THE EFFECTS OF TANTALUM FOR COLUMBIUM SUBSTITUTIONS IN ALLOY 713C

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Summary

IN 713C with four levels of Ta and Cb were examined in the as-cast and four HIP plus heat treated conditions. Tensile and rupture properties were evaluated along with microstructures and phases present for each alloy and processing condition. It was found that the substitution of Ta for Cb improves the heat treatment response of IN 713C, significantly affecting the 1400F(760C) and 1800F(980C) rupture properties after HIP and aging. In particular, a 1.75% Ta-modified alloy with 2200F(1205C) HIP and 1700F(925C) age has greater 1800F(980C) rupture life and ductility than the as-cast reference IN 713C alloy. For the compositions examined, the Ta substitutions increased γ' and carbide stability but resulted in formation of sigma phase (higher Nv); further work to balance the alloy chemistry while retaining the improvements in mechanical properties is recommended.

Introduction

Alloy 713C was the first of several cast nickel-chromium base superalloys developed by the International Nickel Company during the 1950's. The alloy was originally intended to be air melted as master alloy, then remelted under argon for production of castings. With the rapid progress of vacuum technology during those years, it was found that increased high temperature properties could be obtained by vacuum melting both during master alloy formulation and remelting for casting.

The alloy is still being produced and utilized in large tonnage. There are many good reasons for this: the alloy has good castability, possesses excellent strength properties up to 1800F(980C), remarkable resistance to oxidation and thermal fatigue plus microstructural stability. From a strategic raw materials point of view, it also has the advantage of being cobalt-free.

The nominal composition of the alloy includes two weight percent columbium. At the time IN 713C was developed, there was difficulty in separating Cb and Ta as alloying elements. Even the methods of chemical analysis for the elements were uncertain and specifications were written on the basis of the sum of Cb and Ta. Although both of these problems were solved many years ago, the separate effects of Cb and Ta on mechanical properties apparently have not been determined. The effect of substituting Ta for Cb in IN 713C, therefore, is the subject of the present investigation.

Experimental Procedure

Four small heats of IN 713C were produced with different Ta and Cb levels (Table I); the control heat conformed to the nominal composition of IN 713C. Differences in the compositions of the four alloys other than the Ta and Cb variations are believed to be of secondary importance. Also included in Table I is an Nv calculation (PWA 35) for each alloy. It can be seen that the Nv value increases with increasing Ta because, on an atomic basis (Cb + Ta/2), more Ta was added than Cb removed. This was done to enhance the impact of the Ta substitutions even though it decreased the stability of the alloy (increasing Nv).

Table I. Composition of Ta-modified IN 713C Alloys *

Alloy	Ta	Cb	Cb+Ta/2	C	Cr	Mo	Al	Ti	Zr	B	Nv
Control	<0.05	2.0	2.0	0.07	13.2	4.4	6.0	0.8	0.05	0.008	2.15
1.5% Ta	1.5	1.8	2.4	0.09	13.5	4.6	6.3	0.8	0.07	0.011	2.37
1.75% Ta	1.75	1.6	2.6	0.10	13.1	4.5	6.2	0.8	0.07	0.011	2.28
3.5% Ta	3.6	1.0	2.8	0.09	12.7	4.5	6.3	0.8	0.07	0.011	2.35

* weight %

Test material for this program consisted of vacuum investment cast oversize test bars. Sixteen bars were cast in each of three molds prepared for the four alloys. Duplicate mechanical testing was conducted on test bars machined from oversize bars for each alloy in the following conditions:

As-Cast

2200F/15ksi/4h HIP + 1700F/16h age
(1205C/105MPa/4h HIP + 925C/16h age)

2200F/15ksi/4h HIP
(1205C/105MPa/4h HIP)

2165F/25ksi/4h HIP + 1700F/16h age
(1185C/170MPa/4h HIP + 925C/16h age)

2165/25ksi/4h HIP
(1185C/170MPa/4h HIP)

The mechanical tests conducted were room temperature tensile, 1400F/77ksi(760/530MPa) creep rupture and 1800F/22ksi(980C/150MPa) creep rupture. One oversize test bar of each of the four alloys in the five process conditions was heat treated at 1600F(870C) for 1000h to evaluate phase stability. Gradient bar heat treatment and differential thermal analysis were used to measure the γ' solutioning temperature of each alloy in the as-cast condition.

Optical metallography was conducted on each alloy in each condition. Grain size was determined on all rupture test bars by the intercept method and the carbide volume percent was determined using the point count method. Carbide and γ' lattice parameter measurements were made on each alloy in each condition. The volume percent γ' was obtained for each alloy in both HIP'ed and aged conditions using the point count method on transmission electron microscope (TEM) two stage carbon replicas. A detailed analysis of phases was conducted on the control and 1.75% Ta alloys in the as-cast and 2200F(1205C) HIP and aged conditions and also for the same conditions after a 1600F(870C)/1000h stability exposure. These analyses included x-ray diffraction of extracted carbides and _in situ_ semi-quantitative chemical analysis of the carbides, sigma, gamma and gamma prime phases using a microprobe and a SEM (energy dispersive x-ray analysis (EDAX)).

Results

Mechanical Properties

The mechanical property results are shown in Figures 1 and 2. The properties are a complex function of both the variation in Ta and Cb and the thermal processing. The effects are most apparent in the ductility and the 1800F/22ksi(980C/150MPa) rupture lives. The control alloy shows the typical response associated with the thermal processing of IN 713C - a lowering of strength (tensile and rupture) along with a substantial increase in rupture ductility. This behavior extends to the 1.5% Ta alloy but the loss of 1800F(980C) rupture life with thermal processing is reduced. Examination of the properties of the 1.75% Ta alloy shows that this level of substitution has improved the alloy's response to heat treatment. When the alloy is HIP'ed at 2200F(1205C) and aged at 1700F(925C), both rupture life and ductility are increased

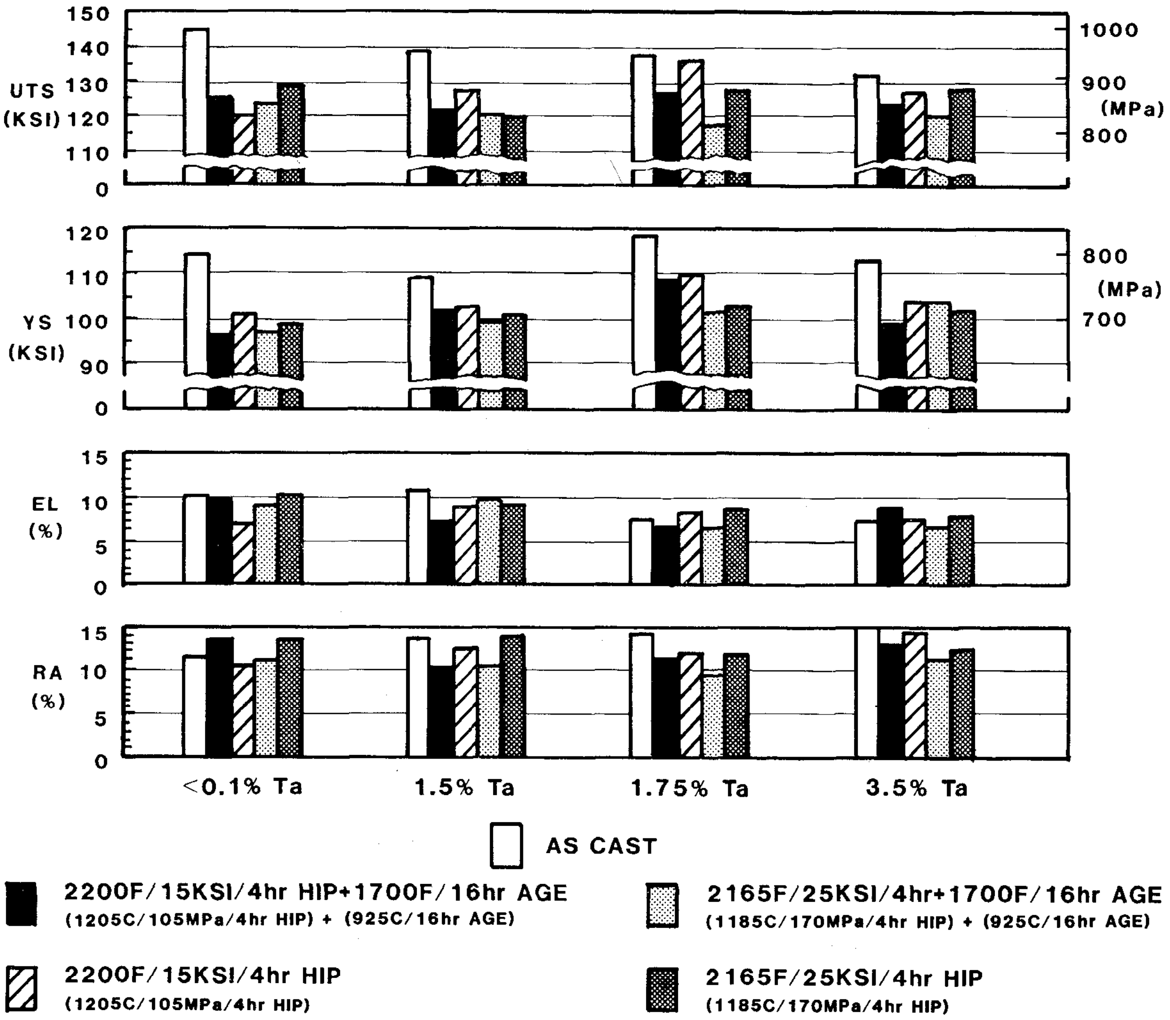


Figure 1. Room Temperature Tensile Properties of a Control (<0.1% Ta) and Three Ta-modified IN 713C Alloys.

compared to the as-cast condition. This is also the only experimental alloy where both the 1400F(760C) and 1800F(980C) rupture life and ductility are improved by the same thermal process. Although the 1400F(760C) rupture life of the 1.75% Ta alloy in the above-mentioned HIP'ed and aged condition is slightly lower than that of the as-cast control alloy, this alloy is clearly superior to the control alloy at 1800F(980C). The 3.5 Ta alloy exhibited the lowest 1400F(760C) rupture life in all thermally processed conditions.

The effect of thermal processing on 1400F(760C) rupture life is similar for all the alloys, only the magnitude of the changes being affected by the Ta level. The pattern of 1800F(980C) properties varies significantly from alloy to alloy. An examination of fracture surfaces and fracture path of the 1800F(980C) test bars did not indicate a cause for these differences.

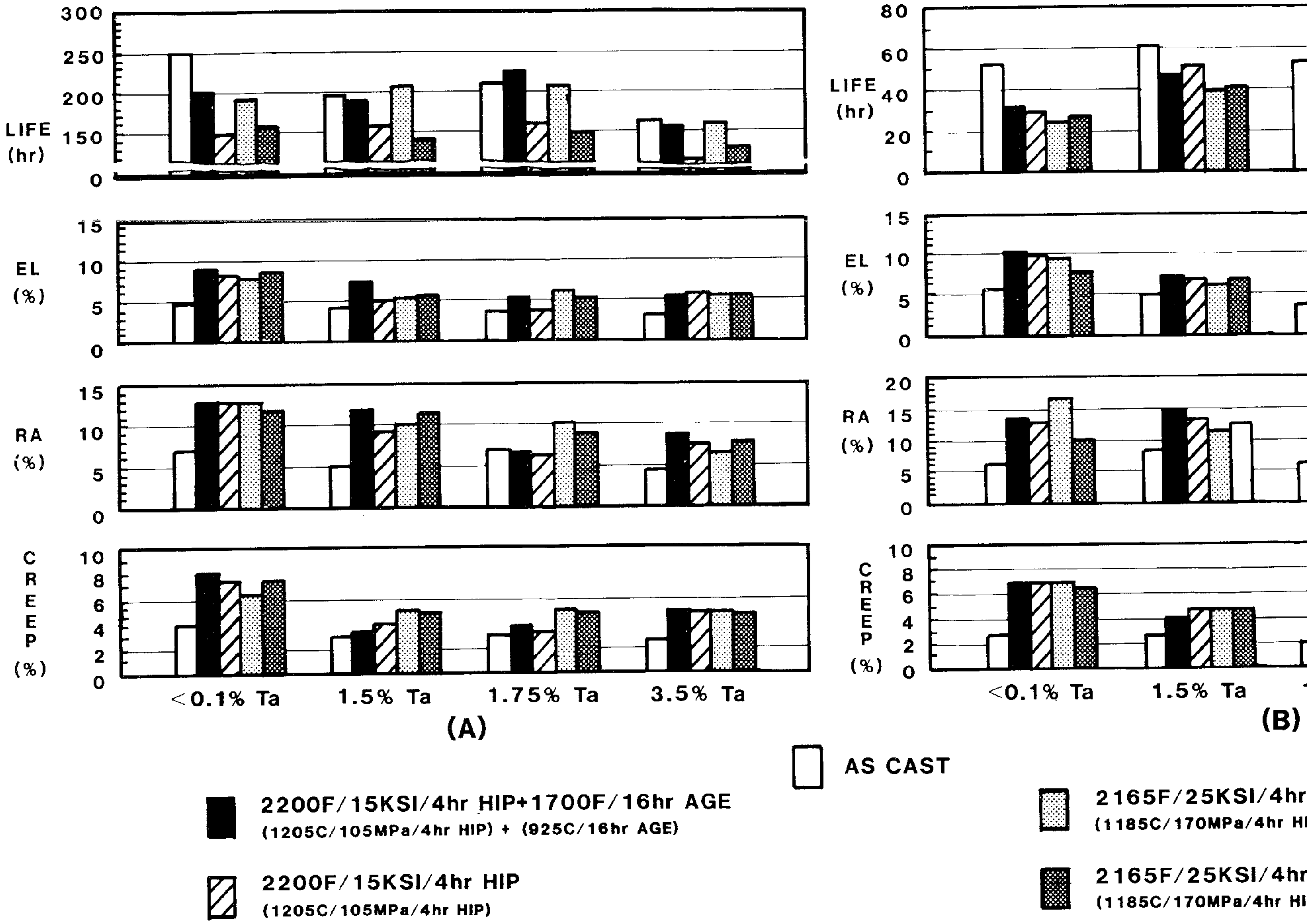


Figure 2. 1400F/77ksi(760C/580MPa) Creep Rupture Properties (A) and 1800F/22ksi(980C/150MPa) Properties (B) of a Control (<0.1% Ta) and Three Ta-modified IN 713C Alloys.

Metallographic Observations

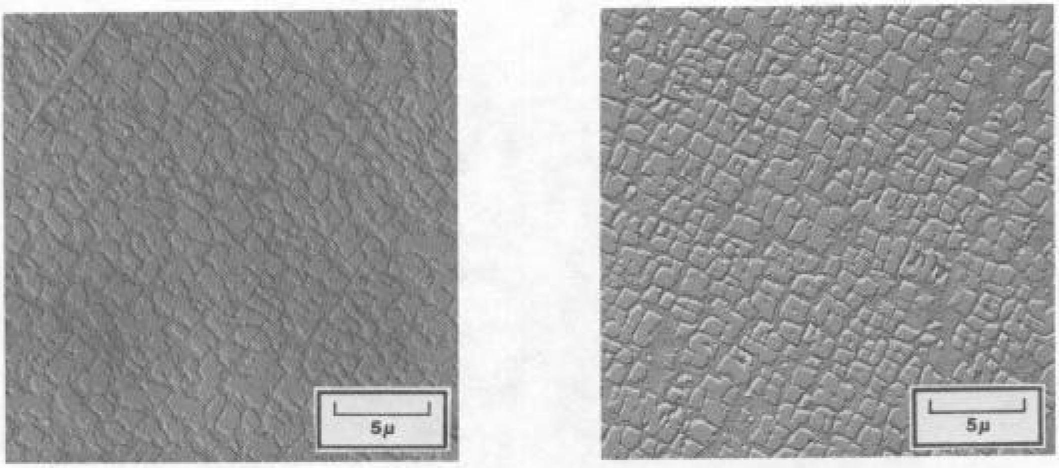
The impact of Ta and thermal processing on the γ' structure is the most prominent feature to be seen metallographically, Figure 3. The as-cast and HIP'ed samples showed a duplex γ' structure with considerable γ' growth after HIP. The HIP'ed and aged samples show no fine γ', it being dissolutioned at 1700F(925C). These general observations were true for all four alloys but the size of the γ' varied with composition. The γ' size tended to decrease with higher Ta concentrations for a given thermal process. This is due to the stabilizing effect of Ta on γ'. The DTA and gradient bar evaluations showed the control alloy to have a γ' solutioning temperature of 2155F(1180C); the 1.5% Ta alloy, 2170F(1190C); the 1.75% Ta alloy, 2200F(1205C); and the 3.5% Ta alloy, 2215F(1215C). These results are consistent with the partial solutioning seen after the 2165F(1185C) HIP in the 1.5, 1.75 and 3.5% Ta alloys and in the 3.5% Ta alloy after the 2200F(1205C) HIP.

Figure 4 shows the stabilizing effect of Ta additions on the MC carbides after HIP and aging. The control alloy shows large amounts of $M_{23}C_6$ carbides in both HIP'ed and aged conditions. The Ta-modified alloys also exhibit $M_{23}C_6$ formation but to a much lesser extent. Microprobe and EDAX analyses show Ta substituting for Cb in MC carbides and γ', but x-ray diffraction of carbides and γ' indicated no change in lattice parameter. This suggests that Ta substitution for Cb in IN 713C either stabilizes the MC carbides or inhibits the formation of $M_{23}C_6$ carbides. The measurements of grain size (grain intercept), volume percent carbide and γ' are shown in Table II. Because the standard deviations of these measurements are large, it is concluded that the Ta substitution for Cb does not have a major effect on any of these characteristics.

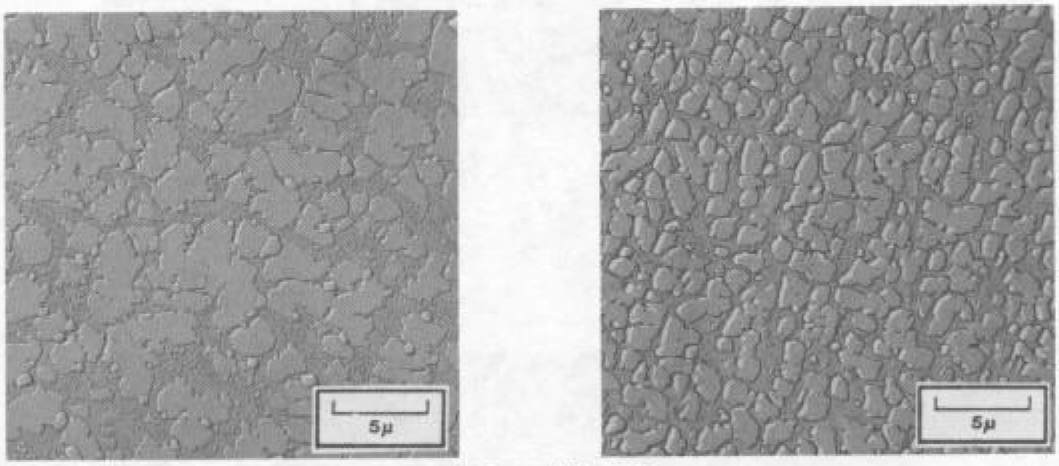
Table II. Microstructural Parameters of Ta-modified IN 713C Alloys

Alloy	Grain Intercept (mm)		Volume% Carbides		Volume% γ'	
	Mean	σ	Mean	σ	Mean	σ
Control	1.1	0.25	4.7	1.5	60	3.8
1.5% Ta	1.4	0.25	4.7	1.0	64	1.7
1.75% Ta	1.4	0.22	4.4	1.1	65	2.0
3.5% Ta	1.4	0.31	4.1	1.3	63	4.3

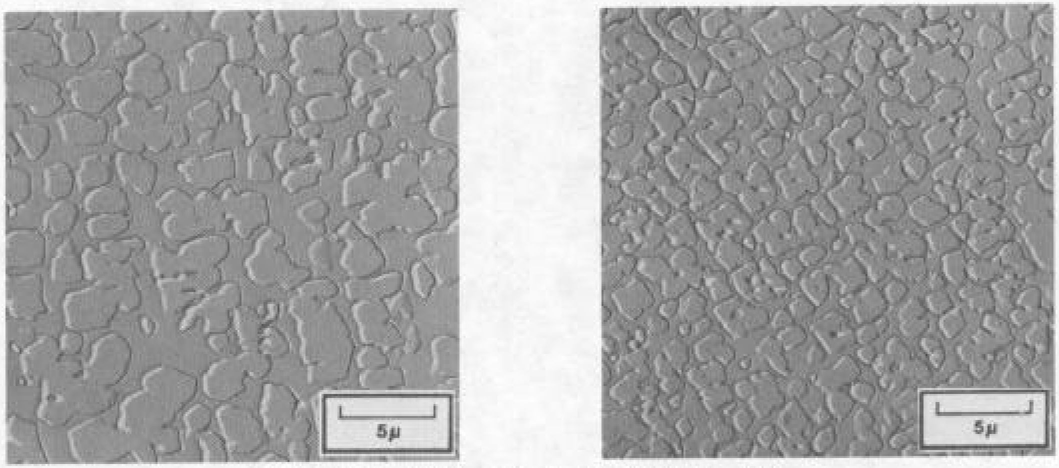
Stability testing at 1600F(870C) for 1000h showed the sigma phase content increases as Ta increases as shown in Figure 5 for the as-cast and exposed conditions. This was expected based on the Nv calculations for the compositions. Further studies are recommended to balance the alloy chemistry to restore microstructural stability while retaining the improved mechanical properties.



AS-CAST



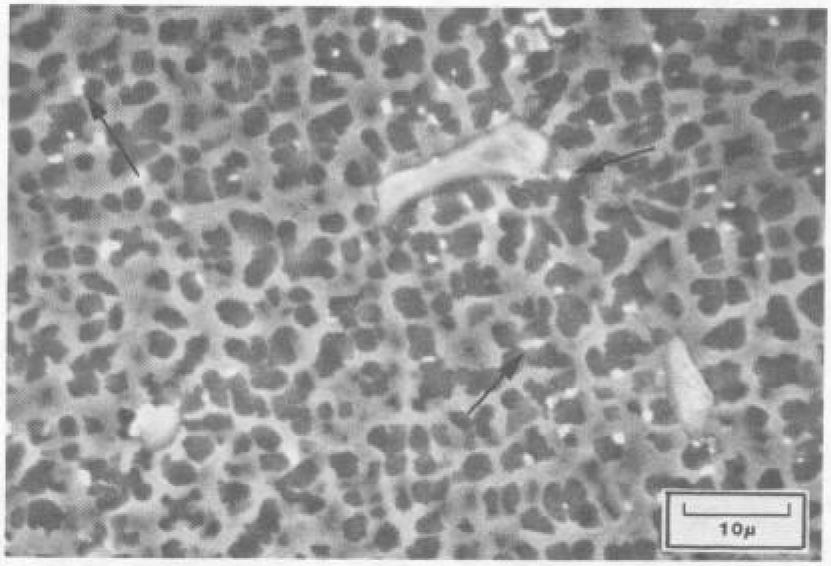
2200F/15KSI/4h HIP
(1205C/105MPA/4h)



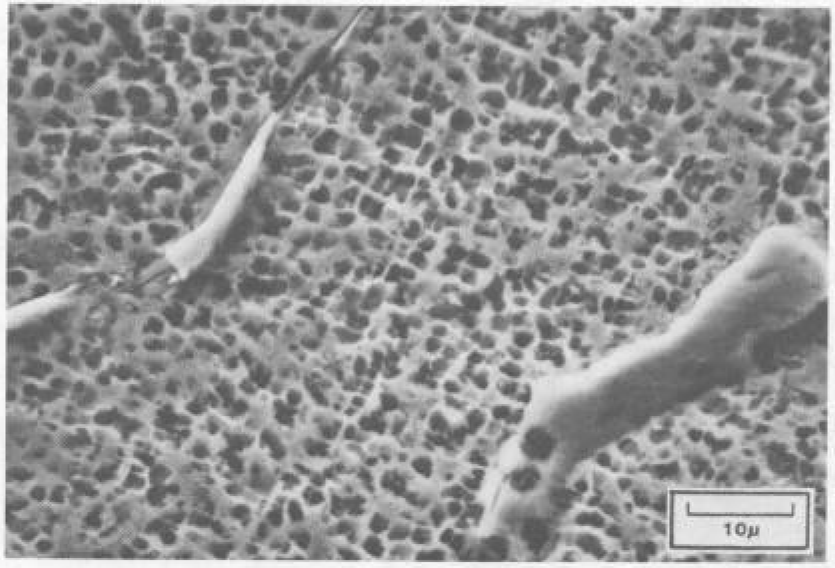
2200F/15KSI/4h HIP + 1700F/16h AGE
(1205C/105C/4h) (930C/16h)

<0.1% Ta Alloy (Control) 1.75% Ta Alloy

Figure 3. Gamma Prime Structure in the Control and 1.75% Ta-modified IN 713C Alloys (TEM replica)

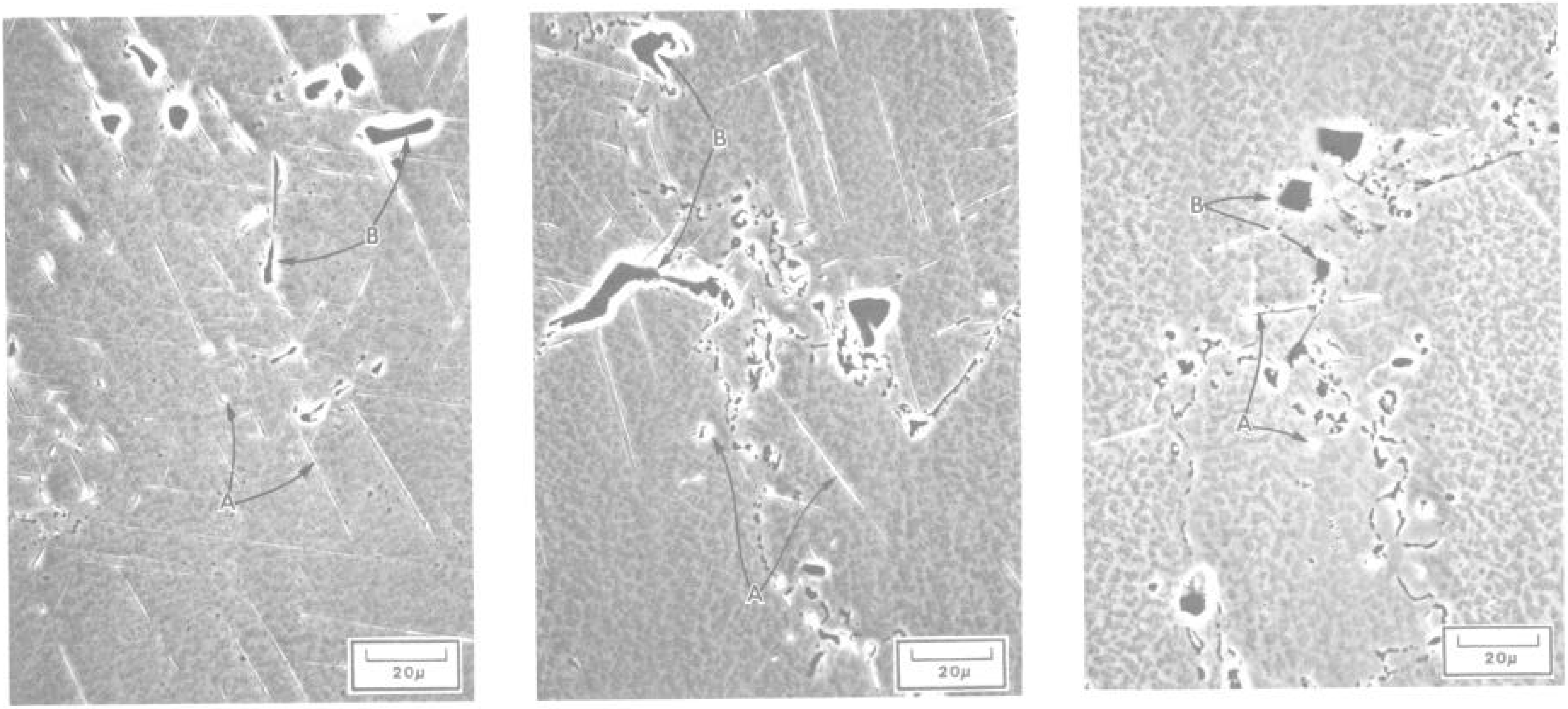


a) <0.1% Ta Alloy (Control)



b) 1.75% Ta Alloy

Figure 4. Scanning Electron Micrographs of the Control and a Ta-modified IN 713C Alloy after 2200F(1205C) HIP and 1700F(925C)/16h Age, showing $M_{23}C_6$ Carbides (arrows) in the Control Alloy.



a) 3.5% Ta Alloy

b) 1.75% Ta Alloy

c) <0.1%Ta Alloy (Control)

Figure 5. Scanning Electron Micrographs Showing Effects of a 1600F (870C)/1000h Stability Heat Treatment on the Control and Ta-modified IN 713C Alloys. A - Sigma; B - $M_{23}C_6$