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MS-4-P-1409 NANOPRECIPITATES OF PHOSPHORUS IN SUPERMARTENSITIC STAINLESS STEELS

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Super martensitic stainless steels (SMSS) exhibit a good combination of strength, toughness, corrosion resistance and weldability properties. Due to these properties, they have been increasingly applied in the oil and gas industries to substitute the more expensive duplex stainless steels for onshore and offshore tubing applications [1]. The chemical compositions of SMSS are based on Fe–Cr–Ni–Mo system and lower contents of the C (≤ 0.02 wt %), N (≤ 0.002 wt %) and P, S (≤ 0.003 wt %). This steels present good strength, toughness and corrosion resistance mainly when microalloyed with Al, Nb, Ti and V [2]. In this work was used the SMSS with high phosphorus content (SMSS+P = 0.012 % C, 12.5 % Cr, 5.36 % Ni, 2.11 % Mo, 0.29 % Mn, 0.19 % Si, 0.0013 % S, ↑0.017 % P (≤ 0.003%), and 0.001 % N). The steel was produced with extra low residual impurity contents in a vacuum induction-melting furnace and hot rolled to 29 mm diameter round bars in Villares Metals Research Centre. The samples of SMSS+P steel were heat treated at: 1000 °C/45 min/oil + 610 °C/2 h/air. Chemical and microstructural characterizations were performed by transmission electron microscopy (TEM) in a TECNAI G2 F20 microscope (200KV), withh Energy Dispersive X-ray chemical microanalysis system. Fig.1 (a) presents a bright field STEM image showing ultra-fine martensite-lath morphologies with recrystallized grains inside and also the presence of subgrains. Fig. 1 (b) presents the corresponding selected area electron diffraction pattern (SAEDP) revealing the high deformation state of the sample and the presence of subgrains. The white circle in Fig. 1 (a) represents the region where it was zoomed in Fig.2 (a), which presents a bright field STEM image showing phosphorus-rich nanoprecipitates (point 1), and in in Fig.2 (b), which presents a dark field STEM image showing nanoprecipitates with sizes of about 8 nm, and that the precipitation occurs preferentially in dislocation lines. The SAEDP in the inset of Fig. 2 (b) shows a diffraction ring of such precipitation together with matrix spots. Indexation of SAEDP revealed the presence of CrP4 along [0,1,0] zone axis, which was confirmed by EDX analysis (Fig 2a, point 1 as indicated) revealing the higher content of phosphorous (0.07 weight%) when compared with the matrix (Fig 2a, point 2 as indicated) where phosphorous was not detected. The presence of such precipitates can justify the good obtained mechanical and corrosion resistance properties.

References: [1] X. P. Maa, et al. Mat. Sci. Eng. A-Struct., A539 (2012) 271.
[2] C. A .D. Rodrigues, et al., Mat. Sci. Eng. A-Struct., A460 (2007) 149.

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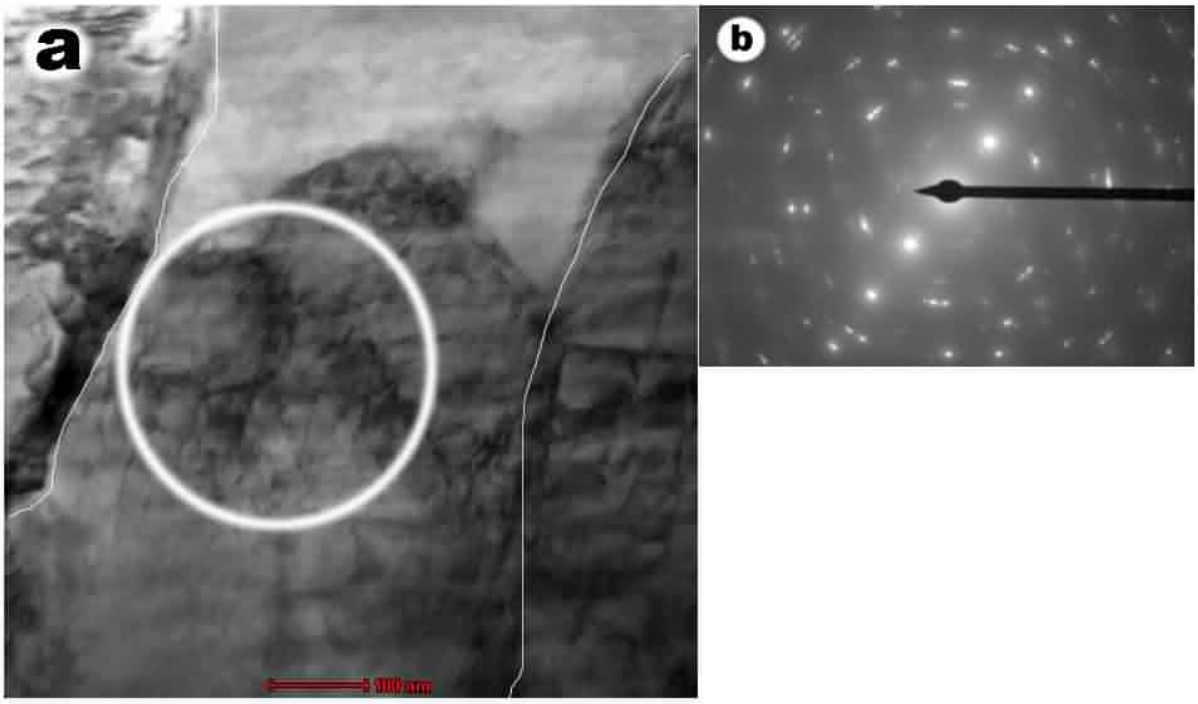

Fig. 1: Fig.1. (a) Bright field STEM image showing the ultra-fine martensitic-lath morphologies with recrystallized grains inside and also the presence of subgrains, and the white circle corresponds to the region where this image was zoomed in Fig. 2. (b) the SAED pattern of the martensitic matrix.

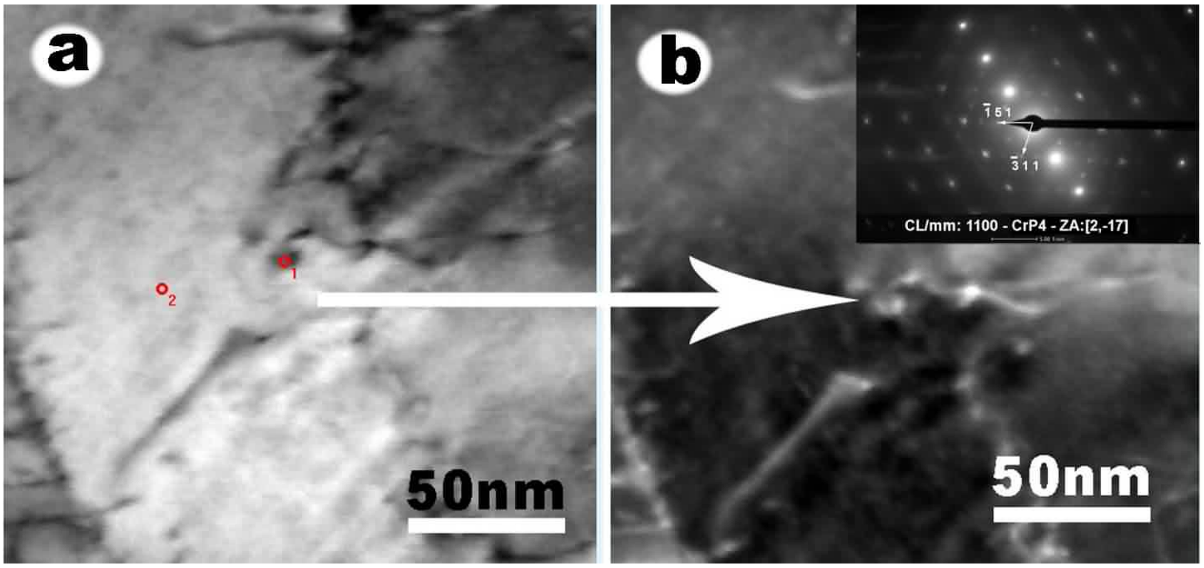

Fig. 2: Fig.2. (a) Bright field STEM image showing phosphorus-rich nanoprecipitates (point 1) located into subgrains of the SMSS+P steel. (b) Dark field STEM image showing nanoprecipitates with size approximate of 8 nm, and top right hand side present the corresponding SAED pattern of the nanoprecipitates.