A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 58 2013 Issue 4
DOI: 10.2478/amm-2013-0186

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FDM 3D PRINTING TECHNOLOGY IN MANUFACTURING COMPOSITE ELEMENTS

ZASTOSOWANIE TECHNOLOGII DRUKOWANIA 3D FDM W WYTWARZANIU ELEMENTÓW KOMPOZYTOWYCH

In recent years, FDM technology (Fused Deposition Modelling) has become one of the most widely-used rapid prototyping methods for various applications. This method is based on fused fibre material deposition on a drop-down platform, which offers the opportunity to design and introduce new materials, including composites. The material most commonly used in FDM is ABS, followed by PC, PLA, PPSF, ULTEM9085 and mixtures thereof. Recently, work has been done on the possibility of applying ABS blends: steel powders, aluminium, or even wood ash. Unfortunately, most modern commercial systems are closed, preventing the use of any materials other than those of the manufacturer. For this reason, the Department of Manufacturing Systems (KSW) of AGH University of Science and Technology, Faculty of Mechanical Engineering And Robotics purchased a 3D printer with feeding material from trays reel, which allows for the use of other materials. In addition, a feedstock production system for the 3D printer has been developed and work has started on the creation of new composite materials utilising ceramics.
Keywords: 3D printing, FDM, rapid prototyping, rapid tooling

W ostatnich latach technologia FDM (Fused Deposition Modelling) stała się jedną z najszerzej i najczęściej stosowanych metod szybkiego prototypowania, stosowanych w różnych aplikacjach. Jest to metoda oparta na osadzaniu topionego włókna materiału na opuszczanej platformie, oferującej możliwość opracowywania i wprowadzania nowych materiałów, również kompozytowych. Materiałem najczęściej stosowanym w tej technologii jest ABS, jak również PC, PLA, PPSF, ULTEM9085 oraz ich mieszanki. W ostatnich latach pojawiły się prace nad możliwością zastosowania również mieszanek ABS – proszki stali, aluminium czy też np. pyłu drewnianego. Niestety większość nowoczesnych komercyjnych systemów jest zamkniętych, blokujących możliwość zastosowania innych materiałów niż producenta. Z tego powodu, w Katedrze Systemów Wytwarzania AGH, została zakupiona drukarka przestrzenna z podawaniem materiału z zasobników szpulowych, co umożliwia zastosowanie również innych materiałów. Dodatkowo, w ramach prac KSW, został opracowany system wytwarzania materiału wsadowego dla drukarki oraz rozpoczęto prace nad wytworzeniem nowych materiałów kompozytowych z wykorzystaniem ceramiki.

1. Introduction

Rapid prototyping procedures make it possible to produce relatively complicated parts based on computer 3D geometries.

Most of the rapid prototyping processes can create parts from a variety of common and special materials. The materials to be selected depend on the type of rapid prototyping technology used. Some technology uses photosensitive resin cured by laser or light from a DLP projector (PolyJet and Stereolitography – SLA). Selective Laser Sintering uses a CO_2 laser to sinter or fuse powdered material, mostly plastic. A thin layer of building material is spread across the platform on which a laser traces a two-dimensional cross-section of the part, sintering the material together. The platform then descends one layer of thickness and the levelling roller pushes material from the powder cartridge across the building platform, where the next cross-section is sintered to the previous. This continues until the part is completed [1, 3].

Developed by Stratasys Ltd., Fused Deposition Modelling (FDM) rapid prototyping systems can fabricate parts in a range of materials including elastomers, ABS (acrylonitrile butadiene styrene), and investment casting wax.

In the physical process of model fabrication, a filament is fed through a heated element, and becomes molten or semi-molten. The liquefied filament is fed through a nozzle, using a solid filament as a piston, and deposited onto the partially constructed part. The newly-deposited material fuses with adjacent material that has already been deposited. The head moves on the X-Y plane and deposits material according to the geometry of the currently printed layer. After finishing a layer, the platform holding the part moves vertically in the Z direction to begin depositing a new layer on top of the previous one. After a period of time, which depends on the volume of printed part, the head will have deposited a full physical representation of the original CAD file. The model is complete and requires no hardening. The production system possesses a second nozzle in the head that extrudes support material. This is responsible for building support for any structure that has

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an overhang angle less than 45° from horizontal as a default. Support materials can be broken away or dissolved [9].

The building material, a production quality thermoplastic, is melted and then extruded through a specially designed head onto a platform to create a two-dimensional cross-section of the model. The cross-section quickly solidifies, and the platform descends to where the next layer is extruded upon the previous layer. This continues until the model is complete, where it is removed from the building chamber and cleaned. FDM creates tough parts that are ideal for functional usage [3, 7].

These methods can produce very complex parts in a single process and offer complete freedom of creation – Fig. 1.

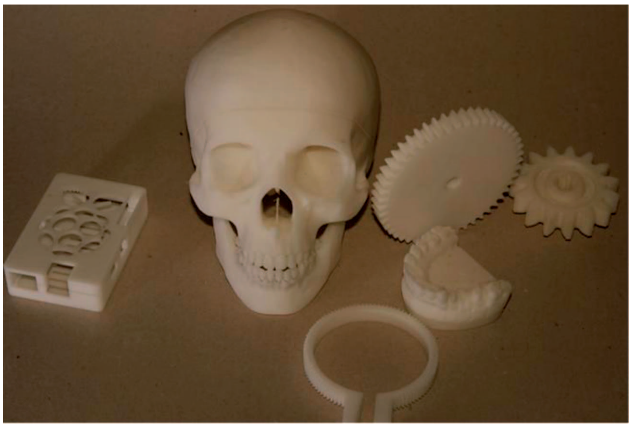

Fig. 1. Sample models printed by FDM method

2. Fused Deposition Modelling

A great deal of research has been conducted at universities and research institutions to expand the applications of FDM and to improve the FDM process. Work has also been in progress in some organisations to develop new metallic or ceramic materials for rapid fabrication of functional components by FDM with higher mechanical properties [5, 6, 8]. However, sometimes development and testing of new material may prove to be difficult due to closed systems. Filament for the printer is supplied in cartridges which cannot be refilled with other material. For this reason, the Department of Manufacturing Systems (KSW) of AGH University of Science and Technology has purchased a production 3D printer with feeding material from trays reel, which allows for the use of different materials, including some developed and manufactured by our team. This Inspire D290 printer has some benefits, such as the previously-mentioned system of feeding material or expanded options for slicing parts. It also includes a chamber, which can be heated up to 100°C, and a dual head: one nozzle for building material and another for support. But it has one drawback: it is necessary to use a bypass to change the temperature of the printing head. This machine is adapted for one material (ABS B501), and in order to use others, it is necessary to modify the electronics or circumvent the thermocouple. Production systems from Stratasys Ltd. can use different types of materials, such as ABS, PC (polycarbonate), ABS-PC, PPSF (polyphenylsulfone), and ULTEM 9085 [2]. After modification, our system can use these materials and many more, including PE (polyethylene), PLA (polylactide), and PA (polyamide). It is also possible to use composite materials by mixing one of these materials with any other material, especially in the form of powder, and create filaments from this mixture.

In terms of costs, this technology is less expensive than SLA or 3D Printing. The cost of the FDM system is only a question of machining cost, which consists of material costs and post-processing costs. The only material wasted is support material. It produces much less scrap compared to SLA, 3D Printing, and even SLS. In the SLS process materials can be reused a few times. Afterwards, it becomes overheated and is no longer usable [4].

3. Fabrication of FDM Filaments

The filament used in the FDM process requires a specific diameter, strength, and certain other properties. For a filament fabricated from a composite mixture, a single screw extruder was developed. Due to the die swell phenomenon during extrusion of a polymer, there is a difference in diameter between the die and the produced filament. To achieve a consistent diameter and minimise this difference, the machine has an adjustable screw speed, pressure, and temperature. All these parameters are examined and selected until an optimum diameter for the filament is reached (1.75 mm). For a smooth filament, a different calibrating nozzle was used. For low-temperature materials (PLA, PE) the calibrating nozzle is made from copper and the heat sealing is made from polytetrafluoroethylene. For high-temperature materials (ABS, PA) the calibrating nozzle is made from aluminium – Fig. 2. The developed extruder consists of one heat zone with controlled temperature. Temperature must be precisely controlled due to overheated polymer swell and rapid degradation of properties. The extruded filament is air-cooled in the calibrating nozzle by a simple fan – Fig. 3.

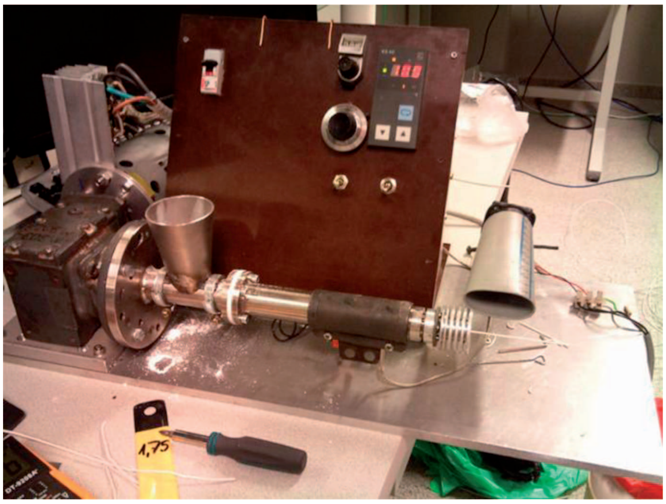

Fig. 2. Developed extruder station for manufacture filament for FDM printer

Fig. 3. Extruder visible in FLIR thermal imager

4. Materials

The author begins his work on the use of commercially available devices for rapid prototyping to produce structural components for low-temperature PEMFC fuel cell stacks for airborne applications (unmanned aerial vehicles). Application of this method allowed the constructors to manufacture – according to their own projects – components of stacks housing, and also to implement additional channels evenly distributing hydrogen fuel in this generator of electricity. It should be noted that in the case of applying fuel cell technology in unmanned aerial vehicles, the reduction in weight of the entire power unit is extremely important.

The next stage of work included composite materials for aeronautic industry, as well as medical applications. This method can be used for developing composite cellular structure, which can be applied in bone tissue engineering.

To develop new composite materials, the extruder was tested and calibrated with clean ABS pellets. After obtaining stable diameter of the filament, the extruder was used to create a ceramic-polymer composite from a 1:1 mixture of polyamide powder and hydroxyapatite (HAP). This mixture was also used for testing the SLS process, but the result was unsatisfactory. The mixture was not homogenous, and recoating of powder did not work correctly. After sintering one layer, the part was very porous and fragile. It is possible to create parts correctly from HAP/nylon composite, but hydroxyapatite particles must be coated with polyamide.

The polyamide powder used in the composite was PA12, taken from the SLS machine. It has reasonably good thermal and mechanical properties – Table 1.

Hydroxyapatite powder was purchased from Sigma-Aldrich in Poland. The purity of powder was above 90%. In order to achieve a homogeneous mixture, polymer powder was mixed with hydroxyapatite in a mixing station for 10 min. An additional mixing process occurred in the extruder. Material was extruded at 185°C.

The microstructure of printed samples was examined by scanning electron microscopy. Fig. 4a-d present the cross-section and surface of the PA12-HAP composite. As can be seen, the HAP is rather uniformly distributed over the PA12 matrix. The visible small differences in distributions of HAP in PA12 matrix can origin from not adequate mixture process. The preparation of starting materials and homogenization process before printing should be improved. The further experiments will be performed.

TABLE 1

Properties of PA 12 (after processing in the SLS machine)

Mechanical properties of PA12			
Tensile Modulus	DIN EN ISO 527	1700±150	N/mm^2
Tensile Strength	DIN EN ISO 527	45±3	N/mm^2
Charpy Impact Strength	DIN EN ISO 179	53±3.8	kJ/m^2
Charpy Notched Impact	DIN EN ISO 179	4.8±0.3	kJ/m^2
Ball indentation hardness	DIN EN ISO 2039	77.6±2	
Thermal properties PA12			
Melting point	DIN 53736	172÷180	°C
Vicat softening temperature B/50	DIN EN ISO 306	163	°C

Based upon SEM investigations and other mechanical properties, the process of printing can be optimised.

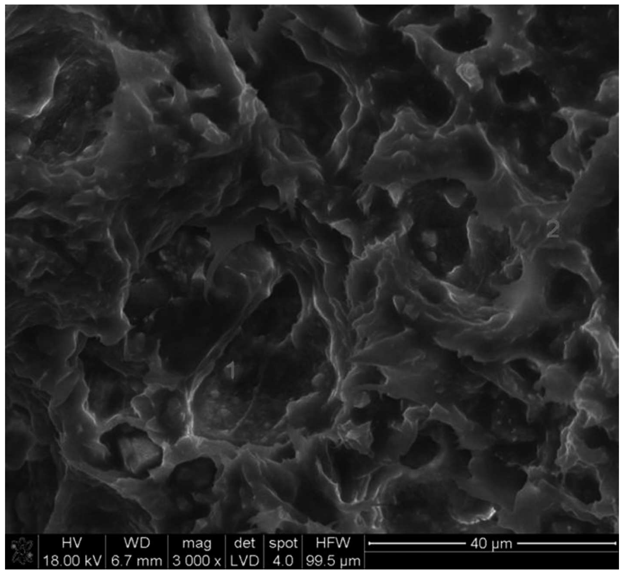

Fig. 4a. The cross-section of composite PA/HAP

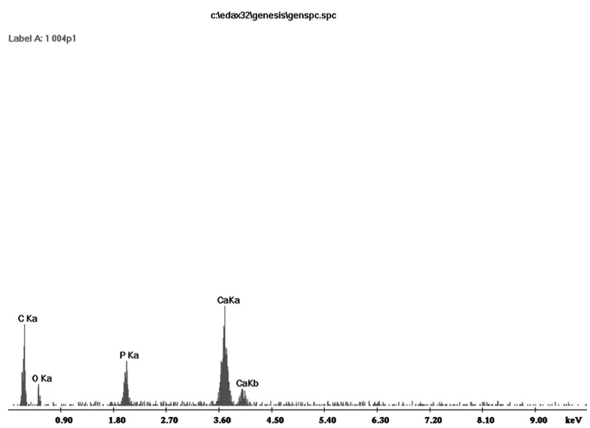

Fig. 4b. EDX analysis in point 1

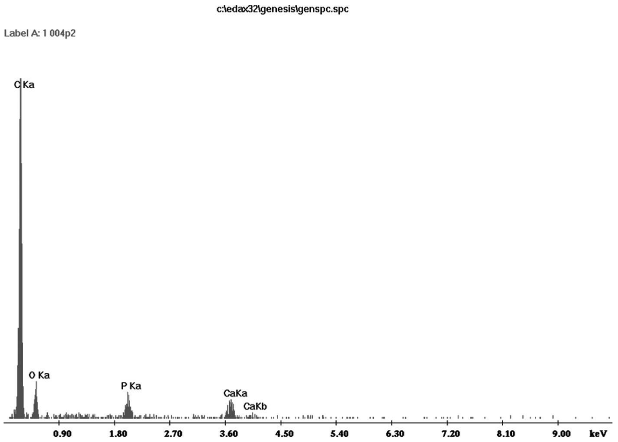

Fig. 4c. EDX analysis in point 2

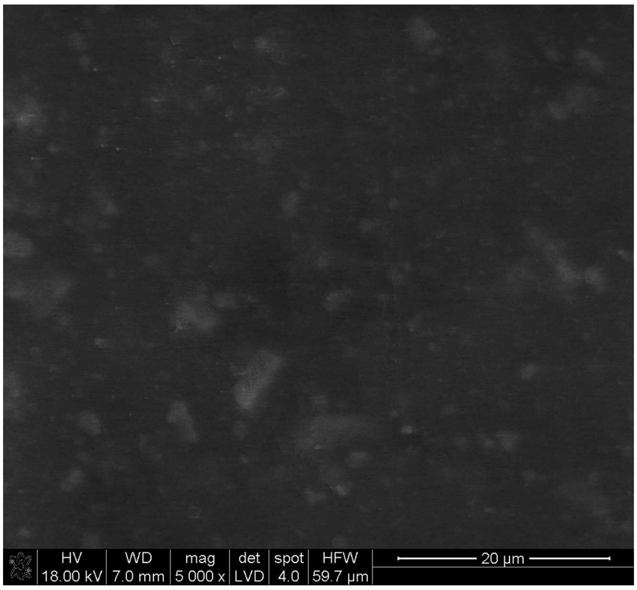

Fig. 4d. SEM microphotograph of surface composite PA/HAP

5. Conclusions

A new composite material with HAP-filled particles in nylon polymer has been successfully developed for direct application in the Fused Deposition Modelling rapid prototyping process. The flexible filaments of the new material have been successfully produced and processed in the existing Inspire D290 machine to produce sample parts.

Future work will concentrate on investigating other composite materials, such as copper, iron, or Al_2O_3 in conjunction with PA12, polyethylene, and PLA materials. Also, it is necessary to examine the mechanical and thermal properties of these materials.

Fused Deposition Modelling method allows the use of a wide variety of thermoplastic materials with the possibility of combining them with the ceramic or metallic powders. This enables the development of composite materials with improved internal structure, as well as mechanical and thermal properties. This technology can also be used in medical applications such as bone tissue engineering, development of customized prostheses, etc.

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Received: 20 September 2013.