Mechanical and structural characterisation of layered ceramics for gas permeable thermoforming moulds

M. Rudolphi, M.C. Galetz, M. Schütze
e-mail: rudolphi@dechema.de
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Introduction

Thermoforming is a method to create various shapes of plastic by heating a plastic sheet to a pliable temperature and pressing it into a mould of the desired shape. Removing the sheet from the mould and trimming the plastic results in the final product. Vacuum forming is one common thermoforming technique, where the pliable plastic sheet is sucked into the mould by applying a vacuum between mould and plastic sheet. Typically, vacuum forming moulds are made from an aluminium block with chip machining tools, which limits the grade of detail that can be achieved. Furthermore, suction holes have to be drilled into the mould to be able to apply a vacuum, which creates unwanted artefacts.

A novel layered slurry ceramics material, which was invented by our project partner Kunstguss-Team Grundhöfer GmbH, Niedernberg, is presented as a promising alternative, allowing very fine details to be formed and vacuum application *through* the porous ceramic without the need for suction holes.

KUNSTGUSS-TEAM GRUNDHÖFER GMBH
Niedernberg, Germany

The aim of this study was therefore to

- Investigate fracture toughness of novel layered slurry ceramics
- Determine porosity and gas permeability as a function of production parameters
- Find optimum compromise between lowest shrinkage, maximum fracture toughness and maximum gas permeability
- Construct a functioning prototype mould from layered slurry ceramic material

The layered slurry ceramics approach

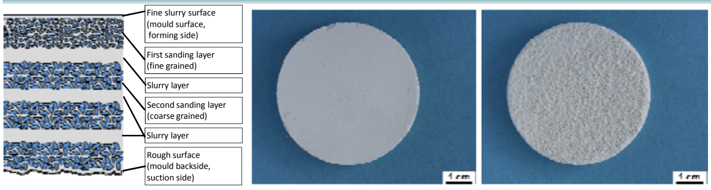

Figure 1: Schematics of a layered slurry ceramic (left) and photographs of surface (center) and backside (right) of a slurry derived ceramic plate.

Slurry	Sanding	Descriptor
Silicate binder & Al_2O_3 (45µm)	Al_2O_3 0.1-0.3 mm (fine)	fine
Silicate binder & Al_2O_3 (45µm)	Al_2O_3 0.5-1 mm (coarse)	coarse
Silicate binder & Al_2O_3 (45µm)	1 x fine coarse until finish	fine & coarse
Silicate binder & Al_2O_3 (45µm)	fine and coarse, pre-mixed	mixed

Table 1: Variations of slurry and sanding used to produce slurry derived ceramics.

Materialography

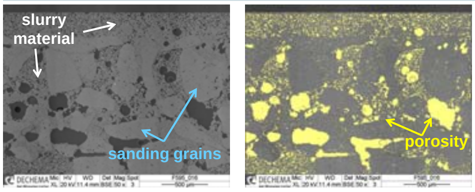

Figure 2: The SEM micrograph of the ceramic (left) shows the slurry material and the grains of the first sanding layer below. Image analytical processing was used to determine porosity, highlighted in yellow (right).

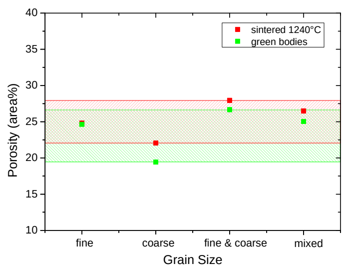

Figure 3: Porosity of slurry ceramic as a function of sanding grain size used for production and sintering parameters.

4-Point Bend Testing

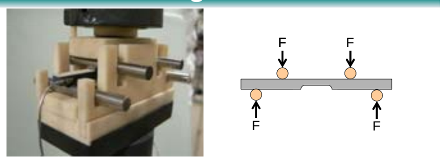

Figure 4: Photograph and schematics of the 4-pt. bend specimen fixture.

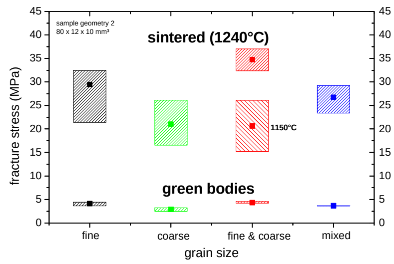

Figure 5: Fracture stress of slurry ceramic material as a function of sanding grain size and sintering parameters. The variant with fine & coarse grained sanding showed the highest fracture toughness.

Dilatometry

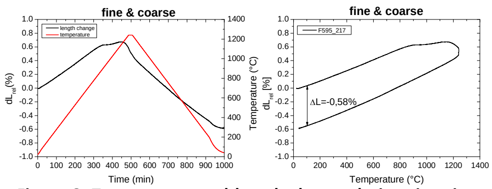

Figure 6: Temperature and length change during sintering step (left) and shrinkage determination (right).

Grain size	Sintering parameters	Shrinkage
fine	2,5°C/min 1240°C, 20 minutes	-0,76%
coarse	2,5°C/min 1240°C, 20 minutes	-0,35%
fine & coarse	2,5°C/min 1240°C, 20 minutes	-0,58%
mixed	2,5°C/min 1240°C, 20 minutes	-0,56%

Table 2: Shrinkage during sintering for the different grain sizes used to produce the slurry derived ceramics. Low shrinkage values below 1% are observed for all different grain sizes, the lowest value was found for the coarse grained slurry ceramics.

Gas Permeability

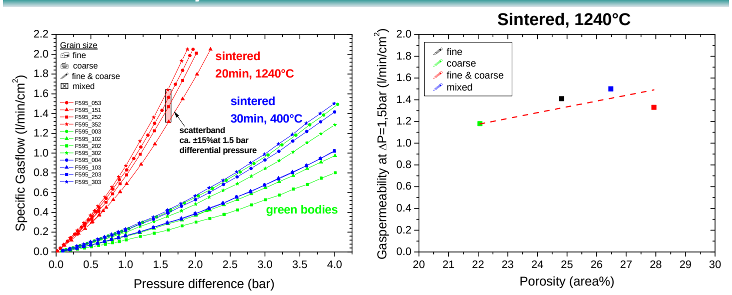

Figure 7: Specific gas flow of different slurry ceramics as a function of pressure difference between surface and backside (left) and gas permeability as a function of porosity (right). Gas flow increases only marginal when release wax is burned (sintering at 400°C) while significant increase is achieved by sintering at 1240°C when the silicate binder decomposes. Gas permeability increases slightly with porosity, however, all produced ceramic variants scatter by only ± 15% in permeability at ΔP=1.5bar.

Prototype Construction

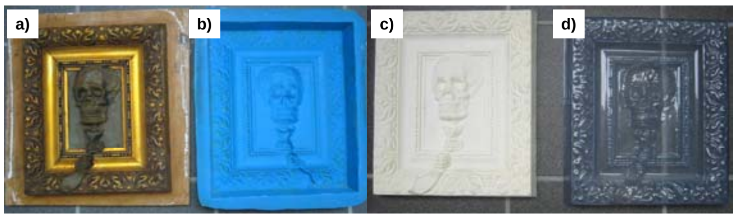

Figure 8: Image sequence to illustrate the production process of a thermoforming mould and the final formed plastic. An art object was used to serve as illustration object with high amount of detail and fine structures to be reproduced (a). A silicon negative form is produced from the art object (b). Filling the silicon form with slurry ceramic of optimized layer composition results in the thermoforming mould (c). The mould has shown very good performance in first vacuum forming tests as can be seen from the resulting plastic (d).
In contrast to many state-of-the-art materials used for thermoforming moulds no water cooling of the mould was necessary during the plastic forming process.

Conclusions and Outlook

- The novel layered slurry ceramics provide the opportunity to influence microstructural and physical properties by varying the layer structure
- The experimental results showed the highest mechanical stability for slurry ceramics produced with the sanding variant "fine & coarse", while furthermore providing a high porosity and gas permeability and reasonable shrinkage of about -0.6%
- A prototype thermoforming mould was successfully constructed using the optimum layer composition "fine & coarse"
- First thermoforming tests have shown excellent results for several types of plastic, achieving a very high level of detail and eliminating the need for water cooling