The superior properties of the 9Cr1MoNbV steel (P91) at high temperatures depend on the maintenance of its microstructure throughout its service life: a high density of dislocation with M₂₃C₆ and MX type I (NbCN), type II (VN) or type III (“wings”) precipitates.

As precipitation strengthening is one of the most effective mechanisms active in the P91 steel, the precipitates present in the fusion zone (FZ), coarse-grained (CGHAZ), fine-grained (FGHAZ) and intercritical (ICHAZ) heat affected zones generated by a FCAW process, with a rutile slag wire as filler material, were identified by means of TEM on carbon extraction replicas, before to doing the PWHT.

Precipitates found in the base material (BM) were shown in a previous work. The M₂₃C₆ carbides (M = 55.4Cr-32.2Fe-11.5Mo-0.9V) were the major observed precipitates. They were followed by isolated or clusters of VN precipitates with a chemical composition of 54.9V-22.3Cr-22.8Nb and “wings”.

The FZ exhibited inclusions (18.8Cr-2.9V-41Mn-34.2Ti-3.1Nb) and a fine distribution of elongated M₃C (M = 16.6Cr-83.4Fe) formed as a result of autotempering during cooling (Fig. 1). The CGHAZ subzone (Fig. 2) showed a reduction in the quantity and size of M₂₃C₆ carbides compared to the base material. Almost all had a spherical shape and the EDS analysis of these carbides showed that the most of them had M = 51.2Cr-36.6Fe-8Mo-4V, but few carbides with M = 56.2Cr-22.2Fe-21.6Mo were also detected. Equiaxed particles, approximately 90 to 290 nm in diameter, were identified as primary NbCN (M = 89.9Nb-5.7V-3.2Cr-1.1Ti). The size and morphology suggest they are residual precipitates undissolved during the thermal cycle experienced by CGHAZ subzone. Minority, small spherical NbCN (M = 83.4Nb-6.9V-9.6Cr) and VN (M = 24.4V-49Nb-26.6Cr) precipitates were also observed.

The FGHAZ subzone M₂₃C₆ (M = 50.4Cr-34.5Fe-10.9Mo-3.5V) isolated or clusters as shown in Fig. 3. Then, the NbCN precipitates (M = 87.5Nb-6.4V-6.1Cr) were identified and a few “wings” with very little VN particles were observed.

In the ICHAZ subzone, M₂₃C₆ carbides with M = 57.1Cr-31.6Fe-9.3Mo-2V and M = 42.3Cr-38.1Fe-19.6Mo were observed. Then, all types of MX were identified: NbCN (M = 82.8Nb-9.7V-7.5Cr), VN (M = 61.8V-21.3Nb-16.8Cr) and elongated wings. (Fig. 4). The M₂₃C₆ carbide was the major observed precipitate in all zones. According to thermodynamic calculations its dissolution is completed at ~900 °C but it was observed even in the CGHAZ. Only traces of the VN were detected in the CGHAZ and in the few “wings” observed in the FGHAZ. A change in a chemical identity of the MX precipitates, from V-rich to Nb-rich was observed in the FGHAZ. The ICHAZ showed large M₂₃C₆ particles and all types of MX precipitates, included the NbCN which was not observed in the BM.
Fig. 1: TEM micrograph of a carbon replica extracted from the FZ.

Fig. 2: TEM micrograph of a carbon replica extracted from the CGHAZ.

Fig. 3: TEM micrograph of a carbon replica extracted from the FGHAZ.

Fig. 4: TEM micrograph of a carbon replica extracted from the ICHAZ.