

# Development of Steels for Application in Power Plants and Petrochemical Industry

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Material characterization using electronic microscopy, mainly transmission electron microscope (TEM), is widely used in scientific research and failure analysis. However, it is also an important tool used in the development of alloys and prediction of their behavior during service life. In this case a great number of samples under different simulation situation are analyzed and the use of extraction replicas allows obtaining analytical results in large scale. Two cases where the importance of the technical application of electronic microscopy is shown are presented: Modified HP stainless steel development with the addition of strong rare earth carbide formers and new generation of Cr-W ferritic steel development.

**Modified HP stainless steel development:** The development of centrifugally cast austenitic stainless steels HP-type for reforming furnaces is based on the control of the morphology and stability of the precipitate network mainly located in the interdendritic region. The basic chemical composition of steel HP-type has been modified since its introduction in that market aiming to improve the creep properties giving rise to the modified steels HP-type. The addition of niobium allowed a partial substitution of chromium carbides by niobium carbide NbC, more stable to coalescence. During this phase of the development, fragmentation of the primary carbide network and *in situ* transformation of niobium carbide to G phase were observed after long exposure to high temperatures. The G phase which is a nickel-niobium silicide with stoichiometry  $Ni_{16}Nb_6Si_7$  is considered to prejudice creep resistance. In a next stage, it was observed that lower silicon contents helped to delay the transformation of niobium carbide to G phase, therefore improving creep properties. The combined addition of niobium and titanium led to a more refined microstructure, a more uniform secondary precipitation and, at the same time, delayed the formation of G phase. In this case, the transformation of the carbide formed (NbTi)C to G phase is controlled removing titanium, insoluble in the latter. In the actual stage of development, the addition of yttrium led to a fragmentation of the carbide network, especially chromium carbides and reduced sulphur content in the matrix. Yttrium carbide, formed at higher temperatures,  $Y_3C$ , acts as preferential heterogeneous nucleation site for other particles resulting in increased fragmentation of the primary carbide network.

**New generation of Cr-W steels development:** The development of advanced ferritic heat-resistant steels with sufficient creep-rupture strength at high temperature. bainitic 3Cr and tempered martensitic 9 to 12 Cr steels strengthened by W that have become of great interest for application in refineries and high-temperature plants, such as ultrasupercritical (USC) power plants. The analysis was focused on the evaluation of the effect of the presence of C, Cu, B, W and the Mo concentration reduction. The microstructural degradation and mechanical behavior were correlated, through the evaluation of the role of the carbide precipitation in the creep strength of these alloys. These changes are the basis for the new Cr-W ferritic steel development, which will potentially replace the conventional Cr-Mo steels. This study allowed the identification of the role of B in the change of the carbide precipitation routes, the degradation of the creep strength due to the absence of Mo and the adequate W concentration. The fine carbides precipitation with (V,Nb)C stoichiometry and the W in solid solution were identified as main metallurgical variables for the creep strength in the studied alloys as well as the need of Cu to reduce the delta ferrite amounts on high Cr grades.