PLASTIC DEFORMATION IN MATERIALS PROCESSING

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Abstract. This paper examines the effects of plastic deformation during processing. In particular, the processing variables *stress*, *strain*, and *temperature* are compared and contrasted for five different processing techniques - sheet metal stamping, severe plastic deformation, hot isostatic pressing, foaming, and forging. Ultimately, the similarities and differences are connected in a deformation mechanism map to obtain an overview of the types of plastic deformation to be expected for each materials process.

1. Introduction

Plastic deformation occurs when a material is stressed above its elastic limit, i.e. beyond the yield point, as illustrated in Figure 1. The resulting plastic deformation is permanent and cannot be recovered by simply removing the stress that caused the deformation. The energy applied to the material was consumed as the material yielded by dislocation slip and/or twinning. In the case of materials processing, it is important to understand the plastic deformation involved in order to most effectively device a fabrication method for an object of a certain final shape.

Plastic deformation in the form of slip occurs along the close-packed lattice planes, where the energy requirement for dislocation motion is minimized. Slip inside a crystal progresses until the dislocation line reaches the end of the crystal, where it results in a visible step - a so called slip band. Slip happens progressively, one step at a time, such that the crystal structure for all times remains the same. For most metals, the close-packed plane is the (111); therefore, slip bands usually occur at 45^o to the stress-axis.

In the case of twinning, on the other hand, the lattice structure does change. Twinning is a kind of kinking of the crystal lattice that creates mirror images of the crystal structure across the twin boundary. During twinning, the atoms move only a fraction of an interatomic spacing;

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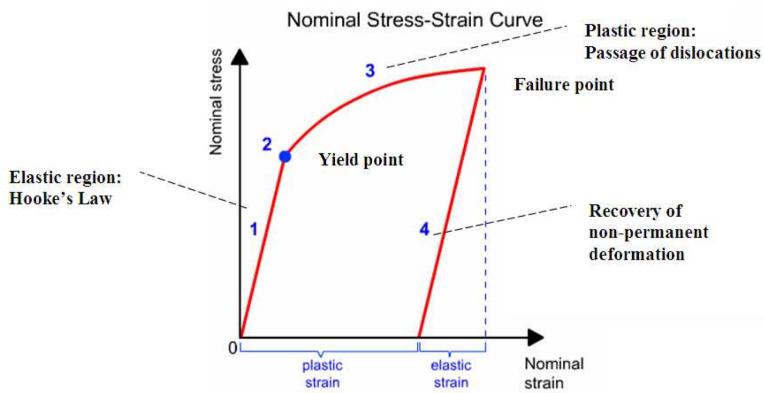

FIGURE 1. Graph showing the elastic and plastic strain of a material under uniaxial stress. [1]

still, due to the simultaneous flipping of many involved atoms, a macroscopic change in the crystal lattice can be observed, and sometimes even heard! [2]

In this project we will investigate the plastic deformation present in the following materials processes:

(1) Sheet Metal Stamping
(2) Severe Plastic Deformation
(3) Hot Isostatic Pressing
(4) Foaming
(5) Forging

The processes will be connected by parallels drawn to physical processing parameters such as:

- Stress
- Strain
- Temperature

Where applicable, we will also look at certain engineering economical issues, such as cost, throughput, quality, practicality, and scaling possibilities.

2. Sheet Metal Stamping

Sheet metal stamping is a materials processing technique by which metal parts are stamped out from thin sheets of metal using a punch and a die. The die fixes the sheet metal in the desired position, while the punch delivers a high-energy, rapid punch using hydraulic machinery. Stamping is frequently employed for high volume production of parts for the aviation-, car-, and electronics industries. Both metal and metal alloys can be used for stamping. The most common stock

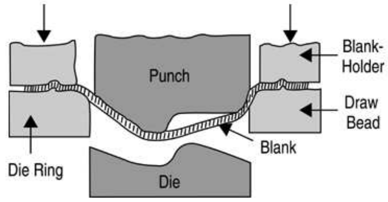

FIGURE 2. Diagram showing the deformation stretching of a blank in between a punch and die set. [5]

materials are aluminum, brass, steel, copper, titanium, and zinc. [4] The inexpensive materials and the high level of automation possible during stamping allow for lucrative mass production of metal parts at low cost and low cycle time.

In this section, we will start with a discussion of the stress-state during sheet metal stamping, then look at how plastic deformation can lead to failure in metal stamping, and finally conclude with a numerical example of sheet metal stamping.

2.1. **Analysis of Stress-State.** In sheet metal stamping, parts are formed by stretching a thin sheet of metal, called the *blank*, over a shaped punch and die set, as can be seen in Figure 2. During the deformation, the blank is kept in position by the blank-holders. Consequently, in contrast to forging where the material stock is deformed by *compression*, stamping results in *stretching* of the blank. Therefore, for the most part, the material is only in contact with the tooling on one side, and the contact pressure is small compared with the flow stress.

Let us now analyze the stress-state of the blank in Figure 2. We assume plane stress deformation with negligible through-thickness stresses and proceed with a two-dimensional analysis of the infinitesimal stress-element illustrated in Figure 3.

By convention we define the principal stress-directions so that $\sigma_1 > \sigma_2$ and the third direction is perpendicular to the surface where $\sigma_3 = 0$. We will also introduce the stress ratio, α, and the strain ratio, β, where

$$\alpha = \frac{\sigma_2}{\sigma_1}; \tag{1}$$

$$\beta = \frac{\epsilon_2}{\epsilon_1}; \tag{2}$$

$$\epsilon_3 = -\left(1 + \beta\right) \epsilon_1. \tag{3}$$