ARCHIVES of FOUNDRY ENGINEERING

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

ISSN (1897-3310)
Volume 11
Special Issue 3/2011

81 – 88

15/3

Wear resistance of nodular cast iron with carbides

G. Gumienny
Department of Materials Engineering and Production Systems, Technical University of Łódź
Stefanowskiego 1/15 Street, 90-924 Łódź, Poland
Corresponding author: E-mail address: grzegorz.gumienny@p.lodz.pl

Received 25.07.2011; accepted in revised form 27.07.2011

Abstract

In this paper results of abrasive and adhesive wear resistance of selected grades of nodular cast iron with carbides are presented. It was demonstrated, that the maximum wear resistance has got nodular cast iron with the microstructure of upper bainite, lower bainite and carbides. This cast iron with hardened steel and sulfonitrided steel is the most advantageous friction pair during adhesive wear testing. It was found, that the least advantageous friction pair is pearlitic nodular cast iron with carbides and normalized steel.

Keywords: Innovative foundry technologies and materials, Nodular cast iron with carbides, Abrasive and adhesive wear resistance.

1. Introduction

In the Department of Materials Engineering and Production Systems from a few years research are conducted to obtain new grades of nodular cast iron with greater wear resistance than applied today. To this end nodular cast iron with carbides with different metal matrix microstructure obtaining without heat treatment was worked out [1 ÷ 7]. Preliminary results wear resistance of new nodular cast iron was presented in paper [8]. Now applied technology enables obtaining of nodular cast iron with carbides and metal matrix microstructure as following: pearlite, upper bainite, lower bainite, ausferrite, martensite and their mixture. In order to obtain a.m. kinds of cast iron as-cast a combination of chromium, molybdenum, nickel and copper is put. Cast iron nodulization was made using Inmold method. The goal was studying abrasive and adhesive wear resistance of chosen kinds of new nodular cast iron with carbides.

2. Work methodology

To wear resistance tests nodular cast iron with carbides and metal matrix microstructure as following was used:

– pearlite,
– upper bainite,
– upper and lower bainite,
– upper and lower bainite, pearlite, martensite and ausferrite,
– martensite.

The chemical composition of each cast iron was tested with using SPECTROMAXx stationary metal analyzer made by Spectro Analytical Instruments GmbH. It is presented in Table 1.

Maximum P and S concentration amounted to 0,04% and 0,01% properly.

Tribological research was conducted on the special test station. Its scheme is presented in Figure 1.

Table 1.
The chemical composition of tested kinds of nodular cast iron with carbides

Kinds of cast iron metal matrix	Chemical composition, %							
	C	Si	Mn	Cr	Mo	Ni	Cu	Mg
pearlite	3,60 ÷ 3,86	2,37 ÷ 2,61	0,26 ÷ 0,32	0,70 ÷ 0,90	_	0,70 ÷ 0,90	0,96 ÷ 1,15	0,04 ÷ 0,05
upper bainite	3,30 ÷ 3,36	2,33 ÷ 2,53	0,07 ÷ 0,11	_	1,98 ÷ 2,11	0,97 ÷ 1,10	_	0,04 ÷ 0,05
upper and lower bainite	3,30 ÷ 3,57	2,45 ÷ 2,61	0,26 ÷ 0,32	_	1,39 ÷ 1,55	2,03 ÷ 2,19	_	0,04 ÷ 0,05
upper and lower bainite, pearlite, martensite, ausferrite	3,68 ÷ 3,86	2,48 ÷ 2,61	0,26 ÷ 0,32	0,50 ÷ 0,55	1,45 ÷ 1,52	1,01 ÷ 1,08	0,96 ÷ 1,05	0,04 ÷ 0,05
martensite	3,32 ÷ 3,46	2,41 ÷ 2,53	0,07 ÷ 0,11	0,40 ÷ 0,50	0,25 ÷ 0,29	3,98 ÷ 4,08	0,98 ÷ 1,05	0,04 ÷ 0,05

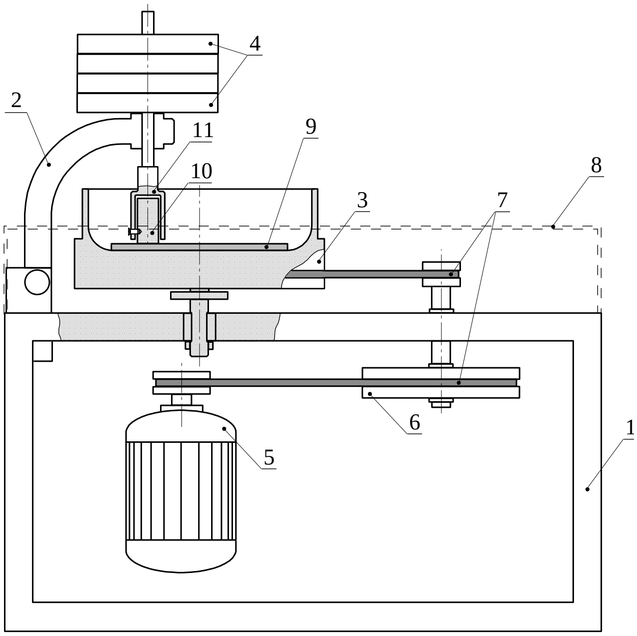


Fig. 1. The scheme of abrasive and adhesive wear testing stand: 1 – housing , 2 – mobile lever, 3 – revolving pan, 4 – load, 5 – engine, 6 – flywheel, 7 – driving belts, 8 – cover, 9 – abrasive paper or counter-specimen, 10 – specimen, 11 – specimen chuck,

Specimens overall using to abrasive and adhesive wear resistance are presented in Figure 2.

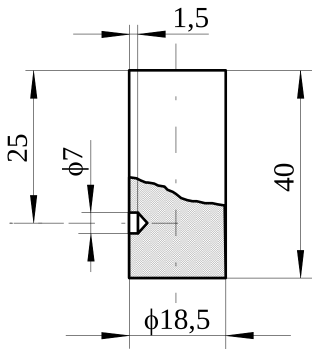


Fig. 2. Specimen overall using to abrasive and adhesive wear resistance

Experimental conditions were as following:

- specimens' load on abrasive paper and steel counter-specimen: 98,0655 N,
- specimens' abrasive surface: 268,8 mm^2,
- specimens' unit pressure:

$$\sigma = \frac{F}{S} = \frac{98{,}0665\ N}{268{,}8\ mm^2} = 0{,}36\ MPa,$$

- rotational speed: ω = 75 RPM.

To cast iron abrasive resistance testing the abrasive paper with the grit size 40 was used.

To cast iron adhesive resistance three counter-specimens in the form of ϕ100mm and 10mm thick disk were used. They were made of C55 toughening steel and subjected to three different heat treatments: normalizing, hardening and low-temperature tempering, sulfonitriding.

Cast iron and counter-specimens microstructure was tested on metallographic specimens etched by nital, magn. ×500 and ×1000, with use of Eclipse MA200 Nikon metallographic microscope.

Abrasive and adhesive wear resistance was measured as mass decrease with using „Sartorius CP 224S-OCE" exact to 0,0001 g (measuring error ± 0,0003 g).

3. Results

In Figure 3 ÷ 5 the microstructure of counter-specimens made of C55 used to adhesive wear testing is presented.

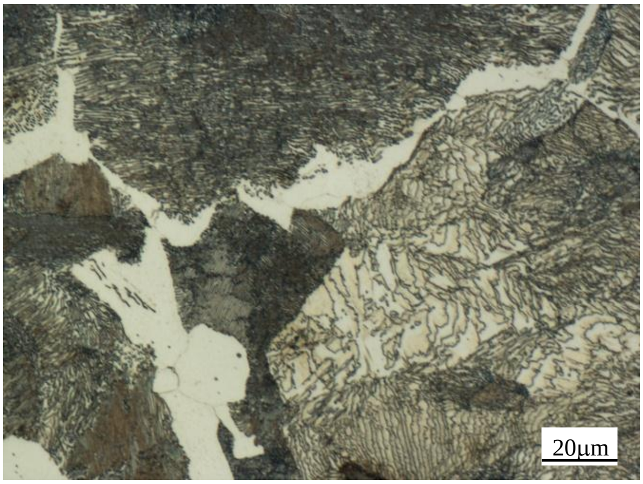


Fig. 3. Counter-specimen microstructure after normalizing: pearlite, ferrite, non-metallic inclusions

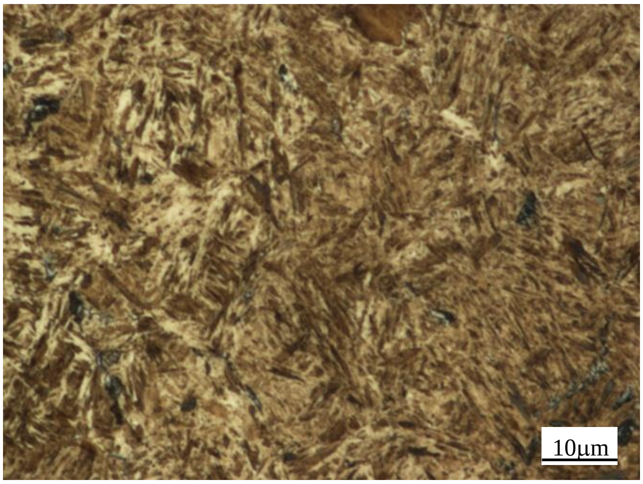
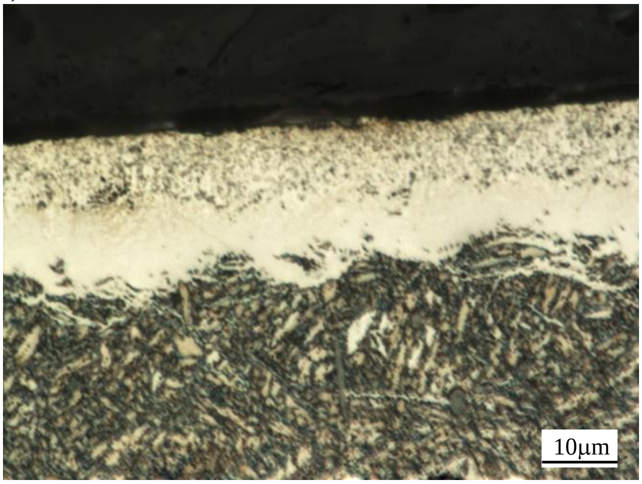


Fig. 4. Counter-specimen microstructure after hardening and low-temperature tempering: low-tempered martensite, retained austenite, non-metallic inclusions

a)



b)

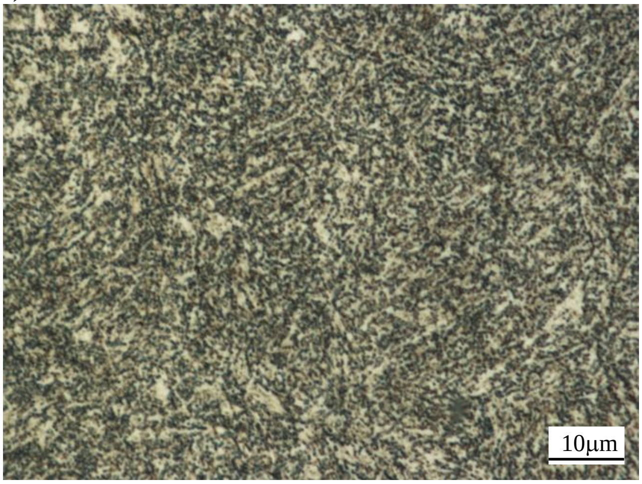
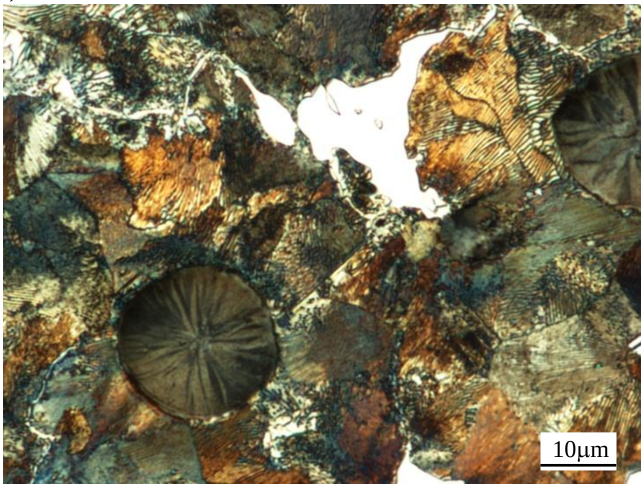


Fig. 5 (a, b). Counter-specimen microstructure after hardening and sulfonitriding: sulfonitrided layer (a): sulfurized zone with FeS and Fe_2S; nitrogen compounds zone ε, ε + γ', γ' („white layer") without FeS and Fe_2S, FeS fine compounds zone in ε phase, core (b): sorbite, non-metallic inclusions

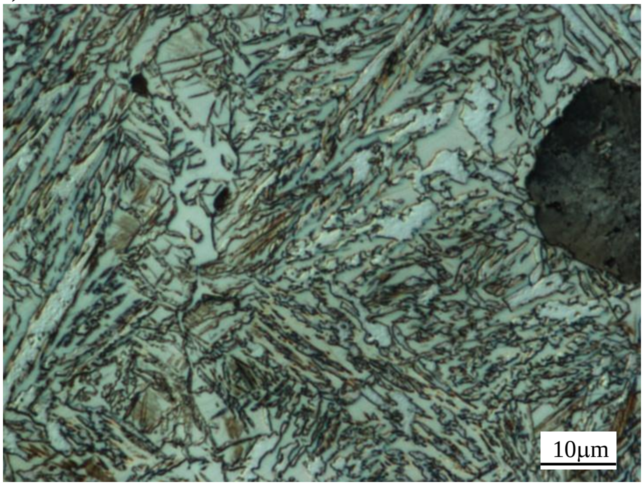
In Figure 6 (a ÷ e) the microstructure of tested cast iron with carbides with metal matrix consists of: a) pearlite, b) upper bainite, c) upper and lower bainite, d) upper and lower bainite, pearlite, martensite and ausferrite, e) martensite is presented.

a)



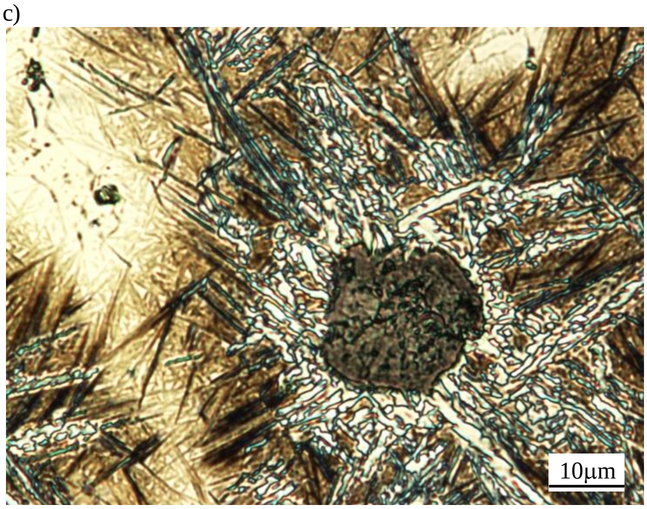
microstructure: nodular graphite, pearlite, carbides

b)



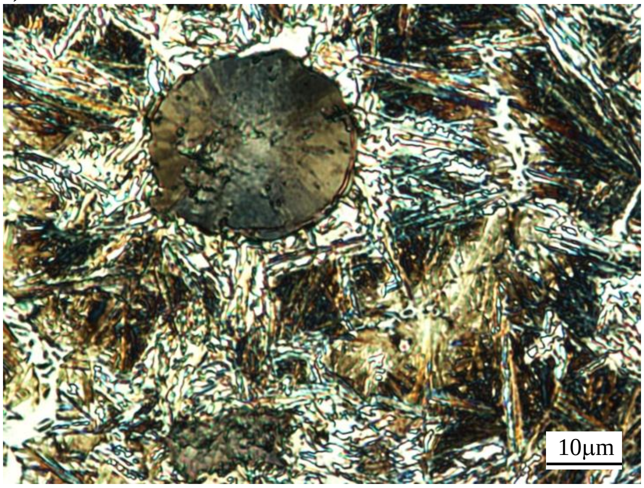
microstructure: nodular graphite, upper bainite, carbides

c)



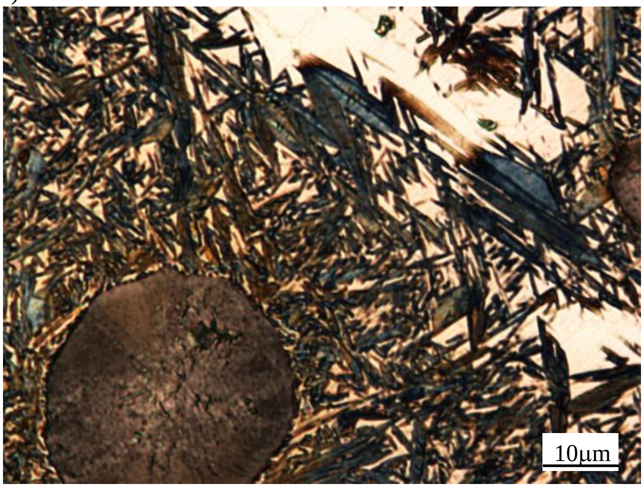
microstructure: nodular graphite, upper bainite, lower bainite, carbides

d)



microstructure: nodular graphite, upper bainite, lower bainite, pearlite, martensite, ausferrite, carbides

e)

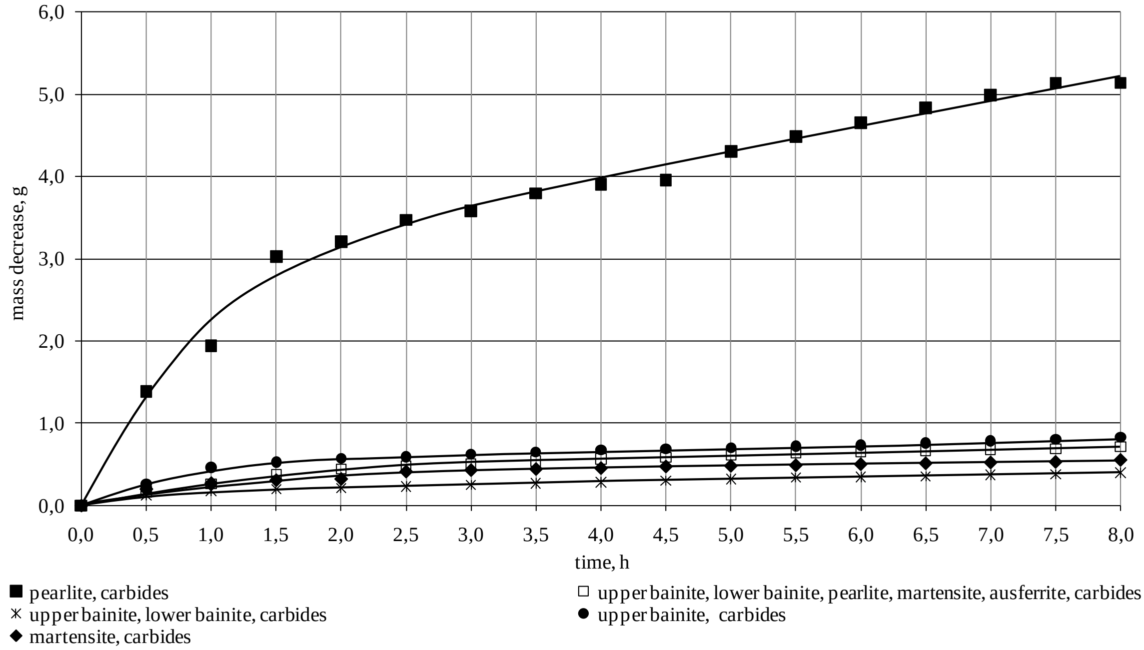


microstructure: nodular graphite, martensite, retained austenite, carbides

Fig. 6 (a ÷ e). The microstructure of tested grades of nodular cast iron with carbides

In Figure 7 (a ÷ b) results of abrasive wear of cast iron mating with abrasive paper with the grit size 40 are presented.

a)



b)

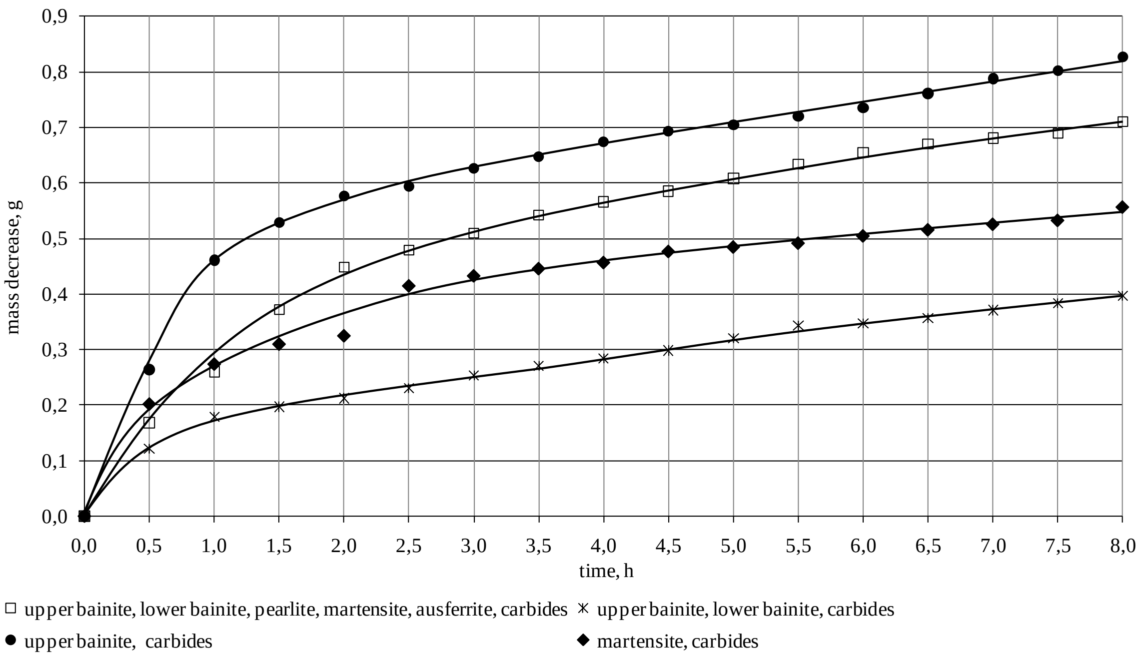


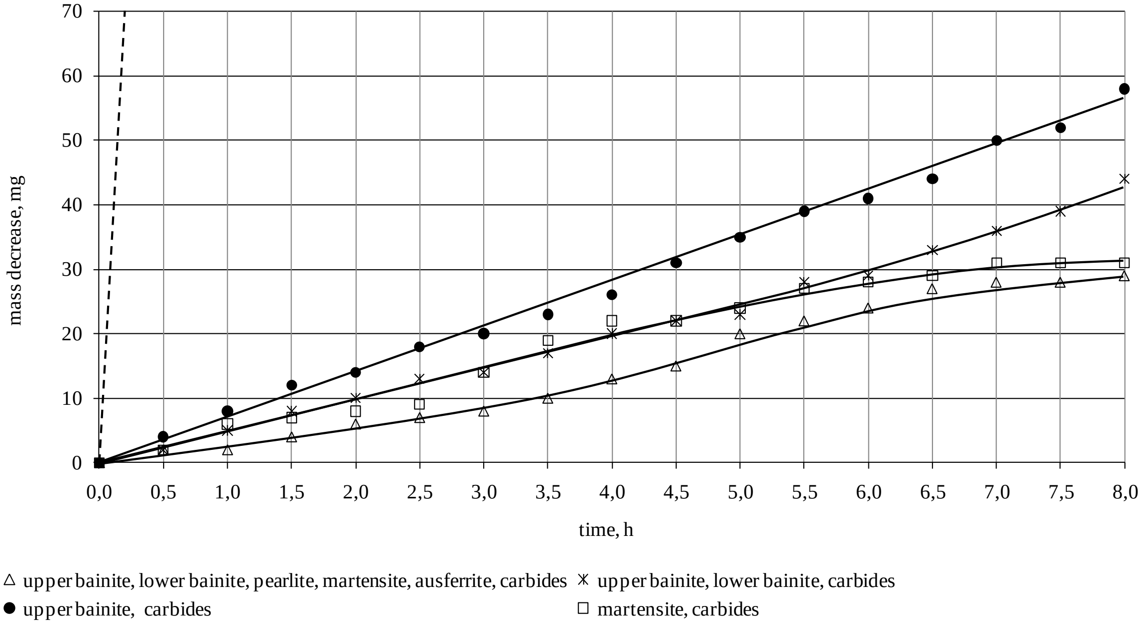
Fig. 7 (a, b). Abrasive wear of tested kinds of nodular cast iron with carbides

From Fig. 7a results, that pearlitic nodular cast iron has the least abrasion resistance. The mass decrease after 8 h amounted to over 5 g. Remaining grades of tested cast iron show decrease below 1 g during abrasion cycle. The change of their mass decrease is shown in Fig. 7b. During first 90 minutes of the test there was the period of the most intense increase of wear for all kinds of tested cast iron.

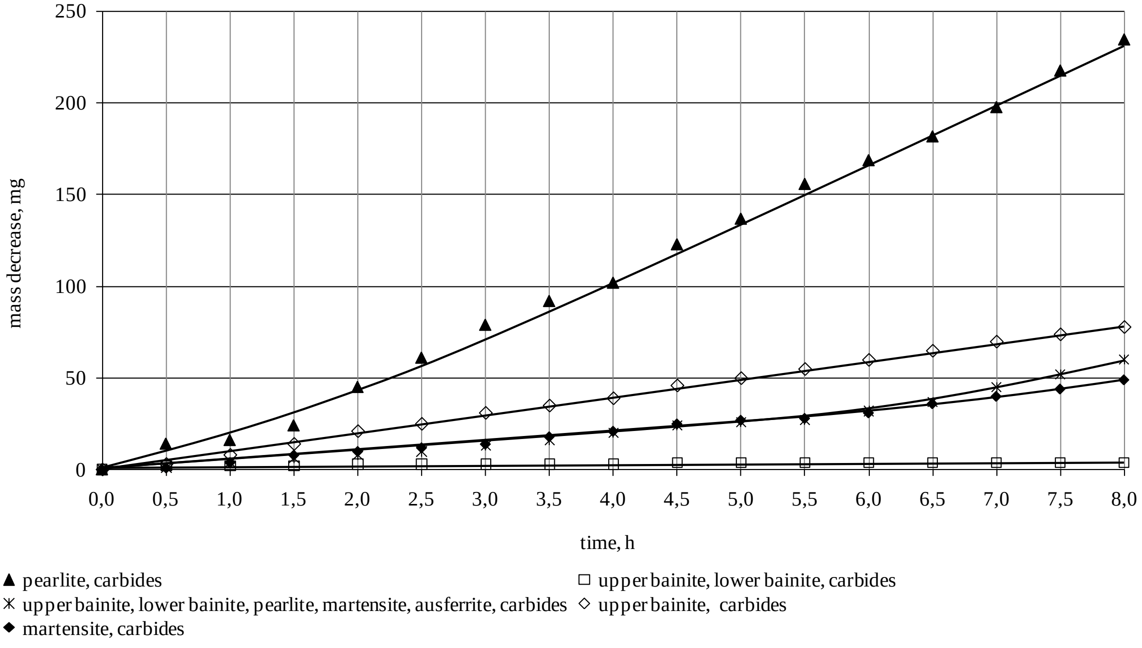
Nodular cast iron with carbides and with upper and lower bainite is the most abrasion resistant material. The mass decrease after 8 h abrasion cycle do not exceeded 0,4 g.

In Figure 8 (a ÷ c) results of adhesive wear of nodular cast iron with carbides mating with C55 steel after normalizing (a), hardening and low-temperature tempering (b), sulfonitriding (c) are presented.

a)


mass decrease, mg
70
60
50
40
30
20
10
0
0,0 0,5 1,0 1,5 2,0 2,5 3,0 3,5 4,0 4,5 5,0 5,5 6,0 6,5 7,0 7,5 8,0
time, h
upper bainite, lower bainite, pearlite, martensite, ausferrite, carbides
upper bainite, lower bainite, carbides
upper bainite, carbides
martensite, carbides

b)


mass decrease, mg
250
200
150
100
50
0
0,0 0,5 1,0 1,5 2,0 2,5 3,0 3,5 4,0 4,5 5,0 5,5 6,0 6,5 7,0 7,5 8,0
time, h
pearlite, carbides
upper bainite, lower bainite, carbides
upper bainite, lower bainite, pearlite, martensite, ausferrite, carbides
upper bainite, carbides
martensite, carbides

c)

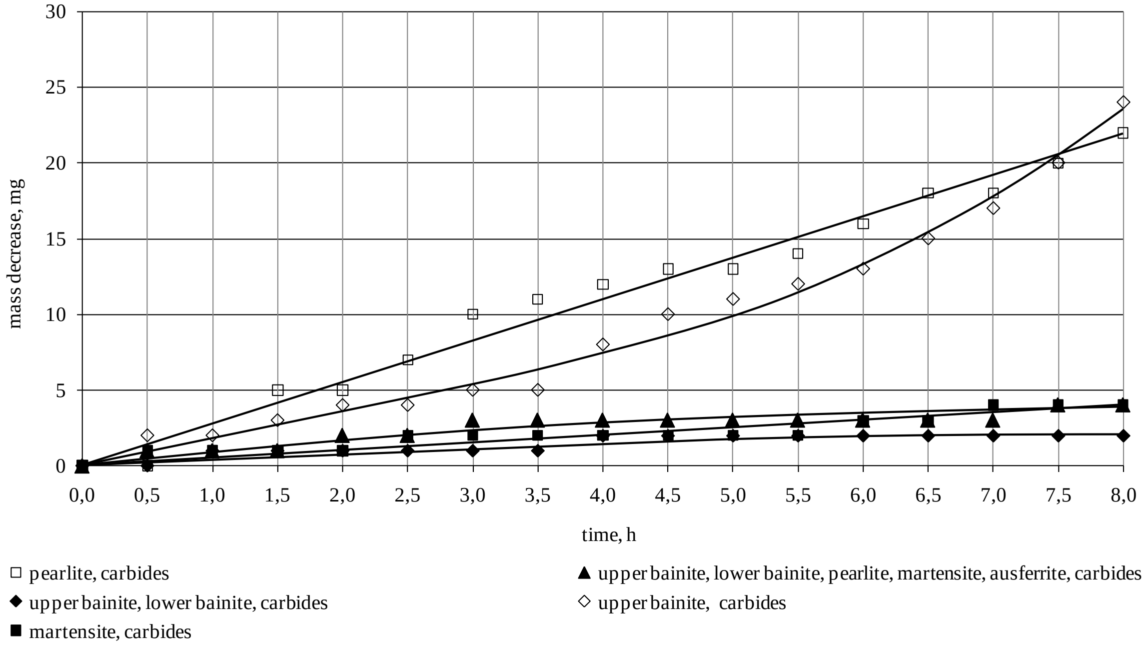


Fig. 8 (a, c). Adhesive wear of tested kinds of nodular cast iron with carbides mating with counter-specimens made of C55 steel after: normalizing (a), hardening and low-temperature tempering (b), sulfonitriding (c)

In Fig. 8a broken line means very intense adhesive wear of specimen made of pearlitic nodular cast iron with carbides. Its mass decrease after 1,5 h amounted to over 16,5 g and it was about to three orders of magnitude greater than remaining kinds of tested cast iron.

From comparison remaining kinds of cast iron results, that the greatest adhesive wear during the mating with normalized steel shows cast iron with upper bainite. The least mass decrease shows cast iron with metal matrix microstructure consists of: upper bainite, lower bainite, pearlite, martensite, ausferrite and carbides. It does not exceeded 30 mg after 8 h of the test. Moreover for this kind of cast iron increase of mass decrease reduced during last two hours of the test. Similar character of wear shows martensitic cast iron with carbides. The mass decrease of the rest kinds of cast iron was approximately uniform during the test.

From Fig. 8b results, that hardened steel with nodular cast iron with carbides and the mixture of upper and lower bainite is the most advantageous friction pair. The wear of specimen made of this kind of cast iron was minimal and does not exceeded 4 mg after 8 h of the friction.

Hardened steel and pearlitic cast iron with carbides was the least advantageous friction pair. The mass decrease of this cast iron was uniform and exceeded 230 mg after 8 h of the test.

Martensitic cast iron and cast iron with the mixture of an upper and lower bainite, pearlite, martensite, ausferrite and carbides shows nearly identical adhesive wear during the test.

From Fig. 8c results, that pearlitic cast iron and cast iron with upper bainite mating with sulfonitrided steel show the greatest mass decrease. It was uniform for pearlitic cast iron but for bainitic it increased. The rest kinds of cast iron show similar character of adhesive wear decreasing during the test. Simultaneously it was slight and amounted to maximum 4 mg for martensitic cast iron and cast iron with the mixture of an upper and lower bainite, pearlite, martensite, ausferrite and carbides and 2 mg for cast iron with upper and lower bainite.

4. Conclusions

Results have indicated the following:

- nodular cast iron with carbides with the metal matrix consists of upper and lower bainite is the most abrasive resistant material among tested kinds of cast iron,
- the least abrasive and adhesive wear resistance has pearlitic nodular cast iron with carbides,
- pearlitic nodular cast iron with carbides shows nearly implosive wear during mating with normalized steel,
- nodular cast iron with carbides with the metal matrix consists of upper and lower bainite makes the most advantageous friction pair with hardened and sulfonitrided steel.

Acknowledgements

Scientific project financed from means of budget on science in years 2009 ÷ 2012 as research project N508 411437.

References

[1] Pietrowski S., Gumienny G., Crystallization of nodular cast iron with carbides, Archives of Foundry Engineering. 2008 Vol. 8, Issue 4/2008, p. 236-240.

[2] Pietrowski S., Gumienny G., Nodular cast iron with carbides, Archives of Foundry Engineering, No 19, 2006, p. 233-238 (in Polish).

[3] Pietrowski S., Gumienny G., Bainite obtaining in cast iron with carbides castings, Archives of Foundry Engineering, 2010 Vol. 10, Issue 1, p. 109-114.

[4] Pietrowski S., Gumienny G., Crystallization of nodular cast iron with additions of Mo, Cr, Cu and Ni, Archives of Foundry Engineering, No 22, 2006, p. 406-413 (in Polish).

[5] Pietrowski S., Gumienny G., Bainite obtaining in cast iron with carbides castings, Archives of Foundry Engineering, 2010 Vol. 10, Issue 1, p. 109-114.

[6] Gumienny G., Bainitic-martensitic nodular cast iron with carbides, Archives of Foundry Engineering, 2010 Vol. 10, Issue 2, p. 63-68.

[7] Gumienny G., Chromium and copper influence on the nodular cast iron with carbides microstructure, Archives of Foundry Engineering, 2010 Vol. 10, Issue 4, p. 47-54.

[8] Gumienny G., Wear resistance of cast iron, Archives of Foundry Engineering, 2008 Vol. 8, Issue 3, p. 173-180.