# OXIDATION OF Nb-Cr-Si ALLOYS AT TEMPERATURES ABOVE 1000$^{O}$C

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## Introduction

Materials with adequate oxidation resistance at temperatures above 1000$^{o}$C are being explored for potential aerospace applications. Ceramics are available for such applications but the processing becomes quite challenging. Thus metallic systems (containing composite phases) are particularly desirable for the ease of fabrication. The present research uses Nb based alloys to explore the feasibility of a potential high temperature material. The authors [1-3] have used Mo and B additions to Nb based alloys to determine the oxidation resistance in air up to a temperature of 1400$^{o}$C.

Nb-20Mo-15Si-5B-20(Cr,Ti) alloys have been studied indicating the beneficial effects of Cr in this alloy system using a composite of different of microconstituents. The Laves phase, $NbCr_2$, formation provides the much needed oxidation resistance in the system. However, the alloys display pesting behavior in the temperature range from 900 to 1100$^{o}$C although they exhibit adequate resistance at temperatures both above and below this temperature range. The purpose of this paper is to present the results on the determination of the oxidation resistance in air for 4 experimental alloys in a range of temperature from 700 to 1400$^{o}$C.

## Experimental

*Materials*
Nb-20Mo-15Si-25Cr (25Cr), Nb-20Mo-15Si-25Cr-5B (25Cr-5B), Nb-20Cr-20Si-5Hf (Hf), Nb-20Cr-20Si-5Al (Al) alloys with compositions in atomic percent were fabricated by the Ames Laboratory of Iowa State University using electric arc melting in inert argon gas atmosphere. Cubes of 5 mm size were used for the oxidation resistance studies using computer temperature controlled programmable furnaces. The surface was finished on a 600 grit paper.

*Oxidation*
Short term oxidation (STO) consists of heating the alloy at a rate of 10$^{o}$C/min up to the desired temperature, held there for a period of 24 hours, and the furnace cooled to room temperature. The weight of the crucible before and after heating was used to determine the weight gain per unit area (W) which is a direct measure of oxidation resistance. A graph between W and temperature is referred to as oxidation curves under STO conditions.

*Characterization*
The oxidation scale was examined using various SEM modes (EDS, x-ray mapping, back scattered electron, BSE, imaging) and XRD techniques in a Hitachi H-8000 field emission scanning electron microscope (FESEM).

## Results and Discussion

*As-Cast Microstructures*
Figure 1 shows the microstructures of the alloys in the as-cast condition.

Figure 1. Nb-based alloys with different alloying additions: a) Nb-20Cr-20Si-5Al, b) Nb-20Cr-20Si-5Hf, c) Nb-20Mo-15Si-25Cr, d) Nb-20Mo-15Si-25Cr-5B

Al alloy shows the presence of Laves phase ($NbCr_2$), Niobium silicide ($Nb_5Si_3$), and a solid solution ($Nb_{ss}$). The microstructure of Hf alloy consists of similar phase but contains an additional pure Hf phase. Both 25Cr and 25Cr-5B alloys have similar microconstituents as the other two alloys. The appearance of the Laves and solid solution phase has a characteristic eutectic microstructure. However, the role of this microconstituent on the oxidation resistance of the alloys is a subject of investigation by the authors.

Figure 2 Oxidation curves for the four alloys used in this study: Nb-20Mo-15Si-25Cr (25Cr), Nb-20Mo-15Si-25Cr-5B (25Cr-5B), Nb-20Cr-20Si-5Hf (Hf), Nb-20Cr-20Si-5Al (Al).

Figure 2 shows the STO curves for the 4 alloys of this study. The composite structure of the 4 alloys has a definite influence on the oxidation behavior of these alloys. The 25Cr alloy shows a large weight gain per unit area at 900$^{o}$C which is, perhaps, the result of pesting of the alloy and has been observed to be quite characteristic of this Nb-Cr-Si alloy system. It must be noted that an addition of 5B to this alloy seems to completely suppress the pesting of this alloy and, in fact, the 25Cr-5B alloy is showing the best oxidation resistance of all the 4 alloys used in this study. The lower weight gain per unit area has been used as a measure of better oxidation resistance. However, the higher W value at 700$^{o}$C and then a decrease at 800$^{o}$C is feature that is being explored at this time. The oxidation resistance of 25Cr-5B alloy appears to have stabilized between 800 and 1400$^{o}$C according to Figure 2. The 25Cr alloy, on the other hand, shows significant improvement in the oxidation resistance from 1000 to 1300$^{o}$C. But at 1400$^{o}$C it shows higher W value and it has been observed that there was a partial melting of this alloy at this temperature. The oxidation products resulting from the high temperature treatments in air are being evaluated to determine the composite structure effect on the oxidation resistance of these alloys.

Hf and Al alloys behave in a similar fashion as far as their STO curves are concerned. The Al alloy shows a marked pesting behavior at 1000$^{o}$C while Hf alloy shows a range of temperature, from 900 to 1100$^{o}$C, in which the pesting is present. Al alloy shows a good oxidation resistance from 1100 to 1400$^{o}$C. But it can be seen that the weight gain per unit area is higher than the 25Cr and 25Cr-5B alloys in this temperature range. The beneficial effects of combined addition of Mo and B can be seen from the results of this study. However, Al and Hf additions did not show very promising results for the oxidation resistance available from this system.

**Conclusions**

The oxidation resistance of 4 alloys from Nb-Cr-Si system has been evaluated in air from 700 to 1400$^{o}$C. The composite microconstituents appear to influence the oxidation characteristics. The addition of B has a beneficial effect for Nb-20Mo-15Si-25Cr alloy as it suppresses the pesting problem. Nb-20Cr-20Si-5Hf and Nb-20Cr-20Si-5Al alloys both result in the powder formation in 900 to 1100$^{o}$C but show considerable improvement in oxidation resistance at elevated temperatures.

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**References**

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