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# Prototype Stand for Determining Quantities of Gasification Products of Polystyrene Model

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## Abstract

Disposable foundry models constitute an increasingly important role in a unitary large-size foundry. These models have many benefits, but technologies using such materials require an understanding of degradation kinetics at the time of filling. The studies presented in the article determine the size of the polystyrene combustion products used for disposable foundry models. The results were obtained by carrying out the combustion process of the polystyrene model in a special combustion chamber, in different configurations. The pressures generated during thermal degradation vary depending on process parameters such as model density or the use of an additional adhesive binder. The results of laboratory tests may suggest what values of pressure are generated when filling in full-mold and lost foam technologies. The studies provide a prelude to further analysis of materials used for disposable foundry models and quantitative evaluation of their thermal degradation products for computer simulation.

**Keywords:** Lost foam, Full mold, Polystyrene model, Prototype research stand

## 1. Introduction

The full-mold casting involves the complicated kinetics of filling the mold cavity. The polystyrene model is burned out for the cause stream of liquid metal. As a result of this combustion, a gas gap is formed between the front of the liquid metal and the model, which has not yet been thermally degraded [1,2, 3].

The results of the size of the gasification products of the polystyrene model in the context of different material densities were presented in the works [4, 5]. Studies have found higher pressure values for a higher density model. In addition, increased pressure was observed in the gas gap when filling the mold cavity with an iron compared to aluminum alloys. The reactions in the full-mold casting affect the flow rate of the molten metal in the form, which affects the filling rate of the mold cavity. The stand in this work gives the opportunity to test the size of gas products during filing [6, 7, 8].

This work develops a concept stand for determining the quantity of polystyrene gasification products. The presented studies were carried out on a prototype of the designed stand. The developed method allows recording the changes in pressure and temperature during the combustion of the sample of the polystyrene model usually used in the full-mold casting.

## 2. The concept of the measuring stand

The concept of the measuring stand (fig. 1.) was developed to determine the possibility of carrying out combustion studies of polystyrene models. The stand consists of a sealed chamber (1), resistance heating elements, pressure (2) and temperature (6),(7), (8)sensors, compensating cables (3), (4), analogue digital converter, and computer with special software (5), aluminosilicate elements refractory and insulation (11), (12)structural elements. The total gasification temperature of polystyrene is approximately 400ºC [9], combustion of a sample with a volume of 5-10 $cm^3$ should happen in about 60 s [10].

The use of a sealed closed chamber will allow for accurate measurements of pressure changes as a function of the temperature in the combustion chamber, and comparison of the results of the heating cycle of the empty chamber with the heating and gasification of the sample will allow determining the quantity of combustion products of the polystyrene model.

The geometry of the individual position elements has been pre-defined. The necessary power of the heating element and the required measuring range of the pressure sensor will be determined on the basis of the results of computer simulation of the operation of the device according to the developed concept.

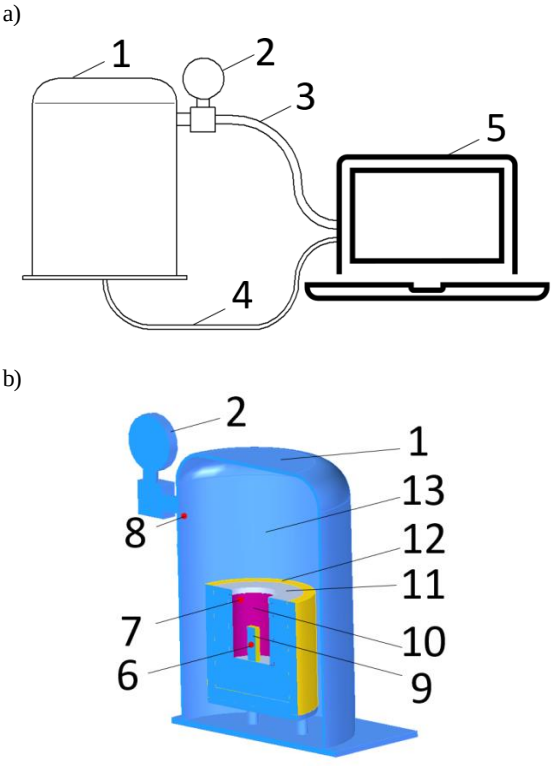


Fig. 1. Measuring stand. a) workstation's schematics; b) view in the section of the combustion chamber.
1-sealed chamber, 2-pressure sensor, 3, 4- compensating cables, 5- a computer with special software, 6, 7, 8- temperature sensors, 9-polystyrene sample, 10, 11, 12- aluminosilicate, refractory and insulation structural elements, 13- combustion chamber.

## 3. Verification of the developed concept

As a result, the predefined concept of the measuring station, presented in point 2, geometric and material assumptions of the individual components of the device have been developed additionally, appropriate initial and boundary conditions have been established. The device model was developed using the assumptions in the ANSYS-Fluent software. A simulation cycle was performed to verify the concept for appropriate thermal conditions in the combustion chamber and the selection of a pressure sensor with the appropriate measuring range. For this purpose, the model assumes three temperature measurement points according to conceptual assumptions (fig. 1). The change in air pressure caused by the increased temperature in the measuring chamber of the device was calculated using Charles's law. According to which the gas pressure in a constant volume is increased by a fixed fraction of the pressure of that gas measured at temperature 0°C when the temperature rises by 1°C (1). The calculation uses the current average air temperature in the chamber.

$$p = p_0 \left(1 + \frac{T}{273}\right) \tag{1}$$

where:
$T$ – temperature [℃],
$p_0$ –gas pressure at temperature 0 ℃.

Examples of simulation results in the form of temperature distribution in the measuring chamber are shown in the figure 2. On the other hand, the course of temperature changes in the measuring points and the average air pressure in the chamber is shown in the form of a graph in the figure 3.

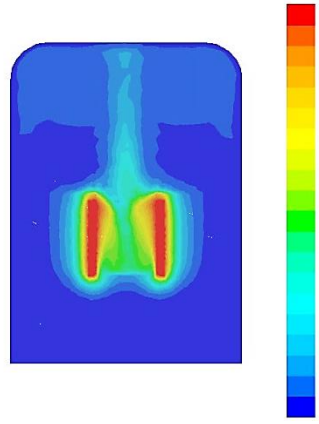

Fig. 2. Temperature field in the measuring chamber – simulation results

Compilation of the simulation results was done without data verification and model validation. However, the obtained simulation results are sufficient to decide to create a stand.

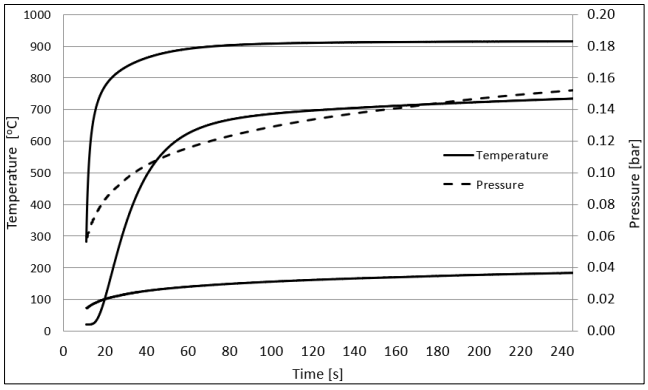


Fig. 3. Simulated temperature and pressure changes

The results of the simulation confirmed the correctness concept and the geometric-material assumptions of design the stand to determine the quantity of gasification products of materials for models in full-mold casting. The temperature value obtained in the combustion chamber is sufficient, with adequate allowance, to completely gasify the model sample. The calculated pressure value allowed to determine the measuring range of the pressure sensor was finally decided on a sensor with a range of 0-0,4 bar.

## 4. Tests studies

Based on the developed concept and the results of the verification of assumptions, the final design of the measuring stand was determined, and a prototype was made. The stand was developed on universal dedicated equipment. A sufficient standard was established at the testing stage. A view of the complete prototype of the stand, including the power supply system for analogue-digital converters and computers for registration, is shown in figure 4.

Fig. 4. Complete measuring and testing stand during measurements

The test cycle was based on repeated temperature and pressure measurements during heating in the combustion chamber. The heating process was carried out both under conditions with polystyrene samples and without. In each of the options provides the same process conditions.

The first stage of the test measurements consisted of heating for the chamber without a sample. Figures 5 and 6 present a summary of the temperature and pressure change curves simulated and measured for the empty combustion chamber.

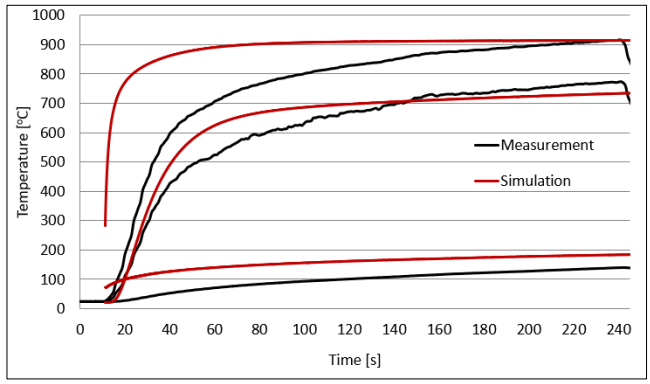


Fig. 5. Temperature change curves in the combustion chamber, simulation, and measurement results during tests

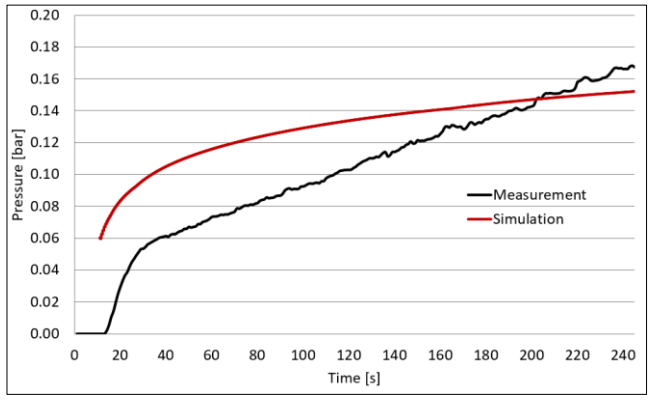


Fig. 6. Pressure changes curves in the combustion chamber, simulation, and measurement results during tests

The measurement of the quantity of gasification products and material for disposable models was carried out in two stages. The first was to heat up the empty (without polystyrene sample) measuring chamber over time 240s which resulted in a temperature of about 900°C at the measuring point 7 (fig. 1). After this time, the heating element was disconnected, and the closed chamber was cooled down by 10 min. Further cooling, up to ambient temperature, of all components of the device took place with the open measuring chamber. After cooling, a sample of the material for gasification was placed in the chamber and the entire device was closed. The second stage of the measurement consisted of the same process of heating and cooling of the measuring chamber as in the first stage. The consequence of such action were the results of measurements carried out in possibly similar conditions for the heating and cooling cycle with the sample and without. By comparing the results of the two cycles, it is possible to accurately determine the differences in their course and on this basis accurately estimate the quantity of gasification products of the test sample.

A summary of the sample results from both stages of the studies is shown in figure 7. The curves in the graph show the changes in

temperature and pressure values during the heating of the chamber without and with the polystyrene sample.
After the test tests were performed, a series of 6 main tests were carried out, the data on the tested samples are presented in table 1. For two measurements, the polystyrene samples were additionally glued together. Two types of glue were used to connect the samples: universal polymer and dedicated to the industry of connecting polystyrene models.

Table 1.
Data of investigated expanded polystyrene

| No | polystyrene density kg/m$^3$ | sample weight g | adhesive | ultimate weight g |
|---|---|---|---|---|
| 4. | 26.12 | 0.216 | - | 0.216 |
| 5. | 23.42 | 0.204 | - | 0.204 |
| 6. | 26.12 | 0.237 | - | 0.237 |
| 7. | 26.12 | 0.199 | - | 0.199 |
| 8. | 26.12 | 0.199 | polymer | 0.257 |
| 9. | 26.12 | 0.205 | for LF | 0.327 |

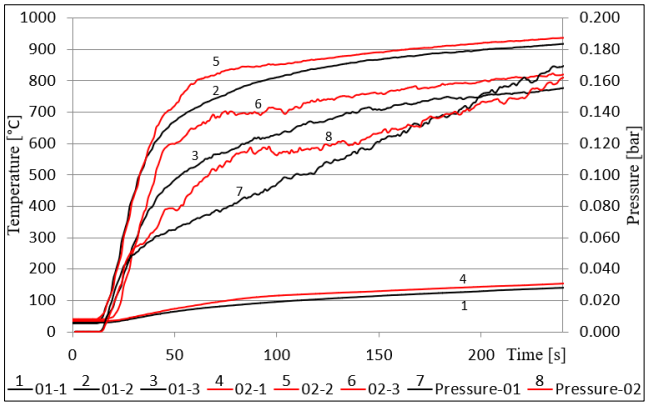


Fig. 7. Summary of temperature and pressure results as a function of time. 4, 5, 6, 8 - heating process with polystyrene sample. 1, 2, 3, 7 - heating process without polystyrene sample

## 5. Test results

The obtained results of the performed measurements are summarized in the diagrams presented in figures 8 - 13. The graphs compare the waveforms of pressure change curves during heating in the empty chamber and with the sample as a function of temperature. The differences in the course of these curves are the result of the appearance in the measuring chamber of gasification products of the material sample on disposable models.

The analysis of these differences will allow the estimation of the amount of gases and the implementation of the test results in a computer simulation.

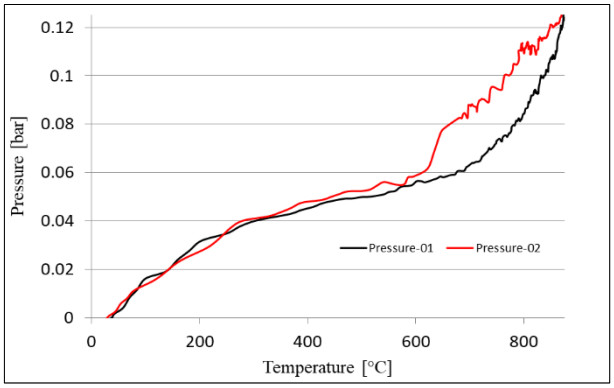


Fig. 8. Dependency graph pressure - temperature - sample number 4

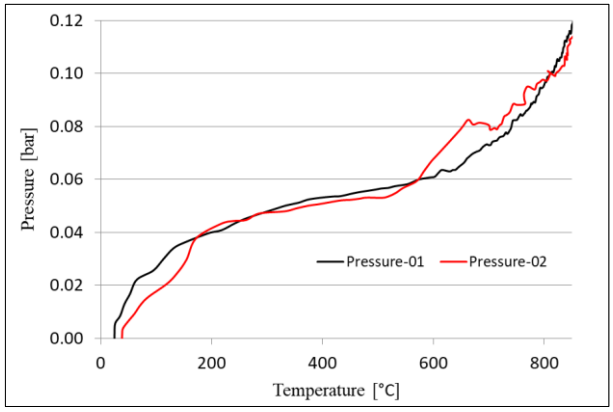


Fig. 9. Dependency graph pressure - temperature - sample number 5

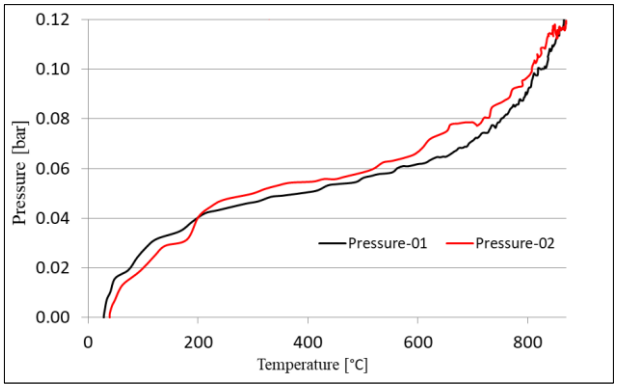


Fig. 10. Dependency graph pressure - temperature -sample number 6

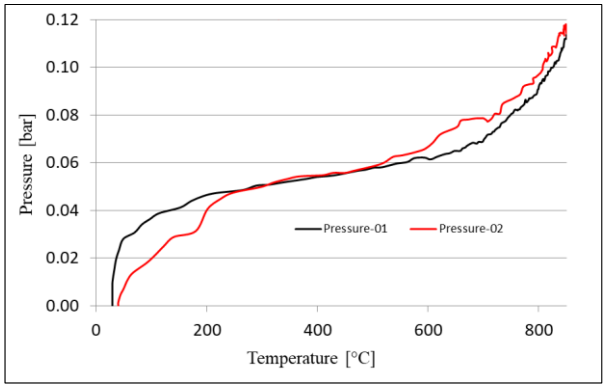


Fig. 11. Dependency graph pressure - temperature -sample number 7

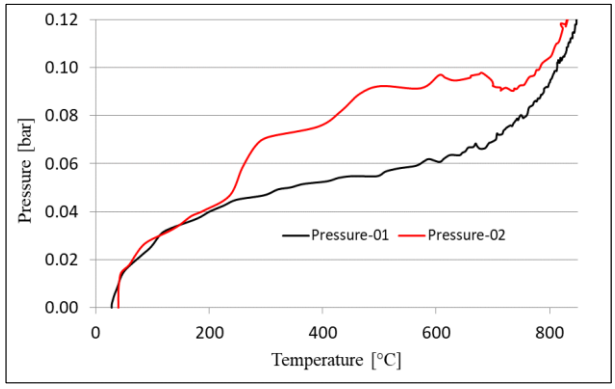


Fig. 12. Dependency graph pressure - temperature -sample number 8

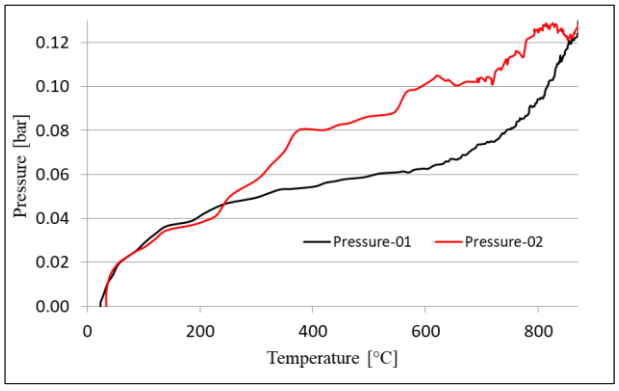


Fig. 13. Dependency graph pressure - temperature - sample number 9

In figures 15 and 16 shows graphs with a summary of the pressure differential curves in the measuring chamber for measurement with and without sample, according to the samples 4, 5, 6 (different polystyrene densities), and 7, 8, 9 (impact of the use of glue).

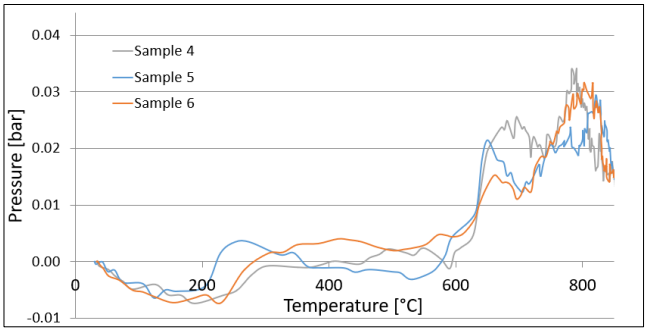


Fig. 14. Pressure difference as a function of temperature for samples 4-6

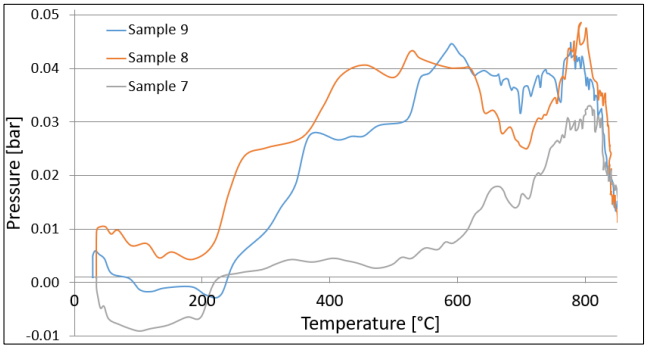


Fig. 15. Pressure difference as a function of temperature for samples 7-9

## 6. Analysis of results and conclusions

When analyzing the obtained test results for the gasification process, a slight drop in pressure in the measuring chamber can be noticed below the temperature of 200ºC for measurements with a sample compared to measurements without a sample (fig. 3-6). This is caused by the melting of the polystyrene sample, which causes an increase in the volume of the chamber and an obvious pressure drop. The increase in pressure in the chamber with the sample compared to the empty chamber occurs above the ~500 ºC and is caused by the appearance in the measuring chamber of the gasification products of the sample. The pressure difference in the chamber without sample and with the sample above temperature 500 ºC is directly a consequence of the appearance in the chamber of gases that are the product of polystyrene combustion. This allows a quantitative estimation of the amount of gases generated during mold filling in full-mold casting.

Material density on disposable models has no sharp noticeable effect on the nature of pressure change curves as a function of temperature, slightly higher pressures occurred for samples of material with a higher density (fig. 14).

The largest pressure differences in the measuring chamber with the sample compared to the empty chamber were recorded for glued samples. An increase in pressure recorded for glued samples compared to „clean" can be estimated at 3 – 4 multiple times (fig. 15). Naturally, this is due to a higher mass (table 1) of material that

has been gasified and consequently more exhaust gases. In addition, in the case of glued samples, there is no initial temperature of 200ºC, pressure drop observed for samples „clean".

In the computer simulation of the full-mold casting, it is extremely important to correctly define the number of gasification products of a disposable model. This has a fundamental impact on the correctness of the calculation results, the adoption of not correct values can multiply the discrepancies between the simulation results and the actual process, especially the stage of filling the mold cavity. Therefore, it is necessary to determine the number of gasification products of the model each time for a given material and the adhesive used.

The conducted research and analysis of the obtained results can be summarized with the following conclusions:

- In full-mold casting, precise data on the number of gases and kinetics of the gasification process of the polystyrene model are extremely important.
- For the purpose of quickly determining the quantity of gasification products of the disposable model, the concept has been developed
- and made a prototype of the stand, simulations, and tests performed confirmed the correctness of the conceptual assumptions.
- The results of the research carried out on the built prototype stand for determining the quantity of gasification products of the disposable model indicate the possibility of relatively precise determination of the quantity of pyrolysis products of the model and their ease of implementation in simulation programs.

## Acknowledgement

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