SCP5.1

Balanced properties of Mo-V-Si-B alloys modified with small amounts of titanium

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Multiphase Mo-Si-B alloys have a great potential for replacing nickel-based superalloys in the aerospace and energy sector because they show excellent mechanical properties and the potential for good oxidation characteristics, due to the Mo silicide phases. However, the oxidation behavior of such alloys is still a critical issue, since catastrophic oxidation failure occurs locally at the Mo solid solution phase at intermediate temperatures [1]. It was shown that the addition of vanadium to Mo-Si-B alloys leads to a significant density reduction, which is even lower than the density of a state-of-the-art nickel-base superalloy CMSX-4. This phenomenon is directly related to the high solubility of vanadium in molybdenum and the respective Mo silicides, while vanadium has no effect on the phase fractions of the Moss-Mo3Si-Mo5SiB2 triangle. In this context it was found that alloys with the composition Mo-40V-9Si-8B exhibit the best set of properties with respect to normalized mechanical strength and ductility. On the other side, alloying with vanadium leads to a reduction in creep resistance. In addition, such alloys have a significantly higher oxygen content [2]. For this reason, titanium is will be added to the Mo-V-Si-B alloy in order to somewhat mitigate disadvantages of the vanadium addition. Furthermore, titanium has a high affinity for oxygen and therefore it is believed that titanium may act as a getter for dissolved oxygen and thus contribute to improve the ductility as well as to minimize internal oxidation in these alloys.

Elemental powders of Mo, V, Si, B and TiH2 of 99.95%, 99,5%, 99,5%, 98% and 99,5 % purity, respectively, were used to produce different alloys with chemical composition of Mo-40V-9Si-8B-xTiH2 (in at. %, x=0, 2, 5) by a multi-step powder metallurgical process. Mechanical alloying of the powders was carried out in a planetary ball mill with powder to ball weight ratio of 1:13 and a rotational speed of 300 rpm. Weighing, mixing and powder removal was done under protective argon atmosphere in order to keep the oxygen content as low as possible. In the first step of this work, a milling study of mechanically alloyed Mo-40V-9Si-8B was carried out in order to optimize the powder metallurgical processing route. Then, 2 at. % and 5 at. % titanium were added to this alloy, substituting both the molybdenum and the vanadium in all constituents, which improves the stress-strain properties even further. The analytical methods used to determine the milling progress of the respective powder alloys include SEM analysis, XRD analysis, oxygen content analysis, microhardness measurements and laser diffraction. In the next step, the Ti-modified alloy powders and the reference material (Mo-40V-9Si-8B) were subjected to heat treatment. In this way, a multi-phase microstructure was formed in which the intermetallic phases Mo3Si and Mo5SiB2 are embedded in a continuous Mo matrix [3]. After compaction via field assisted sintering the compacted material was analyzed with respect to microstructure, mechanical properties and oxidation resistance to verify whether the addition of titanium contributes to an improvement in this respect.

In the following, initial results from the milling studies will be presented. The milling progress for the first two alloys can be seen from the SEM images in Fig. 1. At the beginning of ball milling (2 h), larger light (light grey, molybdenum-rich phase) and darker areas (vanadium-rich phase) occur within the individual powder particles. As the milling time increases (10 h), a lamellar structure then gradually forms, indicating that vanadium is increasingly dissolving in the molybdenum and, as a result, the microstructure is becoming more homogeneous.

However, after 20 h of ball milling, a completely homogeneous microstructure is not yet evident, because lamellar structures can still be detected in some particles for both alloys, which in turn suggests that the mechanical alloying of the powders is not yet fully completed at this point.

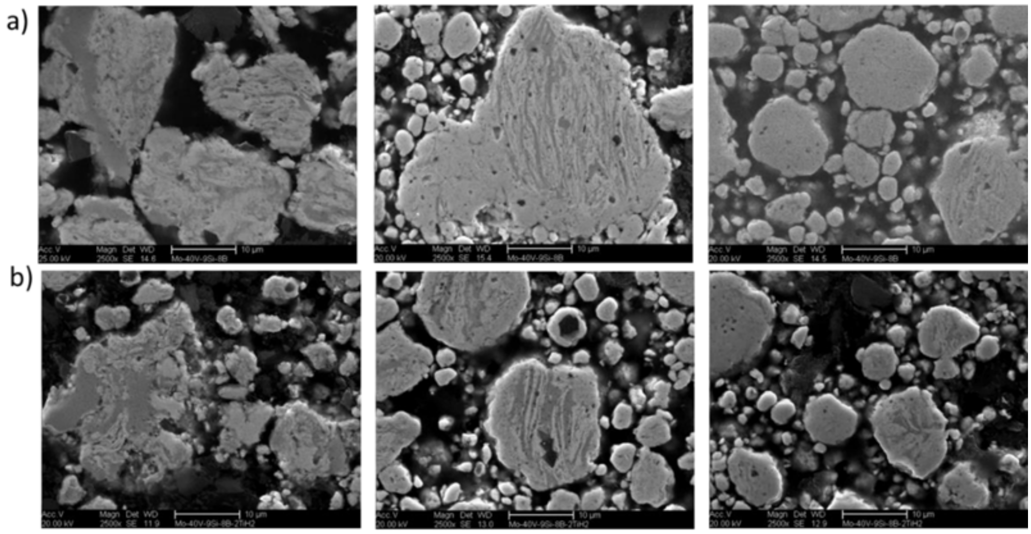

Fig. 1: Microstructure of the mechanically alloyed powders after 2, 10 and 20 h. a) Mo-40V-9Si-8B b) Mo-40V-9Si-8B-2TiH$_2$

Furthermore, microhardness measurements were carried out as a function of milling time (see Figure 2), in order to obtain a first tendency regarding the mechanical properties. In the first five hours of milling, the microhardness in both alloys initially increases, which, in addition to solid solution strengthening, is also due to grain refinement and work hardening at this early stage of mechanical alloying. In the further course, the microhardness does not change significantly. However, the microhardness of the reference alloy Mo-40V-9Si-8B is at a slightly higher level throughout the milling time than that of the alloy with 2 at. % TiH2, which means that titanium dihydride, at least in small amounts, does not lead to any improvement in this respect in the powder state. This will probably change after a heat treatment.

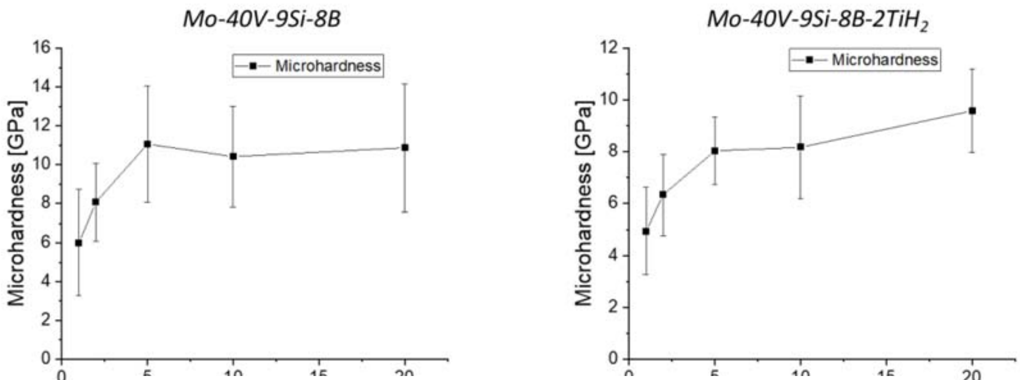

Fig. 2: Microhardness profile of the two alloys investigated as a function of milling time

References:

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