GRAPHITE CAST IRONS SUITABLE FOR APPLICATIONS IN THE AREA OF HYDRAULIC MACHINES

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Abstract

This paper assesses the possibilities of graphitic cast iron parts and components of hydraulic turbines. The experimental program evaluated the behavior of spheroidal and vermicular graphite under conditions which simulated challenging work environment hydraulic machines. Five different graphitic irons allowed to assess the influence of the chemical composition, structure, basic metal matrix and character of graphite (shape, size and distribution) to the overall degradation of the material. The intensity of the damage was evaluated by testing the erosive wear, corrosion tests and metallographic analysis. Mechanical properties were verified by a tensile test, impact bending at room temperature and hardness test. The results confirmed the assumption that in achieving the appropriate structure, can spheroidal graphite cast respect predominant degradation mechanism of specific water machines and can be a suitable alternative to frequently used stainless steels.

Keywords: Graphitic cast iron, hydraulic turbines, erosion, abrasion, corrosion

1. INTRODUCTIONS

Working environment and conditions significantly affect the durability, reliability and safety of water facilities. Material degradation is a result of a synergy effect of different factors of which the most important are the corrosive environment and the dynamic effects of the flowing medium. The overall degradation of the material is then influenced by different degree by abrasion-erosive wear, corrosion damage and cavitation wear. Therefore during a material selection, it is necessary to take into account both dimensional and performance parameters of the turbine and the conditions of its operation and a dominant degradation process. Traditional, in practice verified materials used for the water machines are high-alloyed corrosion resistant steels. However, constantly increasing economic demands also require the use of cheaper materials, from which a modified graphite cast iron offers great possibilities.

2. EXPERIMENTAL MATERIALS AND METODS

2.1. Experimental materials

The experimental program was carried out on different types of graphite cast iron, which varied in chemical composition (**Table 1**), character of the graphite particles and metal matrix structure.

Table 1 Chemical composition of graphite cast irons [wgt.%]

Material	C	Si	Mn	S	P
LKG - M	2.82	2.44	0.31	<0.01	0.02
LKG - Ž	2.95	2.35	0.11	0.01	0.04
LKG - ADI	Chem. composition is based on LKG - Ž cast iron				
LVG - Ž	2.26	2.61	0.14	0.01	0.03
LVG - AL	3.02	2.29	0.16	0.05	0.04

Attention was focused on spheroidal graphite cast iron (LKG - M, LKG - Ž), vermicular graphite cast iron (LVG - Ž, LVG - AL) and cast iron LKG - Ž austempered into condition of ADI (LKG - ADI) - [1]. The reference material used to compare the results of other graphite cast irons was spheroidal graphite cast iron (marked as LKG - M), which is already used in practice in the production of water turbine blades.

2.2. Experimental metods

Samples of examined cast irons intended for the microstructure observation using Neophot 32 light microscope samples were prepared by a standard metallographic procedure. In order to make the individual components of the structure visible, the Nital (2%) etchant was used. Evaluation of graphite in etched and unetched samples was in accord with ČSN ISO 945-1 standard. The mechanical properties of the examined cast iron, strength and plastic characteristics were determined by a tensile test using INSTRON 5582 (100 kN) tensile testing machine at ambient temperature according to CSN EN ISO 6892-1 on rod test-pieces with a diameter of 6 mm with a thread. Cast iron hardness was measured by a Brinell method according to CSN EN ISO 6507. Wear evaluation took place in a specially designed and constructed testing device simulating abrasive-erosive wear of water turbines blades. The conditions of the test (shape and location of the test samples, revolutions per minute, abrasive particles concentration, test duration, etc..) were constant in case of all examined cast irons. Weight loss (referred to the starting weight and expressed as a percentage) of each sample was determined. Also wear character of each sample was documented using the stereomicroscope Nikon SMZ 1500 - [2, 3]. To evaluate the corrosion resistance a immersion exposure corrosion test which determined the corrosion rate of the individual cast irons was used. The test conditions were identical for all evaluated materials. Measurements were carried out in a mineralized drinking water, in which the pH factor was adjusted to 5, 6 and 8 corresponding to values of the working environment of water machines. Measurements were also complemented by a metallurgical evaluation of corrosion - [3, 4, 5]

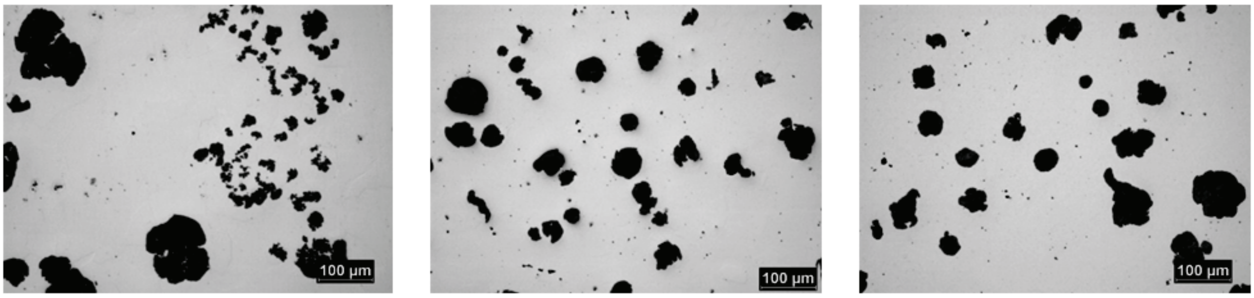
3. RESULTS AND DISCUSSION

The results of metallographic analysis of graphite in polished state and determining the ratio of structural components in etched state of evaluated cast irons are summarized in **Table 2**. The nature of graphite particles is documented in **Fig. 1** revealing deviations from the perfectly spheroidal shaped or vermicular graphite. Structural components are shown in **Fig. 2** showing the distribution of ferrite and pearlite in the metallic matrix - with the exception of the bainite structure in austempered cast iron LKG - ADI. The last column of **Table 2** shows the proportion of pearlite in the matrix.

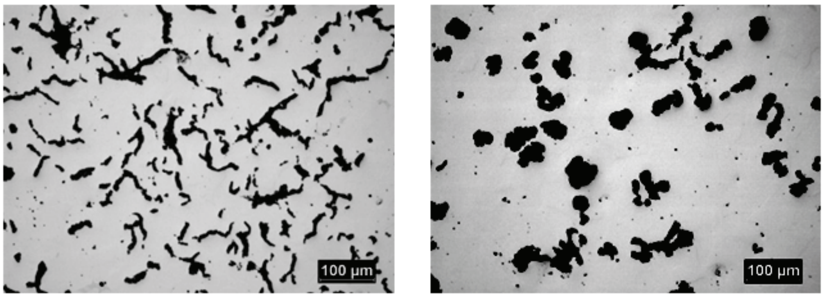
Table 2 Evaluation of cast irons structures in unetched and etched state according to ČSN ISO 945-1

Material	Graphite form (form percentage)	Graphite distribution	Graphite size (Dimensions in mm)	Pearlite proportion in the matrix
LKG - M	V+VI (50:50)	A	0.06 to 0.12	57%
LKG - Ž	V+VI (30:70)	A	0.03 to 0.12	86%
LKG - ADI	V+VI (30:70)	A	0.03 to 0.12	100% bainit
LVG - Ž	III	A		33%
LVG - AL	III+V (85:15)	A		38%

III - vermicular, V - imperfectly spheroidal, VI -spheroidal, A - uniform

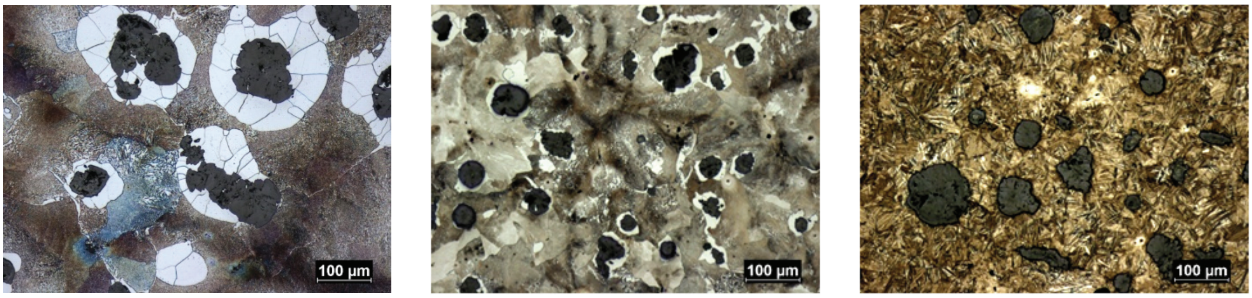


a) LKG - M b) LKG - Ž c) LKG - ADI

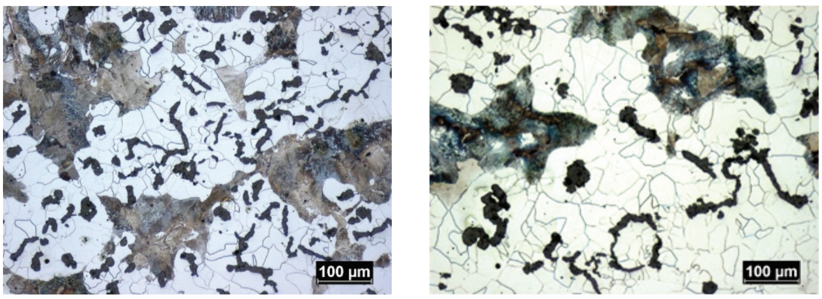


d) LVK - Ž e) LVG - AL

Fig. 1 Shape, size and distribution of graphite particles in examined cast irons, unetched state



a) LKG - M b) LKG - Ž c) LKG - ADI



d) LVK - Ž e) LVG - AL

Fig. 2 Microstructure of examined cast irons, etched state

The description of the structure correlates well with the values of mechanical properties obtained by the tensile test and hardness test **(Table 3)**. The highest values were measured on austempered cast iron LKG - ADI whose metal matrix consists of lower bainite. Mechanical values of cast irons in the initial state are affected by both the amount of ferrite in the metal matrix and the shape of the graphite. Tensile strength and hardness vales are higher in case of nodular cast iron, where cast iron LKG - M has lower values compared to LKG - Ž because of greater amount of imperfect spheroidal graphite and occurrence of Chunky graphite rich areas in the structure - [6].

Table 3 Measured mechanical properties

Material	Tensile strength Rm [MPa]	Ductility A [%]	HardnessHBW
LKG - M	481	5,2	107
LKG - Ž	684	4,8	227
LKG - ADI	1510	1,8	475
LVG - Ž	312	3,6	126
LVG - AL	342	3,8	178

The structure and thus the mechanical properties of the evaluated cast irons affect the process of wear. The values obtained during the carried out tests simulating abrasion-erosion wear are shown in **Fig. 3**. Character of the weight loss is similar in case of all tested materials. It can be stated that the more ferrite is present in the structure, the higher is the wear. Important factor is also the form of the graphite. Spheroidal graphite cast irons better withstand the wear mechanism when compared to vermicular cast irons throughout the whole duration of the test (15 hours). The exception is the LKG - M cast iron whose wear resistance is lowered by the presence of the above-mentioned Chunky graphite in the structure. Austempering of the LKG - Ž cast iron into ADI cast iron (LKG - ADI) with a bainite matrix led to a deterioration of wear resistance. As a demonstration, the sample of the LKG - M cast iron before and after the wear test is documented in **Fig. 4.** Wear character of the other materials is identical.

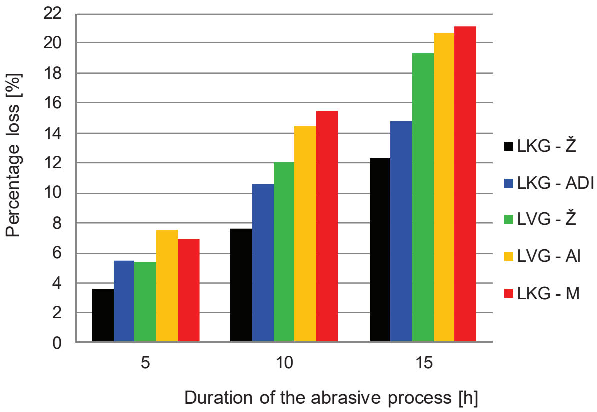


Fig. 3 Percentage of weight loss of evaluated cast irons during the course of wear test

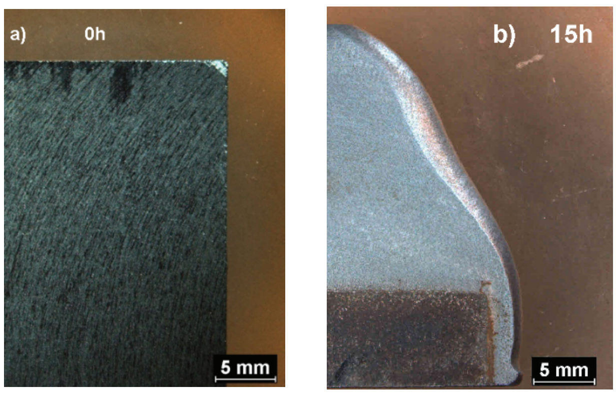


Fig. 4 Appearance of the LKG - M cast iron sample in the beginning (a) and at the end (b) of the wear test

With regard to the fact that corrosion is considered very significant degradation mechanism, much attention was focused on corrosion resistance. The values of corrosion rate, measured using the immersion exposure tests at three different pH values are given for the individual cast irons in **Fig. 5**. From the figure it is apparent that the corrosion rate decreases with increasing pH factor in case of materials LKG - Ž and LVG - Ž. Materials LKG - M and LVG - AL show that during the increase of the liquid´s pH the corrosion rate decreases at first and increases. Heat treated LKG - ADI cast iron exhibits almost constant corrosion rate for all pH values. The corrosion process is slower in the environment with pH 5 and pH 6.8 in case of the vermicular LVG - AL cast iron. In the environments with pH 8 the slowest corrosion occurs at LVG - Ž cast iron. The resulting corrosion attack is apparent from the structures in **Fig. 6**. The corrosion attack is localized in graphite areas, being more distinct in nodular cast irons.

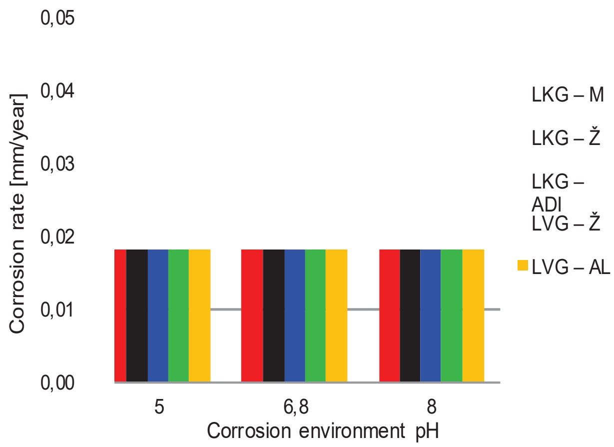
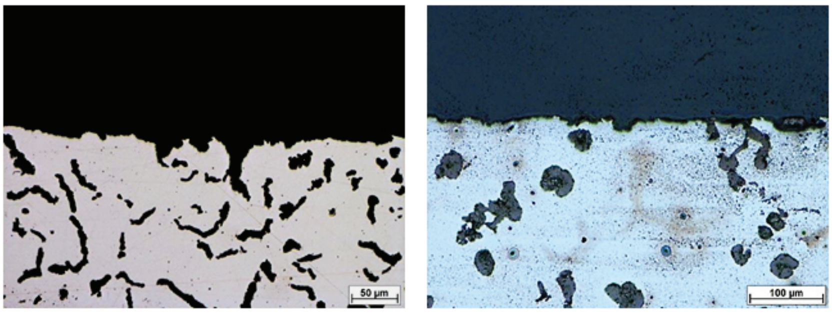


Fig. 5 Corrosion rates of examined cast irons in environments with different pH

a) LKG - M b) LKG - Ž c) LKG - ADI



d) LVK - Ž e) LVG - AL

Fig. 6 Metallographic evaluation of the sample surface after corrosion resistance test

4. CONCLUSION

Modification of the structure and morphology of graphite made on the examined materials may help to improve the properties of graphite cast irons. When used in environments where corrosion is the dominant damage process, it is necessary to respect the pH factor and it will be more convenient to use a vermicular cast iron. In the case of abrasion-erosion degradation the spheroidal graphite cast iron will be more suitable. It is always necessary to keep the volume fraction of ferrite, pearlite and graphite in the structure, also the size, distribution and especially form of graphite particles in both types of cast irons. All proposed cast irons (LKG - Ž, LKG - ADI, LVG - Ž and LVG - AL) achieve in overall better performance than LKG - M cast iron used in practice.

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