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# Technology of manufacturing foundry cores using additive methods

# Technologia wytwarzania rdzeni odlewniczych metodą addytywną

**Abstract**
The use of additive manufacturing methods for the production of sand cores with organic binders is currently the latest trend in small and unit production, as it allows for a quick and simple way to get a final cast part; this is known as Rapid Prototyping. In this article, manufactured additive method cores were analyzed that were made of quartz sand with furfuryl resin and cores made of synthetic sand. Derivatographic measurements were compared, and examples of the high complexity cores are shown. Furthermore, the aspect ratio of the grains was determined by microscopic observation. Each type of core was characterized by a different flexural strength and differentiated results of abrasion. The results were collected and compared.

**Keywords:** additive methods, 3D printing, foundry cores with quartz and synthetic sand, furfuryl and phenolic resin

**Streszczenie**
Wykorzystanie przyrostowych technik zwanych „szybkim prototypowaniem" do produkcji rdzeni z mas ze spoiwami organicznymi jest obecnie najnowszym trendem w produkcji małoseryjnej i jednostkowej. Techniki te umożliwiają otrzymanie gotowego wyrobu w bardzo szybki i prosty sposób. W niniejszym artykule przeanalizowano wytworzone metodą addytywną rdzenie z piasku kwarcowego ze spoiwem furfurylowym oraz rdzenie z piasku syntetycznego ze spoiwem syntetycznym, porównano wyniki pomiarów derywatograficznych oraz pokazano przykładowe rdzenie o dużym stopniu skomplikowania. Ponadto na podstawie obserwacji mikroskopowych wyznaczono współczynnik kształtu ziaren. Każdy typ rdzenia charakteryzował się inną wytrzymałością na zginanie oraz zróżnicowanymi wynikami ścieralności. Wyniki zostały zebrane i porównane.

**Słowa kluczowe:** metody przyrostowe, druk 3D, rdzenie odlewnicze z piasku kwarcowego i syntetycznego, żywice furfurylowe i fenolowe

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# 1. Introduction

An analysis of the literature [1–3] showed that, for a long time in the American and European foundry industry, an additive manufacturing method has been used, determining the success of traditional foundries. However, it is still rather rarely used in the domestic industry. The available scientific data comprises many studies related to the choice of additive manufacturing methods.

Three-dimensional printing, which is commonly used for the production of mass cores with organic binders, is very promising for foundries not only due to their high quality and relatively low price but also for the very short time for delivering a reliable cast to the customer. This is very important, especially in small-scale or individualized mass production.

The additive manufacturing technique especially helps to prototype new parts as well as check and correct modern design solutions. In the case of printing sand cores, it allows us to create diverse shapes as a one part instead of combining several or even many elements into a single element. It is frequently applied in the fabrication of cores that reproduce complex oil channels in hydraulic equipment and in water jackets, for example. Until now, preparing the cores with the use of conventional methods required the designing and building of many core boxes, which resulted in very high manufacturing costs. Although the determination of the production cost in the case of classic furan cores, for example, is very simple; however, it is rather difficult for 3D printing because each core and its quantity should be considered individually. The cost of printed cores depends to a large extent on their size and complexity, size and type of printing machine filling of the processing chamber, type of sand, type of binder, and additional processes.

We could not find any information in the analyzed material in the literature about the mechanical properties of sand cores obtained with the help of additive manufacturing methods. The properties of additive shaped cores depend on the type of sand, parameters of working of 3D Printer (i.e., layer thickness, speed of the head), and toughening method of the printed core.

Additive methods allow us to not only produce complex geometric shapes in a short time relative to subtractive manufacturing but also to provide a foundry method without the need for additional technological tools.

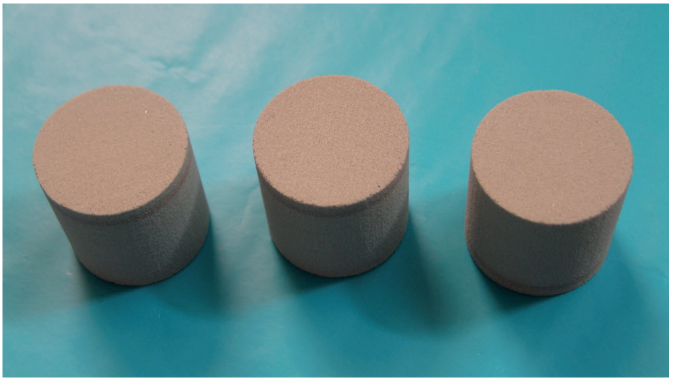
# 2. Concept, methodology, and results of experimental research

From a broad spectrum of sand cores applied in foundry engineering [4–6], examples were collected (Tab. 1) for the present work comprising the fabrication of sand cores with the help of additive manufacturing methods. The proposed concept and methodology of the experimental research was focused on the determination and comparison of the properties of the printed samples with strength tests of conventional sand core materials (Fig. 1), their permeability, and their abrasibility.

*Table 1. Summary of test samples*

| Marking of samples | Type of core sand | Binder | Comments |
|---|---|---|---|
| FS003 | quartz sand | furfuryl resin | – |
| FS001 | quartz sand | furfuryl resin | – |
| KL001 | quartz sand | furfuryl resin | conventional technology |
| FS001 CHP | synthetic sand | phenolic resin | – |
| FS053 | synthetic sand | phenolic resin | microwave cure |

a)



b)

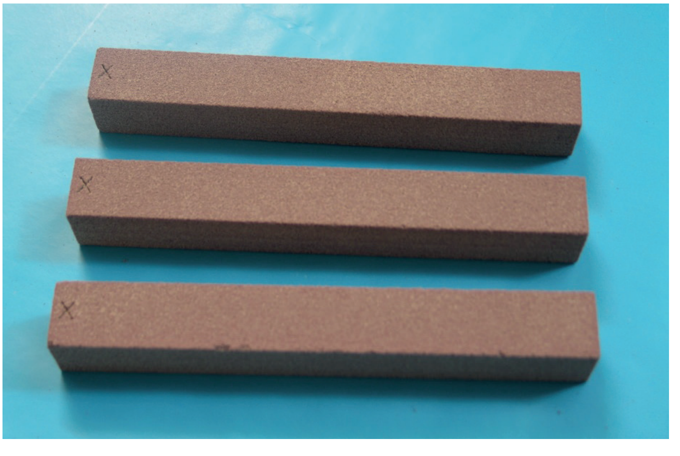
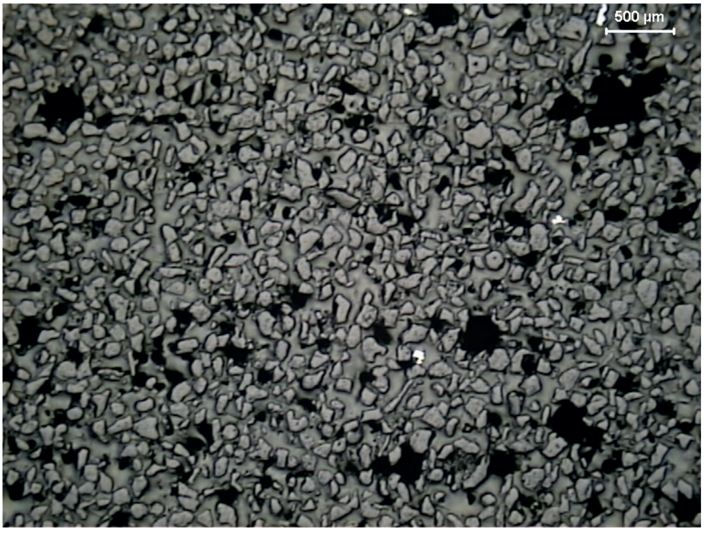


*Fig. 1. Printed molding to test mechanical properties as well as physical and technological analysis of core sand (Tab. 1)*

The investigations of the printed sand cores manufactured with the use of additive methods included cores of sand grain quartz sand and synthetic sand with binders of furfuryl and phenolic resins (Tab. 1) were carried after five hours of their fabrication.

The microstructure images of the investigated grain of quartz sand and grain of synthetic sand are presented in Figures 2 and 3.

a)




b)

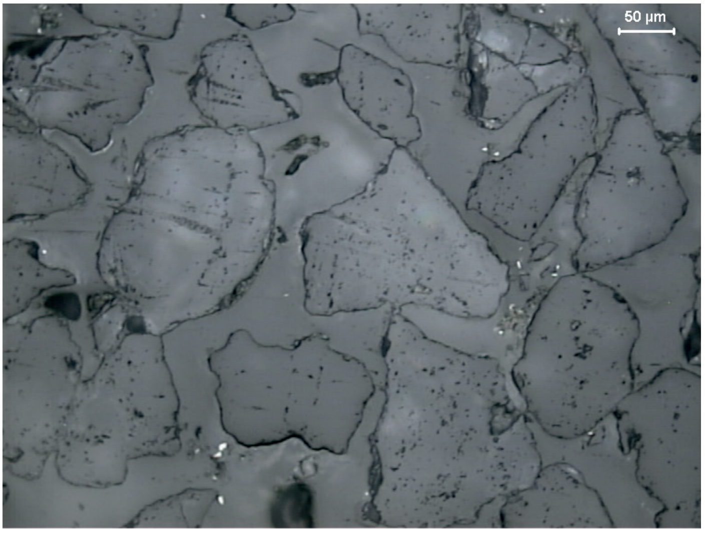
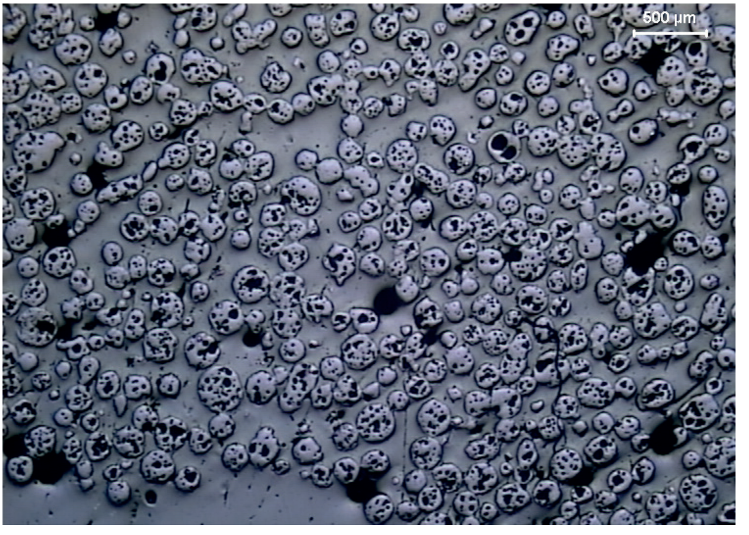



*Fig. 2. Characteristic grains of quartz sand, being sand grains core sandwich furfuryl resin (average factor of shape $k_c$ = 0.644): a) macrostructure; b) microstructure*

a)




b)

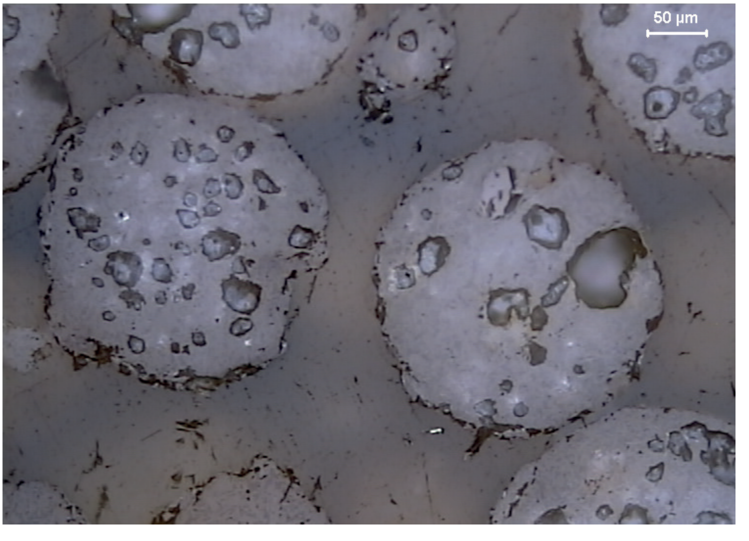



*Fig. 3. Characteristic grain of synthetic sand, with phenolic resin (average factor of shape $k_c = 0.985$): a) macrostructure; b) microstructure*

A sample was taken for derivatographic studies from the printed sand core fittings (Tab. 1, Fig. 1). The measurements were made by applying a constant heating rate of 10°C/min. The recorded results of the measurements are shown in Figures 4–7. It should be mentioned that, under industrial conditions in conventional sand cores on quartz sand grains with furfuryl resin, losses as a result of burning resin are about 1.8%.

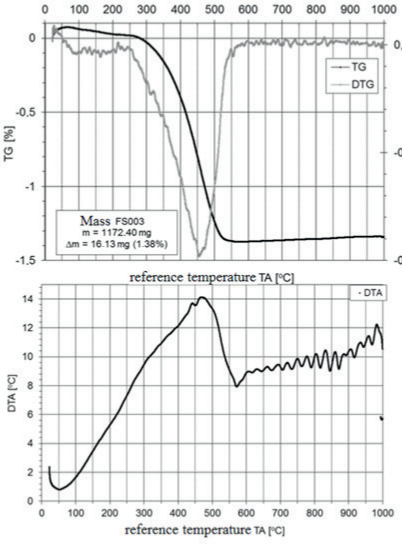



*Fig. 4. Graph curves TG, DTG (a), and DTA (b) for sand core (FS003) on sand grain quartz sand with furfuryl resin. Weight of sample subjected to heating m = 1172.40 mg. Heating rate of 10°C/min. Total weight loss Δm = 16.13 mg. Percentage loss: 1.38%*

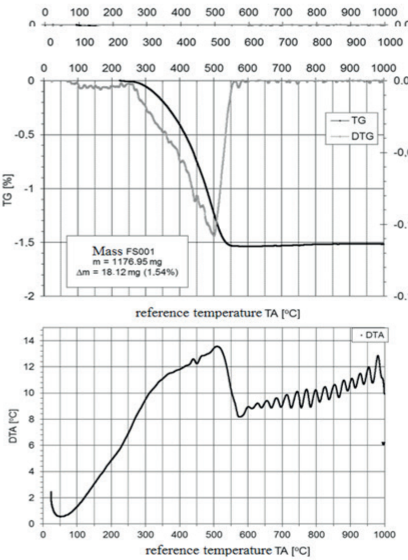



*Fig. 5. Graph curves, TG, DTG (a), and DTA (b) for sand core (FS001) on sand grain quartz sand with furfuryl resin. Weight of sample subjected to heating m = 1176.95 mg. Heating rate of 10°C/min. Total weight loss Δm = 18.12 mg. Percentage loss: 1.54%*

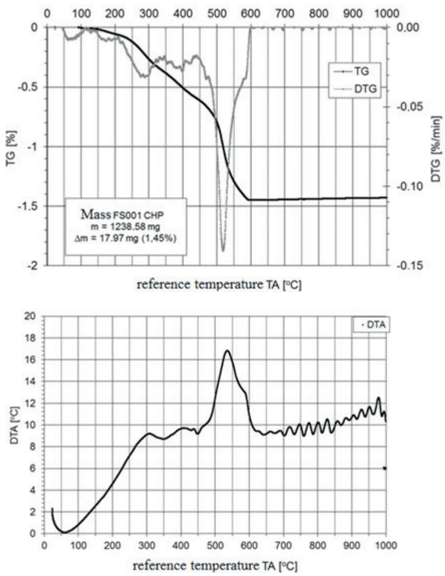



*Fig. 6. Graph curves TG, DTG (a), and DTA (b) for sand core (FS001 CHP) on sand grains with synthetic sand with phenolic resin. Weight of sample subjected to heating m = 1238.58 mg. Heating rate of 10°C/min. Total weight loss Δm = 17.97 mg. Percentage loss: 1.45%*

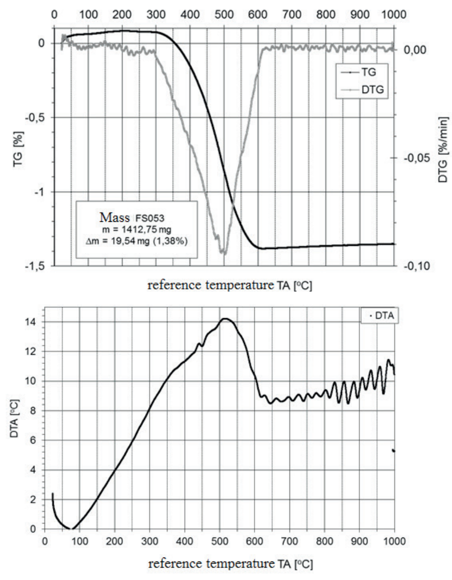



*Fig. 7. Graph curves TG, DTG (a), and DTA (b) for sand core (FS053) on sand grains with synthetic sand with phenolic resin, microwave cured. Weight of sample subjected to heating m = 1412.75 mg. Heating rate of 10°C/min. Total weight mass loss Δm = 19.54 mg. Percentage loss: 1.38%*

The bending strengths of the printed fittings (Fig. 1b) of the analyzed sand cores was investigated on an LRu-2e Multiserw-Morek machine. The results are summarized in Figure 8.

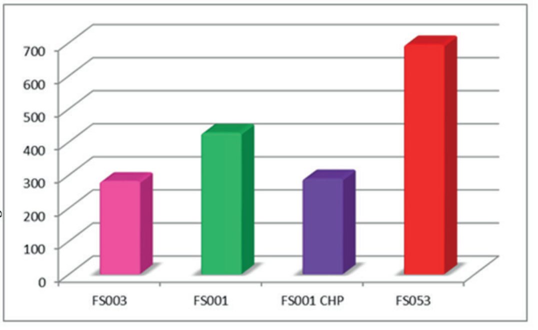



*Fig. 8. Average of results of bending strength measurements $R_g^u$ printed filled*

As can be seen in the above plot, particular printed cores possess comparable bending strengths; only in the case of the phenolic binder (modified and microwave cured) was the value of the bending strength twice as high as the rest. These types of properties should be very useful for the manufacturing of complex oil channel cores.

In the next stage of the work, a wear-resistance test of the printed cores was carried out. Wear was determined with the use of the equipment available in Huta Stalowa Wola. A cylindrical fitting is mounted in the equipment holder and rotates at a speed of 1 rpm/s. From a height of 307 mm, a 1750 g steel ball with a diameter of 1 mm falls on it. The results are shown in Figure 9.

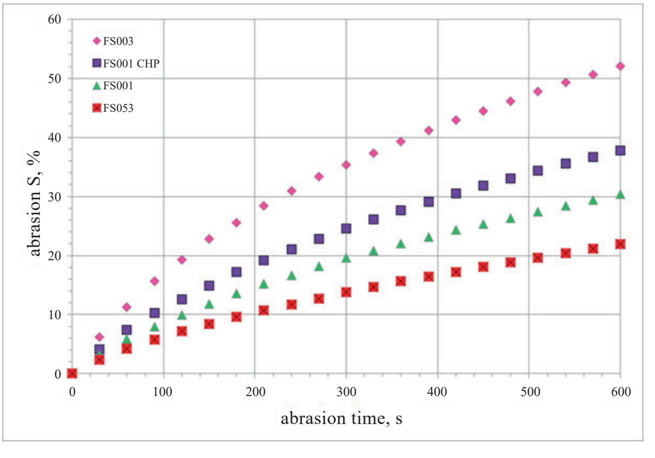
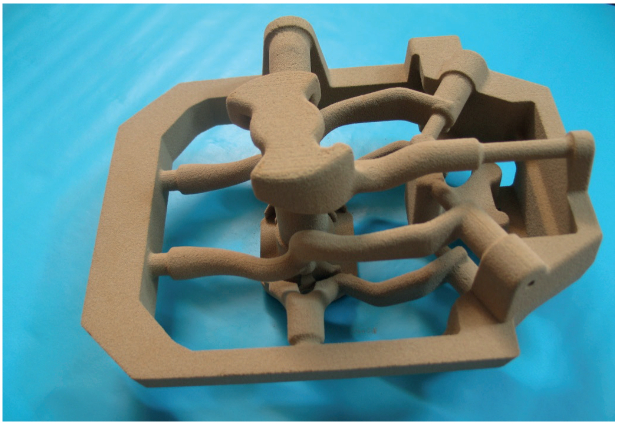



*Fig. 9. Results of wear-resistance tests*

In the chart above, one can observe a very interesting phenomenon; i.e., the highest wear resistance is for fitting FS053 printed on sand grains of synthetic sand with a binder from modified phenolic resin and microwave cured. Much less wear resistance was obtained for the samples on sand grain quartz sand with the furfuryl resin.

Examples of complex printed sand cores is shown in Figure 10.

a)



b)

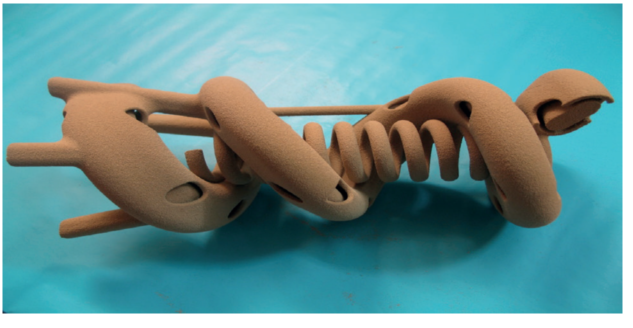


*Fig. 10. Examples of complex printed sand cores*

## 3. Conclusions

Sand cores fabricated by additive manufacturing methods are characterized by significantly increased mechanical and technological properties as related to conventional ones.

They can be used on the most-complex cores, which are almost impossible to produce in classical technologies. Thus, instead of building complex core boxes, the cores may be printed with the use of additive manufacturing methods for individual production of small and medium series. Another advantage of such an approach is the short time of printing the cores (which can be obtained in about 24 hours) without the cost of tooling building. In a very simple way, various technological solutions may be checked in a short time, even during the design phase.

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