

Lecture 37: Deformation Processing

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Key words: Hot working, cold working, annealing

Introduction

The ultimate goal of a manufacturing engineer is to produce steel components with required geometrical shape and structurally optimized for a given application. One of the method is the deformation processing. Deformation processing exploits the ability of steel to flow plastically without altering the other properties. The required forces are often very high. Cast ingots, slabs, blooms and billets are reduced in size and converted into plates, sheets, rods and others. These forms experience further deformation to produce the desired products formed by processes such as forging, extrusion and other sheet metal forming. The deformation may be bulk flow in three dimensions, simple shearing, simple bending, or any combination of these and other processes. The stresses could either be tensile or compressive or shear or combination of them. In this connection the steel chemistry and cleanliness are important factors for deformation processing.

In the following, some aspect of deformation processing is discussed. This is given to appreciate the efforts of steelmakers in producing quality steels. The readers should also understand the reverse engineering approach and to appreciate the steelmaking. Deformation processing can be carried out either under hot or cold condition. In the following general features of hot and cold working are described. Details can be obtained in any text book on deformation processing.

Hot working

It is plastic deformation of metals above their recrystallization temperatures. Hot working of steel requires to heat steel near 1000°C for plastic deformation. Hot working of steel involves the deformation of fcc austenite.

- ❖ Hot working does not produce strain hardening. Hence no increase in either yield strength or hardness occurs. In addition yield strength decreases as temperature increases and the ductility improves.

- ❖ Hot working can be used to drastically alter the shape of metals without fear of fracture and excessively high forces.
- ❖ Elevated temperatures promote diffusion that can remove chemical inhomogeneties; pores can be welded or reduced in size during deformation.
- ❖ The dendritic grain structure, small gas cavities and shrinkage porosity formed during solidification in large sections can be modified by hot working to produce a fine, randomly oriented, spherical-shaped grain structure which results in a net increase in strength, ductility and toughness.
- ❖ Hot working results in reorientation of inclusions or impurity particles in the metal with the result that an impurity originally oriented so as to aid crack movement through the metal can be reoriented into a “crack arrestor” configuration.

The various hot working processes are rolling, extrusion, forging, hot drawing etc.

Cold working

Cold working is plastic deformation of metals below the recrystallization temperature and is generally performed at room temperature. *Some advantages are:*

- No heating is required
- Better surface finish and superior dimensional control are achieved
- Strength, fatigue, and wear properties are improved
- Directional properties can be imparted

Disadvantages:

- Heavier forces are required
- Strain hardening occurs (may require intermediate annealing treatment to relieve internal stresses)
- Residual stresses may be produced

For cold working, the ductility and the yield point stress of steel are important. The effect of ductility is shown below:

Figure 37.1: Stress strain diagram for low carbon and high carbon steel to understand the suitability of steel for cold working

In figure 37.1 variation of stress with strain is shown for (A) low carbon steel and (B) high carbon steel. Permanent deformation can not occur until strain is greater than X_1 . At the other extreme if steel is strained to X_4 , the metal will fracture. From coldworking point of view the following is important:

- The magnitude of yield stress, which indicates the force required to initiate the permanent deformation and
- The extent of region of strain that is 0 to X_4 which determines the extent of plastic deformation

If considerable deformation is required then the tensile properties of steel should be that depicted in figure 37.1A. Greater ductility would be available in the material and less force would be required to initiate and continue the deformation.

High carbon steel which shows stress strain behaviour like figure 37.1B is not suitable for cold deformation but may be suitable for shearing operations

Cold working properties are also affected by the grain size and must be controlled during solidification of steel. Too large and too small grain size have undesirable effects.

Springback

Springback is also present in cold working operations. In the elastic region, the strained material returns to its original size and shape. But removal of load in the plastic region, decreases the strain from x_3 to x_2 as shown in the figure 37.1 for metal A i. The decrease in strain, $x_3 - x_2$ is elastic springback.

Thus, in cold working the deformation must be carried out beyond the desired point by an amount equal to the springback.

The various cold working processes are squeezing, bending, shearing and drawing

Annealing

Plastic deformation of polycrystalline material in cold working produces microstructural and property changes that include (a) change in grain shape, (b) strain hardening, (c) increase in dislocation density.

Appropriate heat treatment such as annealing reverts back to the pre-cold worked states. The purpose of annealing may involve one or more of the following aims:

- To soften the steel and to improve machinability

- To relieve internal stresses induced by rolling, forging etc.
- To remove coarseness of grains

The annealing consists of

- ❖ Heating the steel to a certain temperature
- ❖ Soaking at this temperature
- ❖ Cooling at a predetermined rate

Such restoration results from recovery, recrystallization, which may be followed by grain growth.

During recovery some of the stored internal strain energy is relieved by virtue of dislocation motion due to atomic diffusion.

Even after recovery is complete, the grains are still in a relatively high strain energy state. Recrystallization is the formation of a new set of strain-free and equiaxed grains (having approximately equal dimensions in all directions). Strength and hardness decrease, but ductility increases.

After recrystallization is complete, the strain-free grains will continue to grow, if the metal is left at the elevated temperature.

References:

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