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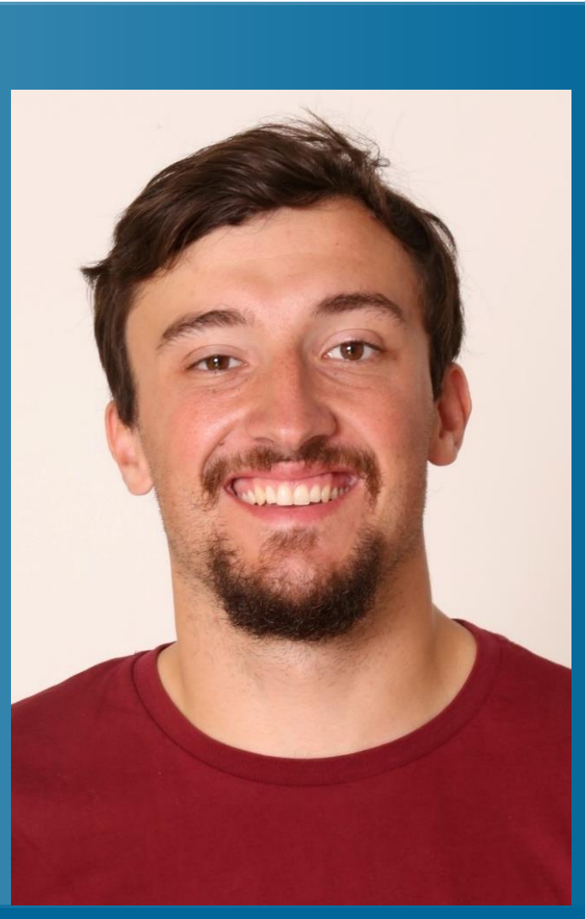

The near-surface decarburization of microalloyed boron steel under varying oxygen partial pressures and its influence on the near-surface hardness

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Abstract

The carbon content in micro-alloyed steels plays a vital role on the microstructure and accessible hardness [2], and the carbon content in the surface near regions is strongly influenced by the surrounding atmosphere and the alloying of Boron in the range of a few wt. ppm [3]. We investigated the influence of varying oxygen partial pressures and varying atmosphere annealing temperatures on the decarburization behavior of surface near regions by heat treatment experiments under a controlled gas atmosphere. Moreover, we analyzed the resulting carbon distribution by EPMA measurements. After annealing at 1100 °C and 1000 °C and oxygen partial pressures ranging from a few Pa up to 10000 Pa, EPMA measurements indicated oxygen as the determining factor for decarburization. 500 Pa oxygen partial pressure is already high enough to reach a saturation level of decarburization. We found lower annealing temperatures to decrease the depth of the decarburized area. Boron alloying increases the decarburized depth, whereas Titanium alloying did not appreciably influence the decarburization behavior. Picoindentation measurement revealed a remarkable decrease in hardness towards the surface in oxygen atmosphere treated material.

Problem description

Boron in the range of a few ppm in micro-alloyed steels is used as a cheaper hardenability promoter than, e.g., chromium, molybdenum, or nickel. Boron microalloyed steel with boron contents around 30 ppm shows a more distinct decarburization zone close to the surface than B-free steel. It is assumed that boron oxide formation at the surface facilitates decarburization, associated with C loss to the atmosphere as CO or CO_2, due to a synergistic effect of B and C [1]. Understanding of the coupling effects of involved, relatively light and volatile species C, B and O is of importance, since affected carbon concentration in steel influences the hardness of martensite and thus determines the surface-near mechanical properties [2].

Method

We heat-treated samples of micro-alloyed steel, see compositions in table I, in an atmospheric furnace under varying oxygen partial pressures and temperatures at ambient pressure. After homogenization annealing at 1100°C for 1 hour in an inert Argon-atmosphere, the samples were heat treated in an Argon-Oxygen atmosphere at 100000 Pa with oxygen partial pressures ranging from a few Pa to 10000 Pa at temperatures of 1000˚ C and 1100˚ C and finally quenched, see figure 1. We used EPMA and picoindentation method for the analysis.

Results

Oxygen, besides the temperature, is the determining factor for the decarburization of the surface near regions of microalloyed steel, in which only small fractions of oxygen in the atmosphere are necessary to decarburize seriously, see figure 2. Increasing the oxygen partial pressure from 500 Pa to higher values did not particularly alter the decarburization profile, see figure 3. We found that decreasing the temperature of the atmospheric treatment also decreases the depth of decarburization into the material. Figure 4 compares the decarburized depths for alloys 1,2, and 3 at 1100˚ C and alloy 2 at 1000˚ C. Alloying Boron in the range of 30 ppm increases the decarburized depth compared to boron-free steel, comparing the green (B-alloyed) and red (B-free) curves in figure 4. Titanium alters the microstructure by forming more stable TiN than BN [4], which directs Boron into solid solution in the matrix phase and segregation at the grain boundaries [1,5] and makes Boron available for the formation of B_2O_3 [6] and boro-carbides such as $M_{23}(B,C)_6$ or $Fe_{23}(B,C)$ [3,7]. The decarburization behavior apparently is not affected by the alloying of Titanium, see figure 4, comparing the green(Ti-free) and blue(Ti-alloyed) curves, suggesting that the facilitated formation of B_2O_3 in Ti-stabilized steels does not alter the surface near decarburization. Here we need to point to the difference in the alloys' carbon fraction, which also plays a role. The influence of Ti on the decarburization can not be entirely determined since there is also a difference in carbon content between the investigated alloys. Picoindentation measurements of alloy 2 after atmospheric treatment of 500 Pa O2 and 1100˚ C revealed the hardness evolution of the surface near regions, see figure 5. We noticed a remarkable decrease in hardness towards the surface in the martensitic microstructure.

Material

Table I: chemical composition of the reviewed microalloyed steels

alloy	C / wt%	B / wt%	Ti / wt%	N / wt%
1	0.3	0.003	0.04	0.004
2	0.52	0.003	0.002	0.004
3	0.52	0.0002	0.002	0.004

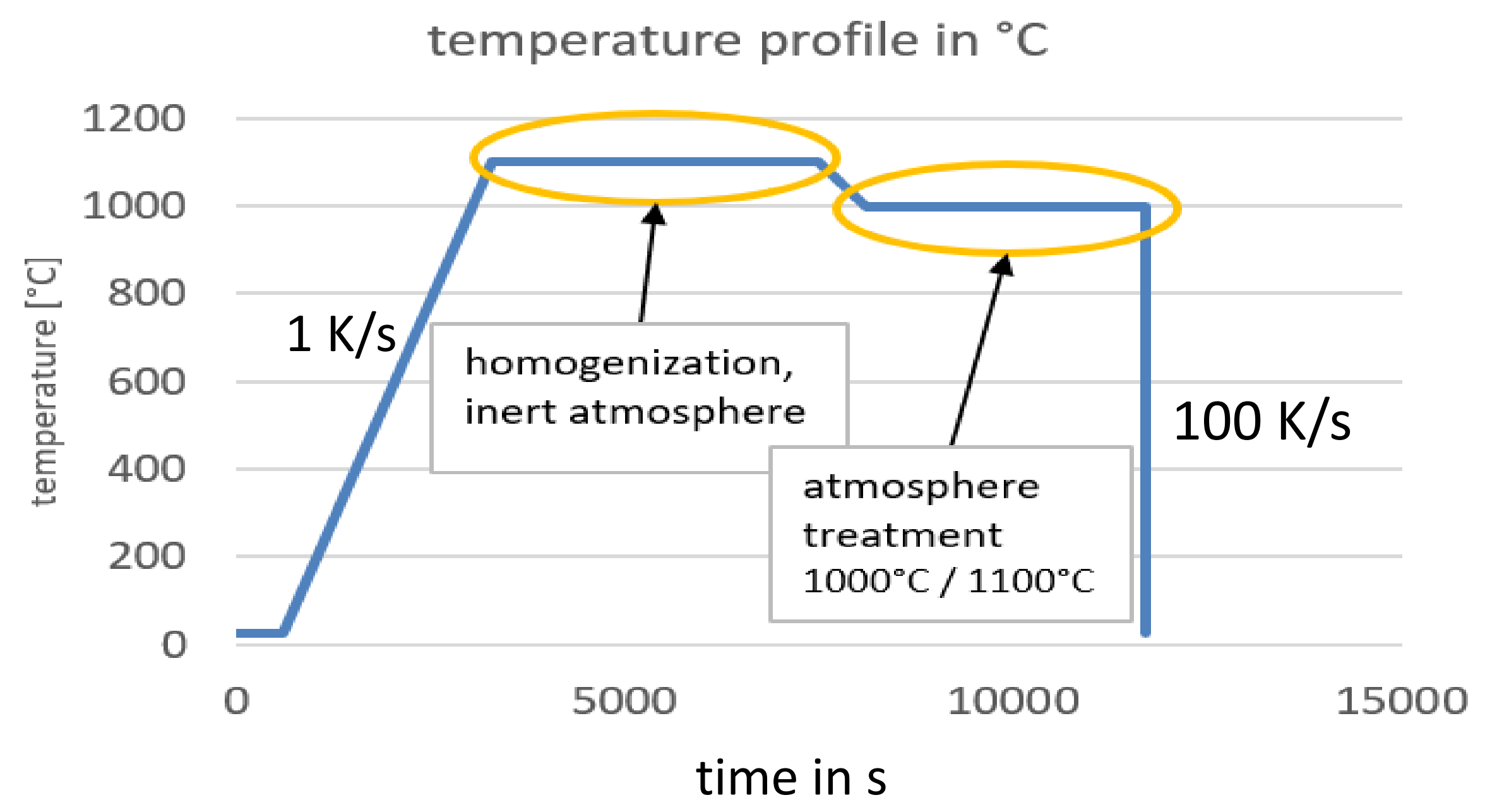

Figure 1: heat treatment temperature profile

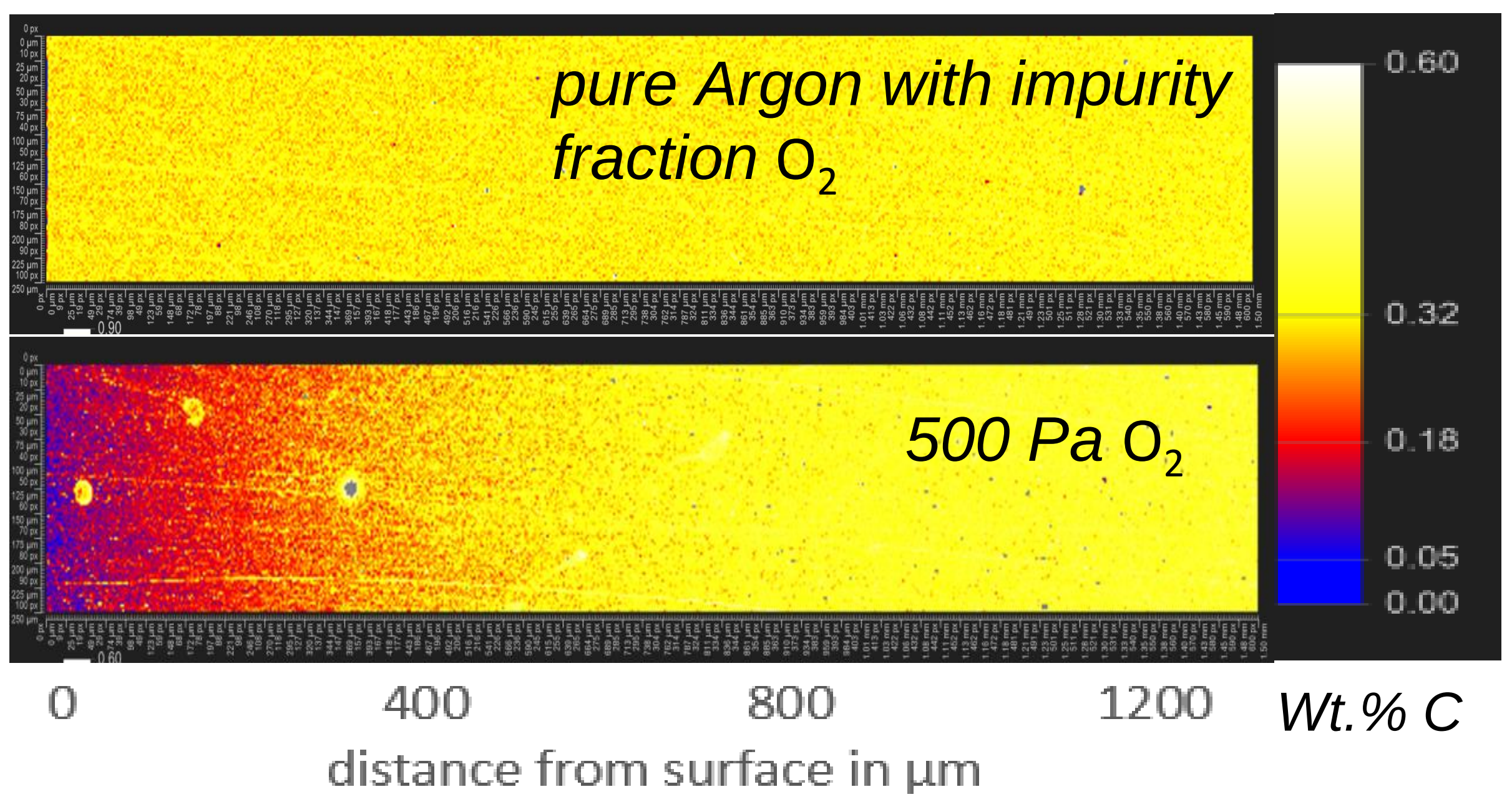

Figure 2: carbon EPMA mapping in the range from 0 to 1.2 mm from the surface of alloy 1, treated at 1100°C and oxygen partial pressures of impurity O_2 a and 500 Pa

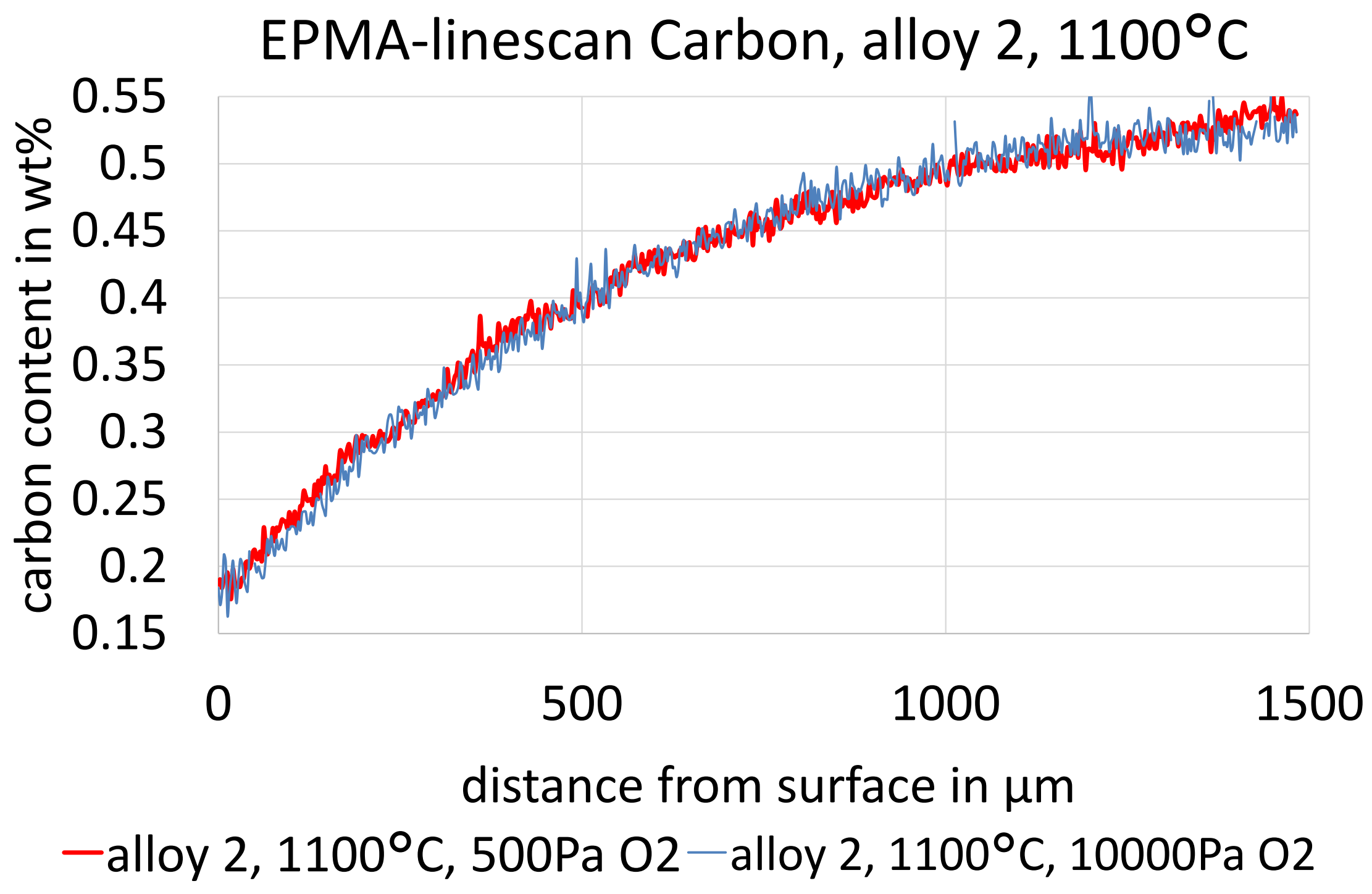

Figure 3: EPMA linescan for alloy 2 treated at 1100°C, carbon composition in wt.% plotted over the distance from the surface in µm for oxygen partial pressures 500 Pa and 10000 Pa, nominal composition 0.52 wt.%

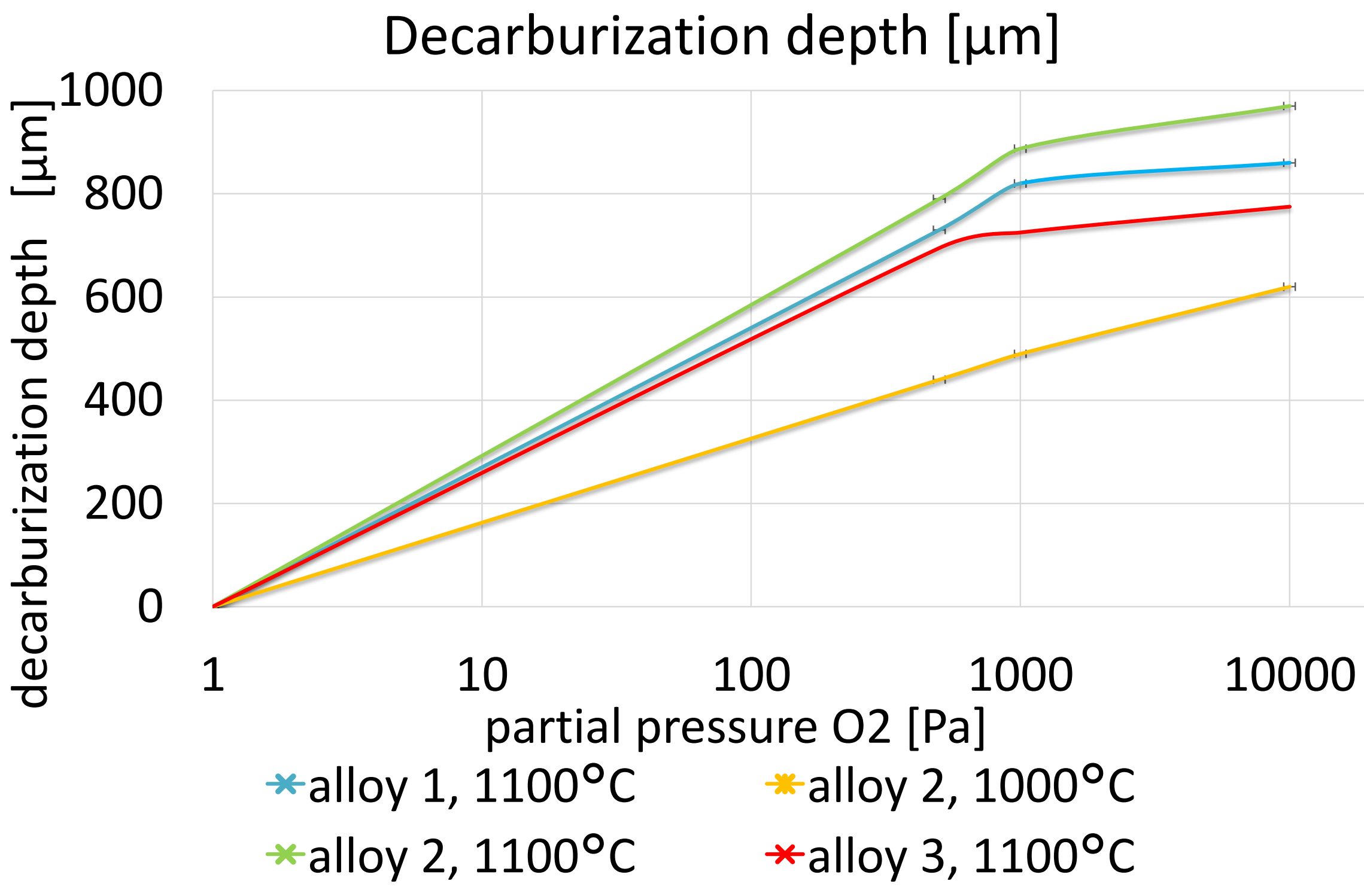

Figure 4: decarburized depth into the material till reaching nominal value in µm for varying partial pressures, measured from the surface. Temperature 1100°C for alloy 1 and 2 (red and blue) and 1000°C for alloy 2 (green). Lines are guide to the eye, points are experimental results.

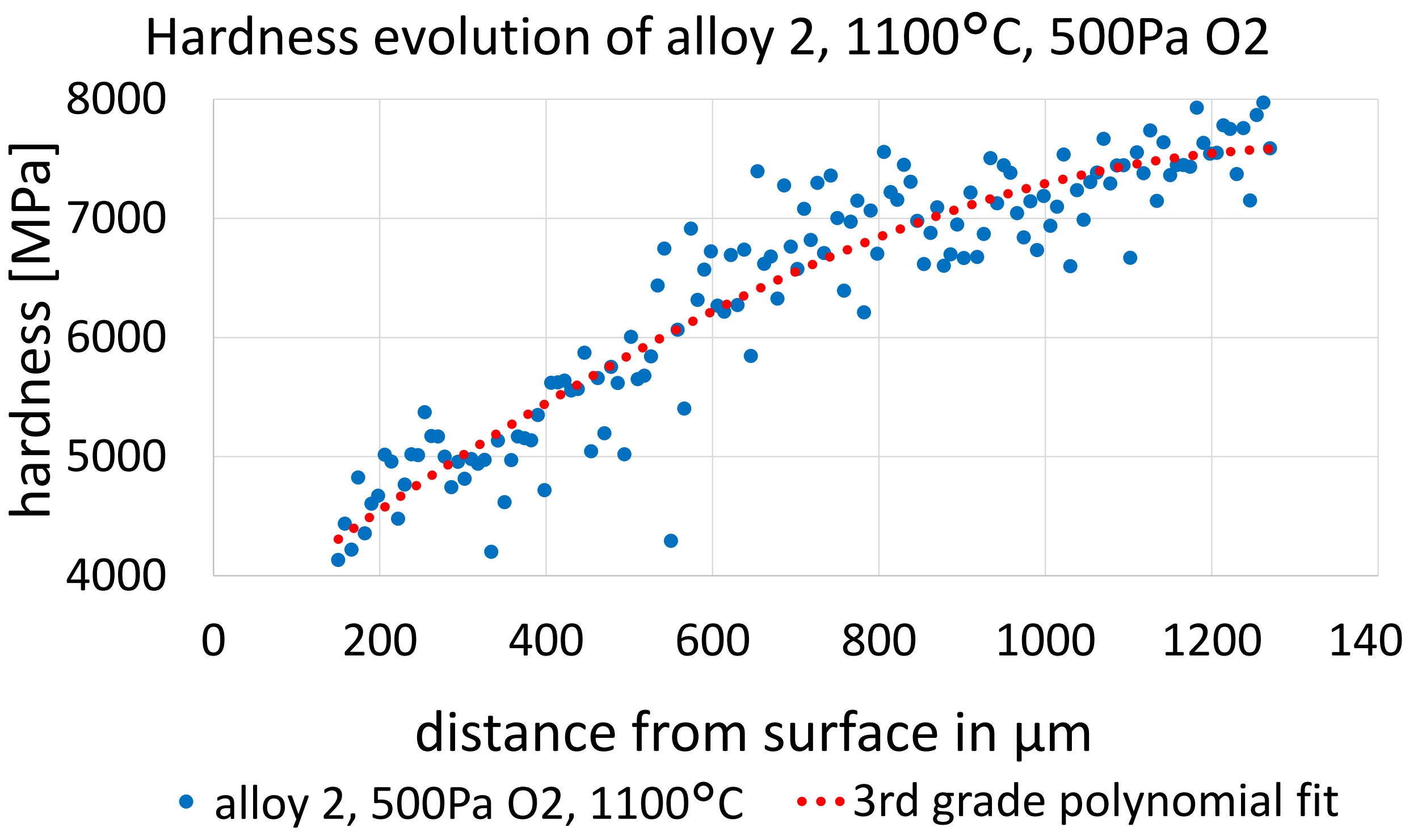

Figure 5: hardness evolution in MPa of the surface near-regions of alloy 2 at 500 Pa O2 and 1100°C. Measurement, carried out by the Picoindentation technique, was only possible starting at 150 µm from the surface. Blue points are experimental data, red points are 3rd grade polynomial fit.

Summary

- ☐ The oxygen partial pressure strongly affects the decarburization depth
- ☐ A saturation of the decarburization depth at the higher temperature of 1100 °C is already reached at 500 Pa O_2
- ☐ Decreasing the temperature decreases the decarburized depth
- ☐ Boron in the range of 30 ppm increases the decarburized depth compared to B-free steel
- ☐ Remarkable decrease in hardness towards the surface in oxygen atmosphere treated material

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