ABSTRACT

Two different high-strength B-containing microalloyed steel strips produced in industrial processing conditions, one treated with Ti and the other treated with Al, processed by controlled rolling, accelerated cooling and coiling in two different temperatures ranges (450 °C to 460 °C) and (360 °C to 380 °C) were subjected to tensile testing, bend testing, and Charpy impact testing.

The Ti treated steel coiled at the higher temperature of 460 °C showed the best bending performance. The relatively softer (tensile strength of < 900 MPa) and homogeneous microstructure containing mostly granular bainite and upper bainite to ~300-400 μm depth below the surface, generated at the higher coiling temperature, is preferred for bendability. The lower temperature coiling resulted in the formation of a hard surface layer dominated by martensite which is undesired as the steel becomes prone to shear cracking and interphase separation due to strain-localization. The combined effect of beneficial texture components such as γ-fiber, {332} <113> and even {112} <131> in the sub-surface region as well as with a low intensity of BCC shear texture components (e.g., {112}<111>), generated at the higher coiling temperatures (450-460 °C), is preferred for bendability (more resistant to shear cracking during bending). Moreover, the uniformity of the through thickness texture of the rolled sheet improves the bendability. In the presence of crack initiators, like coarse and brittle TiN particles found in the Ti treated steel, a harder microstructure and the presence of Cube and Goss texture in the sub-surface layer, seen for the lower coiling temperature can cause local transgranular cleavage cracking. Finally, the post-uniform elongation obtained from tensile testing and bendability follow a good correlation.

Furthermore, the tensile and Charpy impact properties of four strip samples have been evaluated and correlated to the microstructural parameters, dislocation density, and the intensity of high-angle boundaries. The volume fraction of the individual phase constituents (namely, granular bainite, upper bainite, lower bainite and tempered martensite) and their hardness, local deformation response and strain-hardening ability, as determined from nanoindentation testing, influenced the bulk properties such as hardness, tensile properties (strength and ductility), Charpy impact properties (upper shelf energy, USE, and ductile-to-brittle transition temperature, DBTT) and strain-hardening abilities under both quasi-static and dynamic loading conditions. The dominance of granular bainite and upper bainite (75-90%) reduced the strength (670-722 MPa yield strength), improved ductility (16.7 – 19.5% elongation to failure) and USE (35-42 J) in the samples coiled at the higher temperatures. In contrast, a higher fraction of tempered martensite and lower bainite (78-82%) significantly increased the strength (808-814 MPa), reduced ductility (13.0-14.5%) and USE (19-29 J) in the lower temperature coiled samples. The DBTT showed a complex trend with the microstructural parameters. It depended on the USE level, as well as on the ‘effective grain size’ of the matrix. The hard surface layer dominated by martensite developed at lower coiling temperatures (360-380 °C) promoted cleavage cracking and is, therefore, undesired for bendability and impact toughness. The impact toughness at -40 °C improved with the intensification of high angle boundaries, refinement of effective grain size, and the reduction of detrimental ‘rotated cube’ texture component. Finally, as the different properties are correlated, a decrease in yield strength, an increase in ductility (particularly post-uniform elongation) and tensile toughness are found to be beneficial for bendability and USE. It can be concluded that a higher coiling temperature is preferred to achieve a softer bainitic microstructure if improved bendability and toughness are required rather than higher tensile strength.

Keywords: Ultra-high-strength steel; Coiling temperature; Bainite-martensite microstructure; Bend test; Microstructural homogeneity; Crystallographic texture; Charpy impact testing; Upper shelf energy; Ductile-brittle transition temperature.