Effect of ausforming on the bainitic transformation in medium carbon steels

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During the last years, an increasing interest in improving the mechanical properties of the materials which some automobile parts are made out of has emerged. Among those materials, the third generation of advanced high-strength steels can be named as one of the most successful, because of their high strength vs. ductility ratio, among others. A recent metallurgical development known as nanostructured or low temperature bainite has been found to provide an unrivalled combination of properties with yield strength (YS) of 1.4 GPa, ultimate tensile strength (UTS) of 2.2 GPa and about 30% of ductility.

The best contribution to the strength of bainitic microstructures is due to the scale of the bainitic ferrite plates. In order to improve this strength, it is important to understand and control the parameters that define the final bainitic microstructure. Among them, the strength of the austenite from where the bainite grows and the driving force of the transformation are the most influential parameters. Historically, controlling the transformation temperature and the chemical composition has been the common way of increasing both, the strength of the austenite and the driving force of the transformation. Such required values were only achievable in high carbon steels, which do not permit to have a good weldability because of the formation of untempered, brittle martensite in the coarse grained heat affected zones of the joint.

Recently, the viability of increasing both magnitudes has been tested by a process called ausforming, that consists on applying plastic deformation prior to the transformation, obtaining in this way not only thinner bainitic ferrite plates, but also an acceleration of the bainitic transformation. Some projects are already focusing on obtaining nanobainite in lower carbon contents by means of this thermomechanical treatments, such us the EU Project which this Master's Thesis is within the framework of. In the current Master's Thesis, a medium carbon high silicon steel has been chosen to study the effect of some of the most important ausforming parameters on the final microstructure.

First of all, some pure isothermal treatments have been performed. Three different isothermal temperatures have been selected, all of them low enough not to obtain martensite on cooling after holding such temperatures for one hour. The thermal treatments and the final microstructures have been studied by means of several techniques, such as dilatometry, X-Ray Diffraction or Scanning Electron Microscopy (S.E.M.). Plate thickness measurements were made from the S.E.M micrographs in order to quantify the bainitic ferrite plates size that are as important as previously explained. As the theory predicted, lower isothermal treatments led to decelerated kinetics, although also to higher ferrite volume fractions and lower plate thickness. As both factors affect positively the mechanical properties, higher hardness values were also detected for the lowest isothermal temperatures.

Several ausforming treatments were also performed. The three isothermal temperatures were kept the same and three different deformation temperatures were chosen, one of them classified as medium temperature because it is in the range at which neither bainite or ferrite forms during an isothermal treatment, i.e. the hiatus between the ferritic and the bainitic regions. The two left temperatures were lower than the previously mentioned, i.e. low deformation temperatures. From now on, they will be named as T_{def1}, T_{def2} and T_{def3}, where $T_{def1}>T_{def2}>T_{def3}$. Regarding the applied strains during the deformation steps, different levels were selected. For T_{def1}, the reached stresses during the deformation step were not as high as for the other cases, so three different deformation levels could be applied. The higher stresses obtained for the left deformation temperatures only allowed to apply two different deformation levels at T_{def2} and only one at T_{def3}.

The final microstructures were also studied by means of the same techniques than were used previously. However, the analysis and the interpretation of the results were much harder to make. First of all, the anisotropy introduced by deformation altered the dilatometric longitudinal signal, which even became negative for some cases, and for that reason the treatment kinetics could not be quantified. This effect has been mostly reported when applying stress during the isothermal held and it is explained to have to do with a crystallographic variants favoring. It was confirmed experimentally that, as the transformation occurs preferably in specific directions, the longitudinal and the radial direction do not coincide anymore, as usually happens during the pure isothermal treatments.

In addition, microstructures obtained after ausforming treatments turned out to be rather different that the pure isothermal ones. First of all, a preliminary study showed microstructural differences among different sample locations as the barreling effect provokes a non-uniform stress and strain distribution throughout the sample. For that reason, all the microstructures were inspected at the central part of both the transverse and the longitudinal sections.

Second of all, unlike in the transverse section, in which the changes were more difficult to be noticed, the longitudinal sections showed rather significant microstructures. On the one hand, microstructures deformed at the T_{def1} are much more disordered. On the second hand, at the two lowest deformation temperatures, plates seem to have formed along specific directions, which are always at about ±45°. Plates thus cross one another at a 90°angle. Those cases in which the microstructure looks aligned coincide with the ones in which negative dilatometric signals were detected. Moreover, because of bainite growth preference, blocky austenite seems to be present much less frequently at low deformation temperatures than in the other left case, which can make mechanical properties improve for those cases as TRIP effect cannot take place.

Regarding plate thickness measurements, such ordination probably makes the method not valid anymore, as it assumes isotropy. For that reason, no trend was found for the plate thickness results. Deformation also hindered the XRD analysis and only volume fractions seemed to be trustable. Because of a phenomenon called mechanical stabilization, the higher the applied deformation and the isothermal temperature, the lower the bainitic ferrite volume fractions are.

To summarize, although the deformation prior to the bainitic transformation was proved to nullify some of the techniques that, thus, must be used more carefully, the experiments carried out in the present Master’s Thesis are worthy as have been useful to identify some anisotropy problems that could arise when using ausforming to obtain nanobainitic microstructures. In addition, some other effects have been also studied, such as the ferrite volume fraction reduction due to the austenite mechanical stabilization.