Ni_3Al-Fe-Cr Alloy Processed by Combined Mechanical Alloying - Reactive Synthesis

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Abstract

The paper investigates the possibility to avoid extrinsic embrittlement of Ni_3Al, also increasing the high temperature strength, by alloying with both Fe – of a high strengthening effect and Cr - able to remove a part of diffused oxygen along the grain boundaries. As Cr homogenization in Ni_3Al is difficult because of its low diffusion coefficient, for its improving a mechanical alloying (MA) step before the compound synthesis by Self-propagating High-temperature Synthesis (SHS) was adopted. The obtained better homogenization resulted in higher mechanical resistance and deformability than of the unalloyed Ni_3A/ Ni_3Al alloys of the same composition obtained without MA step.

Keywords: Nickel aluminides, Mechanical alloying, SHS, Ni_3Al alloyed with Fe and Cr

1. Introduction

Ni_3Al presents a special interest as potential substitute for superalloys in the high temperature structural applications owing to its unusual property of the yield strength increasing as temperature increases up to ~ 600 ^{0}C, associated with an outstanding oxidation and corrosion resistance at these service temperatures [1]. However, its applications are still limited by the moderate strength at high temperatures, high intrinsic brightness at ambient one and extrinsic embrittlement over 450 ^{0}C in oxidation media due to the oxygen diffusion along the grain boundaries [2].

Among the proposed methods to overcome these limitations, alloying with B proved to improve the ambient temperature ductility and with transition elements like Fe, Ti, Hf, Ta etc. – the high temperature resistance [2]. Related to the extrinsic fragility alleviation, from the few existing published information seems that alloying with Cr is suitable as it remove a part of the diffused oxygen [3], [4].

This paper investigates even the possibility to alleviate this Ni_3Al embrittlement and to improve its high temperature resistance by alloying with both Cr and Fe through combining a Mechanical Alloying (MA) step with Self-Propagating High-temperature Synthesis (SHS).

2. Experimental and Results

Stoichiometric Ni_3Al and three variants of Ni_3Al alloys - with (A) 4 at.% Fe, (B) 4 at.% Cr and (C) 2 at.% Cr plus 2 at.% Fe - have been adopted. For their elaboration by SHS, appropriate powder mixtures were prepared from atomized Al, carbonyl Ni, reduced Fe and electrolytic Cr elemental powders. They were subjected to MA for 3 hours in a planetary ball mill, in argon atmosphere. From each mixture, round samples of 16 x 10 [mm] were then cold compacted at 700 [MPa] and subjected to the Ni_3Al synthesis and alloy formation by SHS in thermoexplosion mode under a pressure of 20 MPa, in a vacuum furnace at 10^{-3} [Pa]. For sintering completion, after synthesis the temperature was raised and kept at 1150 ^{0}C for 60 min. The obtained alloys were subjected to XRD, SEM and EDS analyses, as well as to the compression tests in air at temperatures up to 800 ^{0}C.

Morphological evolution of powder particles during MA. The SEM images of powder mixtures (Fig. 1) show flattened particles for the MA powder, being not possible to make a distinction between species. This proves their good homogenization, even if XRD pattern (not included) shows distinct peaks for each component (no compound formed).

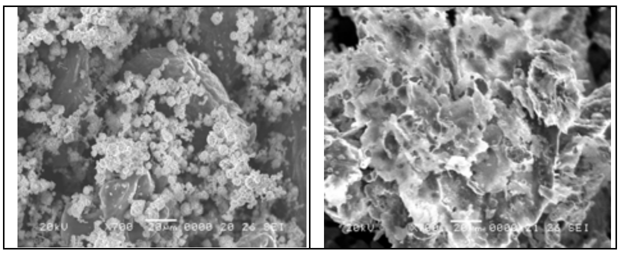


Fig. 1 SEM images of A powder mixture (4 [at.%]F e), initial (left) and for 3 h MA time. (right).

Composition and Microstructure of the processed alloys. From XRD pattern of the Ni_3Al-Cr-Fe MA-SHS processed alloy (Fig. 2) results that Ni_3Al really formed. However, beside its peacks, peacks of other phases appeared: NiFe, $Al_{13}Fe_4$ and pure Cr. By these compounds formation, Fe atoms, occupying both Ni and Al sites in the Ni_3Al crystal lattice [2], produced its disordering - breaking the dislocation motion and determining a strengthening effect. Instead, unreacted Cr produced only local lattice distortions - of a smaller effect on mechanical properties. However, it could react with diffused oxygen along the grain boundaries, breaking the extrinsic embrittlement.

Similar peaks and effects appeared in Ni_3Al-Fe/Cr alloys.

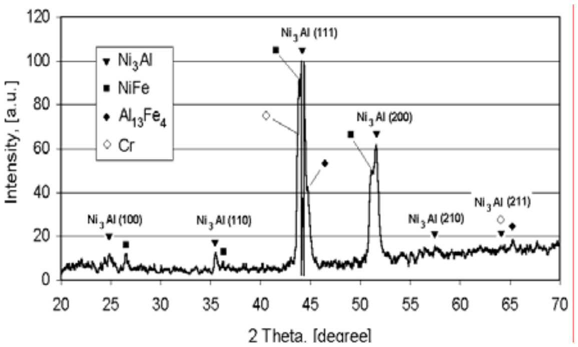
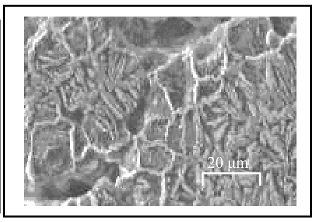


Fig. 2 XRD pattern for Ni_3Al alloyed of 2 at.% C r and2 at.% Fe (C) composition.

Fig. 3 presents the results of SEM and EDS analyses for the same Ni_3Al-Cr-Fe alloy. As is to be remarked, the obtained microstructure is a typical one for Ni_3Al [3].

Element	Weight %	Atomic %
Al K	11.21	23.06
Cr K	1.90	1.87
Fe K	2.27	2.09
Ni K	84.62	72.98
Totals	100.00	



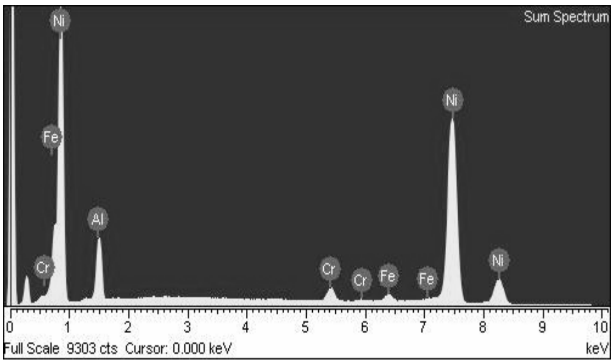


Fig. 3 SEM and EDS analyses of Ni_3Al alloyed with 2 at.% Fe and 2t.% Cr. Etching: Aqua Regna.

Mechanical properties. The above discussed structural features proved to have a notable influence on both mechanical resistance and deformability of the processed Ni_3Al alloys. The obtained values of Ultimate Compression Strength (UCS) and Specific Deformation in compression (SDc) for the most of them increase as temperature increases up to 800 ^{0}C (Fig. 4). They are higher for alloys processed from MA powders than from common powders (circular symbols), as well as of the unalloyed Ni_3Al. Also, they exhibit a higher increase with temperature. These increases are smaller for Cr addition, much higher for Fe and have highest values for both. However, for the unalloyed Ni_3Al and for Ni_3Al-Fe alloy, the values of both these properties increase only up to ~ 600 ^{0}C, while for the fully alloyed grades they continue to increase. These prove the Cr effect of the alleviation of extrinsic fragility and of Fe on both the ambient and high temperatures mechanical properties enhancing. As these effects are additive, the best properties has Ni_3Al-Cr-Fe alloy obtained from MA powder.

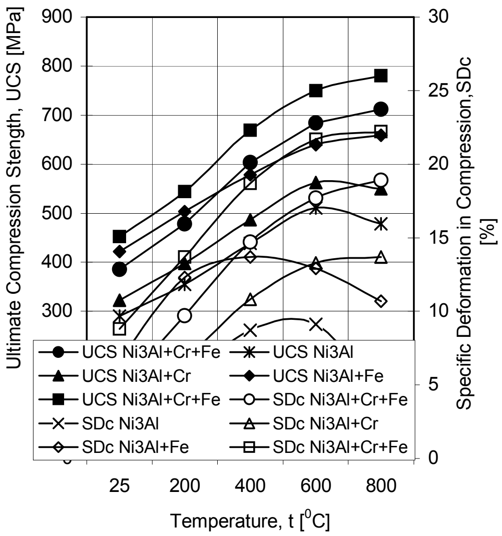


Fig. 4 Ultimate Compression Strength (UCS) / Speci ficDeformation (SDc) vs. temperature for the process ed alloys.

3. Summary

Fe and Cr using as allying elements in Ni_3Al determines a notable effect of mechanical properties and deformability enhancing. These properties are higher for alloys processed by SHS from MA powders and increase with temperature up to 800 ^{0}C. Cr proved to contribute to the extrinsic embrittlement alleviation, while Fe to both the ambient and high temperatures mechanical properties enhancing.

4. References

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