**Sintering Stages**

The kinetics of the process can be broken down into three sintering stages:

**1. Initial Neck Growth**

Sintering initially causes the particles that are in contact to form grain boundaries at the point of contact through diffusion. This is the point contact stage and does not result in any dimensional changes. The greater the initial density of compaction (increased particle contact and potential grain boundary area), the higher the degree of coherency in the material

In this initial stage of sintering, necks begin to form at the contact points between adjacent particles see Figure 3-5. This stage is therefore referred to as the "neck growth" stage .No change in the dimensions is observed nor does porosity decrease .

Neck formation is driven by the energy gradient resulting from the different curvatures of the particles and the neck, Surface diffusion is usually the dominant mass-transport mechanism during the early stages of neck growth, as the compact is heated to the sintering temperature

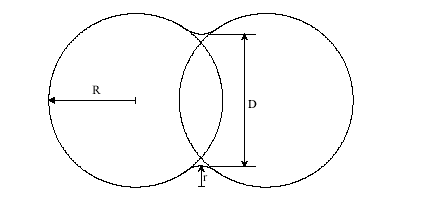


Figure (3-5) neck formation

**2. Intermediate Stage sintering**

Intermediate stage sintering begins when adjacent necks begin to impinge upon eachother. This occurs when the quantity D/2R= 3.0, see Figure 3.5. Densification and grain growth occur during this stage.

The packing density and coordination number of the green packing are important during this stage. A high green packing density produces rapid sintering with relatively few pores in the final object .

The intermediate stage is pore channel closure where interconnected pore charnels are closed off isolating porosity. One of the causes of pore channel closure is neck growth. Another cause is the creation of new contact points by pore shrinkage within the pore itself .

Very low green packing densities (around 40%), which are also associated with low coordination numbers, can lead to coarsening (increase in mean grain size) without densification (decrease in porosity). In extreme cases, this may lead to open-pore structures lacking in structural integrity, See Figure 3-6 .

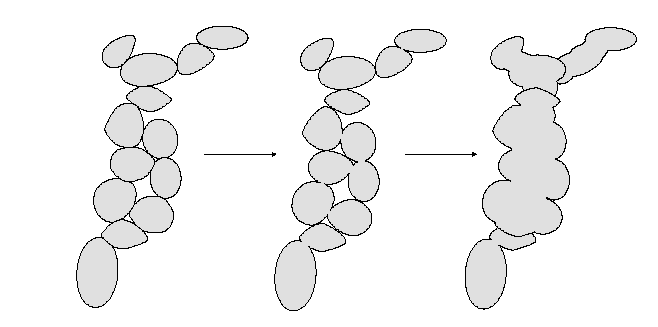


Figure (3-6) Coarsening resulting from low coordination number

At the beginning of the intermediate stage, the pores form a network of interconnected cylindrical pores broken up by necks. By the end, the pores are smoother and begin to pinch off and become isolated from each other.

Bulk transport mechanisms, such as grain boundary diffusion and volume diffusion, dominate the sintering process during this stage. As stated previously, these bulk transport mechanisms cause material to migrate from inside the particles to the surface, resulting in contact flattening and densification .

**3. Final Stage Sintering**

Final stage sintering begins when most of the pores are closed. As sintering proceeds, the pores, which during intermediate stage sintering form a network, have become isolated from each other.

Final stage sintering is much slower than the initial and intermediate stages. As grain size increases, the pores tend to break away from the grain boundaries and become spherical . Pore shrinkage is the most important stage in sintering. For this stage to occur; solids must be transported into the pores and a means must exist by which the gas in the pores can escape to the surface. The resultant effect is to decrease the volume of the sintering mass .

Smaller pores are eliminated, while larger pores can grow, a phenomenon called Ostwald ripening. In some cases, pore growth during final stage sintering can lead to a decrease in density, as gas pressure in the larger pores tends to inhibit further densification .

**Densification Curves**

Figure 3-7 illustrates the densification in three stages of sintering. The density- time curve in the figure is composed of three distinct portions. The first portion reflects the initial stage where densification is due to only neck growth. The densification in the intermediate stag is due to concurrent grain growth and reduced number of interconnected pores. When the pores is completely in the closed form, the rate of densification is reduced as shown in the final stage .

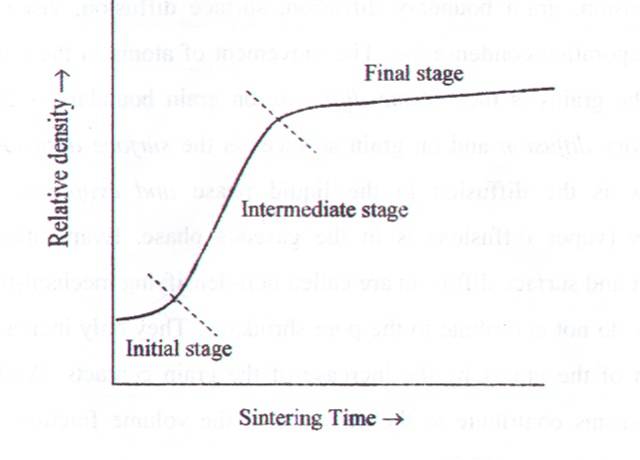


Figure (3-7) typical densification curve