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Mechanical properties of amorphous Fe-based melt spun ribbons with Cr additions

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Abstract

The effect of Cr substitution for Fe on the mechanical properties of $Fe_{78-x}Cr_xSi_{10}B_{12}$ and $Fe_{77.5-x}Cr_xSi_{7.5}B_{15}$ $(0 \leqslant x \leqslant 8)$ melt spun alloy series is presented. The tensile strength of the as-cast ribbons increased slightly with the substitution of Fe by Cr from 1.5 GPa $(x = 0)$ to 2.5 GPa $(x = 8)$ for $Fe_{78-x}Cr_xSi_{10}B_{12}$ alloys, and from 2.2 GPa $(x = 0)$ to 2.9 GPa $(x = 8)$ for $Fe_{77.5-x}$ $Cr_xSi_{7.5}B_{15}$ alloys. The Vickers microhardness remained almost constant for all Cr contents. In addition, the effect of annealing (30 min at various temperatures) on both, the tensile stress and microhardness of $Fe_{70}Cr_8Si_{10}B_{12}$ alloy was also determined. A gradual decrease with increasing annealing temperature was observed at the former and an increasing trend with higher anneal temperatures for the latter. Results are explained in terms of enhanced bond interaction metal–metalloid and of structural relaxation after heat treatment.

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1. Introduction

Amorphous metallic alloys in the form of filaments have been raising considerable research interest since their appearance during the last century [1]. These alloys are characterized for possessing very high mechanical strengths, specially the Fe-based alloys [2]. Unlike crystalline metallic materials, amorphous alloys manifest a very localized plastic deformation process in which yielding proceeds by the nucleation and propagation of discrete shear bands [3]. During tensile tests the samples fail simultaneously with yielding. Because metallic glasses do not workharden, the yield stress is a measure of the intrinsic strength of the material [4]. It is well known that Cr replacement of Fe in Fe–Si–B ternary alloys leads to an increase in their glass forming ability together with an enhancement of their mechanical properties. On the other hand, many iron based amorphous alloys become brittle after annealing below the crystallization temperatures [5] along with a detrimental effect on their mechanical properties. In this report, the effect of Cr substitution for Fe and various heat treatments on the mechanical properties of rapidly solidified $Fe_{78-x}Cr_xSi_{10}B_{12}$ and $Fe_{77.5-x}Cr_xSi_{7.5}B_{15}$ $(0 \leqslant x \leqslant 8)$ alloys are studied.

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2. Experimental

Alloys of the composition $Fe_{78-x}Cr_xSi_{10}B_{12}$ and $Fe_{77.5-x}Cr_xSi_{7.5}B_{15}$ $(0 \leqslant x \leqslant 8)$ were prepared by melting pure constituent elements in an RF induction melting unit under inert atmosphere. Amorphous ribbons were produced by melt spinning using a roll speed of $\sim$32 ms^{-1} in a controled helium atmosphere. The tensile strength, σ_{TS}, was evaluated using an Instron universal testing machine, whilst the Vickers microhardness H_v, was measured by means of a Leits microhardness tester. Experimental errors on both quantities were determined from the standard deviation of an average value calculated on 100 repetitions. Various heat treatments of 30 min at 100, 200, 300 and 400 °C were carried out on a selected composition ($Fe_{70}Cr_8Si_{10}B_{12}$). TEM observations were realized in a Philips Tecnai F20 Field Emission Gun Transmission Electron Microscope (FEG-TEM).

3. Results

In Fig. 1. H_v and σ_{TS} as a function of Cr content are shown. For the $Fe_{78-x}Cr_xSi_{10}B_{12}$ alloy system, both σ_{TS} and H_v exhibits an overall increasing trend with increasing Cr addition while for the $Fe_{77.5-x}Cr_xSi_{7.5}B_{15}$ alloy series, H_v remains nearly constant for all Cr contents together with a slight improvement in σ_{TS} for increasing Cr contents. In general, σ_{TS} was higher for $Fe_{77.5-x}Cr_xSi_{7.5}B_{15}$ alloys compared with $Fe_{78-x}Cr_xSi_{10}B_{12}$ samples for all Cr concentrations. On the other hand, values of H_v and σ_{TS} as a function of annealing temperature for $Fe_{70}Cr_8Si_{10}B_{12}$ sample are plotted in Fig. 2. Initially, H_v reduces at 100 °C from its Cr-free original value showing a gradual increment with higher temperatures up to 10.8 GPa at 400 °C. In contrast, σ_{TS} decreases monotonously with increasing temperature. In Fig. 3, σ_{TS} is plotted against the number of $(s+d)$ electrons contributed by the metal atoms per atom (e/a), calculated

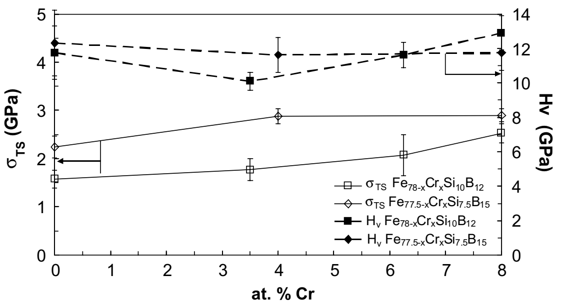

Fig. 1. Tensile strength and Vickers microhardness as a function of Cr content in melt spun FeBSi alloys. Connecting lines are for eye guide only.

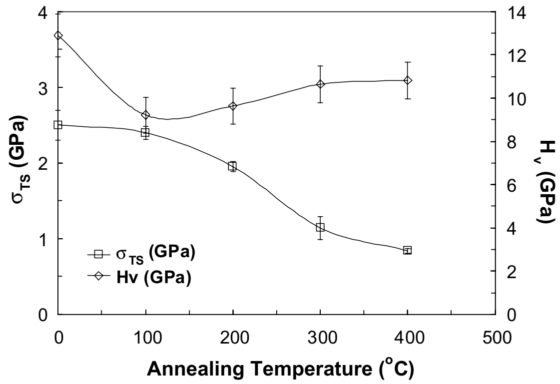

Fig. 2. Tensile strength and Vickers microhardness of the $Fe_{70}Cr_8Si_{10}B_{12}$ alloy ribbon as a function of the annealing temperature. Connecting lines are for eye guide only.

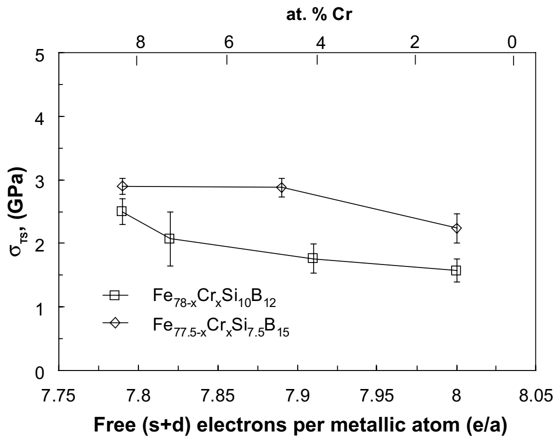

Fig. 3. Tensile strength plotted against the average outer electron $(s+d)$ concentration of metallic atoms (e/a) for Cr-containing melt spun FeBSi alloys. Connecting lines are for eye guide only.

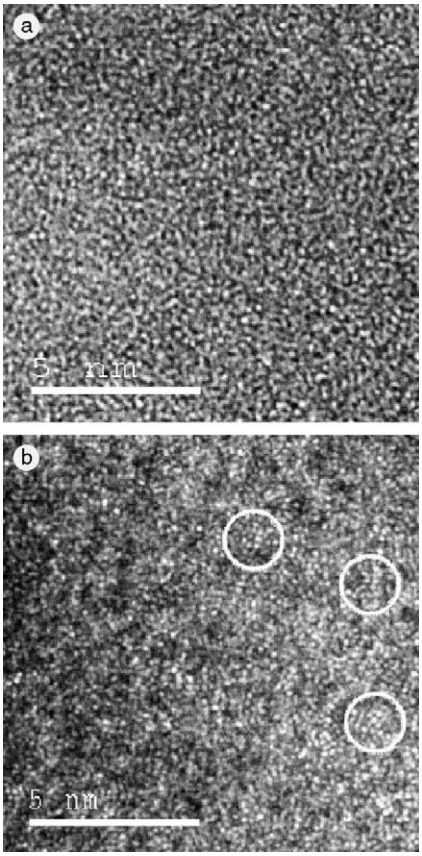

Fig. 4. FEG-TEM photomicrographs of $Fe_{70}Cr_8Si_{10}B_{12}$ alloy ribbon (a) as-cast and (b) sample annealed for 30 min at 400 °C, circles indicate cluster formation.

assuming no charge transfer from the metalloid elements, in the following way [6]:

$$e/a = \frac{[\text{at.\%Fe} \ * \ (s+d)_{\text{Fe}}] + [\text{at.\%Cr} \ * \ (s+d)_{\text{Cr}}]}{\text{at.\%Fe} + \text{at.\%Cr}}, \tag{1}$$

where $(s+d)_{\text{Fe}}$ is 8 and $(s+d)_{\text{Cr}}$ is 6. For both Cr-containing alloy series, a diminishing trend of σ_{TS} is evident with increasing e/a. In Fig. 4, TEM micrographs for $Fe_{70}Cr_8Si_{10}B_1$ sample are shown for as-cast state (a) and after annealing at 400 °C (b). A fully disordered structure is evident at the former, whilst some structural arrangements in the form of clusters of ~0.5 nm appeared for the latter.

4. Discussion

Tensile strength results can be explained on the basis of the number of $(s+d)$ electrons contributed by the metal atoms per atom e/a, in these alloys [6]. It has been reported that as Fe is replaced for Cr in wires of the same composition, the degree of covalent character increases gradually [2]. As it is shown in Fig. 3 the increase of σ_{TS} with diminishing e/a and thus, with increasing Cr content for both alloy series, is also attributable to a stronger bond interaction metal–metalloid, or covalency, which is enhanced with the presence of a second metallic element, Cr for the present case. The decrement for both σ_{TS} and H_v observed for the $Fe_{70}Cr_8Si_{10}B_{12}$ alloy after the first annealing treatment (100 °C) (Fig. 2) is attributable to a structural relaxation. Then, as the annealing temperature is increased H_v increased, may be due to segregation *y*/or appearance of cluster nucleation whose proportion will increase during subsequent annealing stage. If the amorphous alloy is assumed to be made of 'frozen in' nuclei formed during the fast solidification, it is probable that the supply of thermal energy during annealing will make easy atomic rearrangements and will essentially lead to the process of cluster creation [7] (see Fig. 4(b)), which results in the additional detriment observed in σ_{TS} and increase of H_v.

5. Conclusions

An overall enhancement of σ_{TS} and H_v for both as-cast alloy series was attained upon Cr substitution for Fe. Structural relaxation at anneal temperatures below 400 °C causes a decrement of both mechanical properties at a selected composition, whilst at 400 °C, formation of small clusters results in further decrement of σ_{TS}.

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