FORMATION OF THE DUAL-PHASE STRUCTURE DURING CONCURRENT DEFORMATION OF A LOW CARBON CHROMIUM-MOLYBDENUM STEEL AND ITS MECHANICAL PROPERTIES

by
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CERTIFICATE

This is to certify that the thesis entitled, "Formation of the Dual Phase Structure during Concurrent Deformation of a Low Carbon-Chromium-Molybdenum Steel and its Mechanical Properties" by R.K. Piplani submitted to the Indian Institute of Technology, New Delhi (India) for the award of the degree of Doctor of Philosophy in Applied Mechanics Department is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion has reached the standard fulfilling the requirements for the Doctor of Philosophy Degree. The research report and the results presented in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Rapid developments in the dual-phase steel technology have initiated a new facet of study in high-strength, low-carbon, low-alloy steels. To study the effect of concurrent deformation on austenite to ferrite transformation, the steel composition is so chosen, as to promote rapid ferrite formation to suppress the pearlite reaction and to form a deep bay in the transformation curve to prevent transformation of austenite to bainite. The concurrent deformation implies simultaneous deformation and transformation achieved here in a single pass reduction, in a 2-High rolling mill. Starting with an austenitisation temperature of 970°C, the temperature of the steel sample drops almost instantaneously by ~200°C in the deformation zone by roll quenching and most of the rolling time interval (~1.5 sec) is in the constant temperature zone at 670°C. The progress of the transformation is evaluated during the two treatments given to the samples. In Treatment I, the samples are concurrently deformed and quenched in water and during Treatment II, the samples after concurrent deformation are isothermally annealed for various time intervals at different temperatures.

Concurrent deformation and transformation of austenite to ferrite in the processing of dual-phase steel not only modifies the transformation kinetics but also the resultant morphology of the microstructural components

and the mechanical properties. The results are analysed for the transformation kinetics using the classical nucleation and growth concepts. The kinetic parameters obtained from the experimental data in Treatment I indicate that the proeutectoid ferrite undergoes diffusion controlled growth with most of the nuclei present at the start of the transformation. It is estimated that during Treatment I, the rate of nucleation is 5 orders of magnitude higher than that in the unstrained austenite.

Analysing the data during Treatment II shows that the variation of half-time transformation with corresponding temperatures shows 'C curve' characteristics. The concurrent deformation promotes rapid ferrite formation and after 32.5% reduction, the rate of transformation increases by two orders of magnitude. Analysis by extrapolating back the kinetics from Treatment II to Treatment I indicates that strain induced ferrite formation occurs along with heterogenous copious dynamic nucleation during the concurrent deformation.

The morphology of the proeutectoid ferrite and ferrite-martensite phase distribution is altered with increase in the concurrent deformation, because of the changed mode of transformation. At low deformation the ferrite nucleates mostly at the grain boundaries with limited intra-granular nucleation. With increase in percent deformation, the ferrite is nucleated within the grains of deformed austenite at defect regions like deformation bands resulting in very fine grainsize approaching 1 μm. The strength increases with an increase in martensite content. At a particular martensite level the increase in strength, and the increase in elongation at a particular strength level, with increase in the concurrent deformation, is due to the fine grainsize obtained.

The strength - microstructural parameter correlation in the Bucher-Hamburg relationship is given by, $\sigma = 365 + 10.5 (\%M) + Kd^{-1/2}$, where σ is the tensile strength, %M is the martensite content, d is ferrite grain size and K is constant. This correlation matches well with the experimental data, when K is taken to be proportional to the amount of concurrent deformation.

A log true stress versus log true strain plot of the tensile data shows strain dependence of the work-hardening behaviour. These curves show a typical continuous yielding behaviour, with low yield stress, which is attributed to the transformation induced mobile dislocations, present near the ferrite/ martensite interface and the quenching streses. With an increase in the isoannealing time the overall yielding behaviour gradually changes from continuous to conventional discontinuous yielding behaviour, because of decreasing martensite, volume fraction, increasing grainsize and other parameters.

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