Glass coating to prevent adhesion

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Abstract

The structuring of glass in hot forming processes is accompanied by massive problems during the separation of mould and glass after the embossing process. Achieving a geometrically accurate transfer of the structure in the lowest possible embossing time requires a replication at low viscosities and isothermal annealing. Especially at high temperatures, this leads to increased adhesion and sticking effects. Tool coatings improve the long-term stability of the mould but do not prevent the glass from sticking. The conditions which cause the glass to stick to the mould were subject of numerous studies, partially with conflicting results, and hence are not completely understood. It is, however, only generally accepted that the glass viscosity has the strongest effect on the sticking behaviour, inhibiting hot embossing at low viscosities.

In contrast to other studies, a new coating strategy was developed to decouple the viscosity in the glass volume from the sticking behaviour at the glass surface. Instead of the mould the glass substrate was coated with a thin, adhesive and ductile layer. The subject of the presented research activities was optimizing the layer thickness for reaching a maximum ductility and a minimum adhesion of the glass substrate to the tool. The aim was to find suitable layer systems with an optimal coating for applications in micro-optics and micro-fluidics. In addition, the influence of the coatings on the function of the embossed components was investigated.

1 Research Background

As shown in the state-of-the-art field of glass embossing technology, glass composition has little influence on adhesion and sticking of the glass to the tool surface in the embossing process. The aim of recent research was to achieve a decoupling of viscosity and sticking by coating the forming tools. However, this method proved to be less successful and satisfying results could only be achieved when conventional moulding was used. For this reason glass coatings were investigated in order to avoid adhesion and sticking [1]. This research analysed the effect of amorphous carbon layers, metallic chromium- and gold coatings as well as on thin layers made of ceramic titanium oxide, silicon oxide and zirconium oxide (see Table 1).

Table1: Reviewed coatings in research

System	**Coating Material**	**Formula**	**Coating Process**	**Coating Thickness**
metallic	gold	Au	PVD	10 nm – 50 nm
	chrome	Cr	APCVD	10 nm – 50 nm
amorphous	carbon	C	PVD	50 nm
oxidic	Pyrosil®	SiO_x	CCVD	20 nm – 70 nm
	silicon dioxide	SiO_2	SolGel	40 nm – 100 nm
	titanium dioxide	TiO_2	SolGel	40 nm – 100 nm
	zirconium oxide	ZrO_x	PVD	6 nm – 36 nm

2 Effect of the Glass Coating

By coating of the glass substrates, a shift of the critical sticking tendency of all investigated coatings has been recorded close to the softening point of the glass. Furthermore it could be observed that adhesive forces were minimized for less than 90 % in comparison to the uncoated substrate. Figure 1 summarizes the investigation results of the coating influence on the adhesive forces during demoulding. In addition, it illustrates that the sticking temperature shifts to ranges outside of the typical embossing conditions above the softening point of the glass.

	Soda-lime float uncoated	Borofloat uncoated	Soda-lime float **coated**	Borofloat **coated**
sticking viscosity	$10^{8,5}$ dPas	$10^{9,2}$ dPas	$\geq 10^{7,7}$ dPas	$\geq 10^{7,9}$ dPas
sticking temperature	680 °C	720 °C	≥720 °C	>800 °C
mean adhesive force (at temp.)	27 N (670 °C)	34 N (700 °C)	0..2 N (70 °C)	0..6 N (800 °C)

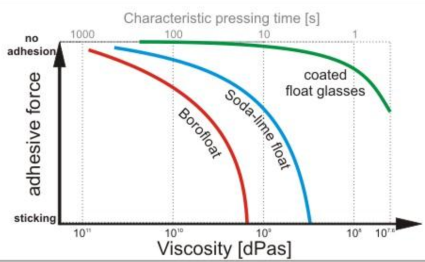

Figure 1: Effect of the glass coating on sticking and adhesive forces in hot embossing

For the sake of comparison, isothermal glass pressing tests were carried out under atmospheric conditions in order to investigate the effectiveness of the glass coatings in the presence of atmospheric oxygen [2]. This has shown that the oxidic coatings achieve a comparable effect under atmospheric conditions – though arguably less effective – to the effect in hot embossing.

3 Optimization of the Coating

In order to implement the glass coating in hot embossing of micro-structures for sensor components it is necessary to find the optimum coating thickness combining the maximum ductility and minimum adhesion. Hot embossing tests were conducted using an embossing tool for micro-fluidic channels. This tool realizes multiple deformation steps of the coating. At the same time the glass coating thickness was varied.

The tests confirm the assumption that the coatings on the glass substrate are more ductile as they become thinner. However, the low adhesion effect needs to be ensured as well. When using the CCVD method for SiO_2 coating, completely dense coatings are only achieved starting with a coating thickness of at least 20 nm. For this reason, it is inappropriate to further reduce the coating thickness. Glass samples coated with 6 nm zirconium dioxide were initially investigated. Adhesive strengths in the range of the uncoated glass samples were measured during this process. Under the same hot embossing conditions as above, the adhesive strengths of the coated samples (6 nm ZrO2) amounted to approximately 25 % of those of uncoated reference samples. Thus, low adhesion was evidenced but not as effective as with coatings of 20 nm to 30 nm.

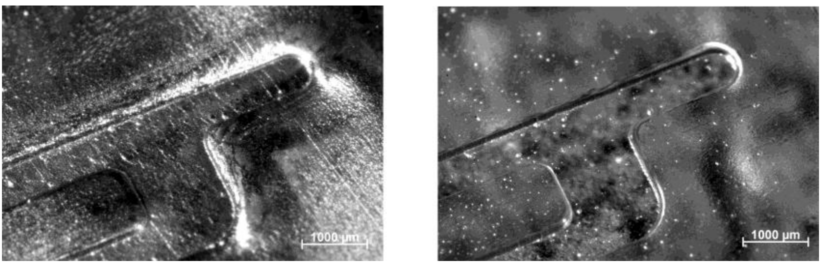

Figure 2: Detail of a micro-fluidic structure, hot embossed with different process parameters (left: with carbon coating; right: coating removed)

In order to examine the changes of the coatings at the edges of the structure and along steep flanks, micro-fluidic structures were investigated with regard to their embossability (Figure 2). For this investigation, silicon-carbide forming tool inserts structured by laser ablation were utilised for hot embossing.

4 Discussion

The results show that tool coatings cannot improve the precision of micro-structuring of glass by hot embossing, even though coatings improve the wear behaviour of tools in conventional glass forming.

In contrast, glass coatings enable hot embossing at high shear rates and low viscosities. This has a positive influence on accuracy and process reliability. Furthermore, undesirable residual stresses in the glass are reduced during embossing. It was found that metallic and oxidic coatings as well as carbon coatings are suitable in order to reduce adhesion and sticking tendency of the glass to the tool. The optimal range of coating thickness lies between 20 nm and 30 nm. The preferred type of coating depends on the specific application. Oxidic coatings which are specifically glass-like suit optical and fluidic applications as long as no residue removal is required after hot embossing; however they are a bit less ductil. Carbon coatings can very easily be removed by oxidation. Metal coatings can be applied for additional functions. Even combinations of metallic and oxidic coatings are possible and of functional advantage. The new coating strategy enables glasses with a high adhesion tendency to be structured and expands the range of applicable tool materials. Thus hot embossing of coated glasses enables embossing of complex geometries in order to achieve large-scale micro-structuring of inorganic glasses.

References:

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