Abstract

This thesis signifies the importance of the meticulous selection of alloy composition and proper design of heat treatment schedule to obtain superior strength-low temperature impact toughness properties in steels used for naval, automotive, and armor applications. In accordance with the property specifications of the mentioned steel grades for their respective applications, the concentration of particular alloying elements and heat treatment parameters are varied to observe their effect on diverse microstructural parameters and features such as prior austenite grain size, martensite substructural unit size, volume fraction and stability of different phases, size, shape, distribution of different phases and second phase particles, volume fraction of substructural feature such as twins, severity of segregation or banding, etc.

Three industrially hot-rolled low carbon naval grade steels with varying Al and Si concentrations were subjected to quenching followed by tempering at three different temperatures to obtain an enhanced strength-toughness combination. An increase in the tempering temperature led to the enhancement of impact toughness at the cost of strength, because of refined structural unit size (Bain width), along with the presence of some amount of retained austenite, and coarse Cu precipitates (diameter > 5 nm) with wide inter-precipitate spacing (greater than 50 nm). A higher fraction of retained austenite resulted in superior impact toughness of the Base steel than the other ones. The formation of an ordered intermetallic B2-NiAl shell around Cu precipitates in the Al containing steel enhanced the strength significantly at the expense of toughness. An excellent strength-toughness combination (YS > 750 MPa, toughness > 100 J at - 40 ℃) was achieved in the Base steel tempered above A_{e1} temperature.

To extend the application of the medium Mn steels in the manufacturing of automotive and structural components designed for use in cryogenic conditions, an effort was made to improve the impact toughness of medium Mn steels with varying C and Mn contents through inter-critical annealing treatment at different temperature without significant reduction in strength. Furthermore, the research explored the relative influence of C and Mn content on the evolution of the fibrous microstructure and its resulting mechanical properties. The 'low-C, high-Mn' steel displayed a higher retained austenite fraction, superior yield strength, and toughness in comparison to the 'high-C, low-Mn' steel, signifying the advantageous influence of Mn enrichment over C while allowing the attainment of near-equilibrium composition. The ‘low-C, high-Mn’ steel intercritically annealed at a lower temperature (A_{e1}+30 ℃) displayed an outstanding balance between strength (YS ~ 665 MPa) and toughness (~ 64 J at - 40 ℃)

owing to its finer microstructure and higher retained austenite fraction in comparison to other steel samples. Except for the LCHMn A_{e1}+30 sample, all other samples exhibited the Mn redistribution phenomenon, which decreased the fraction of stable austenite. The presence of a substantial amount of retained austenite at various martensite substructural boundaries of the LCHMn A_{e1}+30 sample refined the structural unit size (Bain width) to a great extent, leading to the remarkable improvement of both strength and impact toughness.

Since the twin is often observed as a substructural feature in the martensitic armor grade steel, the efficacy of these martensite twins on resisting the local scale cleavage crack propagation was studied in an industrially hot-rolled medium carbon armor grade steel. Fine twins (width < 10 nm) were found ineffective in deflecting the {100} cleavage crack propagation. In contrast, the coarse twins provided significant hindrance to crack propagation by deflecting the crack through stepwise crack path propagations, e.g., {100} matrix-twin cleavage cracking or {100} matrix-{112} twin-matrix interface cracking. The C-enriched clusters, present along the twin boundaries, resulted in {112} interfacial cracking. Enhancing the overall toughness necessitates the presence of numerous twins having a width of more than 10 nm.

The same armor steel was austenitized at various temperatures and then tempered at a low temperature to investigate the manifold effects of austenitization temperature on the microstructural evolution and the subsequent variations in strength and impact toughness. Surprisingly, the sample austenitized at a lower temperature (800 ℃) showed low impact toughness despite possessing a finer substructural unit size than the other samples. Such reduction of impact toughness in the sample austenitized at 800 ºC is attributed to centerline fissure cracking, facilitated by the presence of severe segregation-induced tensile residual stress in the mid-thickness region. In contrast, higher austenitization temperature (1200 ℃) led to reduced toughness owing to larger substructural unit size. An outstanding impact toughness (~ 45 J at - 40°C) and remarkably high yield strength (~ 1090 MPa) was achieved at an intermediate austenitization temperature (1000 ℃). This was ascribed to the finer martensitic substructural unit size and limited segregation, signifying the importance of developing an optimized microstructure to get a superior balance between strength and impact toughness in chemically inhomogeneous armor steel.

Keywords: Naval grade steel; medium Mn steel; armor grade steel; strength; impact toughness; heat treatment; alloy content; retained austenite; microstructure; martensite twin; substructural unit refinement; Bain width; Cu precipitate; fissure; segregation.