ABSTRACT

Driven by the increasing demand for superior mechanical performance and low density, the present work is focused on establishing the high Al, medium Mn multicomponent steel as the candidate material for the automotive application. The design philosophy of the developed material is totally based on the calculation of stacking fault energy and analysis of thermo-dynamic phase diagrams. The investigated steel is prepared through the conventional process of melting and casting, followed by homogenization at 1373K for 2 hours. The homogenized steel is further subjected to the different stages of thermo-mechanical processing via hot forging (HF), hot rolling (HR), and cold rolling (CR) accompanied by the intermediate annealing at each stage. The HF specimen, with ferrite-austenite as the starting microstructure, undergoes a phase transformation from a duplex phase to a single ferrite phase, when it is exposed to a higher annealing temperature of 1273K and a time period of 150 mins. Apart from the phase transformation at 1273K, the recrystallization process also initiates in the ferrite grains. A sharp rise in the Avrami exponent (n) value is noticed following annealing at 1273K, which denotes that the disappearing austenite-ferrite interfaces facilitate the migration of the ferrite boundaries that stimulate recrystallization. In spite of the increasing values of n with the annealing temperature, its maximum value (at 1273K) remains close to 1 that clearly indicates the sluggish nature of the recrystallization process in the developed steel. In contrast, the CR-annealed specimens have exhibited faster recrystallization kinetics than HF-annealed and HR-annealed conditions, as reflected by the higher Avrami exponent (~1.28) and requirement of minimum annealing temperature-time (1073K-50 min) for maximum recrystallization. Further, the specimen cold rolled and annealed at 1073K for 3 min (CR-1073K-3 min annealed) has exhibited excellent tensile properties owing to the co-existence of both deformed and recrystallized grains. The refinement of ferrite grains and the lower austenite aspect ratio are the other parameters that are responsible for better strength-ductility combination in the CR-1073K annealed specimen in comparison to the HF-1273K and HR-1273K annealed variants.

Similar to the CR-annealed specimen, another set of HR-1273K-10 mins plates have been subjected to warm rolling (WR) and subsequent annealing treatment within the temperature range of 1073-1273K for 3 mins. It is observed that both the CR-1073K and WR-1073K annealed specimens exhibit the excellent combination of strength (1141−1184 MPa) and ductility (18.1−22.2% elongation) due to the presence of fine ferrite grains. A higher fraction of fine $Mn_5(Al,Si)C$ precipitates have restricted the grain boundary migration thus leading to smaller ferrite grains in this annealing temperature. However, dissolution of the $Mn_5(Al,Si)C$ precipitates and the simultaneous increase in the grain size of ferrite at higher annealing temperature (i.e., 1173K and 1273K) deteriorates the strength-ductility relationship in both the cold rolled and warm rolled annealed specimens.

Further, the addition of micro-alloying elements like Ti modifies the tensile properties of the developed steel during annealing at 1073K for a longer duration (~50 mins). The grain refinement occurring through the simultaneous dissolution of $Mn_5(Si,Al)C$ precipitates and the evolution of Ti-rich intermetallic carbide precipitate leads to the better strength-ductility combination in Ti-modified steel in comparison to the Ti-free steel after 50 mins of annealing at 1073K. Besides the phase transformation, precipitation strengthening, grain refinement, and recrystallization kinetics, the lesser volume fraction of cube fibers of the ferrite phase, evolve within the Taylor factor range of (~2-3) and the higher volume fraction of γ-fibers of ferrite phase evolves within the Taylor factor range of (~3-4) also influences the strength-ductility combination of the investigated steels, significantly.

Apart from the better tensile properties of the investigated steels, the presence of higher Al content reduces the specific density of the developed materials. Therefore, considering the combined exhibition of superior tensile properties and lower specific density, the developed steels can be employed under the domain of third generation advanced high strength steel for automotive application.

Keyword: Medium Mn multicomponent steel; Phase transformation; Recrystallization Kinetics; Precipitation strengthening; Texture; Taylor factor distribution; Tensile properties.