The Role of Microstructure in the Mechanical Behaviour of Ti-1.5wt%Fe Alloys Containing O and N

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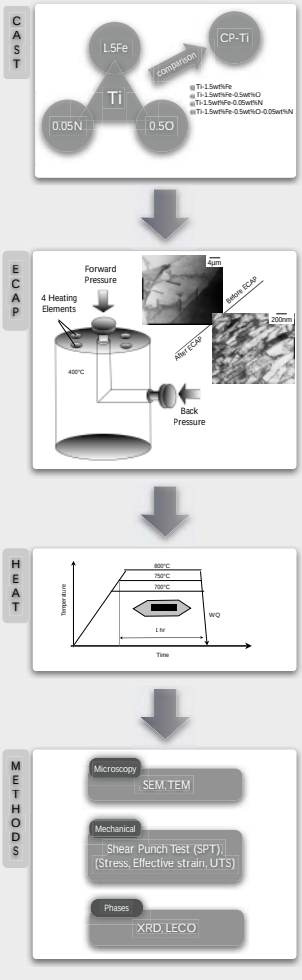
Introduction

In the past 15 years there has been an increasing interest in dilute alloys based on the Ti-Fe system [1]. It has been proved that a small addition of oxygen and/or nitrogen are necessary to achieve mechanical properties intermediate between those of CP Ti and Ti6Al4V. The effects of small changes to the heat treatment temperature in the σ+σ phase field on the properties of a Ti-1.6wt.%Fe-0.56wt.%O-0.04wt%N alloy are described. To identify contributions from the individual alloying elements the binary Ti-1.6wt.%Fe and ternary Ti-1.6wt.%Fe-0.6wt.%O and Ti-1.6wt.%Fe-0.04wt.%N alloys were also investigated, with particular reference to the role these elements play in the formation of σ phase. It was observed that Fe at the 1% level had a significant embrittling effect on the alloy, but that at 2%Fe addition the failure was via a ductile mode [2]. A preprocessing step involving Equal Channel Angular Processing (ECAP) of the cast ingots was carried out in order to reduce the as cast grain size.

Experiments



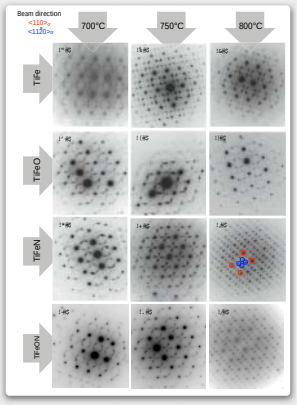
Results

Microstructure

★Recrystallisation has been achieved at all annealing temperatures and a mixture of the σ and σ phases exists.

★The σ phase is primarily equiaxed in nature, but the σ phase exists in two different morphologies depending on the alloying additions: a fine single grain at triple points for the alloy containing Fe alone, and a "finger-like" boundary structure along several grains in the quaternary alloy.

★Athermal σ was detected, in both σ morphologies at all annealing temperatures.

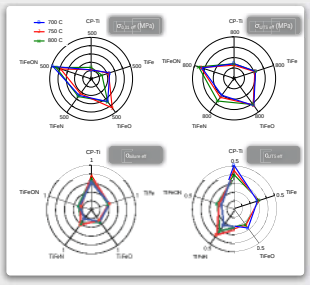


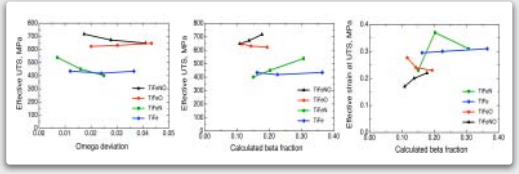
Shear Punch Test Results

★The $\sigma_{0.01\ eff}$ is the stress at 0.01 effective strain, and $\sigma_{UTS\ eff}$ is the maximum stress achieved. The strain at the $\sigma_{UTS\ eff}$ and the strain at failure may show whether or not any flow softening has occurred.

★The addition of Fe in Ti leads to an increase in the failure stress, with further increases by additions of oxygen. The quaternary alloy has a stress over twice that of CP Ti. Nitrogen, however, either alone or in combination with oxygen increases the strength as the annealing temperature increased.

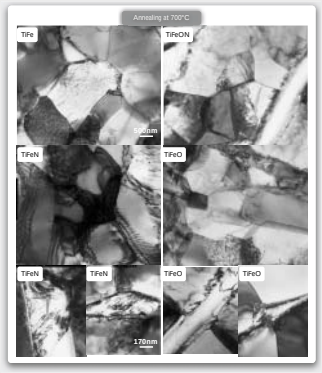
★The effective strain results are affected by both alloying addition and annealing temperature. The ductilities of all the alloys are considerably lower than that of the CP Ti.





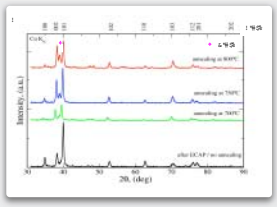
★The strength of alloys with N decreases as omega deviation increase.

★The intrinsic strengths of the σ and σ phases are either equal or are not making a significant contribution to the deformation mechanism



★The form of spots on the SAED patterns markedly changed as the annealing temperature changed.

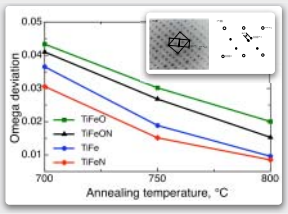
★XRD traces show the majority of the peaks being α-Ti and σ peak increases the size as the annealing temperature is increased .

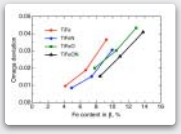


Incommensurate omega

★σ becomes increasingly disordered as the annealing temperature is decreased

★There is a linear relationship between the deviation from ideal and the annealing temperature, with the higher temperature being closest to the commensurate structure.





★Increase in annealing temp leads to decrease of Fe in σ with an effect on the nature of the ordering in σ.

★At any specific Fe content in the σ phase, the interstitial elements improves the ordering of the σ phase.

Discussion

★There has been a considerable refinement in the microstructure with the addition of Fe, and this effect has been well documented in the literature [3]. It is interesting to note that the severely deformed ECAP structure is readily recrystallised at temperatures between 700°C and 800°C, but that excessive grain growth does not accompany the recrystallisation.

★The mechanical response of these alloys is affected by more than just the overall composition. The alloying elements shift the σ_t line, which naturally affects both the fractions of σ and σ phases present, and the composition of the σ phase in particular.

★It had been expected that the presence of interstitial elements would encourage disordering, and this is apparently the case in the alloys containing oxygen [4]. Nitrogen, however has had the opposite effect, with the Ti-Fe-N alloy showing a significantly lower deviation from ideal than that of the binary alloy at all temperatures.

★σ/σ boundaries in the alloys containing N were low angle and may be the major contributing factor to the overall deformation behaviour.

★The alloys without N had random high angle σ/σ boundaries and, with the strength being independent of the fraction of σ phase, it is suggested that slip across the σ/σ and σ/σ boundaries was equally difficult and that this slip transfer dominated the deformation process.

Conclusions

★The mechanical properties of a Ti-1.6wt.%Fe alloy annealed in the σ+σ phase field can be significantly changed by the addition of relatively small amounts of O and/or N or by changing the annealing temperature by as little as 50°C.

★Oxygen has a marked effect on strength, but this effect is independent of the annealing condition. In contrast, the effect of nitrogen is related to the annealing temperature and appears to be directly related to the fraction of σ phase in the microstructure.

★Omega is present in the σ phase of all alloys, but the level of ordering of this phase is affected by the interstitial content of the alloy. The presence of σ does not have an embtittling effect on the alloy.

References

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