Research and Development of 780MPa grade low-density steels

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Abstract. In order to meet the weight reduction of automotive body, low density steels containing about 4wt.% of Al have been newly developed. The microstructure of low-density steel, comprising a mixture of blocky retained austenite, bainite, δ-ferrite and α-ferrite, was produced using a laboratory annealing simulator. The low-density steel exhibits good combination of strength and ductility, whose properties shows tensile strength of 810MPa with elongation of 27.4%. Its extraordinary properties are obtained from δ-ferrite and austenite deformation induced martensite.

1. Introduction
Weight reduction of automotive vehicles is getting more important in order to reduce carbon dioxide emission and to enhance fuel efficiency. Many kinds of high strength steels can be applied to automotive parts in reduced gauge resulting in reduction of weight. Recently, some research activities have been paid to develop special steels with reduced density [1-3]. The low-density steels usually include substitutional light element aluminum. The addition of aluminum as a strong ferrite stabilizer resulted in some δ-ferrite persisted in all the temperature range after solidification. In this study, the microstructure and mechanical properties of low-density steel with approximate 4wt-% of aluminum were investigated.

2. Experimental
The low-density steel used in this study was fabricated by a vacuum induction melting method, and its nominal composition is Fe-0.4C-1.5Mn-4Al (wt.%). After thick plates of 60 mm in thickness were homogenized at 1150 ºC for 2 hours, they were hot-rolled 900 ºC. They were then cooled in a furnace from 630 ºC after holding at this temperature for 1 hour in order to simulate a coiling procedure. The hot-rolled steel sheets of 3 mm in thickness were rolled at room temperature to make 1.5-mm-thick steel sheets. The sheets were annealed at 850 ºC for 500s in a continuous annealing simulator. The density of the studied steel was obtained by Et-320 electronic balance. The mechanical properties of the steels were examined using tensile test machine. Microstructure observations were performed by scanning electron microscopes (SEM) with an energy dispersive X-ray spectroscope (EDS). Structural characterization was carried out by X-ray diffraction (XRD) with Cu K radiation and electron back-scatter diffraction (EBSD).
3. Results and discussions

Figure 1 shows the equilibrium phase diagram of the annealed low-density steel. The equilibrium phase diagram indicates that cementite fully dissolves at temperatures over 785°C and the duplex microstructure has been successfully achieved accordingly by an intercritical annealing at 850°C.

Figure 1. Equilibrium phase diagram of low-density steel

Figure 2 shows the microstructure of the annealed low-density steel. The microstructure contains α-ferrite, δ-ferrite, retained austenite and bainite. Comparing with α-ferrite, the δ-ferrite is revealed as the banded structure with large grain size. EDS was used to identify the composition of different phases during SEM observations. Figure 3 illustrates the relative EDS analysis of α-ferrite, δ-ferrite and retained austenite. A large amount of Al element and Mn element can be seen in ferrite and austenite, respectively. The accumulation of Al in the δ-ferrite is more than in the α-ferrite. Because a significant amount of Al solute partitioned in the δ ferrite at the first stage of the solidification.

Figure 2. Microstructure of low-density steel
The volume fraction of retained austenite estimated by EBSD (Figure 4) is 18vol.-%, which is approximately identical to the results by XRD. The δ- ferrite and α-ferrite could not be differentiated by XRD due to the same crystal structure and very similar lattice parameters.

The low-density steel exhibits good combination of strength and ductility, whose properties shows tensile strength of 810MPa with elongation of 27.4%. Figure 5 shows the engineering stress-strain curve based on the tensile test with a strain rate of 10-3/sec. The steel yields about 410MPa with point elongation of approximately 1–2%. The tensile curves of this steel indicate that there is almost zero post-uniform elongation. To understand the details of deformation behavior, true stress and work hardening rate is plotted with the true strain as shown in figure 6. In general, work hardening rate indicates the incremental work hardening exponent and describes the persistence of work hardening during the plastic deformation[4,5]. It shows that the work hardening rate gradually increases until about true strain=0.02. This reveals that the ferrite is severely deformed. With the progress of deformation, the work hardening rate gradually decreases. The intersection value between strain hardening and the true stress represents the uniform elongation Ag (0.22). The high uniform elongation was attributed to the behaviour of retained austenite with large amount.

The density of the steel was measured to be 7.42g/cm3 by an electronic balance which shows an apparent reduction of 5% in comparison to conventional steels.
Figure 4. EBSD measurement of retained austenite of the δ-TRIP steel

Figure 5. Engineering stress-strain curve
4. Conclusion
The microstructure and mechanical properties of low-density steel with 4wt% aluminium addition were investigated. The low-density steel exhibited the multiphase microstructure. The multiphase microstructure consists of blocky retained austenite, δ-ferrite, α-ferrite and bainite. Comparing with α-ferrite, the δ-ferrite is revealed as the banded structure with large grain size and high Al content. The low-density steel exhibited excellent mechanical properties of high tensile strength over 780MPa with high total elongation over 25%. A large fraction of retained austenite in low-density δ-TRIP steel leads to very high work hardening rate.

References
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