# Investigations on the tool wear in precision glass molding

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**Abstract**

Precision glass molding is an efficient technology for the production of complex optical glass lenses such as diffractive optical elements, aspheric lenses, freeform lenses or lens arrays in medium and large quantities. Similar to other technical components in replication processes, molding tools are subjected to wear, especially because the process of precision glass molding takes place at high temperatures (400°C - 700°C) and under high forces (2 kN -10 kN). The life time of one molding tool determines the number of lenses that can be made and therewith the price of the finished optical components. In order to prevent the wear and for searching for new less expensive coatings for protection of the surface of the molding tools in the process there is a demand for understanding the cause of wear. In this study heating and molding tests were carried out to investigate the wear mechanisms of the molding tools in precision glass molding. Diffusion, which affected the life time of molding tools, was observed.

## 1 Introduction

In order to increase the life time, the molding tools, usually made of tungsten carbide (WC), are coated. Nonetheless the molding tools wear out after a period of time depending on the glass type that is pressed. The most common form of wear in precision glass molding is increased roughness of the mold surface and glass sticking. To gain a better understanding of the wear mechanisms, used molding tools were analyzed using electron probe micro-analyzer (EPMA). Furthermore a goal of this study is also to find a test method for qualifying the suitability of the coatings for precision glass molding in combination with a specific type of glass.

## 2 Experimental details

Three types of coatings ($ZrO_2$, TiAlN and PtIr) were examined. $ZrO_2$ ceramic has been reported to have low adhesion to glass melt [1]. TiAlN is a common anti-wear layer. PtIr is the most widely used protective coating for the glass molding tools [2]. PtIr and TiAlN were deposited in a PVD process on binderless and fine-grained WC substrates. The sol-gel $ZrO_2$ coating was applied in a spin coating process on X42Cr13 steel. Tungsten carbide can not be used as a substrate for sol-gel $ZrO_2$ coatings because of its susceptibility to corrosion during the heat treatment at 600°C in the coating process [3]. In this study, Schott glass of type N-FK5 was used. N-FK5 consists of comparatively few elements (Si, K, B, F, O) compared to many other glass types, which simplifies the analysis. Furthermore, it is known as a glass type which causes rapid tool wear. The chemical composition of the surface of the coating in the glass contact area was analysed by EPMA. The diffusion of glass elements in the coating was investigated by EPMA along a calotte in the coating.

## 3 Investigations

Heating tests were carried out also to verify this test method for qualifying the coatings for precision glass molding. In the heating tests $ZrO_2$-, PtIr- and TiAlN-coated tools were heated in contact with N-FK5 glass for 12 h at 600°C in vacuum. This simulates the thermal load on the molding tools during multiple glass molding processes. The glass contact area was analyzed by EPMA.

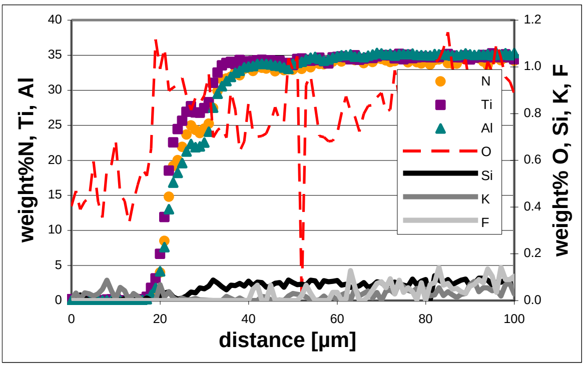


Figure 1: EPMA along the calotte from substrate (left side) to the coating (right side) in TiAlN after heating test with N-FK5 glass

The glass contact area could only be observed visually on $ZrO_2$ sample. On $ZrO_2$ the diffusion of the glass elements fluorine (F) and potassium (K) was detected. In TiAlN the diffusion of the glass element silicon (Si) in the coating was detected, as shown in Figure 1, although no visual change on the surface was observed. In the diagram, a decrease of the glass element concentration along the calotte with the decrease in the concentration of the coating elements means the presence of glass elements in the depth of the calotte and thus within the coating. The diffusion of the glass elements K and F can not be proven with certainty, but these elements are detected on the surface. On the PtIr coating, no glass elements were detected.

In order to verify that the results of this test method correlate to the lifetime during glass molding, molding tests were performed for the coating with the worst ($ZrO_2$) and best (PtIr) behaviour according to the previous test. N-FK5 glass blanks were molded at 580°C, until a visible change in the surface of the molding tool occurred, which was after 6 molding tests for the $ZrO_2$ and after 29 molding tests for the PtIr-coated tools. After the test, the molding tools were examined by EPMA.

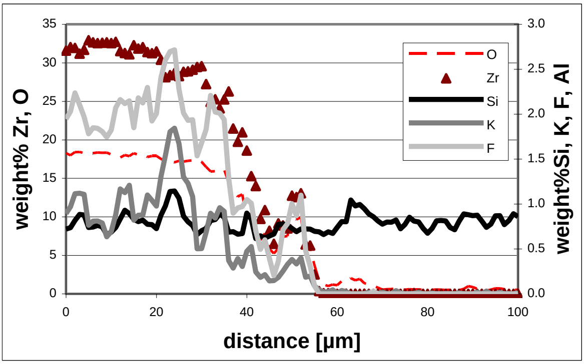


Figure 2: EPMA along the calotte in $ZrO_2$ from coating (left side) to the substrate (right side) after molding of N-FK5 glass

On $ZrO_2$ coating F and K were measured not only on the surface but also in the depth of the coating, as seen in Figure 2. However, the Si in the $ZrO_2$ layer can not be clearly linked to the diffusion of Si from glass, because the $ZrO_2$ coating was applied on the silicon containing X42Cr13 steel. So Si in the coating may also be from the substrate material.

In PtIr coating the diffusion of the glass elements Si and K was measured. In addition to the diffusion, the glass component $K_2O$ on PtIr was detected on glass contact area, as shown in Figure 3.

The results of the molding tests with PtIr (29 molding tests until visual change) and $ZrO_2$ (6 molding tests until visual change) correlate with the heating tests (no glass elements on PtIr, diffusion of the glass elements in the $ZrO_2$). Therefore heating tests can be used for qualifying the suitability of the coatings for precision glass molding.

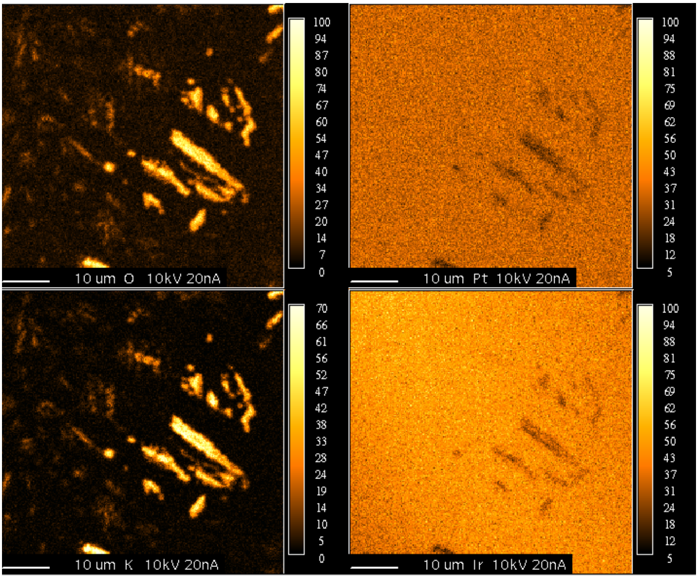


Figure 3: EPMA of $K_2O$ on PtIr coating after molding of N-FK5

**References:**

[1] A. Mehner et. al., "Sol-gel coatings for high precision optical molds", Annals of the CIRP Vol. 55/1/2006

[2] F. Klocke et. al., "Comparison of nitride and noble metal coatings for precision glass molding tools", Key Engineering Materials Vol. 438 (2010) pp 9-16.

[3] SFB/TR4 report, 2008