sciendo CzOTO 2020, volume 2, issue 1, pp. 191-198

CORROSION RESISTANCE OF SiMo- AND SiCu-TYPES OF NODULAR CAST IRON IN NaCl SOLUTION

doi: 10.2478/czoto-2020-0023
Date of submission of the article to the Editor: 13/11/2019
Date of acceptance of the article by the Editor: 3/02/2020

Alan Vaško[1] – *orcid id: 0000-0002-3937-2691*
Viera Zatkalíková[1] – *orcid id: 0000-0003-1924-3785*
Václav Kaňa[2] – *orcid id: 0000-0003-4870-1749*
[1]University of Žilina, **Slovakia**, *alan.vasko@fstroj.uniza.sk*
[2]Brno University of Technology, **Czech Republic**

Abstract: Nodular cast irons are used in a wide range of industrial applications, especially in the automotive industry. SiMo-type of nodular cast iron is suitable for high-temperature applications, for example the exhaust manifolds of the combustion engines; SiCu-type of nodular cast iron is used in various components of tribotechnical units. These automotive components often work in a corrosive environment. Therefore, the aim of this paper is to compare the corrosion resistance of two types of the nodular cast irons (SiMo-type and SiCu-type). Corrosion resistance was determined by the exposure immersion test at ambient temperature. Specimens of both types of nodular cast iron were immersed in 3.5 % NaCl solution (to simulate sea water) and gradually removed from the solution after 1, 2, 4 and 8 weeks. Subsequently, the weight loss (g) and the average corrosion rate (g m^{-2} day^{-1}) were calculated. Experimental results show that nodular cast iron alloyed by Si and Mo has higher corrosion resistance than the nodular cast iron alloyed with Si and Cu. Moreover, the mechanical properties (evaluated by tensile test, impact bending test and hardness test) and fatigue properties of both types of nodular cast iron has been compared in the paper.
Keywords: nodular cast iron, corrosion, exposure immersion test, NaCl solution

1. INTRODUCTION

A technological progress in various fields of industry, including the automotive industry, brings high requirements on durability of devices or components, and it is also an inspiration for the use of new materials and technologies to protect materials working in an aggressive environment. Total elimination of a negative effect on corrosion processes on surface of components is impossible but it can be minimized by selecting a suitable material or by changing the chemical composition and structure of the material (Zatkalíková, 2019).

Nodular cast iron is a material that has found an increasing number of applications in the automotive industry during the last decades. It has a static strength comparable to cast steels and a greater tensile strength, fatigue strength and ductility than grey cast irons. Castability and machinability are good, and all these properties makes it an economic alternative for medium stressed components and for safety critical applications. When nodular cast iron is substituted for cast steel, it is possible to achieve a cost reduction of the components by 30 % or more (Hamberg, 1997). However, other properties of products from nodular cast iron, such as a corrosion resistance, are also important (Mehra, 2002; Ajeel, 2008; Haleem, 2011; Ogundare, 2012).

In the automotive industry, nodular cast irons can be used for engine blocks, gearboxes, turbo charger housings, crank shaft, pistons and piston rings, brake disks and drums, exhaust manifolds and various other automotive components. Many of these components are exposed to corrosion effect of external environment (Rajadurai, 2014). Two types of nodular cast iron (SiMo-type and SiCu-type) were used for the experiments with the aim to determine their corrosion resistance in salt water.

2. METHODOLOGY OF RESEARCH

For experiments, two types of nodular cast irons were used:

- SiMo-type of nodular cast iron, alloyed by 4 % of silicon and 1 % of molybdenum, which corresponds to EN-GJS-X300SiMo4-1;
- SiCu-type of nodular cast iron, alloyed by 4 % of silicon and 1.5 % of copper, which corresponds to EN-GJS-X300SiCu4-1.5.

Both types of nodular cast irons were melted in an electric induction furnace and cast into sand molds in the shape of Y blocks.

Charge composition of the melts is given in Table 1. The basic charge of the melts consisted of 27 kg steel, 20 kg pig iron and additives for the regulation of chemical composition, i.e. carburizer, ferrosilicon FeSi75, ferromolybdenum FeMo65 or copper. The content of these additives was chosen to achieve required chemical composition of the melts and eutectic degree approximately $S_C \approx 1.0$. The sandwich method in a ladle was used for modification and inoculation. FeSiMg7 modifier was used for modification and FeSi75 inoculant was used for inoculation. Resultant chemical composition of the melts is given in Table 2.

Table 1
Charge composition of the melts

Type GJS-	Charging raw materials (kg)						Modification & inoculation		
	steel	**pig iron**	**carbu rizer**	**FeSi75**	**FeMo65**	**Cu**	**modifier FeSiMg7**	**inocu-lant FeSi75**	**cover sheet**
SiMo	27	20	1.2	2.1	1.1		0.5	0.4	3
SiCu	27	20	1.1	2.1		0.7	0.5	0.4	3

Table 2
Chemical composition of the melts

Type GJS-	Content of chemical elements (weight %)								
	C	**Si**	**Mn**	**P**	**S**	**Mo**	**Cu**	**Ni**	**Mg**	**S_C**
SiMo	3.021	4.094	0.376	0.026	0.032	0.938	0.115	0.059	0.039	1.002
SiCu	3.281	4.156	0.363	0.028	0.037	0.009	1.394	0.055	0.049	1.096

Test specimens for structural analysis, mechanical, fatigue and corrosion tests were machined from the Y blocks.

The corrosion resistance of nodular cast irons was evaluated by the exposure immersion test at ambient temperature. The principle of this test consists in immersing specimens into a suitable solution, applying the corrosive environment for a period of time and removing specimens from the solution. Subsequently, the weight loss of the specimens is determined and, after recalculation per unit area and unit of time, the corrosion rate is determined (Fontana, 1987; Baboian, 1995; Revie, 2008).
Twelve specimens were produced from both types of nodular cast iron. The shape and dimensions of the specimens are shown in Fig. 1. The surface of the specimens was prepared by grinding, polishing and finally degreased by ethanol. Before the test, the specimens were weighted out (m_1) using a Mettler Toledo XS205 analytical balance with an accuracy of ± 0.000 01 g. A 3.5 % NaCl solution was used to simulate sea water. The specimens were suspended on the holder using insulated wires and immersed into the solution (Fig. 2). They were left in the solution for 1, 2, 4 and 8 weeks. After the required time, 3 specimens of both types of nodular cast iron were removed from the solution. Subsequently, the specimens were cleaned, washed by demineralized water and ethanol, dried up and weighted out (m_2) again using the analytical balance. The weight loss was determined from the weights before and after the test ($\Delta m = m_1 - m_2$). Then, the average corrosion rate was calculated from the weight loss during the exposure immersion test (Hadzima, 2008; Zatkalíková, 2014).

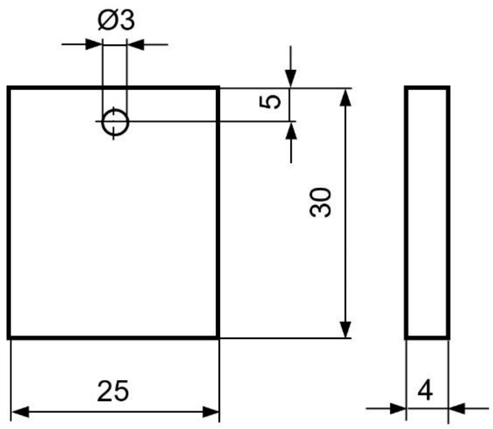


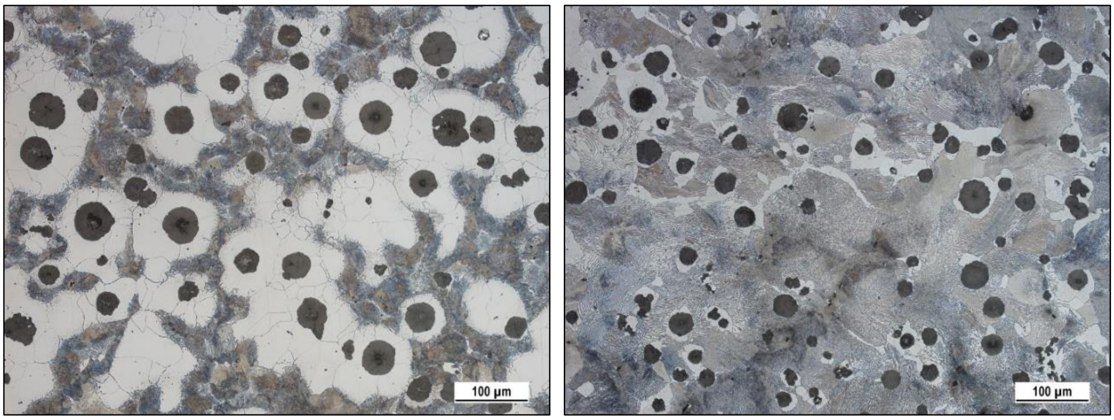
Fig. 1. Shape and dimensions of the specimen for exposure immersion test

a) start of the test b) test after 1 week

Fig. 2. Exposure immersion test

3. RESULTS AND DISCUSSION

From a microstructural point of view, the specimen of GJS-SiMo is ferrite-pearlitic nodular cast iron (Fig. 3a) and the specimen of GJS-SiCu is pearlite-ferritic nodular cast iron (Fig. 3b). The microstructure of the specimens was evaluated according to STN EN ISO 945 (STN 42 0461) and by automatical image analysis using NIS Elements software (shape factor, equivalent diameter of graphite, count of graphitic nodules per unit area and content of ferrite). Results of this evaluation are given in Table 3.



a) GJS-SiMo, ferrite-pearlitic nodular cast iron

b) GJS-SiCu, pearlite-ferritic nodular cast iron

Fig. 3. Microstructure of the specimens

Content of ferrite in the specimen of GJS-SiMo is higher than in the specimen of GJS-SiCu because of pearlitizing effect of copper. Graphite occurs predominantly in a perfectly-nodular shape therefore shape factor of graphite is approximately the same in both specimens. Size of graphite in the specimen of GJS-SiCu is smaller than in the specimen of GJS-SiMo but an average count of graphitic nodules in the specimen of GJS-SiCu is higher than in the specimen of GJS-SiMo. Different microstructure is caused by different chemical composition.

Table 3
Microstructure of the specimens

Type GJS-	Microstructure (according to STN EN ISO 945)	Shape factor	Equivalent diameter of graphite (μm)	Count of graphitic nodules (mm^{-2})	Content of ferrite (%)
SiMo	90%VI6 + 10%V6 – Fe80	0.88	31.2	122.8	59.4
SiCu	90%VI6/7 + 10%V6 – Fe15	0.84	24.3	172.4	19.7

These differences in the microstructure also brought different mechanical properties. Results of mechanical tests (tensile test, impact bending test and Brinell hardness test) are presented in Table 4. The specimen of GJS-SiCu has higher yield strength $R_{p0,2}$, tensile strength R_m and Brinell hardness HBW, but lower elongation A and absorbed energy K0 than the specimen of GJS-SiMo. It has connection with the microstructure of the specimens, especially with the character of matrix (content of ferrite and pearlite) and also with size of graphite and count of graphitic nodules.

The fatigue tests were carried out at low frequency sinusoidal cyclic push-pull loading (frequency f ≈ 75 Hz). The value of fatigue strength σ_c is dependent on tensile strength R_m (fatigue strength increases with increasing tensile strength) therefore the specimen of GJS-SiCu has higher fatigue strength than the specimen of GJS-SiMo (Vaško, 2019).

Table 4
Mechanical and fatigue properties of the specimens

Type GJS-	$R_{p0,2}$ (MPa)	R_m (MPa)	A (%)	K0 (J)	HBW 10/3000/10	σ_c (MPa)
SiMo	515.3	573.9	1.4	11.3	213.7	210
SiCu	631.1	652.7	0.7	8.0	247.3	270

After the exposure immersion test, all specimens were attacked by corrosion. An example of corrosion on the surface of specimens is shown in Fig. 4.

a) before the test b) after 2 weeks c) after 8 weeks
Fig. 4. Corrosion on the surface of specimens of GJS-SiMo

Results of the exposure immersion test (weight loss and corrosion rate) are given in Table 5. Twelve specimens from both types of nodular cast iron (GJS-SiMo and GJS-SiCu) were immersed in a 3.5 % NaCl solution for 1, 2, 4 and 8 weeks. After the required time, 3 specimens (A, B, C) from both types of nodular cast iron were removed from the solution. Then, the weight loss and corrosion rate were calculated. The dependence of the average corrosion rate on the test duration is shown in Fig. 5.
The average corrosion rate, recalculated per m^2 and day, decreases with increasing test duration for both types of nodular cast iron. The specimens of GJS-SiMo have a lower average corrosion rate than the specimens of GJS-SiCu. This dependence confirms a higher corrosion resistance of nodular cast iron alloyed by Si and Mo compared to nodular cast iron alloyed by Si and Cu.

Table 5
Results of the corrosion test

Type GJS-	Specimen No.	Weight before m_1 (g)	Weight after m_2 (g)	Weight loss Δm $m_1 – m_2$ (g)	Corrosion rate (g m^{-2} day^{-1})	Average corrosion rate (g m^{-2} day^{-1})
SiMo	1A	24.13221	24.11346	0.01875	1.39084	1.40790
	1B	23.72329	23.70365	0.01964	1.45686	
	1C	24.02229	24.00374	0.01855	1.37601	
	2A	24.68222	24.64003	0.04219	1.56479	1.40123
	2B	23.04002	23.00519	0.03483	1.29181	
	2C	24.56585	24.52953	0.03632	1.34708	
	4A	23.93264	23.85575	0.07689	1.42589	1.35128
	4B	24.59251	24.52107	0.07144	1.32482	
	4C	23.01357	22.94330	0.07027	1.30313	
	8A	24.20693	24.07879	0.12814	1.18815	1.22218
	8B	23.00772	22.87922	0.12850	1.19149	
	8C	23.94685	23.80806	0.13879	1.28690	
SiCu	1A	27.22933	27.20642	0.02291	1.53665	1.48165
	1B	27.73878	27.71722	0.02156	1.44610	
	1C	27.24078	27.21898	0.02180	1.46220	
	2A	27.48078	27.43623	0.04455	1.49406	1.46768
	2B	27.99161	27.94747	0.04414	1.48031	
	2C	27.47223	27.42963	0.04260	1.42866	
	4A	27.20423	27.11584	0.08839	1.48215	1.43051
	4B	27.92094	27.83820	0.08274	1.38741	
	4C	25.74916	25.66436	0.08480	1.42196	
	8A	27.36995	27.21596	0.15399	1.29108	1.28644
	8B	26.02802	25.87929	0.14873	1.24698	
	8C	28.48367	28.32608	0.15759	1.32126	

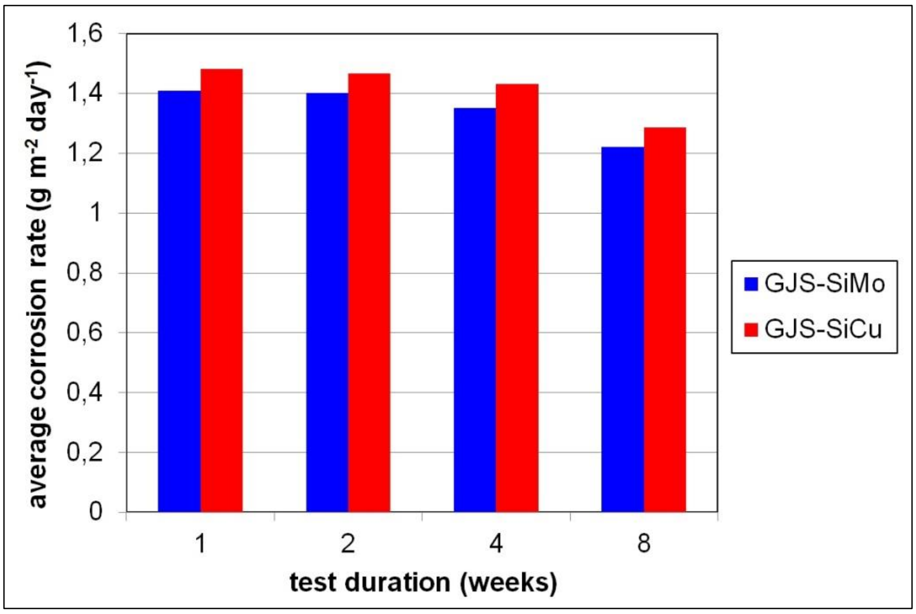


Fig. 5. Dependence of the average corrosion rate on the test duration

4. CONCLUSION

Chemical composition of the melts influences microstructure, mechanical and fatigue properties as well as corrosion resistance of nodular cast iron.

The experimental results can be summarized to the following points:

- nodular cast iron alloyed by Si and Cu (GJS-SiCu) has higher content of pearlite (because of pearlitizing effect of copper), smaller size of graphite and higher average count of graphitic nodules than nodular cast iron alloyed by Si and Mo (GJS-SiMo);
- SiCu-nodular cast iron has higher yield strength, tensile strength, hardness and fatigue strength but lower elongation and absorbed energy than SiMo-nodular cast iron;
- SiMo-nodular cast iron has lower average corrosion rate than SiCu-nodular cast iron; the corrosion resistance of SiMo-nodular cast iron is 5 % higher than that of SiCu-nodular cast iron.

ACKNOWLEDGEMENTS

The research has been supported by the Scientific Grant Agency of Ministry of Education, Science, Research and Sport of Slovak Republic, grant project VEGA No. 1/0398/19 and by the Culture and Educational Grant Agency of Ministry of Education, Science, Research and Sport of Slovak Republic, grant projects KEGA No. 049ŽU-4/2017 and 012ŽU-4/2019.

REFERENCES

Ajeel, S.A., Hasoni, S.M., 2008. *Ductile and gray cast irons deterioration with time in various NaCl salt concentrations*, Engineering and Technology Journal, 26(2), 154-168.

Baboian, R., 1995. *Corrosion Test and Standards: Aplication and Interpretation*, ASTM Manual Series, Philadelphia.

Fontana, M. G., 1987. *Corrosion Engineering*, 3rd Edition, McGraw-Hill, Singapore.

Hadzima, B., Liptáková, T., 2008. *Základy elektrochemickej korózie kovov*, EDIS, Žilina.

Haleem, A. H., Jabar, F., Mohammed, N., 2011. *Corrosion behavior of cast iron in different aqueous salt solutions*.

Hamberg, K., Johannesson, B., Robertson, A., 1997. *Defect sensitivity in nodular cast iron for safety critical components*, European Structural Integrity Society, 22, 37-47.

Mehra, R., Soni, A., 2002. *Cast iron deterioration with time in various aqueous salt solutions*, Bulletin of Materials Science, 25(1), 53-58.

Ogundare, O., Babatope, B., Adetunji, A. R., Olusunle, S. O. O., 2012. *Atmospheric corrosion studies of ductile iron and austenitic stainless steel in an extreme marine environment*, Journal of Minerals and Materials Characterization and Engineering, 11, 914-918.

Rajadurai, S., Afnas, M., Ananth, S., Surendhar, S., 2014. *Materials for automotive exhaust system*, International Journal of Recent Development in Engineering and Technology, 2(3), 82-89.

Revie, R. W., Uhlig, H. H., 2008. *Corrosion and corrosion control: An introduction to corrosion science and engineering*, 4th Edition, John Wiley & Sons, New Jersey.

Vaško, A., Krynke, M., 2019. *Fatigue properties of nodular cast irons alloyed by Si, Mo and Cu*, CzOTO 2019, 1(1), 738-744.

Zatkalíková, V., Markovičová, L., Belan, J., Liptáková, T., 2014. *Variability of local corrosion attack morphology of AISI 316Ti stainless steel in aggressive chloride environment*, Manufacturing Technology, 14(3), 493-497.

Zatkalíková, V., Markovičová, L., Wróbel-Knysak, A., 2019. *Corrosion properties of 1.4512 ferritic and 1.4404 austenitic steels for the automotive industry*, CzOTO 2019, 1(1), 745-752.