

# Investigation of an Advanced Cellulose Profile Used for the Manufacture of Gating Systems

Z. Zawieja<sup>a,\*</sup>, J. Sawicki<sup>a</sup>, G. Gumienny<sup>b</sup>, A. Sobczyk-Guzenda<sup>a</sup>

<sup>a</sup> Institute of Materials Science and Engineering, Lodz University of Technology,  
Stefanowskiego 1/15 Street, 90-924 Łódź, Poland

<sup>b</sup> Department of Materials Engineering and Production Systems, Lodz University of Technology,  
Stefanowskiego 1/15 Street, 90-924 Łódź, Poland

\*Corresponding author. E-mail address: 800521@edu.p.lodz.pl

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## Abstract

The herein paper contains the results of investigations on a new type of cellulose blend used for the manufacture of profiles applied in the process of making gating systems in the foundry industry. A standard cellulose profile was subjected to an experiment. During the experiment the profile was filled with a liquid cast iron and at the same time the temperatures of the liquid metal crystallizing inside the profile were measured as well as the temperature of the outer layer of the profile was controlled. Further, the microstructure of the cast iron, which crystallized out inside the cellulose profile, was analysed and the cellulose, thermally degraded after the experiment, was verified with the use of the chemical analysis method. Moreover, a quality analysis of the original as well as the degraded cellulose profile was run with the use of the FTIR infrared spectroscopy. The presented results revealed that the cellulose blend is aluminium silicate enriched and contains organic binder additives. The cast iron, which crystallized out, tended to have an equilibrium pearlitic structure with the release of graphite and carbides. The generation of disequilibrium ausferrite phases was also observed in the structure.

**Keywords:** Innovative casting materials and technologies, Cellulose profiles, Gating system, Aluminium silicates, Gray cast iron, Ausferrite

## 1. Introduction

Gating system is the first point of contact of the liquid cast iron with casting mould's cavity. The geometry of the whole gating system and consequently the manner the liquid metal is supplied to the mould's cavity, together with the type of the material out of which the gating system is made, may have a significant influence on the process of filling the mould' cavity, and thus on the quality of the casting [1-10]. The quality of the material as well as the technology of making the semi-finished

products in a form of profiles having direct contact with the liquid metal during the process of filling translates directly into the quality of the finished product, i.e. the casting. Previous investigations on modified cellulose blends [11] applied in the manufacture of gating systems have been mainly focused on chemical analysis of the compounds which are being released during the process of temperature increase up to 1000°C. The herein paper broadens the spectrum of investigations on the modified cellulose pulp and its influence on the metal being cast.

## 2. Investigation methodology and schedule

The investigations were carried out with the use of one of the original cellulose profiles available on the commercial market. Only fragments of the tested cellulose profile were used for laboratory purposes. The investigations carried out were as follows:

- the analysis of the absorption spectra of the original cellulose profile,
- the examining of thermal resistance in the conditions similar to the operating conditions present in a foundry facility, i.e. the measurement of the liquid cast iron's temperature inside the profile filled with the liquid cast iron as well as the measurement of the temperature of the outer part of the cellulose profile's wall,
- the analysis of the microstructure of the cast iron crystallized out inside the cellulose profile,
- the analysis of the absorption spectra of the thermally degraded cellulose profile.

The investigations have been conducted at the Faculty of Mechanical Engineering of the Lodz University of Technology.

### 2.1. Investigation of temperature changes

Figure 1 presents the diagram of the stand where the investigations have been carried out. The cast iron temperature was measured with the use of the thermocouple type S (PtRh10-Pt). The thermocouple was placed on the axis of the profile's horizontal cross-section. The profile was moulded in a damp synthetic moulding sand with bentonite binder. The temperature was also measured at the cellulose profile – moulding sand point of contact. The measurement was conducted in a continuous manner, starting from the temperature of filling up to the temperature of approximately 1000°C (of the cast iron inside the profile).

The cast iron of the composition presented in Table 1 was used for the tests.

Table 1.

The chemical composition of the tested cast iron and its eutectic carbon equivalent  $C_e$

Chemical composition, %					
C	Si	Mn	Cu	Mo	$C_e$ , %
3.92	2.47	0.09	1.97	1.83	4.80

The application of the cast iron having the above mentioned chemical composition resulted from the possibility of obtaining ausferrite in the cast iron matrix without the necessity of heat treatment application [11-14].

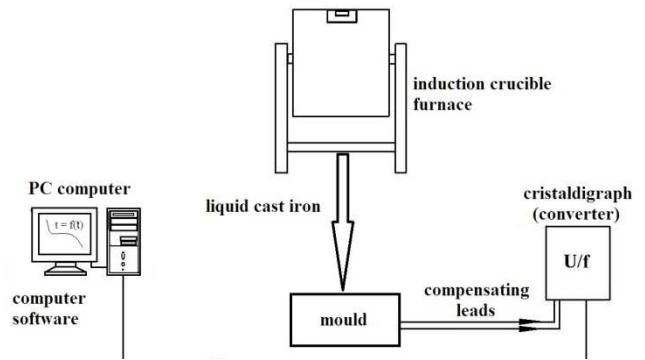


Fig. 1. Diagram of the stand for the measurement of the temperature of cast iron and profile

### 2.2. Metallographic investigations of the cast iron

Samples for the metallographic investigation were cut from the area close to the thermocouple registering the changes of the alloy's temperature. The cast iron microstructure analysis was conducted with the use of the metallographic microscope MA200 by Nikon with the  $\times 100$  and  $\times 500$  magnification.

### 2.3. FTIR examination of the original and the degraded cellulose after the process of filling with liquid metal

The quality FTIR analysis (Fourier Transform Infrared Spectroscopy) was conducted within the measurement range from 4000 up to 400  $\text{cm}^{-1}$  with the resolution of 4  $\text{cm}^{-1}$  and with the use of the FTIR spectrometer, Nicolet iS50 model. The measurement was conducted in the absorbance mode with the application of the DRIFT type diffuse reflection by Harrick company, at the beam angle equal to 80°. The number of scans per one measurement cycle was 64. The examination was conducted with the use of the original as well as the degraded profile after the experiment of filling with liquid metal.

## 3. Results of the investigations

### 3.1. Investigation of temperature changes

Results of the cast iron and profile temperature changes measurement at the surface of its point of contact with the moulding sand were presented in the Figure 3 and 4, respectively.

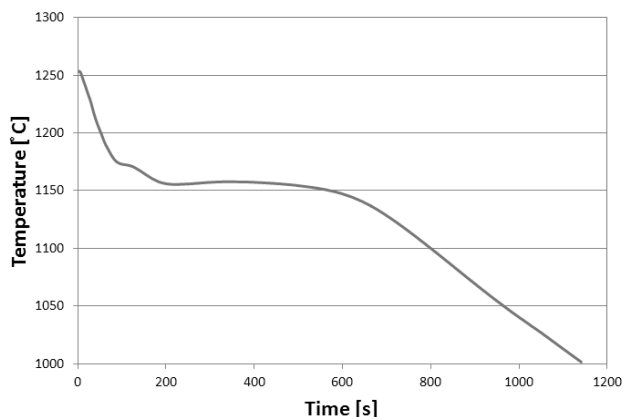


Fig. 2. Liquid metal temperature changes inside the cellulose profile

It was observed (Fig. 2) that in case of the liquid cast iron a decrease of the liquid metal cooling speed takes place within the temperature range of 1219÷1212°C for the, and at the same time the temperature outside the profile increases (Fig. 3). Due to the fact that this is a hypereutectic cast iron ( $C_e = 4,80\%$ ), the primary graphite has crystallized out in the first place. The paper [15] indicates however that the thermal effect of the primary graphite's crystallization on the derivative curve does not occur. Simultaneously, the temperature outside the profile quite rapidly increases from the temperature of 658°C up to the temperature of 717°C, disproportionately more suddenly compared with the process of the whole measurement. The effect was visible during the experiment in a form of strongly exothermic processes. It was presumably a result of cellulose's composition modification by aluminium silicate additives which are characterized by a delayed strongly exothermic ignition.

At the same time, the emission of a considerable amount of gases was observed during the experiment of filling the profile with liquid metal, which was disproportionate to the weight and size of the profile.

A practical application of the profiles being investigated is reasonable due to the lengthening of the period when the cast iron maintains its liquid form, however the emission of a considerable amount of gases may pose serious difficulties in the case of the degassing of foundry moulds, in particular in case of complex casting shapes.

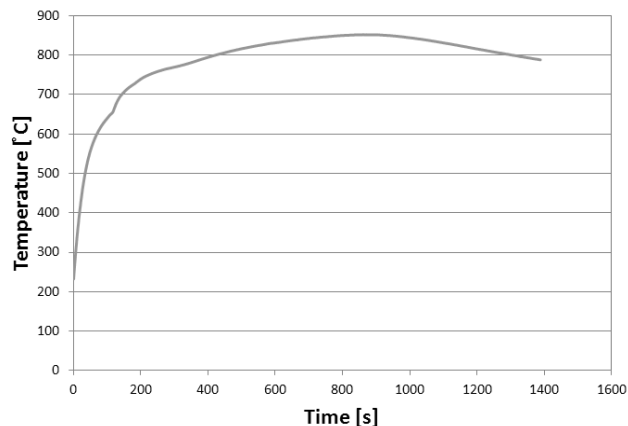


Fig. 3. Temperature changes outside the profile at the point of its surface contact with the mould material

### 3.2. Metallographic investigation of the cast iron's microstructure

Figure 4 (a, b) presents the microstructure of the examined cast iron in the area of thermocouple's location.

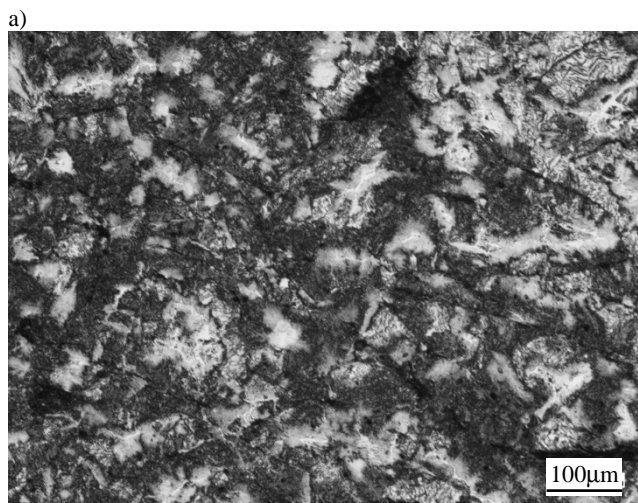




Fig. 4 (a, b). The microstructure of grey cast iron in cellulose profile: flake graphite, pearlite, ausferrite, carbides

The investigations reveal that in spite of the application of cast iron with molybdenum and copper in the amount of approximately 2%, an equilibrium pearlitic structure with the release of graphite and carbides was mostly obtained. At a small rate of the casting's cooling process, most of the austenite was subject to an eutectic transformation into pearlite, while only in case of certain micro areas of an increased concentration of molybdenum and copper the remaining austenite was cooled down to the temperature in which its transformation into a bainitic ferrite was possible. There were no phases observed in the cast iron microstructure which could be created as a result of the liquid cast iron reaction with the material of the cellulose profile.

### 3.3. Analysis of the absorption spectra of the original and thermally degraded cellulose profile

Figure 5 presents the results of FTIR analysis in a form of absorption spectra. Curve A presents the spectrum of an original cellulose profile available on the commercial market, while curve B presents the spectrum of a cellulose profile after the process of filling with liquid metal.

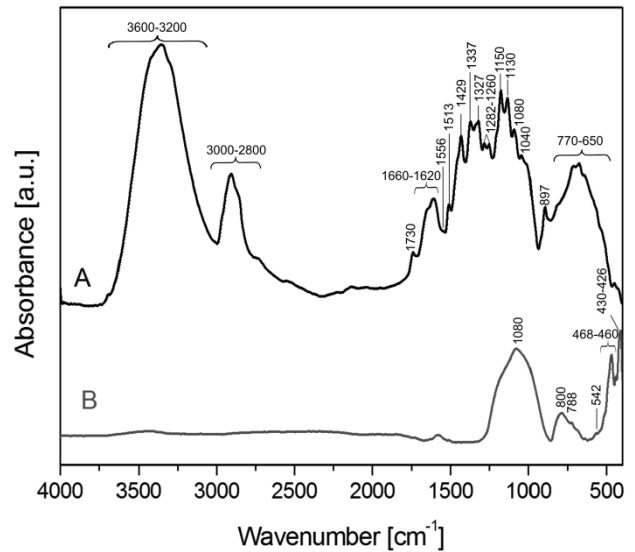


Fig. 5. FTIR spectrum: A – cellulose profile, B –thermally degraded cellulose profile

In the spectrum of an original cellulose profile (curve A – Fig. 5) bands characteristic for the formations derived from cellulose (base) and melamine-urea-formaldehyde resin, functioning both as binding agent and impregnate, could be distinguished. Peaks deriving from non-organic filling material in a form of aluminium silicates used for manufacture of such type of elements, should be within the range of  $1300\text{--}400\text{ cm}^{-1}$ . However, it is hard to distinguish them as they are masked by the bands deriving from organic formations and additionally they were covered within the range from  $770\text{ to }650\text{ cm}^{-1}$  by a broad absorption band deriving from the deformation vibrations of the hydroxyl group (-OH) [16].

A sharp peak, visibly separated from other bands at  $1730\text{ cm}^{-1}$ , indicates the presence of the C=O carbonyl bond. In turn, the presence of a broadband within the range from  $1660\text{ to }1620\text{ cm}^{-1}$ , determines the existence of, among other, groups characteristic for urea, such as: C=O bond next to the -NH<sub>2</sub> group, C=O combined with -NH-, and the sole carbonyl group independent -NH- combination. It was observed that at  $1556\text{ cm}^{-1}$  a peak of slight intensity appeared in the spectrum, which indicates the existence of C-NH- bond deriving from melamine. In turn, the band at  $1513\text{ cm}^{-1}$  indicates the existence of a so called methylene bridge in the N-C-N group [17,18]. A sharply ended band at  $1429\text{ cm}^{-1}$  is connected with the symmetric vibrations of the -CH<sub>2</sub> group connected with the hydroxymethylene group. Such peak is characteristic for cellulose spectra [17]. Two peaks closely located at  $1337$  and  $1327\text{ cm}^{-1}$ , and deriving from the -CH<sub>2</sub>- groups, were observed. Such bands appear in both cellulose spectra and formaldehyde resin. Peaks located within the range of  $1282\text{--}1260\text{ cm}^{-1}$  confirm the presence of -CH<sub>2</sub>- group directly connected with the -CH<sub>2</sub>-O-CH<sub>2</sub>- composition.

Bands at the wave number of approximately 1150 and 1130  $\text{cm}^{-1}$  indicate the participation of asymmetric and symmetric vibrations of the C-O-C bonds in such connections as  $-\text{CH}_2\text{-O-CH}_2-$  and  $\text{CH}_3\text{-O-CH}_2-$  [18,19]. The peak located at the 897  $\text{cm}^{-1}$  wave number confirms the presence of cellulose in the tested composite because at this wave's length a band deriving from the glycoside  $\beta$ -1,4 bond between next glucose molecules of this polymer chain is located [17].

On the B curve (Fig. 5), all bands characteristic for organic bonds described above are not visible. It is connected with the fact that as a result of a high temperature of 1300°C, both cellulose and resin were degraded and the peaks observed in the spectrum are only connected with non-organic additives which did not carbonise. Bands deriving from silicate structures may be, among others, observed in the obtained spectrum: vibrations within the range of 460÷468  $\text{cm}^{-1}$  and 426  $\text{cm}^{-1}$  are the O-Si-O bending vibrations, while the vibrations around 800  $\text{cm}^{-1}$  and 1080  $\text{cm}^{-1}$  are the Si-O-Si type stretching vibrations. Moreover, within the range of 542÷530  $\text{cm}^{-1}$  not only peaks characteristic for Si-O-Al bonds, but also for K-O, Ca-O, and Fe-O groups are located. In turn, the peak at the 788  $\text{cm}^{-1}$  wave number belongs to the Si-Si or Si-Al bond. Moreover, below 430  $\text{cm}^{-1}$  of the obtained spectrum, there are also peaks deriving from asymmetric Fe-OH stretching vibrations [20,21].

## 4. Conclusions

The presented results of investigations prompt the following conclusions.

1. A considerable amount of gases emitted during the process of filling with liquid cast iron may be problematic during the manufacture process in industrial conditions.
2. FTIR analysis indicates that the melamine-urea-formaldehyde resin was used as the bonding agent in the original cellulose profile and that the resin is the reason for an emission of a considerable amount of gases during the process of filling with liquid metal.
3. Thermally degraded cellulose profile exhibited compounds of non-organic filling material, probably aluminium silicates which are responsible for the exothermic effects present during the filling process.
4. Aluminium silicates addition to the cellulose profile results in the lengthening of the metal cooling process, enabling the equilibrium eutectic crystallization in the whole volume of the sample, due to their strongly exothermic combustion during the process of filling with liquid metal.
5. Regardless of the emission of gases and major pyrotechnic effects, no influence of the modified cellulose on the cast iron microstructure was observed.

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