DEFORMATION AND AGING BEHAVIORS OF Fe-Mn-Al-Cr-C DUPLEX ALLOY

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ABSTRACT

The microstructural changes which occur during aging and cold rolling of a new Fe-Mn-Al-Cr-C duplex alloy have been investigated. Two treatments were developed to produce either a good combination of tensile strength and ductility (σ_u = 800 Mpa, σ_y = 525 Mpa, A= 46%) or a high strength (σ_u = 1340 Mpa, σ_y = 1200 Mpa, A = 15%) with a ductile type of fracture after aging at 320 °C. Aging between 550 °C to 700 °C led to a significant decrease in strength and ductility due to the precipitation of the brittle βMn phase. However, aging above 750 °C showed considerable increase in strength and ductility due to the precipitation of very fine grains of ferrite within the austenite phase.

INTRODUCTION

Fe-Mn-Al alloys are developed as a possible substitute for the Cr-Ni stainless steel and have shown some promise as engineering alloys for their low cost, light weight and high strength (1,2). In the chemical design of the Fe-Mn-Cr-C duplex alloy, three major consideration were taken into account; partial substitution of Cr by Al and Si, and Ni by Mn; low activation materials for simplified waste disposal systems because type 304 and 316 stainless steels are heavily alloyed with Ni (3); elevated temperature strength and microstructural stabilization. In recent years, duplex stainless steels are beginning to attract considerable attention for use in sea water environments due to their high localized corrosion resistance. In addition, the duplex steels also possess high strength and toughness, and hence good fabrication properties.

In the present study, the effects of cold rolling at room temperature on the microstructure and tensile properties of the Fe-Mn-Al-Cr-C duplex alloy have been investigated.

EXPERIMENTAL PROCEDURE

The chemical compositions of the Fe-Mn-Al-Cr-C duplex alloy in Wt % is : 2 8 Mn; 7 Al; 1.2 Si; 5 Cr; 0.5 V; 0.4 C; 0.001 N; 0.1 Mo and 0.006 B. The heat was melted, cast, homogenized, hot rolled, then solution treated at 1150° C and water quenched . The as quenched plates were cold rolled up to 75 % deformation at room temperature, and then aged at temperatures varying from 320° C to 820° C. The samples from LM observations were ground and polished and then etched in 2 % nital. Mechanical properties were measured using a Vickers diamond pyramid hardness tester, and an MTS mechanical testing machine.

RESULTS AND DISCUSSION

Typical microstructure of the Fe-Mn-Al-Cr-C duplex alloy after 75 % deformation at room temperature is shown in Fig. 1. It shows a microstructure consisting of two matrices: the austenite and the ferrite. In the design of these microstructures consisting of two matrices, three sets of manufacturing variables become very important: the volume fraction of each matrix: f_γ and f_α, the solute concentration of each matrix $C\gamma$ and $C\alpha$ and the grain size of matrix $d\gamma$ and $d\alpha$. These three sets of manufacturing variables are controlled by the solution treatment, i.e the temperature, the time and the quenching rate. During microstructural development they are controlled by the deformation, aging, transformation (a thermal and deformation induced) and recrystallisation processing.

Fig. 2 shows the strain hardening behavior of the solution treated microstructure. It was observed that at this deformation temperature (room temperature) the austenite deformed by the formation of deformation twins.This was possible for following reasons: first, Mn lowered considerably the stacking fault energy (4) of the Fe-Mn-Al-Cr-C duplex alloy; second, the calculated M_d temperature was below room temperature.

The degree of supersaturation developed in the ferrite matrix by water quenching from 1150 °C was quite high. Thus aging in the low temperature range the cold rolled Fe-Mn-Al-Cr-C duplex alloy resulted in the strengthening, mainly of the ferrite matrix, by the formation of fine dispersion of precipitates. The age hardening responses of the cold rolled Fe-Mn-Al-Cr-C microstructures are shown in figures 3 and 4.

Fig. 3a shows the effect of the aging temperature and aging time on the hardness of the duplex alloy. The maximum precipitation hardening effect was observed at 470 °C for an aging time of 100 hours. Fig. 3b shows the effect of aging time for a constant aging temperature of 470 °C on the tensile properties. The difference in age hardening behavior exhibited by hardness measurement at 470 °C (Fig. 3a) from that of tensile tests (Fig.3b) is due to the formation of very brittle phases at the interfaces of the Fe-Mn-Al-Cr-C duplex alloy. The sharp decrease in strength and ductility observed at 620 °C (Fig. 4) is attributed to the formation of the brittle β_{Mn} phase (5,6). The addition of B and Mo to the Fe-Mn-Al system have enhanced the microstructural stability and strengthened the ferrite/ferrite and the ferrite/austenite interfaces at temperature above 750 °C.

Fig. 5 presents the effect of the aging temperature on the microstructures of the cold rolled Fe-Mn-Al-Cr duplex alloy, showing: 5a (420°C) Very fine precipitation in ferrite with formation of precipitate free zones (white zones); 5b (520°C) significant homogeneous and heterogeneous precipitation in the deformation twins within the austenite matrix and in slip bands in within the ferrite matrix; 5c (620°C) coarsening of precipitates in ferrite and at grain boundaries; 5d (820°C) precipitation of secondary ferrite within the austenite. Aging the deformed duplex alloy at 820 °C for 30 minutes led to the formation of a secondary ferrite within the austenite matrix. Secondary ferrite may have a different composition than the ferrite of the duplex structure due to the nature of its formation. The transformation of thermo-mechanically processed austenite to ferrite is very complex, and is determined by: a) the composition of the austenite and its stability to plastic deformation and temperature, b) the temperature of recrystallisation and the austenite grain size and morphology prior deformation, c) the morphology of the austenite after deformation which will control the ferrite nucleation rate through grain boundaries and deformation twins, d) the presence of undissolved precipitates or deformation twins which will act as nuclei for ferrite formation. An extraordinary increase simultaneously in ductility and strength was observed at temperature above 750 °C (Fig. 4). This is explained by the precipitation of very fine secondary ferrite within the austenite matrix.

CONCLUSION

The effect of cold rolling on the microstructure and the strength of the Fe-Mn-Al-Cr-C duplex alloy have been investigated. The mains conclusions are:

Aging at 320 °C led to a very high strength with a ductile fracture (σ_u = 1340 MPA, σ_y = 1200MPA , A = 15 %). The sharp decrease in tensile properties observed between 470° C to 620° C is due to the precipitation of brittle phases at the interfaces. However, aging the cold rolled microstructure at 820 °C resulted in a increase in tensile properties at room temperature (σ_u = 830 MPA, σ_y = 640 MPA , A= 30 %). This increase in the tensile properties after aging at 820 °C is attributed to the microstructural stability of the duplex alloy, the absence of any brittle phases and to the precipitation of the secondary ferrite within the austenite matrix.

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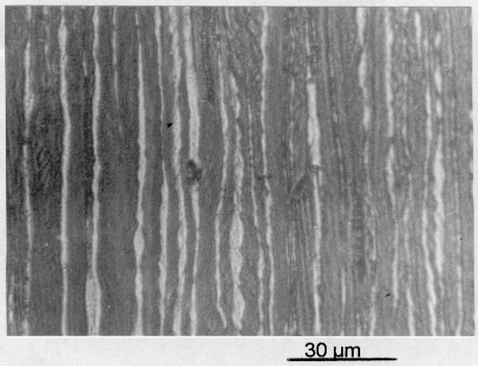


FIG.1: Austenite and ferrite matrices in the cold rolled condition.

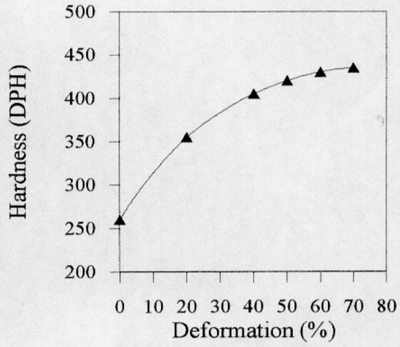


FIG.2: Strain hardening behavior.

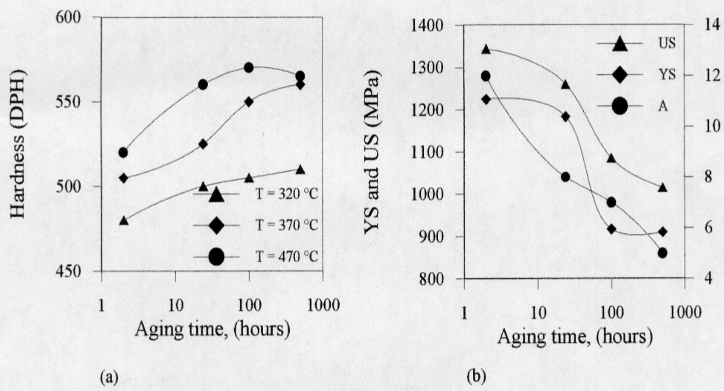


FIG.3: Age hardening behavior of Fe-Mn-Al-Cr-C duplex alloy.

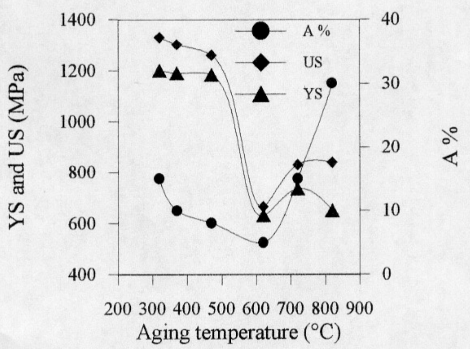
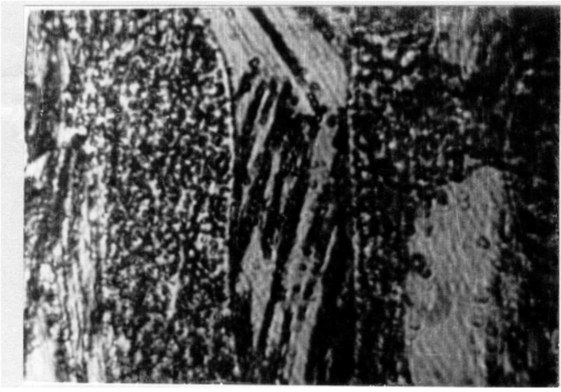
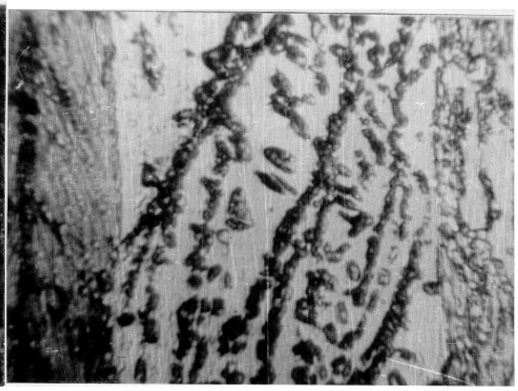


FIG.4: Effect of prior aging temperature (t=24 hours) on the room temperature mechanical properties of the Fe-Mn-Al-Cr-C duplex alloy.

(a) 8μm





(b) (c)

(d) 10μm

FiG.5: Effect of aging temperature (time =100 hours) on the microstructure of Fe-Mn-Al-Cr-C duplex alloy: a) 420°C ; b) 520°C ; c) 620°C ; d) 820°C