Related topics

Mechanical hysteresis, Elasticity, plasticity, relaxation, torsion modulus, plastic flow, torque, Hooke's law.

Principle and task

The relationship between torque and angle of rotation is determined when metal bars are twisted. The hysteresis curve is recorded.

Equipment

Torsion apparatus	02421.00	1
Torsion rod, steel, l 500 mm, d 2 mm	02421.01	1
Torsion rod, Al, l 500 mm, d 2 mm	02421.02	1
Torsion rod, Al, l 400 mm, d 2 mm	02421.03	1
Torsion rod, Al, l 300 mm, d 2 mm	02421.04	1
Torsion rod, Al, l 500 mm, d 3 mm	02421.05	1
Torsion rod, Al, l 500 mm, d 4 mm	02421.06	1
Torsion rod, brass, l 500 mm, d 2 mm	02421.07	1
Torsion rod, Cu, l 500 mm, d 2 mm	02421.08	1
Spring Balance 1 N	03060.01	1
Spring balance 2.5 N	03060.02	1
Stopwatch, digital, 1/100 sec.	03071.01	1
Support base -PASS-	02005.55	1
Support rod -PASS-, square, l 250 mm	02025.55	1
Support rod -PASS-, square, l 630 mm	02027.55	1
Right angle clamp -PASS-	02040.55	2

Fig. 1: Experimental set-up for measuring the hysteresis of metal bars in torsion.

Problems

1. Record the hysteresis curve of steel and copper rods.
2. Record the stress-relaxation curve with various relaxation times of different materials.

Set-up and procedure

The experimental set-up is arranged as shown in Fig. 1. The spring balance acts at right angles to the lever. The measured force or moment and the angle which establishes itselfs are plotted. Except with steel, the elastic limit is very quickly reached, so that the measurements should be carried out either continuously or interrupted by uniform relaxation intervals. For reproducible curves, the torsion bars must not have any kinks or other deformations. In contrast to magnetic hysteresis, in which the crystal structure of the magnetic material is generally unchanged, in the case of mechanical hysteresis a direct relationship is to be found between deformation and moment as a function of time or temperature.

Theory and evaluation

If forces act on a solid body, it is deformed, e.g. with shear stresses, shear deformations will occur. The Hooke's law range is characterised by the linear relationship between stress and torsion.

With solid bodies, there is generally a range adjacent to the Hooke's law range, in which there is no longer a linear relationship between stress and deformation, but in which the deformation is still reversible to some extent. The limit of this range is called the yield point.

The deformation becomes plastic if the stresses become greater than the yield point. The deformation of the bar is then not completely reversed, even in the stress-free condition.

Since the phenomena of plasticity result from displacements of atoms, temperature and time have an influence. According to Hooke's law, the relationship between the stress τ and the deformation γ is given by

$$\tau = \sigma \cdot \gamma,$$

where σ is the shear modulus.

In the plastic range, a simple relaxation theorem approximately applies.

$$\frac{d\tau}{dt} = \sigma \frac{d\gamma}{dt} - \frac{\tau}{\lambda}$$

λ being the relaxation time.

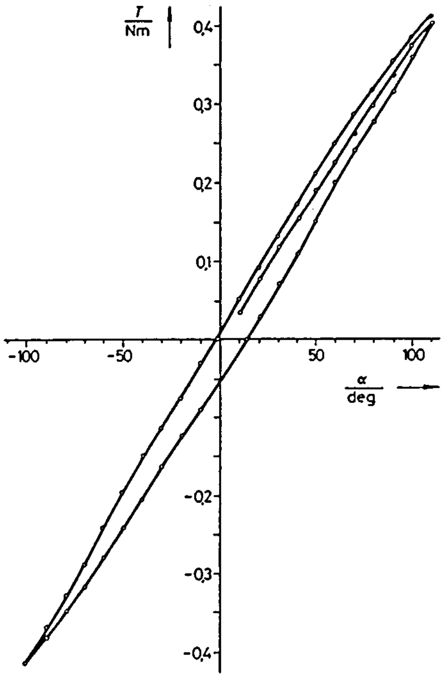
Thus, if the deformation is kept constant, the stress τ after time t is

$$\tau = \tau_o \, e^{-t/\lambda},$$

if τ_o was the initial stress.

If metals are loaded into the plastic range and the material is allowed to relax, it subsequently finds itself again in the Hooke's law range with a new equilibrium position.

Fig. 2: Mechanical hysteresis curve for the torsion of a steel bar of 2 mm diameter and 0.5 m long. The branch which starts from the origin is called the virgin curve (initial curve).



Since, in the torsion of bars, the deformation of the outer layers of the bar is greater than that of the inner layers, from certain angle α_{cr} onwards the outermost layer will reach the yield point. With deformations beyond α_{cr}, a thicker outer layer will reach the plastic range, while the inner layers are still in the elastic range.

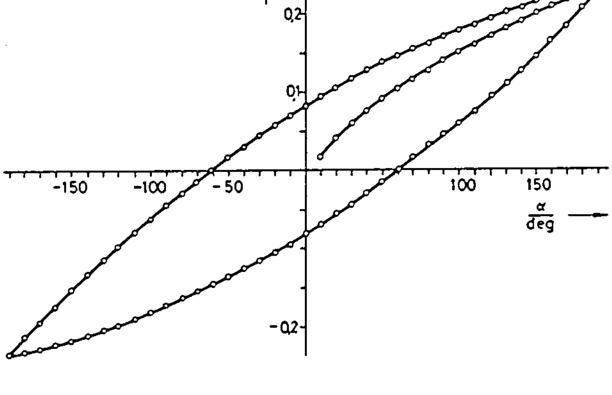
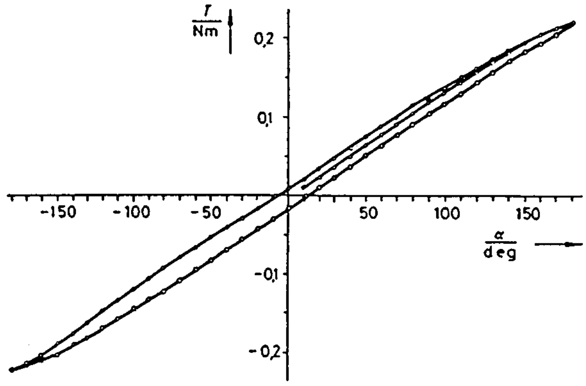


Fig. 3: Mechanical hysteresis curve for the torsion of a copper rod of 2 mm diameter and 0.5 m long.

Fig. 4: Mechanical hysteresis curve for the torsion of an aluminium rod of 2 mm diameter and 0.5 m long.



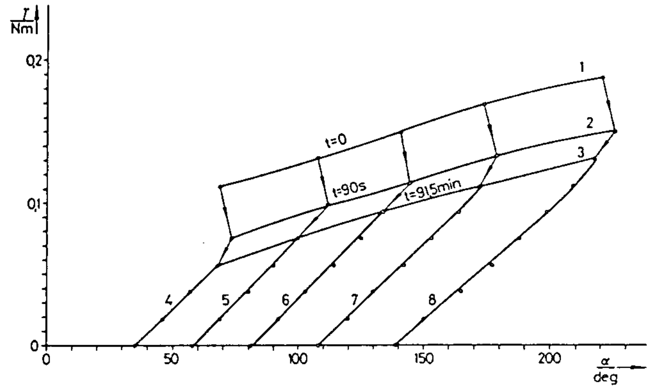


Fig. 5: Relaxation in the torsion of a copper rod of 2 mm diameter and 0.5 m long. The reading times between curves 1 and 2 lie about 90 seconds apart, those between 2 and 3 about 90 minutes. After this recovery process, the bars were unloaded and the curves 4 to 8 were obtained.