

ARCHIVES  
of  
FOUNDRY ENGINEERING



ISSN (2299-2944)

Volume 13

Issue 4/2013

DOI: 10.2478/afe-2013-0083

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

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# Effect of high-manganese cast steel strain hardening on the abrasion wear resistance in a mixture of SiC and water

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Received 28.06.2013; accepted in revised form 02.09.2013

## Abstract

The study attempts to determine the impact of the high-manganese cast steel strain hardening on its abrasion wear resistance in a mixture of SiC and water prepared in accordance with ASTM G75. For tests, the high-manganese cast steel containing 10.7, 17.9 and 20.02% Mn was selected. The results of microstructure examinations and abrasion wear resistance tests carried out on the material in non-hardened condition and after strain hardening with a force of 539.55kN were disclosed. Additionally, the surface of samples after a 16-hour cycle of abrasion tests was examined. Moreover, based on the obtained results, the effect of different contents of Mn in cast steel was studied, mainly in terms of its impact on the abrasion wear resistance. The results obtained on the tested materials were compared with the results obtained on the low-alloyed abrasion wear-resistant cast steel L35GSM.

**Keywords:** Austenite high manganese steels, Microstructure, Abrasive wear resistance, Miller slurry machine test

## 1. Introduction

High-manganese cast steel containing from 8 to 19% Mn and from 0.75 to 1.4% C is included in the family of cast abrasion wear-resistant steels described in the PN-EN 10349 standard [1]. In foundry practice, the most popular grade representing this group of materials is Hadfield cast steel showing high wear resistance under high dynamic loads [2÷4]. In recent years, numerous studies have been conducted to improve the wear resistance through, among others, the introduction of alloying elements such as Cr, Ni, V and Mo [4, 5]. According to the authors of [3, 4, 6÷8], the abrasion wear resistance of metallic materials depends to a great extent on the degree of grain refinement, on the presence of fine-dispersed carbides in the structure, and on the absence of acicular-type carbides (Fe,

Mn)<sub>3</sub>C, usually eliminated by heat treatment (solution heat treatment from a temperature comprised in the range of 1050 ÷ 1100°C). Typical high-manganese Hadfield cast steel after the solution heat treatment is characterised by an austenitic structure, which, despite the low hardness, has good abrasion wear resistance comparable to other engineering materials (L35GSM-PN-H/83156 [9]). The only drawback in the use of the high-manganese cast steel is its low resistance to abrasion wear at pressures that do not cause the cold work hardening effect. In studies of the Hadfield cast steel, there are inconsistencies regarding the events observed to occur during cold work. Some of the authors claim that the increase in material hardness during cold work is to be attributed to structural changes (the appearance of  $\epsilon$  martensite), while others are seeking the source of this effect in the twinning of grains and more compact arrangement of dislocations [4, 10].

In this paper, the influence of the hardening effect on the resistance to abrasion wear of cast high-manganese steel containing 10.7, 17.9 and 20.02% Mn was discussed.

## 2. Methods of investigations

The cast alloyed high-manganese steel used in the present study came from the industrial melts and contained 10.7, 17.9 and 20.02% Mn. This cast steel was solution heat treated under the industrial conditions. The chemical composition of the tested material is shown in Table 1. Samples were tested in non-hardened condition and after strain hardening with a force of

539.55kN. As a result of the impact of this force, a decrease in the height of the samples of the tested material was observed (Table 2). The wear resistance was tested in accordance with ASTM G75 on a Miller machine applying a 16-hour test cycle. The abrasive medium was mixture of SiC and water in a ratio of 1:1. Total loading of the sample in a test cycle was 22.24N. As a measure of the wear resistance, a relative total weight loss was adopted. The cast steel microstructure before and after strain hardening and the condition of the sample surface after the wear tests were evaluated under a Neophot 32 light microscope. Hardness tests in the non-hardened condition, after hardening and after the abrasion wear tests were performed with a Vickers hardness tester at a load of 294.2 N.

Table 1.

Chemical composition of examined alloys

Cast steel group	C	Si	Mn	P	S	Cr	Ni	Ti	Mo
	% wag.								
H	1.25	0.73	10.7	0.04	0.034	1.24	0.05	-	0.16
LGH	1.29	0.73	17.90	0.058	0.006	2.12	0.40	0.007	-
LGH22	1.40	0.44	20.02	0.074	0.007	2.50	0.13	0.02	-

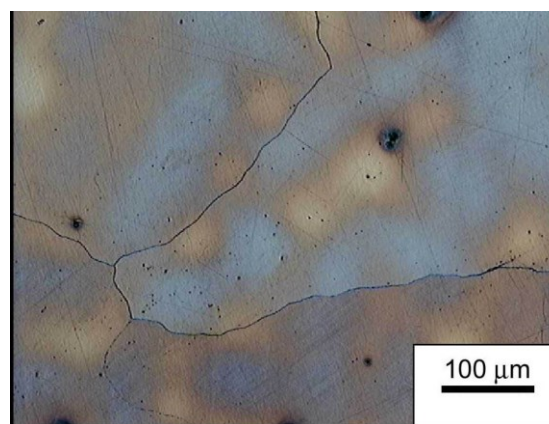
Table 2.

Changes in the height of samples tested for abrasion wear resistance after strain hardening

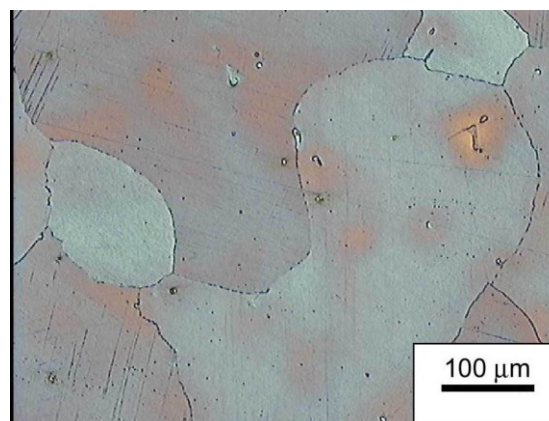
Cast steel group	Sample height before strain hardening [mm]	Sample height after strain hardening with a force of 539.55kN [mm]
H	8	6.7
LGH	9	7.6
LGH22	9	7.4

## 3. Results and discussion

Figures 1 and 2 show the microstructure of materials tested in non-hardened and hardened condition, respectively. The non-hardened high-manganese cast steel is characterised by an austenitic matrix with scarce complex carbide precipitates containing Mn, Fe and Cr (alloyed cementite) and non-metallic inclusions. In the case of material strain hardened with a force of 539.55kN, an increase in hardness by about 130±160 HV<sub>30</sub> was reported (Fig.3). Hardness in the non-hardened condition was 239±241 HV<sub>30</sub> for the cast steel containing 10.7% Mn and 254±301HV for the cast steel containing 20.02% Mn. After strain hardening of the tested material, some changes were observed in its microstructure such as: grain refinement and the presence of dislocations (Fig.2). The applied research technique did not allow revealing the stacking faults typically encountered in materials of this type when subjected to hardening [4].



a) H<sub>bh</sub>



b) LGH22<sub>bh</sub>

Fig. 1. Examples of microstructure of the tested materials in non-hardened condition

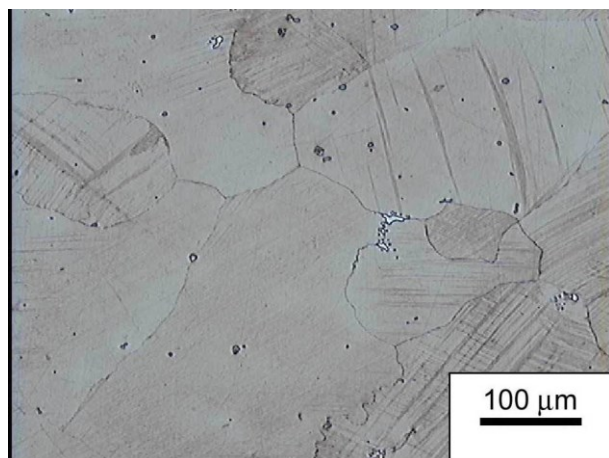
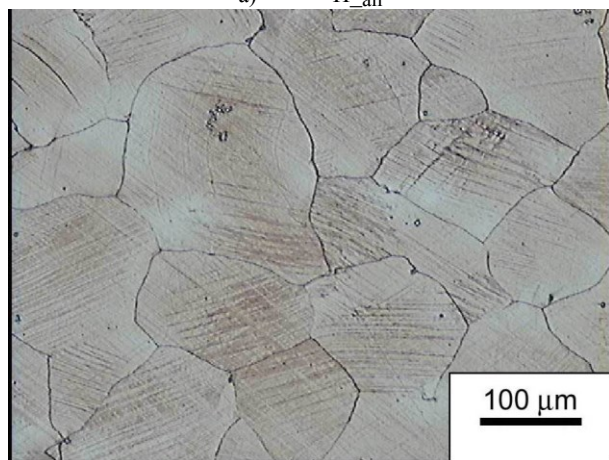
a) H<sub>ah</sub>b) LGH22<sub>ah</sub>

Fig. 2. Examples of microstructure of the tested materials after strain hardening

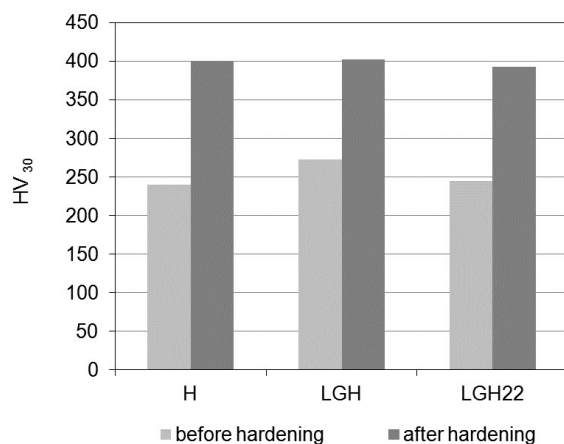
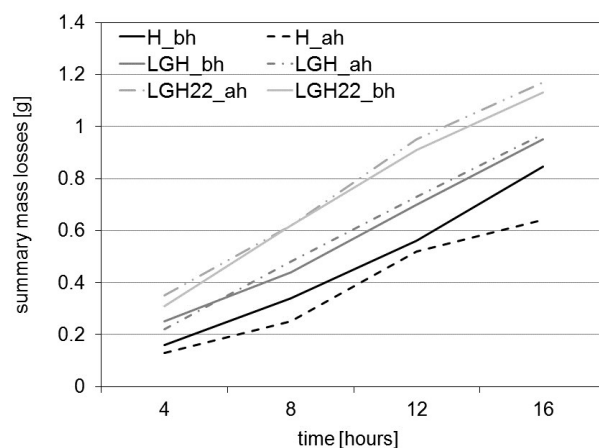


Fig. 3. Hardness of the tested materials

The results of abrasion wear test carried out in a mixture of SiC and water in a ratio of 1:1 are shown in Figure 4. The results were

compared with the results obtained for the cast low-alloy L35GSM steel. After a full 16 hour test cycle, there was only very small difference in total weight loss between the material in non-hardened condition and after strain hardening. The tested high-manganese cast steel, in spite of being strain hardened with a force of 539.55kN, did not show the expected increase in abrasion wear resistance in a mixture of SiC and water.

On the basis of the obtained results, an obvious impact of manganese content in the tested cast high-manganese steel on the abrasion wear resistance in a mixture of SiC and water was stated. With the increasing manganese content (10.7, 17.9, 20.02% Mn), the abrasion wear resistance characterised by the total weight loss was decreasing. For the cast steel containing 10.7, 17.9, 20.02% Mn, the relative total weight loss after 16 hour-lasting test cycle was 0.64, 0.97, 1.17g, respectively, whereas for the cast low-alloyed L35GSM steel it amounted to 0.85±1.1g [11]. Thus, under the conditions of the carried out test, the total loss in weight was comparable for the tested cast high-manganese steel and cast L35GSM steel.

Fig. 4. The relative weight loss observed in the tested cast steel, <sub>bh</sub> - before strain hardening, <sub>ah</sub> - after strain hardening

#### Evaluation of the tested material surface after 16 hour test cycle

After full abrasion test cycle, the sample surface was examined by light microscopy. Based on the visual examination of the surface subjected to the effect of a mixture of SiC and water, an obvious plastic deformation of orientation consistent with the direction of the sample movement in the machine trough filled with a mixture of SiC and water was observed. The recorded images of the surface of the tested material are shown in Figures 5 and 6. Furrowing, scratching and polishing of the surface, as well as abrasive particles embedded in the surface were noted. Places with another type of surface deformation were also observed to exist. Their presence may be due to spalling of e.g. non-metallic inclusions under the effect of hard SiC particles.



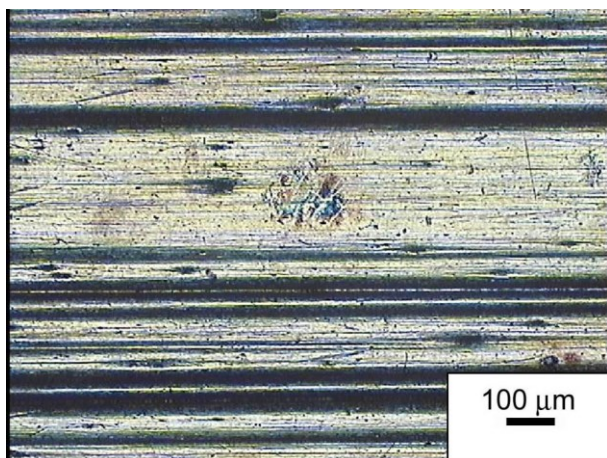


Fig. 5. Image of the H cast steel surface after the completed test

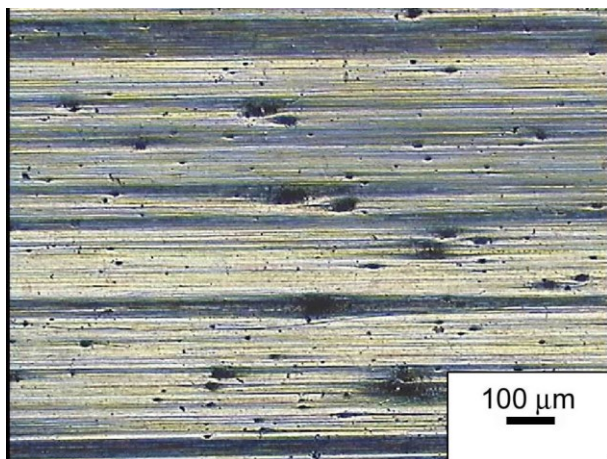


Fig. 6. Image of the LGH cast steel surface after the completed test

## 4. Conclusions

- The tested material was characterised by an austenitic structure with the precipitates of complex carbides enriched in Fe, Mn and Cr.
- Compared with the non-hardened condition, strain hardening with a force of 539.55kN raised the hardness by an average of 40, 32, 38 % in the cast steel containing 10.7, 17.9 and 20.02% Mn, respectively.
- The abrasion wear resistance test did not show any significant differences in the high-manganese cast steel behaviour in the non-hardened condition and after strain hardening. On the other hand, the effect of increased Mn

content on the reduced abrasion wear resistance was well visible.

- The top layer of the tested material after the completed test cycle showed furrowing, scratching and polishing of the surface as a result of impact exerted by the hard SiC particles and water on the surface of samples.

## Acknowledgements

The research part of the study has been partially executed under a Statutory Work no 11.11.170.318 Task no.5 (2013).

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