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Oxygen Removal during Sintering of Steels Prepared from Cr-Mo and Mo Prealloyed Powders

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Abstract

The removal of oxygen during sintering by carbothermic reduction was studied for steel compacts Fe-Cr-Mo-C and Fe-Mo-C prepared from prealloyed powders. The compacts were prepared by pressing at 600 and 1000 MPa and sintering at 1100 and 1300°C in vacuum. It showed that for the Cr-Mo steel, deoxidation strongly depends on the sintering temperature, in contrast to the plain Mo steel; at 1300°C very low oxygen levels were measured with the standard density compact while at high density still significant oxygen is contained. This indicates inhibition of final deoxidation by pore closure, but apparently without adverse effect on the mechanical properties.

Keywords : Sintered steels, Sintering, Chemical reactions, Cr alloying

1. Introduction

For the requirements of PM parts users, in particular the automotive industry, improvement of the mechanical properties is a necessity. Mo and especially Cr-Mo alloyed sintered steels offer attractive property profiles and superior heat treatment response. The main obstacle for the introduction of Cr prealloyed sintered steels has been the tendency of Cr to form stable oxides, which results in higher sensitivity to oxidation during sintering and also in more difficult removal of the oxides inevitably present in the starting powders, oxide layers on the particle surfaces preventing formation of stable sintering contacts [1]. Nevertheless, manufacturing of PM precision parts from Cr-Mo steel powder grades is today state of the art [2], through improved sintering equipment and technology, in particular better atmosphere control [3]. It has been shown however that the deoxidation of Cr-Mo prealloy steel powder compacts requires markedly higher temperatures than than of e.g. plain Fe-C or of Cu, Ni and Mo alloyed grades [4]. This might cause problems in particular at higher green density levels. For materials containing 1.5%Cr it has been shown that the risk of insufficient deoxidation is not too pronounced [5]. In this work, the deoxidation behaviour of compacts prepared from 3%Cr-0.5%Mo prealloyed powder was studied compared to that of 1.5%Mo prealloyed grade.

2. Experimental and Results

Prealloyed powders Fe-3%Cr-0.5%Mo and Fe-1.5%Mo were mixed with 0.5% natural graphite UF4 in a tumbling mixer for 60 min and then compacted under die wall lubrication to impact test bars 55 x 10 x 10 mm^3. The compaction pressure was 1000 MPa; as a reference, compaction at standard 600 MPa was done in parallel. The bars were inserted into a pushrod dilatometer and sintered in rotary pump vacuum, to ensure that only carbothermic reduction would take place. After sintering the density was determined following the water displacement method and then were impact tested using a Wolpert Charpy impact tester with W_{max} = 50 J. Using the broken specimens, chemical analysis was carried out, the oxygen and combined carbon contents being of primary interest.

From the density values the high sintering activity of Astaloy CrM was evident (Fig.1a); despite the markedly lower compactibility of the Cr-Mo alloyed powder compared to the Mo alloyed grade, the resulting density levels were quite similar and in some cases even higher, such as e.g. at standard green density but HT sintering. The impact energy values are generally superior for the Astaloy CrM steels, and the high density / HT sintered materials could not even be broken in the impact tester but were simply bent, once more indicating the very high mechanical integrity obtainable with Astaloy CrM if properly sintered.

The chemical analysis showed that the oxygen and carbon levels in AstaloyMo steels are similar for all manufacturing conditions and the oxygen level is low, indicating that carbothermic reduction is fairly complete. In the case of Astaloy CrM, in contrast, the well known effect of the sintering temperature is discernible: after sintering at higher temperatures less oxygen and also markedly less carbon is left. The carbon loss is slightly less pronounced in the high

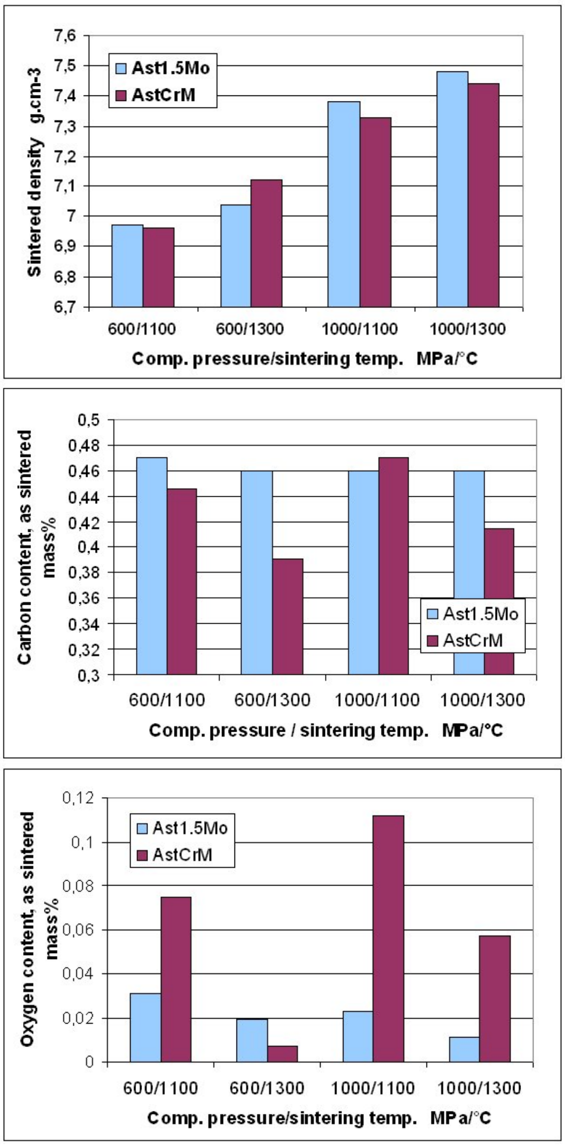

Fig. 1. Chemical analysis of sintered steels with 0.5%C, prepared from Astaloy CrM / AstaloyMo, respectively. Differently compacted, sintered in dilatometer/vacuum.

density material. This is in excellent agreement with the data for the oxygen content: here the high levels after sintering at 1100°C stand out clearly while after sintering at 1300°C significantly lower values have been measured, although a marked effect of the green density is observed: the high density material contains considerably more oxygen after sintering at both temperatures, but the relative effect of the green density is much more pronounced at higher temperatures. This indicates that pore closure effects seal off the internal pore channels before the internal oxides have been completely reduced – which process requires temperatures of about 1250°C - , and then the CO generated through carbothermic reduction cannot be removed any more, thus effectively stopping the deoxidation processs, as described in [5]. The close correlation between the oxygen and carbon levels is visible when comparing Figs.1a and 1b.

This effect may have considerable impact on high density specimens prepared from Cr prealloyed powders since it might be suspected that the remaining oxygen adversely affects the mechanical properties. However, the impact behaviour of the high density/HT sintered material was so excellent that a pronouncedly adverse effect of the higher oxygen content seems to be rather improbable.

3. Summary

The results have shown that for Cr-Mo and Mo prealloy stels sintered in vacuum, the shrinkage and densification occurs predominantly in the isothermal sintering stage, which should leave sufficient time for oxygen removal through carbothermic reduction during the heating stage. The oxygen levels after sintering are clearly related to the carbon levels, low oxygen content – and thus effective reduction – being linked to higher carbon loss during sintering. For the Mo prealloy steel grades the oxygen removal is very complete at all density levels and sintering temperatures. For the Cr-Mo prealloyed materials, deoxidation is more complete at higher sintering temperatures; however, also the density plays a major role, at high density levels about 500 ppm O being measured. The excellent impact resistance of this material however indicates that this remaining oxygen, finely dispersed within the particle cores, does not have any adverse effect on the mechanical properties.

4. Acknowledgement

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