

Cooling Kinetics Effect on Abrasive Wear Behaviour of an ASTM A128 Steel

Oscar Higuera Cobos¹, Mónica Monsalve Arias²
and Hugo González Romero³

¹ CONFORMAT Research Group, Mechanical Engineering Program
Universidad del Atlántico, Puerto Colombia, Atlántico, Colombia

² Department of Mechanical and Mechatronic Engineering
Universidad Nacional de Colombia, Bogotá, Colombia

³ CNCA, Centro Nacional Colombo Alemán- SENA Research Group
Barranquilla, Atlántico, Colombia

Copyright © 2018 Oscar Higuera Cobos et al. This article is distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract

In this work, quench severity effect on abrasive wear resistance on austenitic steel ASTM A128 Grade C samples, were studied. Initial and heat-treated samples were characterized by optical emission spectroscopy (OES), X-ray diffraction (XRD), scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) to determinate present phases, microstructural changes and evaluate their influence on abrasive wear resistance. In addition, wear resistance tests were made according to ASTM G65-00 to determinate abrasive wear resistance and the possible strain hardening produced by the contact of the sample with the abrasive agent.

Keywords: Austenitic manganese steel, Hadfield steel, heat treatment, quenching, quenching severity, wear resistance

1 Introduction

Austenitic manganese steels between 11-14% Mn and 0.7-1.45% C are well-known

because of their great wear resistance and their hardening produced in service conditions; Therefore, they are considered very useful in applications such as: railroad crossings, crushing machine jaws, excavators, and so on. Metals have various forms to introduce alloys in their matrices to increase mechanical properties, in this case manganese steel ASTM A 128 grade C wear resistance was analysed with heat treatment processes and microstructural transformations related with treatment times, austenization temperatures and cooling rates. Heat treatment can be harmful if material decarburization produced by a poor silicon protection is reached during the treatment time, leading to an impoverishment of alloy elements such as manganese and chromium which are carried by the carbides out of the metal. These heat treatments are realized to harden the structure and modify the composition to obtain wear resistance behaviour and understand material dynamics through analysing wear patterns, scanning electron microscopy, X-ray diffraction and optical emission spectroscopy.

2 Methodology

The austenitic steel ASTM A128 Grade C samples were received in their as-cast condition, with the following composition: 12.87 %Mn; 1.05 %C; 2.3 %Cr; 0.82 %Si; 0.003%S; Fe balance, according to the Thermo electron corporation ARL ASSURE Optical Emission Spectrometer. The samples were machined into rectangular specimens with dimensions of 76 x 25 x 5 mm to performed abrasive wear tests using the Dry Sand/Rubber Wheel Equipment described in the procedure E of the ASTM G65-00 standard [6]; The following parameters were used: force against specimen 130 N, wheel revolutions 1000 rpm, lineal abrasion 718 m and testing time 5 min. [6]. The samples were austenitized at 1100 °C for 1 h and then two different cooling methods were applied: water and brine. The microstructure of the samples was characterized using a JEOL-JSM-5910 Scanning Electron Microscope equipped with an Energy Dispersive X Ray detector and a Philips PW1700 X-ray diffractometer equipped with a PW1825 generator, graphite monochromator at an angle of 26° and Cu radiation. Micro-hardness was measured according ASTM E384-11 [5] using a 401 MVA Wilson Wolpert micro-Vickers hardness tester under an indentation load of 1000 g for 15 s [1]. The samples mass loss was measured using an analytical scale with a sensitivity of 0.0001 g. Wear resistance analysis was realized determining the volumetric loss and wear rate of the specimens according to equations of volumetric loss (1) and wear rate (2) [2]. The hardness values for each sample were determinate to compare the performance of the specimens after being heat treated and to calculate the wear coefficient (k) value using the equation (3) [3].

$$\text{Volumetric loss (mm}^3\text{)} = \frac{\text{Loss mass (g)} \cdot 1000}{\text{Density (}\frac{\text{g}}{\text{cm}^3}\text{)}} \quad (1)$$

$$\text{Wear rate} = \frac{\text{Volumetric loss [mm}^3\text{]}}{\text{Lineal abrasion (L)[m]}} \quad (2)$$

$$K = \frac{3 HV}{PL} \quad (3)$$

where: V is the volume of the lost material [mm³], H represents the material hardness [Brinell], P is the load used in the test [kg] and L is the sliding distance [mm], where the material density is 7,440 g/cm³.

3 Results

3.1 Microstructural characterization

Figure 1 shows the microstructures and composition spectrums of the as-cast state, water hardened and 30 % brine hardened steels. Figure 1(a) shows an austenitic grain of variable size (65-90 μm) with the presence of second phase compounds at the grain boundaries, these compounds must be dissolved in the austenitic matrix to obtain a homogeneous structure with better mechanical properties. In Figure 1(b) and 1(c) a coherent microstructural behaviour of an austenitic manganese steel subjected to hardening heat treatment in the absence of an inert atmosphere is presented. Elevated temperature produced considerable surface decarburization and loss of manganese leading to the formation of martensite. The martensite layer is hard and brittle, which allows the loss of material during the abrasive wear process, which results in lower wear resistance compared to the as-cast state material that presents a plastic deformation process allowing the deformation hardening process and therefore a significant increase in its wear resistance [1, 7, 8, 9]. In addition, there is a greater oversaturation of austenitic phase in elements such as carbon, chromium and in 30% brine-cooled material manganese due to the greater severity of hardening causing an increase in hardness which is consistent with the results obtained. Figure 2 summarizes the diffraction spectrums of the as-cast state, water hardened and 30 % brine hardened samples.

Austenitic behaviour is observed, consistent with this type of material; however, the presence of ferrite and second phase compounds such as (Fe, Mn)₃C, MnS, (FeMn₄)_xC and Cr₇C₃ is observed in the as-cast state material. The presence of ferrite and carbide phases is undesirable and must be eliminated completely or reduced by heat treatment to obtain good wear resistance [4, 11, 12]. After hardening heat treatment, the presence of some iron and manganese carbides and the dissolution of chromium carbides are still noted in a very low proportion. In addition, the presence of decarburization-induced martensite (α') is noted, indicating a shared loss of carbon and manganese [10].

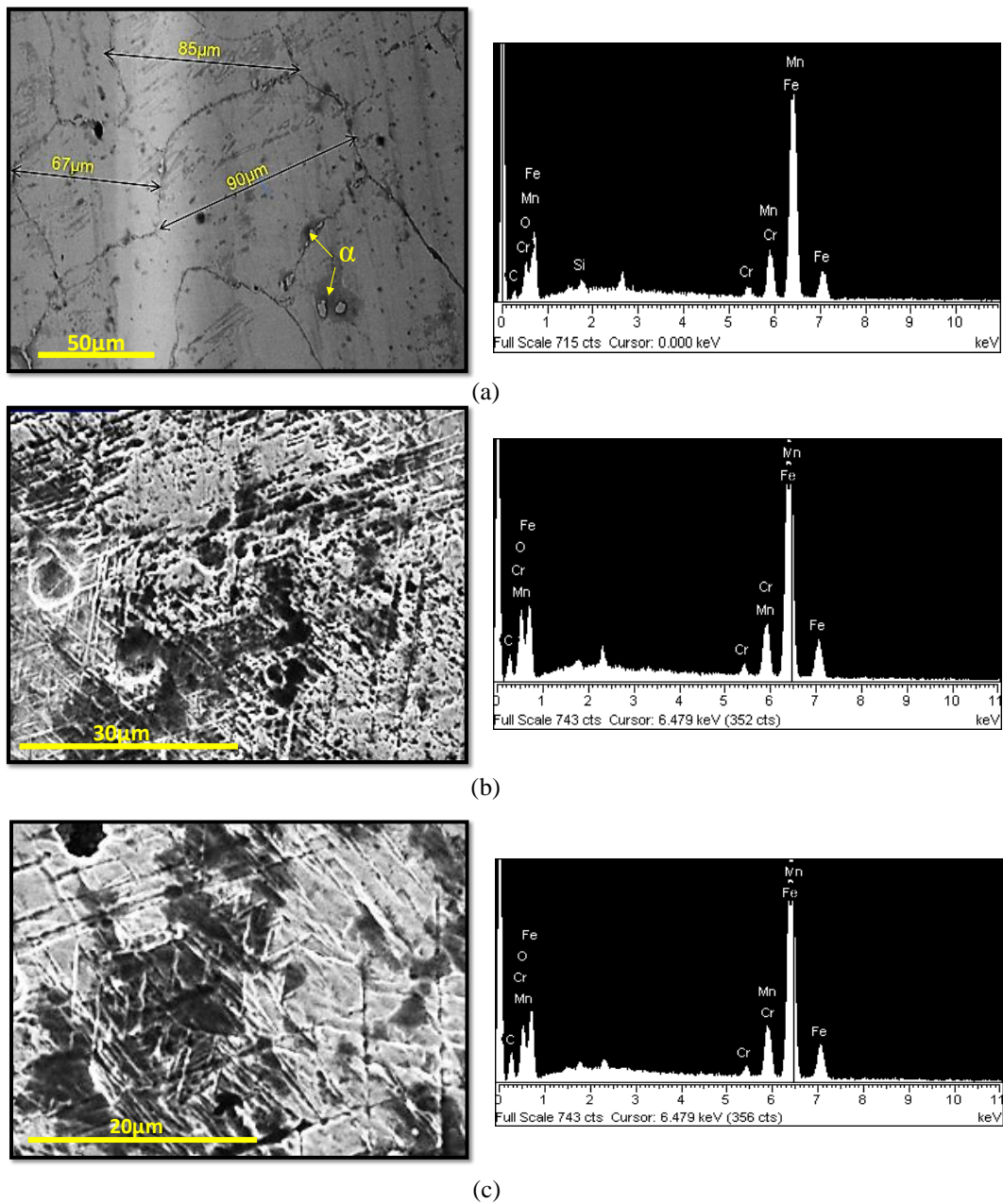


Figure 1. SEM-EDS of austenitic manganese steel. (a) As-cast, (b) quenching in water and (c) quenching in brine at 30%.

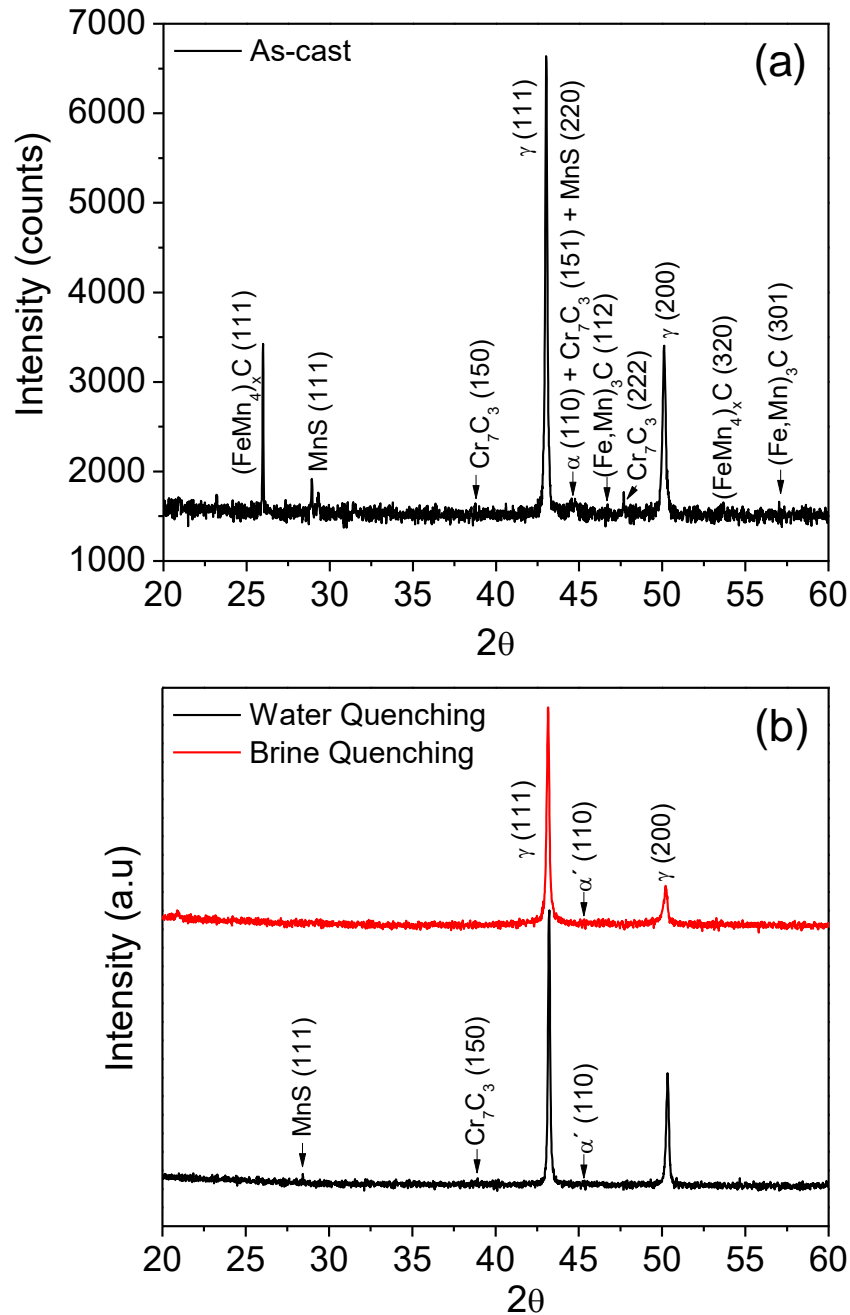


Figure 2. Austenitic XRD Manganese Steel as (a) supplied and (b) heat treated.

3.1 Mechanical characterization

Table 1 shows the gravimetric results obtained during the evaluation of the as-cast state, water hardened and 30 % brine hardened samples. The mechanical behaviour (hardness and wear resistance) of austenitic manganese steel, which has been hardened

in water and brine, is quite special in comparison with the results of the supply material.

SAMPLE	As-cast	Water quenching	Brine quenching
Loss mass (g)	0.2856	0.4115±0.069	0.3912±0.0587
Volumetric los (mm ³)	38.38	55.31	52.58
Wear rate (mm ³ /m)	5.35x10 ⁻²	7.7x10 ⁻²	7.32x10 ⁻²
Wear Coeffcient	2.66 x10 ⁻³	4.14 x10 ⁻³	4 x10 ⁻³
Initial Hardness (HB)	226±5	244±17	248±15
Wear scar Hardness (HB)	344±5	339±19	366±57

Table 1. Gravimetric results of abrasive wear tests

The as-cast material had the lowest hardness (226±5 HB) compared to water hardened (244±17 HB) and 30% brine (248±15 HB). However, it also had the lowest loss of mass. This was due to the presence of martensite induced by the surface decarburization of the material which inhibits the austenite phase deformation hardening phenomenon and thus reduces the wear resistance of the material. It is important to notice that the hardness values in the footprint after the wear test were higher for all cases under study compared to the material before the deformation, which indicates a higher hardening with deformation for the as-cast state and brine hardened samples, with an increase in hardness of 118 HB compared to the water hardened specimens with 95HB.

4 Conclusions

Austenitic manganese steel is a material that has a metastable microstructure under stable conditions and must be heat treated in controlled atmospheres due to the loss of carbon and manganese which induces the martensitic transformation that is undesirable in this type of material.

The wear resistance of austenitic manganese steels is not directly linked to the hardness of the material after a heat treatment, since austenite is the most plastic phase of steels and is supersaturated in carbon, therefore its hardening occurs by deformation of the grain, i.e. by generation of grain limits that reduce the movement of dislocations and the generation of martensite (ϵ -hcp) and not by martensitic transformation as a result of changes in cooling kinetics or by decarburization and loss of manganese in the alloy (α' -tetragonal compact).

References

- [1] E. A. Aleshina, Yu. F. Ivanov, A. V. Kolubaev, S. V. Kononov, V. E. Gromov, Gradient structure-phase states formed in Hadfield steel during dry sliding wear, *Russian Physics Journal*, **51** (2008), no. 11, 1168-1173.
<https://doi.org/10.1007/s11182-009-9151-5>

- [2] ASM Handbook, Properties and Selection: Irons, Steels, and High-Performance Alloys, 10th Ed., Vol. 1, 1990.
- [3] ASM Handbook, Friction, Lubrication, and Wear Technology, 10th Ed., Vol. 18, ASM International. 1992.
- [4] A.A. Astafev, Effect of grain size on the properties of manganese austenite steel 110G13L, *Metal Science and Heat Treatment*, **39** (1997), no. 5-6, 198-201.
<https://doi.org/10.1007/bf02467284>
- [5] ASTM E384, Standard Test Method for Knoop and Vickers Hardness of Materials, West Conshohocken, U.S.A., 2011.
<https://doi.org/10.1520/e0384-10e01>
- [6] ASTM G 65 – 00. Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus, West Conshohocken, U.S.A., 2000.
<https://doi.org/10.1520/g0065-00e01>
- [7] O. I. Balyts'kyi and V. O. Kolesnikov, Investigation of the wear products of austenitic manganese cast irons, *Materials Science*, **40** (2004), no. 1, 78-82.
<https://doi.org/10.1023/b:masc.0000042788.19429.a1>
- [8] S.F. Gnyusov and S. Yu. Tarassov, Friction and the Development of Hard Alloy Surface Microstructures during Wear, *Journal of Materials Engineering and Performance*, **6** (1997), 737-742. <https://doi.org/10.1007/s11665-997-0075-3>
- [9] B. Hutchinson and N. Ridley, On dislocation accumulation and work hardening in Hadfield steel, *Scripta Materialia*, **55** (2006), 299–302.
<https://doi.org/10.1016/j.scriptamat.2006.05.002>
- [10] W. S. Owen, M. Grujicic, Strain aging of austenitic Hadfield manganese steel, *Acta Materialia*, **47** (1998), no. 1, 111-126.
[https://doi.org/10.1016/s1359-6454\(98\)00347-4](https://doi.org/10.1016/s1359-6454(98)00347-4)
- [11] S. B. Sant, R. W. Smith, A study in the work-hardening behaviour austenitic manganese steels, *Journal of Materials Science*, **22** (1987), 1808-1814.
<https://doi.org/10.1007/bf01132410>
- [12] A. Srivastava, K. Das, Microstructural characterization of Hadfield austenitic manganese steel, *J. Mater. Sci.*, **43** (2008), 5654–5658.
<https://doi.org/10.1007/s10853-008-2759-y>

Received: August 14, 2018; Published: August 31, 2018