STRENGTH ANALYSIS OF A SQUARE-FORM PERFORATED MICROFILTER

Ádám Kovács[1], Zsolt Vízváry[1] and András Kovács[2]
[1]Budapest University of Technology and Economics, Budapest, Hungary
[2]Hochschule Furtwangen University of Applied Sciences, Furtwangen, Germany

1. Introduction

Perforated membranes are often used in various engineering applications. As an example, they can serve for microfiltering purposes in micro-electromechanical systems (MEMS). The investigated square-form membrane is very thin and is made from silicon-nitride (SiN), a brittle ceramic material showing very good material properties concerning load-capacity, high temperature and chemical stability. The membrane is produced from a wafer by wet etching technology. Its simplified mechanical model can be seen in Figure 1.

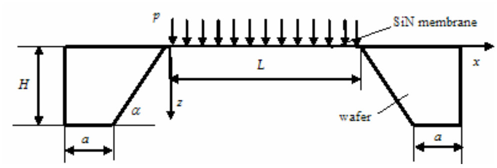

Figure 1: Simplified model of the structure

The performance of the filter highly depends on the perforation rate. In order to obtain better filtration the perforation rate should be as high as possible [1] which diminishes the strength, and consequently, the load capacity of the microfilter. Adequate methods should be used in the design to estimate the critical pressure. In microfiltration the side-length of plates are some order greater than the thickness, therefore classical thin plate theories can not be applied effectively to perform strength analysis. A challenging mechanical problem is the treatment of the very large deflection of the membrane due to even small pressure. Exact solution for this problem is not known.

Van Rijn et al. [2] worked out an analytical approximation for the maximum deflection and maximum load by combining a fixed-edge beam problem with a simply-supported thin plate. Unfortunately, their estimates do not fit well to the results of experiments. We show a simple method to predict the critical pressure semi-analytically from the normal stress at the middle point of the plate using stress coefficients obtained from finite element calculation.

2. Analysis

Because of the simple geometry analytical estimates based on the von Kármán plate theory using Ritz-method can be given for the deflection and the normal stress at the middle point of the fully closed membrane [3] as follows:

(1) $$w_0 = 0.319L\sqrt{\left(\frac{p}{E}\right)\left(\frac{L}{h}\right)},$$

(2) $$\sigma_0 = 0.319E\sqrt[3]{\left(\frac{p}{E}\right)^2\left(\frac{L}{h}\right)^2}.$$

Although displacement could be determined relative good with Ritz' method, it is not suitable to predict the maximum normal stress, which is proportional to the critical pressure. Some thousands of linear thin shell elements were used to mesh the membrane and a nonlinear finite element procedure using total Lagrange description was performed to calculate the stress distribution in the membrane. It was proved that maximum normal stress is proportional to the normal stress in the middle point, so that

(3) $$\sigma_{1\max} = C_\sigma K_\sigma \sigma_0,$$

where where C_σ and K_σ are constant factors. Material properties were measured by experiments.

3. Results and discussion

In order to show the applicability of our method a physically realized structure was analyzed and compared with experimental results (Fig. 2).

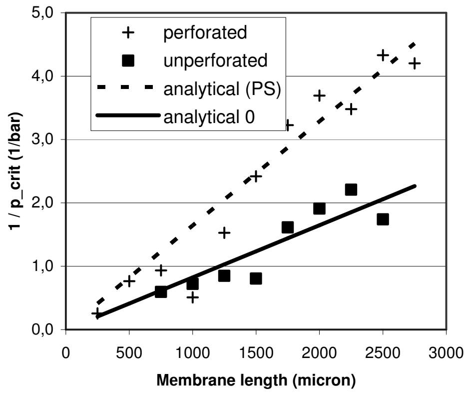

Figure 2 Measured and calculated load-capacity

The theoretical prediction of load capacity of perforated thin membranes requires numerical simulations in order to find appropriate mathematical relation between the maximum principal stress and the normal stress risen in the midpoint of the membrane. Once this relationship has been established, the load capacity can be estimated from measured or simulated mechanical response of an unperforated membrane.

4. Acknowledgment

This work has been financially supported by the National Scientific Research Fund (OTKA) under contract no. T49848, which is highly appreciated.

5. References

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