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R. Möller, S. Brenner, H. Grabke. THE ENRICHMENT OF PHOSPHORUS NEAR Mo₂ C PRECIPITATES IN STEEL. Journal de Physique Colloques, 1986, 47 (C2), pp.C2-277-C2-280. 10.1051/jphyscol:1986241 . jpa-00225675

HAL Id: jpa-00225675

<https://hal.science/jpa-00225675>

Submitted on 1 Jan 1986

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THE ENRICHMENT OF PHOSPHORUS NEAR Mo_2C PRECIPITATES IN STEEL

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Abstract - Atom probe analyses of Mo_2C precipitates in Fe-Mo-C-P alloys have shown that the concentration of phosphorus is enhanced in the vicinity of molybdenum carbide particles and it is proposed that this trapping decreases the phosphorus concentration at grain boundaries leading to a decreased temper embrittleness.

I - INTRODUCTION

The beneficial effect of molybdenum on the temper embrittleness of steels is well known (1) but has not yet been satisfactorily explained. Since molybdenum has little effect on the amount of phosphorus segregated at grain boundaries in carbon-free iron alloys (2) it is quite likely that molybdenum must be in the form of carbides to be able to scavenge the phosphorus.

To test this hypothesis we have used the FIM/atom probe to measure the concentration of phosphorus in molybdenum carbide and in the regions of the matrix surrounding the precipitates.

II - EXPERIMENTAL

An alloy containing Fe, Mo, C, and P was prepared by vacuum casting. Its composition is given in table 1. After forging, the material was cold drawn to 0.2mm diameter. The wires were then sealed in quartz capsules and homogenized at 900°C for 16 hours. They were then given additional heat treatments at lower temperatures. Specimens for field-ion microscopy were prepared in the usual manner (3).

III - RESULTS

Carbide precipitates several nm in diameter as well as larger ones (>30 nm) were observed after annealing for 14h at 600°C. Several carbide particles in close proximity to each other are shown in figure 1. The atom probe analysis of one of them (labeled "1"), shown in figure 2a, gave a composition of Mo_2C . There was no indication of dissolved phosphorus in the carbide. The carbide thus differs from the nitride which dissolves as much as 5 at% phosphorus (4). The region between the carbides (labeled "2"), however, exhibited considerable phosphorus enrichment as indicated by the spectrum in figure 2b. The composition of the interface regions of these particles could not be measured but the analyses of other

precipitates showed no strong adsorption of phosphorus directly at the carbide-matrix interface and confirmed that there is an appreciable enhancement of phosphorus in the matrix surrounding the particles. The distribution of the phosphorus in the carbide and matrix can be displayed most clearly in a plot of the sequence of arrival of the ions at the detector. Figure 3 shows such a plot of the data obtained from a 3nm diameter carbide particle formed during 380h annealing at 600°C. The plot shows twenty atoms per line which was estimated to be approximately equal to the number of atoms collected from each evaporated layer of 0.4Å thickness. No phosphorus atoms are observed in the carbide nor is there an appreciable enrichment of P at the interface. Instead, there is an enhanced phosphorus concentration of about 2 at.% in a region approximately 15 nm wide surrounding the carbide.

IV - DISCUSSION AND SUMMARY

The atom probe results show that phosphorus is enriched in the vicinity of Mo₂C but not directly at the interface between the precipitate and the matrix. A Gibbsian type of equilibrium segregation due to a lowering of surface energies can therefore be ruled out. Since no phosphorus was found within the carbide the heterogeneous nucleation of the carbides at Mo-P clusters is also not likely. The enrichment is probably caused by dislocations formed during the nucleation and growth of the precipitates or by the presence of the elastic strain fields surrounding the precipitates, as discussed by Johnson and Voorhees(5). Long-range interactions of solutes with carbide precipitates similar to those observed in this study were reported previously by Piller, Miller and Brenner for the Fe - TiC - Sb system (6). The effect of the phosphorus trapping on temper-embrittlement will be discussed elsewhere.

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TABLE I. Composition of Alloy (at.%)

	Mo	P	Mn	C	Fe
SM 1706	0.548	0.105	0.042	0.34	98.966

Figure 1. Carbide precipitate formed in alloy during 141 h at 600°C.

Figure 2a. Mass spectrum of carbide ("1" in figure 1.) showing absence of P.

Figure 2b. Mass spectrum of region between carbides ("2" in figure 1) showing P enrichment.

Figure 3. Field-evaporation sequence through carbide and region surrounding it. "M" = molybdenum, "C" = carbon, "." = iron, "P" = phosphorus.