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Effect of Solution Treatment on Grain Size and Toughness of Lightweight Fe-Mn-Al-C Steel

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INTRODUCTION

A significant body of work has been produced on advanced high strength steels to reduce weight and fuel consumption of modern vehicles. Steels with increased concentrations of both aluminum and manganese, termed Fe-Mn-Al-C steel, have been developed to fit this need. Alloys that contain 0.3 to 1.2 wt. pct. carbon and 5 to 11 wt. pct. aluminum are also age hardenable in the temperature range of 840 °F to 1290 °F (450 to 700 °C) [1-9]. Age-hardening will produce a microstructure containing coherent nano-sized κ-carbide precipitate, $(Fe,Mn)_3AlC$. The work by Kayak, and Kim et al. [8,9] showed that through precipitation strengthening high strength and ductile alloys were a prime candidate for springs and landing gears. After age hardening these steels have been shown to have strength and toughness equivalent to quench and tempered steels [2, 3, 8-10]. Alloying with aluminum has a secondary benefit, when concentrations exceed 12 wt. pct. a density reduction of 16-17 pct. can also be obtained [1-3, 11, 12]. This reduction in density is attributed to two root causes: first a dilation of the lattice and the second is the substitution of iron atoms for the less dense aluminum atoms. These steels therefore are an especially attractive candidate for weight reduction in transportation due to the associated decrease in density and a match in strength with current materials.

The deformation mechanisms of these steels are very complicated. A number of hardening mechanisms have been reported for manganese steels including: transformation induced plasticity (TRIP), twinning induced plasticity (TWIP), or slip band refinement (SBR). The activated deformation mechanism is determined by the stacking fault energy (SFE) of the steel. TRIP is reported to be active when the SFE is below 20 mJ/m^2 [13-16] and is identified as a transformation of austenite to ε or α-martensite leading to high ultimate tensile strengths and increased total ductility. Medium SFE steels (20-40 mJ/m^2) are characterized as TWIP steels, where deformation twins are produced during straining leading to high work hardening rates. Steel alloys formulated with SFE in the range of 40-90 mJ/m^2 undergo slip as the dominant deformation mechanism. High SFE alloys $\geq$ 90 mJ/m^2 are described as steels that do not mechanically twin but undergo slip; these steels also display a strong planar glide and have been termed as steels which exhibit slip band refinement [17-19]. With the higher SFE, cross slip should be easier causing a “wavy” glide from the activation of multiple slip systems, however, the addition of aluminum causes these steels to exhibit planar glide from short range ordering. κ-carbide has also been shown to form from this short range ordering reaction [2, 5].

As is typical of most age-hardening systems a solutionizing step is utilized before subsequent age hardening treatments. For most works on both as-cast and wrought austenitic Fe-Mn-Al-C steels, a solution treatment, (referred to as “STQ” for simplicity), has consistently been performed at 1922 °F (1050 °C) [1-6, 8, 9, 20] regardless of the compositional variations between the works cited. This is typically rationalized and cited as being a temperature regime at which a single phase austenite can be obtained due to thermodynamic calculations [5, 7]. The nominal alloy composition for these lightweight steels is typically 1C – 30Mn – 9Al – 1Si – bal.Fe (in wt. pct.). It can be shown from thermodynamic calculations (see Figure 1) that between 1600 to 1920 °F (870 – 1050 °C) a single phase γ-austenite is obtained. The increase in time at the STQ temperature has been shown to have a pronounced effect on the grain size and can be deleterious to both impact properties and precipitation structure.