Microstructures and selected properties of cast irons used for bridge structures at late XVIII and in XIX century

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Abstract

During recent years, in the area of Germany and Poland numerous repair and renovating works are being carried out of old (of XVIII and XIX centuries) structures of bridges and overbridges. In Germany, such works are preceded by generous research programs resulting in well-grounded diagnoses on their wear conditions and properties of that time used construction materials. In Poland, such research works result more from own interest of the individual authors of published papers and elaborations. In Wrocław (Breslau), in use are in this paper, the research subject were cast iron fragments of structure of the Old Mieszczanski Bridge (Wilhelmsbrücke) of 1876 and pillars of the railway overbridge built in 1899. The research was aimed at determining chemical composition of the used materials, their structure properties, as well as selected mechanical properties and referring the results to structures and properties of modern cast irons. It was found using light microscopy and SEM methods that they are grey cast irons with flake graphite, with ferritic and pearlitic matrices. Moreover, they include significant areas of phosphide eutectics and precipitates of titanium-rich phases. These observations are confirmed by results of gravimetric and spectral chemical analyses which indicate maximum phosphorus content of 1.18 % and maximum titanium content of 0.1 % in the examined cast irons. Together with evaluated mechanical properties (based on hardness measurements and previous results), chemical compositions and structures permit classifying the examined materials as cast irons equivalent to grades EN-GJL-100 and EN-GJL-150 acc. to the today's standards.

Key words: metallography, cast iron, structure, properties

1. Introduction

During last years, researchers of various scientific centres are increasingly interested in evaluating degradation degree of old bridge structures of puddled or cast steels [1,2], as well as of cast irons [3].

In the 2nd half of XVIII century, cast iron was widely used in general building engineering and for bridge construction. An example can be the first in continental Europe "iron bridge" built in 1796 on the river Strzegomka (Striegauer Wasser) in Łazany (Laasan) in Lower Silesia. Of cast iron were also made the bridge over Klodnicki Channel in Gliwice (Gleiwitz) in 1816, the Sikorski Bridge (Königsbrücke) over the town moat in Wrocław in 1822 and the suspension bridge in the area of the "Malapanew" Smelter in Ozimek (Hütte Malapane) in 1827. Decline of common use of cast iron for bridge components happened in early XX century, when cast steels became widely used in place of cast irons and puddled steels (e.g. the Old Mieszczanski Bridge in Wrocław). It did not mean that cast irons were eliminated as the materials used for many bridge structure components. The Old Mieszczanski Bridge in Wrocław has its basic structure made of puddled steel, but the platform plates and railings of the bridge are made of cast iron. The researched objects have undisputable historical value, although most of them are still used and subject to routine overhauls. Unfortunately, some of the bridges, like the
above-mentioned bridge in Łażyany, have been destroyed, even if as early as in 1942 the author of [4] stipulated displacing its structure to the Park Szczytnicki (Scheitniger Park) as a monument of engineering craft.

In the authors' opinion, results of the material examinations of old bridge structures are valuable not only for documentation, but are also practical and well justified today, because they permit evaluating the degradation degree of a structure and facilitate reconstruction and repair works.

Examined were cast iron columns of the railway overbridge built in 1899, see Fig. 1. At present, the overbridge is under overhaul. The objects of the examination were also the platform and the railing of the Old Mieszczanski Bridge, built in 1876, see Figs. 2 to 4. Results of the today works were referred to the results presented in [3] performed with participation of the authors of this paper.

Fig. 1. View of two support columns of a railway overbridge with the supporting structure installed for repair period

a)

b)

Fig. 2. Old Mieszczanski Bridge on the background of buildings non-existent today (a); present view (b) [7]

Fig. 3. Fragment of the railing of the Old Mieszczanski Bridge

Fig. 4. Macroscopic view of a fragment of the platform plate of the Old Mieszczanski Bridge
2. Chemical analyses, hardness measurements and macroscopic observations

Results of chemical analysis of the examined cast irons performed by gravimetric and spectral methods are given in Table 1. The table includes also the composition of cast iron used for the bridge in Łażany.

Chemical composition of the cast irons is within the range of concentrations given for grey irons. They usually contain: 2.50 to 3.60 %C; 0.40 to 1.40 %Mn; 0.30 to 3.50 %Si; 0.10 to 1.00 %P and sulphur content should be below 0.12 %.

Table 1. Results of chemical analyses [%]

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge in Łażany</td>
<td>2.10</td>
<td>0.61</td>
<td>1.48</td>
<td>0.57</td>
<td>0.04</td>
<td>-</td>
</tr>
<tr>
<td>Overbridge column</td>
<td>2.50</td>
<td>0.64</td>
<td>2.80</td>
<td>1.18</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>Railing</td>
<td>2.40</td>
<td>0.80</td>
<td>2.50</td>
<td>0.80</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>Platform plates</td>
<td>2.60</td>
<td>0.86</td>
<td>2.37</td>
<td>0.68</td>
<td>0.08</td>
<td>-</td>
</tr>
</tbody>
</table>

The high phosphorus contents found in the material of the overbridge column and railway are probably motivated by care of flowing power and filling the mould during casting slim shapes of the concerned parts. The author of the paper [5] published in Technical Review in 1913 maintains that phosphorus concentration in cast irons should not exceed 0.7 %, but only when no special strength is required from the castings and they do not work at elevated temperatures. However, at very thin walls of the castings ("ornamental and fashionable") phosphorus concentration should not exceed 1.0 %. The author also states that with phosphorus content in cast iron between 2 and 2.5 %, its tensile strength is reduced by half and its impact strength reaches 28 % only of the basic value.

Spectral analysis of the Old Mieszczanski Bridge railing and the overbridge column showed ca. 0.1 % of titanium. According to [5], titanium content in cast irons can range from 0.1 to 0.2 %, improving their mechanical properties. In grey irons with required increased resistance to high temperatures and oxidation, its concentration can reach 1 %. This is reflected by titanium nitrides and carbides present in the material structure.

In the paper [5] published 14 years after manufacture of the cast iron columns of the examined railway overbridge and 37 years after building the Old Mieszczanski Bridge, the following sentence is included: "Titanium is rarely present in raw material, affects properties of cast iron in a very positive way, increasing its temperature and strength, and castings became dense and fine-grained". This statement indicates that titanium present in the examined cast irons is an alloying element introduced deliberately and intentionally to improve their properties.

Scatter of Brinell hardness measurements did not exceed ± 4 units. Average hardness of the overbridge column was 134 HB, of the railing 206 HB and of the platform plate 215 HB.

Figs. 5 and 6 show macroscopic structure of fractures of the examined cast irons. The fractures are of brittle nature, fine-grained, and their topography is not much developed. The fracture of the column that happened during repair works shows a zone with plastic deformation traces close to the outside surface.

It is also worth to note that the examined fragments of the structure revealed only slight corrosion damages of local nature. The overbridge columns and the railing were covered with protective coatings, but the platform plates showed no traces of any coating. Nevertheless, corrosion was of uniform nature, unlike in the structure components made of puddled or cast steel.

3. Microscopic examinations

Microscopic observations of all the specimens in unetched condition showed plain flake graphite with uniform distribution on the specimens' cross-section, see Fig 6. The same form of
graphite was observed in the construction material of the Łaźany bridge [3].

After etching, diversified structures were found in the examined materials. The samples taken from the overbridge column consisted of ferrite grains with small amount of pearlite (lamellar with variable dispersion).

Cast iron of the Old Mieszczański Bridge railing and of its platform plates have pearlitic matrix, identical as the samples taken from the Łaźany bridge. All the specimens contain precipitates of steadite, characteristic for these materials. Review of matrix of the examined cast irons is shown in Figs. 8 to 10.

In consideration of similar chemical compositions of the examined cast irons, differentiation of their matrix should be explained by various cooling speed of the castings that resulted in increasing pearlite content in the matrix along with decreasing wall thickness.

Some supplements and refinements to the description of the examined structures were possible thanks to observations and chemical microanalyses performed by SEM. Fig. 11 shows an image of ferritic matrix of cast iron with precipitates of steadite as well as nitride and carbide phases with characteristic tetragonal shapes.

The distributions of S, Ti, Mn and Fe concentrations shown in Fig. 12 (along the line marked in Fig. 10) document the presence of manganese sulphides and titanium-bearing phases (nitrides or carbides) in the examined materials.
Fig. 11. Microscopic image of matrix of the railing material: 1 - ferritic matrix, 2 - steadite precipitates, 3 - graphite precipitates, 4 - precipitates of titanium nitrides and carbides. Magn. 900x, etched with Mi1Fe, SEM

Fig. 12. Distributions of S, Ti, Mn and Fe concentrations along the line marked in Fig. 10

Fig. 13. Surface distribution of S, Ti, Mn and Fe from the area shown in Fig. 10; A – sulphur, B – titanium, C – manganese, D – iron

Matrix of the material of the Old Mieszczanski Bridge railing is ferritic with small fraction of pearlite. Matrix of the platform plate material of that bridge is pearlitic. Considering the results presented in [3] for the bridge in Łażany, chemical composition of the examined materials ranges as follows: %C from 2.1 to 2.5; %Mn from 0.61 to 0.80; %Si from 1.48 to 2.80; %P from 0.57 to 1.10; %S from 0.04 to 0.09. Moreover, cast iron of the overbridge railing and column contains an addition of 0.10 % Ti. This results in the presence of titanium nitrides and carbides in the structure.

Average hardness of the cast iron with ferritic matrix is 134 HB, but for the other two materials it is 206 HB for the overbridge column and 215 HB for the platform plate. In comparison with the examination scope of the Łażany bridge, the here presented results do not include mechanical tests (tensile and impact tests). These examinations will be carried out in a near future. With respect to graphite form, matrix structure, chemical composition and mechanical properties, the examined materials comply with the requirements of modern standards for grey irons grades EN-GJL-100 and EN-GJL-150. It is also worth to note that the bridges mentioned in the paper will not share the fate of the Łażany bridge. The series of overbridges of XIX century in Wroclaw are currently under repair and are supervised by the conservator of monuments, the Old Mieszczanski Bridge has been reconditioned and the bridge over Malapanew in Ozimek is being displaced to the area of the river embankment as a monument of engineering craft. The changed approach to cast iron structures coming from XIX century is confirmed by the exhibition “European Cast Iron. Gliwice - Berlin - Sayn” in 2007 in Gliwice.

4. Summary
The presented results of examinations of specimens taken from the structures of an overbridge and a bridge built in the second half of XIX century showed that both structures were made of hypoeutectic cast iron with flake graphite.

References


