One-step Production of Superhydrophobic Surfaces Using Laser-based Variothermal Injection Moulding

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Abstract

A new process for the production of water-repellent surfaces by injection moulding makes targeted use of the stretching of microstructures in the demoulding process. The microstructures themselves are shaped in a variothermal injection moulding process. Measurements show that the surfaces have contact angles of up to 165° towards water. The process is capable of producing superhydrophobic plastics surfaces in a single process step.

1 Introduction

Plastics products with functional surfaces offer a great potential for use in biotechnology and medical technology, as well as in packaging. An outstanding example are unwettable, self-cleaning surface structures similar to those known from lotus flowers. The surface modification of existing products by means of etching, painting, coating processes or plasma treatment, is usually very complicated and expensive. A new approach is the development of a process technology for producing unwettable structured surfaces directly in the injection moulding process, without using additives or material combinations. For the direct and precise replication of such microstructures by injection moulding, elevated mould temperatures are required. In this study, a new way of mould heating was developed, using diode laser irradiation to heat the mould cavity surface. The mould is held at a constant temperature using water temperature control to guarantee a demoulding of the part free of damage, while selected parts of the cavity are heated up quickly before the injection of the polymer. An array of cone-shaped dimples was previously generated on the mould surface by ultra-short pulse laser ablation. This structure was designed following the surface structure known from the leaf of the lotus flower. The system is used for moulding experiments which aim for the fabrication of surfaces with superhydrophic properties. As material, polyethylene and polypropylene were used due to their general hydrophobic behaviour. To analyse the moulding quality of the micro structures, scanning electron microscopy is used. The degree of hydrophobicity is determined by contact angle measurements.

2 Experimental Setup

2.1 Injection mould with microstructured mould insert

A special injection mould has been designed that allows to rapidly heat-up the cavity surface by diode laser irradiation. For this purpose, a laser collimation optics is mounted in the moving half of the mould behind the cavity. From the collimation optics, the laser beam is guided through a transparent mould insert made of quartz glass, which is part of the cavity surface. After passing the cavity, the laser beam is absorbed on the opposite side. At this position, a micro structured mould insert is mounted. The mould insert was produced at the Fraunhofer Institute of Laser Technology (ILT), Aachen, Germany. It has a diameter of 70 mm and is made of unhardened tool steel. The functional surfaces are finished by fine grinding. Conical depressions with six different dimensions were introduced into the cavity surface of the mould insert by ultra short pulse laser ablation. The basic diameter of the cones is 10 µm and 20 µm, the depth of the cones varies between 5, 10 and 15 µm. The distance between the cones is 1.5 times the basic diameter.

2.2 Laser-based variothermal process control

For reproducible and steady state thermal conditions during the process, an interface between the laser control system and the injection moulding machine is designed. The system allows integrating the laser heating period of the cavity wall seamlessly into the injection moulding process. At the beginning of the process, the injection moulding machine gives a signal to the control unit, which subsequently gives clearance to the laser system to start the pyrometer-controlled heating period. When the pre-set surface temperature is reached, the laser sends a signal to the control unit, which passes a signal to the injection moulding machine to start the injection of the material. After the holding pressure and cooling time the mould opens, the part is being ejected, and the cycle starts over again. This operation in automatic mode ensures steady state thermal conditions in the injection mould.

3 Results

Figure 1 shows scanning electron microscopy (SEM) pictures of polypropylenes surfaces created using the microstructured mould insert in a conventional and a variothermal injection moulding process. It can be seen that the cavity structures, which have the shape of a cone, were not filled completely during the conventional moulding process. This can be explained by the rapid increase in viscosity as the hot material enters the relatively cold mould. This is illustrated on the left side of Figure 2. As it is shown on the left side of Figure 1, the structure can be demoulded without deformation. The surface which is created using the same mould insert in combination with variothermal process control is shown on the right side of Figure 1. It can be seen, that a unique surface structure was created which does certainly not mirror the structure of the mould insert.

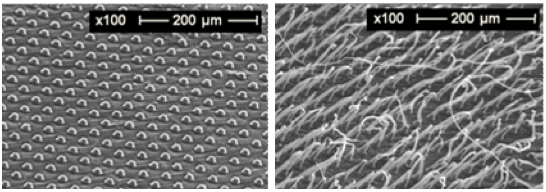

Figure 1: Surfaces created by conventional (left) and variothermal (right) injection moulding

To understand the formation of this special topography, the demoulding process of the part has to be taken into consideration. Undercuts caused by a sub-structure in the nm-scale on the surface of the microstructures lead to an increase of the demoulding force, as the material has filled out these undercuts in the variothermal moulding process (Figure 3, left). This force subsequently induces a stretching and a transversal con-traction of the cones (Figure 3, right). A ductile material behaviour of the polymer that allows the stretching of the cones is required. With a brittle material, the

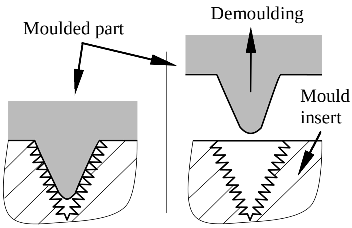

Figure 2: Moulding (left) and de-moulding (right) using conventional temperature control

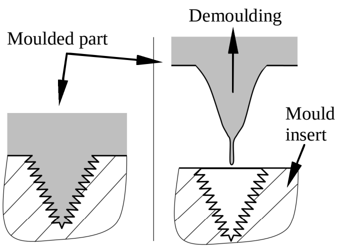

Figure 3: Moulding (left) and de-moulding (right) using variothermal temperature control

structures would break and lead to a clogging of mould insert. To quantify the hydrophobic properties of the moulded surfaces, contact angle measurements were performed. When a droplet of water is placed on a surface, the contact angle describes the angle of the tangent at the phase boundary between the solid surface, the liquid droplet and the gaseous environment. In general, a contact angle larger than 90° means that a surface is hydrophobic, whereas surfaces with a contact angle larger than 150° are called super-hydrophobic [1]. The surface shown in Figure 1 (left) has a contact angle of 130°, which is already higher than the contact angle of 100° measured on a totally flat surface made of the same polypropylene material. However, the surface shown in Figure 1 (right) exhibits a contact angle of 165°, which means that this surface shows excellent superhydrophobic behaviour.

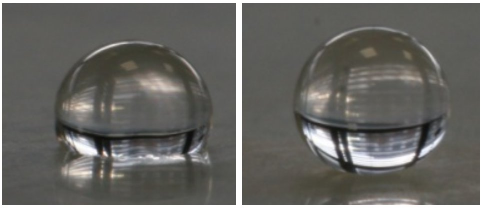

Figure 4: Water droplet on surfaces created by conventional (left) and variothermal (right) injection moulding

4 Conclusion

Superhydrophobic plastics surface can be produced in one single process step. Key factors are a microstructured mould insert superimposed with a nanostructure, a ductile polymer material and a variothermal injection moulding process. The functionality is obtained not only by the precise moulding of the structures, but also by the stretching of the individual microstructures during demoulding.

Acknowledgments

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Reference:

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