APPLICATION OF NODULAR CASTINGS IN THE MODERN INDUSTRY
OF TRIBO-MECHANICAL SYSTEMS TODAY AND TOMORROW

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Abstract: Contemporary technology in mechanical engineering and modern industry makes use of many materials that posses’s specific characteristic, for example, materials that are resistant to wear and with particularly high durability properties. Such a rare combination of properties like the great durability, toughness and wear resistance is contained in the bainite-austenitic structure of the nodular casting. This enables great economizing possibilities by replacing of steel materials with isothermally upgraded nodular castings.

The paper gives an example of the application of isothermally upgraded nodular castings in machine-made constructions.

Keywords: nodular cast iron, bainite, austenite, wear resistance, toughness

1. INTRODUCTION

Nodular cast iron is a new structural material that replaces carbon steel, gray and tempered cast iron, since this material is suitable for made out thin wall castings, and castings weighing up to 150,000 N as well [1].

Nodular cast iron with respect to the exploitation properties has wide application in the motor industry, agricultural machinery, ship building, power industry and rolling stock industry. It is suitable for producing loaded machine elements, e.g. crankshafts, piston rod, camshaft rod, various housing of turbines and pumps, etc...

Especially tough (modular) iron is for years used instead of cast iron and cast steel for a given range of structural elements, however, only in 1976 The General Motors Co. (USA) first announced that hypoid gear, its drive gear and its pinion differentials in some vehicles are manufactured from isothermal improved ductile iron instead of, as hitherto, cement steel (cementing and tempered). For the gear is required mechanical properties combination as following:

- high tensile strength
- good dynamic toughness
- high resistance to wear,
- good ductility and impact resistance (toughness) [2]

The Switzerland renowned manufacturers Sulzer and Georg Fischer developed each, their quality ductile iron heat treated on the bainite based structure with a relatively high proportion of retained austenite. In a joint research project of BMW Munich Institute for Research of gear of the Technical University of Munich and Switzerland Company Georg Fischer examines the application of the cast austempered ductile iron gears and other automobile parts.

In the last ten years in the world is also a trend of expansion of austempered ductile iron in modern means of transport that can meet the demands of highly dynamic loaded elements.

In this way, performed is the substitution of forgings, rolled steel sections and steel castings - with corresponding savings in production costs and increase productivity.

2. PROPERTIES AND THE COMPARATIVE VALUE OF DIFFERENT NOFULAR CAST IRONS

Properties of ductile cast iron priority depend on the structure of the metal base, as well as the quantity, size, layout and shape of nodular graphite inclusions. Side effects of graphite are explained in that the inclusions of graphite, because of its low mechanical properties, acting as many micro-notches which generate significant strain in the stress concentration and thus reduce the overall strength.

Increase of the strength and the other properties of ductile iron explains the facts, however, that graphite inclusions in the metal base form "nodules" (spherical or spheroidal shape) reduce the stress around inclusions of graphite nodules, and that this form of graphite has the lowest ratio of surface to the volume and has the graphite content at least a certain cross-section weakening.

As in, cast iron chemical composition is a very important factor that determines the properties of ductile cast iron, because the composition of the associated changes in the shape of graphite and metal base. In addition, a greater influence on the mechanical properties of nodular iron shows the structure of the metal.
base and impact of the carbon inclusions is smaller than gray cast iron with lamellar shape graphite. Due the structure, in addition to the cooling speed, is dependent on the concentration of certain chemical elements the previous test are carried out in order to determine the most appropriate amount of the individual chemical components in the nodular cast iron.

2.1 The default value

For comparative values it is important to mention standard of prescribed sizes and quantities obtained in the tests performed and the literature data. It is necessary to analyze the structure of the metal base upon which depends properties like: strength, plasticity, but certainly shape, size and distribution of graphite nodules have a significant impact.

In Table 1 are standards values are given:

- mechanical properties are not related to the wall thickness more than 100 mm
- these values are obtained in a test specimens with a V notch at an ambient temperature (23 ± 5°C)

<table>
<thead>
<tr>
<th>Mechanical properties</th>
<th>Type</th>
<th>Tensile strength Rm min N/m²</th>
<th>Conventional tension load Rm0,2 min</th>
<th>Percentage elongation after break</th>
<th>The minimum value of energy impact</th>
<th>Approximate value of hardness HB</th>
<th>The primary structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average values of three tubes</td>
<td>Individually</td>
<td></td>
</tr>
<tr>
<td>EN-GJS-350-17</td>
<td>370</td>
<td>230</td>
<td>17</td>
<td>13</td>
<td>11</td>
<td>do 179</td>
<td>ferit</td>
</tr>
<tr>
<td>EN-GJS-400-12</td>
<td>400</td>
<td>250</td>
<td>12</td>
<td>.</td>
<td>.</td>
<td>do 201</td>
<td>ferit</td>
</tr>
<tr>
<td>EN-GJS-500-7</td>
<td>500</td>
<td>320</td>
<td>7</td>
<td>.</td>
<td>.</td>
<td>do 170 to 241</td>
<td>ferit+perlit</td>
</tr>
<tr>
<td>EN-GJS-600-3</td>
<td>600</td>
<td>370</td>
<td>3</td>
<td>.</td>
<td>.</td>
<td>do 192 to 269</td>
<td>ferit+perlit</td>
</tr>
<tr>
<td>EN-GJS-700-2</td>
<td>700</td>
<td>420</td>
<td>2</td>
<td>.</td>
<td>.</td>
<td>do 229 to 302</td>
<td>perlite</td>
</tr>
<tr>
<td>EN-GJS-800-2</td>
<td>800</td>
<td>480</td>
<td>2</td>
<td>.</td>
<td>.</td>
<td>do 248 to 352</td>
<td>perlite+tempered structure</td>
</tr>
</tbody>
</table>

Table 1. The mechanical properties of nodular cast iron obtained by testing specimens made of enough cast samples [3]

<table>
<thead>
<tr>
<th>Chemical composition in %</th>
<th>EN-GJS-400-12</th>
<th>EN-GJS-500-7</th>
<th>EN-GJS-600-3</th>
<th>EN-GJS-700-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>3.62</td>
<td>3.85</td>
<td>3.67</td>
<td>3.76</td>
</tr>
<tr>
<td>Si</td>
<td>2.52</td>
<td>2.9</td>
<td>3.2</td>
<td>2.35</td>
</tr>
<tr>
<td>Mn</td>
<td>0.076</td>
<td>0.076</td>
<td>0.59</td>
<td>0.51</td>
</tr>
<tr>
<td>Mg</td>
<td>0.28</td>
<td>0.035</td>
<td>0.025</td>
<td>0.020</td>
</tr>
<tr>
<td>P</td>
<td>0.020</td>
<td>0.025</td>
<td>0.025</td>
<td>0.020</td>
</tr>
<tr>
<td>S</td>
<td>0.03</td>
<td>0.04</td>
<td>0.138</td>
<td>0.044</td>
</tr>
<tr>
<td>Cu</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Chemical composition of the tests specimens

<table>
<thead>
<tr>
<th>Material</th>
<th>Tensile strength</th>
<th>Yield strength</th>
<th>Elongation after rupture</th>
<th>Constriction after tearing Z</th>
<th>Hardness HB</th>
<th>Impact fracture store K</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN-GJS-400-12</td>
<td>421 N/mm²</td>
<td>280 N/mm²</td>
<td>22%</td>
<td>19%</td>
<td>150</td>
<td>15 J</td>
</tr>
<tr>
<td>EN-GJS-500-7</td>
<td>485 N/mm²</td>
<td>330 N/mm²</td>
<td>20.6%</td>
<td>18.9%</td>
<td>186</td>
<td>16.6 J</td>
</tr>
<tr>
<td>EN-GJS-600-3</td>
<td>596 N/mm²</td>
<td>378 N/mm²</td>
<td>8.9%</td>
<td>8.9%</td>
<td>270</td>
<td>12.6 J</td>
</tr>
<tr>
<td>EN-GJS-700-2</td>
<td>699 N/mm²</td>
<td>425 N/mm²</td>
<td>4.8%</td>
<td>4.8%</td>
<td>320</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Investigating the mechanical properties [4]

3. ISOThermal HEAT TREATMENT OF QUENCHED AND NODULAR CAST IRON

The heat treatment is carried out isothermally so that the specimen from the austenite temperature is quenched to temperature of the isotherm which is higher than the temperature of onset of the martensite. Holding at a temperature T₁ until it reaches the desired conversion, and then is cooled in air. The aim is to avoid the conversion of the austenite into martensite because it causes stress and cracking in the material.

Fig. 1. Diagram of austempered specimens

Fig. 2a. Nodular cast iron EN-GJS-700-2 with predominantly perlite basis, Fig.2b. after isothermal improved (increased 200x)
Figure 2b shows that the amount of retained austenite is relatively high (between 20 and 40%). The austenite contributes to high toughness and ductility of austempered ductile iron. It may be, by cold forming, convert to martensite, which brings another favorable characteristic of the material, namely, it is the ability to improve on after the heat treatment in addition by the specimen surface treatment (e.g. blasting). This way it is possible to further increase the hardness of the surface and hence the wear resistance, and so created the exact tension in the surface layer, significantly increased fatigue strength.

Fig. 3a. Ductile iron EN-GJS-700-2 predominantly pearlite basis (up to 500x).

Fig. 3b. Ductile iron EN-GJS-700-2 predominantly pearlite basis upon isotherms improvement (increase 500x), (bainite-austenitic structure with a 100mm thick wall, upper bainite with 35% retained austenite, recorded by optical microscopy)

The measured yield strength $R_p 0.2 = 741$ N/mm$^2$, tensile strength $R_m = 1043$ N/mm$^2$, elongation after rupture $A_5 = 9.6\%$, the hardness of 320 HB, impact fracture store at room temperature $11.2$ J at $0 ^\circ C$ $= 9.8$ J with $-40 ^\circ C$ J $= 7.7$, percentage of retained austenite 37%.

Fig. 4. Comparison of mechanical properties of standard quality nodular cast iron and austempered ductile iron castings

Figure 4 shows austempered ductile iron, which can achieve purity value of two times of the standard nodular irons, with the same ductility - in this case, extension (%). This is its important characteristics and advantages. By changing the temperature of austempering may mechanical properties vary in a rather wide area [5].

4. POSSIBLE SAVINGS IN THE USE OF AUSTEMPERED DUCTILE IRON

There are several views regarding the possible savings and exploitation if they are compared with isothermal steel materials with austempered ductile iron:

- Energy savings
- Savings due to casting approximately the final form
- Savings due to better workability
- Savings due to the lower density of ductile iron

4.1. Case study of use of austempered nodular cast iron in mechanical structures

Figure 4 show that the austempered ductile iron has a higher level of fracture toughness than conventional quenched and tempered ductile iron for all hardness values. At higher levels of hardness, austempered ductile iron has a fracture toughness which can be compared with fracture toughness of cast steel (quenched and tempered). Its fracture toughness is lower than the fracture toughness of steel forgings (quenched and tempered) in the longitudinal direction and is equal to or greater than the fracture toughness of steel forgings in the transverse direction for the lower and middle levels of hardness [6].

In isothermal improving obtain spheroidal graphite cast iron structure of bainitic ferrite and coarse carbon-saturated austenite (upper bainite) with a hardness of 30 to 37 HRC and the hardness (lower bainite) is in ranges from 43 to 50 HRC.

Fig. 5. Compare the cost of the gear vibrating roller (Dv = 390 mm, b = 60 mm; module m = 6) made from 20MnCr4 and from austempered ductile iron

Figure 5 shows the sketch of the vibrating roller gear (Dv = 390 mm b = 60 mm, module m = 6) and the corresponding semi-manufacture, made of low-alloy steel rods for cementing 20MnCr4, or from...
austempered ductile iron and a rough comparison of the cost per piece. The total savings in this case are resulting in savings of the amount of material used, the savings in machining and saving of heat treatment [7].

4.2 There is the possibility of a wider application of nodular irons

Fig. 6. Shows the timing gears for diesel engines made from austempered ductile iron EN-GJS-700-2 initial pearlite basis

Fig. 7. Gears for drive of a passenger car axle with transverse-engine and the longitudinally-engine made of isothermal improved irons EN-GJS-700-2

Fig. 8. Teering gear of the planetary gear transmission with inner gear and made of austempered ductile iron EN-GJS-700-2

5. CONCLUSION

Previous research and application examples show that the isometric improving ductile iron can produce a structure (a mixture of bainitic ferrite and austenite is enriched with carbon), which along with high wear resistance (with high strength) has great ductility and toughness. It is, therefore, no conventional annealing, ie. martensitic transformation to get material that matches the high demands in parts of the inverted impact, fatigue and spending.

The first success prerequisite with austempered ductile iron is certainly a good and constant (standard) quality of ductile iron. The most important requirements for its structure are: to be free of inclusions and micro porosity, have a sufficient number of the uniformly distributed graphite balls (nodules), and that there is no segregation of manganese. [8]

The second a prerequisite to success is accurate and repeatable process control of isothermal heat treatment. To specifically selected composition of ductile iron, thickness of the parts and the required mechanical properties it is necessary to optimize and control the process parameters [9].

For wider application of an isometric improved ductile iron it is necessary in practice, on the one hand, a lot of data on mechanical properties for a specific composition and the specific conditions to improve the material - which is possible to obtain its own research.

With the dear side, it is in the constructor and technologists during designing and manufacturing organizations to develop a sense of these and give them the appropriate methods and media for it. In this regard, long-term collaboration between production organizations and relevant research institutions can be of great benefit.

6. REFERENCES


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