

Analytically Speaking

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Characterization of Deposits, Coatings & Electroforms, Part 3: Fundamental Aspects of Mechanical Properties

There are certain fundamental aspects of mechanical properties common to most materials. It is necessary to understand them before the aspects specific to deposits, coatings and electroforms can be discussed. These fundamentals are the topics this month.

Mechanisms

When a material is subjected to stresses, it will generally be deformed to some extent. If the stresses increase sufficiently, the material will fracture, whether it was deformed or not. If it is deformed, there are two ways by which it happens. Initially, the deformation tends to be elastic. Elastic deformation is characterized by return to the original shape when the stresses are relieved. During elastic deformation, the bonds between atoms, or groups of atoms, are stretched or compressed. There is no movement of atoms relative to each other. The strain, the deformation per unit length, is proportional to the stress. The proportionality constant is Young's modulus. During the second, or plastic, mode of deformation, the atoms move relative to each other into equivalent positions. There is a permanent change of shape after the stresses have been relieved.

If materials behaved perfectly elastically, they could undergo repeated stress cycles or vibrations without any loss of energy. In most cases, however, there is an energy loss, called internal friction. Some of the energy is converted into heat. There are several causes of internal friction. One is the strain lagging







behind the stress. A small plastic deformation accompanying the elastic mode can cause this lag and is called anelasticity. Crystal defects, which are the cause of plastic deformation, can also move even before the yield point has been reached. Energy losses can also result when the heat produced by compression is dissipated to the surroundings.

There are essentially four plasticdeformation mechanisms. They are slip, twinning, grain-boundary sliding and diffusional creep. The latter two occur at elevated temperature and are rarely encountered in deposits; therefore, only slip and twinning will be discussed. Slip is schematically represented in Fig. 1. It is the most prevalent mode of plastic deformation in the commonly electrodeposited metals that have face-centered cubic crystal structure. If a shear stress is applied to a series of atom planes, they will deform into equivalent positions. Part of the top plane is then at the level of the second plane. The movement took place along one

Fig. 2—Schematic representation of twinning.

plane, called the slip plane, and is represented by the dotted line in Fig. 1. The slip plane is the one in which the atoms are most densely packed.

Part of the top plane of atoms can also move to the level of the second plane by formation of a type of kink, as shown in Fig. 2. There are now two planes that encompass the kinked region. The kinked region is therefore called a twin and the deformation process is mechanical twinning. Twins are characterized by the fact that the arrangement of atoms on one side of the twinning plane is the mirror image of that on the other side. Mechanical twins differ from growth twins in that they tend to be lensshaped, and in that they both rarely occur in the same types of material.

Effects of Crystal Defects In the first part of this century, scientists were especially baffled by the fact that the theoretical stress to move one layer of atoms over another was several orders of magnitude greater than the yield strength.



Fig. 3—Model of plastic deformation by dislocation motion.

Moving one layer of atoms over another would be the beginning of plastic deformation by slip and, therefore, should equal the yield strength. The shear strain corresponding to the actual yield strength indicated that the rows of atoms that move do not sit in the valley between those beneath it; rather, they reside practically on top of an atom row. Such a condition can exist if there are defects in the crystal. Two such defects are indicated by arrows in Fig. 3a. There are parts of extra planes of atoms squeezed between the regular ones.

The defects are called dislocations. The dislocations can move one row (coming out of the page) at a time, as illustrated in Figs., 3b and 3c. As seen in Fig. 3d, the dislocation movement has caused the top part to have slipped two atom distances, creating a step at the end. Slip can accordingly occur one row at a time, which requires a much smaller stress than if a whole layer moved at once.

Another phenomenon that baffled scientists was that slip steps were visible with the naked eye. In order for a step such as the one seen in Figure 3d to be so visible, millions of dislocations would have to move on one plane. It is impossible for so many dislocations to be present in one atom layer. Also, as illustrated in Fig. 3, once the dislocations have moved to the end of the crystal to create the step, the crystal should become perfect. The opposite occurs in that the more the material is deformed plastically, the more dislocations are present.

The apparent anomalies were explained by the presence of a configuration by which dislocations multiply. If such a configuration is present on a certain atom plane, it can spew out millions of dislocations to create a visible slip step. It can also explain why materials become stronger when they are plastically deformed. This phenomenon, called

work hardening can be easily demonstrated with a paper clip. As a clip is bent back and forth, it requires more force for each cycle until it breaks. If plastic deformation occurs by the movement of dislocations, anything that hinders their movement strengthens the material. Strength can be defined as resistance to deformation. One way to hinder dislocation movement is for many other dislocations to be present. They cause a type of traffic jam. Accordingly, the more dislocations are created, the less they can move and the more difficult it becomes for plastic deformation to occur, and the greater the strength.

If dislocations cannot move, the applied stress causes fracture. For this reason, the paper clip eventually breaks. Also in materials like ceramics, it is inherently difficult for dislocations to move because they must be large. Extra layers of atom groups, such as the metal and oxide ions, must be present to maintain electrical neutrality. Fracture begins at a defect, such as a small crack. Brittle materials tend to possess these small cracks. The interaction of dislocations can also result in a small crack that initiates fracture. For this reason, if materials are subjected to increasing stress, they eventually fracture when they cannot further deform. P&SF

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