Gears castings from ductile iron of improved abrasion wear resistance

D. Kopyciński* a, E. Guzik a, A. Siuta b, K. Siuta b

a AGH - University of Science and Technology, Kraków, Poland
b ASPAMET – Cast Iron Foundry, Oświęcim, Poland

*Corresponding author. E-mail address: djk@agh.edu.pl

Received 01.07.2011; accepted in revised form 27.07.2011

Abstract

The aim of this study was to develop an industrial technological process for the manufacturing of castings from alloyed ductile iron characterized by improved resistance to abrasion wear. The outcome of the study was the implementation of developed technology under the industrial conditions of ASPAMET Foundry Plant and start up of production of a wide range of cast gears.

Keywords: Ductile Iron, Gears, Casting Defects, Pearlitic Matrix, Ausferritic Matrix

1. Introduction

Ductile iron continues being one of the most modern cast materials. Due to its excellent technological properties it has found a way to general technical applications and right now is the material of choice more and more willingly used by designers. In Europe, the largest use of ductile iron is in the automotive industry (36%), in the production of industrial valves (32%), in the construction industry (16%) and for parts of machines (4%).

Modern technologies used in iron foundries combined with the processes of heat treatment and machining operations increase the competitiveness of this type of material in relation to other alloys. The share of all types of ductile iron castings in the total production of ferrous alloys is at present regarded as an indicator of how advanced the local foundry industry is and how modern the foundry plants are. Globally, since 2000, a systematic growth in production volume of ductile iron to about 30% of the overall production of cast iron has been reported. In Poland, since 2003, a significant increase in the production of ductile iron has been observed, and right now it covers over 20% of the total domestic production of cast iron (according to Modern Casting, Dec. 2010 - the produced volume of cast iron with flake graphite was 570 thousand tons; ductile iron - 167 thousand tons). In the past few years, i.e. since 1992, the production volume of ductile iron in Poland increased by over 50% and continuation of this upward trend is to be expected.

Due to the very advantageous functional and casting properties, ductile iron can be a substitute for other cast alloys such as steel and alloyed cast iron, or even aluminium (thin-wall castings of ductile iron), which is also justified economically.

An important role in shaping of the structure and hence the performance properties has the crystallisation of graphite eutectic and pre-eutectic (primary) dendrites of austenite, as shown in [1-5].

From the past experience in production of iron castings, it follows that ASPAMET Foundry Plant specialises rather in alloyed cast iron and cast steel, and produces in minor extent the grey cast iron with lamellar graphite. Yet, to increase their competitiveness, they have recently undertaken the task of launching the production of ductile iron castings for the engineering industry. An example of this activity are cast gears and continued attempts to replace cast steel with ductile iron for castings used in the construction industry. Currently, reporting an increased demand for ductile iron castings and growing quality requirements from potential suppliers, the ASPAMET Foundry...
Plant has been forced to take action and improve the currently used process of ductile iron castings manufacture.

This study discusses the structure and certain aspects of the manufacture of ductile iron for gears. In addition, to ensure optimum performance of gears cast from this iron grade, parameters of their heat treatment were developed experimentally. The gears cast from ductile iron are, moreover, resistant to fatigue cracking.

2. Methodology

Proper selection of charge materials is a must in production of ductile iron and ADI [6]. Specifically, under the conditions of ASPAMET Foundry Plant, due attention was paid to the low content of sulphur and phosphorus. Both these elements have a very negative impact on the outcome of the spheroidization process, and the latter element, segregating on the eutectic grain boundaries can increase significantly its concentration, compared with the initial content in base cast iron.

Table 1 gives the composition of base cast iron for further spheroidisation and use in the manufacture of gears.

Table 1.
Proposed composition of base cast iron for further spheroidisation

<table>
<thead>
<tr>
<th>Designation of cast iron grade</th>
<th>Chemical composition, wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 1563</td>
<td>Cu was additionally introduced</td>
</tr>
<tr>
<td>EN-GJS-600-3</td>
<td>3.6-3.9</td>
</tr>
<tr>
<td>PN-88/H83144</td>
<td>Cu should be additionally introduced</td>
</tr>
<tr>
<td>ZsCu1.0</td>
<td>3.3-3.9</td>
</tr>
</tbody>
</table>

Table 1 gives the starting composition, considered during the research. Ductile iron melts were conducted in an induction furnace at the ASPAMET Foundry Plant applying the following parameters: overheating temperature - 1510°C, time of holding the melt at that temperature - 5 min, reducing the bath temperature to 1450°C, spheroidisation and inoculation at 1420°C, mould pouring at 1380°C.

Castings of the type shown in Figure 1 were produced.

It can be predicted that castings like the item shown in Figure 1 will suffer from the compressive thermal stresses in the rim, and tensile stresses in the arms. The effect of these stresses will be deformation of the rim, as shown schematically in Figure 2.

To ensure simultaneous solidification of casting and its contraction, appropriate mould technology was applied and thermal conductivity was raised in selected places of the casting. After cooling and knocking out of castings, it turned out that the produced cast part was sound and free from the previously occurring depressions, deformations and shrinkage cavities in the hot spots.

So, as a next stage, the castings of gears were manufactured (Fig. 1) from ductile iron according to the developed technology and optimised chemical composition. Cast iron was melted in a medium frequency induction furnace with crucible of 250 kg capacity. Metal charge consisted of process scrap - 45%, steel scrap - 50%, pig iron - 5%. The inoculant was SB-5 added in an
amount of 0.5%. The spheroidising treatment was performed with NiCuMg17Ce master alloy added in an amount of 1.2% respective of the metal net weight. Spheroidising was done by pouring metal over the master alloy placed on the bottom of the ladle. From the cast gears specimens were cut out (Fig. 3) for metallographic examinations and mechanical tests.

In addition, a special heat treatment was carried out to improve the mechanical properties of the investigated castings. Hardness measurements were taken by Brinell technique on four cast gears in raw condition and on four cast gears after heat treatment. The requirements for test conditions, hardness measurements and reference samples are determined by PN 91/H 04350, PN EN ISO 6506-2, and PN EN ISO6506-3, respectively. Measurements were carried out using the indenter of a D = 30 mm diameter and a coefficient K = 30, which gave force F = 2943 N. The specimens were subjected to hardness measurements taken at three different locations. Additionally, the tensile strength Rm was measured.

3. Results of investigations

The cast iron used for gears was characterised by a pearlitic metal matrix with spheroidal graphite, shown in Figure 4.

Figure 5 shows the microstructure of cast iron after heat treatment.
Hardness was measured on samples of cast gears before and after the heat treatment to see how the developed and proposed heat treatment regime affects changes in the structure of the ductile iron gears (Fig. 5). The analysis of the results leads to a conclusion that heat treatment has a beneficial effect on the mechanical properties of castings without the risk of the formation of high stresses. Average values of hardness in samples before heat treatment reached 255 HB units, while in heat-treated castings this value was 444 HB units. Thus, hardness in heat-treated samples almost doubled due to the formation in structure of a beneficial ausferritic matrix. The tensile test was carried out in parallel on a testing machine. As a result of tests carried out on the cast gears, the following parameters of the mechanical properties were obtained: $R_m = 629$ MPa, $A_5$ - 3.5% - average for the four castings without heat treatment, $R_m = 1167$ MPa, $A_5$ - 4.0% - average for the four castings after heat treatment. The results described above indicate that heat treatment can be recommended for castings of this type. It is worth noting that the ductility of castings after the proposed heat treatment has slightly improved, and the elongation increased from 3.5% to 4.0%. While working on the implementation of castings for gears under the industrial conditions of ASPAMEP Foundry Plant also the problem of casting defects, like porosity, shrinkage cavities, etc. was solved. Examples of defects formed in the test castings are shown in Figure 6.

![Fig. 6. Typical defects in cast gear; actual view – (a) and expected location of porosity in the upper part of casting– (b)](image)

As a result of careful analysis of the physico-chemical state of the liquid metal and proper mould design, a final product in the form of the required casting was obtained. So, analogically, in the nearest future, the ASPAMEP Foundry Plant should be able to implement the production of gears cast from ductile iron free from any defects with or without heat treatment.

4. Summary

Following this study it should be noted that the mechanical and technological properties of ductile iron depend on its structure, and hence on the type, shape and content of the crystalline phases. The structure of ductile iron is also influenced by the physico-chemical state of liquid metal, the rate of cooling and solidification, and heat treatment. The study showed that in the production of ductile iron a great impact on the structure is exerted by the technological parameters such as charge materials, pouring temperature and metallurgical treatment, i.e. spheroidising and inoculation, which directly affect the solidification and cooling rate, and the physico-chemical state of molten metal. An additional tool in structure control can be heat treatment.

As a result of this work, a technology has been developed for the industrial production of gears cast from ductile iron with an addition of copper, characterised by improved abrasion wear resistance. The quality requirements for cast iron are consistent with the requirements of PN-EN-1563.

References