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# Buckling Analysis on Thin FilmsMechanical-Thermal Coupled-Field Using Theorotical Calculations

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## Abstract

Devices with feature size on the order of one micrometer have found wide spread applications in science and engineering. MEMS, is a rapidly growing technology for the fabrication of miniature devices which provides a way to integrate mechanical, fluidic, optical, and electronic functionality on very small devices, ranging from 0.1 microns to one millimeter. Recently, it has been proposed that regular patterns can be generated through the mechanical buckling of a thin film. The process of buckling of thin compressed films deposited on polymethylmethacrylate (PMMA) Vs Structral Steel compared under mechanical and thermal loadings has been investigated utilizing an optical microscope. Particularly, thermal cycling analysis on thin film/substrate system under compression has been characterized to discuss the thermal property of PMMA and Structral substrate validate through Therotical Calculations.

***Keywords:***
Mechanical Buckling
Thin Flims
Miniature Device

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## 1. Introduction:

Film/substrate structure in information science occupies an important position, for example, data storage and processing systems on integrated circuits contain a large number of conductive, semi-conductive and insulating films, the magnetic films which play a key role in the disk storage systems, etc.

However, the above-mentioned thin film/substrate system withstand a variety of load at work (such as cutting tools, anti-corrosion coating), thermal stress caused by the heat (such as the micro-chippackaging coating), especially the residual stress in the film, either the thermal mismatch produced in the high-temperature deposition process and the subsequent cooling process, or the internal stress caused by lattice mismatch. Because delamination and buckling is the main failure modes of these devices, so the investigation of buckling is of great significance for its life prediction.

Thin-film buckling (buckle) generally considered refers to a failure mode caused by the compressive force on the film material, characterized by the vertical displacement perpendicular to load direction. Buckling based on specific patterns can be divided into the straight-sided wrinkle; the circular blister or bubble; the telephone cord buckle; The expansion model of straight-sided wrinkle is recognized in the steady-state expansion conditions that the wrinkle expands along the curved front of the oval; while the linear edge formatted subsequently do not expand. The cross-section of straight-sided wrinkle shows the shape of cosine curve. The initial expansion maintains round, but with the increase of residual stress, the bubble mutated into lobe. Some circular buckles have small straight-sided wrinkles through them. Observations of a large number of circular buckling show that in the expansion process, the crack model of bubbles will change from type into ĉ type .ĊAs the load increased further, the straight-sided wrinkle will transform to varicose mode. With the stress increase of in buckling load the straight-sided wrinkle will finally change to the telephone cord buckle.

**2. History of Mems :**

MEMS (micro-electro-mechanical systems) are tiny electo-mechanical devices made by some of the same methods as integrated circuits. The results are some of the smallest machines ever made, capable of being built on a silicon wafer alongside the circuits that control them. Most MEMS devices are still experimental, but they are already being used in cars to deploy airbags and actuate antilock brakes, in integrated optical switches to handle Internet traffic, and in many other areas.

MEMS were first proposed in the 1960s, but not commercialized until the 1980s. Engineers and scientists wanted to use integrated circuit fabrication techniques to make tiny mechanical systems, which could, if necessary, be connected to electronic circuits on the same chip. One of the first commercial applications of MEMS was the tiny nozzle assembly used in the cartridges of inkjet printers. Each of the nozzles in an inkjet printer's printhead consists of a hollow chamber. Inside, ink flows in, is heated with tiny electric heating elements, and is then expelled through a port. The chamber and all its features are created using the same photolithography techniques as an integrated circuit.

In 1982, automotive airbag systems (which had been proposed in the 1950s) were introduced using MEMS sensors to detect a crash. The Analog Devices Corporation elaborated this idea, producing an "accelerometer" for airbag systems in 1991, where the mechanical and electronic portions were integrated on the same chip. The accelerometer chip detects the sudden increase or decrease in speed that occurs during a crash. The same company later introduced a gyroscope-on-a-chip, capable of working with an automobile's global positioning system to create more accurate maps and directions for drivers.

**3. Advantages of MEMs technology**

1. It provides an efficient solution to the need for miniaturization without any compromise on functionality or performance.
2. The cost and time of manufacturing is reduced.
3. The MEMs fabricated devices are more fast, reliable and cheaper
4. The devices can be easily integrated to systems.

**4. Three Practical Examples of MEMs fabricated devices:**

**1.** Automobile Airbag Sensor: The pioneer application of MEMs fabricated devices was the automobile airbag sensor which consisted of an accelerometer (to measure the speed or acceleration of the car) and the control electronicsunit fabricated on single chip which can be embedded on the airbag and accordingly control the inflation of the airbag.

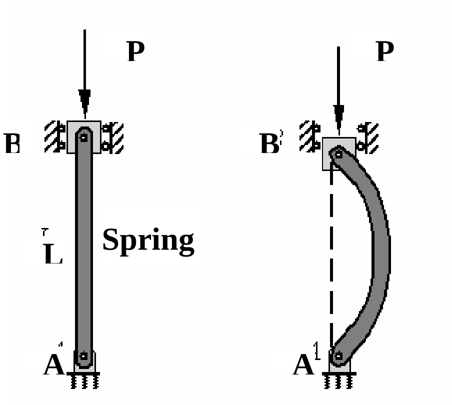
**2.** BioMEMs device: A MEMs fabricated device consists of teeth like structure has been developed by Sandia National Laboratories which has the provision to trap a red blood cell, inject it with DNA, proteins or drugs and then release it back.

**3.** Inkjet Printer Header: A MEMs device has been fabricated by HP which consists of an array of resistors that can be fired using microprocessor control and as the ink passes through the heated resistors, it gets vaporized to bubbles and these bubbles are forced out of the device through the nozzle, onto the paper and instantly solidify.

cross-referencing and computer searching. An improperly titled paper may never reach the audience for which it was intended, so be specific.

**5. Critical Load of a Simply-supported Beam under Compressive Loads:**

Consider a simply supported beam shown in Figure. If the column is fully aligned, the applied compressive load P can be increased until one reaches the compressive strength of the material. Yet, in reality the column will fail due to buckling as shown in the figure on the right in Figure long before this load is reached [10]. Buckling can be catastrophic if it occurs in the normal use of most products. Once the geometry starts to deform, it can no longer withstand even a fraction of the initially applied force.




A Simply-supported beam

The equation governing the deflection is given as:

$$\frac{d^2w}{dx^2} + \frac{P}{EI}w = 0$$

where
*w* = Displacement of the beam;
*P* = Applied compressive load;
*E* = Young's Modulus of the material of the beam (Steel); and
*I* = Moment of inertia of the beam.
This is a second order homogeneous ordinary differential equation with constantcoefficients that has a solution of the form

$$w = C_1 \sin(\lambda x) + C_2 \cos(\lambda x)$$

For the beam to have a nontrivial solution (buckled solution), one must select

$$\lambda = \frac{n\pi}{l}.$$

To get a nontrivial solution to the buckling problem, the axial load must satisfy therelation,

$$P = EI\lambda^2$$

which results in the expression for the critical load given by

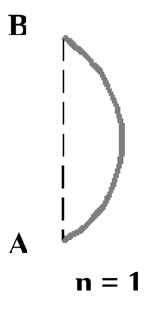
$$P_{cr} = \frac{n^2\pi^2 EI}{L^2}$$

Obviously, the smallest critical load is associated with *n*=1. Therefore, the column will buckle at the load associated with the first buckling mode if the column is not restricted from taking the shape associated with this mode [10].

Therefore, we finally get the critical load as:

$$P_{cr} = \frac{n^2 \pi^2 EI}{L^2}$$

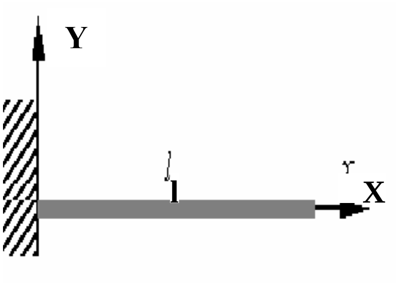
and the corresponding mode shape is shown in *Figure*




The first mode shape of a Simply-supported beam

Now, consider a cantilever beam as shown in *Figure* . The result may be applied to that of a cantilever beam. A cantilever beam may be regarded as one half of a simply-supported beam. Its critical load can be obtained from the formula by replacing $L$ by $2L$ to get:

$$P_{cr} = \frac{\pi^2 EI}{4L^2}$$




A Cantilever beam

**6. Analysis of a Beam-Column :**

Let us consider a simply-supported beam. An axial force $P$, positive in tension, is regarded imposed at the outset, perhaps by a change in temperature while the ends of the bar are not allowed to move axially. An analysis based on energy concepts is as follows:

For small lateral displacement $v = v(x)$ , strain energy in bending is given by theexpression in terms of curvature $v_{,xx}$ .

$$U_b = \frac{1}{2}\int_0^L EI_z v^2{}_{,xx} dx$$

Imagine that $v = v(x)$ takes place without any axial displacement $u$. Each differential length $dx$ becomes a new differential length $ds$, where $ds>dx$. The expression for $ds$ is given as:

$$ds = \sqrt{1 + v^2{}_{,x}}\, dx$$

$$ds \approx \left(1 + \frac{1}{2} v^2{}_{,x}\right) dx$$

Axial membrane strain in the bar is therefore

$$\varepsilon_m = \frac{ds - dx}{dx} = \frac{ds}{dx} - 1$$

$$\text{Hence, } \varepsilon_m = \left(1 + \frac{1}{2}v^2{}_{,x}\right) - 1 = \frac{1}{2}v^2{}_{,x}$$

During small lateral displacement, axial force *P* remains essentially constant. As each elemental length *dx* lengthens an amount $\varepsilon_m dx$, the tensile force *P* it carries, does work, and stores strain energy, in the amount $P\varepsilon_m dx$. Thus, the change in membrane energy is

$$U_m = \int_0^L P\varepsilon_m dx \quad \text{or} \quad U_m = \frac{1}{2}\int_0^L Pv^2{}_{,x} dx$$

Now, let a straight bar or a beam lie along the x axis, and let lateral displacement *v* and rotation$v_{,x}$in the xy plane be determined by nodal d.o.f. {*d*}. Thus

$$v = [N]\{d\} \quad \text{and} \quad v_{,x} = [G]\{d\} \quad \text{where} \quad [G] = \frac{d}{dx}[N]$$

Membrane strain energy $U_m$associated with lateral displacement *v* is given by equation (2.25). With axial force *P* considered positive in tension,

$$U_m = \frac{1}{2}\int_0^L Pv^2{}_{,x} dx = \frac{1}{2}\int_0^L v_{,x}{}^T P v_{,x} dx = \frac{1}{2}\{d\}^T [k_\sigma]\{d\}$$

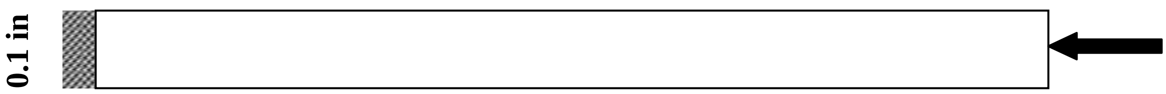
where stress stiffness matrix *[kσ ]* is given by

$$[k_\sigma] = \int_0^L [G]^T [G] P dx$$

If lateral displacement is also allowed in the z direction, additional d.o.f.s are needed in *{* d *}* and displacement w is included in calculations. The resulting *[kσ]* matrices are verysimilar to those for plane deformation but contain more terms

## 7. Geometry and Material Properties of a TestCase

We consider a cantilever beam with geometry given in *Figure 2.5*. The beam has a length of 8 in, breadth of 0.2 in and a thickness of 0.1in.




**Beam geometry**

The beam is assumed to be made of steel. The relevant material properties are given in *Table*

| | |
|---|---|
| Mass density | $7.35 \times 10^{-4}$ Lb-f-s$^2$ / in$^4$ |
| Modulus of Elasticity | $29 \times 10^6$ Lb-f / in$^2$ |
| Poisson's Ratio | 0.29 |
| Thermal Coefficient of Expansion | $6.5 \times 10^{-6}$ / °F |
| Shear Modulus of Elasticity | $11.2 \times 10^6$ Lb-f / in$^2$ |

Polymethylmethacrylate (PMMA) Material Properties:

| S.NO. | DETAILS | UNITS | VALUE |
|---|---|---|---|
| 1 | DENSITY | $g/cm^3$ | 1.19 |
| 2 | YOUNGS MODULES | GPA | 3.8 |
| 3 | POSSION RATIO | | 0.23 |
| 4 | Thermal Conductivity | W/m.K | 0.24 |
| 5 | Co-efficient of thermal condutive | /K | 0.3e-6 |

## 8. Analysis Results andDiscussion

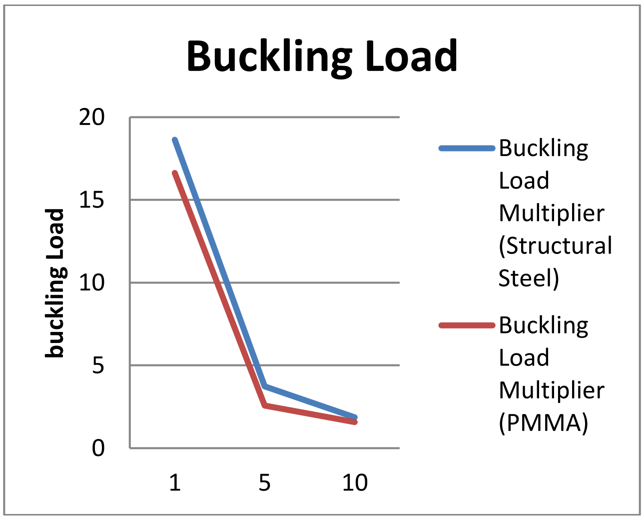
For the cantilever beam with an axial load at the free end, the critical load is calculated according to equation (2.5).

$$P_{cr} = \frac{\pi^2 EI}{4L^2}$$

For the geometry and material of the test case, we find the critical load to be as $P_{cr}$=18.7248**Lbf* For the different axial loads applied, the corresponding buckling load multipliers are given in *Table 2.2*. The total buckling load is the product of the applied load and its corresponding buckling load multiplier. Here, the load is applied at the free end of the beam in the negativex-direction.

**Results for different axial loads**

| Load (Lb-f) | Buckling Load Multiplier (Structural Steel) | Buckling Load Multiplier (PMMA) |
|---|---|---|
| 1 | 18.6359 | 16.63 |
| 5 | 3.72719 | 2.567 |
| 10 | 1.86359 | 1.576 |



## 9. Conclusion:

In the 'Critical buckling load analysis', the computer may give a wrong load by missing the lowest one. This is indicated by a warning message which must not be ignored. To avoid any miscalculations by the algor program, the number of iterations must be increased gradually whenever the warning sign shows up to make sure that the solution has converged accurately within the given convergence limitspecifications.Thin film buckling does occur when the compressive stresses in a film are sufficiently high. In this paper, buckling of thin aluminum films on PMMA substrates in mechanical-thermal coupled-field and thermal cycling analysis were investigated experimentally.

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