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# Modification of Foundry Binders by Biodegradable Material

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## Abstract

The paper presents the impact of biodegradable material - polycaprolactone (PCL) on selected properties of moulding sands. A self-hardening moulding sands with phenol-furfuryl resin, which is widely used in foundry practice, and an environmentally friendly self-hardening moulding sand with hydrated sodium silicate where chosen for testing. The purpose of the new additive in the case of synthetic resin moulding sands is to reduce their harmfulness to the environment and to increase their "elasticity" at ambient temperature. In the case of moulding sands with environmentally friendly hydrated sodium silicate binder, the task of the new additive is to increase the elasticity of the tested samples while preserving their ecological character. Studies have shown that the use of 5% PCL in moulding sand increases their flexibility at ambient temperature, both with organic and inorganic binders. The influence of the new additive on the deformation of the moulding sands at elevated temperatures has also been demonstrated.

**Keywords:** Environmental protection, Innovative materials and foundry materials, Phenol-furfuryl resin, Hydrated sodium silicate, Biodegradable material

## 1. Introduction

Organic-based resin binders are characterized by good technological properties, but they cause high emissions of harmful substances. Consequently, modern scientific research strives to gradually replace the binders obtained from petrochemical raw materials with renewable polymeric biocomposites. This is consistent with the concept of sustainable development, one of the priorities of European Union policy. The trend is also seen in foundry engineering [1-3].

In the area of foundry moulding and core sands, the problem of the environmental impact of the used, but not thermally degradable, residual binders is not resolved [4]. Although the quantity of moulding sands send to landfills is decreasing and the foundries are equipped with moulding sands regeneration systems, the harmful effects of the binders' residues remains a problem.

In the face of restrict environmental requirements, a major alternative to organic resins used in moulding sands are inorganic binders. One such example is hydrated sodium silicate; cheap, easily accessible and non-toxic. However, the unfavorable feature of the hydrated sodium silicate moulding sands is their fragility, poor knock-out properties and low ability to mechanical regeneration [1, 5]. Previous studies have focused on the development of methods to improve the knock-out properties of these moulding mixtures and the quality of their reclaim. In recent times, however, it turns out that the technological problem that is emerging more and more often is the insufficient ability of the moulding sands to undergo flexible deformation at ambient temperature. The problem is particularly evident in automated foundries [6] and concerns all molding and core sands.

In view of the above, it seems appropriate to use plasticizers currently used (organic and inorganic) to provide greater flexibility in the molding and core sands. Literature [7-10] shows that biodegradable materials can be used as additives in petroleum based binders to cause biodegradation of the ingredients from the petrochemical industry. One of the examples is polycaprolactone (PCL), which is compatible with many other polymers [5]. Studies on the biodegradability of PCL blends with other polymers have been presented in the work of Iwamoto and Tokiwa [11].

Another advantage of using a PCL polymer in the form of a biodegradable additive may be to increase flexibility of foundry moulding sands. The use of PCL as a plasticizer for plastics is not a new issue. Polycaprolactone was used as a plasticizer in mixtures with aliphatic polyesters, cellulose esters, aromatic polyesters, polycarbonates, styrene-containing polymers, polyolefins, block copolymers, Novolak resin [1, 12].

## 2. Own research

The purpose of the research is to demonstrate the effect of PCL biodegradable additive on the flexibility of selected moulding and core sands.

New multi-component binders, containing industrial resins and additives in the form of biodegradable polymers, may be less harmful to the environment, both in casting and post-production processes (the subject of future research). Moulding sands with hydrated sodium silicate will not lose their eco-friendly character and their brittleness or lack of “elasticity” at ambient temperature can be reduced (approx. 40% increased elasticity proved in this paper). The research is aimed at developing technologies that do not differ in technological properties from the currently used moulding sands.

The own research conducted under this study included the use of biodegradable poly(-ε-caprolactone) as a component of phenol-furfuryl binder, commonly used in the foundry practice, and as an additive to hydrated sodium silicate moulding sands cured in ester technology. Both organic and inorganic binders have been chosen for the study. They can be characterized with different mechanisms of destruction - organic bonded moulding sands: adhesive destruction, inorganic moulding sands: cohesive destruction. Mechanisms of the destruction of these moulding sands were studied in detail in previously [14].

The following materials were selected for the study:

- Quartz sand from Szczakowa Sand Mine (the granulation 0.20/0.32/0.40; d 50 = 0.31 mm; pH= 7).
- Phenol-furfuryl resin. Kaltharz XA20 and a hardener Aktivator 100T3 from Hüttenes-Albertus.
- Hydrated sodium silicate. A water glass 145 from Z.Ch. "Rudniki" S.A and a hardener Flodur 3 from Z.Ch. "Organika-Sarzyna" S.A.
- Polycaprolactone (PCL) - biodegradable material and plasticizer. PCL in powder form from Polysciences, Inc. In the study polycaprolactone was added to the binders.

This study investigated the effect of PCL additive on the thermal deformation (hot distortion parameter) and bending strength of moulding sands with phenol-furfuryl resin and hydrated sodium silicate and their "elasticity" at ambient temperature. The detailed composition of the mixtures and the type of chosen biodegradable material were based on the previous research [1, 14]. The research was conducted according to the methodology presented in separate publications [1, 14].

### 2.1. PCL as phenol-furfuryl resins’ modifier

The first step in the study was the use of PCL as a phenol-furfuryl binder modifier. The following compositions were tested:

| | |
|---|---|
| Quartz sand | 100 p.p.w. |
| Kaltharz XA20 | 1.045-1.1 p.p.w. (95-100%) |
| Aktivator 100T3 | 0.55 p.p.w. |
| PCL | 0-0.055 p.p.w. (0-100%) |

Outcome of the conducted research is presented in Fig. 1 – 2 [14].

Thermal deformation tests (hot distortion parameter) have shown that the addition of PCL biomaterial influences the course of the furfuryl resin hot distortion curve. The thermal deformation of the moulding sand as a function of temperature has a typical pattern with intense deformation of the sample and its sudden destruction. However, the presented results show that the application of the biodegradable additive reduces the tendency of the material to undergo deformation up to four times (from about 4 mm for the moulding sand without added PCL to about 1 mm for the moulding sands with 5% PCL). Reducing the amount of resin in the new binder to 95% and introducing 5% PCL resulted in a reduction of destruction under the influence of temperature to about 300ºC (Fig. 1). However, in the case of this moulding sand, no influence of the new additive is observed when it comes to the time after which the sample collapses (about 70 s) (Fig. 1).

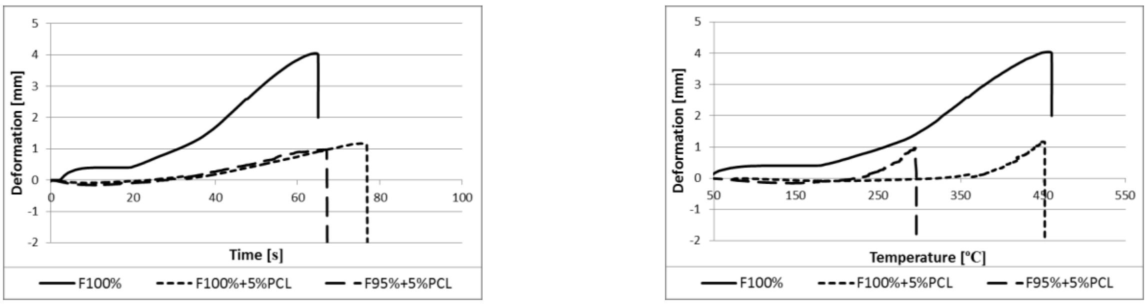



Fig. 1. Influence of PCL on thermal deformation at elevated temperature (hot distortion parameter) of phenol-furfuryl resin moulding sands [14]

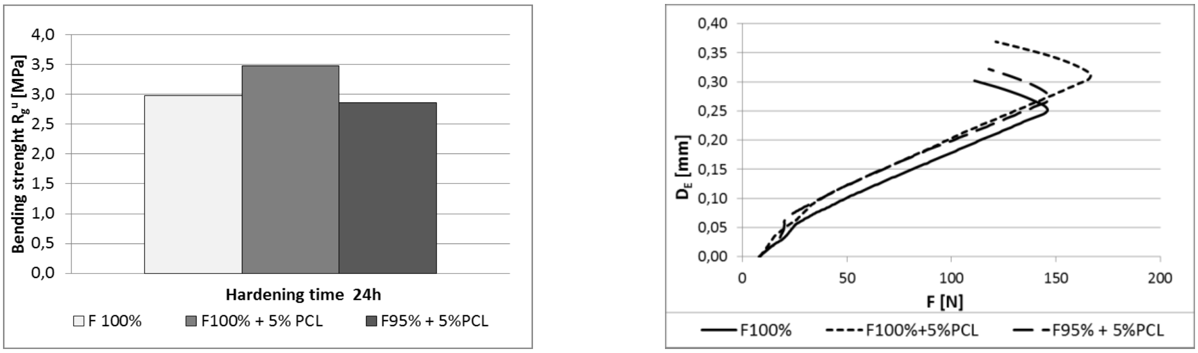



Fig. 2. Influence of PCL on bending strength and "elasticity" of phenol-furfuryl resin moulding sands at ambient temperature [14]

Bending strength tests (Fig. 2) showed that adding 5% of PCL (F 100% + 5% PCL) to the binder resulted in an increase in sample bending strength by approximately 17%. Replacing the binder with a new additive (F 95% + 5% PCL) results in a reduction of the moulding sands' strength (F 100%) only by less than 3%.

The "elasticity" test of moulding sands at ambient temperature (Fig. 2) showed that the mixtures with PCL added to the binder are more elastic than the analogous additive-fee moulding sands. The elasticity of the sample without the additive reaches 0.25 mm with a force of about 150 N – moulding sand F 100%, whereas the introduction of 5% PCL results with an increase of the moulding sands deformation up to 0.28 mm. Replacement of 5% of the binder with PCL (F 95% + 5% PCL) increases the deformation of the moulding sand to approximately 0.32 mm, under the force of around 150 N (nearly 30% increase in comparison to the additive-fee moulding sands).

## 2.2. PCL as moulding sands with hydrated sodium silicate modifier

The next step of the study was the use of polycaprolactone as a modifier for moulding sands with hydrated sodium silicate.

The following compositions were tested:

| | |
|---|---|
| Quartz sand | 100 p.p.w. |
| Hydrated sodium silicate | 2.5 p.p.w. |
| Flodur 3 | 0.25 p.p.w. (10%) |
| PCL | 0.125 p.p.w. (5%) |

Outcome of the conducted research is presented in Fig. 3 – 4.

Thermal deformation tests (hot distortion parameter) showed that the addition of biomaterial PCL prolongs the heat stability of the moulding sands with hydrated sodium silicate compared with the base samples (without the addition of PCL) Both tested mixtures exhibit almost no thermal deformation in the temperature range of 0 - approx. 300°C – and for the samples with the additive in the range of 0 - approx. 400°C. After crossing the above mentioned temperature samples are subjected to mild deformation until the samples are damaged. The use of the PCL additive extends the time needed for the sample destruction from about 50 seconds to about 250 seconds. This can be advantageous in terms of the time of contact of the moulding/core sand with elevated temperature during and after the pouring process.

Bending strength tests (Fig. 4) showed that the addition of 5% PCL to the binder resulted in a reduction in strength - approx. 20% (Fig. 4). Nevertheless, it remains at 1.4 MPa, which is sufficient from the casting practice point of view. The research has shown that the new additive has a great influence on the "elasticity" of tested moulding sands at ambient temperature. The deformation of the no-additive moulding sand is about 0.22 mm at under the force of approx. 82 N, whereas the introduction of 5% PCL yields an increase in deformation of the tested sample to 0.31 mm and force of about 70 N (approx. 40% increase in comparison to the additive-fee moulding sands).

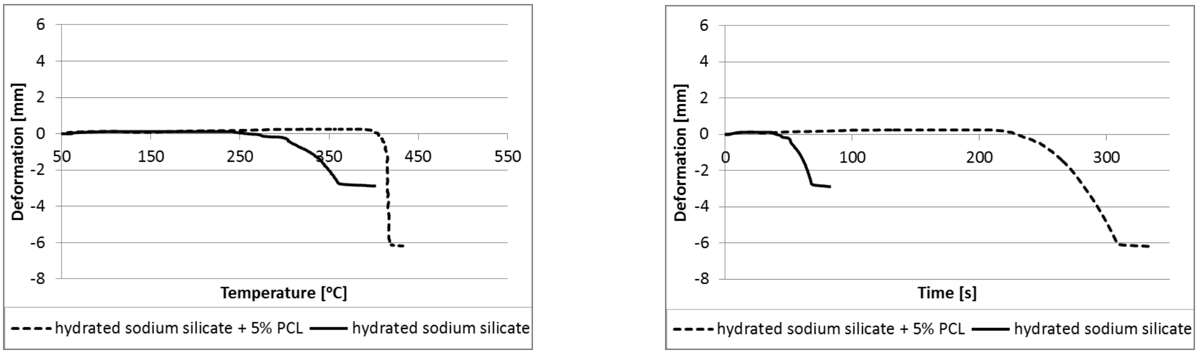
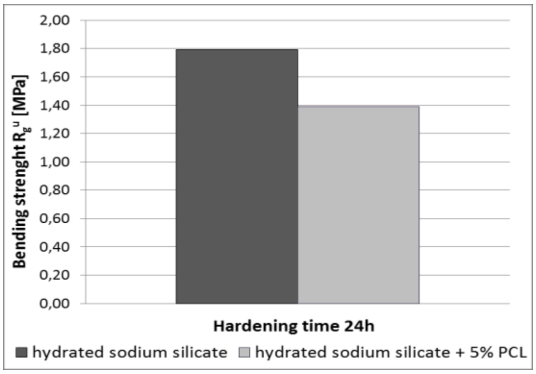



Fig. 3. Influence of PCL on thermal deformation at elevated temperature (hot distortion parameter) of hydrated sodium silicate moulding sands



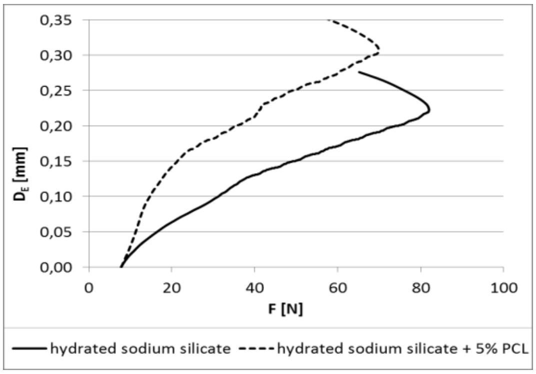




Fig. 4. Influence of PCL on bending strength and "elasticity" of hydrated sodium silicate moulding sands at ambient temperature

# 4. Conclusions

Based on the analysis of the literature data and the results of the presented study, the following conclusions can be made:

- The use of biodegradable additive PCL as a compound of moulding and core sands with phenol-furfuryl resin results in approx. fourfold reduction in thermal deformation of the tested moulding mixtures.
- Replacement of binder parts with 5% PCL additive does not affect the bending strength of moulding sand with the phenol-furfuryl resin.
- PCL increases the "elasticity" of moulding sand with the phenol-furfuryl binders.
- The PCL biodegradable additive improves the thermal stability of the tested moulding sands with hydrated sodium silicate. Extending the time needed for the sample destruction can be advantageous in terms of the time of contact of the moulding sand with elevated temperature during and after the pouring process.
- Adding 5% of PCL reduces the bending strength of the tested moulding sands with hydrated sodium silicate by about 20%, but at the same time it increases their “elasticity” at ambient temperature.

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