Microstructure Evolution during Friction Stir Spot Welding of TRIP steel

Transformation Induced Plasticity (TRIP) steels have been developed for automotive applications due to the excellent high strength and formability. The microstructure of TRIP steels is a complex mixture of various microstructural constituents; ferrite, bainite, martensite and retained austenite. The TRIP effect is activated under the influence of an external load, thereby leading to a martensitic transformation of the retained austenite. This transformation induced plasticity contributes to the excellent mechanical properties of this class of steels and provides high tensile strength without deteriorating the uniform elongation. The unique deformation properties can be exploited in automotive applications for crash resistant parts due to the high energy absorption, thus improving passenger safety. Furthermore, the high strength and good formability permits the application of thinner sheet material and thereby reduced weight of the vehicles.

One of the limitations for the wide application of TRIP steel is associated with joining, since so far no method has succeeded in joining TRIP steel, without comprising the steel properties. In this study, the potential of joining TRIP steel with Friction Stir Spot Welding (FSSW) is investigated. The aim of the study is to assess whether high quality welds can be produced and, in particular, to obtain an understanding of the microstructural changes during welding.

The microstructure of the welded samples was investigated by means of reflected light microscopy, scanning electron microscopy and electron backscatter diffraction. Microhardness measurements and lab-shear tests completed the investigations of the welded samples and allow evaluation of the quality of the welds as seen from a practical point of view. Selected samples were also investigated by X-ray diffraction.

The complementary use of the various characterization techniques allowed subdivision of the microstructure in the weld in different zones: two thermo-mechanically affected zones (TMAZs), and two heat-affected zones (HAZs). The dual behavior of the microstructure in the zones is related to the two transition temperatures in steel: Ac1 and Ac3. The following zones are identified; HAZ-lowT, HAZ-highT, TMAZ-lowT and TMAZ-highT.

In the HAZ-lowT zone the temperature is below Ac1, where austenite transforms into bainitic ferrite and/or ferrite. On entering the HAZ-highT zone, the microstructure reaches an intercritical temperature, which upon cooling leads to a ferritic-martensitic microstructure. In the TMAZ-lowT the temperature was also in the intercritical range, but simultaneously the effect of deformation can be recognized. This leads to various transformations occurring in the ferrite phase. At relatively low strain, dynamic recovery takes place by means of fragmentation of grains and formation of subgrain boundaries. On approaching the weld center, deformation and temperature increase, which is associated with continuous dynamic recrystallization as the mechanism for formation of fine ferrite grains. Close to Ac3, fine ferrite grains also develop from strain-induced transformation, which develop intragranularly in austenite. In the TMAZ-highT zone the temperature is above Ac3, which formed an almost fully martensitic microstructure from recrystallized austenite grains. A narrow region of the TMAZ-highT parallel to the pin hole contains ferrite, which has developed as d-ferrite or decarburization, or by a combination of the two mechanisms.