EFFECT OF COMPOSITIONAL MODIFICATIONS

ON THE MECHANICAL BEHAVIOR OF IN706

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Abstract

The alloy IN706 in the two step heat treatment condition sufferes from the so called stress accelerated grain boundary oxidation "SAGBO" effect at 650°C and 700°C. This was demonstrated by the drop in ductility under constant slow strain rate testing. The effect of Mg, B and Ce additions on the SAGBO effect in IN706 was studied. The B and Mg dopping alleviated the SAGBO phenomena while the Ce caused a degradation in the hot tensile ductility at all strain rates.

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Introduction

Alloys IN718 and its derivative IN706 were developed more than 20 years ago. IN718 has been in use in a wide range of applications. Recently, IN706 has begun to be selected for different industrial applications because of its good mechanical properties, ease of fabrication and good machinability. The metallurgy and phase transformations in both alloys are well documented (1-3). A common characteristic in these iron-nickel alloys is their susceptibility to environmental effects (4,5). The consequences of this environmental effect are degradation in the creep and fatigue crack resistance and increased notch sensitivity (4,5). In fact, the effect of air exposure on the mechanical properties especially ductility, of several nickel-base superalloys has been reported (6,7). It was proposed that the observed embrittlement effects of air exposure in these alloys are due to grain boundary weakening by the diffusing oxygen (6). In addition, it was also reported that minor additions of specific elements such as boron can be useful to reduce such environmental induced embrittlement (6). In case of IN718, it has been reported that applying specific heat treatment schedule can alleviate the degradation in crack growth resisitance (5). The aim of this study was to report on the effects of minor additions of B, Ce and Mg on the susceptibility of IN706 to environmental embrittlement. This has been achieved using constant low strain rate tensile testing.

Materials and Experimental Procedure

A forged heat of IN706, with the chemical composition shown in Table I, was acquired for this study.

Table I Chemical Composition

C	Mn	Si	Cr	Ni	Ti	Al	Nb	Fe
0,021	0,08	0,09	16,02	41,39	1,71	0,18	2,81	base

Several slugs 60mm in length and 12mm in diameter were cut from this heat and were melted under Ar in a water cooled copper crucible. Other slugs were prepared in the same way after adding 0,157%wt B, or 0,008%wt Mg or 0,0065%wt Ce during melting. All of these bars were then heat treated according to the following schedule

Solution annealing	990°C / 10h / oil quenching
Precipitation hardening	730°C / 16h / furnace cooling to 620°C / 16h / air cooling

Hence, one can ensure that all bars were similarly prepared. Tensile test specimens were then machined from these bars. Tensile testing was done in air at constant strain rates ranging from 7.1 10^{-4} sec^{-1} to 3.5 10^{-7} sec^{-1} at different temperatures. The elongation at fracture was determined for all the specimens.

Results and Discussion

Figure 1 presents the results of the constant strain rate tests in the form of tensile ductility vs strain rate at 705°C for the base material as well as the modified compositions. One can clearly see that the base material exhibited a reduction in tensile elongation as the strain rate decreases at 705°C. Fractographic investigations indicated intergranular fracture. In addition, one can observe that the B and Mg additions tend to alleviate this embrittlement effect. It has been reported that the Nb containing alloys are inherently sensitive to environmental effect, specifically oxygen (8). This sensitivity to environment depends on the Nb content in the alloy as well as on the test temperature (8). It is noteworthy to point out that it was shown by Wie and coworkers that the crack growth rate of IN718 is 200 times faster in air than in argon or vacuum at 650°C (8). Hence, it was suggested by Wie that the segregation of Nb to the grain boundaries and its reaction with oxygen to be responsible for the enhancement of creep crack growth in IN718 (8).

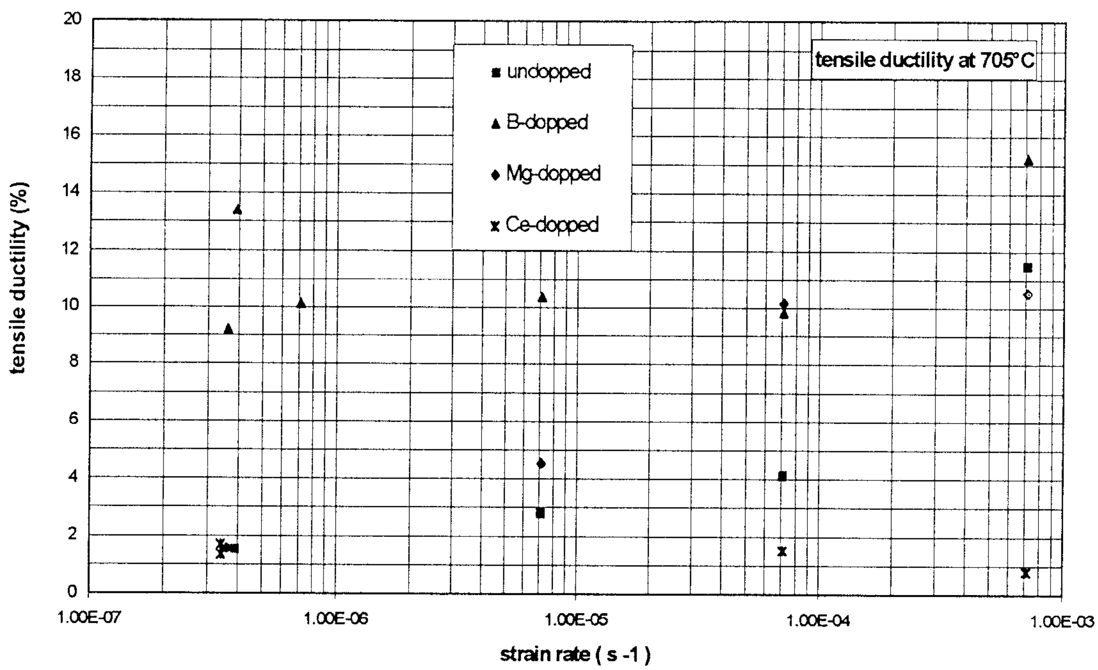

Figure 1 Effect of strain rate on the tensile ductility at 705°C for dopped and undopped IN706

This segregation resulted in part from the decompositions of NbC particles at the grain boundary. It has been long recognized that several nickel-base superalloys are highly sensitive to environmentally enhanced degradation in ductility and crack growth resistance (6). Bain and Pelloux showed that creep crack growth rates in air at 923K can differ by more than three orders of magnitude between different superalloys with very similar mechanical properties (10). They attributed the difference in sensitivity to the influence of grain boundary structure and alloy composition on the oxidation response. Hence, several investigations have been carried out to study the effect of minor alloying additions on the occurence of embrittlement as well as the related phenomena i.e. SAGBO in nickel superalloys and in iron-nickel alloys (6, 11-13). In the case of B additions, it was proposed that boron prevents the complex oxide formation at grain boundaries in the temperature range where it is known to be strongly segregated to grain boundaries (6). This could concievably block oxygen penetration down grain boundaries, which could account for the beneficial effect of boron in IN738 in reducing the susceptibility to air embrittlement (6). Figure 2 shows the effect of test temperature on the tensile ductility of undopped and B-dopped IN706 at a strain rate of 3.5 10^{-7} sec^{-1}. In fact the results of the present study, as indicated in Figures 1 & 2, confirm the observed effect of B on the SAGBO or air embrittlement, in nickel-base and iron-base alloys, in alleviating such environmental induced degradation in mechanical properties (6,14).

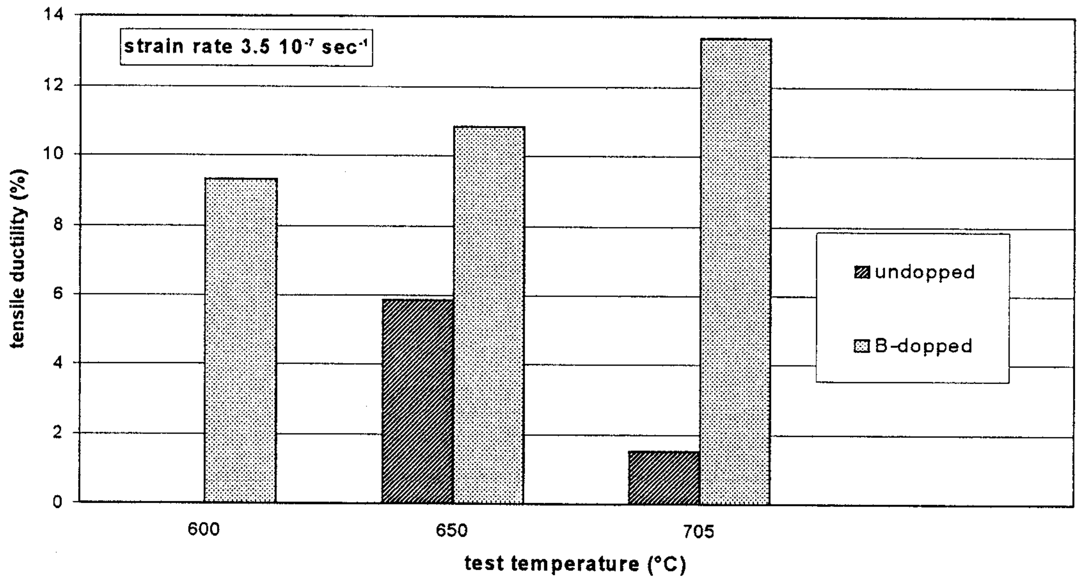

Figure 2 Effect of test temperature on tensile ductility of undopped and B-dopped IN706 at slow strain rate of 3.5 10^{-7} sec^{-1}

In case of Mg additions, one can observe in Figure 1 that the ductility of Mg dopped IN706 has been somewhat improved as compared with that of the undopped version. Recently, similar observations have been reported on the effect of Mg on the mechanical properties of IN718 (15). It was reported that the Mg additions can change the grain boundary precipitation of Ni_3Nb from continous plate-like form to discrete globular shapes and hence retards environmentally induced intergranular cracking (15). Nevertheless, Mg additions has not completely alleviated SAGBO effect.

The effect of Ce addition caused a reduction in the ductility of IN706 at all ranges of strain rates as seen in Figure 1. In fact it has been reported by Cosandey and coworkers, that the Ce plays mainly a refining aid role against S and O (11). They reported that the addition of Ce to nickel-base alloys reduces the total O and S content via the formation of Ce_2O_3, Ce_2O_2S and Ce_2S_3 compounds which are removed from the melt by flotation and convective fluxes. If the maximum Ce solubility in a specific alloy is reached, Ni_5Ce starts to form at grain boundaries. The presence of this brittle intergranular phase results in the loss of high temperature tensile ductility (11). Hence, they reported that the use of Ce for each specific alloy composition requires careful control, since low residual amounts of Ce can cause embrittlement. Therefore, one can attribute the observed embrittling effect of Ce in the present study to an excessive residual Ce amount that induced formation of grain boundary brittle phases. No trial was made in the present study to optimise the Ce addition to IN706.

The effect of these minor elements addition on the forgability of IN706 has not been studied in the present investigation. Nevertheless, Turner has reported that B additions up to 0.01% is beneficial to forgability (16). He has also reported that Mg and Ce additions should be carefully controlled for each alloy composition, since excessive additions of these elements can lead to the formation of brittle compounds that appear as grain boundary films. For example it was reported that more than 100ppm Ce in IN901 could drastically reduce the hot tensile ductility (16).

Conclusions

1.IN706 in the two step heat teatment condition suffers from SAGBO effect in the temperature range of 650°C-700°C, as demonstrated by constant slow strain rate tests.

2.The B addition exihibited a positive influence on alleviating the SAGBO effect in IN706

3.The dopping of IN706 with Mg improved somewhat the hot tensile ductility but to a lesser extent than that of B.

4.-Ce addition caused a drastic drop in the hot tensile ductility of IN706 at all strain rates.

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