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Research on Assessment of the Applicability of Malted Barley Binder in Moulding Sand Technology

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Abstract

The foundry industry is looking for solutions that improve the quality of the finished product and solutions that reduce the negative impact of the industry on the natural environment [26]. This process leads to work on the use of new or previously unused materials for binders. Organic and inorganic foundry binders are replaced by renewable materials of plant origin to meet the requirements of both the foundry customers and the environmental and health and safety regulations. The aim of this work was to identify the applicability of renewable and organic malted barley binder in moulding sand technology. The influence of the malt binder content on dry tensile strength, dry bending strength, dry permeability, dry wear resistance and flowability were evaluated. The results show that the malted barley binder can be self-contained material binding the high-silica sand grains. Selected mechanical properties of moulding sands were found to increase with an increase in binder content. It was observed that malted barley binder creates smooth bonding bridges between high-silica sand grains.

Keywords: Innovative foundry technologies and materials, Mechanical properties, Moulding and core sand, Organic binder, Malted barley

1. Introduction

Binders used in foundry practice are divided into organic, inorganic and organic-inorganic because of their chemical nature [1]. Among the organic binders, it is distinguished by synthetic resins (phenol-formaldehyde, urea-formaldehyde, furan, furfuryl), biopolymers, starches, oils [1, 2]. The group of inorganic binders includes bentonites, clay, cements, hydrated silicates, salts. The choice of binder for a particular application is due to the need to meet the requirements of both the customers and the environmental, health and safety regulations [1].

The idea of sustainable development of moulding sand aims to reduce: non-renewable raw materials, harmful and toxic materials, emission of harmful gases, noise and vibrations in the working environment and to enable the recovery of post-production waste [1, 3]. In order to ensure these conditions foundry binders are replaced by renewable materials of plant origin such as wood rosin, molasses, oils, dextrin, starches, cellulose, natural latex [4-7]. These materials may be binder, shaping the properties of moulding sands, or a special additive which influences the selected properties of moulding sands.

The mixture of malted barley flour (70–80%) and malted barley extract (20–30%) is produced on an industrial scale for the bakery and brewing industries. Malted barley flour is produced by the strong size reduction of malted barley [8]. Extract is a dried product of the process of mashing of the fine malted barley (decomposition of the starch contained in malt grains into sugars) [9]. The mixture consists of the following components: carbohydrates (starch, sugars, dextrins), protein compounds (amylolytic, proteolytic and cytolytic enzymes), fat compounds [10].

The aim of the study was to determine possibility of application of malted barley mixture in moulding sand technology.

2. Materials and methods

2.1. Materials

Moulding sands were prepared from the medium, high-silica sand (Grudzeń Las mine), class 1K main fraction of 0.200/ 0.160/ 0.315 meets the standard PN-85/H-11001, the organic binder in a mixture of malted barley flour (70÷80%) and malted barley extract (20÷30%) and distilled water.

2.2. Research methodology

Laboratory tests of molding sand were prepared according to the instructions in the literature [1]. First, the dry ingredients were mixed for one minute in a laboratory roller mixer LM-1. Then, distilled water was introduced and moulding sand were mixed for another 3 minutes. The moulding sands were prepared under ambient conditions at 21°C and 40% air humidity. After mixing, the moulding sands were stored for 60 minutes in a tightly closed container. The total weight of the dry ingredients was 5 kg. The composition of the prepared moulding sands is presented in Table 1.

Table 1.
Composition of moulding sands

High-silica sand (% wt.)	Binder (% wt.)	Distilled water (% wt.)
98	2	2
97	3	3
96	4	4
95	5	5

The proportions of the molding sands were selected in terms of the use of the smallest amount of binder for their preparation, in accordance with the assumption that the best molding sand is the one that contains as little binding material as possible [1, 28].

Three types of standard laboratory specimens were made: cylindrical, elongated and eight-shaped (dog bone) [1]. Specimens were compacted manually using a standard rammer LU-1.

The specimens were compacted by hitting the rammer three times. The compaction work was about 9.8 J. The specimens were dried in a laboratory drier (Pol-eco Aparatura) with forced air circulation at the temperature of 150°C for 60 minutes [29]. The option of air circulation was chosen for even drying of samples. For each determination was prepared 3 specimens. The parameters for the preparation of the samples were chosen on the basis of preliminary studies made by the authors.

The flowability was determined using method of the H.W. Dietert and F. Valtier. Using laboratory rammer, the cylindrical shape specimen was compacted five times, but the loss of sample height was measured between the fourth and fifth impact. The flowability value was calculated by the formula (1).

$$F = 100 - 40x, \% \quad (1)$$

where: F - flowability number to be determined,
x – the difference in sample height between the fourth and fifth hit of the rammer, mm.

The strength properties were determined in the dried state: tensile strength R_m^s and bending strength R_g^s were carried out on a universal strength testing machine LRu-2e (Multiserw Morek). Results were averaged from three trials and mean error has been determined.

The measurement of the dry permeability was carried out by the accelerated method on digital permeability apparatus LPiR1.

Dry wear resistance was also determined according to BN-77/4024-02 on wear resistance tester at ambient temperature for 3 minutes. The dry wear resistance of the test was calculated from the formula (2):

$$dry\ wear\ resistance = \frac{a-b}{a} \cdot 100, \% \quad (2)$$

where: - dry wear resistance number to be determined,
a - weight of specimen before the test, g; b - weight of specimen after the test, g.

The SEM analysis of microstructure of the moulding sand was carried out by scanning electron microscopy (SEM) using Hitachi TM3030 Scanning Microscope, cooperating with the energy dispersive X-ray spectrometer (EDX).

3. Results and Discussion

3.1. Flowability

Results of moulding sand flowability with increasing binder content are shown in the Figure 1.

It was proved that for a lower binder content the flowability is the highest. Comparing the obtained results for the binder content of 2-5% in the moulding sand, it can be seen that each sand obtained good flowability according to [1] because the flowability exceeded 80%. As a result, the tested moulding sand can be compacted with all known methods, from manual moulding to various machine moulding methods.

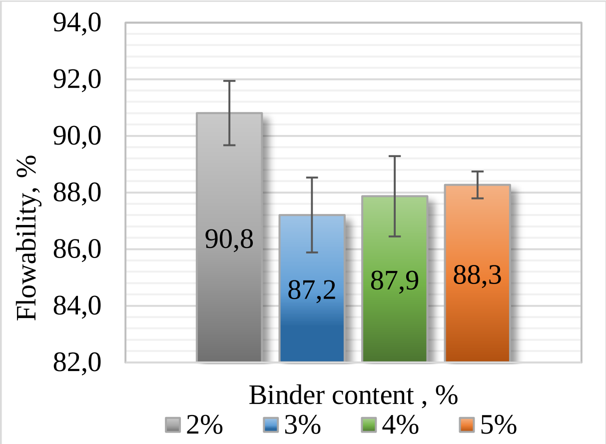

Fig. 1. Results of flowability measurements of moulding sands with malted barley binder

The best flowability is achieved by the sand with the lowest binder content. As the binder content increases, the flowability decreases. This phenomenon is related to the difference in the grain size of the sand and the binder, which affects the internal friction coefficient of the mixture, which in turn translates into lower flowability [14].

3.2. Dry tensile strength

The results of the dry tensile test are presented in Fig. 2. With the increase in the binder content in the moulding sand, its dry tensile strength increases. There is a linear relationship between the binder content and the dry tensile strength, the detailed equation is presented in Fig. 2. The determination coefficient R^2 of 0.97 proves that the obtained linear regression equations are very well matched, which can be used to predict the value of dry tensile strength of the moulding sand with a known content of binding material. The ability to predict the dry tensile strength can help prevent or avoid defects like push out and scrab (PN85/H-83105) [1].

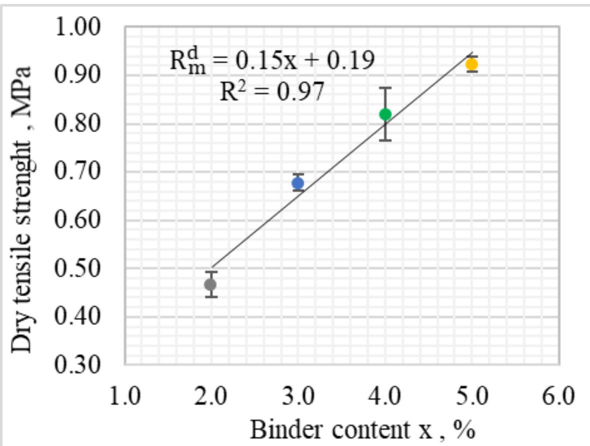

Fig. 2. Results of dry tensile strength measurements of moulding sands as a function of the malted barley binder content

3.3. Dry bending strength

The results of the measurements of the dry bending strength of the moulding sands depending on the malted barley content are shown in Figure 3. It can be observed, similarly to the dry tensile strength results, that an increase in the binder content increases the bending strength. The dry bending strength was also presented as a linear function. The increase in the binder content from 2% to 5% resulted in a threefold increase in bending strength.

In [22, 12] authors proposed a binders classification based on determining the value of the average hardened bending strength R_m^h per 1% of binder in the moulding sand. It was determined on the basis of research that it is possible to divide the binders on the basis of R_m^h also on the basis of R_g^h. Binders may be classified in the following classes:

- class I, for R_g^h> 1 MPa,
- class II, for R_g^h = 0.5 - 1 MPa,
- class III, for R_g^h < 0.5 MPa.

In research, referring to [12], R_g^u was replaced with R_g^s. In the chosen moulding sand, the result of R_g^s was about 0.35 MPa per 1% of binder, which classifies malted barley binder in class III. Table 2 presents the classification from the literature [22].

Table 2.
Binders classification according to obtained tensile strength of moulding sand [12, 22]

Class according to Rm at 1% of the binders	Binding by drainage
I	water glass
II	dextrin, starch,
III	sulfite lye, molasses, starch,

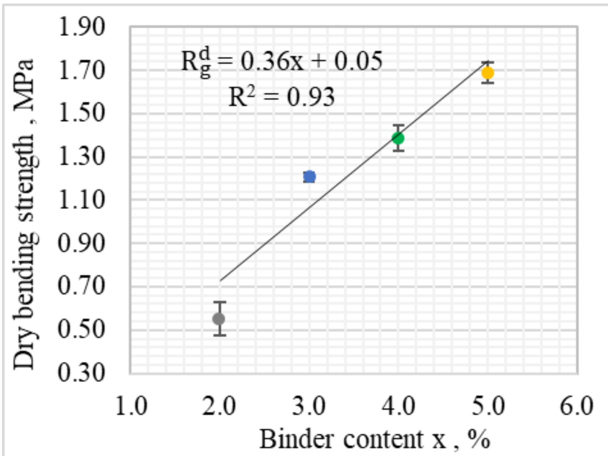

Fig. 3. Results of dry bending strength measurements of moulding sands as a function of the malted barley binder content

3.4. Dry permeability

Results of moulding sand dry permeability with increasing binder content are shown in the Fig. 4. The analysis of the results shows that permeability value is the highest ($317\cdot10^{-8}m^2/Pa\cdot s$) for the moulding sand of 2% of the binder. It results from a larger amount of voids compared to the other moulding sands. The malted barley binder is organic material, which may result in a significant quantity of gases being emitted under the influence of the temperature of the liquid cast alloy, and therefore in practical application the moulding sand of 2% of malted barley binder has the most favourable permeability value.

As the binder content increases, the size of the voids between the moulding sand particles decreases [4, 15, 17]. This leads to a reduction in permeability to $240\cdot10^{-8}m^2/Pa\cdot s$ for moulding sand of 5% of malted barley binder. In this case, in industrial realities, improved permeability is possible by using a mould or core ventilation duct system.

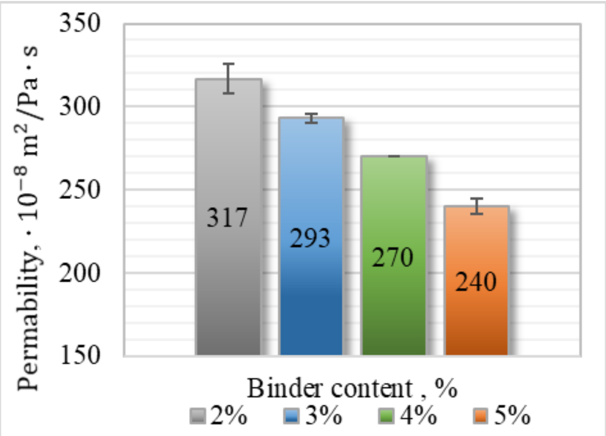

Fig. 4. Results of dry permeability measurements of the different mouldings sands with malted barley binder

3.5. Dry wear resistance

In Figure 5 are shown wear resistance results due to the variation of binder content. With a binder content of 2% wt., the average value of wear resistance was 6.25%. At 3%, it is already 3.41%, which means a reduction in wear resistance by 45% compared to 2%. Increasing the binder content to 4% led in the wear resistance 0.20%, which resulted in a reduction of wear resistance by 97% compared to 2%.

The increase in the binder content causes a decrease in the amount of moulding sand that has fallen off the sample during the wear resistance process. This means that castings defects, especially defect as sand hole and drop (PN85/H-83105) [1] will be less frequent. As a result, the castings will have a surface free of moulding sand, and will also be free of sand inclusions inside.

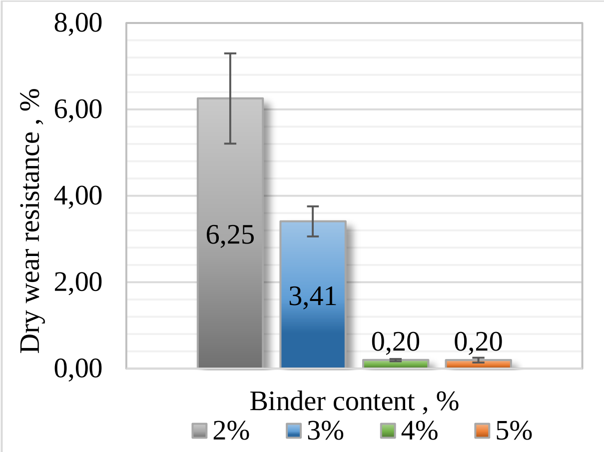

Fig. 5. Results of dry wear resistance measurements of the different mouldings sands with malted barley binder

3.6. SEM analysis

The SEM image of moulding sand with malted barley is shown in Fig. 6. Layer of malted barley binder creating bonding bridges between high-silica sand grains is smooth. Periodically, evident cracks or flakes of malted barley binder have been observed. Slowly heating the moulding sand results in slow water flow into the air stream that is floating the dry load and ensures the quality of the bridges. The binder dried in the form of smooth and mild bridges between the grains allows very good strength properties of the molds and cores.

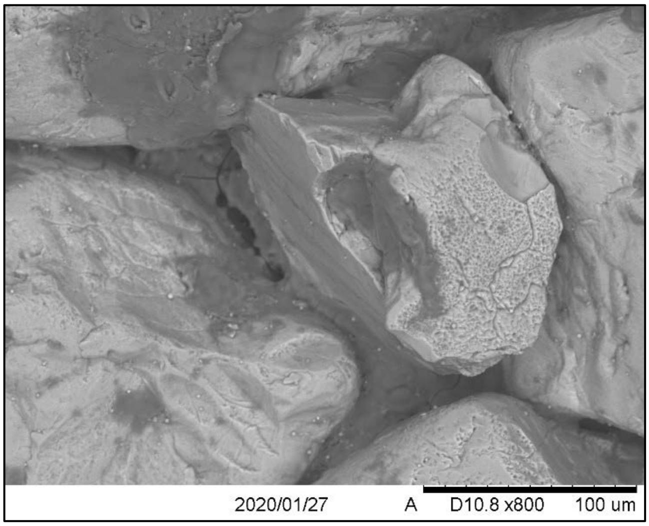

Fig. 6. SEM image of high-silica sand grains bonded with 5% malted barley binder

3.7. Comparison with other moulding sands

Table 3 shows a comparison of the research results of moulding sands with different binders. Compressive strength is the highest in moulding sand with malted barley. The best results were also obtained for dry permeability, dry wear resistance and flowability with malted barley binder. Other properties like dry tensile strength and dry bending strength gave good results in comparison with the remaining compositions of the moulding sands.

In articles [18, 19] it can be assumed that the properties of the moulding sand with a binder content of 4% should allow its use in the production of cast steel and cast iron castings. The chosen moulding sand shows the appropriate strength and technological properties.

Table 3.
Properties of the moulding sands performed with different binders

Qualitative and quantitative composition	Compressive Strength [MPa]	Tensile Strength [MPa]	Bending Strength [MPa]	Permeability [10^{-8} m^2/Pa·s]	Wear resistance [%]	Flowability [%]	Reference
High-silica sand (96%), Malted barley binder (4%), Distilled water (4%);	> 5	0,82	1,39	270	0,20	87,8	-
* High-silica sand (~80%), Bentonite (10%), Humidity (3,65%), Dextrin (2%), Coal dust (5%);	0,060	0,0052	-	200	15,5	79,9	[11]
** High-silica sand (94%), Bentonite (8%), Distilled water (4%)	0,55	-	-	-	18	-	[25]
High-silica sand (97%), Binder Geopol (2%), Hardener SA74 (0,24%);	0,76	-	0,31	210	-	-	[11]
High-silica sand (98%), Binder Rudal A (1,6%), Hardener SA65 (0,2%);	0,99	-	0,38	220	-	-	[11]
High-silica sand (98%), Resin X850 (0,8%), Hardener 100T3 (0,4%);	1,45	-	0,88	190	-	-	[11]
High-silica sand (96%), Water glass 145 (3,5%), Distilled water (0,5%);	-	2,4	4,52	-	-	-	[12, 13]
High-silica sand (90%), Cassava Starch (6 %), Water (14ml - 4%);	0,51	-	-	126	-	-	[15]
High-silica sand (87%), Cassava Starch (6%), Palm oil (6%), Pine oil (2%), Water (3%);	1,35	-	-	85	-	-	[16]
High-silica sand (80%), Rice Starch (20%), Water (40cm^3);	0,035	-	-	122 vol./min	-	-	[17]
High-silica sand (80%), Maize starch (20%), Water (40cm^3);	0,050	-	-	156 vol./min	-	-	[21]
High-silica sand (100 wt.) Binder Geopol (12%), Hardener SA72 (8%), Perlite ore P 7-16 (2 wt.)	0,10	0,85 (R_m^{tk})	-	315	2	(52g)	[23]
High-silica sand (89%), Gypsum (11%), Water (11% by weight from 100% all ingredients);	0,7	0,33	0,38	120	1,5	-	[24]

* results of green moulding sand with bentonite, ** result of dry moulding sand with bentonite.

4. Conclusions

The most important findings in this study are summarized as follows:

- malted barley is an effective binding material for the application of moulding sand technology,
- the application of 4% of the binder provides the moulding sand of the technological properties close to those of industrial scale [20, 21],
- moulding sand with malted barley binder can be compacted by various methods (vibration, ramming, shooting, inflation) - preliminary tests were carried out in the laboratory,
- it is possible to predict the value of dry tensile strength and dry bending strength of the moulding sand with a known content of malted barley binder,
- dry compression strength values for malted barley bonded sand gave the highest values for all binders presented in this paper (table 3),
- increases of the binder content leads to a reduction in permeability [1, 27],

- this study has shown that malted barley is a suitable alternative binder in comparison to others materials,
- malted barley is a renewable material through agricultural production, which is very important in terms of sustainable development of humanity and the earth.

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