Cryogenic treatment of steel: from concept to metallurgical understanding

Subjecting steel to cryogenic treatment to improve its properties was conceived in the 30ies of the previous century. The proof of concept that properties, in particular wear resistance, can indeed be improved importantly, was reported in the next decades. Despite many investigations, the metallurgical understanding of the microstructural changes involved in cryogenic treatment of steel has remained poor. It is believed that the improvement in wear resistance is promoted by an enhanced precipitation of carbides during tempering, but no explanation has been given as to how this enhanced precipitation can be obtained. In the last six years, the authors have applied in situ magnetometry, synchrotron X-Ray Diffraction and dilatometry to enlighten the phase transitions occurring in steels at cryogenic temperatures and to point out the connection between different treatment parameters and the response of the material to tempering. This activity is put into perspective in the present work. Experimental activity on 100Cr6, has shown that martensite forms during cryogenic treatment on cooling, isothermal holding as well as on re-heating to room temperature, and that the fraction of austenite that is transformed to martensite is maximal when cryogenic treatment is performed directly after quenching. Martensite formation evokes compressive stresses in austenite at temperatures higher than -140°C, whereas no compression builds up in austenite when martensite forms below this temperature. The isothermal formation of martensite at T<-140°C, promotes / modifies the precipitation of carbides during tempering. Additionally, cryogenic treatment facilitates the thermal decomposition of retained austenite. Furthermore, time dependent (i.e. isothermal) formation of martensite was investigated in numerous ferrous alloys. The activity was performed both applying isothermal treatments as well as following martensite formation during heating from boiling nitrogen temperature. These investigations showed that time-dependent, i.e. thermally activated, martensite formation is the rule rather than the exception. In systems forming martensite with blocky (lath) morphology the formation of martensite is purely time dependent and can be suppressed on fast cooling to cryogenic temperature. In systems forming plate martensite, martensite formation is only partially time-dependent and cannot be suppressed entirely during fast cooling to cryogenic temperature. Time-dependent martensite formation proceeds very sluggishly at boiling nitrogen temperature (-196°C), but can be pronounced in the temperature range -180°C to -40°C. The improved understanding of the phenomena occurring during cryogenic treatment of steel can find application in the heat treatment of high carbon steels, of martensitic stainless steels and in case-hardened components. Maximum advantage can be obtained if the entire heat treatment cycle is optimized.

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