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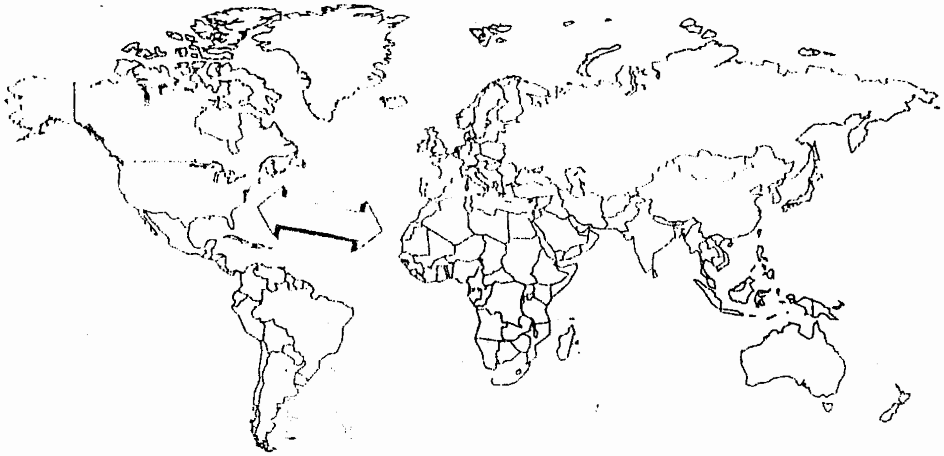

SHERATON HOTEL, IKEJA,
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THE BENEFICIAL EFFECT OF HIGHER MOLYBDENUM CONTENT IN REDUCING BRITTLENESS IN SOME HIGHER STRENGTH MANGANESE STEELS

BY

A.O. INEGBENEBOR
DEPT. OF MECHANICAL ENG.
UNIVERSITY OF MAIDUGURI
MAIDUGRI
BORNO-STATE
NIGERIA

ABSTRACT

The beneficial effect of molybdenum in reducing brittleness in manganese steels were tested by adding 2-4% molybdenum in proportions to manganese alloys between 10-14%. The specimens of the alloys were solution treated under vacuum furnace at 950°C, 1050°C and 1150°C for 1 hour and then air cooled. Furthermore, these were tested for mechanical properties at room temperature.

The broken specimens were examined by using the scanning electron microscope to ascertain that the mode of fractographs of the alloys solution treated at higher temperature, was intergranular at lower molybdenum content. The beneficial effect of a larger amount of molybdenum (about 4%), in reducing the susceptibility to intergranular embrittlement, was noticed in the alloy. Suggestions were made in this paper on how a larger amount of molybdenum (about 4%) was found to prevent embrittlement in high strength manganese steel.

INTRODUCTION

Large quantities of manganese alloy can be used in the fabrication of many engineering materials such as armour plate for military, pressure vessel, automotive, railway crossing and points, mining, agricultural implements, oil and gas, aircraft, medical equipment, and so on.

Nigerian steel companies presently use manganese alloys under 1% in constructional steels. Many African countries have large quantities of manganese mineral deposits which have not been explored. Manganese alloys are cheaper than conventional alloys like nickel, cobalt, titanium, chromium and others. Nickel alloys can be replaced by manganese alloys in many engineering applications because they are both austenite stabilizers.

When manganese in iron-manganese alloys stabilizes austenites, then both the A_1 and A_3 points in the equilibrium diagram are lowered.

So that, if the manganese content is high enough, austenite can be retained with fast cooling rate from the austenite region to room temperature and below. When this happened, the transformation products on fast cooling rate will consist of austenite and two kinds of martensite (Honeycombe, 1981). These are (a) epsilon (ε) martensite and (b) ordinary (α') martensite. There is a difference in their crystal structures; the epsilon martensite is closed packed hexagonal (C.P.H) and the martensite has the more usual body centered tetragonal (b.c.t) structure.

Manganese lowers the stacking fault energy of face centered cubic austenite solid solution (Honeycombe, 1981), therefore bringing the austenite energetically closer to an alternative (C.P.H) structure in which dislocations tend to dissociate and form stacking faults. The martensite which forms first on cooling is thus hexagonal in structure with the habit plane $\{0001\}$ parallel to the stacking fault plane $\{111\}$. The phase nucleates on stacking faults orientation relationship with austenite shown below:

$$\{0001\}_{\varepsilon} // \{111\}_{\gamma}, \langle 1120 \rangle_{\varepsilon} // \langle 110 \rangle_{\gamma}$$

With these extra properties of manganese it can be amenable to be used in many engineering applications. However, high quantities are needed, where high strength and toughness are the key properties for such technology. The drawback of the wider range of high strength manganese steels in these applications is sometime due to the brittleness of the steels in the solution treated condition. The kind of embrittlement usually shown by high strength manganese steels is intergranular or quasi cleavage (Kato et al, 1976 and Yoshimura et al, 1982). A way of avoiding or minimising this effect has not been established.

The process of embrittlement can be likened to that of temper brittleness which generally occurs in low alloy steels and certain chromium-nickel steels. However, the influence of small amounts of (0.5%) molybdenum in reducing temper brittleness in these steels has been known for sometime. Studies of the relationship between toughness and microstructure of some high manganese level steels by (Tomota et. al, 1987) has led to the observation that alloys which undergo phase transformations during deformation and fracture are an intergranular mode.

Unfortunately, little is known about the influence of higher level of molybdenum in reducing embrittlement in some higher levels of manganese containing steels which under go strain-induced phase transformation. The aim of this work is to quantify the effect of higher molybdenum content in reducing embrittlement in high strength manganese steel which undergo phase transformations during straining.

Materials and Methods

The composition of the alloys investigated were 0.020%C, 11.85% Mn, 2.65% M_o, 0.070%C, 11.90% Mn, 1.93% M_o, 0.070% C, 13.60% Mn, 1.91% Mo, and 0.06%C, 13.60% Mn, 3.43% Mo. Full details of producing the ingot has been described else where by (Inegbenebor, 1993).

Tensile specimens were sealed in silica capsules under vacuum and solution-treated in a vacuum furnace at 950°C, 1050°C and 1150°C for 1 hour and thereafter air-cooled. The extent of transformation of $\gamma + \varepsilon \rightarrow \alpha'$ in situ, during the mechanical testing, was monitored continuously by a magnetic reluctance technique.

The impact toughness values were obtained by using charpy impact machine at room temperature. The broken specimens were examined by using scanning electron microscope to ascertain the mode of fractures.

Results and Discussion

All the alloys that had been solution treated at 950°C failed by necking except the alloy containing 0.070%C, 11.90% Mn, and 1.93% M_o that displayed an exceptional work-hardening behaviour. However, premature failure without necking was obtained in the alloy containing 0.020% C, 11.85% Mn, 2.65% Mn after being solution treated at 1050°C.

Premature failure has been associated with epsilon martensite formation (Sipos et al., 1976). Furthermore, it has been reported by (Tomota et al., 1987) that epsilon martensite present in solution-treated condition or formed during deformation lowers the toughness of higher levels manganese containing steels. Thus the role of deformation- induced ordinary martensite in these steels might be to enhance the toughness and work-hardening capability of the steel Table 1, which show the results of the toughness of the alloys at different molybdenum level.

Fractographs shown in fig. 1 and of the alloys solution-treated at higher temperature, showed that the fracture mode is intergranular at lower molybdenum content.

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TABLE 1 Energy absorbed in hounsfield impact testing
(All values are in Joules)

Alloys				Condition and Energy Absorbed			
	C%	Mn%	Mo%	AS-HOT Rolled	S.T. At 950°C	S.T At 1050°C	S.T At 1150°C
1.	0.020	11.85	2.65	29	30	20.5	16.5
2.	0.070	11.90	1.93	19	22	22.5	-
3.	0.07	13.60	1.91	27	42	41.2	44
4.	0.06	13.60	3.43	30.8	46.5	45.2	41.8

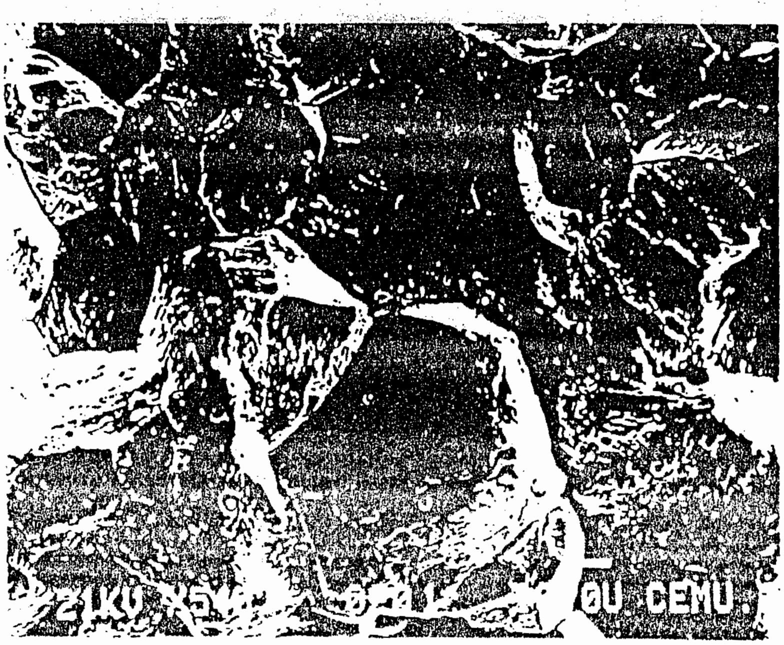

Fig. 1

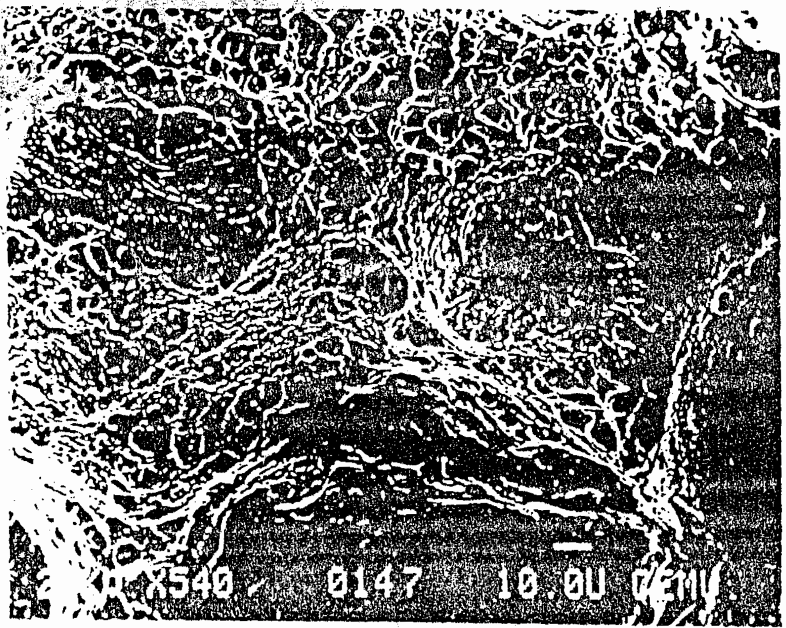

Fig. 2.

The intergranular fracture path favours grain boundaries, (See fig. 1). It is suggested in this paper that in order to prevent this embrittlement in these high strength manganese steel, molybdenum segregates to the prior austenite grain boundaries and maintain their relative cohesion. Molybdenum again as a element that stabilizes the carbides will then prevent the build up of embrittling elements ahead of precipitating carbides, which always favours embrittlement. As it has been suggested by (Tomota et al, 1987), that such brittle behaviour is associated with stress concentrations produced by the intersection of existing epsilon martensite platelets which are thermally generated during cooling at the grain boundaries, with the deformation - induced epsilon martensite platelet, since both are formed concurrently on a single set of (111) planes.

If the suggestion of (Tomota et al, 1987), is taken to account in this work, the effect of the segregation of this large amount of molybdenum will also be to relieve the high internal stress concentrations at points of the high constraint along the grain boundaries where such phenomena may occur. This could be explained that since molybdenum is a ferrite stabilizer, and as would be expected, locally concentrated, this would encourage more ordinary martensite to be formed, which would be beneficial to toughness of the alloys containing higher molybdenum (see table 1). Following this explanation, it would then be expected to find epsilon martensite replaced by ordinary martensite which enhances toughness as been suggested. Preferentially this would occur at the prior austenite grain boundaries. As a result of this replacement of epsilon martensite by the ordinary martensite formation, the high internal stress concentration would be relieved and reduce the embrittlement.

Conclusions

A larger amount of molybdenum (about 4%) was found to prevent embrittlement in high strength manganese steels. It has been suggested in this paper that molybdenum segregates to the prior austenite grain boundaries increases their relative cohesion, a relieves the high internal stress concentrations at points of high constraint along the grain boundaries.

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