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POLIMERY

The use of soluble resin for additive manufacturing of automotive industry prototypes

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Abstract: The article describes the method of producing car parts using the Freeform method (FIM). The injection process into a mold obtained by 3D printing was simulated and the surface condition of the finished product made of high-strength PEEK was assessed.

Keywords: Freeform method, 3D printing, car parts, prototyping, injection molding.

Zastosowanie żywicy rozpuszczalnej do wytwarzania przyrostowego prototypów dla przemysłu motoryzacyjnego

Streszczenie: W artykule opisano sposób wytwarzania części samochodowych metodą Freeform (FIM). Przeprowadzono symulację procesu wtryskiwania do formy otrzymanej metodą druku 3D i dokonano oceny stanu powierzchni gotowego wyrobu z tworzywa o dużej wytrzymałości (PEEK).

Słowa kluczowe: metoda Freeform, druk 3D, części samochodowe, prototypowanie, wtryskiwanie.

The essence of using 3D printing technology for manufacturing products is to reduce time and costs when producing single items, the production of which using classic methods using mass and large-scale production machines is too expensive [1]. Currently, it is used in many industries, from medicine to automotive and aviation. In addition, 3D manufacturing technology provides the ability to create elements with geometrically complex shapes, when classic production is technically impossible or must be divided into several elements.

In the case of car or aircraft engine components, control elements that have a direct impact on the operation of such an engine are very important. Producing these elements in series on a production line is relatively simple [2]. The problem begins when the engine is repaired or damaged and one element needs to be made, which is the main element, e.g., controlling the flow of AdBlue additive [3, 4]. An example of such an element is a spatial turbine with blades that curve at different angles. Making a part using classic 3D printing does not meet 100% of the assumed mechanical strength of a given element [5, 6]. On the other hand, making a complicated metal mold is time-consuming and expensive, or sometimes even impossible. In the described injection technology, the molding cavity made of resin is dissolved in a special solvent, and the manufactured product maintains the assumed requirements and geometric shape necessary for operation. The article presents the procedure for making an example turbine element for controlling a car pump assembly, the production of which using a metal mold is uneconomical from the point of view of its production [7].

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The procedure for preparing a model for printing is universal, independent of a specific printing technology, and is used with great success in the automotive industry. In the case of diesel engines, a high-purity urea solution is used, the so-called AdBlue factor. This compound, which is a 32.5% urea solution, is very toxic to humans and the environment. New standards preventing the emission of harmful substances into the atmosphere, especially the EURO 6 standard, force manufacturers of combustion engines equipped with selective catalytic reduction systems to introduce new solutions to prevent environmental pollution [8, 9]. Due to the high aggressiveness of AdBlue, it is necessary to use special pump elements using modern construction materials, e.g., reinforced with glass fiber or carbon fiber [10, 11]. Materials of this type provide mechanical strength and resistance to corrosion and various fuel additives; however, they are very difficult to produce in the production process (injection, extrusion), and the tools (molds, heads) must be made of high-quality tool steel, which significantly increases the costs production [12, 13].

Therefore, the subject of the work was the production of car parts using the Freeform method (FIM). The injection process into a mold obtained by 3D printing was simulated. The surface condition of the finished high-strength PEEK product was also assessed.

EXPERIMENTAL PART

Materials

In this paper, poly(ether ether ketone) (PEEK) photo polymer was used to inject the AdBlue feed pump element. It is a material that is difficult to process, has very high mechanical strength, high flexibility, and no cracks. PEEK material is successfully used for additive manufacturing and for creating functional and prototype parts [14, 15]. This polymer is resistant to high temperatures, has the highest abrasion resistance and has a very low thermal expansion coefficient [13, 16]. These properties allow it to be used for various types of rotors or turbines with blades with features like similar elements but made of metal. In applications with permanent load and high temperature, these elements will operate much more successfully in the environment containing urea in AdBlue systems [9]. The material from which the resins for printing the mold were made was a mixture based on acrylic resin with additives, trade name Ultracur3D by BASF. A high-performance photocurable resin was used to create the molding insert using 3D printing for subsequent use in the Freeform (FIM) technique from NEXA3D xMold resin which is a mixture based on acrylic resin curable in a UV environment [17]. The obtained mixture is characterized by a very high surface plasticization point, homogeneous internal structure, and high smoothness of the obtained surface [18]. These features enable the production of mold inserts (injection molding elements) without the need for complex design of metal molds. This approach makes it possible to obtain the target detail, in this case a spatial turbine with blades for controlling the flow of AdBlue additive, without having to incur the costs associated with making a conventional injection mold.

Methods

The research included carrying out a computer simulation of the injection process into a universal metal molding cavity and a xMold resin molding insert made by 3D printing using LSPc technology - Lubricant Sublayer Photocuring, based on LCD technology emitting UV light. The composition of the resin was also analyzed and the quality of the surface mapping of the injected product was examined using the profilographometric method, along with reading the surface roughness for a plastic element compared to a metal element.

The injection process was simulated using Autodesk Moldflow simulation software for PEEK with glass fiber (30 wt%), which was injected into a cavity made of special xMold resin. A material from SABIC with the trade name Thermocomp LF006E was selected for testing. As part of numerical research, simulations of the selected material were injected into an injection mold made of classic tool steel and injection into a mold cavity whose forming insert was made using a Nexa3D printer. The characteristics of the material are presented in Table 1. The injection simulation conditions were as follows: mold temperature 170°C, injection temperature 370°C, injection time 0.6 s, pressing time 10 s, pressing pressure 22 MPa. Table 2 shows the characteristics of the PEEK injected material.

T a b l e 1. Properties of Ultracur3D resin

Material characterization	Unit	Value	Standard
Ultimate tensile strength	MPa	38 ± 3	ASTM D638
Young's modulus	MPa	1152 ± 284	ASTM D638
Hardness (Shore D) post curing	ShD	80	ASTM D2240
Toughness	MPa	18 ± 4	ASTM D638
Thermal conductivity	W/m K	0.187	ISO 22007-2 (2015)

T a b l e 2. PEEK characteristic

Material characterization	Unit	Value	Standard
Density	g/cm³	1,53	SO 1183
Tensile strength	MPa	159	ISO 527
Elongation at break	%	1.9	ISO 527
Tensile modulus,	MPa	11200	ISO 527
HDT	°C	>280	SO 75/Af
Melt temperature	°C	380 – 390	–

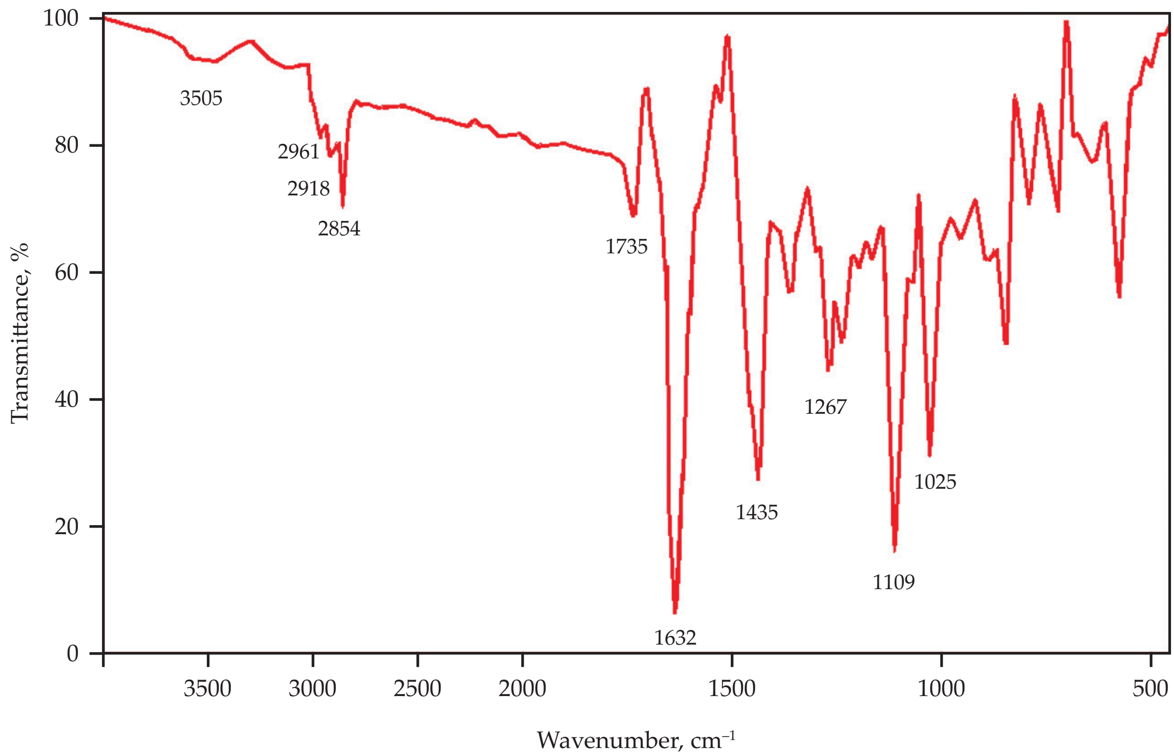

Fig. 1. IR spectrum of the resin

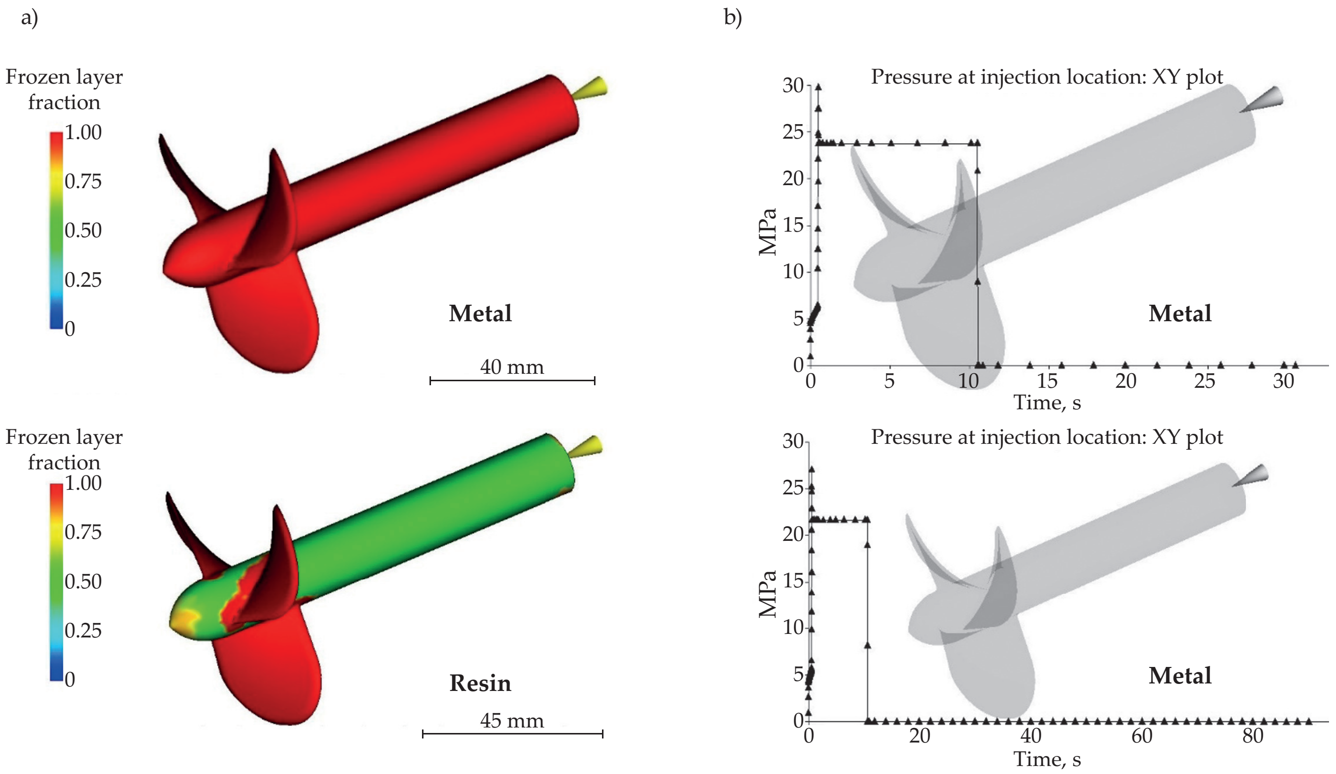

Fig. 2. Injection simulation results: a) comparison of the share of the solid phase of the molding obtained in a metal cavity and in a molding, cavity made of resin, b) comparison of the course of pressure changes in the gate for a metal insert and a resin insert

The composition of the resin was checked by elemental analysis performed using the Vario EL III C, H, N, S and O element analyzer from Elementar (Leipzig, Germany). Element percentage content C – 57.08, N – 6.90, and H – 7.95 is consistent with the composition of the resin. FTIR infrared spectrum analysis was also performed.

The infrared spectrum (FTIR) of the resin allowed for recording the composition. The study was performed using the ALPHA FT-IR instrument from Bruker in the

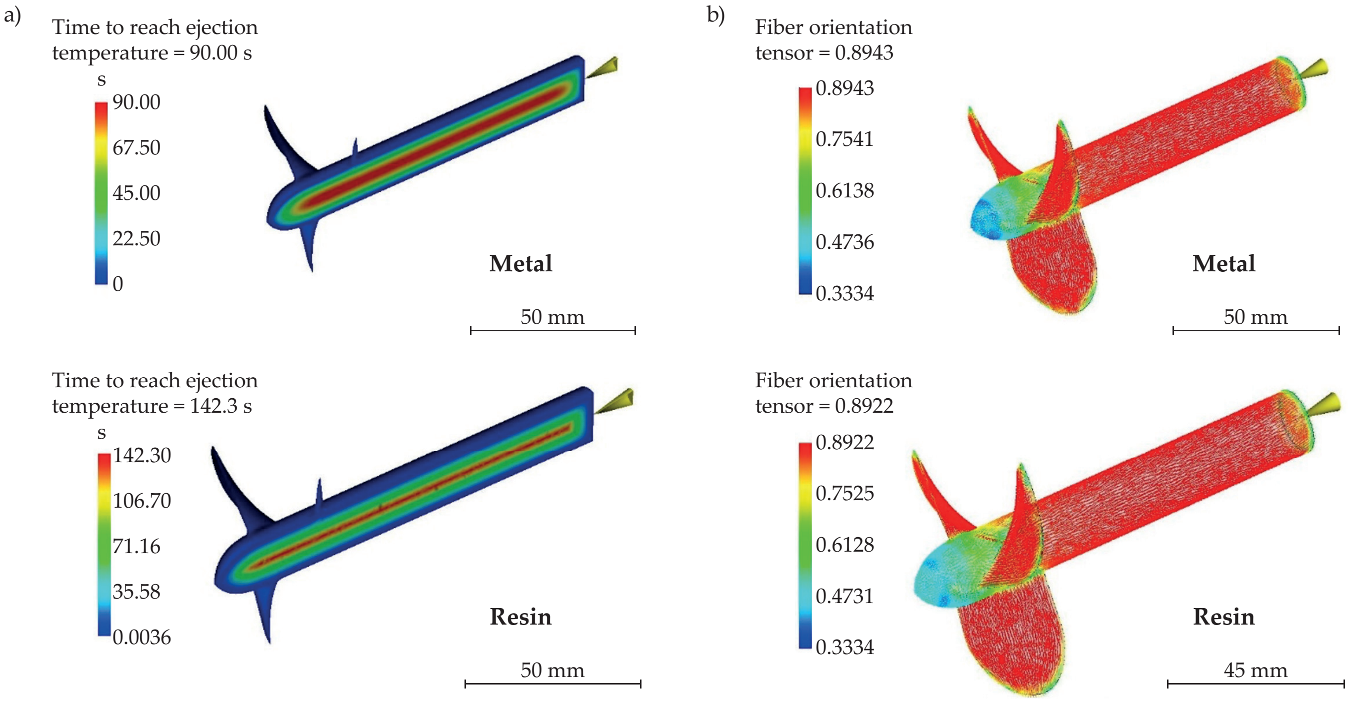

Fig. 3. Results of the injection simulation: a) comparison of the time to reach the removal temperature for metal and resin inserts, b) comparison of the predicted orientation of glass fibres in the molded part for metal and resin inserts

ATR mode in the range of 400–4000 cm^{-1}, with a resolution of 0.01 cm-1. FTIR analysis confirmed the structure of the resin and the presence of ester groups (1735 cm^{-1}) and amide groups (1631 cm^{-1} and 1526 cm^{-1}).

RESULTS AND DISCUSSION

The course and analysis of the injection simulation for a metal insert and a 3D printed resin insert are presented in the following drawings.

Figure 2a shows the expected cycle time for a metal socket. The recorded time was approximately 31 s, while for the resin insert the time for the same model was approximately 90 s. The almost three-fold increase in cycle time for the resin insert results from its low thermal conductivity. The time needed to cool the molded part (in its entire volume) to the removal temperature from the mold is approximately 90 s for a metal insert, while for a resin insert it was 172.3 s. The use of resin inserts makes it possible to produce the correct product but requires significant extension of cycle time. After cooling, the molded part shows the correct properties without any shape deformation. The use of resin inserts allows for effective prototyping of molded parts with complex shapes without the limitations that occur when making metal inserts, and the shape of the molded part can be any.

Fig. 4. View of the Nexa3D machine and the resulting molding cavity

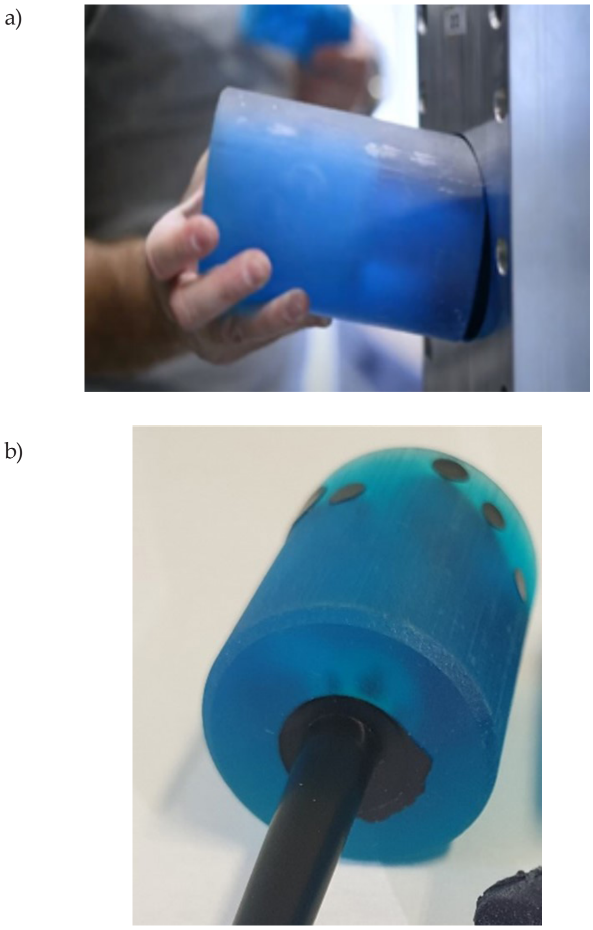

Fig. 5. View of the xMold resin socket attached to the metal mold before injection (a) and after a full PEEK injection cycle (b)

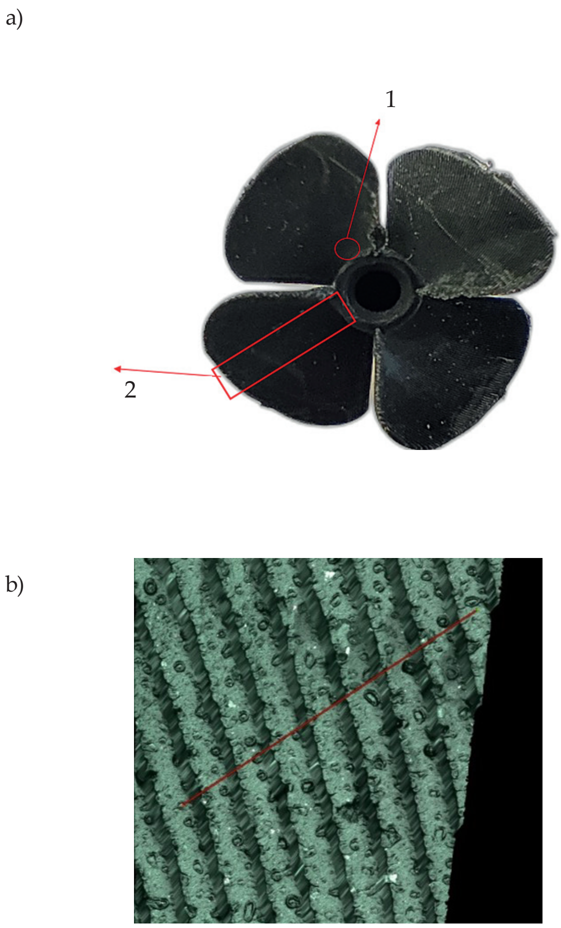

Fig. 6. View of the turbine obtained after dissolving the resin (a), and the structure of the obtained surface (b)

The procedure for producing elements from high-strength materials injected into molding cavities made of this type of resin is that after printing, the resulting molding cavity is attached to the injection mold. Then, a single injection process is carried out, and after cooling, the entire assembly is processed with soluble xMold resin in an acetone solution. The appearance of the molding cavity made of xMold resin, and the cavity filled with PEEK before dissolution and the finished element of the molded turbine are shown in Fig. 4 and Fig. 5.

The roughness micro geometry and surface topography (Fig. 6) of precision components for the automotive industry, aerospace industry and medical technology was performed using the 3D Infinta Focus optical measurement system (Alikona). The results are presented in Table 3.

The surface of the detail obtained after injection molding using a forming insert made of xMold resin has a repeatable structure, which is characterized by greater porosity than the detail obtained by conventional injection. However, this will not have a significant impact on the finished detail functioning. It should be mentioned that thanks to the lower costs associated with the lack of the need to make an injection mold, we can compensate for any activities related to the surface treatment of the manufactured detail. In the case of small-batch production, this is an ideal solution for producing details with virtually unlimited geometry and with great freedom in terms of construction material used.

CONCLUSIONS

Due to the ability to create multiple design iterations in less time (and at little additional cost), 3D printing is an effective tool for developing products that require special

T a b l e 3. Surface roughness parameters for turbine and metal insert

Sample	Measurement direction	R_a µm	R_q µm	R_z µm
Turbine	Direction 1	9.87	13.13	56.38
Turbine	Direction 2	17.96	20.47	74.08
Metal insert	Direction 1	280.83	345.43	1.39
Metal insert	Direction 2	396.68	509.96	3.00

features and properties. The use of 3D printing for prototyping, testing and performance validation is currently one of the most popular applications of this technology in the automotive industry. The low cost of 3D printing means designers can first test the fit and performance of a prototype before investing in expensive and usually labor-intensive molds to produce finished products. The presented FIM process uses ultra-fast Nexa3D printers and xMold resin, which can be used to successfully print injection molding tools. These tools in the form of molding sockets can be used to form products from ready-made materials for injection, including those that are difficult to process or highly reinforced with glass or carbon fiber. Because design, iteration and validation are possible in hours instead of weeks, it is invaluable in any new product development process. The FIM process allows to produce a fully dissolvable tool, providing great design freedom and eliminating the need for time-consuming considerations regarding the design of the injection mold due to the complex geometry and the need to remove the molded part after the production process.

Another aspect is that due to this technology it is possible to produce replacement parts on demand or parts for older vehicles that are often discontinued because keeping them in stock involves significant overhead costs for automotive companies. 3D printing processes can deliver these types of products. To produce spare parts for old cars that are out of stock, only a 3D CAD model and technical material requirements are required. On the other hand, to reproduce them in a conventional way, significant time, resources, and necessary forms are needed. Therefore, 3D printing of soluble molds seems to be an absolute solution to produce spare parts to order, also contributing to the reduction of inventories while using 3D printers for repeatable production.

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