Selection of material for cores hardened with carbon dioxide

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Abstract

The work presents the investigation results concerning the bending and the tensile strength of specimens made of various types of core sands. The investigated core sands for bending tests have been prepared of silica sand from Nowogród Dobrzański and, alternatively, of H33 German sand, both containing a variety of binders, namely Carbophen 5692, Carbophen 7170, Carbophen 8178, Novatec 1000, or SuperEko 2000 phenolic resins, as well as water glass. The tensile strength has been investigated for specimens made of silica sand from Nowogród Dobrzański and the sand supplied by Hüttenes-Albertus Polska, both types bond with Carbophen 5692, Novatec 1000, or SuperEko 2000 resins. All specimens have been tested immediately after the CO\textsubscript{2} hardening process, then after 1 hour and after 24 hours. It has been found that the type of sand grains significantly affects both the bending and the tensile strength. Furthermore, for each type of sand the best bending strength has been achieved for Carbophen 7170, Carbophen 8178, and Novatec 1000 resins, whereas the best tensile strength has been offered by specimens bond with Carbophen 5692 resin.

Keywords: casting technologies, resin-bond CO\textsubscript{2}-hardened sands, moulding sands with water glass, technological properties

1. Introduction

The loose self-hardening chemically bond moulding sands are of principal significance in production of moulds and cores for unit or small lot production of large and medium-size castings. The sands bond with synthetic resins have a remarkable contribution here [1]. They have been the object of investigation described, inter alia, in Refs [2, 3]. The influence of addition of used cores, among them those prepared with use of CO\textsubscript{2}-hardened phenolic resin binders or water glass binder, on the technological properties of sand with bentonite binders has been also examined [4].

Despite the advantageous technological parameters of the synthetic resin-bond sands and the significant part they play in casting production, investigations aimed to develop new binding systems based on the non-toxic inorganic binders are held [1]. The most remarkable are the sands bond with water glass, however they exhibit also some disadvantages, among which the more important are their poor knock-out properties and low flexibility, as well as rather weak susceptibility to mechanical reclaiming [1]. The studies concerning the knock-out properties of the water glass bond foundry sands have been discussed in Ref. [5], and problems of their reclaimation are presented in Ref. [6]. The ultrasound technique can be employed for the quality evaluation of mould elements made of the chemically bond sands [7].

The phenolic CO\textsubscript{2} process has been described in detail by J.L. Lewandowski in Ref. [8]. In this process the hardened mixture consists of the sand grains and the hydrated alkaline phenolic formaldehyde resin of the resol type. Hardening of the compacted sand occurs as a result of CO\textsubscript{2} supplying (the most preferably at the temperature of 25°C). The carbon dioxide reacts with water to the carbonic acid and lowers pH of the system. Because of this the previously stable binder complex is activated and the carbonic acid reacts with alkaline resin. If the CO\textsubscript{2} supply is omitted, the hardening process is extremely slow. As the author of the Ref. [8] states, applying of this core sand is advantageous
from the ecological aspect. Moreover, the sand do not contain combustible components or components of unpleasant smell and emits only a little amount of smoke.

The sand in the self-hardening core sands bond with water glass is usually silica sand containing less than 0.5% of clay binder and less than 5% of dust fraction [8]. Restrictions regarding the clay binder and the dust fraction quantities allow for reducing the addition of water glass, thus influencing advantageously the knock-out properties of the sand. The binder is sodium water glass of modulus M = 2.2-3.3. The modulus value affects the hardening process [8]. Most commonly, sodium water glass of modulus 2.4-2.6 is used. The hardening agent is carbonic anhydride i.e. carbon dioxide. Core sands containing water glass, glass of modulus 2.4÷2.6 is used. The hardening agent is carbonic acid affects the hardening process [8].

Most commonly, sodium water glass is used in casting production is made in mechanised core shops. Basic machines employed there for core making are core shooters. The quality of produced cores depends to a great degree on the sand grains, the binder, and the applied hardening agent. The selection of core sand for particular working conditions should take into account the core making method, the core box type, and the way of hardening. Problems of making cores by the shooting method are presented in Refs [9-11].

2. Authors’ investigations

2.1. The purpose and the range of investigations

The purpose of the work has been the initial determining of basic properties of core sands prepared with use of CO₂-hardened binders and applied for making cores by means of core shooters. It has been assumed that the work will estimate the influence of sand grains and various binder types on the quality of core sands. Three type of sands have been experimentally tested: sand from Nowogród Dobrzanski, further denoted as 'sand A'; H33 German sand, further referred to as 'sand B'; and sand supplied by Hüttenes-Albertus Polska, further recalled as ‘sand C’. It has been determined:

- the influence of sand grains type (sand A and sand B have been used) and the binder (CO₂-hardened phenolic resins have been used, namely resins from Carbophen series designed 5692, 7170, and 8178 [12], Novatec 1000 [13], SuperEko 2000 [14]; and the R-145 sodium water glass [15]) on the core sand bending strength;
- the influence of sand grains type (sand A and sand C have been used) and the binder (namely Carbophen 5692, Novatec 1000, and SuperEko 2000) on the tensile strength of core sands.

2.2. Methodics of examination

All three silica sand types have been examined. The measurements have been carried out according to the valid standards and have included:

- determining of the clay binder content;
- sieve analysis;
- determining of moisture content in the sand;
- determining of the sintering temperature.

The average grain size d₅₀, based on the grain number and the degree of uniformity have been determined according to the published professional recommendations [8]. The bending strength has been examined for core sands containing sand A and - for comparison – sand B.

The core sands for specimens intended for bending strength examinations have been prepared in the laboratory paddle mixer. The basic quantity of silica sand has been 5 kg, and the resin and water glass have been added in proportions of 3 parts and 5 parts, respectively, for each 100 parts of sand by weight. Specimens have been compacted by means of the Luz-1e laboratory jolter; the vibration time has been equal to 60 s. The specimens have been blown with CO₂ at the pressure of 0.1 MPa. They have been of a square cross-section 22.36×22.36 mm and 172 mm length.

Fifteen CO₂-hardened specimens have been made of each type of core sand. Five of them have been examined directly after the hardening operation, the following five after 1 hour’s time, the last five after 24 hours’ time. The bending strength has been measured by means of the Lru-2e device.

The tensile strength has been measured under the industrial conditions in one of Polish foundries. Examinations have dealt with core sands prepared with alternative use of two types of silica sand, sand A and sand C, the latter exhibiting similar properties as sand B used in previous examinations. Carbophen 5692, Novatec 1000, and SuperEko 2000 resins have been applied as binders. Core sands have been prepared in MS-017A paddle mixer with maximum vessel capacity of 0.17 m³. Resin has been added in amount of 3 kg for 100 kg of sand and then the components have been mixed for 4 minutes. Fifteen dog bone specimens have been made of each core sand and blown with CO₂ for 15 s in the special wooden core box. The tensile strength have been measured at the same time intervals as the bending strength, five specimens for each measurement.

Table 1 gathers some parameters of resins used for preparing the examined core sands and catalogue values of bending strength for sands bond with these resins.

Table 1.

<table>
<thead>
<tr>
<th>Resin name</th>
<th>Viscosity at 20°C</th>
<th>Density at 20°C</th>
<th>Bending strength¹ of hardened core sands</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instantly</td>
<td>After 1 hour</td>
<td>After 24 hours</td>
<td></td>
</tr>
<tr>
<td>Carbophen 5692</td>
<td>300-500</td>
<td>1,30-1,32</td>
<td>90</td>
<td>140</td>
</tr>
<tr>
<td>Carbophen 7170</td>
<td>550-750</td>
<td>1,30-1,32</td>
<td>120</td>
<td>220</td>
</tr>
<tr>
<td>Carbophen 8178</td>
<td>500-700</td>
<td>1,30-1,32</td>
<td>130</td>
<td>210</td>
</tr>
<tr>
<td>Novatec 1000</td>
<td>275-345</td>
<td>1,27-1,29</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>SuperEko 2000</td>
<td>180-260</td>
<td>1,31-1,36</td>
<td>Data not available</td>
<td>130</td>
</tr>
</tbody>
</table>

¹ Values given by manufacturers for sands containing 100 parts of sand and 3 parts of resin by weight, CO₂-hardened for 15 s
2.3. Results of examination

Table 2 presents the results of sand grains examinations.

Table 2. Selected parameters of examined silica sands

<table>
<thead>
<tr>
<th>Property</th>
<th>Silica sand type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand A</td>
</tr>
<tr>
<td>Humidity, %</td>
<td>0.015</td>
</tr>
<tr>
<td>Uniformity, %</td>
<td>75</td>
</tr>
<tr>
<td>(d_{50, L}), mm</td>
<td>0.41</td>
</tr>
<tr>
<td>Clay binder content, %</td>
<td>0.29</td>
</tr>
<tr>
<td>Sintering temperature, ºC</td>
<td>1450</td>
</tr>
</tbody>
</table>

As follows from Table 2, sand B and sand C exhibit the same humidity, clay content, and sintering temperature, and moreover they have similar uniformity and average grain size \(d_{50, L}\). Parameters of these both sands significantly differ from the parameters of sand A.

Sands B and C are also similar with respect to the grain size gradation. The main fractions for sand B and sand C have been 0.20/0.325/0.16 and 0.20/0.325/0.40, respectively. The comparable quantities of scaled mesh fractions 0.2/0.325 of sand B and sand C, as well as similar parameters of these materials (see Table 1) form the basis for their equivalent use.

Fig. 1 and Fig. 2 compare the average bending strength of specimens tested after various time periods from the hardening operation for core sands based on sand A and sand B, respectively.

Fig. 3 and Fig. 4 compare the average tensile strength of specimens tested after various time periods from the hardening operation for core sands based on sand A and sand C, respectively. Sand C has been used instead of sand B, not available at the moment of experiment performing.

2.4. Discussion of results

All the examined cases indicate that the core sand specimens based on sand B have higher bending strength than the ones containing sand A (compare Figs 1 and 2). The differences between...
the bending strength values for specimens with different sands, but the same binder, are significant and reach several tens N/cm². For both examined sand types the bending strength increases with time elapsing from the hardening operation. A reason for it is that the full binding process for sands with phenolic resins takes about 24 hours.

Statistic Dixon’s Q-test [16] has been applied for the purpose on estimating the significance of the sand type influence on the average bending strength of the core sand specimens based on sand A and sand B, as measured after 24 hours from their preparation. Calculations have included all types of used binders.

The results of statistical analysis have proved that the differences between these average bending strength values are statistically significant for each type of examined binder.

The bending stress of specimens prepared of the core sand with R-145 water glass binder, irrespective of the sand grains, decreases with the time (see Figs 1 and 2). The cores made of such core sands are not suitable for storage and should be used just after their manufacturing.

It can be stated that under the same experimental conditions the highest bending strength is exhibited by specimens: - based on sand A bond with Carbophen 7170 and Carbophen 8178 resins; - based on sand B bond with Carbophen 7170, Carbophen 8178, and Novatec 1000 resins.

Comparing the data from Figs 3 and 4 one can find that the core sand specimens based on sand C (equivalent of sand B) have reached the higher tensile strength than the specimens based on sand A. Statistical assessment of the significance of difference between the pertinent average values has been performed again using Dixon’s Q-test for outliers.

The results of statistical analysis indicate that the differences between average tensile strength values of specimens based on sand A and the ones containing sand C are also statistically significant for each type of examined binder.

According to expectations, the tensile strength increases with time during the 24-hours’ period after specimen completion for each considered core sand type (compare Figs 3 and 4). The highest tensile strength, irrespective of the sand grain used, was exhibited by specimens bond with Carbophen 5692 resin. It should be noted that the bending strength value for specimens containing this binder has been lower than the value for specimens with other binders. Considering this fact, one can conclude that using the binder assuring the highest tensile strength does not necessarily assure the highest bending strength of the material.

3. Conclusions

It follows from the performed investigations and their analysis that both the type of sand grains and the used binder have significant influence on the properties of core sand specimens. The H33 sand (B), as compared to the sand from Nowogrod Dobrzanski (A), can provide for much higher properties of the core sand as far as the bending strength is concerned. In the case of tensile strength, which has been examined using specimens containing sand A and the sand supplied by Hüttenes-Albertus Polska (C), applying of sand C is much more advantageous.

The highest bending stress, regardless of the sand type, has been achieved while using Carbophen 7170, Carbophen 8178, or Novatec 1000 resins. The highest tensile stress, also irrespective of the used sand type, has been exhibited by specimens bond with Carbophen 5692 resin.

References