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The Assessment of Resistance to Thermal Fatigue and Thermal Shock of Cast Iron Used for Glass Moulds

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Abstract

Constantly developing production process and high requirements concerning the quality of glass determine the need for continuous improvement of tools and equipment needed for its production. Such tools like forms, most often made of cast-iron, are characterized by thick wall thickness compared to their overall dimensions and work in difficult conditions such as heating of the surface layer, increase of thermal stresses resulting from the temperature gradient on the wall thickness, occurrence of thermal shock effect, resulting from cyclically changing temperatures during filling and emptying of the mould.

There is no best and universal method for assessing how samples subjected to cyclic temperature changes behave. Research on thermal fatigue is a difficult issue, mainly due to the instability of this parameter, which depends on many factors, such as the temperature gradient in which the element works, the type of treatment and the chemical composition of the material. Important parameters for these materials are at high temperature resistance to thermal shock and thermal fatigue what will be presented in this paper.

Keywords: Thermal shock, High temperature parameters, Cracking, Cast iron, Production of glass

1. Introduction

Historically, the first people who mastered the technology of making cast iron were the Chinese. Iron obtained in crucible furnaces and shaft, and the obtained alloy was close to white cast iron, which then was annealed [1]. It is assumed that Europeans have reached their own path to the ability to make cast iron. The cradle of cast iron in Europe are territories on the outskirts of Germany, France, Italy and Switzerland. Cast iron was smelted there already in the fifteenth century and hence this ability spread throughout Europe [2]. Nowadays cast iron, although it is well known as a construction material, still has great potential as evidenced by publications both domestic and foreign [3-10]. An important area for the use of cast iron is the glass industry. Currently, glass is used in almost every sphere of our lives. It is found not only in the form of packaging or decorations, but also as a construction material. Due to such mass production and impeccable quality of products, the expectations for foundry moulds used in the production of glass are enormous. These forms, most often made of cast-iron, are characterized by thick wall thickness compared to their overall dimensions as well as difficult working conditions such as:

– heating of the surface layer to temperatures above 700ºC,
– increase of thermal stresses resulting from the temperature gradient on the wall thickness,
– occurrence of thermal shock effect, resulting from cyclically changing temperatures during filling and emptying of the mould.

In addition, glass forms require, for example, no tendency to adhere glass mass, low tendency to grow at elevated temperatures or resistance to mechanical wear. All these features and problems resulting from mass production in difficult conditions show that it is not possible to obtain glass forms that meet all the requirements set for them at an equally high level. Thermal fatigue is a phenomenon studied for about 200 years. Many works have been created on this subject, however, there is still no clear solution to this problem. There is no best and universal method for assessing how samples subjected to cyclic temperature changes behave. Research on thermal fatigue is a difficult issue, mainly due to the instability of this parameter, which depends on many factors, such as the temperature gradient in which the element works, the type of treatment and the chemical composition of the material [11-13]. Resistance to thermal shock is particularly important for materials working as moulds for casting glass.

2. Research material and methodology

The material for the researches were two types of cast iron ductile and grey, whose chemical compositions are presented in Table 1. The choice of material was not accidental because the materials used for casting moulds for the production of bottles were analyzed as grey cast iron was previously used and now it has been replaced by ductile cast iron. The material was melted in electric arc furnace by one of by one of the national foundry and the material was cast into sand molds. Forms before work are relaxed. The authors do not have knowledge about other possible heat treatment treatments performed by the manufacturer before delivery to the recipient.

Table 1.
Chemical composition of the examined materials wt.%

Ductile cast iron									
C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Ti**	**Mg**
3,57	2,00	0,60	0,03	0,04	0,20	0,75	0,70	0,1	0,05
Grey cast iron									
C	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**	**Ti**	**Cu**
3,65	1,74	0,59	0,03	0,03	0,11	0,40	0,13	0,1	0,01

The scope of the tests included measurements of hardness of cast iron, determination of impact strength at room temperature, 75ºC, 150ºC, 190ºC, microstructure testing (evaluation of graphite precipitations) and determination of resistance to thermal shocks, which was made at the station designed in the Department of Foundry of Częstochowa University of Technology Figure 1 [6,14].

Fig. 1. A device for simulating heat shock

In the tests were used specially made samples to determine the resistance to heat shocks, figure 2 [14]. The shape of the sample was chosen so as to facilitate initiation of cracks at its sharpened ends. The samples were heated to about 500°C and cooled. The choice of temperature was caused by the actual value of the temperature difference between the form and the liquid glass appearing in the analyzed technological line.


Fig. 2. Sample for evaluation of the resistance to thermal shocks

2. Research results and their discussion

The microstructure investigations were made using the Nikon ECLIPSE MA-200 optical microscope at 100x, 500x magnification (Figs. 3-6 and 9,10).

As can be seen both materials are characterized with regular graphite formation. This indicates that the material is characterized by high homogeneity. Both cast iron have the matrix composed of ferrite what is presented on figure 3-6. In the microstructure were not observed carbides or nitrides nor perlite.

Subsequently, the samples were tested using a Rockwell hardness B scale, it was found that the harder material is the ductile cast iron, about 72 (about 132HB), while grey cast iron had a hardness of HRB 54 (about 96 HB). The measured values of 72 HRB about 132 HB is from the lower tolerance recommended by the user from whom the research material came from.

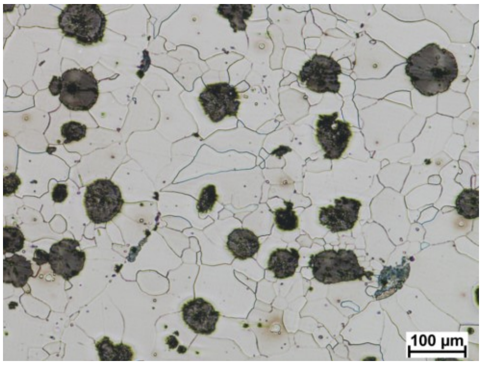

Fig. 3. Ductile cast iron, magnification 100x

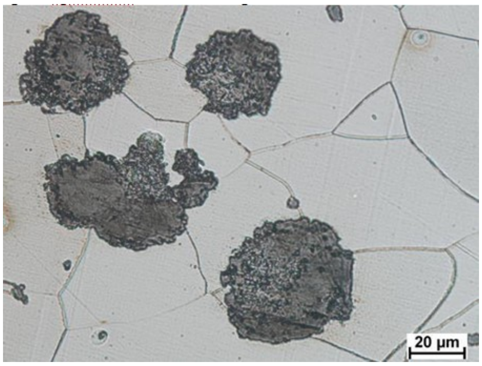

Fig. 4. Ductile cast iron, magnification 500x

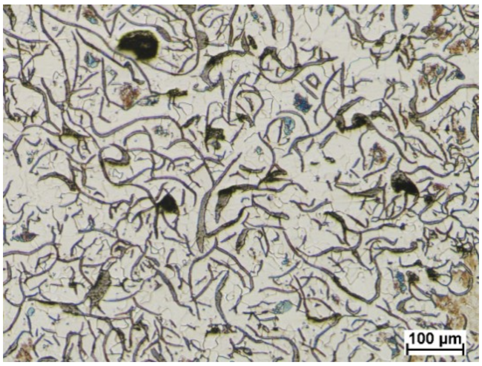

Fig. 5. Grey cast iron, magnification 100x

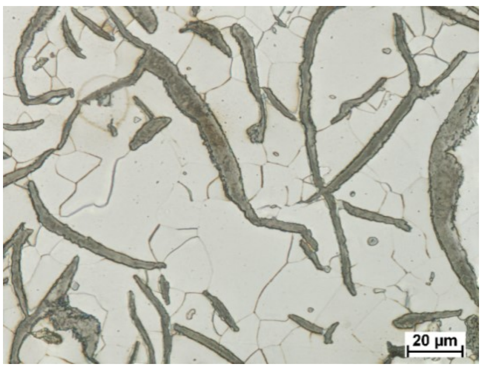

Fig. 6. Grey cast iron, magnification 500x

Assessment of material resistance to cracking is very important due to the tendency to brittle fracture of some alloys, which is usually the cause of major failures. The assessment of the transition of the cast iron to the brittle state was supposed to show that grey cast iron used so far in such difficult working conditions replaced with ductile cast iron is characterized by poorer resistance to mechanical dynamic destruction. The test consisted of heating the samples to temperatures of 75ºC, 150ºC, 190ºC and the next impact measurement and assessment of brittleness of the breakthrough. Impact measurement results for both materials on samples 10x10x55mm with V notch at individual temperatures are given in Table 2. The temperature during heating was examined with use of thermocouple placed in the backfill directly on the samples, and the time to hit was up to a maximum of 3s. It was found that for ductile cast iron 32J [15] was exceeded at 190ºC which proves that in real working conditions it has a good impact resistance.

Table 2.
Impact measurement results

	Breaking energy [J]	
Temperature [°C]	Ductile cast iron	Grey cast iron
20	22,4	3,8
75	20,0	3,8
150	16,3	3,1
190	35,0	3,0

The time of heating up the sample to the set temperature (500°C) was in each case 6 seconds, then the sample was turned over by 180° and cooled in water (fig. 7). The cooling time was 1 second.

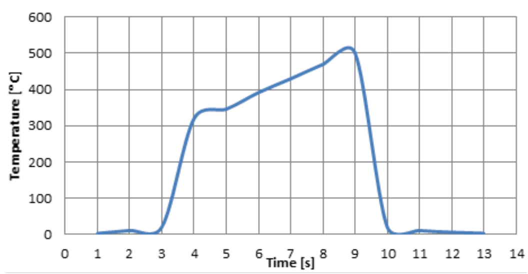

Fig. 7. An example of the course of sample heating

The first cracks in ductile cast iron were observed after five series - 2500 thermal shocks, and in grey cast iron after three series - 1500 thermal shocks. The exact course of occurrence of cracks after each series for both samples is shown in Table 3 and Figures 8 and 9.

Tabela 3.
The order of appearance of cracks

Series number	Number of cycles	Ductile cast iron	Grey cast iron
1	500	No cracks	No cracks
2	1000	No cracks	No cracks
3	1500	No cracks	First cracks
4	2000	No cracks	Visible cracks
5	2500	First cracks	-
6	3000		-

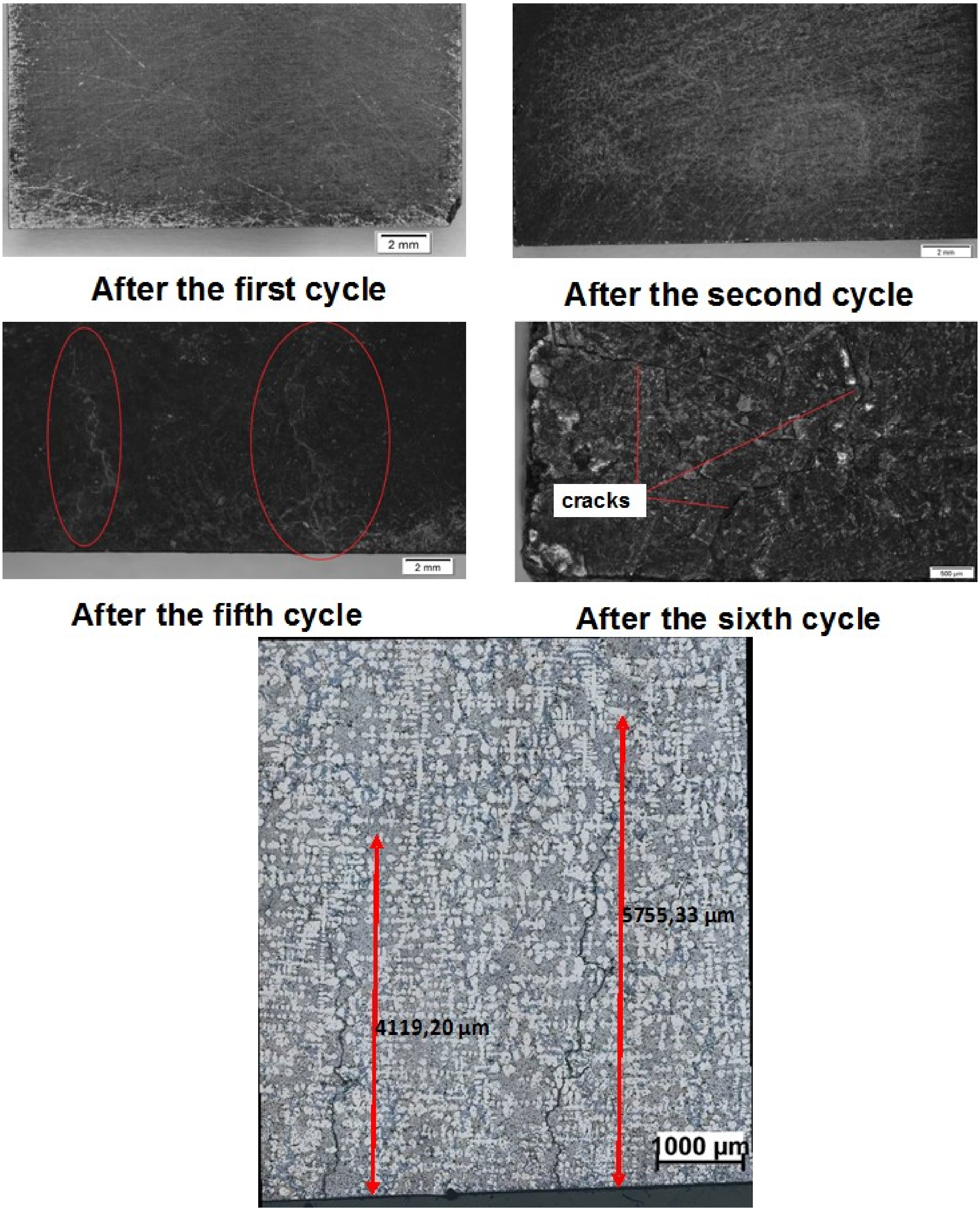

Fig. 8.Macroscopic view of samples after cycles of test and view of microstructure with marked length of cracks- Ductile cast iron

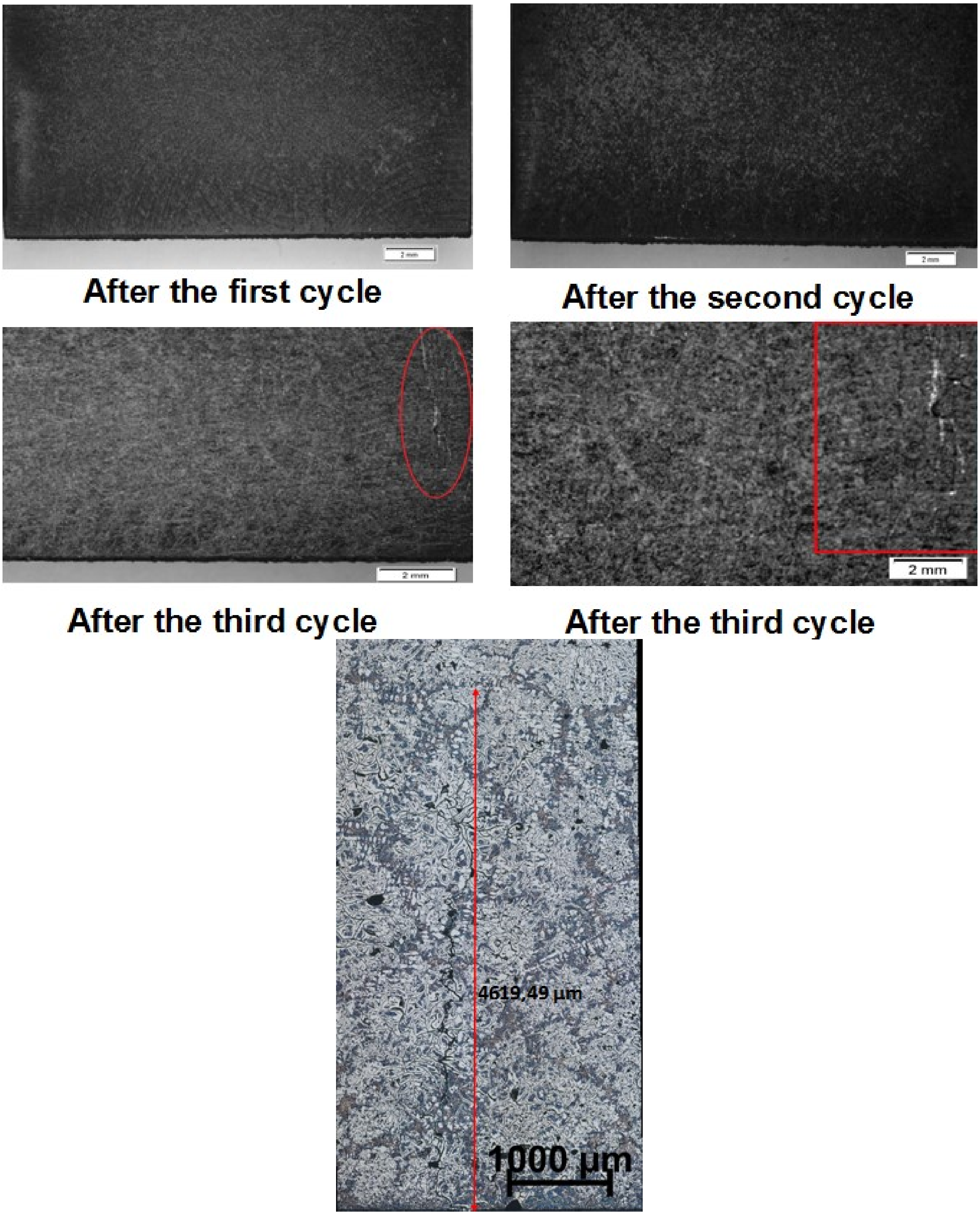

Fig. 9.Macroscopic view of samples after cycles of test and view of microstructure with marked length of cracks- Grey cast iron

The heat shock resistance of the materials analyzed is high, which is evidenced by the fact that despite the extremely difficult test conditions determined by heating and cooling as well as the geometry of the sample, these materials withstood respectively 3 and 6 series of cycles. The sample geometry with a pointed edge is also suitable for assessing thermal fatigue resistance, which is clearly visible in the microstructure of the samples and as cracks (fig. 8 and 9). The nature of the cracks in both materials, clearly

between the crystalline is typical for fatigue destruction. The decarburization of this part of the material is also clearly visible (fig. 8,9). The existance of decarburisation zone is typical in material during such tests or working conditions.
As can be observed, the change of material from grey cast iron to ductile cast iron allowed for almost doubly increasing the life of used moulds.

4. Summary

One of the main criteria that determine whether a given mould may be used in production are economic considerations. Therefore, casting moulds used in glassworks should be characterized not only by the lack of tendency to adhere glass mass, or high resistance to thermal shocks, but above all long durability and low production costs. Therefore, over the centuries, a large number of patent descriptions about heat-resistant cast iron for glass moulds have been created. This fact proves how greatly they can have even small changes in the chemical composition, which will significantly affect the quality and production costs of finished glass products.

The purpose of the work was to assess the resistance to thermal shocks and thermal fatigue of alloys on casting moulds used in glassworks. On the basis of the results obtained, the following conclusions can be made:

1. Although both materials are characterized by a ferritic microstructure, a higher hardness (72 HRB) has a ductile iron
2. The impact measurement showed a higher resistance of ductile cast iron, which is caused by the form of graphite in which it occurs. Graphite flakes occurring in grey cast iron act as voids in the material, which increases the tendency to brittle fracture, and thus cause low impact strength and ductility.
3. During the test of transition temperature 32J fragile condition has been achieved only in the case of ductile cast iron, which may also be associated with a form in which it appears graphite.
4. Ductile cast iron showed approx. 40% greater resistance to thermal shock, which indicates that, from two analyzed, it is an alloy which is more suitable for mould casting and subject to rapid cyclic temperature fluctuations.
5. The analyzed ductile cast iron, with about higher content Cr (about 0,1%), Ni (about 0,57%) and Mo (about 0,62%) showed a greater resistance to long term exposure to high temperature what show that it can be operated longer.
6. Each of the conducted tests unambiguously indicates that, from those presented materials, ductile iron is more resistant to sudden changes in temperature and work under conditions of long-term thermal influence.

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