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Technological Properties of Moulding Sands with Geopolymer Binder for Aluminium Casting

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Abstract

The use of environmentally friendly inorganic binders and new technologies for cores production is widely discussed topic in recent years. This paper contains information about new hot curing process for core making with alumina-silicate based inorganic binders – geopolymers. Main differences between hot cured geopolymers and hot cured alkali silicate based inorganic binders are discussed. The main objective of this research paper was to investigate basic technological properties of geopolymer binder system such as strength, compaction, storage ability and knock-out properties. For this purpose, three mixtures with different powder additives were prepared and tested in laboratory conditions using specific methods. Strength properties evaluation showed sufficient levels as well as knock-out properties measurement, even with additives B and C originally designed for the use with alkali silicate based two component binder systems. Additives B and C were considered compatible with geopolymer binders after casting production trial results. Storage ability of geopolymers seems to be more sensitive than of alkali silicate based binders in the same tested conditions. Mixtures with geopolymer binder showed 20% more decrease of strength compared to alkali silicate binders after 24 hours in conditions of 25 °C and 65 %RH.

Keywords: Inorganic binder, Geopolymer, Sand core, Strength, Knock-out properties, Aluminium

1. Introduction

Foundries are under constant pressure of strict environmental and safety regulations, therefore there is a tendency to replace organic binder systems with more ecologically friendly alternative [1]. In order to fulfil requirements for harmful and odourless core making and casting process, new hot cured two component inorganic binder systems based on alkali silicate solutions were developed mainly for serial production of aluminium castings for automotive industry [2]. Although, developers of alkali silicate based inorganic binder systems significantly improved binder system properties, there remains a connection to technological

problems compared to resin-bonded sands such as low knock-out properties, low ability to reclaim and limited storage of cores [3,4]. Among alkali silicate based binders there is also one related group of binder systems – geopolymers. Geopolymers are alkali alumina-silicate solutions, which have completely inorganic nature. They contain Si, Al and alkali compound such as Na or K. Geopolymers are synthetically prepared by dissolution of alumina-silicates in water and stabilization by alkali oxides. It has a low grade of polymerisation, during curing the grade of polymerisation is increased and it creates the polymer with a high binding ability. In contrast to the alkali silicate based solutions they include not only the composition of $\text{Si}(\text{OH})_4$ tetrahedral, but

also $\text{Al}(\text{OH})_4$ tetrahedron with shared oxygen atom, basic structural unit is illustrated in the Fig. 1 [4-6].

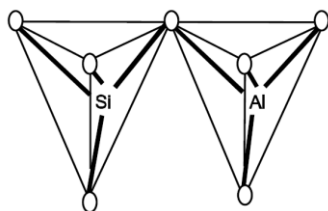


Fig. 1. Basic structural unit of geopolymer [4]

Through the formation of chains of SiO_4 and AlO_4 bonds are being formed. Si:Al ratio influences the properties of the system and its application. Geopolymers with high molar ratio $\text{SiO}_2/\text{Al}_2\text{O}_3$ are liquid compounds with similar properties as colloid solutions of alkali silicates. Binders used these days usually operate with ratio of 10:1 (Si:Al). Curing mechanism of geopolymers can be performed by chemical reaction or physical drying (similarly to alkali silicate based binders) [5]. Geopolymer polysialate structure is more durable than silica gel structure, which consist only of silicon tetrahedron chains. Research showed that modification of alkali silicate solutions with aluminium based additives leads to the improvement of cohesive strength of chemically cured binder. High cohesive strength of the geopolymeric binder shell leads to a mostly adhesive destruction of the binder during shake out, that should grant very good knock-out properties compared to alkali silicate based binder systems with mostly cohesive destruction of binder bridges [7-10].

2. Work methodology and materials

In this investigation, binder systems used are designed for aluminium castings production. Samples for bending strength were prepared from three different mixtures. Mixtures differed in the powder additive which was used as a second component for binder system. Geopolymer binder with specific weight at 20 °C 1.49 – 1.52 g/cm³ and viscosity at 25 °C 120 – 220 mPa·s, produced by company Sand Team s.r.o., was used. Table 1. presents characteristic properties of powder additives described by their suppliers, additive A is designed by the same company as the binder. Since curing mechanism of the geopolymer binder is according to [5] similar to hydrated alkali silicate binders, effect of 2 additives designed for hot cured alkali silicate based binders was also examined.

Silica foundry sand from Slovak locality with average grain size of 0,38 mm and rounded grain shape was used to prepare mixtures. Binder and additives amounts were designed based on manufacturers recommendation as well as on previous experimental results (unpublished). Overview of examined mixtures is presented in the Table 2.

Table 1.

Description of used powder additives

Additive	Properties description
A	Improves moisture resistance, increases hot and cold strength, designed for geopolymer binder, recommended addition 0.3 – 0.6%
B	designed for filigree geometries, high compaction, improved de-coring properties, organic containing, designed for alkali silicate based binder, recommended addition cca. 0.8 – 1.0%
C	high compaction, improved humidity resistance and de-coring properties, superior dimensional accuracy during pouring, 100% inorganic, designed for alkali silicate based binder, recommended addition cca. 0.8%

Table 2.

Composition of tested mixtures

Mixture	Binder amount [%]	Additive	
		Type	Amount [%]
No. 1	1.80	A	0.50
No. 2	1.80	B	0.80
No. 3	1.80	C	0.80

Strength properties of tested mixtures were evaluated by bending strength measurement after 30 s (immediate strength) and after 1 hour (cold, final strength) on the Multiserw Morek LRu-2e universal strength machine.

Knock-out properties were measured using method of abrasion resistance of test bars measurement after thermal load of 400 °C for 10 minutes, which was already described in [11].

Mixtures No. 1 and No. 2 were used for cores production for aluminium casting for automotive part, as a trial of sufficient strength and knock-out properties.

Mixtures No. 2 and No. 3 were also tested for storage ability by keeping the measurement procedure as described in [12]. Samples were putted into the incubator with set up parameters of 25 °C and 65 %RH, which were in previous work described as conditions where inorganic cores have limited time of storage, after certain time intervals bending strength was measured as well as content of free water by halogen moisture analyser [12].

3. Results

3.1 Strength and knock-out properties

Table 3. and Fig. 2 present values of bending strength and compaction differences obtained by using different powder additive in mixtures. Mixture No. 1 has similar immediate strength to mixture No. 3 and slightly higher final strength, but the weight of test bars made from mixture No. 1 is significantly lower. Mixture No. 2 has highest immediate and final strength and similar compaction as mixture No. 3. Additive A which is

designed for the use with geopolymer binder exhibits good strength results, but compaction is significantly lower than with the use of additives B and C designed for alkali silicate based binder. Strength properties with additives B and C exhibit very similar behaviour when used with alkali silicate based binders.

Table 3.
Strength properties and compaction of tested mixtures

Mixture	Bending strength [MPa]		Weight of test bar [g]
	30 s	1 h	
No. 1	1.68	3.81	130.25
No. 2	1.80	4.12	139.60
No. 3	1.72	3.52	140.35

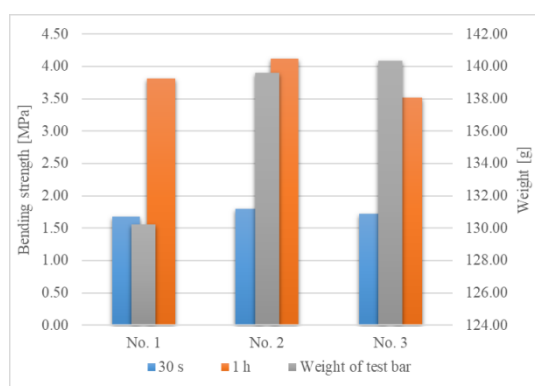


Fig. 2. Strength properties and compaction

Diagram on Fig. 3 presents knock-out properties evaluation by the method of abrasion resistance of test bars after thermal load of 400 °C for 10 minutes described in [11]. All three examined mixtures reached 100% abrasion which means the best knock-out properties that can be obtained by this method. This corresponds with statements based on previous research that geopolymer binder bridges have high cohesive strength and their destruction is mostly adhesive, which results into very good knock-out properties [7].

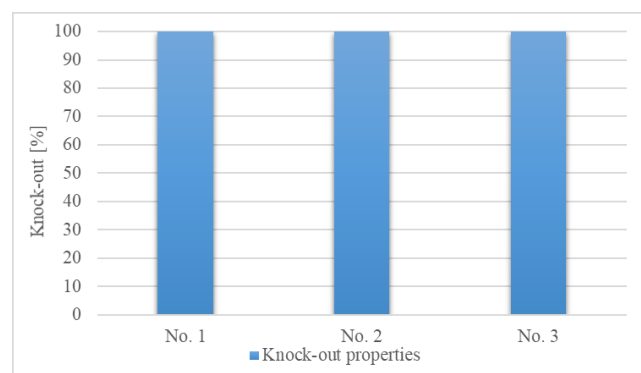


Fig. 3. Knock-out properties

Fig. 4 presents knock-out properties of additive B with alkali silicate based binder compared to mixture with geopolymer used

in this research work. Results show, that with alkali silicate binder obtained knock-out properties are worse, which corresponds with mostly cohesive destruction of alkali silicate based binders.

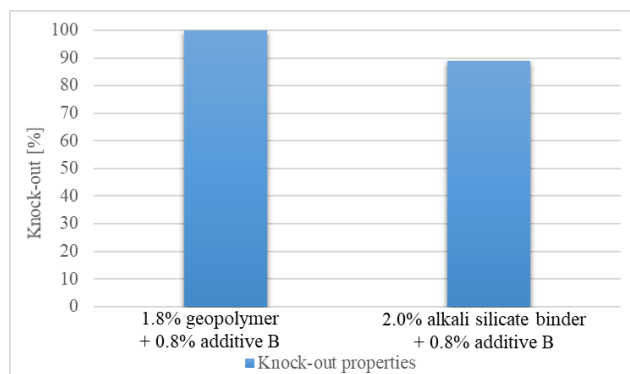


Fig. 4 Comparison of knock-out properties of geopolymer and alkali silicate binder

3.2 Casting production trial

Mixtures No. 1 and No. 2 were used for core production for casting an aluminium part for automotive industry. After casting and shake-out, parts were sawed and channels were controlled for rests of sand. Fig. 5 show a pictures of channels inside trial castings. When mixture No. 1 was used, casting was fully de-cored, but slight penetration was found in the channels (red arrows). With mixture No. 2 channels were without any rest sand or penetration. Explanation for this could be lower compaction with the use of additive A. This shows significant influence of the powder additive composition.

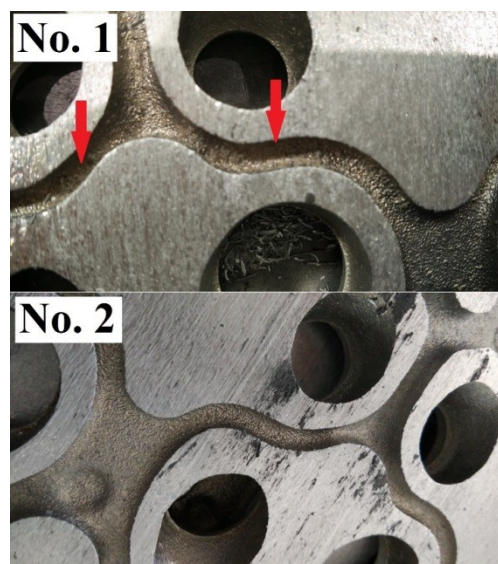


Fig. 5. Channels inside of trial castings: No. 1 slight penetration inside; No. 2 without rest sand

3.3 Storage ability

Based on the casting production trial, only mixtures No. 2 and No. 3 were tested for storage ability. Graph in the Fig. 6 shows influence of the storage time in climatic chamber with set up conditions of 25 °C and 65 %RH on strength behaviour. Free water content was also measured as a measure of reverse curing reaction kinetics. From the obtained results it can be seen, that after 1 - 2 hours of storage time there is a slight decrease of strength and after 6 - 12 hours the drop is becoming significant, which can lead to problems in terms of deformation or breakage of the cores. Increase of free water content in investigated storage time corresponds with the decrease of strength – the higher content of free water the lower strength.

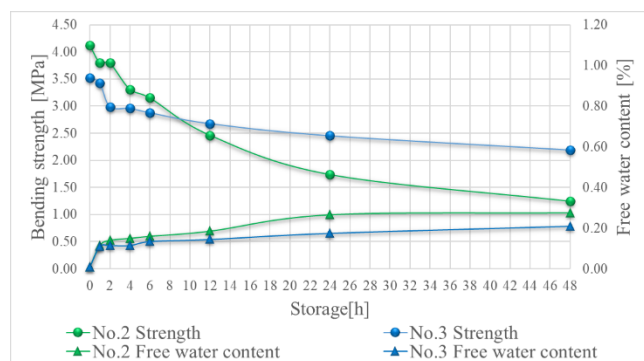


Fig. 6 Storage ability of selected mixtures

When comparing mixtures No. 2 and No. 3, mixture No. 2 seems to be more sensitive for storage conditions. Decrease of strength and also increase of free water content is more visible than by the mixture No. 3, where strength after 48 hours of storage is higher and free water content after 48 hours is lower.

From the obtained results it can be stated that hot cured geopolymer binder are more sensitive for storage conditions than hot cured two component alkali silicate based binders. In [12] alkali silicate based binders were examined for storage ability and with the same conditions of 25 °C and 65 %RH similar strength decrease behaviour and free water content increase was observed. In case of alkali silicate binders drop of strength after 24 hours was about 30%, in case of investigation of geopolymers drop of strength properties is about 50%. Also free water content after 24 hours is slightly higher in case of geopolymer binder.

4. Conclusions

In this research paper, investigation of basic technological properties of hot cured geopolymer binder system such as bending strength, knock-out properties and storage ability in conditions of increased air moisture were carried out. Three mixture with different powder additives were investigated, additive A was designed for use with the geopolymeric binder, other additives B and C are designed for the use with alkali silicate two component binder systems. Obtained results were also compared to the

properties of alkali silicate binders. Based on the obtained results following conclusions can be summed up:

- With the use of all three tested additives, sufficient strength level can be reached for both hot and cold strengths, but the compaction of samples and thus cores is significantly lower when additive A is used.
- Knock-out properties with geopolymer binder generally was proved to be very good by the method of abrasion resistance measurement on test bars after thermal load of 400 °C for 10 minutes. Mixtures with all three tested additives had 100% knock-out.
- Based on the measurements of strength and knock-out properties it can be stated that additives B and C are also compatible with geopolymer binders, not only with alkali silicate based hot cured binder systems.
- Aluminium castings for automotive industry were produced using mixtures with additives A and B, both mixtures had sufficient strength and knock-out properties for the casting production, however when additive A was used, slight penetration was observed inside the channels, meanwhile with additive B channels were without any rests of sand.
- Examination of storage ability of hot cured geopolymer binders showed similar strength decrease behaviour as by alkali silicate based binders, but in contrast drop of strength was about 20% higher, this means geopolymer binders might be more sensitive for storage conditions of cores.
- Geopolymer binder tested in this investigation, especially with additives B and C, can be considered sufficient for aluminium casting production from the point of view of good strength levels and excellent knock-out properties. Disadvantage of this binder system is high viscosity and higher sensitivity for air moisture compared to hot cured two component alkali silicate based binders.

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