Molding of auxiliary elements for molding of the power steering gear’s polymers body made of PDCPD material

L Grabowski, A Baier and M Sobek
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. Every year the polymer and composite materials are being used in a growing number of elements using in automotive industry. During research for a modern solution to replace commonly used steering housings, solutions have been sought to reduce weight and cost of production. Bodies are made of traditional materials, such as steels or aluminum, which is why the choice was on modern polymer materials from the PDCPD materials group. Polymer composite materials loom large increasingly important role in the automotive industry. Materials from the DCPD and PDCPD group have been nowadays used to produce elements of the external surfaces of vehicles, like bumpers or parts of body of a car. However, regarding to a very good mechanical property, it was decided to use the PDCPD material as the body material of the passenger car steering system body. The technology of “wraping in a casting process” of the whole worm and wormgear assembly with polymeric material will be applied. In this process, the elements will be pre-set(arranged), will be encapsulated with the elements of the mold and the casting process will be carried out. The prerequisite for a correct implementation of the process is to keep the mold from leaks of fluid polymeric material. This would not be possible without the use of auxiliary elements (fixing elements). Therefore, the manufacturing process of bodies made of PDCPD material requires an auxiliary element, without which the casting could not take place. These elements are also made of PDCPD material. At the beginning, CAD 3D forms were prepared. The next step was to design the mold making process. After the molds were formed, it was possible to proceed with the casting process. The molding process of the PDCPD material was associated with a number of tests required to determine the casting parameters. Process is quite different from the traditional casting of metal materials. Also, the casting process parameters, temperatures, pressures could influence the correct process of casting. Research and results were described in detail in this paper.

1. Introduction
Every year the polymer and composite materials are being used in a growing number of elements using in automotive industry. During research for a modern solution to replace commonly used steering housings, solutions have been sought to reduce weight and cost of production. Bodies are made of traditional materials, such as steels or aluminum, which is why the choice was on modern polymer materials from the PDCPD materials group. Polymer composite materials loom large increasingly important role in the automotive industry. Materials from the DCPD and PDCPD group have been nowadays used to produce elements of the external surfaces of vehicles, like bumpers or parts of body of a car. However, regarding to a very good mechanical property, it was decided to use the PDCPD material as the body material of the passenger car steering system body. The technology of “wraping in
a casting process” of the whole worm and wormgear assembly with polymeric material will be applied. In this process, the elements will be pre-set(arranged), will be encapsulated with the elements of the mold and the casting process will be carried out. The prerequisite for a correct implementation of the process is to keep the mold from leaks of fluid polymeric material. This would not be possible without the use of auxiliary elements (fixing elements). Therefore, the manufacturing process of bodies made of PDCPD material requires an auxiliary element, without which the casting could not take place. These elements are also made of PDCPD material. At the beginning, CAD 3D forms were prepared. The next step was to design the mold making process. After the molds were formed, it was possible to proceed with the casting process. The modeling process of the PDCPD material was associated with a number of tests required to determine the casting parameters. Process is quite different from the traditional casting of metal materials. Also, the casting process parameters, temperatures, pressures could influence the correct process of casting. For purpose of casting process auxiliary elements need to be casted. These elements will prevent interior of mechanism from leaking of PDCPD liquid phase of material. Without auxiliary elements process would not be succesfull.

Process of injecting of PDCPD material is taking part in regular atmosphere with comparision to DCPD, which have to be performed in Nitrogen environment [1, 2, 3 and 4].

![Figure 1. The process of molding using PDCPD material [13]](image)

For molding process several types of PDCPD material were used. Firstly, PDCPD material, from telene manufacturer, were used. It was performed in the way showed in figure 1. Two different monomers, Monomer A (3a, 4,7,7a-tetrahydro-4,7-methanoindene mixed with Trichlorophenylsilane) and Monomer B (3a, 4,7,7a-tetrahydro-4,7-methanoindene mixed with 2,6-Di-tert-Butyl-p-Cresol) are mixing together. For Telene PDCPD material proportions are 50% of Monomer A and 50% of Monomer B. After two monomers are connected polymerisation process in methathesis reaction is made. For changing life time of material activator should be used. Of amount of activator depend life time of material. It could change from 1 minute to 8 minutes. The traditional PDCPD molding system contains of several elements. On figure 1, as 1 top part of a mold is shown, as 2 down part of mold is shown, as 3 molding element is shown, as 4 mixing head is shown, as 5 nozzle is shown. Also on a figure 1 two Momnomere are shown, described as resin “A” and resin “B”. They are delivered to mixing head by wires. In mixing head material is mixing together and getting injected by nozzle to mold. Air from mold is brought out by ventilation nozzles. Mold is heated to different temperature. From temperature depends
life time of mixture and some mechanical and visual parameters. Temperature of mold is one of the most important factors of molding process [5, 6, 7, 8, 9, 10, 11, 12].

For working with PDCPD material delivered from Apeiron Synthesis testing injections were performed using mixing in cointainers, then injection process was performed using special syringe. Pre-mixed material was injected by wires to mold until the moment of filling air vents. Than on mold was given to vibration process, to prevent from air gaps presence. After molding process mold is being heated for several hours. After cooling of the mold, injected parts could be draw from the mold.

The purpose of injecting elements was moldign two different parts necessary for molding car’s power steering body. These elements which molding process is described in this paper have to prevent liquid PDCPD from leaks and are responsible for positioning elements of worm gear, such as compensators and bearings of worm. Correct position of these elements is requied to receive correct position of worm and wormwheel axis, and to receive correct force of compression of worm axis elements. Correct position of this elements is requied to receive correct resistance torque of mechanism. If resistance torque and position of worm gear elements are in correct place, whole casting and manufacturing process can be recongised as succesfull [8,9, 10, 11, 12].

2. Preparation of molds for the injection process
Before proceeding with the injection molding, CAD models were prepared. After calculation and design stage was done, component elements were manufactured. During design and manufacturing stage all necessary elements, such as venting and injecting noozles, wiring and heating system were prepared. Elements were also equipped with necesary silicone gaskets, to prevent mold from leaks during molding process. Gaskets have to be heat and PDCPD resistant.
The next stage of preparations was to prepare all elements for the injection process. All elements were cleaned and covered with anti-adhesive substance (Loctice Freekote), so that the obtained element does not stick to the surface of the mold. Gaskets were then inserted in the appropriate places. Subsequently, all connections regions were additionally secured with a special silicone. This kind of gaskets guarantees pventing from leakages and the correct results of PDCPD injection, because the material PDCPD has a viscosity similar to that of water, so even the minimum discontinuities in gaskets can result in leaks. Then the molds were equipped with elements necessary to perform the injection process. Inlet pipes and vent pipes have been added. In figure 3, the venting tubes are marked with blue arrows and the injection tubes in red. The connection between the pipes and the mold surfaces has been sealed with silicone. Two venting and one injection pipe were used in the injection mold for the worm plugs, for receiving the appropriate shape of mold, while in the form for the worm sockets one venting and one inlet pipe were used. In figure 4, the venting tubes are marked with blue arrows and the injection tubes in red.

The prepared and sealed molds were postpone for up to 24 hours to cure the silicone.
3. Molding Process and results
After the preparation process, the injection molding process were performed, using the PDCPD material. In the first trials, the molds were not heated, in order to verify the injection process. Then, after the injection process, they were heated to about 70 [°C]. In subsequent iterations the molds were preheated to various temperatures and then re- transferred for several hours to be heated in a suitable heating device, in this case in a laboratory dryer.
The purpose of preheating the molds was to control the time of the polymerization reaction.
After the injection and pulling out the elements from the mold, they were subjected to visual and geometric analysis.

![Figure 5](image_url)

Figure 5. Element molded from PDCPD material, view from both sides.

After the first tests and the removal of the molds and their cleaning, it was found that the injection process was proven to be imperfect. Figure 5 shows numerous imperfections in relation to the intended shape. Numerous discolorations are visible, and the presence of air bubbles is visible. The blue color showed the remains of silicone, which partly mixed with the PDCPD material. The sealant filled in the mold parts causing no material (polymer) to be present in these places. The whit color is visible in places where the mixing of silicone with the PDCPD material occurred, which results in geometric and defects will effect strength of the elements.

The occurrence of silicone material on the joining part of two forms affects the strength of the element, by which the element was weakened in these places. In the place marked with a red arrow, i.e. in the place of positioning feather, there are also factions in which material losses occurred due to the mixing of PDCPD with silicone. While paying attention to the internal structure, could be noticed that the occurrence of numerous gas bubbles, which can significantly weaken the structure of the material. The occurrence of air bubbles inside the material structure may result in lack of its continuity, which may result in the lack of tightness of the element. This may result in a number of leaks during filling process of the entire body of the power steering’s body. It was found that air bubbles are a gas released as a result of the sudden polymerization reaction.
Experiments result in a large dependence of the occurrence of bubbles on the reaction speed, the temperature of the mold and the type of material used. In addition, numerous damage is evident on the surface indicating a non-simultaneous polymerization process. This results in the lack of a uniform surface and surface defects. Another element disqualifying the casting is the occurrence of a crack. It probably occurred due to material shrinkage. It completely disqualifies the element. It’s marked by blue arrow on figure 5.
After the first set of attempts, mold heating was applied. The molds were preheated to about 70 [°C]. Depending on the type of PDCPD polymer used and the time in which the compound was prepared until the injection, differences in the reaction were noted. After heating the mold, it was noticed that the reaction often occurs in direct contact with the heated mold walls. This results in huge problems in the injection process and the achievement of a sufficient quality element. However, when the temperature was reduced and the element was warmed immediately after the injection process, the correct parameters for injection process was achieved. The result is shown in figure 6. It was also decided to use the PDCPD material of which shelf life was shorter. This period was about 5 minutes. In the previous case it was up to twenty minutes.

There is a noticeable improvement in the quality of the external surfaces and the amount of air bubbles that occur. Nevertheless, they are still present and may be the reason for the leakage through the element. After the element leak test, no leaks were noticed, which allows to claim that few gas bubbles appear only in the internal structure of the element. Their number is also small. In figure 7, only a few can be observed. It should be noted that the retaining positioning feather were mapped to 100%. There were also practically no sealing silicone, it occurs only at the site of the infusion and venting. The geometrical form of the achieved element is satisfactory, it also has no cracks. The next step was to achieve a lack of gas bubbles in the element structure.

Further tests were carried out, in which the mold preheating temperature was changed to about 40 [°C], the same material (PDCPD from Apeiron Synthesis) was used as in the sample shown in figure 7. After injection, the mold was preheated at 120 [°C] for 10 hours. There was a significant improvement in the quality of external surfaces and the number of air bubbles presence. The quality of the surface has
been significantly improved, comparing to the previous stages, also no gas bubbles appeared in the material structure. In figure 7 could be seen, there are several places where there was a sealing silicone, this is a mistake that occurred during the assembly of the mold. As previous results showed, it can be eliminated. Surface quality, material structure and geometric form was high quality, which allows to determine the achievement of the correct element in the molding process using PDCPD.

Figure 8. Plug molded from PDCPD material.

The next stage was the use of PDCPD injection into the mold of the retaining plug. On the basis of the collected information and the parameters of the injection process, the preparation of the molds and the process was performed. The mold was preheated to a temperature of about 40 [°C], and then the material was injected to its interior. After the process was performed, the mold was placed in annealing at a temperature of about 120 [°C] for a period of 10 hours. The results of the test are visible in figure 8. A very good surface quality is visible, practically no bubbles appearing in the element structure. One spot has a discoloration due to the existing silicone, although like the previous case, it can be eliminated in subsequent iterations. The geometric form of the element is also satisfying, coincides with the assumed CAD model.

4. Conclusions
The obtained results of molding of components from the PDCPD material prove the correctness of the process. Appropriate change of the process parameters allowed to achieve satisfactory elements that are crucial in the injection molding process of the power steering system. Items with the correct material structure and the correct geometric form were obtained. The elements have sealed, leakproof, walls, protecting against leakage. These elements are characterized by sufficient stiffness to be able to determine the elements of the worm gear. The obtained results will be used in the subsequent stages of casting the body of the power steering system. The pre-developed PDCPD injection process will affect the next steps.

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