(7)

JOURNAL OF ENGINEERING RESEARCH

MAY 1998 VOLUME JER-6 No. 2 ISSN: 0795 - 2333

PAPERS

Publisher:

Faculty of Engineering,
University of Lagos,
Akoka, Lagos, Nigeria

Under the University of Lagos Book Policy

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...ossibilities ... ...oping New Steels ...ith High Manganese Contents in Nigeria

A.O. Inegbenebor
Department of Mechanical Engineering
University of Maiduguri, Maiduguri, Borno State

Abstract

The aim of this study is to investigate the possibilities of Developing New Steels with high manganese content in Nigeria. The steels used as candidates were found to have impressive mechanical properties, attributed to the strain-induced transformation from austenite/epsilon martensite to lath martensite.

1. Introduction

Nigeria has joined steel producing nations for quite sometime now. The products of the steel plant is low carbon steels with minimum manganese content, to be used mainly in construction industry, as discussed by Inegbenebor [1]. However, with the discovery of manganese ore deposit in the country, it is possible to think of developing new steels with high manganese contents.

With some exceptions such as Hadfield Steel, manganese has not been widely used as a high concentration alloying element in steel. The development of nickel maraging steels pointed the way to a possible application of manganese. As the influence of Manganese in the transformation behaviour of iron is similar to that of nickel, could it fully or partially replace Nickel in a new type of maraging steel? The cost-benefits were obvious. This type of maraging steel could be very useful in our aviation industry. The similarity between the Fe-Ni and Fe-Mn equilibrium phase diagrams is readily apparent from Figures 1 and 2.

Mn and Ni are both γ stabilising elements when added to Fe and both reduce the critical cooling speed to form α' following an austenitising treatment. Thus, with sufficient alloying addition, the steel can become air hardened.

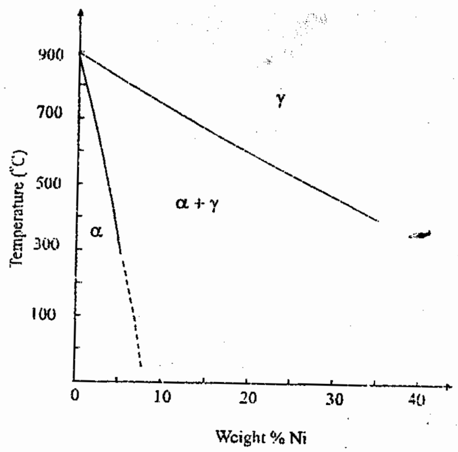

Figure 1: Iron-nickel equilibrium diagram

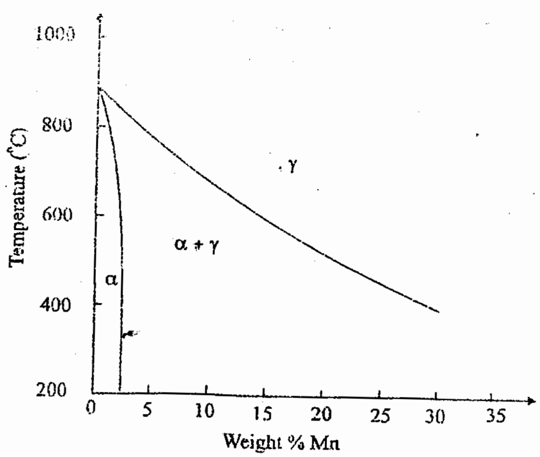

Figure 2: Iron-manganese equilibrium

In Fe-Ni alloys containing 5-25% Ni and in Fe-Mn alloys containing about 2-10% Mn, the martensite formed is bccα'. However, in Fe-Mn alloys at manganese contents between 10 and 15%, hcp ϵ - martensite is formed [2]. Further increases in Mn content lead to the retention of some γ at room temperature following solution treatment [3]. The idea of developing of a High Strength Manganese steel stemed from the work of Jones *et al.* [4] on lower cost maraging steel. Further work on this steel type suggested that it is work-hardened very rapidly in the early stage of deformation and simultaneously possessed higher strength than Hadfield manganese steel [5]. This high strength manganese steel is the one we are now proposing to be produced in Nigeria. The steel comprises, iron-manganese and molybdenum alloy.

The most likely applications of this steel are pressure vessels, chains, diesel engine components, cutting tools, railway points and crossings, and wear resistant castings for use in the mining industry as well as the agricultural sector.

2. Manufacturing Technology

During the course of the development of this steel a large number of experimental steels have been produced using both air and reduced pressure inert gas melting of electrolytic and mild steel bases to which were added electrolytic manganese flake and molybdenum. Chemical analyses of the representative vacuum-melted alloys reported on are given in Table 1.

Table 1: Composition of Alloys (weight %)

Alloy	Mn	Mo	C	Si	S	P
(1) Fe-9Mn-2Mo	8.60	1.99	0.003	0.009	0.018	0.006
(2) Fe-10Mn-2Mo	9.900	1.5	0.1	0.006	0.016	0.005
(3) Fe-12Mn-2Mo	11.90	1.93	0.07	0.19	0.025	0.016
(4) Fe-12Mn-3Mo	11.85	2.65	0.020	0.012	0.024	0.007
(5) Fe-14Mn-2Mo	14.10	2.07	0.003	0.05	0.015	0.011

The alloy ingots were homogenised at 1150 °C for 24 hours and then hot rolled into various bar and slab sizes. Tensile properties were determined with Hounsfield No. 12 specimens and impact tests were carried out using standard charpy V-motch specimens. Conventional optical microscopy with microstructures while fracture surfaces were studied using scanning electron microscopy (SEM).

3. Results and Discussion

The idea of developing new steels high manganese stemed from nickel maraging steels, because as the influence of manganese as the transformation behaviour of iron is similar to that of nickel. To achieve a maraging response with pronounced strengthening, it is necessary to use ternary (and some time quaternary and quinary) additions which have a much larger solubility in austenite than ferrite.

Supper saturation of the solute element is then brought about by transformation rather than by quenching as in conventional age-hardening treatments [4]. Reheating of the super-saturated martensite at temperatures below the reverse shear temperature leads to precipitation of the solute, sometime in a form that can lead to considerable increases in strength. Thus the iron-manganese system has the potential to display maraging if suitable solute addition can be found.

Kapoor [6] examined a number of potential maraging additions to iron-manganese alloys containing 5-12% manganese. The results showed that there is a fairly strong maraging response in the higher manganese alloys containing appreciable quantities of molybdenum which could be attributed to a dispersion of Fe_2Mo type precipitates. The influence of molybdenum was accentuated in the presence of cobalt as in conventional nickel maraging steel which accelerated the precipitates that increased the strength of such steel. The strong maraging response could also be attributed to the impressive mechanical properties of the proposed steels in Table 2 which invariably could be linked to strain-induced transformation of metastable austenite and epsilon-martensite to lath martensite. The alloys of fully martensitic state which do not transform during deformation have a modest mechanical properties. (See Figure 3). It is evident from the results presented

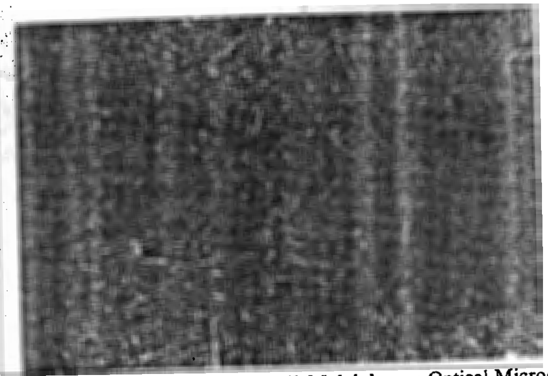

Figure 3: Iron-10% Manganese-2% Molybdenum Optical Micrograph of the fully Martensitic state, S.T. 950°C for 1 hour × 200.

here also that the yield stress or proof stress of the alloys about 14% manganese. The alloys in the range about 12% Mn show high values of tensile strength and high work-hardening coefficients, which were determined at an early stage of deformation. The increased values of tensile strength shown within this range of alloys, result from greater work-hardening caused by the transformation from austenite/epsilon martensite to lath martensite. Similarly the fall in yield strength or proof stress in 14% manganese may be related to the increase in proportions of austenite and epsilon martensite with the former having the major effect due to its low strength level. Also at this composition, the austenite/epsilon phase content is the highest. The assumption is backed up from the evidence of the optical micrograph in Figure 6. Figures 4 and 5, also show the austenite/epsilon phase. Table 3 shows the impact testing results.

As can be seen some of the impact values are not as high as would be expected, however the energy absorbed on impact generally increased with increase in manganese content. Figures 7 and 8 reveal that the fracture modes of the steels consist of a completely ductile fracture showing characteristic dimpled appearance, a mixture of quasi-cleavage and ductile dimpled and also a mixture of intergranular and ductile dimpled.

Table 2: The Mechanical Properties

	Alloy	Elastic Limit (MPa)	.2% Proof Stress (MPa)	Tensile strength (MPa)	Francture stress (MPa)	Elongation in %	Reduction in Area 0.319	"n"
1.	Fe-9Mn-2Mno**		349	882	1245	16	65	0.319
2.	Fe-10Mn-2Mo**		567	892	1181	17	64	0.324
3.	Fe-12-Mn-2M*	422	472	1480	2198	24	50	0.683
4.	Fe-12Mn-3Mo*	455	455	1276	1920	20	25	0.643
5.	Fe-14Mn-2Mo**	89	101	814	1256	33	65	0.218

* Hot-rolled condition, ** Solution-treatment 950°C for 1 hour.

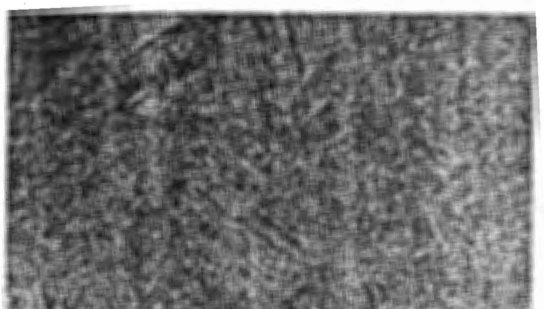

Figure 4: Iron-12% Manganese-2% Molybdenum Optical Micrograph of Lath Martensite and Epsilon martensite, S.T. 950°C for 1 hour × 200

Morris *et al.* [7] attributed the quasi-cleavage fracture to the lath martensite within the substructure which is well aligned, and permits failure by cooperative cleavage through packets of adjacent laths. The intergranular fracture path follows prior austenite grain boundaries. This catastrophic intergranular failure in structural steels is usually attributed to one of two causes: the segregation of an embrittling metalloid impurity to the grain boundary, or the development of a second phase along the grain boundary [8].

Table 3: Energy Absorbed In Hounsfield Impact Testing (All Values are in Joules)

S/N	Allys	Condition and Energy Absorbed	
		As-Hot Rolled	S.T. at 950 °C
1.	Fe-9Mn-2Mo	6	5
2.	Fe-10Mn-2Mo	10	16
3.	Fe-12Mn-2Mo	19	22
4.	Fe-12Mn-3Mo	20	25
5.	Fe-14Mn-2Mo	31	42

4. Conclusions

Low carbon steels containing High Manganese about 12-14% with molybdenum additions of 2-3% can be used as-rolled and heat treated to produce impressive mechanical properties. The same steels exhibit deformation - induced transformation in both as-rolled and solution treatment. This permits high strengths to be developed during cold working which could be exploited in wear-resistant applications.

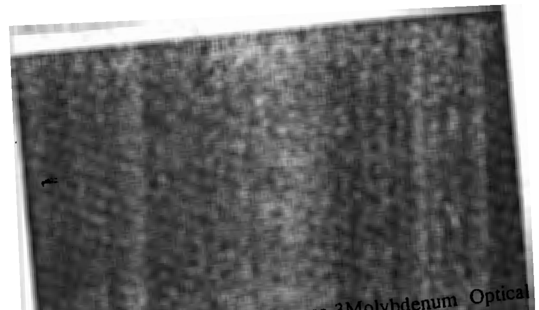

Figure 5: Iron-12 Manganese-3Molybdenum Optical Micrograph of Epsilon Martensite. S.T. 950 °C for 1 hour x 200

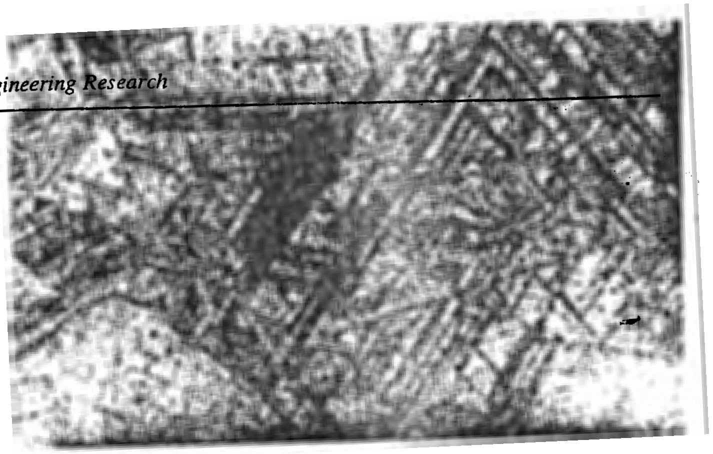

Figure 6: Iron-14 Manganese-2Molybdenum Optical Micrograph of Epsilon Martensite S.T. 950 °C for 1 hour x 200

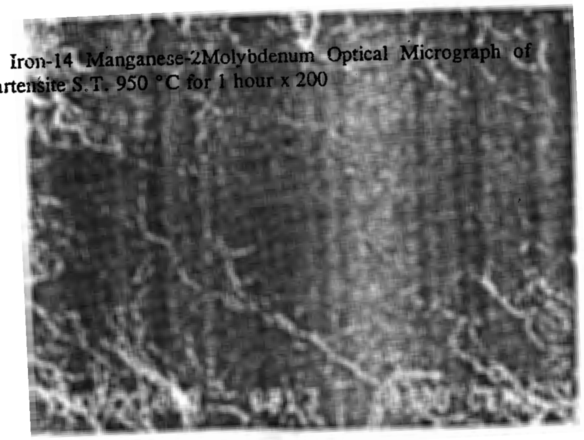

Figure 7: Impact Specimen Surfaces from room temperature tests carried out on Iron-12% Manganese- % Molybdenum showing ductile dimples in the as-solution treated condition

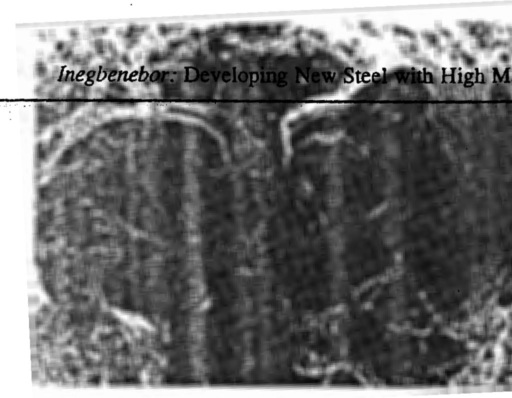

Figure 8: Impact Specimen Surfaces from room temperature tests carried out on Iron - 12% Manganese - 3% Molybdenum showing ductile dimples and intergranular embrittlement in the as-solution treated condition

Acknowledgement

I wish to acknowledge the University of Wale U.K., for allowing me to publish part of my Ph.D thesis in which the experimental work was carried out in the Institute of Materials Laboratory at Newport Road, Cardiff. Also the Federal government of Nigeria and Manageable centre France for Finance assistance for the work.

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