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Effect of Aluminum Addition on the Microstructure and Mechanical Properties of High Manganese Austenitic Steel Fe-18Mn-0.6C

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1- Introduction

Alloying of austenitic manganese steel by adding aluminum is a new research topic in the development of Fe-Mn-Al-C system. High manganese austenitic steels have a good work hardening ability and strength with very high toughness. As a result, these steels are used as automotive steel sheets to improve safety.

The unique mechanical property of these steels is due to the interaction between different mechanisms of plastic deformation and work hardening such as transformation induced plasticity (TRIP), twinning induced plasticity (TWIP), dynamic strain aging (DSA), stacking fault energy (SFE).

Low SFE values in these steels has caused TWIP and TRIP plastic deformation mechanisms to have a more proactive effects on the slip and the interaction of dislocations.

The amount of SFE depends on the chemical composition and temperature. For example, aluminum addition increases the SFE. On the other hand, increasing the SFE alters the TRIP deformation mechanism to TWIP and TWIP to slippage of dislocations.

In this study, the effect of aluminum addition on the microstructure and tensile properties of medium carbon austenitic manganese steel was studied.

2- Experimental

The melting and alloying operations were carried out in a 100kg induction melting furnace under argon atmosphere. After steelmaking, the alloy was poured into an investment casting mold (14mm×6mm×3mm) preheated to 1100°C.

The chemical composition of the investigated alloys (Fe-18Mn-0.6C and Fe-18Mn-0.6C-2.5Al) were determined using inductively coupled plasma-atomic emission spectrometry and XRF, and the results are presented in Table 1. In addition, the SFE values measured by equation 1 are presented in Table 1.

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Table 1 Chemical composition and measured SFE for the investigated alloys

Alloy	wt.%*				SFE
	Mn	C	Al	Fe*	mJ/m^2
1: without Al	18.12	0.62	0.01	bal.	21.7
2: Al alloyed	18.04	0.64	2.32	bal.	34.3
* Si=0. sum of other elements=0.1 wt. %					

$$\gamma_{sfe} = 20 - 259X_{Fe} + 21X_{Mn} - 2459X_C + 297X_{Al} - 90X_{eSi} - 466\frac{X_{Fe}.X_{Mn}}{X_{Fe}+X_{Mn}} + 2550\frac{X_{Fe}.X_C}{X_{Fe}+X_C} + 3323\frac{X_{Fe}.X_{Al}}{X_{Fe}+X_{Al}} + 107\frac{X_{Fe}.X_{Si}}{X_{Fe}+X_{Si}} \quad \textbf{(1)}$$

where X_{Fe}, X_{Mn}, X_{Al}, X_C and X_{Si} are mole fractions of the alloying elements.

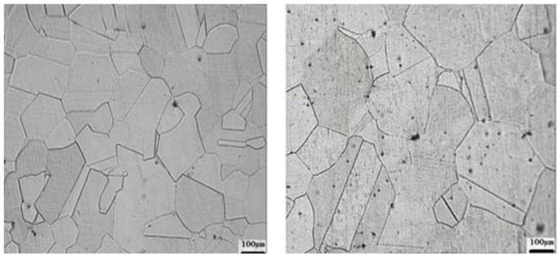
The homogenizing heat treatment was conducted at 1100°C for 2hr followed by a 5 step hot rolling process to reduce the thickness of the specimens from 30mm to 4mm. Then, for heat treating, the as rolled specimens were heated and held at 1100°C for 10min and then cooled in water to obtain full austenitic microstructure.

Tensile test was carried out at ambient temperature. Microstructural investigation and fractography on the two steels were conducted using optical microscopy and scanning electron microscopy (SEM).

3- Results and Discussion

Fig. 1 shows the optical microscopy images of the hot rolled specimens before tensile testing. It is observed that the microstructures contain homogenous austenite grains that have thermal twinning marks in some grains. These twinning marks are due to low SFE values of the alloys. In addition, the aluminum alloyed specimen has some nonmetallic inclusions which might be aluminum oxide or aluminum nitride. Image analysis determined that 2.3 wt.% aluminum addition increases the grain size from 97 to 148µm. This increase is related to the increased SFE. The increased SFE due to aluminum addition has decreased the twinning during and after hot rolling and also decreased the nucleation sites for dynamic recrystallization and as a result, increased the final austenite grains size.

Fig. 2 shows the true stress-strain curves for both alloys (alloy 1: without aluminum and alloy 2: 2.3 wt.% aluminum). It is observed that for alloy 1, the serrated flow started at strain 0.27 and it is continued until the specimen has fractured. This serrated flow is related to the interaction between dynamic strain aging (DSA) and slipping mechanisms. On the other hand, for alloy 2, the serrated flow is lowered due to decreased activity of carbon in the alloy with aluminum addition.



(a) (b)

Fig. 1 Optical microscopy images of the hot rolled specimens; a) alloy 1 (without Al); b) alloy 2 (with Al)

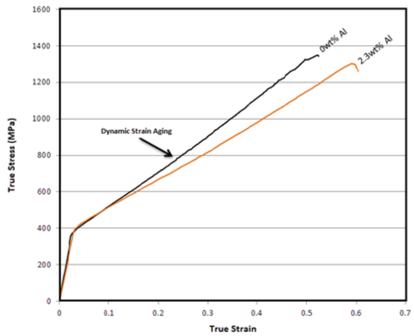
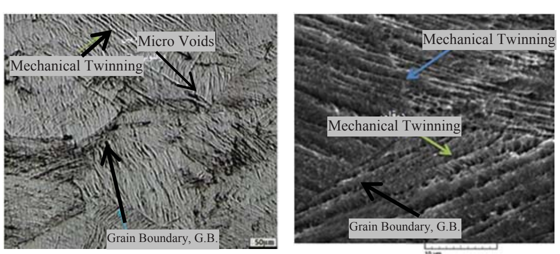


Fig. 2 True stress-strain curves for the studied alloys (alloy 1: ≈0% Al and alloy 2: 2.3 wt.% Al)

Fig. 2 shows that 2.3 wt.% aluminum addition increases all of the tensile properties (yield strength and elongation). Aluminum addition increases the required stress for slippage by solid solution strengthening mechanism. On the other hand, the lower strength during plastic deformation and increased elongation can be related to lowering of the DSA and increasing the TWIP activity in plastic deformation that delay the fracture.

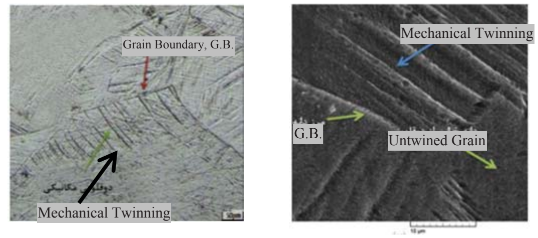
Fig. 3 and Fig. 4 present the optical microscopy and SEM images of the tensile specimen for alloy 1 and alloy 2, respectively (in the vicinity of the fractured surface). It can be observed that twinning is the main plastic deformation mechanism for both alloys but there are some differences between them. The twinning marks and voids can be observed in all of the deformed grains in alloy 1; this is related to the interaction between micro-twins and Mn-C dipoles. This feature is lowered in alloy 2.



(a) (b)

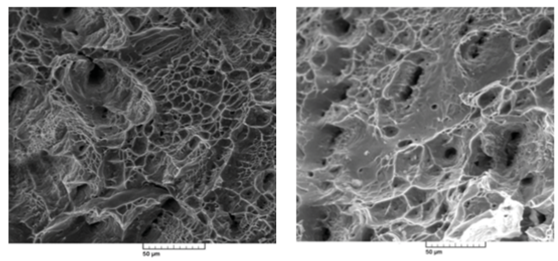
Fig.3 a) Optical microscopy image; b) SEM image of tensile specimen of alloy 1 (near the fractured surface)

Mechanical twins can be observed as micro-twins in the deformed grains. Interactions between the micro-twins and interaction of the micro-twins with Mn-C dipoles (DSA sources) can form micro-voids. These micro-voids can be observed more frequently and appear coarser in alloy 1 as compared to alloy 2.



(a) (b)

Fig. 4 a) Optical microscopy image; b) SEM image of tensile specimen of alloy 2 (near the fractured surface)



(a) (b)

Fig. 5 SEM images of the fractured tensile specimens; a) alloy 1 (without aluminum); b) alloy 2; (with aluminum)

Fig. 5 shows the SEM images of the fractured tensile specimens. The ductile fracture of the alloys can be observed due to more dimples on the fractured surfaces. These dimples are two types: initial dimples and secondary dimples. The initial dimples are larger than the secondary dimples (named micro-dimples which are between the initial dimples). The source of the initial dimples are nonmetallic inclusions or undissolved carbides but the source of micro-dimples are Mn-C dipoles formed by DSA and micro-twins interaction. The occurrence of these micro-dimples confirms that the space between the initial dimples did not fracture by shearing mechanism.

On the one hand, the removal or attenuation of dynamic strain aging phenomenon in alloy 2 reduces strength and by reducing barriers to slip dislocations, the total plastic strain has increased.

4- Conclusions

1. The hot rolled microstructure shows that 2.3wt.% aluminum addition to Fe-17Mn-0.6C increases the austenite grain size from 97 to 148 µm.
2. Aluminum addition increases the tensile properties (yield strength from 366 to 405MPa and elongation from 0.52 to 0.54) but decreases the strength at any plastic strain. The UTS remains unchanged.
3. Aluminum addition decreases serration flow and attenuates dynamic strain aging mechanism.
4. Fractography and microscopic images show that micro-twins and DSA interactions can form micro-dimples between initial dimples which improves the ductile fracture of the alloy.