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## Analysis of Inorganic Binder Bridges Destruction after Thermal Load

I. Vaskova, M. Conev \*

Technical University of Košice Faculty of Materials, Metallurgy and Recycling,

Letná 9, 04200 Košice, Slovakia

Ladomerská Vieska 394, 965 01 Žiar nad Hronom, Slovakia

\* Corresponding author. E-mail address: martin.conev@nemak.com

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### Abstract

Recently, the use of inorganic binders cured by heat as a progressive technology for large scale production of cores is widely discussed topic in aluminium foundries. As practical experiences show, knock-out properties of inorganic binders were significantly increased, although they cannot overcome organic based binder systems. This paper contains information about hot curing processes based on alkali silicate and geopolymer binder systems for core making. Main differences between hot cured geopolymers and hot cured alkali silicate based inorganic binders are discussed. Theory of geopolymer binder states, that binder bridge destruction is mainly of adhesive character. The main aim of this research paper was to examine binder bridge destruction of alkali silicate and geopolymer binder systems. In order to fulfil this objective, sample parts were submitted to defined thermal load, broken and by using SEM analysis, binder bridge destruction mechanism was observed. Results showed that geopolymer binder system examined within this investigation does not have mainly adhesive destruction of binder bridges, however the ratio of adhesive-cohesive to cohesive destruction is higher than by use of alkali silicate based binder systems, therefore better knock-out properties can be expected.

**Keywords:** Inorganic binder, Dehydration, Alkali silicate, Geopolymer, Adhesive and cohesive forces

### 1. Introduction

Foundries are constantly pushed into reducing of harming emissions and odour by more and more strict environmental and safety regulations, therefore there is a tendency to replace organic binder systems with more ecologically friendly alternative [1]. In order to meet requirements for harmful and odourless core making and casting process, inorganic binder systems based on alkali silicate solutions cured by heat were developed mainly for production of aluminium castings for automotive industry [2]. Although, developers of alkali silicate based inorganic binder systems significantly improved binder systems properties by adding a second component in form of powder additive, there remains a connection to technological problems compared to resin-bonded sands such as low knock-out properties or low

ability to sand reclamation [3,4]. Silicate network formed via dehydration is illustrated in the Fig. 1 [5].

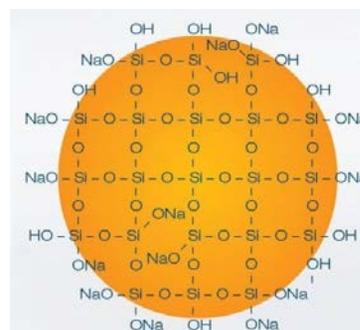


Fig. 1. Silicate network scheme [5]

Among alkali silicate based binders there is also one related group of binder systems based on geopolymer. 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, scheme of inorganic polymer is illustrated in the Fig. 2 [6,7]. Through the formation of chains of  $\text{SiO}_4$  and  $\text{AlO}_4$  bonds are being formed. Si:Al ratio influences the properties of the system and its application. Binders used in foundries 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) [6]. 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 bridge 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 [8-11].

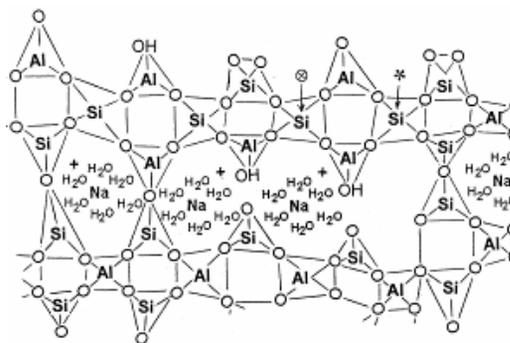


Fig. 2. Scheme of inorganic geopolymer [4]

## 2. Work methodology and materials

This investigation was focused on character of destruction of binder bridges of alkali silicate and geopolymer systems cured by dehydration. Samples for bending strength measurement were prepared using alkali silicate based binder (AS) and geopolymer binder (GP). Powder additive used as well as silica sand in both mixtures were of the same type. Table 1. presents characteristic properties of used materials.

Strength properties of examined mixtures were evaluated by bending strength measurement after 30 s (hot, immediate strength) and after 1 hour (cold, final strength). 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 [12]. Basic properties of examined mixtures are presented in the Table 2. Both mixtures have similar strength properties, but according to used testing method, mixture with geopolymer binder have better knock-out properties when comparing to the alkali silicate binder system.

Table 1.

Basic properties of used materials

Component	Properties description
Alkali silicate	specific weight at 20 °C: 1,36 – 1,47 g/cm <sup>3</sup> viscosity at 25 °C: 20 – 60 mPa·s
Geopolymer	specific weight at 20 °C: 1,49 – 1,52 g/cm <sup>3</sup> viscosity at 25 °C: 120 – 220 mPa·s
Powder additive	designed for filigree geometries, high compaction, improved de-coring properties, organic containing, used in alkali silicate based binder systems
Sand	Silica sand from Slovak locality d <sub>50</sub> = 0,38 mm, rounded grains

Table 2.

Basic properties of tested mixtures

Sample	Binder [%]	Additive [%]	Hot Strength [MPa]	Cold Strength [MPa]	Knock-out [%]
AS	2,40	1,10	1,90	4,15	75,37
GP	1,80	0,80	1,80	4,12	100

Samples for bending strength measurement made from these 2 mixtures were used for SEM analysis of binder bridge destruction before thermal load and after thermal load of 400 °C for 5 and 10 minutes. Character of destruction of binder bridges was observed on break surface after bending strength measurement.

## 3. Results and discussion

Analysis of binder bridge destruction was done using scanning electron microscope pictures of samples made with alkali silicate and geopolymer binder after defined thermal load in laboratory conditions. Fig. 3 shows destruction of alkali silicate binder bridge before thermal load. It can be seen that before thermal load, cohesive destruction appears, which is typical for inorganic binders based on alkali silicate solutions.

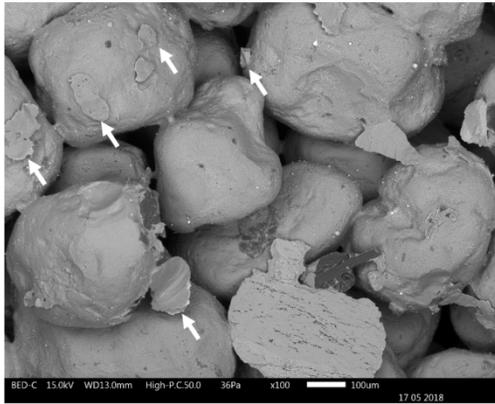


Fig. 3. Binder bridge destruction of AS before thermal load (mag. 100x)

Fig. 4 shows destruction of geopolymer binder bridge destruction after breaking the sample before thermal load. As in case of alkali silicate based binder mostly cohesive binder bridge destruction can be observed.



Fig. 4. Binder bridge destruction of GP before thermal load (mag. 100x)

Fig. 5 presents alkali silicate binder bridge destruction after breaking sample which was thermally heated at 400 °C for 5 minutes. It can be seen that the nature of binder bridge destruction changed from cohesive to combination of cohesive and adhesive-cohesive destruction. The ratio of cohesive destruction to adhesive-cohesive destruction in this case appears about 50:50.

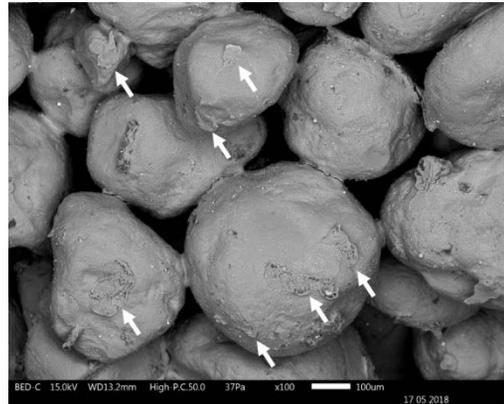


Fig. 5. Binder bridge destruction of AS after thermal load 400 °C for 5 minutes (mag. 100x)

Destruction of geopolymer binder bridges after thermal load of 400 °C for 5 minutes can be observed in the SEM picture on Fig. 6. Based on this picture, it can be stated that after thermal load, character of binder bridge destruction changed towards mostly adhesive-cohesive destruction. If we compare Fig. 5 and Fig. 6 it can be clearly seen the difference between destruction of alkali silicate and geopolymer binder bridge. About 80% of destructed geopolymer binder bridges have adhesive-cohesive mechanism, the rest which can be seen in the picture has cohesive.

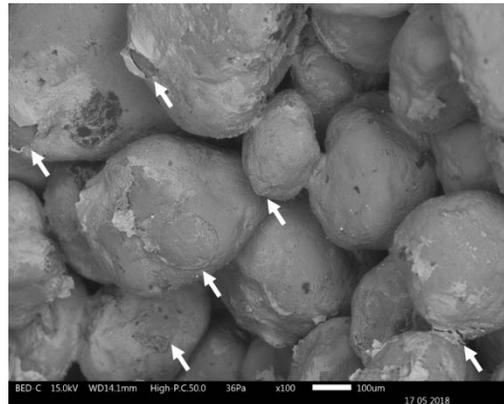


Fig. 6. Binder bridge destruction of GP after thermal load 400 °C for 5 minutes (mag. 100x)

Next series of SEM pictures at Fig. 7 and Fig 8 presents destruction of alkali silicate and geopolymer binder systems after thermal load of 400 °C for 10 minutes. Both pictures show that ratio of adhesive-cohesive to cohesive destruction is increasing with the higher thermal load. For geopolymer binder the ratio is higher compared to alkali silicate based binder. Since both examined mixtures were selected in order to have comparable strength properties it can be stated that geopolymer binder systems have better knock-out properties due to the more favourable nature of binder bridge destruction.

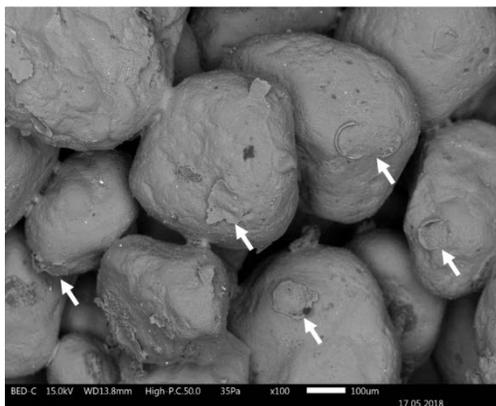


Fig. 7. Binder bridge destruction of AS after thermal load 400 °C for 10 minutes (mag. 100x)

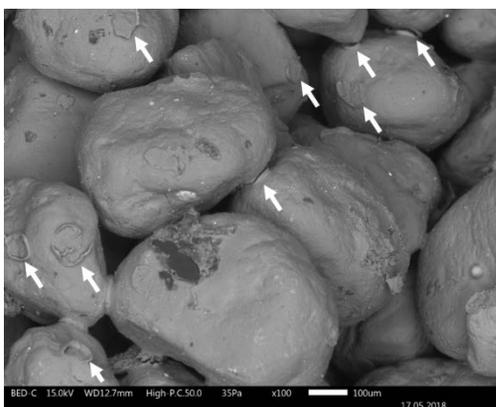


Fig. 8. Binder bridge destruction of GP after thermal load 400 °C for 10 minutes (mag. 100x)

## 4. Conclusions

Within this research work, investigation of inorganic binder bridge destruction was done before and after defined thermal load. Two binder systems cured by dehydration were examined, first was based on alkali silicate solution, second was based on geopolymer. Samples – test bars were produced from mixtures with comparable strength properties. SEM pictures were taken on break surface after bending strength measurement and character of binder bridge destruction was observed.

Samples with alkali silicate binder before thermal load had cohesive destruction of binder bridges and geopolymer binder bridges by the same conditions had mostly cohesive destruction.

With the thermal load 400 °C for 5 minutes of both samples, change of destruction nature could be observed. Alkali silicate binder bridges had combination of cohesive and adhesive-cohesive destruction in ratio about 50:50, meanwhile samples with geopolymer binder had higher ratio of adhesive-cohesive destruction.

With higher thermal load of 400 °C for 10 minutes, ratio of adhesive-cohesive destruction increased for both binder systems,

geopolymer binder system exhibits higher amount of favourable adhesive-cohesive destruction than alkali silicate binder systems.

From this investigation it can be stated, that both alkali silicate and geopolymer binders cured by dehydration have well improved their knock-out properties. Neither on one of investigated binder systems could be observed pure adhesive destruction of binder bridges. Geopolymer binder had higher amount of adhesive-cohesive destruction which should result in better knock-out properties compared to alkali silicate based binders. This was also measured by method of abrasion resistance measurement after thermal load. Mixture with geopolymer binder had 100% value obtained by this method, meanwhile mixture with alkali silicate binder had about 75%.

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