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
2/2011
175–179
34/2

Grey cast iron as construction material of bridges from the 18th and 19th century

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Received 11.04.2011; Approved for print on: 26.04.2011

Abstract

Many bridges and railroad viaducts, which have been operated at the western and southern regions of Poland, were erected at the end of the 18th or beginning of the 19th century. In recent years they undergo overhauls and renovations requiring familiarity with the construction materials they have been made of. It is necessary for estimation of their load capacity (possible reinforcements) and determining their suitability for further utilisation. Among the materials in the old bridges the puddled steels and cast irons predominate. Aim of the work is identification and documentation of microstructure and selected properties of the cast irons used for production of parts for the bridge in Łażany, the Old Mieszczański Bridge in Wrocław, the hanging bridge in Ozimek, as well as the columnar piers of the railroad viaduct in Wrocław. Using the methods of light microscopy and scanning electron microscopy, as well as the results of hardness measurements and chemical analysis, it has been shown that the objects have been built of grey cast iron with flake graphite having the ferritic-pearlitic or pearlitic matrix. The diversification of their chemical analysis resulting from the type, size and geometry of the cast parts was indicated. The tested materials fulfil requirements of the contemporary standards related to grey cast irons of the EN-GJL-100 and EN-GJL-150 grades.

Key words: metallography; bridges; cast iron; microstructure; properties.

1. Introduction

Since the end of the 18th century, along with the development in metallurgy, the cast iron found its application in general building engineering and in erecting bridges. The structures of the first „iron bridges" were made fully of that material (mainly as the arch bridges). Later, until beginnings of the 20th century, the cast iron served as a construction material for floor beams, columnar piers of halls, railway stations, or viaduct columnar piers. They were commonly used for platform plates, as well as balustrades set in the stone plates using the melted lead. The dusk of the common grey cast iron use happened at the beginning of the 20th century when the cast steel displaced the earlier used puddled steels (exposed to the structural degradation processes), as well as just the cast irons.

The need for scientific treatment of the "old bridge structures" issue was seen in Wroclaw much earlier, the examples of which are the works [1, 2]. Research into the problems has been continued at the Wroclaw University of Technology in the form of both, the work concerning particular objects [3, 4], and in a more generalised and synthesising way [5].

In 2005, the very extensive report appeared [6], dealing with the current condition of the old bridge passages, in which cast iron as the construction material has also been considered. This testifies for topicality of the undertaken problems both, in Germany and, in particular, in the western regions of Poland. On the interest in cast iron as the construction material also testifies the exhibition organised in Gliwice in 2007, „European cast iron. Gliwice – Berlin – Sayn”.

The present article refers to the earlier published works [3, 4] concerning cast iron used in building of the 18th and 19th century bridge passages. The works referred to parts of the Łażany bridge (1796), the Old Mieszczański Bridge in Wrocław (1876), and the railroad viaduct in Wrocław (1899). The study results presented in the publications have been supplemented by the test results for the Ozimek bridge erected in 1827. That way the contemporary data base concerning overview of the chemical analysis, specific structure features and the selected properties of the cast irons used for making the parts of bridges built at the end of the 18th and the 19th centuries have been created.

2. Concise characteristics of the studied objects

Structure descriptions of the Old Mieszczański Bridge and the railroad viaduct are presented in work [4]. Below, short characteristics of the two remaining objects have been presented.

Erecting of the **arch bridge in Łażany made of cast iron** was initiated in 1793, and terminated in 1796. Initially, it was planned as a stone bridge [5]. However, when the news spread that in England and in America the similar cast-iron structures were built, a decision was taken to use such a material. In order to manufacture the iron the new foundry furnaces were built and the existing ones and other equipment modernised in the Mała Panew metallurgy plant in Ozimek. The bridge had been used until 1945, when it was destroyed and its parts scrapped. Structure of the object has been presented in Fig.1.

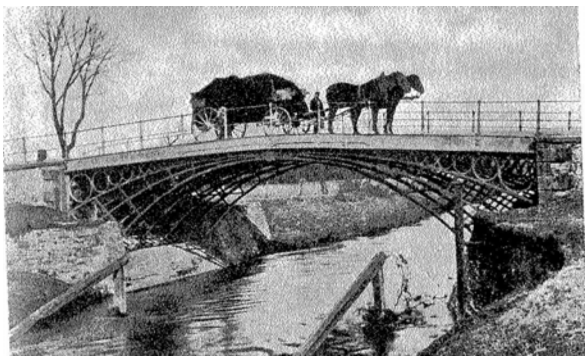

Fig. 1.View of the bridge in Łażany over the Strzegomka river [7]

The suspension bridge over the Mała Panew river in Ozimek – the oldest suspension bridge in the old Prussia was built within 1825 – 1827 (Fig.2). For its build 14,2 tons of the „construction iron”, as well as 57,8 tons of the iron casts were used [5]. The cast iron was used for making the segmented openwork pylons. Samples for tests were collected just from the pylons material.

Fig. 2. View of the suspension bridge over the Mała Panew river in Ozimek [8]

3. Chemical analysis and hardness measurement results

Table 1 presents results of the chemical analysis for the tested cast irons (performed with the use of gravimetric method and verified with the spectral method) and the hardness measurement results.

Table 1. Chemical analysis and hardness measurement results

Pos.	Object name	% C	% Mn	% Si	% P	% S	% Ti	HB W avg.
1	Bridge in Łażany [1]	2,10	0,61	1,48	0,57	0,04	-	172
2	Old Mieszczański Bridge [2]							
	balustrade	2,40	0,80	2,50	0,80	0,09	0,10	206
	platform plate	2,60	0,86	2,37	0,68	0,08	-	215
3	Railroad viaduct column [2]	2,50	0,64	2,80	1,18	0,07	0,09	134
4	Bridge in Ozimek - pylon	3,12	0,48	0,85	0,64	0,10	0,01	164

Chemical analyses of the tested materials remain within the content ranges foreseen for the grey cast irons. In the materials the content of carbon ranges from 2,50 to 3,60%; % Mn from 0,40 to 1,40; % Si from 0,30 to 3,50; % P from 0,10 to 1,00;

sulphur contents should not exceed 0,12%. The interesting light on the chemical analysis results is thrown by the data presented in work [9] published in 1913. It concerns the presence of phosphorus and titanium in chemical analysis of the tested cast irons.

High content of phosphorus in the tested irons (especially in the railroad viaduct column material - pos. 3, in Table 1) indicate for the need of providing for the high fluidity of the material during casting of the slim structure parts. Author of that work claims that phosphorus content in the cast irons should not exceed 0,70%. However, for the very thin cast walls („the ornamental and stylish" as expressed in the publication), its share must not exceed 1,00%. The Author motivates the limitation with the fact that at the phosphorus content in the cast iron in the range of 2.00 to 2,50% their stroke resistance (undoubtedly he meant the impact resistance according to the modern nomenclature) drops by as much as 72%. This is caused by presence in the material structure the high quantity of hard and brittle phosphorus eutectics. The same work [9] contains information on the titanium influence on structure and properties of cast irons. Citation of the fragment of the text is as follows: „…titanium is seldom present in the raw material, very positively influences the cast iron properties by increasing its temperature (probably the ability of the cast iron parts to work in higher temperatures is considered here) and strength and the casts become compact and fine-grained". The data is consistent with information provided in work [10], in which the Authors state that titanium in quantities of 0,10 to 0,20% improves mechanical properties of the cast irons. Instead, in the cast iron exposed to the influence of higher temperatures and subjected to oxidation, its contents may reach up to 1,00%. Increase in titanium contents results naturally in the cast iron matrix structure, in which besides ferrite, pearlite and phosphorous eutectics, also titanium nitrides and carbides appear.

Thus, the results of the chemical analysis of the tested materials indicate, that their chemical composition was selected consciously and carefully and was correlated with the requirements related to their applications. Phosphorus and titanium present in them were introduced on purpose, for shaping their properties. That way they are not impurities but the alloy additives. The high craftsmanship of the then foundry men is confirmed by the results of hardness measurements. Measurements performed at the whole thickness of the cast walls have shown dispersion not higher than ± 6 units. This indicates for homogeneity of the structural build, and the resultant homogeneity of properties at the construction part thickness.

4. Macroscopic and microscopic test results

Macroscopic observations of the studied bridge structure fragments have shown that in the conditions of exposure to atmospheric corrosion they coat with multilayer cover of corrosion products, and the corrosion itself is close to the uniform in its character. Only in the places of construction „corrosion traps" and the areas of water seepages the pitting corrosion was observed. Such pattern of corrosion changes is more advantageous than that observed in the old bridge constructions made of the puddled and cast steels [11].
ractures of the tested materials have shown brittle, fine-grained Fand slightly developed surface topography in their macroscopic images. Exemplary fracture build for the sample material collected from the Old Mieszczański Bridge has been shown in Fig.1.

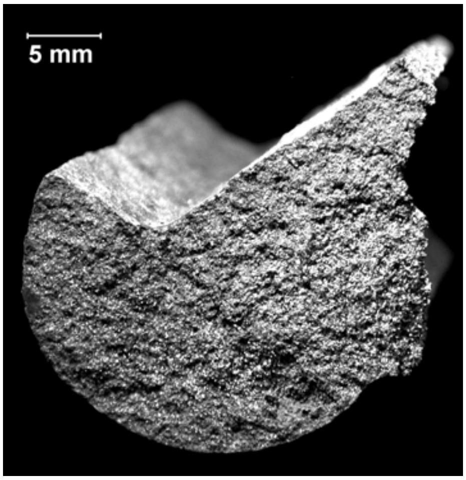

Fig. 3. [4] Macroscopic image of fracture for the sample from balustrade of the Old Mieszczański Bridge.
The fracture is brittle in character

Microstructures of the tested materials (Fig. 4 – 10) result from their diversified chemical composition (Table 1) and the cast cooling conditions. Graphite of the plain flake shape appeared in them in all cases. Instead, the matrix structures were changing from pearlitic – ferritic (Fig.4) to pearlitic (Fig.6).

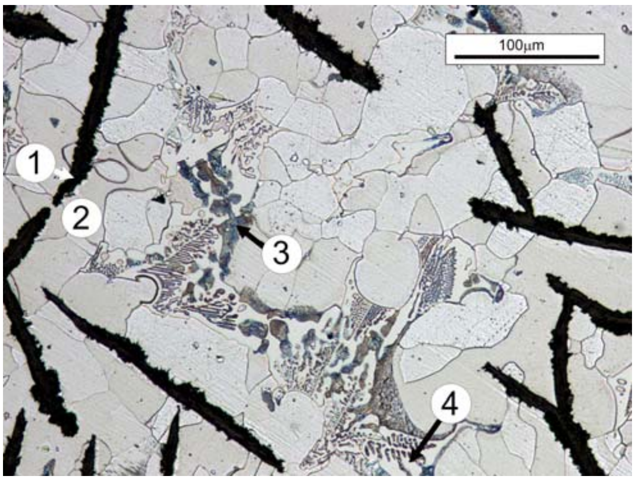

Fig. 4. [4] Microstructure image of sample collected from the viaduct column:
1 – graphite; 2 – ferritic matrix; 3 – colonies of pearlite of diversified dispersion ; 4 – phosphoric eutectics.
Etched with Mi1Fe; light microscopy

Fig. 5. Bridge in Ozimek – cast iron with flake graphite.
Graphite precipitations shape: flaky – I,
Graphite precipitations arrangement: non-uniform – C,
Graphite precipitations size: from 0,25 to 0,50 mm – 3.
Non-etched state, light microscopy

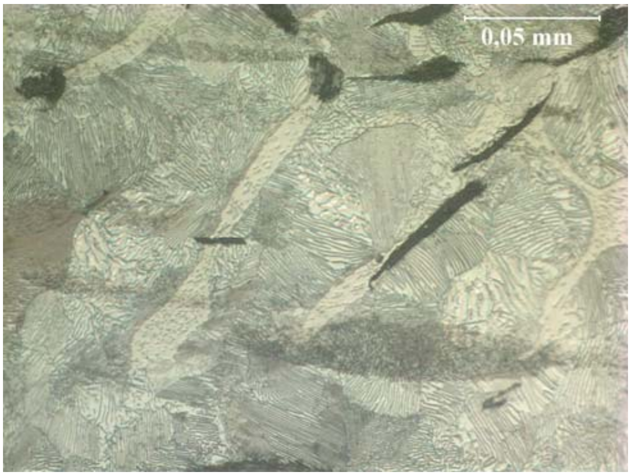

Fig. 6. Bridge in Ozimek – microscopic image of the grey cast iron structure with pearlitic matrix, flaky graphite and precipitations of the ternary phosphoric eutectic (phosphide). Metallic matrix type: lamellar pearlite – Pf1, pearlite quantity: over 98%, ferrite up to 2% - Pfe0, lamellar pearlite dispersion from 1,3 to 1,6 µm – Pd1,4, phosphoric eutectic structure – ternary, fine-grained – F2, phosphoric eutectic inclusions arrangement – slightly shaped lattice - Fr2, phosphoric eutectic lattice mesh diameter from 250 to 500 µm – Fd400, phosphoric eutectic inclusion size up to 2000 µm – Fw2000.
Etched with Mi1Fe, light microscopy

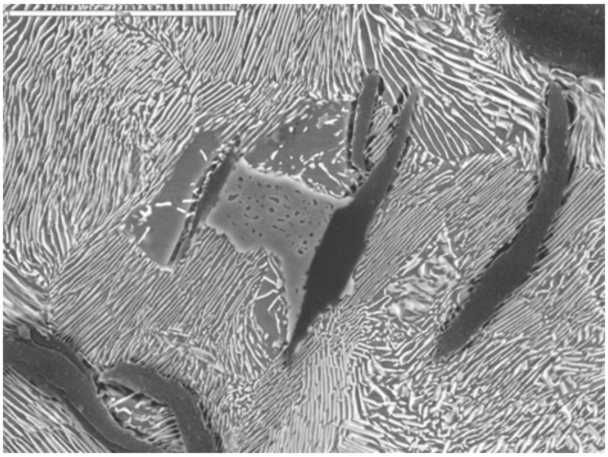

Fig. 7. Bridge in Ozimek – magnified image of the microstructure shown in Fig.6.
At the background of the fine-dispersion pearlitic matrix of the lamellar build visible dark precipitations of flaky graphite and the phosphoric eutectic area in the centre.
Etched with Mi1Fe, scanning microscopy

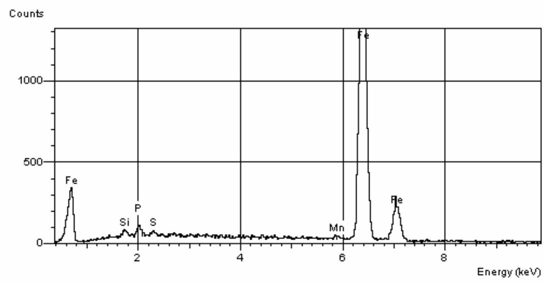

Fig. 8. Energy spectrum of the X-ray radiation from the area shown in Fig.7

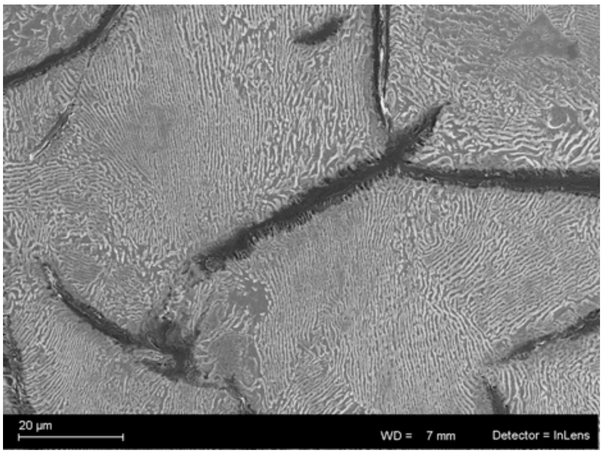

Fig. 9. Bridge in Ozimek – microstructure image of the sample from the area free of the phosphoric eutectic.
Pearlite of the lamellar build with graphite precipitations.
Etched with Mi1Fe, scanning microscopy

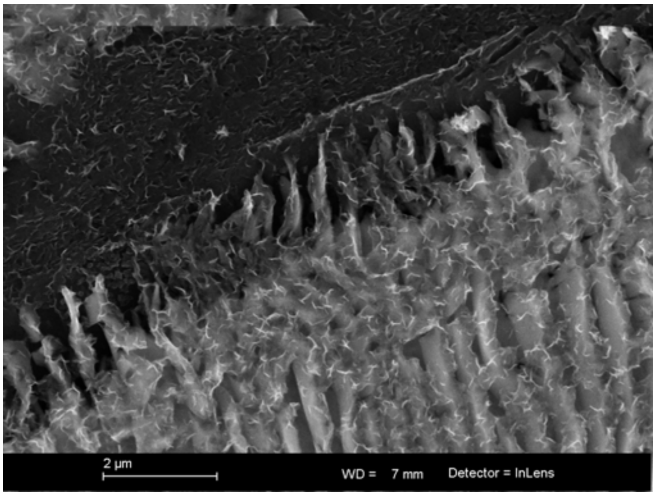

Fig. 10. Bridge in Ozimek – magnified image of the central part of the microphotograph from Fig.9.
Visible singular flake of graphite (black area) in the pearlite matrix of the lamellar build
Etched with Mi1Fe, scanning microscopy

5. Summary

In the article the study results for cast iron structure parts collected from the open-work pylon of bridge in Łażany, the Old Mieszczański Bridge in Wrocław (platform plates and balustrade), railroad viaduct column in Wrocław, and the bridge in Ozimek (pylon segment) have been presented. It has been shown that they have been made of grey cast iron with plain flake graphite, differing in the type of matrix. The railroad viaduct column has been made of the material of ferritic matrix with small quantity of lamellar pearlite, and all the remaining bridge parts have been made of cast iron with the pearlitic matrix. Structure of the tested samples contained phosphide eutectic, the biggest quantity of which has been found in the viaduct column material. Besides that, in the material of the viaduct column and the balustrade of the Old Mieszczański Bridge precipitations of titanium nitrides and carbides appeared. Average hardness of the cast iron of matrix with ferrite predomination amounts to 134HB, and hardness of the cast irons with pearlitic matrix instead, stays within the range of 164 HB (bridge in Ozimek) to 215 HB (platform plate of the Old Mieszczański Bridge). The tested materials fulfil requirements of the currently valid PN-EN 1561: 2000 Standard, concerning grey cast irons of the EN-GJL-100 and EN-GJL-150 grades. As opposed to the bridge in Łażany (destroyed in 1946), the objects of which the samples for tests were collected were overhauled within the last three years. In the course of these repair works, among others, the material test results presented in the article were utilised.

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