ABSTRACT

ON

STUDY ON HOT DEFORMATION BEHAVIOUR AND WELDABILITY OF EN30B/EN25 STEEL GRADES

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ABSTRACT

The thesis aims to investigate two medium carbon low alloy steel (MCLA) grades, EN30B and EN25, on two major aspects, namely the hot deformation behaviour and joining characteristics using sophisticated electron beam welding. These MCLA grades contain Ni in the range of 2.4 to 4% along with Mn, Cr, Mo and are primarily used for producing heavy machineries in mining industries like excavators and shovels, besides their application in aerospace and automobile industries.

Although several studies have been reported on the hot deformation behavior of various MCLA, studies on the hot deformation behavior of EN30B and EN25 steels are conspicuously absent in the literature. It is also observed that the hot deformation behavior of various MCLA grades is different and a vital function of alloying elements and their amount. Therefore, each steel grade possesses unique processing maps identifying safe deformation zones. Therefore, developing constitutive equations for flow stress vs. strain rate, temperature relationship, and processing maps for these European grades was found to be essential and form one of the objectives of the present study. Additionally, inclusions in steel influence the dynamic response of the material under hot deformation and the evolution of the safe deformation zone. However, a study correlating the evolution of inclusion with the material's hot deformation dynamic response has rarely been reported for MCLA steel, especially for EN30B and EN25 steel.

Although the welding issue for medium carbon steel is well known, the welding behavior of MCLA, especially EN30B and EN25 steels, needs to be reported better in the literature.

Electron beam welding (EBW), characterized by low heat input and contamination-free welding, has not been attempted for EN30B and EN25 for sophisticated joining. Therefore, EBW of EN30B and EN25 also form another objective of the present study.

The hot deformation behaviour of EN30B and EN25B steel grades have been studied using the Gleeble® simulator 3800. The experimental flow stress values were analysed to generate the processing map based on dynamic material modelling reported in the literature. Such maps identified the safe deformation zone in the two-dimensional domain of strain rates and temperatures at various strain levels with maximum deformation up to 70%. At a comparatively lower strain, the safe zone locates in the high temperature and high strain rates regime for both the steel grades. At higher strain, the safe zone moves to lower strain rates and moderate to high-temperature regime for EN30B steel, while it moves further to higher temperature and slightly expands to lower strain rates for EN25 steel. The development of such safe deformation zones has been explained based on the evolution of microstructure, estimated DRX, inclusions, and precipitates during deformation. At lower deformation levels, microstructural examination indicated lack of mobile dislocations, which reduced the deformation ability for microstructural change at low strain rates. At a higher deformation level, which generates several dislocations and also defects for nucleation of DRX, safe zones move to lower strain rates and high temperatures, which allows sufficient time and thermal activation for dislocation movement and rearrangement to form strain-free grains through DRX. At higher strains, the instability region also expands, especially at high strain rates, due to the formation of deformation bands leading to inhomogeneous deformation, crack formation, and failure.

The non-metallic inclusions (NMIs) analysis was carried out by electrolytic extraction and subsequently analyzed by SEM and XCT. The results demonstrated that the count and size of the inclusions decreased at high strain rates and temperatures, corroborating the location of the safe deformation zone. In fact, at the higher strain levels, the competition between the favorable and unfavorable deformation, assisted by the presence of second phases in the matrix determines the location of the safe zone. Cracks originated at complex inclusions where Al_2O_3 and MnS were embedded and propagated through unstable plastic deformation zone in the processing map at lower temperatures and higher strain rates. Crack propagation was restricted in the safe deformation zone, attributed to the higher volume fraction of the dynamically recrystallized grains.

Butt welding of EN30B and EN25 steel grades was performed using electron beam welding with or, without beam oscillation at different oscillation beam diameters. The evolution of non-metallic inclusions, microstructures, and mechanical properties of these steel grades have been investigated. Beam oscillation is an useful tool to develop a fine surface finish, and weld with minimal defects, attributed to generating churning action and heat mixing in the weld seam. Some common features that were observed for welding of both the steel grades are: (i) beam oscillation promoted equiaxed grain in the center region of the fusion zone, attributed to breaking of unidimensional temperature gradient and heat mixing in the weld seam. ii) The retained austenite in the weld was higher in weld produced with beam oscillation, especially with higher oscillation diameter, and became minimum for weld produced without beam oscillation, attributed to decreasing cooling rate and strain induced transformation. iii) The application of beam oscillation resulted in a significant decrease in the size of the non-metallic inclusions, attributed to rapid cooling. Residual stresses were tensile in the fusion zone, irrespective of beam oscillation. Weld produced with beam oscillation was characterized with high amount of dislocations, lattice strains, residual stress, hardness, and wear resistance. In the case of EN30B steel, weld strength was lower than base metal; however, the weld's strength and ductility improved with beam oscillation. In case of EN25 steel, the tensile sample braked in the base metal, indicating good strength of all welds.