PARTICLE-FOAM COMPOSITE INJECTION MOLDING

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Abstract

In the Particle-foam Composite Injection Molding (PCIM) process a compact material is injection molded onto foam. PCIM parts combine the positive properties of both material types, compact materials and particle foam in one part. This means it is possible to manufacture parts with thermal insulation properties, force absorbing properties, a high degree of stiffness and attached elements like snap-fits and screw fittings for example. The University of Applied Sciences Osnabrueck examines the adhesion properties between these components. This results in a mechanical characterization of PCIM parts, which will allow dimensioning of these composites in the development phase of PCIM products. The project is supported by the Federal Ministry of Education and Research (BMBF) and the companies Arburg, Krallmann and Ruch Novaplast are project partners.

Introduction

Particle foam has very good properties in terms of thermal insulation. In addition, the density of particle foam is very low, which makes it interesting for lightweight construction. It can also absorb forces very well. Unfortunately, particle foam has a few very big disadvantages. A major drawback is the limited mounting possibility. This disadvantage is avoided by combining particle foam and compact material. In the PCIM process, the positive properties of both materials are combined [1].

Previously, it was only possible to attach these two materials through the use of adhesives or the already known process backfoaming. However, the backfoaming process does not allow to manufacture parts with properties as good as properties of PCIM parts. The new process enables the user to attach compact materials such as PP (polypropylene), PA (polyamide) and TPE (thermoplastic elastomers) to particle foams such as EPP (expanded polypropylene), EPS (expanded polystyrene) and various particle foam compounds. The resulting composite parts combine the particular features of both types of material in a single injection molded part. Additionally, the particle foam and the compact material are permanently associated like a welded connection. These features open up completely new fields of application, for example in the automotive and aircraft industry and in industries in which lightweight and insulating materials are of great importance [2].

The mechanical properties of parts produced with PCIM are still largely unexplored. This applies particularly to the adhesion between the particle foam and the compact material. Therefore, the University of Applied Sciences Osnabrueck investigates mechanical properties and the influence of particle foam on the possible flow paths.

The Process and Challenges of PCIM

In case of Particle-foam Composite Injection Molding, compact material is injection molded onto particle foam (Figure 1). The blank foam part is located as an insert in the cavity during the process. The injected hot polymer melts the surface of the particle foam and this results in a welded connection between both components. This integral connection makes it possible to produce a non-detachable, high strength, dust-tight and liquid-tight connection.

Usually injection molded parts are manufactured using high pressures. Especially these high pressures can damage the particle foam significantly. This can cause collapsing of the foam and a rough topography of the joining zone. A basic requirement of investigating the mechanical properties is a defined and reproducible connection between both components. This is precisely the challenge for PCIM. In order to achieve a defined joining zone, there should, at best, be no collapsing of individual particles in the joining zone. The process differs fundamentally from conventional injection molding with regard to the process parameters. In particular, the pressures in the conventional injection molding process are not permissible for the PCIM process. Besides the mechanical characterization of the joining zone, it is also of great importance to characterize the influence of each process parameter in terms of mechanical properties and the reproducibility of the joining zone. Apart from this, the investigation of the joining zone in relation to process parameters can help to generate guidelines for manufacturing PCIM parts.

The companies Arburg, Krallmann and Ruch Novaplast have demonstrated that PCIM processes, which are already fully automated, can be realized and a stable production process can be ensured with the K-Fix element (Figure 2), which is already on the market. The K-Fix element is used as a cable connector in climate housings [3].
Advantages of PCIM

In recent years, the technical properties of particle foam have been improved. Thus, the foam opened up new possibilities and with it new problems arose. It is possible to manufacture foam parts with extremely high surface qualities and good mechanical properties but the foam is very difficult to attach to other components. Particle-foam Composite Injection Molding provides the solution for all the problems of each single component, the compact materials like PP as well as the particle foam like EPP. In PCIM the advantages of particle foam and compact material are combined. Components produced by this process have low density, insulation properties and good assembly possibilities. Due to the high proportion of particle foam a weight reduction is achieved. In addition, the foam has force-absorbing properties. With the inserted compact material, functional elements, such as snap-fits, can be attached. Combining the positive features of both material types provides a wide range of application possibilities. A possible application example for this technique could be a door interior panel with integrated mounting opportunities. In this case the door interior panel is a weight-reduced, noise-cancelling and force-absorbing component which provides diverse, easy and fast options to attach this component to the car body [4].

Injection Molding of Test Specimens

Because there are currently no mechanical properties available and PCIM parts have not yet been investigated in any way, various test specimens have been developed. To define the mechanical properties of the joining zone, such as tensile strength, shear strength and peel strength separately, the development process of test specimens plays a key role. A comprehensive investigation of the mechanical properties is to be carried out using tensile test specimens, shear test specimens and peel test specimens (Figure 3, Figure 4, Figure 5). The aim is to obtain important information for the characterization of PCIM components.

To determine the characteristic values, the test specimens are subjected to static short-term tests. Dynamic and static long-term tests are designed to simulate realistic stress situations. In addition, information on the service life of PCIM components is to be determined. Furthermore, the aging can be assessed with dynamic stress on the PCIM components. The influence of aging on the characteristic values of the composite can be determined. To investigate the long-term properties of the test specimens a testing machine has been developed. As an essential parameter of the tests mentioned, the temperature is varied.

The tensile test specimen (Figure 3) is mainly used to determine the tensile properties of PCIM parts. In the examination, both the hollow cylinder and the particle foam are clamped in a universal testing machine to apply forces into the joining zone until failure occurs.

The shear test specimen (Figure 4) is used to determine the shearing properties of PCIM parts. In this case, the hollow cylinder is loaded with tensile stress while the particle foam is fixed in its position. This results in shearing of the joining zone.
The peel test specimen (Figure 5) is used to determine the properties of peeled joining zones. Thermoplastic elastomers of different types are injection molded onto particle foam during the production of these test specimens. The resulting flexible flap can be peeled off the particle foam perpendicularly to the joining zone to obtain the mechanical properties.

To manufacture these test specimens a PCIM mold has been developed. All specimens can be manufactured with this injection mold by using insert-elements. By replacing the insert-elements of the injection mold it is possible to change the cavity fast and easily. Especially the gating position and defined cooling is of great importance to ensure a properly working PCIM process. The direction in which the melt should flow into the cavity is also of decisive importance for the quality of the joining zone. The melt should ideally flow parallel to the surface to avoid collapsing of particles. Moreover, the joining zone of compact material and particle foam should be located at the end of the flow path. This keeps the stress on the particle foam as low as possible. Especially the thermal insulating property of particle foam is a reason why the cooling of the mold is very important for the process.

Investigations on Test Specimens

Mechanical investigations on PCIM parts provide information about how well these two materials build up a connection. Furthermore, it can provide information about the influence of process parameters on the mechanical properties. The adhesion between particle foam and compact material depends on the compatibility between the used polymers and on the process parameters.

To investigate the influence of density of the particle foam on the mechanical properties of the PCIM parts, first studies have been made on the tensile test specimens (Figure 3). The following figure shows a comparison between PCIM parts produced with high and low density particle foam components (EPP) and polypropylene. It shows a significant increase in average of maximum tensile stress by increasing the density of the particle foam parts from 60 kg/m$^3$ up to 100 kg/m$^3$. The maximum tensile stress of tensile test specimens with higher density particle foam achieved values of about 1.46 MPa. In comparison, the test specimens with lower density achieved values of about 0.83 MPa. The maximum change in length until failure occurs reached values up to 4.8 mm for the high density EPP and 3.6 mm for the lower density EPP (Figure 6).

To compare the mechanical properties of test specimens depending on the used type of compact material, further investigations have been made. Figure 7 shows the maximum tensile stress of tensile test specimens in average. The test specimens were produced with particle foam density of 60 kg/m$^3$ combined with unfilled polypropylene, 20% mineral filled polypropylene, 20% glass fiber reinforced polypropylene and unfilled polyamide. The reinforced and the mineral filled polypropylene reach tensile stresses of about 0.94 MPa or rather 0.97 MPa. Due to the lower processing temperature of unfilled polypropylene the adhesion between both
components is not as good as the adhesion between the mineral filled and the reinforced polypropylene (0.83 MPa). The limited compatibility between polyamide and EPP causes worse maximum tensile stress of about 0.58 MPa. Furthermore, the higher melting point of polyamide can increase the number of collapsed particles in the joining zone.

![Figure 7. Tensile stress of PCIM parts with different compact materials](image)

Figure 7. Tensile stress of PCIM parts with different compact materials

Figure 8 shows the average of maximum tensile stresses and standard deviations. The figure points out that it is possible to manufacture parts with reproducible mechanical properties and that is a basic requirement for the use of PCIM parts in different future applications.

![Figure 8. Tensile stress of PCIM parts with different compact materials](image)

Figure 8. Tensile stress of PCIM parts with different compact materials

After failure occurs, microscopic analysis of the joining zone has shown that the properties of the joining zone between filled PP and EPP are at least as good as the properties of the particle foam itself. In this case failure occurs in the particle foam component rather than in the joining zone between both components. In contrast, the adhesion properties of unfilled PA and EPP are worse. Figure 9 shows adhering particles on the surface of glass fiber reinforced polypropylene (left) and only a few adhering particles on the surface of polyamide (right).

![Figure 9. Adhering particles on PP-GF20 (left) and unfilled PA (right) after failure](image)

Figure 9. Adhering particles on PP-GF20 (left) and unfilled PA (right) after failure

To visualize a completely unstressed joining zone and to characterize its structure, classical microscopy is insufficient. Computer tomography represents a possibility to do exactly this. Figure 10 visualizes the joining zone of the already mentioned K-Fix element. Basically, the darker the color of the visualized area is, the lower is the density of the material. As a result of pressure and temperature individual foam particles collapsed during processing. This creates a rough topography of the joining zone. Especially the lighter colored areas in the joining zone indicate the welding of both components. The CT image was taken at the Institute of Plastics Processing at RWTH Aachen University.

![Figure 10. CT image of K-Fix element](image)

Figure 10. CT image of K-Fix element

The definition of the limits in PCIM processes, in terms of flow paths, is very important for the further use and the future of this new process. Especially in the automotive sector long flow paths are essential to replace already existing materials. A flow spiral is used to assess the influence of the particle foam on the possible flow paths of the melt. In this case the compact material flow spiral is directly injection molded onto the particle foam surface. Due to the thermal insulating properties and its rough surface the particle foam influences the possible flow paths both ways. This means that it can increase or decrease the flow paths. Furthermore, the possible flow path depends to a large extent on the compact polymer
used, its viscosity and fillers. In terms of flow paths the used particle foam material and its properties are also very important.

**Conclusion**

PCIM is a new process in which the positive properties of compact materials like PP, PA and TPE are combined with the properties of particle foams such as EPP and EPS. It is possible to manufacture parts with thermal insulation properties, force-absorbing properties, a high degree of stiffness and attached elements like snap-fits, for example. Particularly in the fields of automotive, aircraft and insulation industries, PCIM offers great potential. For example, as interior parts in the automotive sector. In this case, the interior parts combine properties like low weight, force-absorption and insulation. Moreover, it is possible to attach these parts fast and easily to the car body by using snap-fits. In the context of the project, it is necessary to characterize the properties and define the limits of the process in order to enter new fields of application.

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**References**


