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Current state of Fe-Mn-Al-C low density steels

Shangping Chen [a,*], Radhakanta Rana [a], Arunansu Haldar [b], Ranjit Kumar Ray [b]

[a] Tata Steel, PO Box 10000, 1970CA IJmuiden, The Netherlands
[b] Tata Steel, Jamshedpur 831007, Jharkhand, India

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ABSTRACT

Fe-Mn-Al-C steels, previously developed in the 1950s for replacing Fe-Cr-Ni steels, are currently generating a lot of interest with potential applications for structural parts in the automotive industry because they are lighter. This paper provides a review on the physical metallurgy, processing strategies, strengthening mechanisms and mechanical properties of Fe-Mn-Al-C steels from the published literature over a period of many years, and suggests avenues for future applications of these alloys in the automotive sector.

The addition of Al to Fe-C steels leads to a reduction in both density and Young's modulus. A 1.3% reduction in density and a 2% reduction in Young's modulus are obtained per 1 wt% addition of Al. Due to the addition of the high amounts of Al, together with Mn and C, the physical metallurgy, general processing, microstructural evolutions and deformation mechanisms of these steels are largely different from those of the conventional steels.

The addition of Al to high-Mn austenitic steels brings two other important effects: increasing the stacking fault energy (SFE) and producing short-range ordering (SRO) and/or κ′-carbide precipitation. Plastic deformation of low-density Fe-Mn-Al-C steels with a high SFE, which involves SRO, is dominated by planar glide. New deformation mechanisms such as the microband induced plasticity (MBIP), the dynamic slip band refinement (DSBR) and the shear band induced plasticity (SIP) are introduced to describe plastic deformation of Fe-Mn-Al-C austenitic steels in addition to the transformation-induced plasticity (TRIP) and the twinning-induced plasticity (TWIP), which are often observed in Mn TWIP steels. These new deformation mechanisms are related to the formation and uniform arrangement of the SRO or nano-sized κ′-carbides which are coherent with the austenitic matrix. The κ′-carbide precipitation is a unique strengthening mechanism in the austenitic Fe-Mn-Al-C steels bearing high amounts of Al and C.

The lightweight Fe-Mn–Al-C alloys can produce a variety of microstructures and achieve a wide range of properties. These alloys can be classified into four categories: ferritic steels, ferrite based duplex steels, austenite based duplex steels and austenitic steels. The austenitic steels are the most promising in terms of properties and processing. The tensile properties of the austenitic lightweight steels are similar to those of high Mn TWIP steels. The impact toughness of these steels in the solution treated condition is slightly lower than that of Cr-Ni stainless steels but is higher than that of the conventional high strength steels. The energy absorption at high strain rate is similar to that of high Mn TWIP steels and higher than that of conventional deep drawing steels. The ferrite based duplex low-density steels is another promising alternative. A bimodal microstructure can be obtained here through process control for steels with lower alloying contents, in which the plastic deformation of the ferrite and the TRIP and/or TWIP effects from the retained austenite can be profitably used. This type of Fe-Mn-Al-C steels exhibits an improved combination

* Corresponding author.
E-mail address: Shangping.chen@tatasteel.com (S. Chen).

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of strength and ductility compared with the first generation advanced high strength steels. The ferritic Fe-Al steels have tensile properties comparable with HSLA steels of 400–500 MPa strength level. The corrosion behaviour of Fe-Mn-Al-C steels is not improved in comparison with the conventional high strength steels. The application properties such as the fatigue behaviour and formability of Fe-Mn-Al-C steels cannot be properly understood at this stage, because of the limited experimental results so far. Some other application aspects such as weldability, coatability are not well documented.

The applications of the Fe-Mn-Al-C steels in the automobiles is still not prevalent due to the lack of knowledge related to application properties so far. Above all, the reduced Young's modulus of these steels and the processing problems as a result of the high Al and high Mn contents are the main issues. The future developments will therefore have to concentrate on the alloying and processing strategies and also on the methods to increase the Young's modulus. An improved processing strategy and a high value for the Young's modulus will go a long way towards upscaling these steels to real automotive applications.

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