Before you begin: Turn on the sound on your computer. There is audio to accompany this presentation.

Deformation Processes

- Designed to exploit a remarkable property in metals – plasticity – the ability of a metal to flow as a solid without deteriorating their properties
- Everything is done in the solid state so we don’t have to worry about handling molten metal or the solidification process
Advantages/Disadvantages

- Metal in these processes is simply moved around rather than removed by chips (machining) so waste is reduced or eliminated.
- However, because the strength of metals is so high, the forces required to deform the materials is also very high and requires heavy, expensive equipment.

Uses

- Nearly all metals go through deformation processing at some stage in their manufacture.
- Example processes include:
  - Rolling
  - Forging
  - Extrusion
  - Sheet metal forming
  - Bending

Types of Deformation

- The deformation that is done can be classified in several different ways
  - Bulk deformation – flow in three dimensions
  - Shearing – compressive cutting type of operation
  - Bending – deformation about an axis
  - Combinations of the above
Stresses Produced

Along with these operations, several types of stresses will be introduced into the parts:
- Tension
- Compression
- Shear
- Bending
- Torsion
- One or more planes/axes (simple/complex)

Table 15-1: Classification of Sorts of Stress

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Independent Variables

- Independent variables are those that we have direct control over their input values during the process.

- Forming processes are complex and consist of several variables – independent, dependent, and interrelations between the two.

In forming processes, independent variables are the following:
- Starting material
- Starting geometry
- Tool and/or die geometry
- Lubrication
- Starting temperature
- Speed of operation
- Amount of deformation

Dependent Variables

- Dependent variables are those that we do not directly have control over – they result from the process and the independent variables that we do control.

- Most of the time, though, the important features of the final product (those that our customers demand for quality etc) are the dependent variables of the process.
Dependent Variables

- In forming operations, dependent variables are the following:
  1. Force or power requirements
  2. Material properties of the product
  3. Surface finish and precision
  4. Nature of the material flow
  5. Exit or final temperature
- Items 2-4 are obviously important variables that the customer specifies. But these are not controlled inputs – so how do we predict their output???

Relationship between Variables

- The problem is that we can control only independent variables, but we need to know what our output or dependent variables of the process will be.
- We really want to have a handle on the dependent variables so we have to know how changing the independent variables affects the output of the process.
- Hence → inter-relationships.

How do we figure this out?

- Three ways to get the inter-relationships or the interdependence between variables
  - Experience
  - Experiment
  - Process modeling
Experience

- This is the guy who’s been doing his job for 20-30 years and knows exactly what’s going to happen if you change this variable.
- Problem comes when he retires and no one gets the benefit of all his years of wisdom.

Experiment

- Not sure – test it out.
- This will eliminate all doubt because you performed testing, but…
- Testing takes a long time and is also very costly.

Process Modeling

- Recent advances in mathematical modeling of processes has resulted in programs that can “predict” what will happen if variables are changed.
- Based on “theory” of processes. Offers a first glance at what might happen.
- Doesn’t take the time involved with experience and doesn’t require the cost associated with experiment.
- Major disadvantage – the output is only as good as the input and the model.
General Parameters

Some knowledge is specific to an operation, but there are certain common features in all metal forming processes:

- What is the material being deformed?
  - Know and understand everything you can about your material.
- What is the speed of the deformation?
  - How will this affect your material?
- What are the friction, lubrication, and temperature of my processes?

Friction and Lubrication

- High forces or pressures are being applied through tools to induce deformation – so friction is a big consideration.
- Some processes require more than 50% of input energy to overcome friction.
- Changes in lubrication can affect the following:
  - Alter the mode of material flow
  - Create or eliminate defects
  - Alter the surface finish and dimensional precision
  - Modify properties of the material

Controlling Friction

- The ability to determine and control friction between the tool and the work piece will affect:
  - Production rates
  - Tool design
  - Tool wear
  - Process optimization
- In most cases we want to reduce the effects of friction…however, some processes can only work with sufficient friction (i.e. rolling).
Different Type of Friction

- Friction involved in the deformation processes is different from friction in mechanical devices.
- In mechanical devices, two materials of similar hardness’s and strengths are interacting to create friction effects.
- In these processes, the tool is designed to be a very hard, very strong material that causes deformation to a softer working material.

Friction

- Friction proportional to pressure for light, elastic loads.
- Friction independent of pressure for high loads – function of strength of weaker material.

Surface Deterioration or Wear

- Another phenomenon related to friction
- Since the work piece only interacts with the tooling, work piece wear is not objectionable
- Wear on the tooling, however, is another story.
- Tooling is expensive and we want it to last as long as possible
Tooling Wear

- Tool wear means that the dimensions of the tool are changing and they no longer reflect the initial geometry.
- Effects of this can means:
  - Tolerance control is lost
  - Increased frictional resistance
  - Poor surface finish
  - Loss of production due to tool changes

Lubrication is Key

- Lubrication is critical in metal forming operations.
- They are generally selected to reduce friction. But, other important features include:
  - Action as a thermal barrier
  - Ability to retard corrosion
  - Ability to act as a coolant

Temperature Concerns

- Workpiece temperature is one of the most important process variables.
- As a material is heated, generally its strength is decreased and ductility is increased
- Forming processes are therefore classified in the following way:
  - Hot working
  - Cold working
  - Warm working
Hot Working

- Recrystallization can be defined as the process in which grains of a crystal structure are come in new structure or new crystal shape.
- Hot working is defined as deformation of a metal at temperatures above the recrystallization temperature.
- Temperature > 0.6 melting temperature (K or R).
- Recrystallization eliminates the strain hardening effects of plastic deformation by producing a new grain structure, and returning the material to its original soft, strain free state.

Recrystallization

- Recrystallization temperatures depend on the melting point of the metal being worked and the amount of plastic deformation involved.
- Recrystallization temperatures:
  - Steel ≈ 2000 °F
  - Tungsten ≈ 4000 °F
  - Tin ≈ room temperature

Hot Working

- Cast ingots or slabs tend to form with:
  - Some chemical separation.
  - Inconsistent grain size.
  - Undesirable grain shape.
  - Gas cavities and porosity.
- Recrystallization results in:
  - Growth of fine grain structures.
  - Orientation of grain.
  - Elimination and/or reorientation of impurities.

Figure 15-3. Cast copper bar with as-cast grain structure.
Conclusions about Hot working

- In most cases, hot working processes indicate higher temperatures – but the major factor that determines hot working is the presence of recrystallization.
- No recrystallization – no hot working.

Advantages of Hot Working

- Since at temperatures above recrystallization, the metal is softer and more ductile, it takes less force to obtain the desired amount of deformation.
- No strengthening effect is exhibited by the material.
Disadvantages of Hot Working

- Higher fuel cost to heat metals.
- Poor surface finish – scale is typically produced.
- Lower tolerance control.

Cold Working

- Cold working is plastic deformation that is not accompanied by recrystallization.
- Temperature < 0.3 melting temperature (K or R).
- Mostly performed at room temperatures, but heat due to friction can raise temperatures and some heat can be added to the process as long as no recrystallization occurs.

Figure 15-6. Use of true stress-true strain diagrams to assess the suitability of two metals for cold working.
Advantages of Cold Working

- No heating is required.
- Better surface finish.
- Excellent dimensional control.
- Strength, fatigue, and wear properties are enhanced by strain hardening.
- Contamination problems are minimized.
- Directional properties can be imparted.

Disadvantages of Cold Working

- Higher forces are required to produce desired deformation.
- Heavier, more expensive equipment is needed.
- The limit on the amount of deformation obtainable in one pass is significantly less than in hot working.
- Metals must be clean and scale free.
- Intermediate anneals may be required to obtain final dimensions.
- Directional properties may not be desirable.
- Residual stresses imparted may not be desirable.

Cold Working

![Diagram showing mechanical properties of pure copper as a function of the amount of cold work.](image)
Springback

- Springback is a phenomenon related to cold working.
- Take a paper clip, bend it slightly and let go. What happens?
  - The clip springs back to its original shape
- This time, bend it until it is deformed and let go. What happens?
  - The clip doesn't go back to its original shape, but it does still spring back – why?

Springback

- Energy stored during elastic deformation gets returned regardless of whether elastic or plastic deformation has occurred.

Warm Forming

- Warm forming is somewhere in between cold and hot working temperatures.
- The temperature is not high enough for recrystallization, but is high enough that some effect on the materials strength and ductility can be seen.
- Offers an intermediate step to help overcome some of the disadvantages of the other processes (hot and cold).
### Advantages of Warm Forming

- Higher temps expand the range of materials that can be deformed.
- Less scale and decarburization compared to hot working.
- Better dimensional control and surface finish than hot working.
- Requires less heat energy than hot working and lower forces than cold working.
- Tools last longer – even though they must exert 25 – 60% higher forces than in hot working.

### Isothermal Forming

- Isothermal (constant-temperature) forming can be used to deform temperature-sensitive materials.
- Tooling must be heated to same temperature as workpiece – sacrifices tool life.
- Forming speed must be slowed to allow heat generated by deformation process to be removed.
- Generally results in close tolerances, low residual stresses and uniform metal flow.

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**The End – See Oncourse for Videos**