Manufacturing process management for cast iron brake blocks

F Bucur, A Josan, A Socalici and O Gaianu

Politehnica University of Timisoara, Department of Engineering and Management, 5 Revolution Street, Hunedoara, 331128, Romania

E-mail: flavius_bucur@yahoo.com

Abstract. In order to insure a proper management in cast iron foundries it is necessary to coordinate all the processes that are involved in manufacturing cast parts. The organisation management offers the necessary conditions for developing activities, with great emphasis on the activity of quality control. The paper presents the necessity of establishing a management strategy which can lead to the supervision of the entire manufacturing cycle of cast iron brake blocks for rolling stock. To this end, it is necessary to measure, monitor and analyze the results obtained in the industrial practice and to compare them with product standards.

1. Introduction

The process of casting parts plays an important role in manufacturing machinery, equipment and consumption goods. The insurance of proper management in casting foundries also represents the key to medium and long-term success. To this end, it is necessary to control all the processes involved in casting brake blocks made of cast iron. Quality is a key indicator in any organisation. The arguments supporting this statement are linked to the fact that the quality of a product is influenced by all the composing departments of an organisation, but it also has an influence upon them. Thus, the management of a casting foundry needs to keep in mind that quality insurance must be at the centre of the foundry manager’s attention. The organisation management sees to insure the necessary conditions for developing activities, with great emphasis on the activity of quality control. The activity of quality control in the departments of a casting foundry is one of the most complex compartments of quality control in general. Besides inspecting the ways in which raw materials and auxiliary materials are used, it is necessary to supervise the manufacturing cycle as well, in order to intervene for diminishing the loss of material through waste. The management strategy relies on: defining an objective as well as planning actions and means to reach that objective; carrying out the activity of planning; verifying whether the result corresponds to the demands; making the necessary corrections to achieve the objective [1]. Applying the management strategies in the departments of a casting foundry results in identifying all the nonconformities registered and in removing/preventing them.

The flaws in the cast parts are the result of either objective or subjective causes which occur during the technological casting process, from conception to delivery. By flaw we mean any deviation from shape, size, mass, exterior appearance, macrostructure, microstructure or mechanical and chemical properties prescribed by standards or other contractual conditions. The notion of flaw in a cast part is submitted to differing conventions, as the same flaw may be acceptable, unacceptable or reworkable, depending on technical conditions prescribed by standards or by contracts. Most flaws in cast parts
occur as a result of an inadequate casting technology, and some of the most important flaws are porosities, superficial holes or cracks [2], [3].

Cast iron, which has very diverse forms of graphite, very good casting properties and a wide range of characteristics, has always been the most employed casting metal. The use of cast iron derives from an increased demand for cast iron parts in the renewable energy department and the transport department, as well as in heavy equipment production [4]. The phases of the graphite in the cast iron develop together with the metal matrix during the solidifying process. Understanding and controlling the structure of the graphite, as well as its numeric density and morphology, are essential to the properties of the cast iron. The size, distribution, crystallography and shape of the graphite particles may be controlled by directing the solidification process and adding modifying elements such as Mg, Ti, Ce, etc. [5], [6].

2. Phosphorous cast iron made for casting brake blocks
When gray cast iron is alloyed with phosphorus and solidifies, the phosphorus in the structure is found mainly under the form of ternary phosphorous eutectic, made of: solid solution \((\text{Fe} - \text{C} - \text{P})\), iron phosphide \((\text{Fe}_3\text{P})\) and cementite \((\text{Fe}_3\text{C})\), with the following chemical composition: 1.96-2.40\% C, 6.89\% P, 90.71-91.15\% Fe.

Due to a low solidifying temperature (under 1000°C), the phosphorous eutectic will be distributed in the intercellular gaps, with isolated segregations (under 0.2\% P), in the form of a discontinuous lattice (0.4-0.6\% P) or a continuous one (over 0.6\%P), depending on the phosphorus content. The phosphorous eutectic is characterised by an increased hardness (500-600HB) and high brittleness \((\sigma_r = 30-70 \text{ N/mm}^2, \ A \approx 0)\), the reason for which it greatly influences the properties of the cast iron [7]. The quantity of phosphorous eutectic in the cast iron is directly dependent on the phosphorus content, being also influenced by the factors which increase the segregation tendency of the phosphorus.

Another particularity of gray cast irons with eutectic solidification consists in the presence of certain areas inside the eutectic cells, namely at their core, which are rich in phosphorus. The eutectic cells display specific structures in gray phosphorous cast iron [7]:
- arched graphite layers, ranging in size and with a regular layout, respectively very fine layers at the centre, fine layers in the middle and thick layers at the exterior of the eutectic cells;
- the presence of graphite layers in the intercellular gaps, belonging to neighbouring cells;
- phosphorous eutectic segregations (usually ternary) in the intercellular gaps;
- areas which are rich in phosphorus at the core of some eutectic cells combined with very fine graphite.

Phosphorous gray cast irons are extremely sensitive to the formation of porosity areas of central contraction. This process is emphasized by the graphitisng change of these cast irons, much more so as the number of eutectic cells tends to increase. Thus, the graphitisng change of this type of cast iron is a problem, having a positive influence when it comes to eliminating carbides, but a negative one by emphasising central porosity, especially micro-porosity. This aspect is mainly particular to gray cast irons because of the micro-cavities caused by contraction, which occur in the intercellular gaps, but it is heavily emphasised in the case of phosphorous cast iron, as these gaps solidify at low temperatures, resulting in phosphorous eutectic segregations.

Main braking systems with brake blocks or discs achieve friction force based on coulomb friction which takes place in the friction couplers of the rolling stock. Brakes with brake blocks are usually equipped with cast iron brake blocks or composite brake blocks. Brake blocks made of phosphorous cast iron are mainly used for rolling stock which runs at speeds of no more than 140km/h. Establishing the quality of the brake blocks while functioning is done according to the following criteria [7], [8]: the stability of the braking path, the lowest specific wear degree, the highest thermal load capacity, the lowest tear sensitivity possible and low tendency of igniting sparks.

When manufacturing brake blocks intended for rolling stock, phosphorous cast iron P10 is most widely used. These brake blocks have limited usage as their friction coefficient decreases notably when braking at high speed, and the wear caused by the tendency to jam increases as the temperature...
in the friction coupler rises [9]. Gray cast iron is a pearlitic cast iron with high phosphorus content. A ternary phosphorous eutectic, called steadite, can also be found in its structure. It is made of pearlite, cementite and iron phosphide $\text{Fe}_3\text{P}$ [10]. The strong resistance of the cast iron is given by its pearlitic metallic mass, so the pearlite-cementite cast iron and the phosphorous cast iron have the highest hardness. The high vibration absorption capacity is given by the ferritic metallic mass, which holds the maximum quantity of graphite possible [9], [10].

Cast iron that bears higher quantities of phosphorus has good casting properties and is used for casting parts which have thin outer layers or parts which are wear-resistant under dry or wet friction conditions. An example of such cast iron parts are the brake blocks made for rolling stock.

The shapes, sizes and dimensional tolerances of the brake blocks and of the reinforcement strips for train wagons are compliant to the following specifications [4], [9], [10-12]:

- STAS 109 – 86 Brakes for railway wagons with normal gauge. Brake block holders with removable brake blocks. Measures, with the exception of brake block S3, which has a length of 380 mm;
- Sheet UIC 542 – O Brake parts;
- Manufacturing drawing for wagon brake blocks made by the Public Documentation Service, namely CFR V.08 – 01.00.0/C and authorised by the Romanian Railway Authority, the National Passenger Railway Transport Society and the National Freight Railway Transport Society.

Types of brake blocks for engines and freight/ passenger wagons (Figure 1) [13]:

- S1 – brake blocks size 1 for freight/ passenger wagons;
- S2 – brake blocks size 2 for freight wagons;
- LDH – brake blocks for 1250 HP Diesel hydraulic engines;
- LDE – brake blocks for 2100 HP Diesel electric engines;
- LE – brake blocks for 5100 kW and 3400 kW electric engines.

![brake blocks](image)

**Figure 1.** Types of brake blocks for engines and freight/ passenger wagons [13]

3. **The process of manufacturing brake blocks**

The process of manufacturing brake blocks type S2 used in the transport industry (motor and towed rolling stock) is presented in Figure 2.
The foundry department is supplied with modern equipment such as: three electric induction furnaces - two with a 2 ton capacity and one with a 5 ton capacity, an automated moulding machine with an air pressing current- HFP 2 model, and a semi-automated casting line for manufacturing SNCFR brake blocks, type P10, sizes S1, S2 and S3, made of phosphorous cast iron for railway motor and towed rolling stock.

The cast parts are approved and the supplying services are authorised by the Romanian Railway Authority, AFER.

The number and the succession of the operations required in the manufacturing process depend on the nature of the alloy which is being cast and on the type of the moulding-casting procedure. The casting procedure used in this case is casting into rough moulds, which are mechanically compacted – raw casting.

The technological process of raw casting has three process flows, as follows [14-18]:
- the process flow of preparing the mixtures for obtaining the moulds (Figure 3);
- the process flow of obtaining the liquid alloys (Figure 4);
- the process flow of detaching and cleaning the cast parts (Figure 5);

*The technological process of obtaining the raw moulds* includes the following operations:
- the processing of the raw materials in order to prepare the mixtures for the moulds;
- preparing the mixtures for the moulds;
- the execution of the moulds and the cores;
- the assembly and fastening of the moulds for casting.

*The technological process of melting and obtaining the liquid alloys* is different from one alloy to another, depending also on the nature of the furnaces and the raw material used. This technological process usually includes:
- preparing and dosing the metallic and auxiliary load meant for obtaining and melting the alloys
- melting and correcting the chemical composition and the temperature of the charge, and
- the actual casting into moulds.

*The technological process of detaching, cleaning and inspecting the cast parts* includes the extraction of the parts from the moulds after they have solidified and cooled, the removal of the runners and feeders and the preparations for shipment, according to the technical requirements and the directions provided in the cast part drawing. This processing refers to applying heat treatment in order to correct the structure and relax it, cleaning the surfaces, adjusting and correcting surface flaws and, possibly painting the parts.
Figure 3. The technological process of preparing the moulds

Figure 4. The technological process of obtaining and casting the liquid alloy

Figure 5. The technological process of detaching the brake blocks
4. Methods of checking and testing the quality of brake blocks
For the quality analysis of the brake blocks made of phosphorous cast iron there has been taken data from 70 industrial charges, obtained in a brake block production factory.

The management system in the casting foundry insures the existence of procedures and work instructions which establish the quality checking and testing methods of the brake blocks made of phosphorus cast iron throughout the technological process. To this end, it is necessary to follow the next stages:

4.1. Checking the chemical composition of the brake block material and of the reinforcement strip
The chemical composition check of the cast iron and steel used when manufacturing brake blocks is done according to standards in force. The brake block manufacturer must provide the beneficiary with a certificate of the results of the chemical analysis. The chemical composition check needs to be made by an AFER certified laboratory.

The data referring to the standard chemical composition of the obtained cast iron, as well as the experimental data is presented in Table 1. From the analysis of the experimental data it is noticeable that the chemical composition meets the product standard. The chemical and structural homogeneity of the brake blocks leads to small variations in hardness values, which translates into small variations in durability while using the brake blocks.

| Conditions  | Values     | Chemical composition, [%] | Cr+Mo+Ti+Nb+V+W |
|-------------|------------|---------------------------|----------------|
|             |            | C  | Si  | Mn  | P   | S   |                  |
| Standard    | maximum    | 3.30| 2.00| 1.00| 1.10| -   | -                |
|             | minimum    | 2.90| 1.20| 0.33| 0.80| -   | -                |
|             | average    | 3.1 | 1.60| 0.665| 0.95| -   | -                |
| Experimental| maximum    | 3.30| 1.94| 0.71| 1.09| 0.12| 0.22            |
|             | minimum    | 2.90| 1.20| 0.45| 0.80| 0.02| 0.09            |
|             | average    | 3.08| 1.52| 0.58| 0.98| 0.05| 0.14            |

4.2. Checking the appearance, shape and size of the brake blocks
Checking the geometrical characteristics refers to checking the appearance, shape and size of the brake block. Checking its appearance is done visually, with the naked eye or by employing ordinary measuring instruments for determining possible casting flaws. Checking the shape and size is done by using universal measuring instruments with calibrated templates.

4.3. Testing the Brinell hardness
Testing the hardness is done according to SR EN ISO 6506-1:2006.

Measuring the hardness is done:
- In one point for each extremity of the block, on its side, after removing 2mm of material by polishing or milling;
- In three points of the diagonal, on the surface of samples resulted from sectioning brake blocks which have broken during shock resistance testing;

Any value that is below the required minimum, which might result from an irregularity on the broken brake block or a porosity, leads to another breaking attempt on the same brake block or to the replacement of the whole lot of brake blocks.

Table 2 presents the data referring to variations of hardness for brake blocks, which has been determined according to SR EN ISO 6506-1:2006, both on the surface of the brake block (HBs, Hbd), as well as its cross section (HBss, HBsc, HBsd) in the measuring points specified by standards. The average values of hardness on the block surface (HBs+Hbd)/2 and its cross section (HBss+HBsc+HBsd)/3, as well as their difference are presented in Table 3.
From the analysis of the data it can be observed that there are small variations of hardness measured on the side surface and cross section of the block, respectively their average. This is due to a minor variation in the chemical composition of the brake blocks. With respect to the difference in hardness, measured on the side surface and cross section, the resulting values are relatively small, which indicates a good chemical homogeneity of the blocks. The values of the obtained hardness during industrial experimentation fall within the value range of 197-255 HB, being in compliance with international standards UIC 830-O.

Table 2. Hardness of sampled brake blocks

| Values | According to the tender specifications No.1/SFMR/SDT/2000 [HB] | Hardness according to SR EN ISO 6506-1:2006, [HB] |
|--------|---------------------------------------------------------------|-------------------------------------------------|
|        | HB_s  | HB_d  | HB_ss | HB_sc | HB_sd | HB_sd |
| maximum| 255    | 255   | 255    | 248    | 230    | 255   |
| minimum| 197    | 197   | 198    | 197    | 198    | 200   |
| average| 226    | 225.87| 226.00 | 222.66 | 212.90 | 225.91 |

Table 3. Average hardness and hardness difference for the experimental samples

| Values | Hardness, average values on the side surface and cross section (HB_s+HB_d)/2 | Hardness, differences on the side surface and cross section (HB_s+HB_d+HB_sc)/3 | | HB_s-HB_d | HB_ss-HB_sd |
|--------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------|-----------------|----------------|----------------|
| maximum| 264.50                                                                      | 243.30                                                                         | 18.00           | 19.00          |
| minimum| 197.50                                                                      | 197.30                                                                         | 0.00            | 0.00           |
| average| 226.36                                                                      | 217.16                                                                         | 5.50            | 5.30           |

4.4. Testing for shock resistance of the brake block and reinforcement strip, checking the resistance of the reinforcement strip; checking the appearance of the fracture

For shock resistance testing, the brake block needs to have the same temperature as the environment. The testing is done at temperatures above 0°C.

The brake blocks broken during shock testing are kept until the entire lot is examined and approved. The examination of the fracture in the cast iron is done using a magnifying glass with a 5x magnification. Checking the resistance of the reinforcement strip is done manually, by pulling cast iron pieces of the brake block broken during shock testing.

4.5. Testing the bend of the reinforcement strip

For reinforcement strips thicker than 3 mm, the bending test will be done according to specifications in SR ISO 7438:1993, for a simple full 180° bend, with a spacer; the spacer will be 25 mm high.

4.6. Checking the condition of the grip and the positioning of the reinforcement strip

The condition of the brake block’s grip is checked with the naked eye or by using magnifying glasses with various magnifications. The visible length of the reinforcement strip, its positioning and its type are checked using factory measuring instruments adapted to the magnitude and precision order required.

The brake blocks have to be resilient, without cracking or breaking at the first loading shock, or during the shock resistance testing of the brake block and the reinforcement strip, or during the checking of the resistance of the reinforcement strip, respectively during the checking of the appearance of the fracture. After the next shock(s) are administered in order to break the brake block, the reinforcement strip must remain whole and keep the broken cast iron pieces together; the grip of the block can, however, detach, but without showing any structural flaws. The reinforcement extracted from the brake block made for motor and towed rolling stock needs to pass the bending test defined
through ‘testing the bend of the reinforcement strip’, without cracking or breaking. It is necessary to do this testing only when certifying a new supplier or when homologating brake blocks, or when there have been deflections from the manufacturing standards for quality, or in the case of changes in the process or the products used for superficial protection of the reinforcement.

4.7. Checking the metallographic structure

Examining the metallographic structure is done:

- by microscope with 100x magnification, on polished test tubes without chemical attack, for graphite check;
- by microscope with 200x, 50 or 100x, respectively 25 or 50x magnification, on the same test tubes attacked with nital (an alcoholic solution with 4% nitric acid), for examining the structure, with a normal attack time for checking the pearlite and ferrite, and with a longer attack time for checking the phosphorous eutectic lattice.

The brake blocks are made even and sanded, all leakage traces, airing ducts and feeders are removed, as well as any other visible casting flaw that could affect the assembly or usage of the brake blocks. The prominences left are no higher than 2 mm and present a risk during manipulation of the brake blocks.

Casting flaws (superficial holes, voids), with the exception of mechanical and nonmechanical inclusions, are accepted on the surface of the brake block (except for the center) and inside the fracture, after shock testing, only between the following limits [4], [8]: one flaw with a maximum diameter of 10 mm or multiple flaws with diameters smaller than 10 mm, which have the area sum below 10 mm² of the whole surface of the brake block. After shock fracturing, the fractured areas of the analyzed brake blocks have a homogeneous ash-coloured appearance. The reinforcement strips do not show any overlaps of material or surface flaws.

5. Conclusions

The concept of quality in modern competitive economy is specific to humans and their activities. It defines their place and role in society. Quality is both a purpose and a result, an aim which is achieved and overreached through the quality of the factors which accomplish the design, execution and distribution of the products, as well as the providing of services.

The flaws of the cast parts are consequences of either unique causes or mutual actions of complex origins, each of these depending, in turn, on a great number of specific variables (i.e. two flaws with a totally different external appearance may have one or more common causes).

In the case of brake blocks, we can encounter the following flaws: superficial holes, voids around the sprue, local indents, roughness, lack of material, inclusions in the moulding mixture. In order to prevent such flaws, the following measures are recommended:

- using a well-prepared, homogeneous mixture, with a normal moisture and uniform spread;
- stuffing the mixture uniformly throughout the mould (usually, mechanized moulding ensures a uniform stuffing of the mixture);
- drying the moulds or chemically hardening the moulding mixture;
- using a binder which can ensure a higher superficial resistance of the moulding or core mixture;
- high permeability of the mixture;
- adding organic substances and coal dust which, on heating, become a paste that gives the mixture a certain degree of plasticity.

In conclusion, obtaining superior quality cast parts that have minimal flaws is conditioned by drawing up a correct fabrication technology, accompanied by the strictest technological discipline.

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