Predicting replication and planarity of a CO_2 gas sensor

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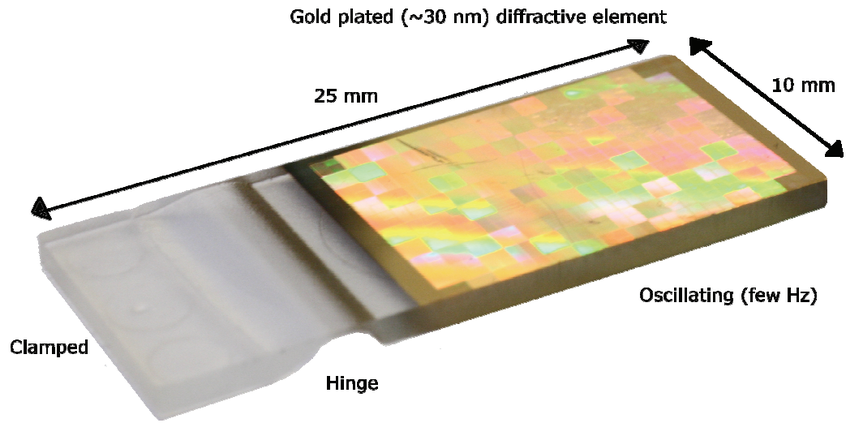
Introduction

CO_2 concentration, an important indicator for indoor air quality, can be accurately measured using IR spectroscopy. This is implemented in a robust and cost-effective way with the sensor in this study, based on a diffractive optical element (DOE).

The sensor, for ventilation-on-demand applications, is developed and commercialised by the Norwegian company OptoSense (www.optosense.com).

The reflective DOE oscillates at 2 Hz with 2° deflections, scanning three selected IR absorption bands per cycle. The oscillation is driven in the same way as a loudspeaker.



Main objectives

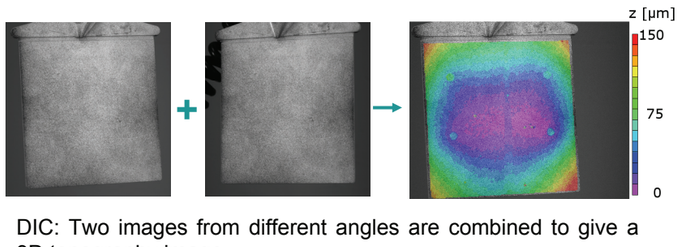
- Good replication of the diffractive grating
- High planarity of surface with diffractive grating
- No fatigue in the hinge throughout product lifetime

Experimental

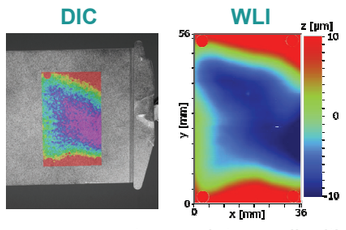
- Mould insert made using e-beam lithography followed by nickel electroplating
- Injection moulding on a Battenfeld EM 50/120
- Main material: Lexan OQ 1026, a DVD grade polycarbonate
- Surface characterisation: AFM, white light interferometry, 3D digital image correlation
- Fatigue testing

Measuring curvature using digital image correlation (DIC)

- Two cameras shoot the sample from different angles
- Sample prepared with speckle pattern (white spray paint + dash of black)
- Software (Vic-3D from LIMESS) calculates the surface topography
- Resolution *(x,y,z)* ~ 5 µm



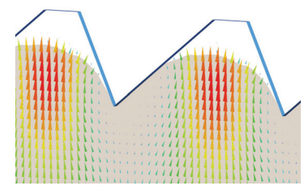
DIC: Two images from different angles are combined to give a 3D topography image



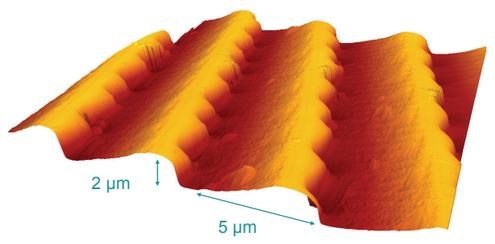
DIC measurements correlates well with white light interferometry (collage of ~100 images).

Replication of optical grating

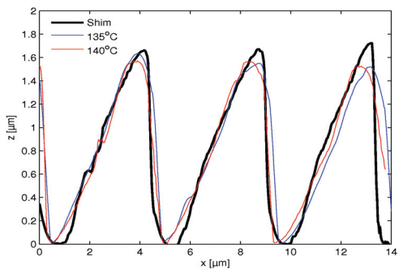
- Good replication achieved
  - High mould temperature
  - High injection speed
- Simulations are performed in two steps
  - Filling of main geometry in Moldflow
  - Microscale simulation using Ansys CFX
  - One way pressure / temperature coupling
  - Simulations show complete replication



Microscale filling simulations, performed using pressure from a macroscopic simulation.



Topography of moulded DOE measured with AFM.



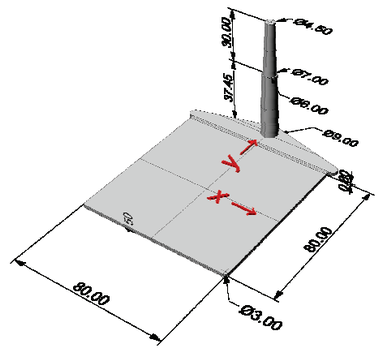
Cross section on shim and moulded parts measured with AFM.

Planarity study

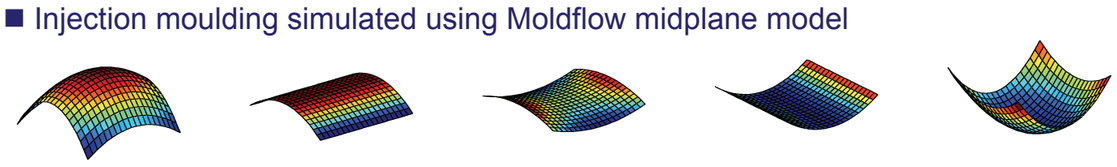
Procedure

- Flat plates injection moulded to investigate how processing settings affects curvature
- The curvature on both sides measured with 3D DIC
- Surface topography fitted to a polynomial on the form

$$z = \tfrac{1}{2} c_{xx} x^2 + \tfrac{1}{2} c_{yy} y^2 + d, \qquad x^2 + y^2 < (25\ \text{mm})^2$$



- Three experimental parallels for each setting
- Injection moulding simulated using Moldflow midplane model

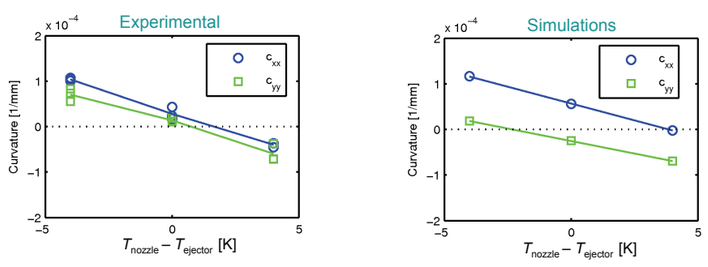


$c_{xx} > 0,\ c_{yy} > 0$ | $c_{xx} = 0,\ c_{yy} > 0$ | $c_{xx} < 0,\ c_{yy} > 0$ | $c_{xx} < 0,\ c_{yy} = 0$ | $c_{xx} < 0,\ c_{yy} < 0$

The ideal shapes described by the polynomial with given coefficients.

Results

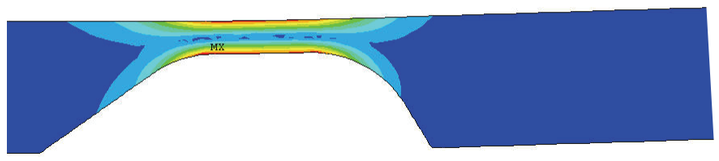
- Simulations show that the main cause of warpage is the slow cooling of the sprue
- Asymmetric mould temperature makes the part curve towards the warmer side
  - The curvature change is the same in the *x* and *y* directions: $\Delta c_{xx} = \Delta c_{yy}$
  - The shape of the curvature is affected by processing



The curvature was slightly reduced by applying a longer cooling time. Previous work has shown that lower mould temperature and higher holding pressure reduces the curvature. The effects of these changes were not statistically significant in this work.

Fatigue life of hinge

- Structural analysis (FEM) to reduce stress concentration at hinge
  - Constraints: Maintaining a planar DOE surface during bending, and having a good design in terms of processability



Simulated von Mises stresses at the hinge
Maximum stress: 6 MPa, 10% of yield stress

- Fatigue bending testing of the part in the actual application
  - Frequencies: 2 Hz and 20 Hz, temperatures: 23 °C and 50 °C
  - Polycarbonate materials have performed well so far ($1.5 \cdot 10^8$ cycles)
  - This applies to DVD grades (rather low molecular weight) as well as regular grades
  - Other materials have fractured or are too stiff for the application
- Residual stresses in PC parts assessed by solvent exposure method
  - No crack formation; indicating no detrimental residual stresses

ACKNOWLEDGEMENTS

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