The ductile cast iron standard in Europe also considers new ductile cast iron grades with a unique combination of tensile strength with high elongation (e.g., Rm 725 psi with \( \text{A}_5 \) 14%) achieved by the solution strengthening of the ferritic matrix by silicon with contents between 3% and 4.3%. The new grades tolerate a higher amount of pearlite and carbide stabilizing elements without the generation of embrittling pearlite or carbides in the microstructure. The presence of Cr, Mn, and V do not influence the elongation significantly. An advantage of the new cast irons is the cost efficient machining due to lower tool wear. The tool life with the machining of the fully ferritic grades GJS-500-14 and GJS-600-10 is about 50–60% longer in comparison to the ferritic-pearlitic grades. The investigated grades show very good cyclic mechanical properties but lower dynamic properties. The pre-condition to achieve optimized properties by well-shaped graphite nodules, achievable with special inoculation techniques, adjusted to the high silicon content and the solidification rate, otherwise threaten graphite degenerations. There is no increased danger of dross generation or of a worsening flowability (investigated with special test equipment). Also the supposed inclination to the generation of porosities with the higher Si content was not confirmed.

Keywords: new silicon-alloyed ductile cast iron grades, ferrite, solution strengthened, tensile strength, elongation, hardness, machinability, DIN EN 1563, GJS, Germany, continuously cast products, rollers and pinion cages.

Introduction

EN-GJS (European Standard for ductile cast iron) is used in many areas of mechanical engineering, automotive and engine construction as well as energy, environmental and nuclear technology. In all these applications, the EN-GJS grades must be in line with the applicable standards. When the DIN standard EN 1563 established in March 2012 was revised, the ferritic, solution strengthened grades EN-GJS-450-18, EN-GJS-500-14 and EN-GJS-600-10 with higher Si contents were newly added to the standard. (DIN = Deutsches Institut für Normung, German Institute for Standardization) The values listed in Table 1 are valid for a nominal thickness \( \leq 1.18 \) in. The conventional ferritic/pearlitic grades continue to be in the standard without any modifications. Due to the benefits associated with the new ferritic grades—namely higher yield strength and greater elongation, the number of applications is expected to increase quickly.

The mechanical properties of the ferritic/pearlitic EN-GJS grades under EN 1563 are set by adjusting the ferritic/pearlitic ratio through the addition of pearlite forming agents. These cast iron grades usually contain between 2.0% and 2.5% Si. Strongly varying wall thicknesses in EN-GJS-500 and EN-GJS-600 castings with pearlite contents of approximately 30%-70% may lead to strongly varying pearlite fractions and as a result significant differences in hardness. This makes it difficult to comply with close hardness tolerances. The unique combination of yield strength and tensile strength with high elongation in the new material grades

<table>
<thead>
<tr>
<th>Material</th>
<th>GJS-450-18</th>
<th>GJS-500-14</th>
<th>GJS-600-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength ( \text{Rm} ) [N/mm² / psi]</td>
<td>450 / 65268</td>
<td>500 / 72520</td>
<td>600 / 87024</td>
</tr>
<tr>
<td>Yield strength ( \text{Rp0.2} ) [N/mm² / psi]</td>
<td>350 / 50764 (310 / 44982)</td>
<td>400 / 58016 (320 / 46413)</td>
<td>470 / 68169 (370 / 53865)</td>
</tr>
<tr>
<td>Elongation ( \text{A}_5 ) [%]</td>
<td>18 (10)</td>
<td>14 (7)</td>
<td>10 (3)</td>
</tr>
</tbody>
</table>
is achieved by solution strengthening of the ferrite matrix through higher silicon contents. To the user of the castings, these materials provide the advantages of better machinability, and uniform hardness and strength throughout the casting. At the same time, it provides the possibility of reducing the wall thicknesses (light-weight construction) with the intention of saving energy and raw materials. An important benefit for the foundries is that it becomes less difficult to comply with hardness tolerances.

When the new DIN EN 1563 standard became effective, very little knowledge was available as to the production and properties of the new ferritic, solution strengthened grades. The German and Austrian governments sponsored a research project which had the objective of filling this gap of material-related and casting technological information.

**Experimental Procedure**

Within the framework of this project, alloys were produced in a 150 kg induction furnace (medium frequency). The basic analysis of the alloys was C: 3.5-3.6 %; Si: 2.3-2.5%; Mn: 0.15-0.2 %; P: <0.02 %; S: <0.009 %; Mg: 0.04-0.05%. This basic analysis was used as reference to determine the effect of higher Si contents. During tundish cover treatment with FeSiMg, the pre-alloy was covered by very finely cut steel sheet. The tapping temperature from the induction furnace was set at 2,768°F - 2,804°F, the casting temperature was between 2,516°F and 2,534°F. Inoculation took place in the pouring basin during casting. The melting tests were all conducted with the same basic charge—40% steel and 60% Sorel metal. The melting parameters were the same for all tests. The silicon contents were all set using FeSi 90, with the carbon content being adjusted by means of electrode graphite to a CE value of ~4.3. Except for specific inoculation tests, the amount of inoculants was 0.3% for all tests. The inoculants were added to the pouring stream of the magnesium-treated melt while it was being poured into the basin.

The stoppers of the pouring basin were pulled upon reaching a casting temperature of 2,516°F-2,534°F. This made the casting temperature and the casting speed of all test melts comparable. A pattern from previous projects was used for casting radial specimens for the basic material-technological examinations. For this project, a 0.20-in.-thick plate was added to the radial pattern (Figure 1). In addition to this radial specimen, technological test pieces were cast in a mould for standard specimens of the dimensions specified in DIN EN 1563 as well as Y2 and Y4-keel block. The two moulds were filled with metal from the same pouring basin in order to guarantee that the metallurgical preconditions are the same. Additionally, three shrinkage specimens were cast on the same mould plate. For complementary shrinkage tests, additional plate-, cylinder- and cube-type castings were produced (not in the figure shown). Tensile test pieces and metallographic sections were taken from the thermal center of the radial specimen. The results of the examinations were documented and evaluated.

The fatigue tests were carried out under rotation bending conditions within minimum 15 samples (stress ratio R=-1). The test frequency was 200 Hz and the investigations were conducted at room temperature. The sample length and diameter were 6.30 in. and 0.28 in. respectively.

**Test Results**

**Influence of the Si Content on the Static Mechanical Properties**

Melting tests were conducted with Si contents between 2.4 and 6%. From the cast specimens, test bars were taken and tested. When the Si content is increased starting from 2.4%—which is the usual Si content in EN-GJS—the tensile strength values increase up to a maximum, which is reached at an Si content of 4.3%. After surpassing this Si content, the tensile strength drops from the peak of 89,000 psi down to 72,500 psi at a Si content of 5% (Figure 2). The yield strength only starts to drop at a Si content of about 4.6% (Figure 3), an effect known from ductile cast iron grades, such as EN-GJS-400-18. In these grades, growing generation of embrittling elements or graphite degeneration first lead to decreasing tensile strength and elongation, before the yield strength decreases due to further advancing embrittlement and graphite degeneration. At 5% Si, the yield strength and the tensile strength values coincide. In the tests,