.027) carbon heats are shown in Table I. Columbium was reduced slightly for the low carbon heat relative to the standard heat to account for a decrease in the amount of columbium partitioned to columbium carbides. The medium carbon heat had very low columbium to allow evaluation to oil patch applications which require low columbium.

TABLE I CHEMICAL ANALYSIS OF 718 HEATS (WT. %)

Elements	.008 C	.018 C	.027 C
C	.008	.018	.027
Ni	52.78	52.47	52.96
Fe	18.97	19.74	18.42
Cr	17.92	17.64	17.82
Cb	5.24	5.08	5.31
Ta	.01	.01	.02
Mo	2.92	2.89	2.92
Ti	.93	.94	.95
Al	.51	.52	.44

Ingots were press forged at 2025°F to an intermediate size of 14 inches in diameter. In order to establish if a relationship exists between processing and carbon level, the intermediate size was radial forged on a Model 55 GFM machine by two different processes; standard and mini-grain. Standard processing entailed radial forging above the delta solvus at 1875°F. Mini-grain billet was radial forged well below the delta solvus temperature. Also prior to radial forging, the 14 inch diameter billet was heated at 1650°F to precipitate out delta phase for grain size control. As-forged grain size at mid-radius and center locations for standard processing was ASTM 6/7. For mini-grain processing, grain size was ASTM 10 and extensive delta phase was present.

Table II shows the two heat treatments that were used; A is the standard aerospace heat treatment while B is appropriate for oil patch applications where corrosion and toughness become important factors. Only heat treatment A was used for mini-grain material. The solution temperature for heat treatment B increased the as-forged grain size to about ASTM 5 with grains as large as (ALA) 3.

TABLE II HEAT TREATMENTS

H. T. Code	Heat Treat Cycle
A	1750°F/1 HR/AC, 1325°F/8 HRS/FC to 1150°F/8 HRS/AC
B	1875°F/1 HR/WQ, 1450°F/6.5 HRS/AC

Evaluation

At-size tensile, stress rupture, and creep test samples were from longitudinal mid-radius locations. Charpy specimens were transverse with the notch parallel to the billet axis such that the crack propogated radially outward. Results from at-size testing represent the average of three tests. Pancakes were produced by hammer forging coupons 2 inches thick to 5/8 inches thick at 1850°F. Average as-forged grain size for pancakes was ASTM 8.5 with grains as large as ASTM 5. Pancake specimens were from positions corresponding to near center billet locations.

Results

Tensile Properties

Tables III and IV present at-size room and elevated temperature tensile data for heat treatments A and B, respectively, for standard processing; these data are shown graphically in Figures 1 and 2. Similar data is given in Table V and Figure 3 for mini-grain processed material with heat treatment A. Strengths are higher for mini-grain processing because of the finer grain size. Pancake tensile properties for standard processing are shown in Table VI and Figure 4 for heat treatment A.

It can be seen that lowering carbon is not detrimental to tensile properties. In pancakes, where carbide stringers are not aligned along the tensile samples, a ductility improvement with lower carbon was observed.

TABLE III AT-SIZE TENSILE PROPERTIES - HEAT TREAT A

Temperature	% C	UTS (ksi)	.2% YS (ksi)	% EL	% RA
Room	.008	202.3	177.3	18.8	40.8
Room	.027	205.8	175.3	22.0	38.3
1200°F	.008	163.7	147.9	21.8	59.2
1200°F	.027	171.3	149.9	24.5	60.0

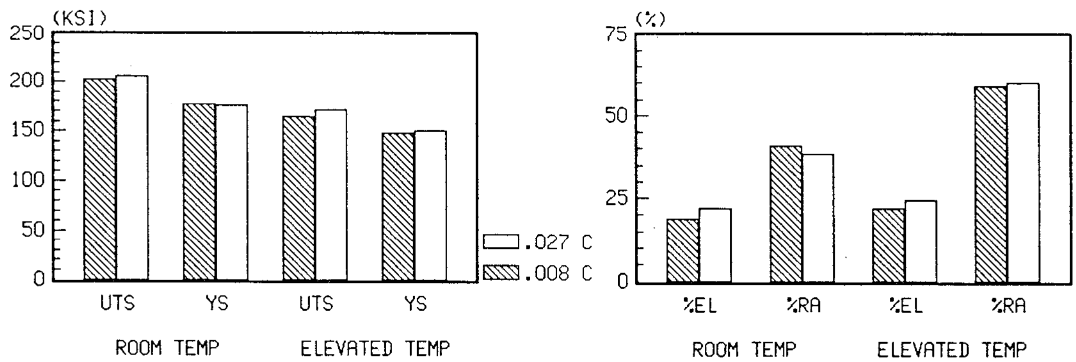


Figure 1: At-size tensile properties - Heat Treat A.

TABLE IV AT-SIZE TENSILE PROPERTIES - HEAT TREAT B

Temperature	% C	UTS (ksi)	.2% YS (ksi)	% EL	% RA
Room	.008	174.9	126.9	32.9	48.7
Room	.018	174.4	123.9	32.7	53.2
Room	.027	177.8	126.9	32.4	50.2
250°F	.008	167.6	121.4	32.5	49.1
250°F	.018	167.4	119.4	31.6	51.5
250°F	.027	168.6	121.7	31.3	50.0

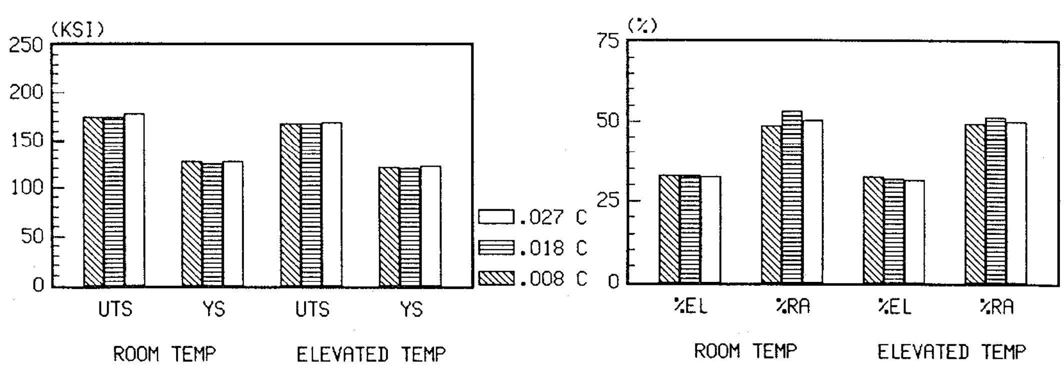


Figure 2: At-size tensile properties - Heat Treat B.

TABLE V AT-SIZE MINI-GRAIN TENSILE PROPERTIES - HEAT TREAT A

Temperature	% C	UTS (ksi)	.2% YS (ksi)	% EL	% RA
Room	.008	218.8	179.9	19.3	31.9
Room	.027	212.5	172.3	18.4	31.7
1200°F	.008	178.1	148.5	24.5	60.7
1200°F	.027	175.5	143.3	27.2	59.6

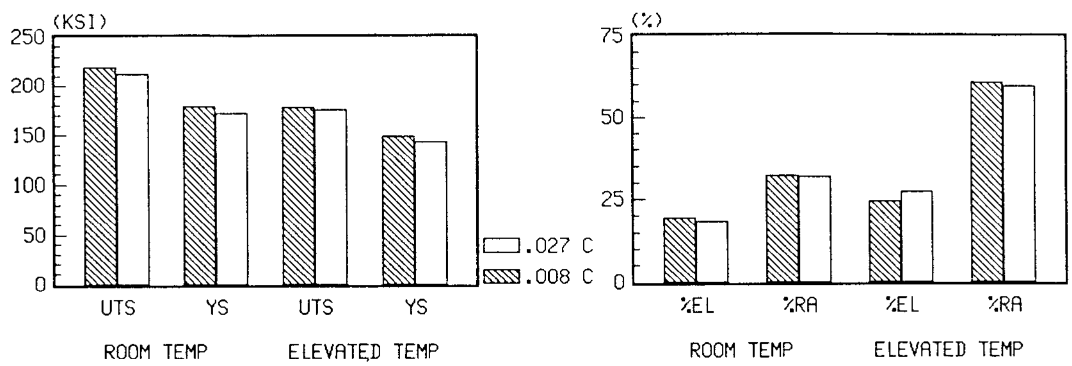


Figure 3: At-size tensile properties for mini-grain Heat Treat A

TABLE VI PANCAKE TENSILE PROPERTIES - HEAT TREAT A

Temperature	% C	UTS (ksi)	.2% YS (ksi)	% EL	% RA
Room	.008	211.0	175.2	19.6	35.2
Room	.027	212.1	178.7	17.7	31.0
1200°F	.008	174.4	151.8	25.5	64.4
1200°F	.027	178.6	155.2	19.7	45.9

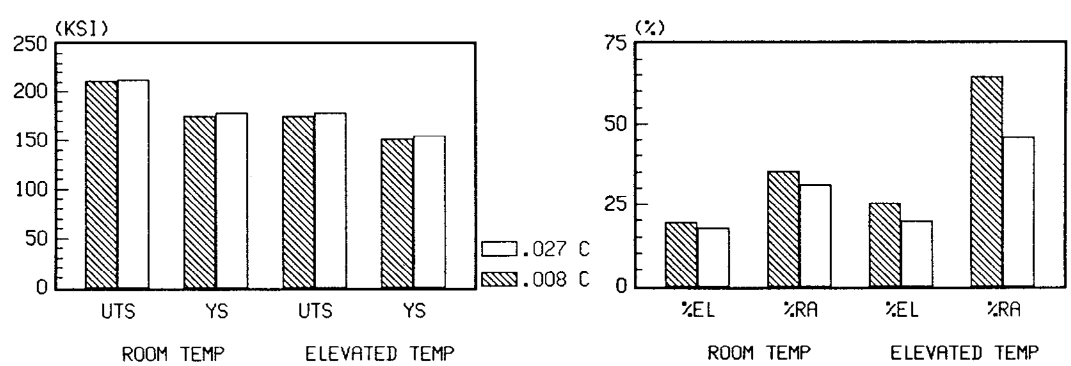


Figure 4: Pancake tensile properties - Heat Treat A

Stress Rupture and Creep Properties

At-size stress rupture results are given in Table VII for both standard and mini-grain processing with heat treatment A. Creep results are presented in Tables VIII and IX for standard and mini-grain processing, respectively. There does not appear to be any significant effects of carbon on stress rupture or creep rates.

TABLE VII AT-SIZE STRESS RUPTURE PROPERTIES AT 1200°F AND 100 KSI - HEAT TREAT A

% C	Processing	Life Hrs.	% EL
.008	Standard	282.7	21.3
.027	Standard	329.8	30.2
.008	Mini-Grain	66.7	33.0
.027	Mini-Grain	88.3	31.5

TABLE VIII AT-SIZE CREEP PROPERTIES AT 1100°F AND 120 KSI - HEAT TREAT A

% C	% Creep After 25 Hours	% Creep After 870 Hours	Life @ .2% Creep
.008	.052	1.034	319.2
.027	.074	.890	235.9

TABLE IX AT-SIZE MINI-GRAIN CREEP PROPERTIES AT 1100°F AND 120 KSI - HEAT TREAT A

% C	% Creep After 25 Hours	Life @ .2% Creep
.008	.105	74.7
.027	.094	76.2

Charpy and Fracture Toughness Properties

Both Charpy and fracture toughness improved substantially with decreasing carbon for heat treatment B as demonstrated in Table X and Figure 5. This improvement also occurred with heat treatment A as shown in Table XI. However, the toughness values for all carbon levels are lower for heat treatment A.

TABLE X AT-SIZE CHARPY AND FRACTURE TOUGHNESS PROPERTIES
HEAT TREAT B

% C	CHARPY TEST Energy Ft-Lbs	Mils Lateral Expansion	Percent Shear Fracture	FRACTURE TOUGHNESS K_{EE} ksi(In.)$^{1/2}$
.008	81.0	42.7	30.0	303.7
.018	68.7	36.0	30.0	277.7
.027	47.0	22.7	20.0	243.5

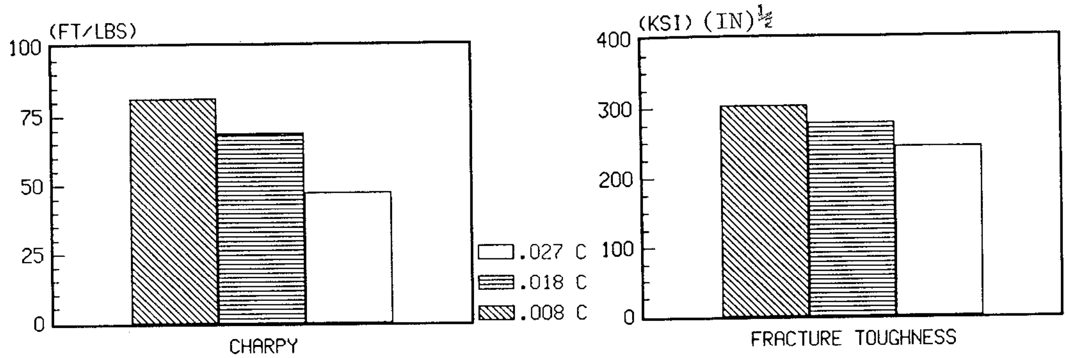


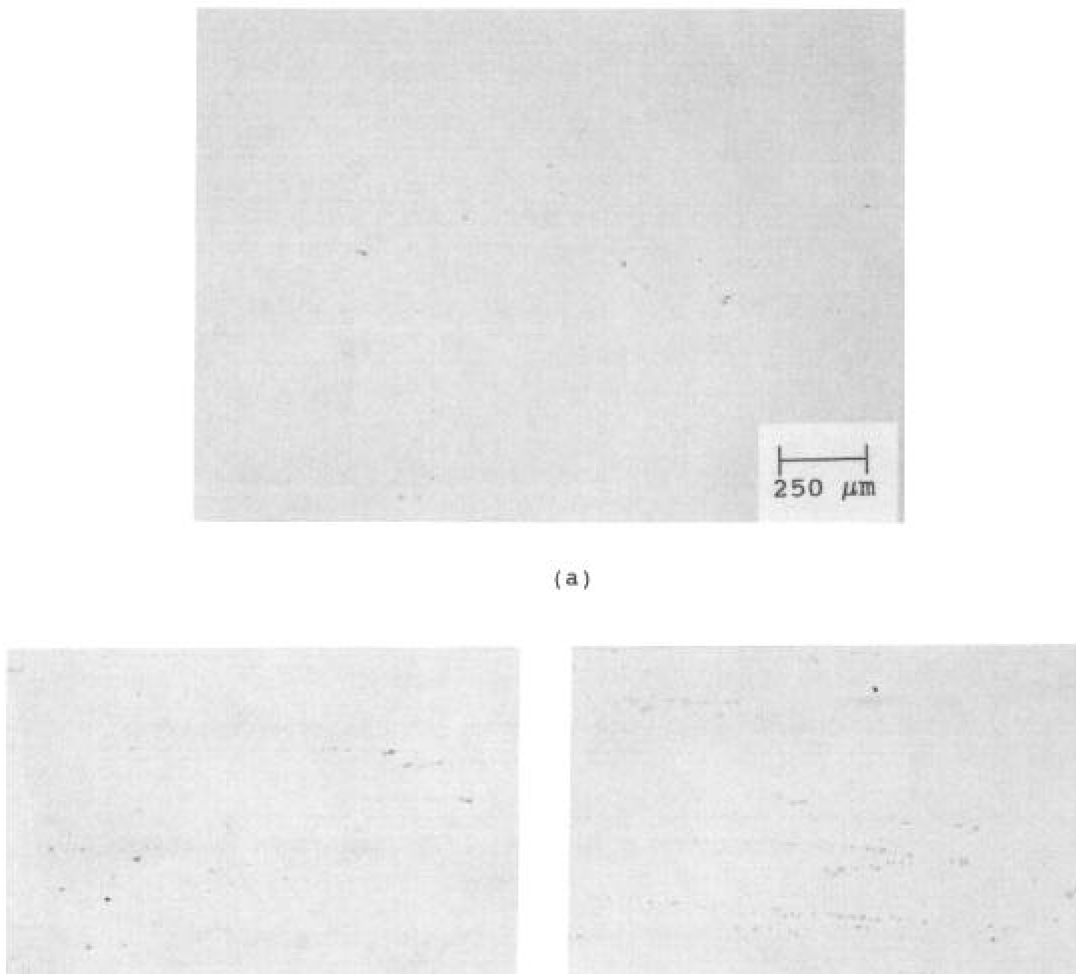
Figure 5: At-size Charpy and Fracture Toughness Properties
Heat Treat B

TABLE XI AT-SIZE CHARPY AND FRACTURE TOUGHNESS PROPERTIES
HEAT TREAT A

% C	CHARPY TEST Energy Ft-Lbs	Mils Lateral Expansion	Percent Shear Fracture	FRACTURE TOUGHNESS K_{EE} ksi(In.)$^{1/2}$
.008	20.5	10.0	10.0	138.9
.027	14.0	4.0	10.0	111.4

Structures

The improvement in carbide distribution with decreasing carbon is illustrated in Figure 6. With .008 C, no significant carbide stringers were observed. Pictures were taken at a magnification of 50X.



(a)

(b)

(c)

Figure 6: Typical longitudinal carbide distributions for
(a) .008 C (b) .018 C (c) .027 C

Grain size stability was evaluated by heating billet samples at temperatures from 1800 to 1900°F in increments of 25°F for 2, 4, and 8 hours. Grain size results for selected temperatures and times are shown in Table XII for standard processed material. Over the temperature range and times evaluated, a significant effect of carbon on grain size stability was not observed.

TABLE XII GRAIN SIZE STABILITY

	Grain Size	
Temp.°F/Time (Hrs)	.008 % C	.027 % C
1800/8	7	7
1875/2	5 ALA 2	5 ALA 3
1875/8	3 ALA 0	3 ALA 1
1900/8	1 ALA 0	1 ALA 0

Discussion

The lack of any deleterious effects on tensile, stress rupture or creep properties even at very low carbon levels is consistent with results reported by J. M. Moyer(4). As suggested by J. M. Moyer, the low stress rupture results observed by Stroup and Pugliese(1,2) for .008% C were probably related to melt practices in effect at that time (1967). Since there are no deleterious effects, decreasing carbon offers potential for improving LCF life by reducing the frequency and size of carbide stringers and clusters. However, engine designers may not be able to take advantage of this improvement until melt practices are such that clusters of oxides and/or nitrides are not present.

If at-size tensile testing had been done transverse rather than longitudinal in this study, an increase in ductility with decreasing carbon probably would have been observed. This effect was seen for pancake testing where testing was done across carbide stringers.

The improvement in toughness, as measured by Charpy V-Notch and Fracture Toughness testing, was substantial. It provides an opportunity to increase toughness in 718 components for oil patch applications where toughness is of major concern. Lower carbon apparently improves toughness by improving carbide distributions.

Although grain growth was not found to be dependent on carbon content for temperatures up to 1900°F, grain growth could be extensive for very low carbon at higher temperatures. For example, J. M. Moyer(4) found more grain growth for .003% C compared to .034% C with increasing temperature between 1900°F and 2200°F.

Conclusions

1. Reducing carbon in alloy 718 to .008% had no significant deleterious effect on tensile or creep properties for material processed above or below the delta solvus temperature. This was true for both aerospace and oil patch heat treatments. Properties included room 250°F, and 1200°F tensile, 1200°F stress rupture, and 1100°F creep tests.

2. Frequency and size of carbide stringers were reduced with decreasing carbon and were virtually eliminated at .008% C. Therefore, reducing carbon has the potential to improve LCF life.

3. Toughness, as measured by Charpy and Fracture Toughness testing improved substantially with decreasing carbon.

4. Grain growth was found to be essentially independent of carbon over the ranges of temperatures and times investigated. The temperature range extended to 1900°F.

References

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