Abstract

Quenching and partitioning (Q&P) is a new processing route to develop multiphase microstructures consisting of decarburized martensite with a reasonable amount of carbon-enriched metastable retained austenite. In this work, a low carbon (~ 0.2 wt. % C) steel suitable for Q&P treatment was designed and was prepared in the laboratory via melting and casting. Various semi-empirical equations and thermodynamic software were used to understand the influence of alloying elements on the optimum quenching temperature (QT^{opt}) which maximizes the amount of retained austenite at room temperature, critical cooling rate for martensite transformation, thermal and mechanical stability of retained austenite and cementite precipitation from austenite. An alternative method to quantify the Q&P microstructures using the dilatation data provided a close estimate of the amount of retained austenite stabilized at room temperature.

Speer's model which is commonly used to predict the QT^{opt} and the corresponding amount of retained austenite was reviewed critically. A significant deviation between the actual QT^{opt} and that predicted by the Speer's model and the corresponding amount of retained austenite was observed which was attributed to autotempering of primary martensite during initial quenching, bainite transformation during partitioning, incomplete carbon partitioning from primary martensite, carbide precipitation and segregation of carbon atoms at dislocations. The Speer's model, revised after incorporating some of these reactions, gives a good match between the experimental and predicted results. The amount of retained austenite and its carbon content was found to depend not only on the quenching temperature but also on the partitioning temperature and time. The formation of cementite from carbon-enriched retained austenite may take place when the duration of the partitioning treatment is relatively long.

Studies on the microstructure-property relationship showed that the best combination of strength and ductility is achieved corresponding to the quenching temperature which yields the maximum amount of retained austenite possessing high stability. The yield strength (YS) of the Q&P steel was also calculated considering different strengthening contributions. Although the calculated YS of the Q&P samples was slightly overestimated, the overall behaviour of the YS with increasing QT was predicted correctly. Primary martensite has the highest contribution to the YS of Q&P microstructures for the lower QTs because of its higher volume fraction. Since the amount of bainite increased for

the higher QTs, its contribution to the YS was higher.

The carbon partitioning behaviour between primary martensite and untransformed austenite was examined using thermodynamic models such as constrained carbon equilibrium (CCE) and constrained carbon equilibrium incorporating carbide precipitation (CCEθ). The kinetics of carbon partitioning was predicted using DICTRA simulation. The actual carbon partitioning behaviour, estimated using X-ray diffraction and atom probe tomography (APT) analysis, was found to be significantly different from the predicted behaviour. These discrepancies were interpreted based on the carbide precipitation inside martensite, incomplete carbon partitioning from martensite and the segregation of carbon atoms at dislocations or defects which were ignored during the thermodynamic calculations and DICTRA simulation.

Some more studies on an alternative Q&P treatment were carried out where austenite stabilization at room temperature was achieved by Mn enrichment rather than C enrichment in austenite as in the usual Q&P treatments. The spheroidization treatment of the as-quenched hot-rolled material resulted in Mn-enriched cementite particles dispersed in the ferrite matrix. During short-duration intercritical annealing of cementite and ferrite mixture, cementite dissolved to austenite and retained its high Mn content. Retained austenite that was stabilized after the short duration intercritical annealing and Q&P treatment of the spheroidized material possessed higher stability against deformation-induced martensite transformation than the retained austenite stabilized in the as hot-rolled material.

Keywords: Q&P steels, martensite, bainitic-ferrite, carbides, spheroidization, DICTRA, constrained carbon equilibrium.