Gouging Abrasion Resistance of Austenitic Manganese Steel with Varying Titanium

Eduardo R. Magdaluyo, Jr., Marthony S. Ausa and Robert J. Tinio

Abstract—**Austenitic manganese steel was alloyed with varying amount of titanium (0.05, 0.1 and 0.2 weight %), a carbide forming element to investigate its gouging abrasion, hardness and microstructural properties. The gouging abrasion test with 0.1% titanium had the least amount of material loss and showed the highest work hardening effect. Alloying up to 0.2% was already detrimental to its mechanical properties. There was an increasing hardness value from 0% to 0.1% titanium modified austenitic manganese steel but decreasing at 0.2% content. Metallurgical examination of the unmodified manganese steel revealed high degree of manganese sulfide micro-nodules and grain boundary carbide formation in the austenitic matrix. The titanium modified manganese steel showed titanium-containing precipitates in the austenitic matrix, which increases strength and toughness through precipitation hardening and grain size refinement respectively. Both successfully increase the resistance of the austenitic manganese steel to slip and plastic deformation.**

Index Terms — **Gouging abrasion, austenitic manganese steel, ferrotitanium addition**

I. INTRODUCTION

AUSTENITIC manganese steel has been widely used in numerous engineering applications such as mining, quarrying, earthmoving, railways and construction industries due to its excellent wear resistance with high strength and ductility. The machining of this type of steel is difficult because of its hardness, low thermal conductivity and strain hardening behavior [1]-[2].

High austenitic manganese or Hadfield steel performs best in gouging abrasion conditions such as in dragline buckets, gyratory rock crushers, roll crushers, jaw crushers and among others, where toughness is a prime requirement. It is an extremely tough alloy and has built up an enviable record as outstanding material for resisting severe service condition that combines abrasion and heavy impact [3]-[4]. Moreover, there are standard specifications for austenitic manganese steel comprising a number of grades with additional alloying elements such as chromium, nickel, molybdenum, titanium and among others to impart specific properties for specific applications.

One primary mechanism of the metal castings deterioration involved in many industrial applications is the abrasive wear. Gouging abrasion is one type of wear resulting from combination of high-stress or low-stress abrasions with some degree of impact and weight. The metal surface receives prominent gouges and grooves when massive objects are forced with pressure against them. Gouging abrasion also places a premium on toughness and sometimes at the expense of harder and more abrasion resistant alloys [5]-[6].

The material composition of these metal castings varies widely depending on the type and conditions of target applications. The basic criteria for the material selection should be high resistant to wear and tear as well as showing best response when exposed to other factors such as temperature and corrosion [7]. The incorporation of different alloying elements into the steel matrix has been done to further improve the wear resistance of metallic materials.

This study aims to develop Hadfield manganese steel alloyed with titanium. The amount of titanium alloy was varied to investigate its effect on the gouging abrasion resistance of Hadfield manganese steel using a laboratory scale jaw crusher. Change in the Rockwell hardness value was also determined and the formation of complex titanium-containing precipitates in the austenitic matrix and its effect to grain size distribution were also investigated.

II. EXPERIMENTAL PROCEDURE

A 200 kg of manganese returns, 300 kg of steel scraps, 30 kg of high-carbon ferromanganese steel, 47.5 kg of low-carbon ferromanganese and 3 kg of ferrosilicon were melted in an induction furnace to obtain the typical composition of manganese steel. The result of the spectrometric analysis of the cast manganese steel is shown in Table 1.

The manganese steel melt was modified by successive alloying with ferrotitanium, following the 0.05, 0.1 and 0.2 weight percent of titanium content. Table 2 shows the amount of ferrotitanium successively added to the manganese steel melt.

Manuscript received March 23, 2015. This work was supported by the Tiger Machinery and Industrial Corporation (TMIC) and the Faculty Research Dissemination Grant (FRDG) by the University of the Philippines Engineering Research and Development Foundation Incorporated (UP ERDFI).

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Table I: Chemical composition of the unmodified manganese steel

Composition	Weight %
C	1.0715
Si	0.4837
Mn	11.324
P	<0.0130
S	<0.0074
Cr	0.6247
Ni	0.0704
Mo	0.0718
Al	0.0060
Sn	<0.6729
V	<0.0320

Table II: Variation of ferrotitanium additions

% Titanium	Ferrotitanium equivalent (kg)
0	0
0.05	0.18
0.1	0.30
0.2	0.70

The modified and unmodified manganese steels were cast into the prepared furan sand molds. The tapping temperature of the unmodified manganese steel was 1550°C while titanium modified manganese steel at 1770°C. Both modified and unmodified manganese steels were poured at 1450°C. The castings were allowed to cool for 24 hours. The modified and unmodified manganese steel were austenitized in an industrial muffle furnace at a temperature of 1050°C for 2 hours.

The different set of samples was soaked for 15 minutes in a water tank fitted with submersible pumps for quenching. The quenched manganese steel jaw plates were machined down to specified dimension (240x115x20mm). Samples with dimensions (25x25x12.5mm) were obtained to be used for jaw crusher plate. Metallographic examination was done using 3% nital followed with viella etchants. Microstructure and surface morphology of the etched samples were then taken using metallurgical microscope and scanning electron microscope.

The number of grains per square millimeter was calculated based on the Planimetric or Jeffries method of grain size determination according to ASTM E112 [8]. Rockwell C hardness was also determined. The performance of the modified and unmodified manganese steel jaw plates was evaluated using the modified jaw crusher gouging abrasion test. The ore was manually fed into the jaw crusher, with equal amount of 450 kg being crushed using each jaw plate.

III. RESULTS AND DISCUSSION

The ideal austenitic structure of the high manganese steel is a carbide-free structure and the carbon and manganese are homogenously distributed across the austenite matrix. However, carbides exist at the grain boundaries. Figure 1 shows the photomicrograph of the modified manganese steel which revealed non-uniform distribution of carbides in the austenite matrix. High concentration of carbide particles was noticeable at the grain boundaries. The relative abundance of alloy element has high degree of manganese sulfide micronodules and grain boundary carbides in austenite matrix.

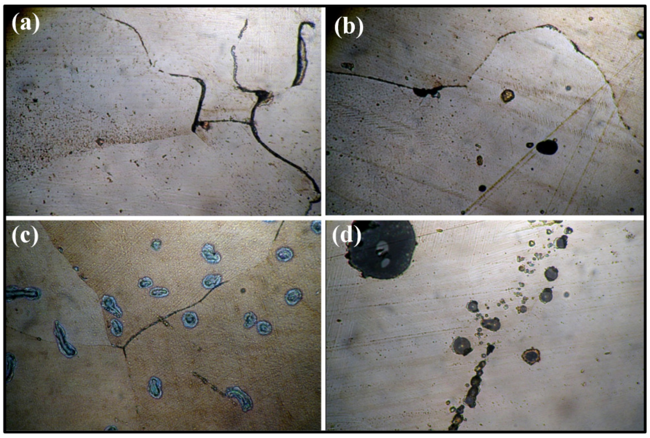

Fig. 1. Microstructure of austenitic manganese steel using nital etchant with (a) 0%, (b) 0.05%, (c) 0.1% and (d) 0.2% titanium addition (1000X)

Titanium modified manganese steel showed manganese sulfide micronodules, titanium inclusions and grain boundary carbides in matrix austenite. The grey particles were nonmetallic inclusions, while the dark spots were shrinkage pores. The inner matrix may contain pearlite, acicular carbides, martensite, meta-stable austenite and other unstable austenitic compositions.

The outer portion of the surface of the manganese steel has high hardness compared to the central area of the section which is more ductile. Grain size at the outer portion of the casting was finer and getting coarser grained towards the center. Figure 2 shows the effect of titanium in the initial Rockwell C hardness value of the Hadfield manganese steel. There was an increasing hardness value from 0% to 0.1% titanium addition but decreasing at 0.2%.

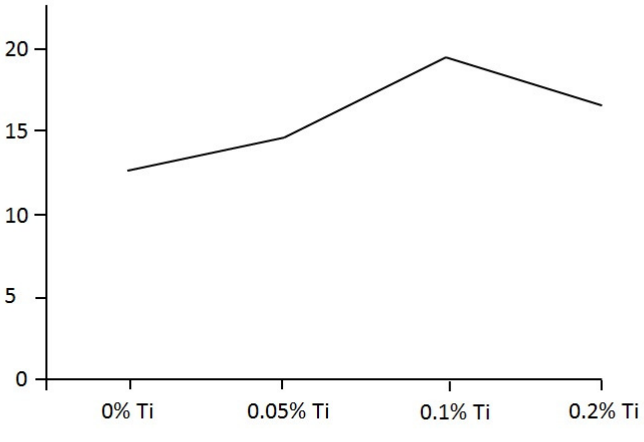

Fig. 2. Initial Rockwell C hardness values

Figure 3 shows the mass loss of each jaw plate after the gouging abrasion test simulation wear was done. The

ISBN: 978-988-14047-0-1
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

jaw plate with 0.1% titanium has the least amount of material loss. The low wear loss of the jaw plate with 0.1% titanium can be explained by solid solution strengthening effect of titanium inclusions.

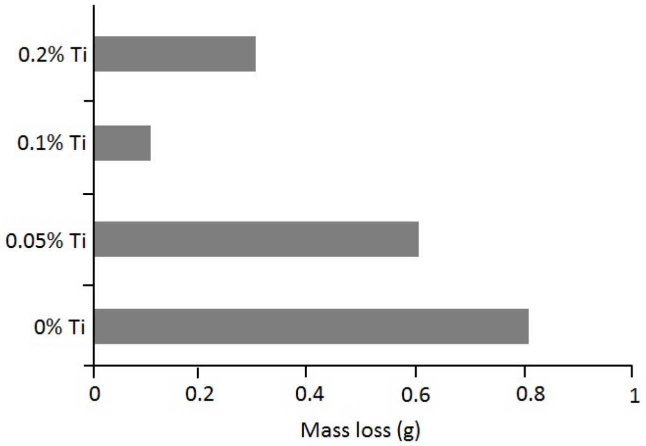

Fig. 3. Mass loss after gouging abrasion test

The angular impurities as shown in Figure 4 are titanium inclusions. The scanning electron microscopy (SEM) image of manganese steel with 0.1% titanium contained the most number of angular impurities. These titanium inclusions go into solid solution imposing lattice strains on the surrounding host atoms. Thus, there is a lattice strain field interaction between dislocations and the impurities, consequently, dislocation movement is restricted.

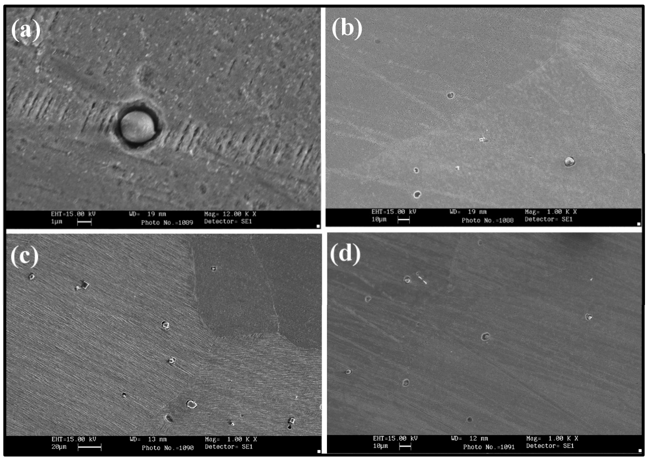

Fig. 4. Surface morphology of manganese steel with (a) 0%, (b) 0.05%, (c) 0.1% and (d) 0.2% titanium

The increase in the Rockwell C hardness of the jaw plate after the gouging abrasion test confirmed the work hardening behavior of manganese steel as shown in Figure 5. Jaw plate containing 0.1% titanium has the highest increase in Rockwell C hardness.

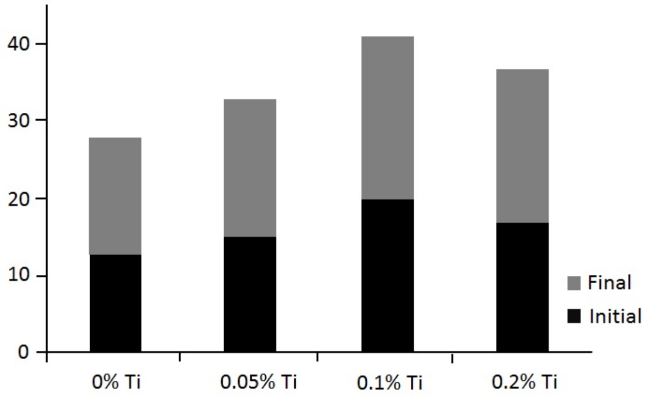

Fig. 5. Initial and final Rockwell C hardness values

Difference in Rockwell hardness values can be explained by the grain refinement property of titanium. Photomicrographs of unmodified and modified manganese steel were taken at same magnification for comparison. Figure 6 shows clearly the microstructural grain distribution of the titanium-modified austenitic manganese steel. The manganese steel with 0.1% titanium size has the smallest grain size. The fine grain size influences the mechanical properties; it is harder and stronger compared to the one that is coarse grained.

Fine grained material has a greater total grain boundary area to impede dislocation motion. The average grain size of the modified and unmodified manganese steel is shown in Table 3. The incorporation of 0.1% titanium has the best result for the refinement of grain size of austenitic manganese steel.

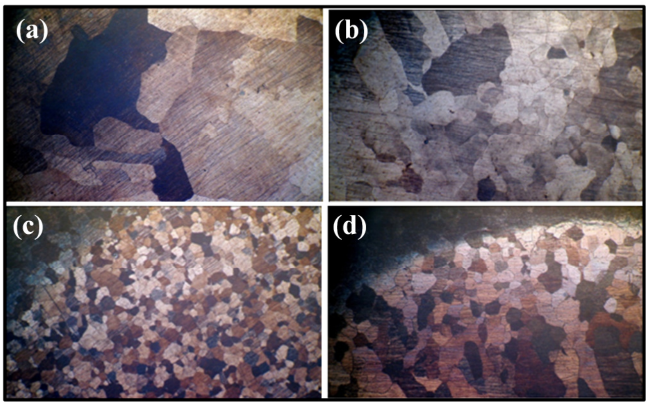

Fig. 6. Microstructure of austenitic manganese steel using nital and viella etchants with (a) 0%, (b) 0.05%, (c) 0.1% and (d) 0.2% titanium addition (25X)

Table III. Average grain size

Manganese steel with % Ti	Number of grains/mm^2	Average grain area (mm^2)	Mean grain diameter (mm)
0% Ti	2.25	0.444	0.666
0.05% Ti	6.50	0.154	0.392
0.1% Ti	39.25	0.025	0.158
0.2% Ti	15.00	0.067	0.259

In addition, it has been reported that the fine grain size can inhibit the formation of deformation twins in low stacking-fault energy type such as the high manganese Hadfield steels [9].

IV. CONCLUSION

The alloying of manganese austenitic steel with titanium can improve its hardness and wear resistance properties. Through solid solution strengthening and grain refinement, titanium successfully enhances the gouging abrasion resistance of Hadfield manganese steel.

ACKNOWLEDGMENT

The authors would like to extend their appreciation to President Michael C. Ang of the Tiger Machinery and Industrial Corporation (TMIC) for the use of materials and facilities as well as their engineers for the technical expertise. Sincere thanks and gratitude are also extended to the UP DMMME faculty and staff, especially to Prof. Brian Buenaventura for the assistance.

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