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Effect of Matrix Type on Properties of Moulding Sand with Barley Malt

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Abstract

The aim of the following work was to determine the possibility of using barley malt as a binder in moulding sands technology. The moulding sands prepared on the basis of three kinds of sands, i.e. quartz, olivine and chromite ~~sands~~ were analyzed. In order to determine the properties of moulding sands, typical determinations were made, i.e. moisture content, flowability, permeability, strength properties and abrasion wear. The obtained results indicate that it is possible to use barley malt as an independent binder for masses made of quartz, olivine and chromite sands.

Keywords: Moulding sands, Barley malt, Properties of moulding sands

1. Introduction

The foundry industry is an important sector of the economy in many countries around the world. The global metal casting market size reached $151.6 billion in 2022. According to the Metal Casting Market report, it is estimated that by 2028 this market will reach a value of USD 236.7 billion, showing a CAGR of 7.71% in 2022-2028.

The requirements for the foundry industry are mainly related to the need to maintain an appropriate quality-price ratio of the product and to maintain an appropriate production regime that takes into account modern legal solutions related to environmental protection [1]. The concepts of environmental protection are inextricably linked with the assumptions of the so-called sustainable development - Conference in Rio de Janeiro in 1992. The implementation of the concept of sustainable development in foundry technology results in research on materials that can replace previously used materials that come from non-renewable sources and on those that have a highly unfavorable impact on the environment [2,3].

In the final decades of the 20th century and the beginning of the 21st century, research works appeared that addressed the possibility of replacing organic and inorganic synthetic binders with materials of plant origin [4-6]. So far, among the organic binders, foundries most often use synthetic resins: phenol-formaldehyde, urea-formaldehyde, furan, furfuryl [7]. Recent years have been a period in which research and implementation works on the use of biopolymers, starch and oils have been carried out [8,9]. Among the materials mentioned above, biopolymers are used in industry. The remaining materials analyzed by researchers were not implemented into production. However, active actions taken in the research field were and are caused by new guidelines for the foundry industry. They concern restrictions on the use of materials: harmful, toxic, causing emission of dangerous gases, noise, vibrations, and materials that cannot be reused after the recycling process [8–15]. Analysis of the possibilities of using other moulding materials based on a literature review indicates that raw materials such as wood rosin, molasses, oils, dextrin, starch, cellulose, natural latex - can be used as moulding materials [12,16-19]. The mentioned materials may constitute an independent binder shaping the properties of the moulding sands or be a special additive influencing selected properties of the sands. However, the possible selection of a specific material must take into account the requirements set by the foundry (recipient) and must also meet new regulations regarding environmental protection and health and safety regulations [2,3,8].

The binder in the form of barley malt analyzed in this work belongs to the 4th generation of moulding sands, according to the classification of moulding sands proposed by D. Boenisch and supplemented by P. Jelinek [21]. Barley malt as the 4th generation of masses is bound at elevated temperatures through the phenomenon of dehydration (drying). The dehydration process, i.e. drying materials, involves the elimination of water from the material to the environment by diffusion [22-26]. The presented article is therefore in line with the mentioned trend of searching for materials that come from renewable sources and have a lower negative impact on the environment [4-6].

2. Materials and methods

The moulding sands were prepared in accordance with the recommendations from the literature [8]. A laboratory circular mixer LM-2e (Multiserw-Morek, Marcyporęba, Poland) was used to prepare the masses. Preparation of the masses began by mixing the weighed dry ingredients. The dry mixing time was one minute. Distilled water was then added to the mixture and all ingredients were mixed for another 3 minutes. The conditions for preparing the moulding sands and the ambient conditions during the preparation of the moulding sands were the same, i.e. temperature ~21°C and air humidity of approximately 40%. After preparing the masses, they were stored for 60 minutes in a tightly closed container to standardize the moisture content. The total weight of dry ingredients used was 5 kg. Three types of moulding sands based on medium sands were tested: quartz from the Grudzień Las mine (Poland), olivine from the North Cape Minerals mine (Norway) and chromite from Kratos Polska (Ozimek, Poland). In order to compare the grain size of the sands selected for the experiment, a sieve analysis was performed according to: PN-H-11077:1983 (Foundry moulding materials - Sieve analysis of foundry sand and bentonite). The results are presented in Table 1. The study showed that all matrices are classified as medium sands, as demonstrated by the manufacturers.

Table 2 shows the basic parameters of the grain matrix used in the tests.

As shown by the data in Table 2, most of the parameters characterizing the tested molding sands are very similar to each other. Only the main fraction of chromite sand is smaller compared to quartz and olivine sand, but all sands are still classified as homogeneous sands [8]. The degree of uniformity also for chromite sand is the lowest and amounts to 67%.

The selected materials for the matrix of the molding sands were also characterized on the basis of the grain surface topography, which is shown in Figure 1.

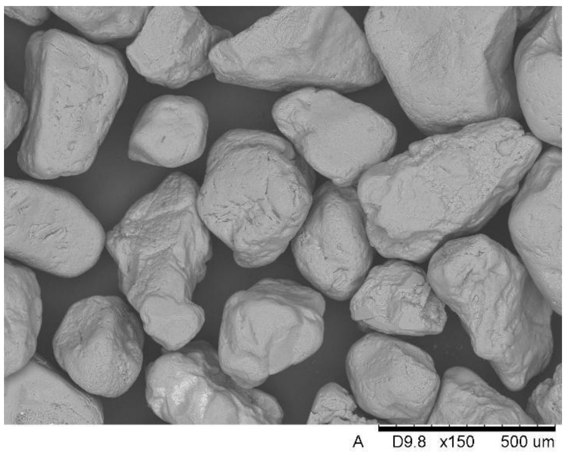
Table 1.
Sand sieve analysis

Mesh size sieve	Residue on the sieves, %		
	Quartz	Olivine	Chromite
1.600	0	0	0
0.800	0	0	0
0.630	0	0	0.34
0.400	3.34	1.28	12.00
0.315	**19.95**	**27.38**	**20.72**
0.200	**61.67**	**55.10**	**42.98**
0.160	**10.42**	**10.34**	**17.06**
0.100	4.62	5.18	6.58
0.071	0	0.68	0.32
0.056	0	0.04	0
Bottom	0	0	0
Sum	100	100	100

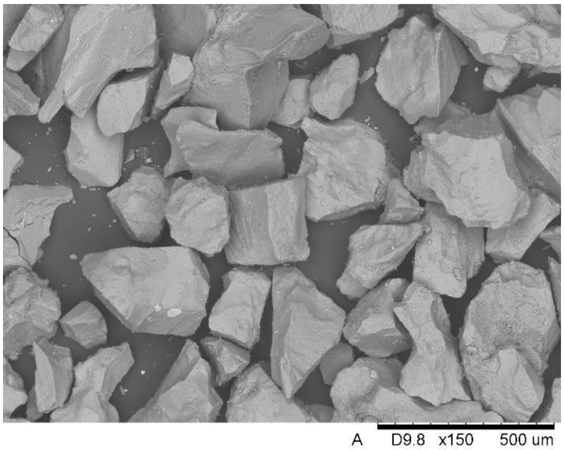
Table 2.
Characteristic indicators of the tested sands

Mesh size sieve	Unit	Material		
		Quartz	Olivine	Chromite
Number of grains AFS		52.32	52.68	52.52
Average grain size	mm	0.24	0.24	0.24
Geometric average	mm	0.19	0.19	0.19
Aritmetic average	mm	0.19	0.19	0.20
Harmonic average	mm	0.18	0.18	0.18
Median	mm	0.26	0.27	0.27
Average grain size	mm	0.26	0.27	0.27
Main fraction	%	92.04	92.84	80.76
Surface area	m^2/kg	0.075	0.070	0.069
Degree of homogeneity	%	77	83	67

a)



b)



c)

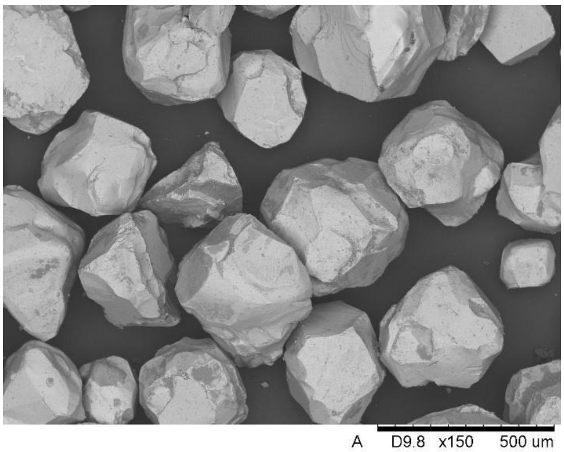


Fig. 1. Surface topography of sand grains: quartz (a), olivine (b), chromite (c), SEM (magnification x150)

The photos in Figure 1 indicate that quartz sand has the most spherical grains among the analyzed sands. This shape is called rounded grains. In turn, olivine sand grains correspond to the shape of angular grains, and chromite sand to sub-angular grains. Sand in the shape of rounded grains guarantees good permeability and fluidity, but poorer durability of molding sands compared to sand in the shape of angular and sub-angular grains.

The designation and composition of the prepared moulding sands are presented in Table 3.

Table 3.
The characteristics of the examined masses

Designation of the moulding sands	Type of sands used	Amount of sand [%]	Amount of binder [%]	Amount of water [part by weight]
QS	quartz	95	5	5
OS	olivine	95	5	5
CS	chromite	95	5	5

2.1. Preparation of samples for testing the properties of moulding sands

Preparation of samples for determining the properties of moulding sands involved making three standard types of measurement samples: cylindrical, elongated and figure eight [8]. The samples were compacted using a manual laboratory tamper type LM-1 (Multiserw-Morek, Marcyporęba, Poland). Compaction consisted of hitting the moulding sands three times with a rammer placed in an appropriate shape reflecting a specific sample format. The compaction work was approximately 9.8 J. Then, the samples were dried in a laboratory dryer SLW 115 (Pol-Eko-Aparatura, Wodzisław-Śląski, Poland), which carried out a drying program with forced air circulation at a temperature of 150°C for 60 minutes. After drying, the samples were cooled in the air.

2.3. Methods for determining the properties of moulding sands

In order to determine the properties of the moulding sands, the following properties were determined: moisture content, flowability, permeability, abrasion, bending and tensile strength. Humidity was determined using a three-station Lap-3 rapid radiation dryer. Liquidity was determined using the H.W. Dietert and F. Valtier method. Abrasion was determined according to BN-77/4024-02 using an LS type device (WADAP, Wadowice, Poland). Permeability was determined using the accelerated method on a digital permeability device LPiR1 (Multiserw-Morek, Marcyporęba, Poland). The determination of the bending and tensile strength parameters was carried out on the LRu-2e universal testing machine (Multiserw-Morek, Marcyporęba, Poland).

3. Results and discussion

The study analyzed moulding sands made of three types of sands matrix: quartz, olivine and chromite. Each of the masses were prepared with the same percentage of binder, i.e. 5%. Therefore, the analysis of the results was based on the differences between the prepared masses. The results of the influence of the type of matrix on the properties of the moulding sands are presented in Figures 2–7. Figure 2 shows the results of measurements of moisture of moulding sands depending on the type of matrix. In this determination, all masses were analyzed after a storage time of 1 h. Comparison of the obtained moisture contents shows that the individual results are similar to each other.

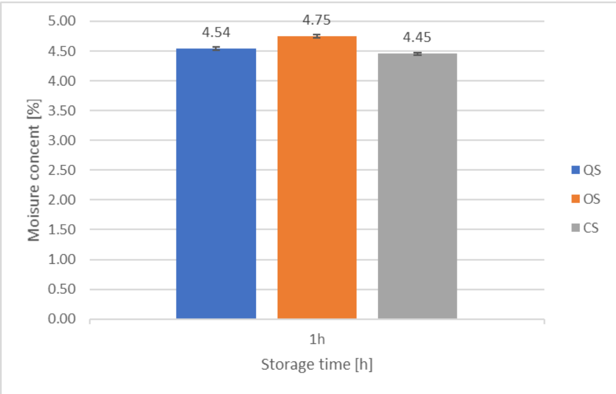


Fig. 2. Results of measurements of the moisture of moulding sands depending on the type of matrix

The determination of the flowability results is shown in Figure 3. Similarly to the above, all masses were analyzed after a storage time of 1 hour. The best flowability was obtained for the mass where the matrix was quartz sand.

The second best result was obtained by a mass based on olivine sand with a decrease of 5% compared to the mass made from a quartz matrix. The third result was obtained by the chromite sand mass with a decrease of 8% compared to the quartz sand mass. However, the difference between the chromite sand mass and the olivine sand mass was 3% in favor of the olivine matrix. Comparison of the obtained results showed that the type of sand matrix affects the flowability. The recorded difference in flowability of the analyzed masses is most likely caused by the shape of the matrix grains and the friction coefficient (the friction in question is interparticle friction), which is different for different materials. Grains with a shape similar to a ball have the best flowability due to the point friction of the grains. However, grains with an oblong shape are characterized by poorer flowability due to point and linear contact points between the grains, which translates into a larger contact and friction surface.

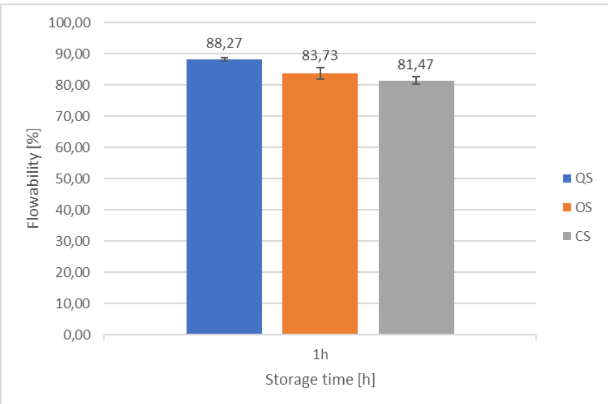


Fig. 3. Results of measurements of the flowability of moulding sands depending on the type of matrix

Figure 4 shows the permeability results of moulding sands in the hardened state. The permeability of the analyzed moulding sands was determined for two storage times of 1 hour and 24 hours, respectively. For a storage time of 1 hour, the percentage difference between the mass based on quartz sand and olivine sand was 39%. However, the difference between the mass based on quartz sand and chromite sand was 13%. The recorded difference in permeability of the analyzed masses is related to the specific shape and homogeneity of the sands used. Masses stored for 24 hours behaved similarly.

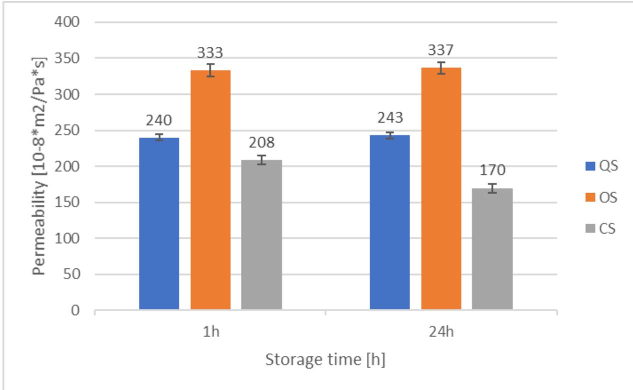


Fig. 4. Results of measurements of the permeability of moulding sands depending on the type of matrix

The influence of the type of sand matrix on the abrasion resistance of moulding sands in the hardened state is presented in Figure 5. Comparison of the results of two storage times showed a decrease in abrasion, i.e. an increase in the abrasion resistance of sands stored for 24 hours. In the case of masses with quartz sand, the abrasion resistance increased by 35% compared to 1 hour. In the case of olivine sand masses, the mentioned increase in abrasion resistance was 9%. However, for the mass with chromite sand, an increase in abrasion resistance by 44% was noted. Based on the results obtained, it can be seen that the time and storage conditions have an impact on abrasion. The reason for this could be the increased humidity, which contributed to the appearance of van der Waals-type interactions between water atoms.

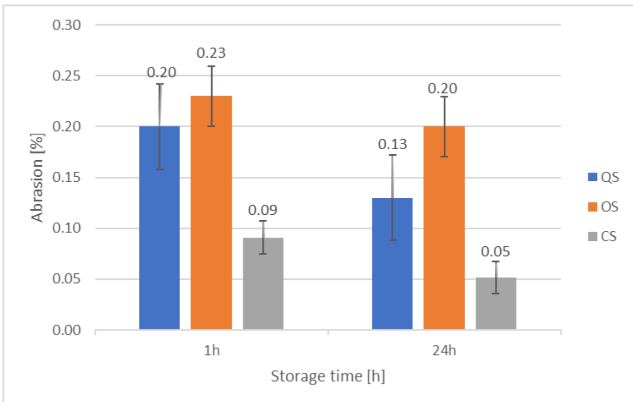


Fig. 5. Results of measurements of the abrasion of moulding sands depending on the type of matrix

The results of the bending strength of moulding sands in the hardened state are presented in Figure 6. In the case of quartz sand, a 23% decrease in the strength of the sand stored for 24 hours compared to 1 hour was observed. A tendency to decrease in bending strength was also recorded in the case of olivine sand masses. The mass stored for 24 hours gained 21% lower strength compared to the mass stored for 1 hour. For masses made of chromite sand, the bending strength remained at the same level.

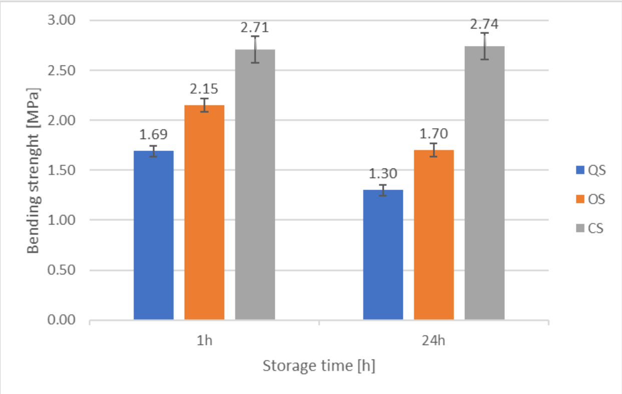


Fig. 6. Results of measurements of the bending strength of moulding sands depending on the type of matrix

The results of the tensile strength of moulding sands in the hardened state are shown in Figure 7. Comparison of sands with the same composition only with different storage times showed a decrease in the tensile strength of moulding sands stored for 24 hours compared to 1 hour. The decrease in tensile strength was respectively: 14% for quartz sand, 17% for olivine mass, and 16% for chromite sand mass. The obtained differences in tensile strength results are most likely caused by the difference in the shape of the grains of the sands used [27].

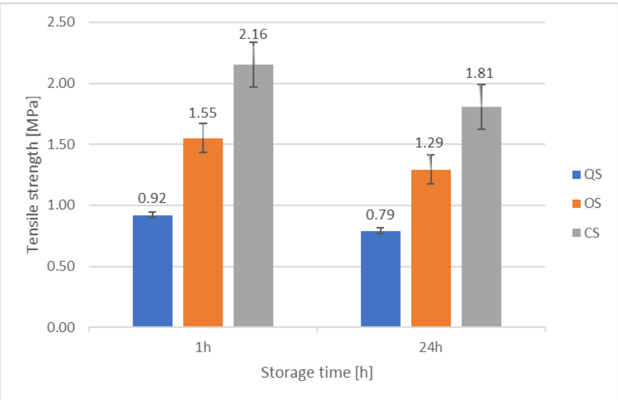


Fig. 7. Results of measurements of the tensile strength of moulding sands in the hardened state depending on the type of matrix

4. Conclusions

The results obtained during the research on the properties of moulding sands allow us to conclude that it is possible to use barley malt in moulding sands technology. The addition of 5% barley malt as a binder guarantees relatively good strength and abrasion properties, which are required for commonly used moulding sands. Good fluidity of the moulding sand, above 80%, allows us to conclude that the binder used, in the form of barley malt, is suitable for moulding using classic methods, i.e. manual and machine moulding methods. Barley malt, being a natural and renewable raw material through agricultural production, can therefore be an alternative material to conventional binding materials, thus fitting into the concept of sustainable development.

Analyzing the results, it was noticed that some results were not consistent with the information presented in the literature regarding the shape of sand grains. These differences may result from the pH of individual sands and the binder in the form of barley malt. The pH of light barley malts is around 5-6 and such malt was analyzed in this work. This means that it is a slightly acidic material. In turn, quartz sand has an acidic pH, olivine sand has an alkaline pH, and chromite sand has a slightly alkaline pH [8]. This may mean that various reactions may occur between the sand and the binder in the presence of water, which was a component of the molding sand. Salts can be formed between the reaction products between alkaline and acidic pH, which form strong bonds. However, this requires additional, more detailed analyses, which will be the subject of further research.

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