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Analysis of Selected Properties of Green Sands with Modified Starch-based Additives

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Abstract

The aim of this study was the preliminary assessment the effectiveness of application of sodium carboxymethyl starch (CMS-Na) as an additives to green sands with bentonite. Two modified starches CMS-Na having a low and a high degree of substitution (DS), 0.2 and 0.9 respectively, were chosen for preparing moulding sands. Influence of modified starch with different DS on the properties of the green sand was determined based on the results of the determination: apparent density, permeability, free flowability, friability and compressive strength, tensile and shear green sands with the addition of starch. The properties of the starch without starch-based additives were compared with the properties of green sand containing in the composition of CMS-Na with different degree of substitution.

Keywords: Innovative moulding materials, Green sand system, Additives for moulding sand, Carboxymethyl starch sodium

1. Introduction

An application of additives in the form of native starch or starch derivatives in order to improve the properties of the moulding sands is known in the green sand system. Starch additives are used mainly in foundries, where are using moulding materials with the participation of bentonite [1, 2].

Native starch (native), as an inexpensive and easily available material, is normally used as a material aid improves features of green sands form. The introduction of native starch in the form of cooked starch solution helps prevent casting defects associated with the expansion (polymorphic transformations to occur without any deformation of the quartz form are possible in the high temperature accompanying the burning of moulds). In addition, the effect of the adding to the moulding sands starch solutions may cause a reduction the tendency of the green sands to casting defects, i.e. scabs and veining [1, 2].

Moreover, the presence of these materials reduces the tendency to surface drying, reduces friability, improve the water-binding capacity and increases the strength of moulding sand before curing or drying [1].

The negative effect of the presence of starch in green sands is a deterioration of fluidity and resistance to erosion as well as the penetration of the metal into the mould [1, 3-5].

Limitations of using starch in the native form are a result of natural properties of this biopolymer, e.g. insolubility in cold water and the necessity to heating the solution to obtain a viscous colloid [6].

The use modification of the starch allows to obtain a water soluble product and colloids with improved adhesiveness and viscosity [6-8]. The example of modified starch is starch carboxymethyl starch (CMS) and its sodium salt (CMS-Na). Generally CMS is obtained by etherification of the starch slurry in ethyl alcohol monochloroacetic acid (Williamson synthesis) [7,8].

Depending on the conditions of preparing carboxymethyl reaction can be obtained substances having different properties. Changes of the physicochemical properties of the sodium salt of carboxymethyl results from the degree of substitution (DS), which is defined as the average number of substituted hydroxyl groups in each glucopyranose ring in the Williamson synthesis. Also a viscosity, water solubility and stability modified starch increases proportionally to the degree of substitution [7,8]. In addition the modified starch, compared to carboxymethyl native starch, has better binding capacity of the matrix grains in moulding sands and core sands, which is also associated with the degree of substitution [9,10].

The aim of this study was to determine the effect of modified starches of various degrees on the selected properties of the classic moulding sands and the preliminary assessment of the appropriateness of using additive starch in green sand system.

2. Experimental

2.1. Materials

The materials used in this study were:

1. silica sand (BK D 0.16-0.32 MM, Sibelco Europe),
2. activated bentonite (Bentonite Specjal, ZGM „Zębiec")
3. low-substituted carboxymethyl starch sodium (Polvitex Z, Xenon); DS 0.2; pH 11.4.
4. high-substituted carboxymethyl starch (West Pomeranian University of Technology; Szczecin); DS 0.9; pH 9.6.

2.2. Preparation of moulding sands mixtures

Moulding sands were prepared in the laboratory roller mixer type LM-1 applying the following amount of adding substances (table 1):

Table 1.
The content of green sands in part by mass

Symbol of molding sand	Benton ite (B)	CMS-Na additive		Silica sand	Moisture content, %
		low DS (L)	high DS (H)		
B	6.0	-	-	100	1.30-2.80
B+L	6.0	1.0	-	100	1.65-3.00
B+H	6.0	-	1.0	100	1.40-3.80

Dry ingredients were mixed for 3 minutes in the mixer with water addiction. After that, molding sands were sieved and protected against drying.

Thus prepared material was used for the study of selected properties. Cylindrical samples were compacted by three times hitting of the standard rammer.

In each case, after completing the measurement of parameters of the moulding sand for specific moisture content, the whole of mixture was placed into a laboratory mixer and moistened proper amount of water. Then it was mixed, sieved and selected properties were investigated for the moulding sand with increased water content.

During the moulding sands preparing and measurements the relative humidity in the laboratory was in the range 35-48% and the temperature 23-25 °C.

2.3. Methods

Apparent density

Determination of apparent density (ρ_0) was performed by measuring the volume and weight of cylindrical shapes prepared with the studied green sand. After removing the sample from the metal sleeve for forming the standard cylindrical-shaped samples (ϕ50, h=50 mm) it was measured to the nearest 0.2 g [7].

Permeability

In the fast method for determining permeability (P^w) the pressure present in the space under the test samples indicated by the gauge in an electrical apparatus for determining permeability LPiR1 type was measured (PN-80/H-11072).

Green strength properties

Determination of the of the moulding sands were performed on a universal apparatus for determining the mechanical properties of the LRU type (MULTISERW Morek) according to PN-83/H-11073/EN. Suitable mounting jaws and handle allowed the measurement of compressive (R_C^w), shear (R_t^w) and tensile strength (R_m^w) on normalized cylindrical-shaped samples. The results are given in MPa.

Friability

Friability (S) were tested in the apparatus for determining the wear resistance LS type. Standardized fitting cylindrical was weighed to the nearest 0.1 g and placed on rollers LS apparatus. Then radiant lamp and roller rotating motor were turned on for 5 minutes, so that the part of matrix grains were detached from the surface of the green sand sample. After the time an engine was turned off and the green sand fitting was removed from the rolls and re-weighed (BN-77/4024-02).

Free flowability

In this method, regardless of the moisture content and the content of binder in the moulding sand are weighed 150 g of material, and sieved (using a brush) through a sieve with a mesh of 4x4 mm to a funnel-shaped container with an opening bottom. After sieving, the lock of container bottom is released and moulding sand contained in the container falls from a height of 3 feet (0.914 m) on the sieve with mesh 6x6 mm. The measure of free flowability (Ps) is expressed in an amount by weight (g) that pass through the sieve. The mass is weighed to the nearest 0.1 g. It is assumed that the flowability is the better if more moulding sand passes through a sieve [1].

Moisture content

The moisture content of the moulding sand weight was measured in three chambered laboratory dryer. There was weighted 50 g (together with the measuring container) of tested green sand nearest to 0.01 g. Then the weighing of the material was introduced into a drying chamber heated to 105-110 ℃. It was dried to a constant weight. After property drying time for the testing material the dried sample was removed from the dryer and was cooling to ambient temperature. Then, it was again weighed to the nearest 0.01 g [1].

3. Results and discussion

The results of selected properties depending on the water content are shown in figures 1 to 7.

The changes of the apparent density depend on the degree of substitution of CMS-Na additive into the moulding sand (Fig. 1). The use of CMS-Na with a low degree of substitution resulted in a marked increase of the value ρ_0 moulding sand (B+L), while the addition of CMS-Na with a higher degree of substitution decreased ρ_0 in the entire moisture content range (B+H). The minimum of apparent density of the green sand B was 1.47 g/cm^3 at a moisture content of 1.9%, and the adding of CMS-Na into the moulding sand composition caused shifting this minimum ρ_0 to a higher moisture, i.e. 2.3%, and it was equal to 1.51 g/cm^3 for the moulding sand B+L and 1.45 g/cm^3 for the moulding sand B+H.

Pathways of permeability changes in all three compositions also showed that the degree of substitution of modified starch CMS-Na has a significant effect on the moulding sand.

The moulding sandf B+L in the range of 1.6-2.3% moisture content was characterized by a lower permeability than the moulding sand without additives, and when the moisture content was higher than 2.3% the determined P^w remained at a similar level as in the moulding sand B.

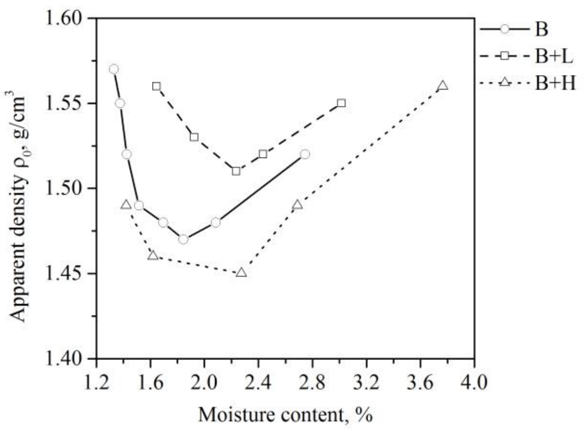

Fig. 1. Apparent density of moulding sand: B-without additives, B+L –with low-substituted CMS-Na, B+H –with high-substituted CMS-Na

However, the moulding sand B+H in all relevant moisture content range showed the highest permeability among the three tested mixtures (Fig 2). The maximum permeability of the moulding sand with starch additives was determined at a higher water content than the moulding sand B ($300\cdot10^{-8}$ m^2/Pa·s at 1.9% of moiusture content): $261\cdot10^{-8}$ m^2/Pa·s for the mass B+L and $373\cdot10^{-8}$ m^2/Pa·s for moulding sand B+H at 2.3% of the moisture content.

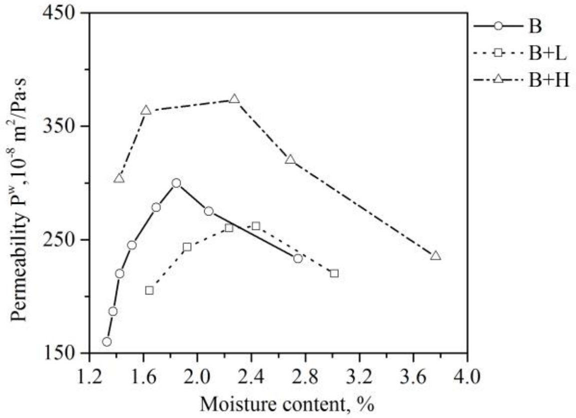

Fig. 2. Permeability of moulding sand: B-without additives, B+L –with low-substituted CMS-Na, B+H –with high-substituted CMS-Na

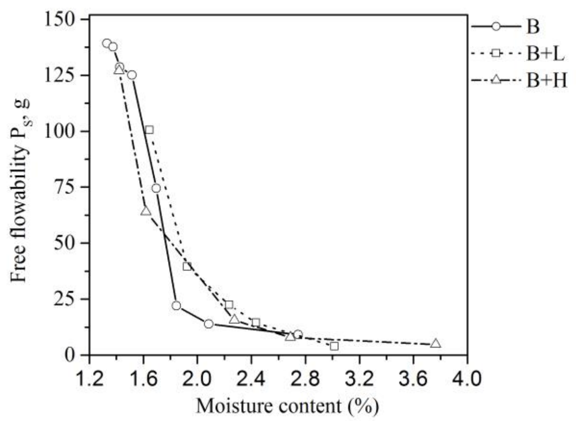

Fig. 3. Free flowability of moulding sand: B-without additives, B+L –with low-substituted CMS-Na, B+H –with high-substituted CMS-Na

Analysing the results shown in Figure 3 it was found that, despite the expected adverse effect of additions of starch [1,2] on the flowability of the moulding sand, for low-substituted modified starch (B+L), there was no deterioration of the properties compared to the green sand B (Fig. 3), and CMS-Na improved this property in the range of from 1.8 to 2.8% moisture content.

A material with a higher degree of substitution at the moisture content of approx. 1.5 to 1.8% lowered the moulding sand (B+H) liquidity, however, above 1.8% moisture content was obtained higher P_S compare to the green sand without additives (B).

Results of the green compressive strength (R_c^w), green tenslile strength (R_m^w) and green shear strength (R_t^w) of moulding sands were summarized in Figures 4-6.

The adding of starch materials, regardless of their degree of substitution, decreased the strength of the moulding sand compared to the green sand only with the bentonite (Fig. 4-6). The maximum strength of moulding sand B were observed in the 1.5-1.7% moisture content and amounted to R_c^w = 0.17 MPa, R_m^w = 0.028 MPa and R_t^w = 0.034 MPa. The analysis of changes in the strength of the green sands containing CMS-Na showed that depending on the degree of substitution of the applied starch caused varied effect.

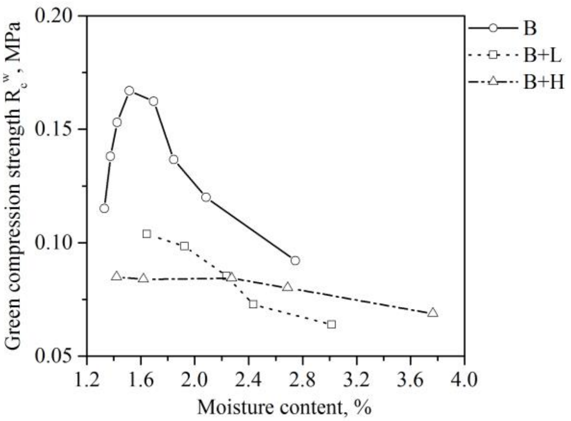

Fig. 4. Green compression strength of moulding sand: B-without additives, B+L –with low-substituted CMS-Na, B+H –with high-substituted CMS-Na

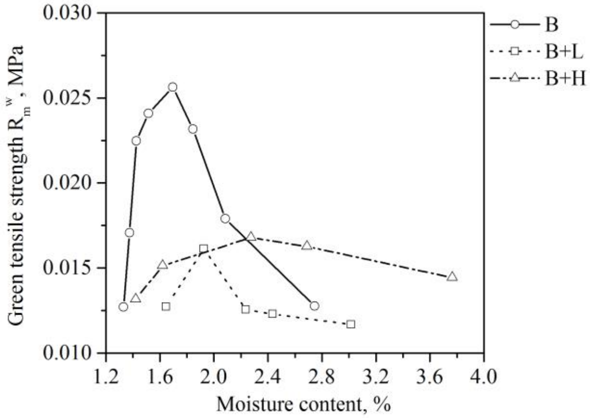

Fig. 5. Green tensile strength of moulding sand: B-without additives, B+L –with low-substituted CMS-Na, B+H –with high-substituted CMS-Na

Based on the analysis of the course changes for moulding sand B+L has been found that due to the adding of CMS-Na with DS 0.2 strength properties has been significantly lowered throughout the tested range of moisture content. The maximal strength of the moulding sand B+L were determined in the slightly higher moisture content than moulding sand B (1.6-1.9%), and was equal to R_c^w = 0.10 MPa, R_m^w = 0.016 MPa and R_t^w = 0.023 MPa.

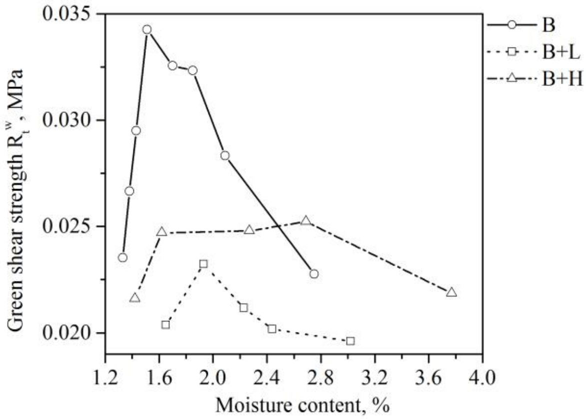

Fig. 6. Green shear strength of moulding sand: B-without additives, B+L –with low-substituted CMS-Na, B+H –with high-substituted CMS-Na

It was observed that the change in strength properties of the moulding sand with the high-substituted CMS-Na had almost linear course, which indicated on low sensitivity to changes in moisture content in moulding sand.

Moulding sand B+H in range of 1.3-2.3% moisture content was characterized by the lowest compressive strength of the respondents green sands and had a maximum at R_c^w= 0.084 MPa. Compiled in Figures 5 and 6 the results of green tensile strength and green shear strength of moulding sand with the addition high-substituted CMS-Na allowed seen that in the theoretical operating moisture content range of 2 to 3% [1], initially, the moulding sand B+H achieved a lower value than moulding sand B, but increasing the moisture content of more than 2.3%, allow to obtain the highest tensile strength and shear strength of all tested green sand.

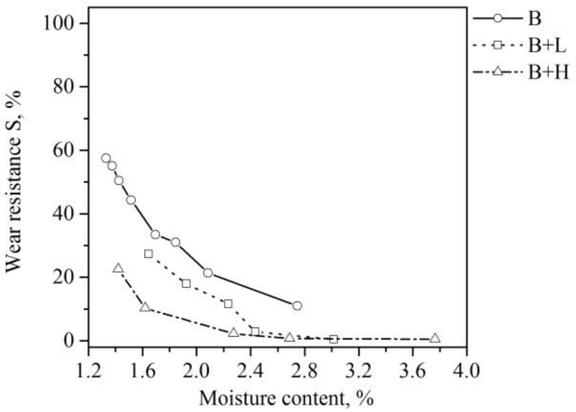

Fig. 7. Friability of moulding sand: B-without additives, B+L –with low-substituted CMS-Na, B+H –with high-substituted CMS-Na

Figure 7 shows the results of the friability determination of the green sands. Friability is indicator of surface quality moulds and cores, which has a significant impact on the quality of the product in industrial conditions [1]. Comparing the values of S obtained for the green dand without additives and the green sands with the addition of CMS-Na clearly stated that regardless of moisture content the presence of modified starch in moulding sand contributed to a decline friability. The best effect was obtained for using high-substituted CMS-Na, making it possible to several-fold reduction S at 1.3-2.8% of moisture content. Both starcg additations in the green sands at moisture content over 2.3-2.4% caused reduction S to almost to zero.

4. Summary

The analysis of the obtained results showed that the use of modified starches as additional material in green sands has a significant impact on selected properties of the moulding sands, i.e. green compressive strength, tensile, shear, measuring the permeability, apparent density, free flowability and friability.

Considering the degree of substitution selected to testing a starchy materials it was found that more favourable results were obtained for the moulding sand with the participation of CMS-Na with DS 0.9. The moulding sand with this modified starch achieved higher permeability and apparent density throughout the whole range of the moisture content. It was noted that the above 2.3-2.4% of moisture moulding sand was characterized by the highest green tensile strength and green shear strength, higher than the moulding sand without additives. Regardless of the degree of substitution of CMS-Na was possible to significantly reduce friability of green sand.

However, it was observed that the use of CMS-Na did not guarantee a satisfactory green strength properties of the moulding sand, especially the moulding sand with low-substituted CMS-Na. Thus in future, next studies on the enrichment of a moulding mixture with other additives for improving the bonding strength properties, will be carried out. In order to verify the quality of the moulding sand with CMS-Na additives, preparing of moulds and experimental castings is planned.

Acknowledgements

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