FILM GUIDE

影　片　指　南

Engineering Film Series: Strength of Materials Laboratory

工程影片集：材料力学实验

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影 片 提 要

“变形与应变”（1号片）讨论均匀和非均匀应变的定义和量测。

“荷载与应力”（2号片）示出各种试验机中施加荷载的方法，以及拉应力、压应力和剪应力的确定。

“拉伸试验，Ⅰ”（3号片）展出一自动实验，并阐述应力—应变图。

“拉伸试验，Ⅱ”（4号片）比较各种材料的试验结果，并介绍真应力—真应变图。

“压缩与屈曲”（5号片）示出了拉伸试验与压缩试验之间的相似与差异，并检验柱的屈曲中的有关变量。

“弯曲”（6号片）检验梁的理论，并将其结果与使用计算机的纯弯曲和横力弯曲实验比较。

“扭转”（7号片）示出以各种材料在弹性和塑性区域

on various materials both in the elastic and plastic regions and looks into the membrane analogy. (0-07-074607-9)

Hardness and Impact Tests (Film#8) explains the significance of these experiments and their relation to material properties such as transition temperatures, notch sensitivity, and ductility. (0-07-074608-7)

The Creep Test (Film#9) examines creep tests on lead wire at various temperatures and loads and relates these to each other. (0-07-074608-5)

Fatigue (Film#10) introduces the phenomenon, the testing machinery, and failure surfaces, together with some typical results. (0-07-074610-9)

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内进行试验，并观看薄膜比拟。

“硬度与冲击试验”（8号片）阐述这些实验的重要性，以及它们与诸如临界温度、切口灵敏度、延性等材料性质的关系。

“蠕变试验”（9号片）考察铅线在各种温度和荷载下的蠕变试验，并将这些彼此加以联系。

“疲劳”（10号片）介绍现象、试验机、断裂面，以及某些典型的结果。

FILM 1. DEFORMATIONS AND STRAINS

The mechanical behavior of engineering materials subjected to loads and environmental effects can be examined in the laboratory. A qualitative experiment is performed illustrating that the end of a steel bar cooled in liquid nitrogen breaks when hit by a hammer, while its other end that was kept at room temperature onlybends. However, to obtain a quantitative measure of the energy required to break a steel bar, a testing machine such as an impact tester has to be used.

It is explained that the determination of mechanical properties of materials is a fourfold problem. It consists of the application and measurement of loads and stresses, of measurement of deformations and strains, of the establishment of quantitative relations between them, and of the examination of failures.

As an axial load, P, is applied to a rubber bar, its original length, L_0, changes by an amount ΔL to L. The so-called engineering strain ε is defined as the length change per unit original length of material. That is,

$$\varepsilon=\frac{L-L_0}{L_0}=\frac{L}{L_0}-1 \qquad (1)$$

影片1. 变形与应变

承受荷载及环境影响的工程材料，其力学性能可以在实验室中加以考察。作出了一个定性的实验，用来说明在液态氮中冷却的钢杆一端，当用榔头锤打时断裂了，而它的保持为室温的另一端仅仅弯曲。然而，为了得到折断一根钢杆所需能量的定量的量度，则必须使用试验机，譬如冲击试验机。

影片阐明，材料力学性能的确定包含有四个方面。这个问题包括：（1）荷载与应力的施加及量测，（2）变形与应变的量测，（3）它们之间数量关系的建立，以及（4）破坏的检验。

当轴向荷载 P 施加于一根橡胶杆时，它的原长 L_0 变化一个量 ΔL 而成为 L。所谓工程用的应变 ε 定义为材料每单位原长的长度变化。即

$$\varepsilon=\frac{L-L_0}{L_0}=\frac{L}{L_0}-1 \qquad (1)$$

Strain is a dimensionless quantity. A negative strain means shortening. Another definition of strain, called "true strain," is explained next. After a load, P, is applied to the rubber bar, the length changes from L_0 to L. An additional differential load, dP, produces an incremental length change, dL. The strain, dε, due to this increment, is equal to the change in length, dL, divided by the length prior to the application of the load increment:

$$d\varepsilon = \frac{dL}{L} \tag{2}$$

The total strain during loading will be the sum of strain increments from the original length, L_0, to the stressed length, L. Therefore, true strain, ε_T can be expressed as an integral of the strain increment:

$$\varepsilon_T = \int_{L_0}^{L} \frac{dL}{L} = ln\frac{L}{L_0} \tag{3}$$

For a very small strain, both definitions give essentially the same value, and hence, the simpler engineering-strain definition will be used. For a large strain, the true-strain definition is more meaningful. The two definitions can be related to

应变是一个无量纲的量。负的应变意味着缩短。下面阐述另一个称为“真应变”的应变定义。当荷载P施加于橡胶杆之后，长度从 L_0 变到 L 。一个附加的微分荷载dP，产生一个增加的长度变化dL。由这个增量引起的应变dε等于长度的变化dL除以荷载增量施加前的长度：

$$d\varepsilon = \frac{dL}{L} \qquad (2)$$

加载过程中总的应变将是应变增量当杆件长度从原长 L_0 增加为受力长度L时的总和。因此，真应变 ε_T 可以按应变增量的积分来表示：

$$\varepsilon_T = \int_{L_0}^{L} \frac{dL}{L} = \ln \frac{L}{L_0} \qquad (3)$$

对于一个很小的应变，两个定义给出基本上一样的值，所以，将应用较简单的工程用的应变定义。对大的应变，真应变的定义更富有意义。两个定义可以彼此加以联系。如果

each other. If the engineering strain **Eq.** (1) is substituted into the true-strain expression **Eq.** (3),

$$\varepsilon_T = ln(1+\varepsilon) \qquad (4)$$

is obtained.

In contrast to normal forces that produce changes in length, the application of shear forces to a rubber membrane results in angular distortion. Right angles drawn on the surface of the sheet change into acute or obtuse angles under the influence of shear. True shear strain γ is defined as the tangent of the change from the initial right angle to the deformed angle:

$$\gamma = \tan\alpha = \frac{\Delta L}{L_0} \qquad (5)$$

The tangent of a small angle is equal to the angle itself. Hence, for small shear strain,

$$\gamma = \alpha \qquad (6)$$

When the rubber sheet is deformed, circles inscribed on it before deformation change into ellipses. Tension produces a lengthening, compression a shortening, and shear a reorientation of the ellipses' axes. Measurements of the change in length, position, and orientation of their major and minor axes can be used to determine local strain in the material.

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把工程用的应变的式（1）代入真应变表达式的式（3），便得到：

$$\varepsilon_T = \ln(1+\varepsilon) \qquad (4)$$

不同于产生长度变化的法向力，把剪力施加于橡胶膜导致的是角变形。画在该薄片表面上的直角在剪力的影响下变为锐角或者钝角，真正的剪应变 γ 被定义为从初始的直角成为变形了的角度时角度变化的正切：

$$\gamma = \tan\alpha = \frac{\Delta L}{L_0} \qquad (5)$$

小角的正切等于该角本身。因此，对于小的剪应变，

$$\gamma = \alpha \qquad (6)$$

当橡胶薄片变形时，变形前画在它上面的圆变为椭圆。拉伸产生伸长，压缩产生缩短，而剪切使椭圆的轴线重新定向。椭圆长轴和短轴的长度、位置以及取向之变化的量测可以用来确定材料中的局部应变。

When strains are the same at every point in a material, we talk about homogeneous strains. During homogeneous straining, straight lines remain straight, though their length and orientation may change. The phenomenon is again illustrated on a rubber specimen. Another rubber specimen with a hole in its center is srtetched. Deformation changes circles drawn on it into ellipses, but in this case their orientation and ellipticity are different at every point. Therefore, the strain also varies from point to point and is said to be inhomogeneous. Originally straight lines become curves in the presence of inhomogeneous strain. Strains are usually inhomogeneous near abrupt changes in cross sections, as indicated by the curved line in the vicinity of the fillets on a dog-bone-shaped specimen.

Strain measurements are usually confined to that portion of a specimen where strains are homogeneous.

The determination of strains in engineering materials where deformations are invisibly small requires the amplified measurements of changes in length and rotations. Several means of amplification are illustrated with the aid of a rubber bar, whose elongation under load is marked as ΔL.

Instruments used to measure axial strains are

当材料内每点处应变相同时，我们称为均匀应变。均匀应变时直线保持为直的，虽然它们的长度和取向可能变化。该现象再一次在橡胶试件上说明。拉长中心带孔的另一个橡胶试件。变形使得画在它上面的一些圆变为椭圆，但是在这种情况下，它们的取向和椭圆率在每点处是不同的。因此，应变在点与点之间也是变化的，而称为非均匀应变。在非均匀应变的情况下，原来的直线变为曲线。在横截面突变处附近，应变通常是非均匀的，就象在异径联接的试件上内圆角附近弯曲的线条所指示的那样。

应变的量测通常局限于试件中应变是均匀的部分。

在变形小得肉眼看不见的工程材料中，应变的确定需要把长度的变化和转角放大来量测。影片借助于一根橡胶杆阐明了若干放大的方法，橡胶杆在荷载作用下的伸长被标记为 ΔL。

用于量测轴向应变的仪器被称为“引伸仪”。最简单的

called "extensometers." The simplest amplifying extensometer is a lever. The ratio of the length of its arms provides an amplification factor. The specimen deforms along a straight line while the tip of the lever moves along a circular path graduated in units of length. To obtain a large amplification, the lever would have to be very long and, because of its weight, unwieldy.

Specimen deformation is converted into the rotation of a mirror that in turn reflects a beam of light onto a curved screen. The beam of light serves as a weightless lever arm.

A rack and pinion system is another variation of the lever idea. Here, amplification is obtained through gear ratios. The rack and pinion system is used in the dial gages shown. A mechanical extensometer which combines a lever with the dial gage is demonstrated. The distance between points of attachment on a specimen is called the "gage length," in which the deformation is measured and is assumed to be homogeneous. A mechanical extensometer has to be read by the observer and its output recorded manually. Consequently, it can be used only for static or very slow experiments.

In a dynamic experiment, strains are usually converted into optical or electrical signals, which

放大用引伸仪是一根杠杆。杠杆臂的长度比提供一个放大倍数。试件沿着直线变形，而杠杆的末端沿着按长度单位刻度的圆弧移动。为了放大得大，杠杆就必须很长，而由于它的重量将难于使用。

试件的变形被转变为一镜子的转动，后者又把光束反射到弧形屏幕上。光束起无重量杠杆臂的作用。

齿条和齿轮系统是杠杆概念的另一种变化。在这里，放大是通过齿轮传动比来得到的。齿条和齿轮系统被用于所示的百分表中。影片说明了由杠杆与百分表组成的机械式引伸仪。试件上接触点之间的距离被称为“标距”，所量测的就是标距范围内的变形，并假设在该范围内变形是均匀的。机械式引伸仪必须由观察者来读数，并用手工记录。因此，它仅能用于静态的或变形很慢的实验。

在动态实验中，应变通常被转变为光的或者电的信号，它们又可以被记录在电子仪器上或者胶片上。把机械应变转

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in turn can be recorded on electronic instruments, or on photographic film. Systems that convert mechanical strain into magnetic, electrical, or optical signals are called "transducers."

An iron core is moved in and out of a coil of wire through which electrical current is running, and the inductance of the system changes. This change in inductance is a function of the core displacement and is measured in electronically amplified form on a meter. This principle is utilized in so-called linear variable differential transformers, often referred to as LVDTs. The amount of twist in a bar is measured with the aid of a variable capacitor. In this case, the change in capacitance indicated on a meter is a measure of the shear strain in the specimen.

Next a tensile force is applied to a wire. It becomes longer and thinner, and a rearrangement of its internal crystal structure takes place. As a consequence, its electrical resistance increases and is measured. Change in length, ΔL, and change in resistance, ΔR, are related to each other through a material constant called the "gage factor," which is the ratio of the change in resistance divided by the original resistance and the strain in the wire:

$$k = \frac{\Delta R / R_0}{\Delta L / L_0} \qquad (7)$$

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