HIGH-ALLOY MANGANESE-ALUMINUM STEELS
FOR CRYOGENIC APPLICATIONS

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INTRODUCTION

In most of the recently developed austenitic steels for cryogenic applications, nickel is replaced partially or totally by simultaneous additions of manganese and nitrogen. Such alloys also contain a sufficient amount of chromium (12-18%)* to render them stainless while the nitrogen additions both strengthen the alloy and stabilize the austenite.

Our present study is based upon the two following considerations: replace all the nickel by manganese, and chromium by moderate additions of aluminum, in order to develop a new and more economical alloy for cryogenic applications.

From the work of Schumann1-3 and the more recent results of Holden, Bolton, and Petty,4 only those binary Fe-Mn alloys containing 28-50% manganese possess stable austenites when cooled to room temperature. For manganese contents between 15 and 28% there exists a two-phase region—austenite + hexagonal ε-martensite—whereas for still lower manganese contents (< 15%), the austenite transforms partially into tetragonal α'—martensite responsible for the sharp decrease in toughness at low temperature.

In this work we have studied the mechanical properties in tension and resilience at 300 and 78 K of both Fe-(20-40)Mn alloys with and without 5% Al additions. We restricted our study to maximum aluminum additions of 5%, since, according to Schmatz, higher aluminum contents impair the stability of the austenite.

*All compositions used in this paper are in wt.%.
Since the alloys do not contain any strong carbide-forming elements, we also studied the influence of increasing carbon content on these mechanical properties and the stability of the austenitic phase in the alloy Fe-23Mn-5Al.

**EXPERIMENTAL PROCEDURE**

The alloys were prepared in a sealed induction furnace from ARMCO iron, electrolytic manganese powder, and refined aluminum (99.99%).

The sealed melting chamber was evacuated to a pressure of $10^{-1}$ torr to dry and degas the charge. When the temperature of the latter attained approximately 500°C (930°F), the partial vacuum was replaced by an argon protective atmosphere (static pressure of about 1 bar). The liquid metal was then cast under the same argon atmosphere into a water-cooled copper mould. The resulting ingots weighed 1.2 kg (2.6 lbs) or 2.4 kg (5.2 lbs), depending upon the size of the mould employed.

Carbon additions were introduced using a master alloy Fe-13Mn-5C prepared under the same conditions described above.

The ingots were given a thermomechanical treatment consisting of deformation by rolling to a 33% reduction in thickness, followed by a homogenization treatment of 48 h at 1150°C (2100°F) to break up the large-grained, cored, as-cast structure. This first treatment was followed by a second thermomechanical treatment to refine the grain, which consisted of a new plastic deformation of 33% reduction in thickness by cold-rolling, followed by a recrystallization heat-treatment of about 25 min at 925°C (1700°F).

When ε-martensite was present in the structure, cold-rolling was replaced by hot-rolling at 900°C (1670°F).

Specimens for tension tests, having threaded ends ($L_0 = 25 \text{ mm}$, $\phi = 5 \text{ mm}$), as well as the Charpy KCV impact specimens, were then machined. In the case of those alloys exhibiting a low yield strength of a metastable austenite, a heat treatment of about 15 min at 900°C (1670°F) was performed on the machined specimens sealed in quartz tubes under an argon atmosphere before testing.

Tensile tests were performed on an Instron machine using a speed of 5 mm/min. Those tests performed at room temperature used an extensometer to determine the yield strength after 0.2 and 1% elongation. No extensometer was used in the 78-K tests, performed by immersing the specimen assembly and specimen grips in a bath of liquid nitrogen.