Composite materials molding simulation for purpose of automotive industry

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Abstract. Composite materials loom large increasingly important role in the overall industry. Composite material have a special role in the ever-evolving automotive industry. Every year the 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. The initial choice of method for producing composite bodies was the method of molding injection of composite material. Molding injection of polymeric materials is a widely known and used for many years, but the molding injection of composite materials is a relatively new issue, innovative, it is not very common and is characterized by different conditions, parameters and properties in relation to the classical method. Therefore, for the purpose of selecting the appropriate composite material for injection for the body of power steering system computer analysis using Siemens NX 10.0 environment, including Moldex 3d and EasyFill Advanced tool to simulate the injection of materials from the group of possible solutions were carried out. Analyses were carried out on a model of a modernized wheel case of power steering system. During analysis, input parameters, such as temperature, pressure injectors, temperature charts have been analysed. An important part of the analysis was to analyse the propagation of material inside the mold during injection, so that allowed to determine the shape formability and the existence of possible imperfections of shapes and locations air traps. A very important parameter received from computer analysis was to determine the occurrence of the shrinkage of the material, which significantly affects the behaviour of the assumed geometry of the tested component. It also allowed the prediction of existence of shrinkage of material during the process of modelling the shape of body. The next step was to analyse the numerical analysis results received from Siemens NX 10 and Moldex 3D EasyFlow Advanced environment. The process of injection were subjected to shape of prototype body of power steering. The material used in process of injection was similar to one of excepted material to be used in process of molding. Nextly, the results were analysed in purpose of geometry, where samples has aberrations in comparison to a given shape of mold. The samples were also analysed in terms of shrinkage. Research and results were described in detail in this paper.
1. Introduction

Composite materials loom large increasingly important role in the overall industry. Composite material has a special role in the ever-evolving automotive industry. Every year the 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 (aluminium) 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. [1, 2, 3, 4, 5]

![Figure 1.1. CAD Model of power steering’s body](image)

The object of the study was the redesigned body of the real power steering system, of which geometry has been adjusted in such a way that allow performing injection of the composite material. This shape has been simplified for all kinds of embossing, chamfers, bendings and similar geometric parts that could prevent high quality injection of composite material. In the geometrical model of body base surfaces were unaffected, because of their necessity in the positioning process during tests on test stands. Appropriate modifications of shape were made for improving the extraction of the injected body from the mold without causing breakage or damage of the produced element. The geometry was also changed in such a way to provide the appropriate thickness required to maintain the mechanical properties of produced element, in relation to the actual body’s shape, which is made of aluminum. In bodies of this type of power steering, gearing consisting of worm and worm wheel are mounted. The body also has suitable mounting locations for the electric motor for power steering. Despite the changes made to the basic model, body of power steering has full functionality, such as aluminum counterpart. [6, 7, 8, 9]

2. Model preparations for injection of composite material simulation

Firstly, the model was reviewed in terms of the possibility of extraction of shoted element after the molding process. The next step was to choose a proper material from which body could be shot. Because of their properties material LCP Ticona, marked C150 was selected. This material was selected due to its high content of a carbon fiber in a structure (of up to 50%) and sufficient strength parameters. The material has the following properties: density plastic (polymer) was 1.35 [g / cm$^3$], the Poisson's ratio equal to 0.3, and the Young's modulus equal to $E = 2e + 011$, which was ten times greater value than most other plastic materials. The carbon fiber had a density which was equal to 2.55 [g / cm$^3$], the Poisson's ratio equal to 0.2, and the Young's modulus equal to $E = 011 + 7e^{10}$. The
ratio of length to diameter of fibers (Whiskers) used as a reinforcement of the composite material is 20:1.

| Process condition          | Process condition |
|----------------------------|-------------------|
| Melt temperature (minimum) | 300 °C            |
| Melt temperature (normal)  | 320 °C            |
| Melt temperature (maximum) | 340 °C            |
| Mold temperature (minimum)| 100 °C            |
| Mold temperature (normal)  | 120 °C            |
| Mold temperature (maximum)| 140 °C            |
| Ejection temperature      | 240 °C            |
| Freeze temperature        | 250 °C            |

**Figure 2.1.** Temperature parameters of LCP C150 Ticona material

In the Siemens NX 10 software, and EasyFill Advanced module, the quality of the FEM mesh was set to maximum accuracy level, resulting in the highest possible accuracy of the calculations and the very long calculations - close to 24 [h]. Created finite element mesh, was containing up to 850.648 finite elements and 652.580 nodes connecting finite elements together. The volume of injected material was 539.7 [cm³]. The mass of injected material amounted 834.24 [g]. An aluminum body with the same geometrical form has a mass of 1463.80 [g] that gives 629.56 [g] gains in the advantage of the composite body.

Position of the injection nozzles were arranged to ensure spreading of the material from the left (side of mounting DC motor of power steering) to the right side. This solution let to yield targeted location of potential air traps in the zones with the lowest required shape accuracy, where there will not be assembled any elements of the power steering. This leaves the possibility of symmetrical injection of each nozzle, because of the most important geometrical accuracy of cylindrical surfaces, on which bearings for worm will be assembled. Anticipated problems with the quality of the injection may also occur in the place of sharp edges and a ring (flange) at the location where the worm wheel bearings will be assembled. Problematic could be also thin-walled components. Injection nozzles are shown in Figure 3.1. There are four points around the occurrence of red color.

In the software parameters of highest accuracy of calculations has been set. Total injection time has been set at 16.4 [s], followed by the process of packing, which lasted 22.1 [s], to compensate plastic shrinkage behavior.

The amount of shoted material was 99.9669 [%] of volume, because of complicated geometrical form of the flange in place, of the worm wheel bearings placement, which prevented the ideal dissolution of the composite material.

After the calculations were performed the results were analyzed. The results in the majority of cases are presented in graphical form. [2, 5, 6, 9]

3. Result analysis

The first analyzed result of the analysis was to analyze the time of material injection - Melt front Time. The result shown time that the material is in the mold from the beginning of the injection process. Analysis of the results of this type allows to check a number of basic information and allow to determine the correct injection and detect basic imperfections made during the simulation of injection composite material. An optimized Melt Front Time result should show balanced flow contribution of each gate and all flow path should reach the cavity wall at the same time. It is the most useful result in injection molding simulation. One of issues that could be interpreted from Melt Front Time analysis is hesitation. It is a condition where the flow slow down along a particular path significantly. It could cause so called short shot, when the material flows too slowly and eventually stops before it completely fills the cavity.

During the analysis of Melt Front Time, most of the results were consistent with the assumptions, material flow took place correctly. The only place where short shot occurred was the location of flange of bearings of wormwheel, which could be seen in Figure 3.1. This problem has resulted directly from the geometric form of modeled body. Dimensions of flange, with respect to the whole body were very
small, making difficulties for the material to penetrate and fill the described area. After the simulation of the injection were performed, the geometric form of the body were changed, what resulted in a modification of flange and resulted in 100% appropriate course of shot of material.

Injection were performed according to assumptions in which the material remained for the longest time since the beginning of the injection in the places were places which were least responsible for the strength and with lowest significance in terms of geometric accuracy. In these places there will also be mounted no significant elements of the power steering system.

Figure 3.1. Melt Front Time.

The next analysis concerned the occurrence of air traps. An air trap is formed by converging melt fronts, trapping a small bubble of air. Occurrence of this effect may occur at multiple locations inside the cavity. Air traps occurred at the location where melt front comes in all directions. An air trap occurs where the melt traps and compresses a bubble of air or gas between two or more converging flow fronts, or between the flow front and the cavity wall. Typically, the result is a small hole or a blemish on the surface of the part. In extreme cases, the compression increases the temperature to a level that causes the plastic to degrade or burn.

Air traps may be acceptable if they occur on a surface that does not have to be visually perfect, but when it occurs inside body will affect strength and durability of construction.

The occurrence of a large amount of air traps may suggest the presence of Short Shot and resulting of lack of material. The occurrence of the air traps in most cases coincides with the occurrence of Weld Lines, which were places where the material were incoming from different directions and from different nozzles (inlets) meet each other. Eliminating Air traps can take place by improving ventilation (adding vents), changes injection parameters, such as speed of injection or eventually change the location of the injection nozzles. In the case of the analysis of the composite body the majority of the Air traps result directly from the presence of Weld-lines. A significant amount of occurred air traps were in the area which was described previously, that confirms the occurrence of short shot. In the present case, air traps do not occur inside the volume of the body. This allows to claim that the strength of such construction will be as expected.
Another analysis was conducted for check occurrence of weld lines. In Figure 3.3 is shown a graphical analysis of the prevalence of Weld-lines with the enabled temperature of the material at the moment of contact of the weld lines. Temperature occurring on weld should not be lower than 20 [°C] of the temperature of the injection. Then weld is described as good, so allows claiming that despite of occurrence of weld lines their impact on the whole structure would be negligible. Weld lines should be omitted in areas where structural strength is most important.

In the case of the presence of the test body Weld lines is provided in such a way that their existence does not affect the strength of the structure. This was confirmed and shown in Figure 3.3. Also the temperature occurring on Weld lines is adequate, allowing confirm the accuracy of the injection.

In Figure 3.4 Weld lines Meeting angles were presented. This result shows the distribution of meeting angle of melt fronts on weld lines. Weld Line Meeting Angle is the angle between meeting two melt fronts, ranging from 0 to 135 degree, between two converging melt fronts. If the welding angle is 180 degree, then the two melt fronts can be considered as one. If the welding angle is 0 degree, then two melt fronts converge head-on. Generally, the smaller the meeting angle, the weaker the strength of the part becomes and the more obvious the weld line will be after the part is ejected.
For the particular case of the analysis incidence of Weld Lines Meeting Angle were placed in the most places with high values, which allows to claim that it would not have a significant effect on the strength of the element, especially that the previously discussed temperature performance of weld lines have appropriate values to determine the quality of the weld lines is good.

Volumetric shrinkage result showed on Figure 3.5 shows the distribution of part volume change percentage as the part is cooled from high temperature and high pressure to ambient temperature and ambient pressure. This calculation is based on PVT relationship for the plastic materials. Positive value represents volume shrinkage while negative value represents volume expansion. For an optimized condition, uniform volumetric shrinkage is desired.
The analyzed element showed a majority of the body were close to have the same shrinkage values, excluding the injection nozzles, at the location of the screws by which an electric, DC motor is mounted to the body. The values of occurring shrinkage were close to the maximum value of 3\%\%. These values allow claiming that the composite body of power steering has the uniform form. Result allows claiming that injection process ran correctly. In Figure 3.6 were shown the results of volumetric shrinkage after packing process, aimed to reduce shrinkage of the composite material. Archived values were significantly lower than before packing process, allowing predicting the final geometry of the injected element. This is necessary for parts or regions requiring high dimensional accuracy. Places of higher shrinkage values do not need to have perfect dimensional compatibility to basic model.

![Figure 3.6. Volumetric Shrinkage – after packing process.](image)

After analyzing the results previously obtained, analyzed was Moldability, which identify opportunities and quality of injection of composite material for a analyzed geometry. For the study, geometric form and shown places of injection nozzles and their parameters, Moldability was defined as GOOD at 99.6\%\%, as shown in Figure 3.6. The only places designated as LOW has been exactly the same place, for which the problems of injection have been described previously (the flange for bearings of wormwheel). Once again it endorsed the need for a change in the geometry in order to improve the quality of the injection. After making changes, quality issues should be removed.

![Figure 3.7. Moldability.](image)  ![Figure 3.8. Gate Contribution.](image)

Analysis was also performed to volume fraction of the material injected from each of the nozzles in the total injection process. Information obtained from this type of study allows to validate the initial settings of injection and their parameters. Maintaining a balanced share of each of the nozzles ensures
the quality of the injection, but in this case one of the nozzles had parameter of reduced flow set, to allow adequate, previously designed and described in detail the flow of composite material in the injection mold. The results confirm the initial assumptions. The amount of material injected by nozzle with the lowest flow is 12 [%] of total volume and for the subsequent nozzles were nearly 21, 30 and 37 [%]. This was shown in Figure 3.8. For considerations of composite materials very important element of the analysis is arrangement directions of the fibers and their distribution. During the analysis occurrence of a very negative phenomenon called over packing could be checked. It may provide the accumulation of significantly more fibers into a particular place in contrast to other places. It could provide incorrect injection, where injection is one place is early terminated than in other places, but occurrence of short shot effect is not appearing. In the case of injection of composite materials containing whiskers, in this case, carbon fiber, a direction of their arrangement is very important. By analyzing the direction of their arrangement strength of the shouted part could be predicted. In case of the analyzed composite body, the fibers are distributed asymmetrically and hetero-directionally, what could predict that the strength of this element will be similar in all directions of impact loads (Figure 3.9). Tendency for the arrangement of fibers in accordance with the movement of the material could be observed, but because of the complicated shape of the body material is mixed several times, resulting in non-uniform distribution of fiber direction. Fiber distribution is shown in Figure 3.9.

Another performed analysis is the study of Melt Front Temperature. This result shows the temperature values of the composite melt as it reaches the given point. By Melt Front Temperature the injection molding problems can be identified. In the present case, very uniform distribution Melt Front Time should be noticed. Only in places described previously, on a flange, where for worm wheel were mounted, provide Melt Front Temperature difference, by nearly 20 [°C] less than the maximum and the assumed temperature. The occurrence of different places with lower temperature were shown at Figure 3.10, although it is significantly lower, up to 15 [°C] in relation to the base temperature. These areas coincide with the locations of Weld Lines and Weld Lines Temperatures. The areas with lower temperatures values, should not affect the strength of the element, because of continuity within normal limits.
4. Final conclusions
By analysis of the injection it is possible to simulate a virtual simulation giving information about the process of shot. Constructor has the ability to draw conclusions from the study and predict the outcome of the injection molding process. Based on the analysis, the results providing information on the need for a change in the geometry of the current model of the body. In addition, obtained information about the correctness of the analyzed injection simulation, allows to perform the following actions to create the actual mold and to carry out the actual injection of composite material. The results are satisfactory consistent with those what was planned. Also receiving a real-composite body will confirm the validity of the analyzes, while the verification of the correctness of simulation parameters.

5. 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.

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