Cracking behavior of compressible filter cakes

S.Strubel[*], H. Anlauf[*], and H. Nirschl*

[*]Institute for Mechanical Process Engineering and Mechanics, Karlsruhe Institute of Technology, Karlsruhe, Straße am Forum 8, 76131 Karlsruhe, Germany
(E-Mail: sarah.strubel@kit.edu)

Abstract
In cake filtration, shrinkage cracking is an undesirable phenomenon as it leads to deterioration of the filtration process in terms of residual moisture, gas consumption and overall cost. Whereas shrinkage cracking has been extensively studied for thermal drying, there is little research on shrinkage and cracking behavior in a filtration process. Aim of this work is to investigate the relationship of dewatering, shrinkage and crack onset and propagation for compressible filter cakes during vacuum filtration. We combine an image analysis technique with laser displacement measurements to investigate in-plane and vertical shrinkage during cake dewatering. The influence of the boundary on cracking behavior and the saturation at crack onset are determined. The influence of filtration pressure on crack area and crack propagation speed will be discussed.

Keywords. shrinkage behavior - vacuum filtration - compressible filter cakes - shrinkage cracking

INTRODUCTION
Shrinkage cracking is a common phenomenon during dewatering of saturated particle systems. In cake filtration, cracking can be observed frequently when dealing with fine particles that form compressible cakes. When liquid is removed, tensile stresses arise and cause shrinkage of the filter cake. If shrinkage is hindered, tensions build up and lead to cracking (Peron 2009). Shrinkage cracking significantly deteriorates the performance and feasibility of filtration processes, yet there are few investigations that deal with shrinkage and cracking behavior of filter cakes (Wiedemann 1996, Wakeman 1974). In contrast to previous publications, this work investigates the shrinkage and cracking of non-consolidated filter cakes that are dewatered by gas pressure, right after cake formation. Filter cake shrinkage and cracking will be determined via image analysis and laser displacement measurements. Results will be discussed regarding the influence of boundary condition, stage of dewatering and pressure difference.

METHODS
For the filtration experiments we used two different vacuum filtration units with a filtration area of 7200 mm² and 7004 mm² respectively. The two devices differ in terms of boundary condition, either allowing or limiting in-plane cake shrinkage (see fig. 1). To determine porosity and saturation of the filter cake, stainless steel sample takers with an internal diameter of 12.07 mm were used to obtain samples of defined geometry. A laser displacement sensor (LK-G157 by Keyence Deutschland GmbH) was used to measure both sample height and vertical shrinkage of the filter cake during dewatering. Crack area was determined by image analysis with the public domain image processing program ImageJ.

Figure 1: Vacuum filtration unit without boundary (left) and with boundary (right)

Experiments were conducted for two materials of different particle size distribution and compressibility. The first material is a precipitated calcium carbonate (PCC) with a density of 2610 kg/m³ and a mean particle size $x_{50,3}$ of 5.2 µm. The particle size distribution is relatively narrow with a span $(x_{90}-x_{10})/x_{50} = 1.4$. Furthermore we used a commercially available Polyvinylpyrrolidon (DiverganF® by BASF SE) with a density of 1200 kg/m³, a mean particle size $x_{50,3}$ of 30.1 µm and a span of 2.6. Both materials were suspended in deionized water.

RESULTS

Comparison of the results from the two filtration devices showed opposing trends for the evolution of crack area with cake height. We contribute this to the difference in boundary condition. If the filter cake is constricted at the circumference, the occurring shrinkage manifests completely in crack area and can be easily detected via image analysis. Therefore we used solely the device that constricted shrinkage to further investigate the cracking behavior. Combination of laser displacement measurements and image analysis showed that crack onset takes place while the cake is still shrinking (see fig. 2). It was also observed that filter cake cracking occurs at the onset of cake desaturation with a saturation S close to 100 %. The change in overall crack area with filtration pressure was analyzed and found to be independent of filtration pressure. Analysis of the crack propagation speed of individual cracks however showed a slight dependence on filtration pressure. The increase in crack area with time was almost 50 times faster for PVP than for PCC. Furthermore the final crack area reached 1.75 times the value of PCC. We attribute this to the higher compressibility of PVP and also to the faster desaturation kinetics due to the difference in particle size distribution.

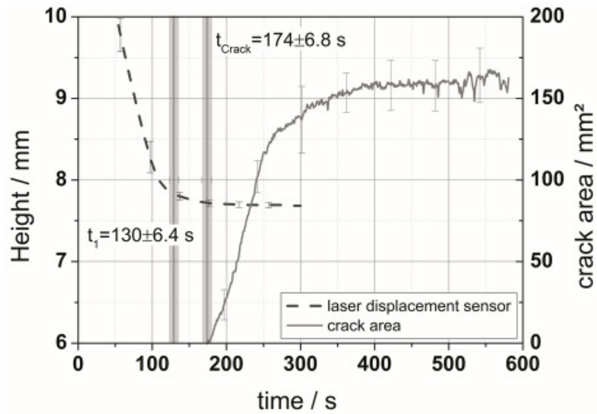

Figure 2: Vertical and horizontal shrinkage of PCC filter cake at -0.8 bar

CONCLUSION

The experiments show that filter cake cracking occurs at the onset of cake desaturation. This is in conclusion with results reported from the area of drying technology (Peron 2009, Kitsunezaki 2013). We attribute this to rapidly rising tensions in the cake during the onset of shrinkage, due to fast dewatering and shrinkage hindered by the filter medium and the boundary. In view of this result, the use of filter membranes with high capillary entry pressure might be a valid option for filtration of materials prone to shrinkage cracking (Anlauf 1987). Total degree of cracking was found to be independent of filtration pressure. This might be caused by changes in material properties of the cake during desaturation that counteract further shrinkage and crack opening respectively. Further investigations will focus on the relation of cracking speed and material properties and correlation of cracking speed and shrinkage speed.

REFERENCES

Anlauf, H. (1987). Cake forming filtration without gas throughput - a new filtration process. Aufbereitungs-Technik, 12, 711-721.

Peron, H. et al. (2009). Fundamentals of desiccation cracking of fine-grained soils: experimental characterisation and mechanisms identification. Canadian Geotechnical Journal, 46(10), 1177–1201.

Kitsunezaki, S. (2013). Cracking condition of cohesionless porous materials in drying processes. Physical Review E, 87(5), 052805-1 - 052805-10

Wakeman, R. J. (1974). The Role of Internal Stresses in Filter Cake Cracking. Filtration & Separation, 11(4), 357–360.

Wiedemann, T., & Stahl, W. (1996). Experimental investigation of the shrinkage and cracking behaviour of fine particulate filter cakes. Chemical Engineering and Processing: Process Intensification, 35(1), 35–42.