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# Technological Properties of Thermo-insulating Moulding Sands with Organic Binder

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## Abstract

A thermo-insulating moulding sand with a binder made of aluminosilicate microspheres with organic binder was subjected to testing. The aim of the analysis was to determine selected technological properties of the developed compounds. Compressive strength, friability and gas permeability were determined. The binder content was changed within a range of 5÷20 wt% with a 5% step. The applied matrix is characterized by good thermo-insulating properties and a small size of grains, while synthetic organic binder has favourable functional properties, among which the most noteworthy are the extended life and setting time, good rheological properties as well as high resistance to chemical agents. The intended use of the compound is the casting of 3D CRS (Composite Reinforced Skeletons), which are characterized by a well-developed heat transfer surface area, good absorption of impact energy, low mass and a target thickness of connectors within a range of 1.5÷3 mm. The construction of 3D CRS castings is an original concept developed by the employees of the Department of Foundry Engineering at the Silesian University of Technology.

**Keywords:** Skeleton castings, Moulding sand, Organic binder, Technological properties, CRS

## 1. Introduction

The condition for making a casting with required properties is using a properly selected moulding sand. Classic moulding sands complying with *PN-85/H-11003 Foundry moulding materials. Foundry bentonite* standard consist of a matrix (usually sand), a binding material in the form of bentonite and water. To improve some of the properties, the following additives are also used: clays and binders (to increase strength), coal dusts (to improve the cast surface), loosening materials (to enhance permeability and plasticity) and moisture-retaining materials (to prevent the drying and dusting of edges) [1÷3].

Improper selection of moulding sands results in technical and economic difficulties, which have an adverse impact on the duration of mould making, casting cleaning, defective products repair, mechanical treatment as well as tools' wear, the number of rejects and the caster's work effectiveness. A description of issues related to the maintenance of required properties of classic moulding sands is contained in reference item [4]. Studies [5÷7] present the results of investigations into the influence of various kinds of additives on moulding sands' properties.

The manufacture of CRS castings (Fig.1) developed at the Department of Foundry Engineering of the Silesian University of Technology, with a pre-set size and type of unit cells, requires the use of modern moulding sands that are able to properly reproduce

the model, have appropriate technological properties (in particular, compressive strength, friability and permeability) and enable making a proper casting.

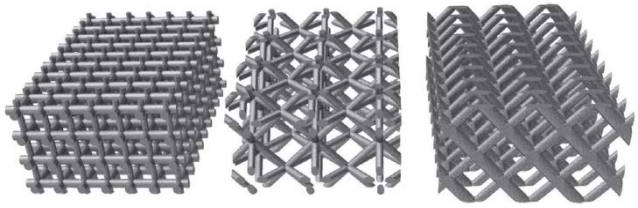

Fig. 1. Topology of CRS castings [6]

# 2. Technological properties of moulding sands

Technological properties of moulding sands are indicators defining their basic features. They enable (however, not all of them, due to research norms or lack of determination methods) comparing different kinds and determining the conditions necessary to obtain castings characterized by appropriate quality castings.

Laboratory samples with dimensions of Ø50x50 mm, made of moulding sand at a precisely defined and standardized degree of densification were subjected to investigations [6].

## 2.1. Compression strength

Standardized analysis [12] involves determining compression strength, which characterizes the compound's resistance to external forces [13] at both ambient and elevated temperatures.

Compression strength is determined by the external resultant force, which overcomes: 1) the forces of adhesion on the boundary of two materials (matrix and binder) and 2) cohesion forces inside the monolithic material per a unit of cross-sectional area [13]. The values of both forces largely depend on the material's structure, i.e. the mutual arrangement of matrix grains covered with binder: the grains are the most loosely packed when the angle of the rhomb inscribed into their geometrical centres is 90°, and the most tightly packed - when the rhomb angle is 60° (Fig. 2).

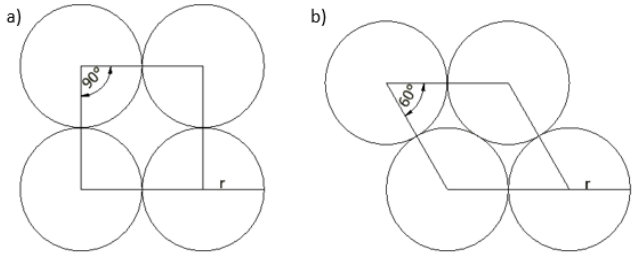


Fig. 2. Diagram of an ideal compound's structure with: a) the most loosely packed and b) the most tightly packed particles [14]

## 2.2. Abrasion resistance

A standardized technological trial [15] involves determining the indicator characterizing the compound surface resistance to abrasion when subjected to friction forces [13]. The liquid metal flowing through the mould cavity encounters numerous obstacles on its way, among others drainage channel walls, thresholds, narrowings, filters etc. Due to the continuous movement of the liquid travelling on the metal-mould contact area, the compound particles are detached from the mould or the core inside the mould

Detachment of single particles of the compound is an unfavourable phenomenon as they frequently flow out onto the surface of a raw casting, thus deteriorating the quality of the casting, which must be subjected to grinding procedures. Moreover, the detached particles or lumps of the compound closed inside the casting may cause defects referred to as sand holes.

The friction forces of the metal travelling in the gating are proportional to i.a. metallostatic pressure of the casting as well as its density and depend on the flow rate. This is the reason why pouring heavy alloys into moulds is not easy and, additionally, necessitates the use of compounds characterized by high abrasive strength in the gating. The non-laminar liquid stream enhances the abrasion of the compound from the mould cavity and/or the core as well as from the surface of channels through which the liquid metal flows.

Laboratory investigations into standardized samples abrasion should be considered a simplified representation of the phenomenon which occurs in real conditions. The measure of abrasibility is so-called friability. Investigations into the moulding compound's friability enable accurate evaluation of the binder quality as well as a proper selection of particular components of the compound and an appropriate manner of its processing.

Friability is determined according to formula (1).

$$S = \frac{m_1 - m_2}{m_1} \cdot 100\ [\%] \tag{1}$$

where:
$m_1$ – shape's mass before determination [g],
$m_2$ – shape's mass after determination [g].

## 2.3. Gas permeability

A standardized measurement [16] of the indicator characterizing the compound ability to permeate gases [13] depends directly on its structure, in particular the shape, size, homogeneity, type and content of the binding material as well as the degree of density, i.e. the number and volume of empty spaces between matrix grains (Fig. 2).

As shown by practice, sharp-edged grains cause worse permeability of the compound than round grains. A similar effect can be observed in the binding material, the type and content of which has a considerable influence on permeability. The use of mould cavity protective coatings on the one hand prevents burns and improves the quality of the casting surface, while on the other, it decreases the permeability of gases produced in the

process of mould casting. It is frequently enhanced by puncturing the moulds, which is a time-consuming procedure.

If cores are used, the direction of gas flow should be the same as that of mould casting.

The permeability of a moulding sand is calculated according to formula (2).

$$P = \frac{V \cdot h}{F \cdot p \cdot \tau} \left[\frac{m^2}{Pa \cdot s}\right] \quad (2)$$

where:
V –volume of air flowing through the cylinder shape [$m^3$],
h – shape's height [m],
F – cross-sectional area of the cylindrical shape [$m^2$],
p –pressure of air under the shape [Pa],
τ –time of flow of air volume V through the shape [s].

## 3. Aluminosilicate microspheres

Moulding sands are usually covered with chromite sands, zirconium silicates and corundum. In this work, sanding sands were based on microspheres. Microspheres are spherical aluminosilicate particles filled with carbon dioxide and nitrogen, which are produced in the process of hard coal burning in power engineering facilities [17].

As a result of coal combustion in a power boiler, plastic slag in the high-temperature zone forms gas-filled granules due to the presence of gases in the hearth [18]. The material formed gets to a water sediment tank, from the surface of which it is transported to the drain tank. The drying process lasts until the material reaches the humidity of ca 20%. Next, the material is packed and distributed. The structure and physical properties of aluminosilicate microspheres are presented in Fig. 3 and in Table 1.

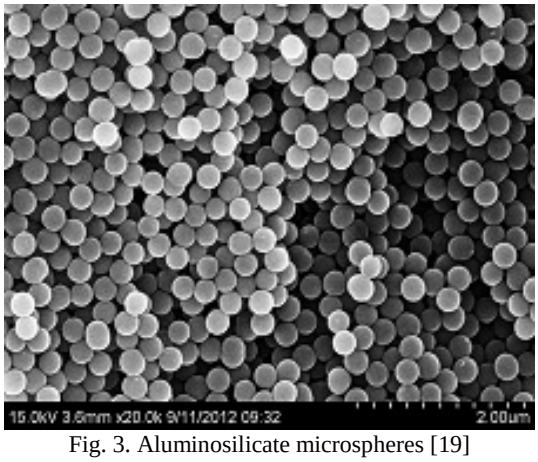

Fig. 3. Aluminosilicate microspheres [19]

Table 1.
Physical properties of microspheres [20]

| Property | Value | Unit |
|---|---|---|
| Dry bulk density | 400 ± 30 | $kg/m^3$ |
| Density of aluminosilicate envelope mass | 2 200 ± 200 | $kg/m^3$ |
| Relative density | 690 ± 50 | $kg/m^3$ |
| Thermal conductivity | 0.07 ± 0.03 | W/(m·K) |
| Melting point | 1 495 ± 10 | °C |
| Softening point | 1 220 ± 10 | °C |
| Internal pressure in microsphere | 0.2 ± 0.1 | Bar |
| Content of water in dry microsphere | < 0.5 | % |
| Hardness in the Mohs scale | 6 ± 1 | |
| Water extract pH | 7 ± 1 | |
| Colour | light to dark grey | |

## 4. Author's own studies

The investigations were aimed at analysing selected technological properties of moulding sands having a matrix made of aluminosilicate microspheres with organic binder within a range of 5÷20 wt. %. The main purpose of using organic binders is not to impair the thermal insulation properties of the molding sand, in which the thermal destruction of the binding material occurs with an exothermic effect, which is not the case with the use of inorganic binders. In addition, the oxidation of the organic binder gives a reducing atmosphere in the mold cavity. As before, inorganic binders do not provide similar opportunities. The organic binder used belongs to the group of duroplasts with maximum strength properties and minimal dynamic viscosity, which allows to minimize its share in the molding mass. During investigations the following materials and equipment were used:

- F150 grey microspheres,
- organic binder,
- ML-92M laboratory mix,
- LU-1 manual laboratory rammer,
- strength testing machine with a mechanical drive/WPM universal strength testing machine,
- LS abrasibility testing apparatus,
- LPiR-3 apparatus for determining permeability.

The scope of testing included:

- weighing the set amount of matrix,
- weighing the planned content of binder,
- making the compound,
- preparing laboratory samples,
- compression strength tests,
- friability tests,
- permeability tests,
- analysis of results.

Stages of moulding compound preparation:

- weighing the components in required proportions,
- mixing the components until homogenous consistence was achieved
- samples hardening.

In the investigations organic binder characterized by high mechanical properties and low viscosity under normal conditions was used. The composition of the developed compounds have been given in Table 2.

Table 2.
Composition of compounds

| Compound designation | Microsphere [%] | Binder* [%] |
|---|---|---|
| P5 | 100 | 5 |
| P10 | | 10 |
| P15 | | 15 |
| P20 | | 20 |

* mass content calculated in relation to microsphere mass

# 5. Results of investigations

Table 3 presents conversion of the mass fraction into the volume fraction of the organic binder mass used in tests. The results have been presented in Figures 4÷9 and in Tables 4÷6.

Table 3.
Conversion of binder mass fraction into volume fraction in relation to aluminosilicate microspheres

| Compound | Mass fraction [%] | Volume fraction [%] |
|---|---|---|
| P5 | 5 | 3.07 |
| P10 | 10 | 6.13 |
| P15 | 15 | 9.20 |
| P20 | 20 | 12.27 |

## 5.1. Compression strength

Table 4.
Compression strength results

| Measurement No. | P5 | P10 | P15 | P20 |
|---|---|---|---|---|
| | [MPa] | | | |
| sample 1 | 7.96 | 9.90 | 11.81 | 14.45 |
| sample 2 | 7.59 | 10.19 | 12.55 | 13.31 |
| sample 3 | 8.58 | 10.62 | 12.72 | 13.96 |
| sample 4 | 7.92 | 10.41 | 12.63 | 13.99 |
| sample 5 | 7.57 | 10.57 | 12.37 | 13.84 |
| sample 6 | 8.64 | 10.50 | 12.58 | 13.95 |
| mean | 8.04 | 10.36 | 12.44 | 13.92 |
| variance | 0.22 | 0.08 | 0.11 | 0.13 |
| standard deviation | 0.47 | 0.28 | 0.33 | 0.36 |

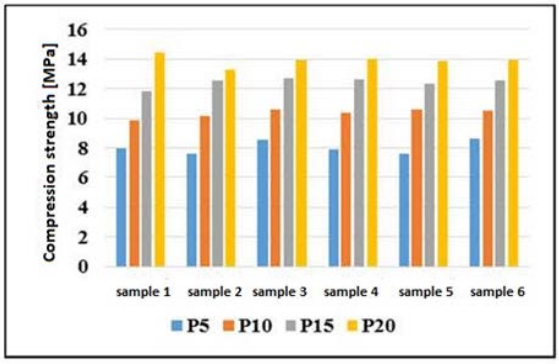


Fig. 4. Compression strength of samples 1÷6 of compounds P5÷P20

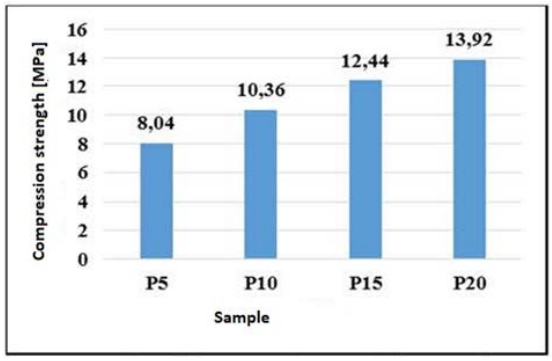


Fig. 5. Average values of the compression strength of compounds P5 ÷ P20

The strength properties of the samples subjected to testing largely depended on the content of binder. As its content increased, the samples' strength was observed to rise. The measured value increment between subsequent samples was 22, 17 and 6 %, respectively.

The greatest discrepancy between results, reaching ca 12% (min. 7.59, max. 8.64 MPa) was obtained for compound P5, which most probably resulted from the low volume fraction of the binder, leading to the compound's greater nonhomogeneity. In the case of the remaining compounds the discrepancies did not exceed 8%.

## 5.2. Friability

Table 5.
Friability results

| Measurement No. | P5 | P10 | P15 | P20 |
|---|---|---|---|---|
| | [%] | | | |
| sample 1 | 0.107 | 0.023 | 0.017 | 0.023 |
| sample 2 | 0.050 | 0.032 | 0.024 | 0.023 |
| sample 3 | 0.062 | 0.036 | 0.024 | 0.019 |
| sample 4 | 0.019 | 0.016 | 0.019 | 0.027 |
| sample 5 | 0.116 | 0.020 | 0.024 | 0.025 |
| sample 6 | 0.026 | 0.032 | 0.019 | 0.027 |
| mean | 0.063 | 0.026 | 0.021 | 0.024 |
| variance | 0.001640 | 0.000063 | 0.000008 | 0.000010 |
| standard deviation | 0.0405 | 0.0080 | 0.0029 | 0.0031 |

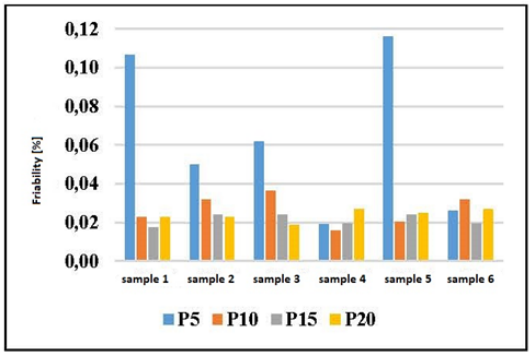


Fig. 6. Friability of samples 1 ÷ 6 compounds P5 ÷ P20

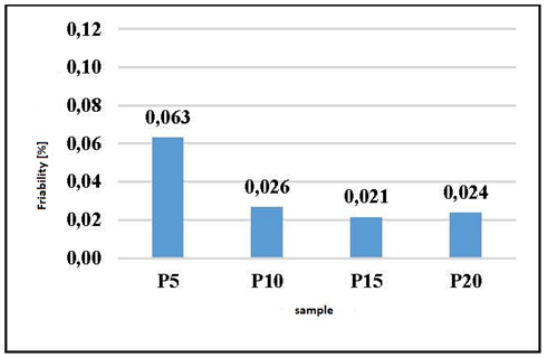


Fig. 7. Average values of friability of compounds P5 ÷ P20

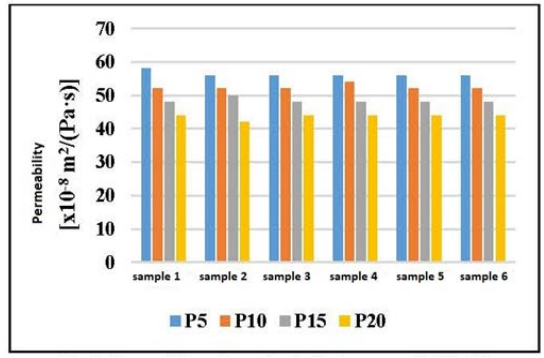


Fig. 8. Permeability of samples 1 ÷ 6 of compounds P5 ÷ P20

It seems that an increase in the binder content should be accompanied by an increasingly smaller loss in the examined samples' mass. The formulated hypothesis,, however, is not reflected in real conditions as compound P15 is characterized by the lowest friability.

A very high variability of results is observed in compound P5, ranging from 0.026 to 0.116 %, which means that the maximum value is 4.5 times higher than the minimum one. This is probably due to a small volume fraction of the binder in relation to the matrix – ca 3% (5 wt.%), which leads to the compound's greater nonhomogeneity, and the fact that the compound's homogeneity was not obtained.

A similar correlation was observed in the case of compound P10, with differences between the minimal value reaching 0.016 and 0.036 %, which is slightly more than a 2-fold increase in the value. It can be presumed that the volume of binder in relation to that of matrix is still low.

The lowest spread of results was obtained for compound P20.

## 5.3. Gas permeability

Table 6.
Gas permeability results

| Measurement No. | P5 | P10 | P15 | P20 |
|---|---|---|---|---|
| | [x10$^{-8}$ m$^2$/(Pa·s)] | | | |
| sample 1 | 58.00 | 52.00 | 48.00 | 44.00 |
| sample 2 | 56.00 | 52.00 | 50.00 | 42.00 |
| sample 3 | 56.00 | 52.00 | 48.00 | 44.00 |
| sample 4 | 56.00 | 54.00 | 48.00 | 44.00 |
| sample 5 | 56.00 | 52.00 | 48.00 | 44.00 |
| sample 6 | 56.00 | 52.00 | 48.00 | 44.00 |
| Mean | 56.33 | 52.33 | 48.33 | 43.67 |
| Variance | 0.667 | 0.667 | 0.667 | 0.667 |
| standard deviation | 0.816 | 0.816 | 0.816 | 0.816 |

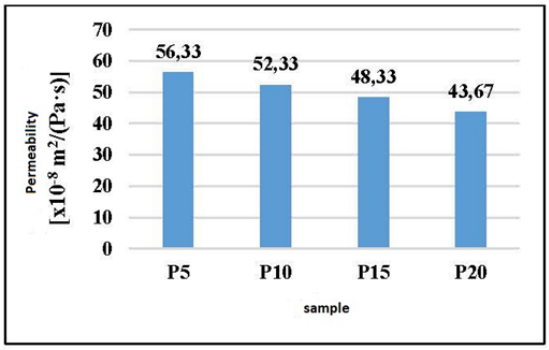


Fig. 9. Mean permeability values for compounds P5 ÷ P20

In each type of compound a very high repeatability of the obtained results was noted. In each test one result was observed to deviate from the remaining ones. The obtained differences reached 3.5÷5 %.

The difference between the mean values of compounds P5 and P10 as well as P10 and P15 was 8%,, whereas between P15 and P20 it reached 11%. There is a visible steady decline in the obtained mean values, reaching ca $4 \cdot 10^{-8}$ [m$^2$/(Pa•s)].

# 6. Conclusions

The conducted investigations allow concluding as follows:

a) the content of binder influences the technological properties of the compounds subjected to testing, which is particularly visible in compressive strength tests,
b) despite using 5 ÷ 20 wt. % of the binder, the amount of binder used is relatively small after converting it to volume fraction (3÷12 %), which results from the low density of the microspheres' mass,
c) compared to traditional moulding sands used in foundry casting, the developed compounds are characterised by very good technological parameters, and the results obtained for compounds P15 and P20 should be considered favourable and promising in the practical application of skeleton castings manufacture.

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