

# THE USE OF STEEL CASTINGS IN MECHANICAL AND CIVIL ENGINEERING – GERMANY. 1850-1950

**Volker Wetzck<sup>1</sup>**

## **Keywords**

Steel Castings, Cast Steel, Bridge Bearings

## **Abstract**

In contrast to other historic building materials such as cast and wrought iron or rolled steel, historic steel castings have been widely neglected in the technical literature dealing with construction history. Indeed, steel castings represent only a minor part within historic structures. However, steel castings were often used for crucial structural elements with high demands in terms of structural safety, durability and other such factors in the field of mechanical and civil engineering. Propellers for engines and bearings for bridges may serve as examples to name but a few.

This paper deals with historic steel castings produced in the years between 1850 and 1950 and used for structural purposes in mechanical and civil engineering. After a brief summary of the history of steel castings fabrication, the paper focuses its engineering use and refers to specific mechanical properties and chemical compositions. The appropriation of historic steel castings as a material for bridge bearings is especially emphasized and compared to that of contemporary state-of-the-art of steel castings' use in mechanical engineering. This analysis yields insights into the stage of the metallurgical development in the case of steel castings and broadens the base for their structural assessment.

The research is based on findings from a recent research project to provide options for the preservation of historic bridge bearings made of steel and still in use. The project, a co-operation between the Brandenburgische Technische Universität and the Bundesanstalt für Materialforschung und -prüfung, was being funded by the German Research Foundation (DFG).

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<sup>1</sup> BTU Cottbus-Senftenberg, PF 101344, 03013 Cottbus, Germany; volker.wetzck@b-tu.de

## INTRODUCTION

If liquid steel is poured into a fire-proof mould for the direct casting and shaping of elements, the products are referred as *steel castings* in structural engineering. The process to fabricate steel castings is usually referred as *steel casting* or *shape casting*. In the early evolutionary stages of steel castings' production the procedure received a couple of different German denominations such as Stahlformguss or Stahlfaßguss (*steel shape casting*).

The historic development of producing steel castings has been reported elsewhere (Wetzk 2013); those findings will be summarised here and supplemented by some more details. Based on this research, the following introduces the different areas of applying steel castings and evaluates them according to the material properties.

## FROM STEEL INGOTS TO STEEL CASTINGS

The English city of Sheffield in South Yorkshire is considered to be the cradle of steel casting, for it was here that Englishman Benjamin Huntsman (1704–1776) succeeded in melting smaller quantities of wrought steel in a clay crucible and pouring the liquid into ingot moulds. These steel ingots still had to be forged into the final application. The refined form of this technique, where the molten steel went into the mould directly shaping the final product, was only mastered by 1850. This form of steel casting allowed for combining the almost infinite shaping possibilities of iron casting with the high mechanical properties of both forged and rolled steel.

By the year 1900 the crucible process had lost its monopoly-like position and had to make way for industrial refining procedures. The latter broadened the range of products from steel casting with regard to their quality as well as to their size, weight and shape. Initially the procedure was simply denominated as steel casting. But at the beginning of the 20<sup>th</sup> century in the field of unalloyed steel casting alone distinctions had to be made between acidic or alkaline Siemens-Martin-steel casting, converter steel casting or electric steel casting (fig. 1). However, the refining equipment employed for the mass production of steel often failed, when it came to meet the requirements for delicate steel shape casting where tasks were increasingly complex. Small-size furnaces were developed to meet those requests and after 1900 the production in electric furnaces gradually became the prevailing procedure. (Wetzk, Dogru 2013)

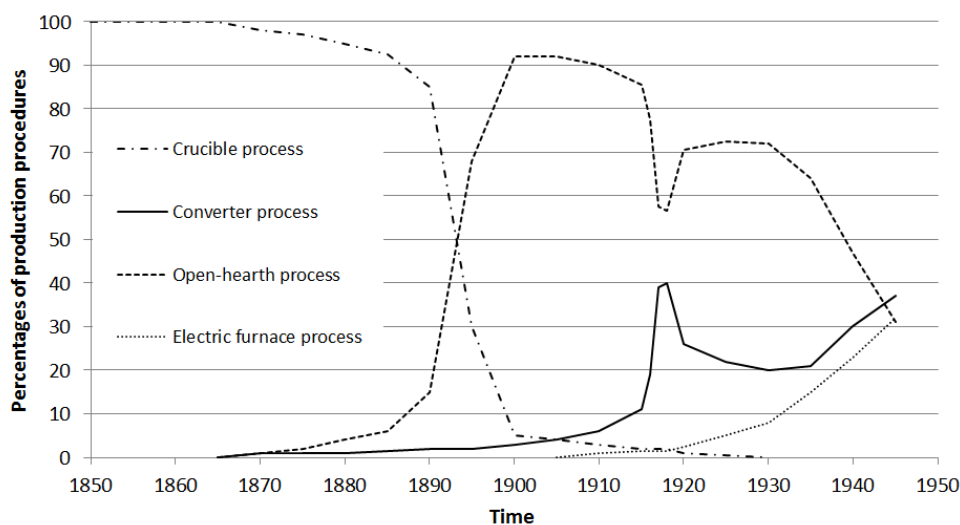


Figure 1: Common procedures for casting steel in Germany until c.1950 (Wetzk, Dogru 2013)

## EARLY PRODUCTS

The ingots, produced in Sheffield from the mid-18<sup>th</sup> century onwards, were comparatively small and did not permit any large-scale application. Nevertheless, steel from Sheffield marks the initial production of mild steel, its outstanding quality allowing for the subsequent forging of the ingots into those high-quality tools in high demand in the nascent Industrial revolution.

In Germany Friedrich Krupp (1787–1826) was able to produce ingots of cast steel in 1816 (Beyer 2007, 178). Alfred Krupp (1812–1887), his son, was already able to cast large ingots from a number of crucibles. He surprised experts at London World Exhibition in 1851 with a cast steel ingot weighing 2 metric tons (Beyer 2007, 389). After the middle of the 19<sup>th</sup> century “Gußstahlfabrik Krupp” (Krupp Cast Steel Factory) was to thrive on the stupendous development and expansion of the railroad industries by producing springs for wagons and locomotives, axles and seamless railroad tyres etc. (Krupp 1912a, 17ff). However, the cast steel products made by Krupp shared one thing: All of them were forged out of ingots as an additional step of work. Apparently Krupp thought direct production by means of shape casting was technically not possible (Beyer 2007, 371). Not so his competitors!

As early as the mid-1820s Johann Conrad Fischer (1773–1854) from Switzerland had successfully melted even low-carbon wrought iron, a prerequisite for the shape casting of objects with a filigree design (Schib, Gnade 1954, 37). While travelling in 1845 he presented a selection of steel castings such as gunlocks (op. cit., 61). On the London World Exhibition Fischer presented a small gear wheel with a conical shape, cast from soft steel (op. cit., 76) (fig. 2). It remains unclear, whether he tried to sell his inventions without success or whether he did not strive for that all. Anyway, it was only very much later, that his descendants chose to integrate steel castings into the portfolio of their cast steel factory in Swiss Schaffhausen (op. cit., 65).

In Germany Jakob Mayer (1813–1875) is taken to be the inventor of steel castings. He established a foundry for cast steel in 1842, which became “Bochumer Verein für Bergbau und Gusstahlfabrikation“ (Bochum Association for Mining and Cast Steel Production) in the year 1854 (Bertram 1938, preface). By 1850 Mayer’s factory had become a veritable competitor for Krupp.

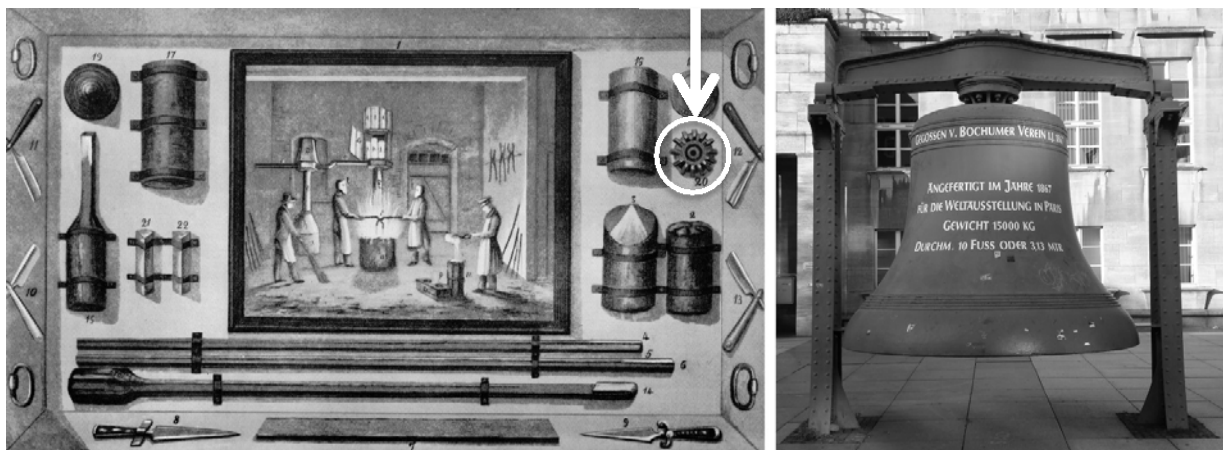


Figure 2; left: Image of Fischer’s range of products on the 1851 London World Exhibition with the small gear wheel (highlighted) made from steel casting (Schib, Gnade 1954). Right: A 15-metric-ton bell cast from steel from Bochumer Verein for the 1867 Paris World Exhibition, nowadays placed in front of Bochum city hall (Photo M. Zimmer)

On the one hand Mayer offered a variety of semi-finished products and tools forged from ingots. All the while, however, he also pursued the challenge of pouring liquid steel into a mould shaping directly the final product. Presumably Mayer made his first successful attempts of shape casting in the 1840s (Bertram 1938, 24; Schib, Gnade 1954, 65). Church bells were among the first steel castings from his factory, which he presented on the 1852 Düsseldorf Industrial Exhibition and on both World exhibitions held in Paris in 1855 and 1867 (fig. 2).

Repeated successes with bells made by steel casting pointed to the end of the development stage of this procedure by 1855. The actual quality of the products had been only of secondary significance, as long as the central issue was, whether shape casting with steel could be possible at all. Small wonder that the bells Mayer exhibited in Paris in 1855 led to an *éclat*. His competitor Krupp, also being exhibitor in Paris, still thought of shape casting as an unattainable goal. Thus he alleged the bells were cast of iron and requested a material examination on the spot. He was disproved, since the bells were cast from steel (Bertram 1938, 27; Däbritz 1934, 74).

### STEEL CASTINGS IN MECHANICAL ENGINEERING

By the second half of the 19<sup>th</sup> century the casting complemented the forging and rolling as a third procedure of shaping steel. Through advances in the technologies for shaping, casting and melting of steel, the procedure of shape casting soon came to enter new fields of application, mainly for railways, shipbuilding and mechanical engineering. A growing number of factories began to produce castings. A prime example was a firm initially founded in 1870 as “Stein & Co” and later renamed as “Stahlwerk Asthöwer & Cie” (Asthöwer Steelworks) based in St. Annen, whose castings possessed toughness as well as softness in levels unknown before. A major strength of Asthöwer & Cie was bringing to perfection the castings for tools and weapons, items to be used in railway construction as well as gearwheels of every shape and size (Baedecker 1912, 238) (fig. 3). The factory became part of the Krupp company in 1886.

Steel casting was primarily employed for goods with two requirements: Due to their complex design, producing them by forging or rolling could only be achieved with great difficulty, if at all, and secondly cast iron was ruled out as a material due to its brittleness. Products were soon to cover a broad range: disc wheels, pistons, frogs and cross pieces (for railway industries), pinions (for machine engineering) as well as propellers and stems (for shipbuilding) (Osann 1904, 651) including some very large objects. As early as 1872 a propeller with four blades, cast at Bochumer Verein, measured 5 metres in diameter and weighed 9 metric tons (Osann 1903, 101).

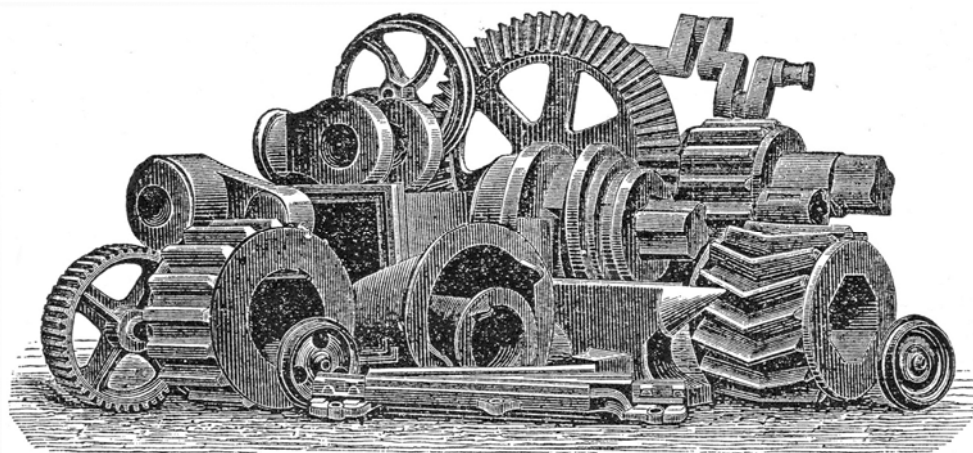


Figure 3: Selection of steel castings from Asthöwer & Cie; advertising poster (Asthöwer 1881)

The material properties attained were impressive as well. Already in 1887 a steven was cast at Krupp factory with a strength of some 400 N/mm<sup>2</sup> with more than 20 % elongation (op. cit., 101). In the early 20<sup>th</sup> century strengths of some 500 N/mm<sup>2</sup> with a 20 % elongation posed no problems (Krieger 1918, 349). If required and by using a higher carbon ratio, the level of strength could be raised to 800 N/mm<sup>2</sup>, however, that meant a decrease in elongation (Irresberger 1918, 482). By that time very soft castings could be made as well by using low quantities of both carbon and manganese. Such products were ordered by the electric industry for instance for generators with special magnetic properties. The qualities of the individual materials processed by steel casting depended on the right choice of the melting furnace and the appropriate formulation for the molten metal. By the year 1900 for instance, Krupp used alkaline-coated furnaces for steel for generators with a chemical composition in the following ranges 0.1–0.15 % C, 0.2–0.3 % Mn and 0.2–0.4 % Si (Osann 1904, 719). (fig. 4)

Altogether steel castings remained an expensive good for a long time. Only few companies could produce it according to the requirements. High quality steel was still cast from crucibles. However, with the widespread establishment of Martin furnaces in the late 1880s steel castings came gradually to be seen as a reliable material in other areas of industrial production as well. (Op. cit., 651) The arms industry became an important source for commissions. Around 1886 Krupp began to cast heavy and complex parts for gun carriages (Krupp 1912b, 253). Between 1880 and World War II the quantity of products made with steel casting multiplied in Germany, during the First World War mainly for producing grenades (Wetzck, Dogru 2013).

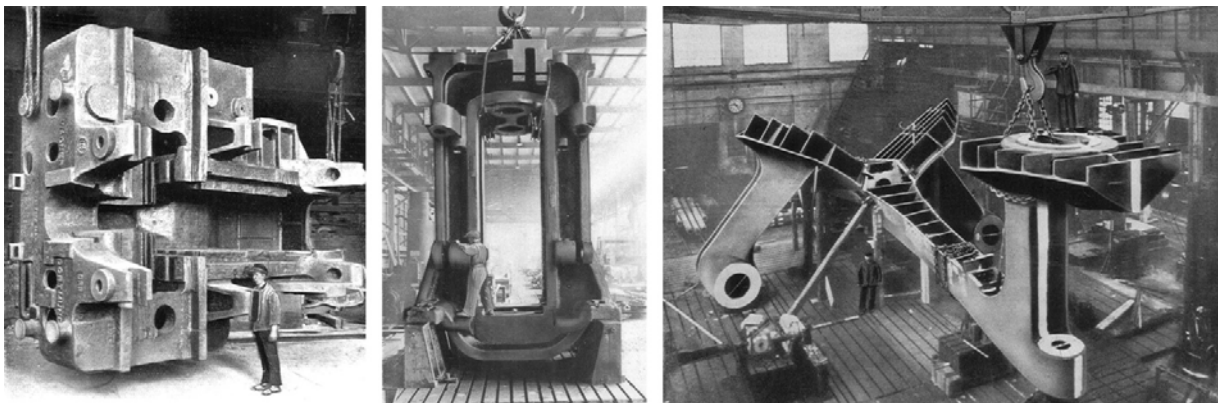


Figure 4: Selection of steel castings cast at about 1930 (Bertram 1938)

## STEEL CASTINGS IN CIVIL ENGINEERING

Next to the employment of steel castings in mechanical engineering, the amount of such products in the field of civil engineering has always been but small. However, building also relies on steel castings, when it comes to crucial structural elements with high demands in terms of structural safety and with a geometrically complex design. In the recent past steel castings have had something of a Renaissance, since they are increasingly being used for large joints with complex geometry in wind power plants or bridges.

In structural engineering the bearing technology was a very early instance of appropriating steel castings. Beginning in the 1870s the irregular geometrical shapes of tilting plates and bearing plates were the field, where steel castings became a serious competitor for the last domain of iron castings in bridge building. By 1880 steel castings were ranked as an excellent, albeit expensive substitute for cast iron, since costly crucible castings were still the only accepted material in bridge building at that time; the increasingly popular Martin steel had not yet reached the

quality level required for steel castings (Mehrtens 1882, 212f). Finally, by 1890 Martin steel had superseded crucible steel for castings in many places in Germany (Ledebur 1891, 453). This process is revealed in the bearings of the second Dirschau Bridge (1889–1891) crossing River Weichsel: The pivots and stilts with a simple geometric design and to absorb heavy loads were forged from expensive crucible steel ingots, whereas the other main parts of the bearings already were Martin steel castings (Goering 1890, 334f.). (fig.5)

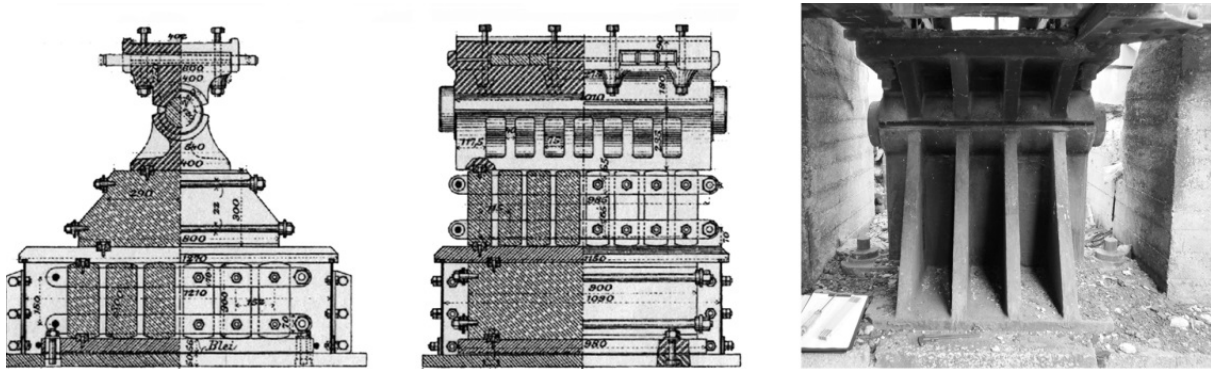


Figure 5; left: Moveable bearing of the Dirschau Bridge (1889-1891) (Anon 1895); Right: Fixed Bearing of the Hamburg Brooks Bridge (1887) (Lorenz & Co., Berlin)

Establishing steel casting as the dominant mode of production also resulted in a specific geometry for the cast bearing parts. Initially the moulds established for iron casting were used (Krieger 1918, 350), but soon foundry practice required castings with an almost equal thickness. Plates with stiffened ribs became characteristic for bearings cast with steel; an example is shown in figure 5 at the fixed bearings of the Brooks Bridge (Hamburg, 1887). This measure served to avoid large shrinkage holes. Nevertheless massive bearing castings without ribs were used well into the 20<sup>th</sup> century. If the casting was performed incorrectly, such bearings might contain significant shrinkage holes (fig. 6).

Steel casting was often the procedure of choice for bearings, since the material has a much higher tensile strength than cast iron. Table 1 is a brief synopsis of selected results from an analysis of bearings' parts for the period covered by this paper.

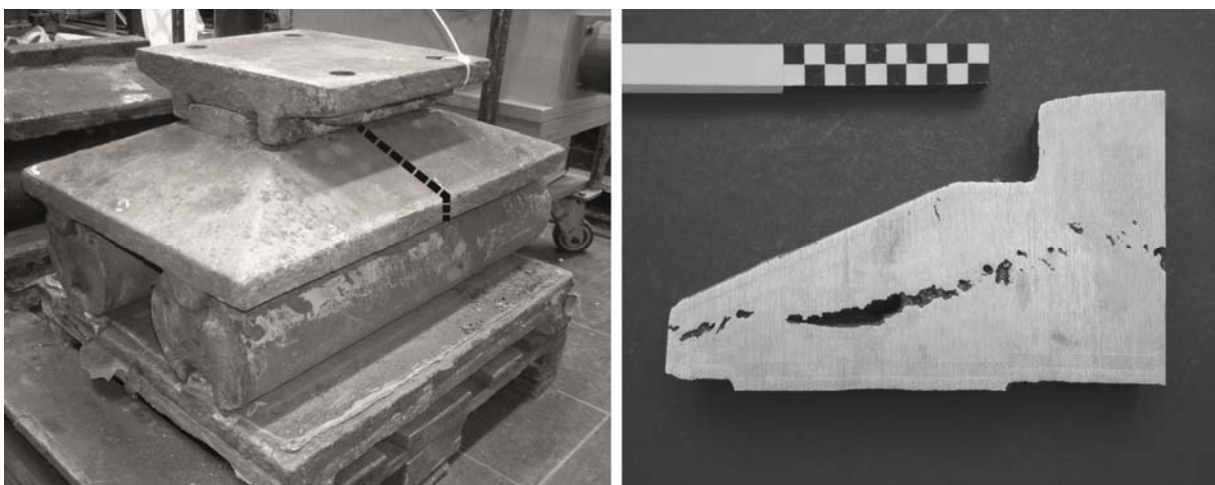


Figure 6; left: Moveable bearing of the Berlin elevated railroad line No.2, bearing cast c.1939; Right: Slice taken out of upper bearing plate as indicated dashed in left figure revealing large shrinkage hole (Miene 2013)

Year	Object	Number of bearings analysed	Tensile Strength [N/mm <sup>2</sup> ]	Elongation [%]	Chemical Analysis (excerpt) [%]			Reference
					C	Mn	Si	
c.1890	Dirschau, Weichselbridge	N.N.	450...550	9...24	0.35	0.60	0.25	(s 1889)
c.1905	Wiesbaden, Main station	1	414	28	0.19	0.78	0.24	(Wetzck 2013)
c.1910	Berlin, Elevated Metro Line 2	10	586...656	16...25	0.43...0.56	0.78...0.85	0.25...0.42	(Wetzck 2013)
c.1927	Berlin, Elevated Metro Line 2	1	449	31	0.31	0.58	0.32	(Wetzck 2013)
c.1939	Berlin, Elevated Metro Line 2	1	449	23	0.60	0.65	0.28	(Miene 2013)

Table 1: Selected results from analysis of bearing steel castings (averages of individual measurements)

It has to be borne in mind that steel castings were indispensable elements of bridge bearings well into the 1960s. So this table cannot represent a statistically sound interpretation of these bearings in their entirety. However, compared with the complex requirements the foundries had to cope with from the field of mechanical engineering (see fig. 4), the technical specifications for the production of bridge bearings were modest, in particular thanks to their simple geometric design. In addition the above analysis of the bearings indicates a variation of the chemical components and mechanical properties within unproblematic boundaries.

Maybe this led to something of a “routine attitude” among steel foundrymen, when it came to cast bridge bearings causing imprecisions during production, which in turn could lead to significant structural flaws under certain circumstances. It has to be kept in mind that efficient methods to prevent shrinkage holes had been known for a long time, when the bearing shown in figure 6 was cast.

## CONCLUSIONS

By the second half of the 19<sup>th</sup> century casting supplemented forging and rolling as a third procedure for shaping steel. Initially it was quite expensive and not used very often. However, by the year 1890 it had come to conquer many fields of industry by virtue of being a very reliable option to produce even huge and complex-shaped elements. At the turn of the century a lot of steel foundries offered a wide range of castings in a variety of sizes, weights and geometries as well as with specific material qualities.

In structural engineering steel castings were very soon used for bearings. Substituting cast iron, this material was able to comply easily with the increasing demands in bridge bearing technology. However, if compared with the products required from foundries for applications in mechanical engineering, the shape casting of bearing parts was no big challenge.

Nowadays, for a structural assessment of those bearing castings the routine status at production may be comforting, since a problem-free fabrication can be assumed. On the other hand material analysis of historic bearings revealed that even parts with very simple geometries possessed serious volumetric flaws. In the case of non-destructive in-situ-inspection the detection of such flaws is a challenge by itself, but even more so the adequate assessment of them, which is often an issue of keeping a historic bearing in its place or not.



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