IOP Conf. Series: Materials Science and Engineering **227** (2017) 012051 doi:10.1088/1757-899X/227/1/012051

Molding of strength testing samples using modern PDCPD material for purpose of automotive industry

Ł Grabowski[1] **A Baier**[2], **M Sobek**[3]
[1,2,3] Silesian University of Technology, Gliwice, Poland, The Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems

E-mail: lukasz.grabowski@polsl.pl

Abstract. The casting of metal materials is widely known but the molding of composite polymer materials is not well-known method still. The initial choice of method for producing composite bodies was the method of casting of PDCPD material. For purpose of performing casting of polymer composite material, a special mold was made. Firstly, the 3D printed, using PLA material, mold was used. After several attempts of casting PDCPD many problems were encountered. The second step was to use mold milled from a firm and dense isocyanate foam. After several attempts research shown that this solution is more resistant to high-temperature peak, but this material is too fragile to use it several times. This solution also prevents mold from using external heating, which can be necessary for performing correct molding process. The last process was to use the aluminum mold, which is dedicated to PDCPD polymer composite, because of low adhesiveness. This solution leads to perform correct PDCPD polymer composite material injection.
After performing casting operation every PDCPD testing samples were tested. These results were compared together. The result of performed work was to archive correct properties of injection of composite material. Research and results were described in detail in this paper.

1. Introduction

Polymer composite materials loom large increasingly important role in the overall industry. The composite material has a special role in the ever-evolving automotive industry. Every year the polymer composite materials are used in a growing number of elements included in the cars construction. Development requires the search for ever new applications of composite materials in areas where previously were used only metal materials. Requirements for modern solutions, such as reducing the weight of vehicles, the required strength and vibration damping characteristics go hand in hand with the properties of modern composite materials. The designers faced the challenge of the use of modern composite materials in the construction of bodies of power steering systems in vehicles.

With the help come cold-formed composite, the amount of which in the global market, due to its properties, is gradually increasing.

The PDCPD class materials will be used for the composite power steering body in the future. The first step of this project was to perform a trial injection, to obtain the knowledge about performing the moulding process. For this purpose, aluminum molds for die castings have been modeled in CAD software and manufactured. Molded test elements were used in strength tests in accordance with the tensile strength test standards. These studies were aimed to verify the mechanical properties of the

IOP Conf. Series: Materials Science and Engineering **227** (2017) 012051 doi:10.1088/1757-899X/227/1/012051

obtained plastic material. The results of the study were necessary to carry out a further series of numerical analyses and the injection of further components of the power steering body [1-4].

2. Methods of mold preparation

The first part of this work was to perform CAD model of the mold and to perform molding simulation. The simulation was performed in Siemens NX environment. This analysis was based on parameters of the molding machine. It is shown that the time necessary for performing molding was close to 5 seconds. The parameters were performed for material with the same viscosity as PDCPD. Also, the parameters of injecting were similar to that used in a process of injection of polymer on a real machine, shown in Figure 1. The velocity of polymer fluid was set at a level of 2 [cm^3/sec].

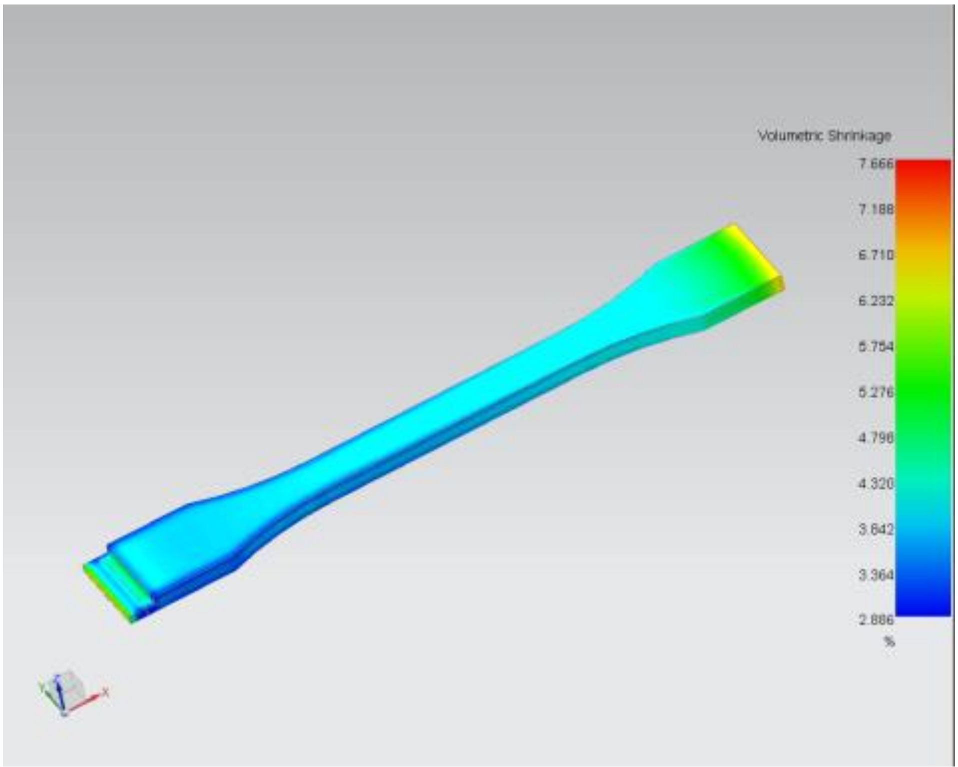
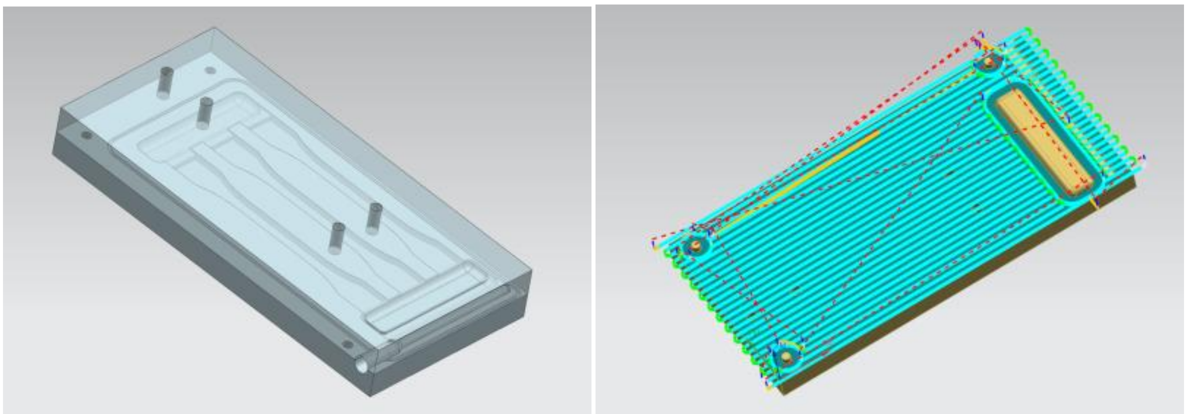


Figure 1. Molding simulation in Siemens NX 10 [4].

For three testing samples, which shape is similar to “paddle”, the time of molding will be close to 15 seconds. After this test results of shrinkage were obtained. Maximum volumetric shrinkage was close to 7 [%]. From producers data sheet this parameter is close to 6 [%], so obtained a result of simulation by FEM could be compared together [5-8].



a) **b)**

Figure 2. CAD model of mold (a) and CAM process for manufacturing cold injection molds (b).

The next part of the preparation of injection mould was performed a CAD mould model. The 3D geometry contains all necessary mixers and parts, described in polymer material manufacturer's standards. Using this parts is necessary for archiving high-quality results of molding. CAD model was used to make correct CAM programs which were used in manufacturing process on CNC machine. CAD model and CAM in Siemens NX 10 are shown in Figure 2 [8, 9].

Figure 3. Part of manufactured mold.

After designing CAM (manufacturing) process for the two-part injection molds, the mold was manufactured using a CNC Certus 4040. In the manufacturing process, many different types of mills- finger and ball end - had been used, with diameters of 10 [mm] to 2 [mm]. The machining process was divided into two types of machining - roughing and finishing. During roughing, planar milling programs were used, for the finishing milling, the target was to perform operations with the plurality of contouring paths. Milled mold could be shown in Figure 3. The mold was made of aluminum, the material recommended by the polymer manufacturer, due to its excellent anti-adhesive properties. Mold after machining was cleaned and equipped with the necessary gaskets, filler tubes and other components that directly affect the correct injection process.

IOP Conf. Series: Materials Science and Engineering **227** (2017) 012051 doi:10.1088/1757-899X/227/1/012051

3. Moulding of PDCPD testing samples

After preparation of the mold, the injection process was started. The injection was performed using a dedicated APCOM automatic dosing machine. This machine is a machine designed for injection of PDCPD cold-injecting polymer materials. With the use of pressurized nitrogen as well as the pumps, the medium is fed through two separate tubes to the pre-mixer and then to the injection mold. Figure 4 presents the machine prepared for the injection process and the casting mold during the casting process [4, 5].

Figure 4. Injection machine and performed cold mould of testing samples.

The main purpose of performing the injection of samples for static stress testing of PDCPD material was to determine the material parameters and to determine the parameters for performing the correct injection process. The same material was used during the experiment. This material has always been pumped in the same way as described above. In the process, the influence of the mold heating on the received sample quality, the quality of the samples, and the severity of the polymerization reaction were also checked. The first attempts were made to verify the way the injection was performed. After the acceptance of the method, regular samples were injected, which were then tested using a strength machine and subjected to a visual inspection. Exemplary results of the injection process are provided in figure 5. The presence of ingots and materials in the mixers and inlet tubes could be noticed. After the injection process, samples should be prepared by mechanically removing the ingots and other unnecessary components. The samples thus prepared were then subjected to a tension test [6, 9].

Figure 5. Molded testing samples.

Seven series of samples were made in the cold molding/injecting process. Each series has been carried out by other casting parameters. Series 1A, 2A, 3A parameters were subjected to injection without heating the mold to the recommended temperature. After the injection process, the mold temperature was verified. It was 16, 23, 24 °C in succession. In subsequent series, molding was performed with the process of heating the mold. The mold temperature was between 60 and 80 °C. In the 4B, 5B, 6B, 7B series, the internal mold parts temperatures reached the following mean values: 61, 70, 75, and 81°C. The series could be shown in Figure 5.

Figure 6. Molded testing samples and differences between two moulding series.

4. Results

During the injection process, the temperature of the polymerization reaction was also checked. It was discovered that the material in the reaction reached a peak of a temperature of up to 211 [°C]. It has also been observed that the reaction proceeds more rapidly and takes place in a shorter time in the case of heated moulds. The time at which the polymerization reaction started to occurred was from 2.5 [min] to 4 [min].

Another observed phenomenon was the significant ease in the removal of cast samples from the mold after injection process from heated moulds to non-heated molds. The next phenomenon observed when comparing samples was the occurrence of bubbles of gas in the case of non-heated forms. Gas bubbles can significantly affect the resulting cross-sectional area of the sample and could influence the actual strength of the tested element. Differences in an appearance of bubbles are shown in Figure 7.

Samples were tested for tensile strength. The results in the tabular form are shown in Table 1. Figure 6 shows the samples after the tensile strength measuring process

Figure 7. Testing samples after tensile strength tests.

Table 1. Results of tensile strength analysis.

Nr	m_E GPa	R_{p02} MPa	R_m MPa	F_m kN	A_{80} %	Name
1	2	16	40	1.70	9.8	1A
2	2	8	39	1.70	8.7	2A
3	2	17	37	1.60	9.3	3A
4	2	19	41	1.71	5.6	4B
5	2	15	40	1.69	8.3	5B
6	2	15	1	1.69	6.2	6B
7	2	18	41	1.71	5.1	7B

5. Conclusions

The obtained results are an introduction to subsequent studies and have allowed determining the basic material properties of the tested samples. The results obtained will allow to use them in subsequent strength analyzes using FEM, performing more complicated analysis of more complicated complex systems. The pre-developed PDCPD injection process will affect the next steps in the design of new components as well as the technology of the injection molds.

6. Acknowledgments

The work was carried out under the project number PBS2/A6/17/2013 realized as a part of the Applied Research Program, funded by the National Research and Development Centre.

7. References

[1] Herbuś K, Ociepka P 2016 Integration of the virtual model of a Stewart platform with the avatar of a vehicle in a virtual reality *IOP Conf. Series: Materials Science and Engineering* **145** 042018,

[2] Herbuś K, Ociepka P 2016 Determining of a robot workspace using the integration of a CAD system with a virtual control system *IOP Conf. Series: Materials Science and Engineering* **145** 052010,

[3] Sobek M, Baier A, Buchacz A, Grabowski L, Majzner M 2015 Carbon fiber based composites stress analysis. Experimental and computer comparative studies *IOP Conference Series-Materials*

Science and Engineering **95 (2015),** Article Number: 012011, IOP Conference Series-Materials Science and Engineering, Romania

[4] Grabowski L, Baier A, Majzner M, Sobek M 2016 Composite materials molding simulation for purpose of automotive industry, *IOP Conference Series: Materials Science and Engineering* **145 (2)**, 022023

[5] Baier A, Brajza M, Erm M, Grabowski L, Papaj P, Sobek M 2013 Advanced analysis of the Greenpower race car, *International Journal of Materials & Product Technology*, Modtech 2013, Sinaia, Romania

[6] Baier A, Baier M, Dusik D, Sobek M, Papaj P, Grabowski L 2014 Computer aided Process of designing the mechatronic Silesian Greenpower electric car, *Advanced Materials Research* **1036** 674-679, Trans Tech Publications, Switzerland

[7] Baier A, Baier M, Dusik D, Grabowski L, Miera A, Sobek M 2013 Computer aided Process of designing the mechatronic Silesian Greenpower electric car, *Selected Engineering Problems,* **4**, Gliwice

[8] Niedworok A and Baier A 2015 Numerical Modeling of the Phenomena of Frictional Coupling Between Wheel and Rail to Describe and Verify the Operation of Surface Condition Detector, *Solid State Phenomena* **Vols. 220-221** pp. 251-256,Trans Tech Publications, Switzerland

[9] Grabowski L, Baier A, Buchacz A, Majzner M, Sobek M 2015 Application of CAD/CAE class systems to aerodynamic analysis of electric race cars, *IOP Conference Series-Materials Science and Engineering* 95 Article Number: 012044