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Original Research Article

# The mechanical properties and the microstructural degradation effect in an old low carbon steels after 100-years operating time

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ABSTRACT

The paper presents the results of historical types of steel after over 100 years of operating. The object of interest were parts of steel structure of the hall historic 19th-century Main Railway Station in Wroclaw. The study has shown the presence of the microstructural degradation processes in puddled steel. In all the analysed steels (low carbon puddled steel) microstructure degradation processes were related to: presence of numerous precipitations of carbides and nitrides (or the carbides–nitrides) of iron inside the ferrite grains, presence of continuous precipitations of cementite at ferrite grain boundaries. In order to restore the initial state of the microstructure, all tests were carried out in two stages of heat treatment; as-received state and after the normalisation (950 °C, 2 h, cooled in air) state. The microstructures degradation significantly influenced the mechanical properties. Its influence is most strongly emphasized in the impact resistance test results. It has been shown that the presence of degradation processes significantly changes the type of fracture; from ductile to the cleavage. This fact is well illustrated by the SEM-images of crack path. Results of the fatigue crack growth rate test indicate for worsening of resistance to the fatigue crack propagation of the material depending on the degree of degradation processes intensity in tested steel. The differences in the kinetics of fatigue cracking are also well illustrated by the SEM-images along the fatigue crack path. The authors have proposed a new kinetic equation of the fatigue crack growth rate for puddled steel.



## 1. Introduction

Operation of the advanced in age technical objects becomes a common phenomenon in the current reality. The problem becomes particularly acute in the bridge sector. Based on the papers [1,2], in Europe, the age of 68% of rail-road bridges exceeds 50 years, while 28% of them are over 100 years old objects. Maintenance of such aged objects in full usefulness and reliability requires precise diagnostic methods and evaluation of their condition frequently departing from procedures adopted in normative regulations for the modern

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technical objects. In case of objects erected at the turn of the 19th and 20th centuries, the diversification of operating conditions, as well as peculiar characteristics of materials used for their building require individualized approach in the assessment of their condition. It should be noted that the structures coming from 19th and 20th centuries have been made of puddled or cast steel. Despite the old steel grades frequently fulfil the fundamental strength criteria based on static tensile tests, the tendency for brittle cracking of those steels implies application of other criteria of estimation than those set for the modern low-carbon bridge steels. In the steels coming from the turn of the 19th and 20th centuries (more often puddled and effervescing cast steels) the tendency reveals to microstructure degradation processes [3]. Recently, an increasing number of publications concerning the diagnosing methods and the ways of evaluating condition of aged objects have been observed. Particular attention is given to minimally invasive diagnostic methods. The results of corrosion tests given in [4] are particularly interesting. In this work, the usefulness of the electro-chemical test methods for the assessment of microstructural degradation of old steel from historic buildings has been shown. This issue was also taken into account within the frames of the VI European Frame Research Program [5], concerning safety of steel bridge structures from 19th and 20th centuries. The interest in this topic has been observed not only in Europe. The need for developing proper research tools was formulated also in the report of the American Association of State Highway and Transportation Officials (AASHTO) [6], published in the United States. It was noticed that among almost 590 thousand bridge objects about 38% exceeded its 40 years in operation, and 43 years is the average age of American bridge, which was one of the five most important problems of the American road infrastructure. The cited data justify the need for testing those old structural materials, especially in the aspect of tendency of those materials to changes (degradation) taking place in their microstructures. For that reason particular attention should be paid to structures erected from the puddled steels. Motivation for research of brittleness issues, the tendency for cracking and development of cracks as a result of fatigue in the puddled steels constitutes the sentence expressed already in year 1878, and cited in the papers [7,8]: ''*Life of bridges made of puddled steels was an object of interest already at the time of their erecting. After 50–100 years the old iron constructions will show cracks more often than we assume it at present*''.

## 2. Examined objects, material and strength investigation

The object of interest was the fragments of steel structure ''Wroclaw Glowny'' Main Railway Station in Wroclaw (1855–1857). Two steel beams were taken for examination. One bar (rail-shaped) was a structural element of basement ceilings (in this paper marked as the ''RS'' steel). The second element was the I-beam I220 – typical for 19th century civil engineering – in this paper marked as the ''B'' beam. As it is stated in the introduction, in the historic construction materials degradation processes can occur. In order to evaluate the intensity and development of the microstructural degradation processes all investigations are performed in to two state; after-operating state and after heat treatment procedure – normalization. For a such type of low-carbon steels (in terms of chemical composition) the normalization process consists in maintenance of the material in furnace in 950 °C during 2 h. After this, the material was cooled in the laboratory air. The similar procedure is commonly used in the theory of degradation and its material aspect [8,9]. After normalization the microstructure of investigated material can be treated as close to the equilibrium state. A heat treatment of course does not change the number and orientation of non-metallic inclusions, as well as the chemical composition. There is no rational way for comparison of the intensity of intensity of degradation processes (in case of the steels from 19th century). Even if it is possible to take the steel with the same chemical composition, the ancient way of manufacturing such a type of steel will be completely different. For the above reason, all metallographic observations and strength tests are conducted in two states of the material.

### 2.1. *Metallography examination*

The chemical analysis has been made using a gravimetric method. A representative part of shavings were taken for testing – the place of extraction has been indicated using circle in Fig. 1. The chemical compositions of the analyzed steel have

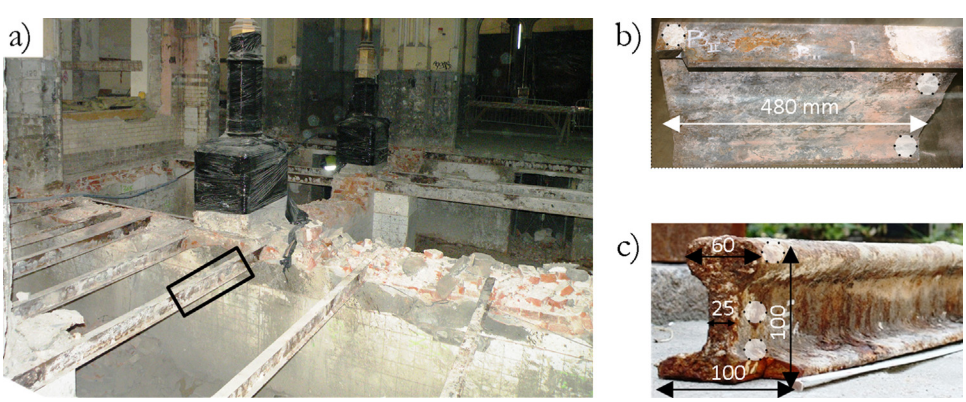


**Fig. 1 – (a) Places of the material cutting from steel structure of the main hall – marked with the black frame – (B-material), (b) general view of the B-beam I220 with the main dimension in rolling direction, (c) the rail-shaped beam (RS-steel) with dimensions (in mm) – total length *L* = 1200 mm.**