# Tempered Hardness of Martensitic Steels

Tempering a martensitic structure leads to precipitation of carbides and/or intermetallic phases. Depending on the phases precipitating out, martensitic steels can be classified into two types. In Type I steels, cementite is the dominant stable precipitate. Plain carbon steels and low alloy steels belong to this type. In Type II steels, stable precipitates include alloy carbides and intermetallic compounds. The tempering of Type I steels has been dealt with in an earlier report [1], which corresponds to the calculations of "Tempered Hardness" and "Tempering Properties" in JMatPro. This report is focused on the tempering of one class of Type II steels, the martensitic power plant steels, which corresponds to the calculation of "Simultaneous Precipitation" in JMatPro.

Various types of precipitates form in martensitic type power plant steels during tempering or service at elevated temperatures, including carbides and intermetallic compounds. The precipitation process usually occurs in a complicated manner, beginning with phases which are easy to nucleate but metastable. It is usually only after prolonged aging that the equilibrium phase mixture might be obtained. These precipitates interfere with each other, not only by reducing the volume available for transformation, but most importantly by removing solutes from the matrix and thereby changing its composition. A computer model has therefore been developed to handle several precipitation reactions simultaneously whereby the different phases may influence each other [2].

The precipitates considered in the model include M_3C, $M(C,N)$, $M_2(C,N)$, M_7C_3, $M_{23}C_6$, M_6C, Z-phase and Laves phase. The precipitation kinetics model is based on the classical Johnson-Mehl-Avrami theory with an adaption that allows the morphology of the precipitate to be considered as well as specifics associated with potential nucleant sites. Details of this model can be referred to one of our early publications [3]. The size of the precipitates has also been calculated which considers nucleation, growth and coarsening stages with automatic transition. Many critical issues involved in simultaneous precipitation have been considered in the model, including cementite enrichment, solution partition and dissolution of metastable phases, which follows a similar approach to that of Robson and Bhadeshia [4,5]. The ability to track the microstructure evolution (i.e. the amount and size of various types of precipitates) during tempering enables the ultimate calculation of tempered hardness and strength via employing proper precipitation hardening mechanisms, which is the focus of this report.

Fig. 1 shows the evolution of microstructure and hardness of two power plant steels, 9Cr–1Mo–0.2V and 8Cr–2W-0.1Ta, during tempering at 700°C, in comparison with the experimental data taken from Refs. 6 and 7. It should be noted that the experimental hardness values at 0.0001 hour in Figs. 1(e) and 1(f) are the measured martensite hardness of the two alloys before tempering, respectively. The "hump" shown in the hardness plots at tempering time below 0.1 hour is linked to the formation and dissolution of metastable precipitates and their strengthening. The stable precipitates, such as M(CN) and $M_{23}C_6$, become dominant after 1 hour tempering at 700°C for these two alloys.

(a)   (b)
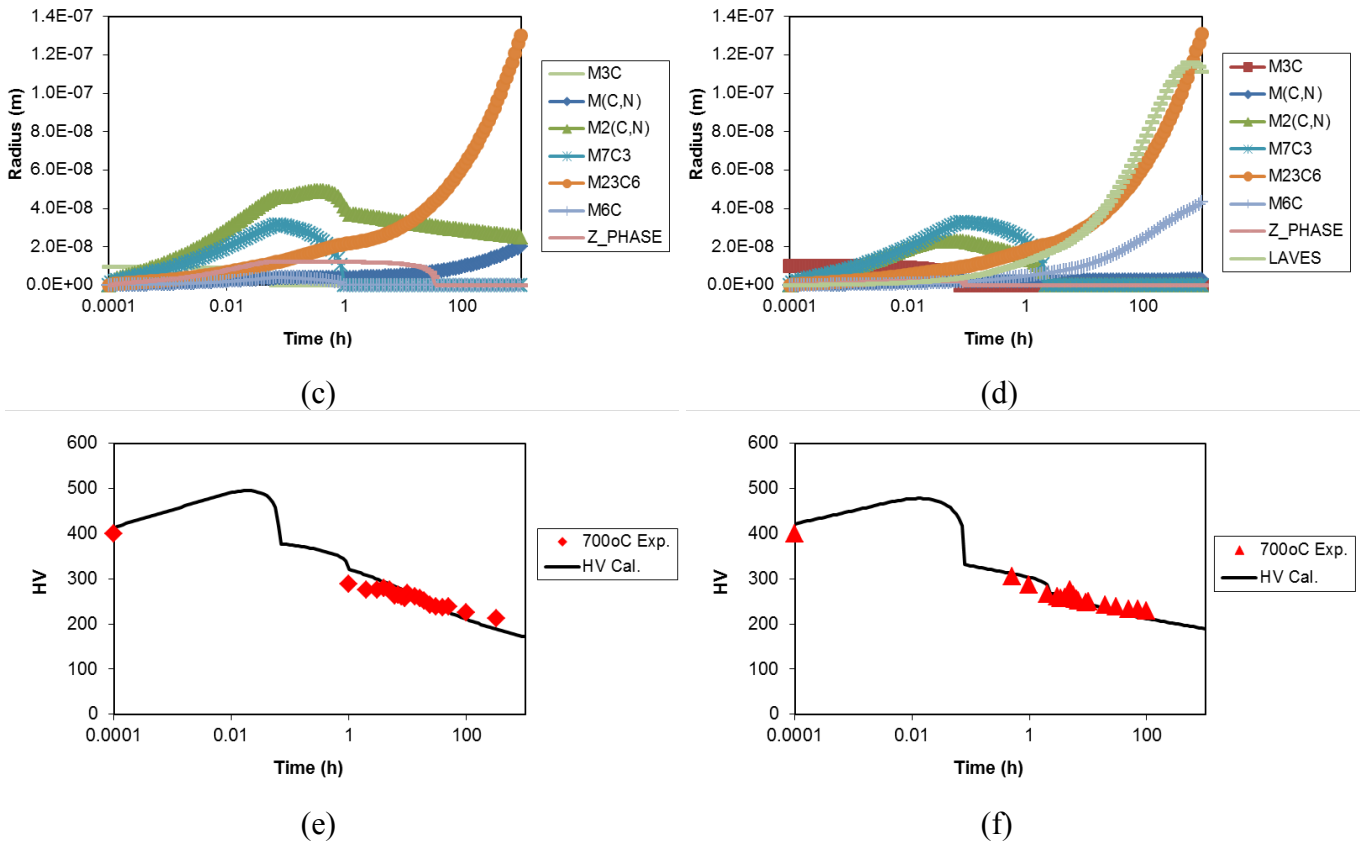
(c)

(d)

(e)

(f)
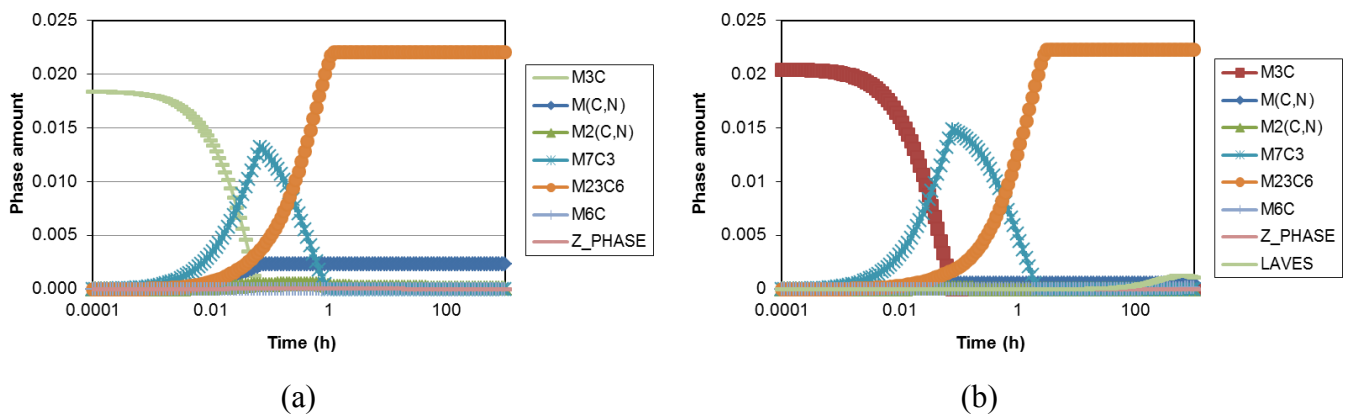
Fig. 1, Evolution of precipitate fraction, size and hardness during tempering at 700°C for steel 9Cr-1Mo-0.2V (a, c, and e) and steel 8Cr-2W-0.1Ta (b, d, and f).

More hardness comparisons during tempering at various temperatures for these two steels are given in Fig. 2, together with a P91 steel [8]. The agreement with experimental data are generally quite good except the case of 650°C tempering for steel 8Cr-2W-0.1Ta. Simultaneous precipitation calculation is designed for martensitic power plant steels, but it can be applied to other martensitic type steels as long as the dominant precipitates are considered in the model, e.g. Type 1 steels. It is also for this reason that the current model cannot be applied to precipitation hardening stainless steels and maraging steels as they contain precipitates which are not yet considered, which is the direction of future model development.
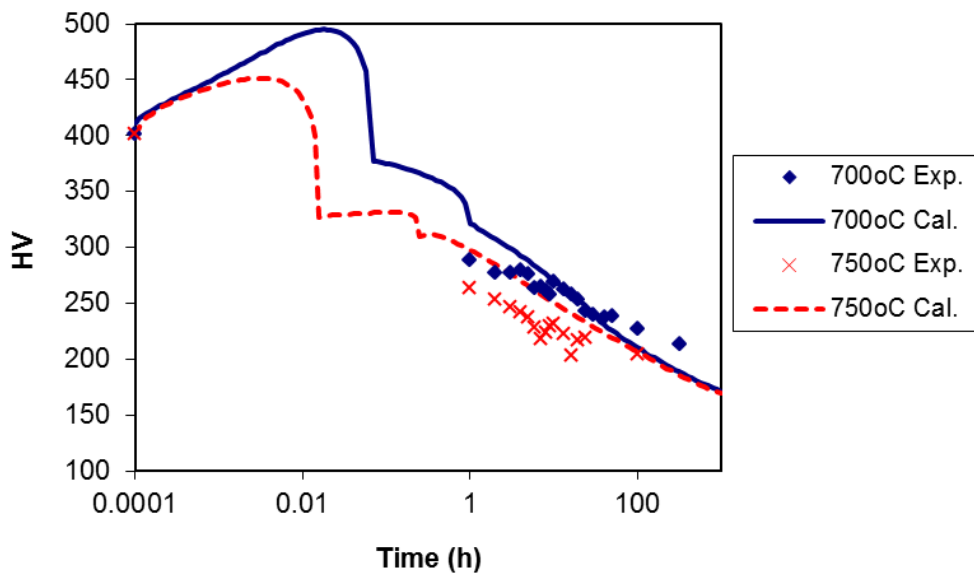
(a) Steel 9Cr-1Mo-0.2V
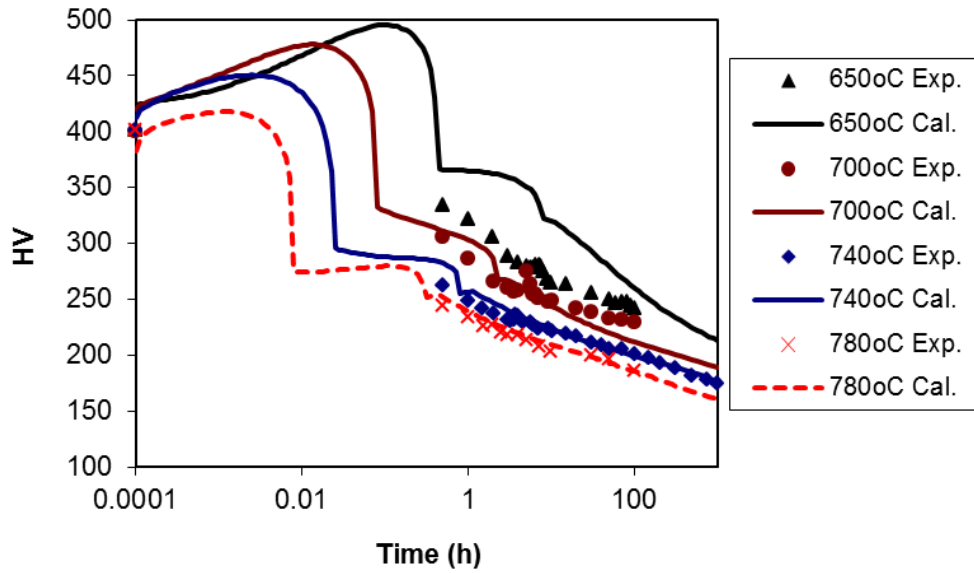
(b) Steel 8Cr-2W-0.1Ta
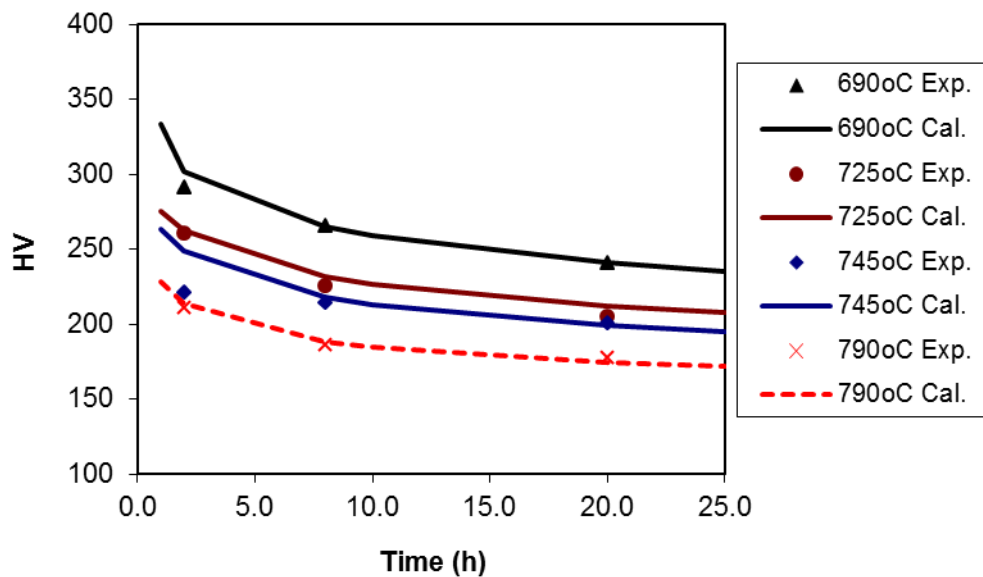
(c) Steel P91

Fig. 2, Evolution of hardness during tempering at various temperatures for (a) steel 9Cr-1Mo-0.2V, and (b) steel 8Cr-2W-0.1Ta.

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