1. INTRODUCTION

1.1 KINETICS OF SINTERING

Investigation of kinetics of sintering of powder compacts presents a fascinating area of research in the fields of powder metallurgy and ceramics because of the inherent complex nature of the process of sintering. The process of sintering of powder compacts is a summation of many complicated phenomena [like : bonding among particles, neck growth, densification or pore annihilation, structure formation and grain growth etc.] which may occur simultaneously or sequentially and because of this complexity its kinetic studies have gained in importance not only from a theoretical point of view, but also from the point of view of their industrial applications. Undoubtedly, a proper understanding of the process would enable a practical powder metallurgist to have a better control of the process as a whole in order to improve the quality of the sintered products.

For such a complicated process, practised over the last few decades, the present-day knowledge is far from complete. However, attempts have been made, and are being made, to characterize and explain the process from various theoretical standpoints. As a direct result of such studies, a good amount of informations regarding the kinetic studies on sintering under isothermal conditions is available at present. A short review of such studies is given below.

1.1.1 STUDIES ON ISOTHERMAL KINETICS OF SINTERING

Various studies on isothermal kinetics of sintering with particles of definite geometrical shapes and sizes have been

and are being carried out by which deeper insight could be obtained into the atomistic phenomena occuring during sintering. Pioneering works (both theoretical and experimental) on model studies by Kuczynski [1] have led to further advancements in the knowledge in this area. Kuczynski has proposed a relationship of this type :

$$x^n \propto t \qquad \ldots\ldots\ldots (1.1)$$

where,

x = radius of interface (i.e. neck) formed during sintering between two particles (Figure 1.1),

t = time of sintering,

n = constant (which has different values for different sintering mechanisms).

The mathematical relationships for different sintering mechanisms are given below :

I) Viscous or plastic flow : $x^2 \propto t$, ...(1.2)

II) Evaporation and condensation : $x^3 \propto t$, ... (1.3)

III) Volume diffusion : $x^5 \propto t$, ... (1.4)

IV) Surface diffusion : $x^7 \propto t$, ... (1.5)

Based on the fundamental studies of Kuczynski, various model studies have been carried out by others, and these have been reviewed extensively by Shaler [2], Thümmler [3] and Exner [4].

1.1.2 STUDIES ON NON-ISOTHERMAL KINETICS OF SINTERING

These theoretical studies on sintering (under strictly isothermal conditions) suffer from a serious drawback, in spite of the fact that important informations regarding the

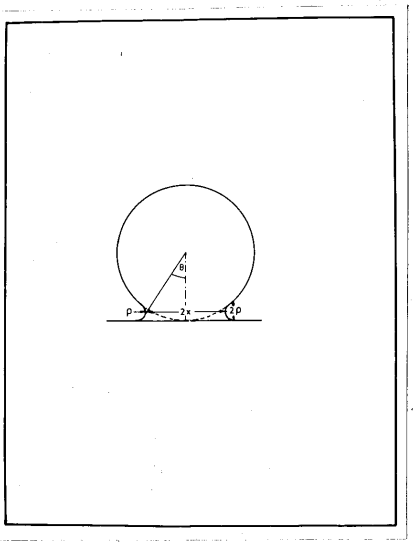

FIGURE 1.1

SCHEMATICAL REPRESENTATION OF THE CROSS-SECTION OF A SPHERICAL PARTICLE SINTERED TO A METALLIC BLOCK [1]

x = RADIUS OF THE NECK

mechanism of sintering processes are obtained from these types of studies.

Isothermal densification studies are difficult to accomplish in the early stages of sintering when the compact is being heated upto the test temperature. If the powder compact is heated rapidly upto the test temperature (in order to reduce the heat-up period) an expansion of the compacts results due to rapid evolution of the occluded gases. On the other hand, if the heating rate is decreased in order to get rid of the expansion, an appreciable amount of densification takes place during the non-isothermal heat-up period. This situation demanded the necessity of the study of densification of powder compacts during early-stages of sintering under controlled heating program (especially under constant heating rates). It has been hoped that these non-isothermal experiments will provide additional informations regarding the densification process of powder compacts during sintering which will, in turn, enable one to have a better understanding of the sintering process as a whole.

A short account of the works done on non-isothermal sintering is outlined below.

1.1.2.1 EARLIER WORKS

Duwez and Martens [5] carried out extensive dilatometric investigations to study the effect of heating rates on the sintering characteristics of powder compacts. They have found that upto a heating rate of 10 K/min, the initial expansion of the copper compacts closely approximated that of solid copper, after which shrinkage set in. The onset of shrinkage occured

at approximately the same temperature for each heating rate, although the amount of shrinkage at any higher temperature increased with decrease of heating rate.

The results of these experiments have demonstrated the usefulness of the dilatometric methods in studying the sintering process of metal powder compacts. For a pure metal compact, the thermal expansion curves recorded in the dilatometer at a constant rate of heating give valuable informations on the rate at which shrinkage proceeds as the temperature is increased. In addition, such a test also offered a simple means of detecting any abnormal behaviour of a metal powder compact exhibiting swelling during sintering. This is particularly expected when a compact made up of two metals undergoes sintering, since abnormal dimensional changes are likely to occur as a result of diffusion. According to the authors [5], considered as a first step, the method is of great help in determining the conditions under which the more reliable, but more tedious, isothermal experiments should be conducted to bring out maximum amount of informations in the minimum time.

Hoar and Butler [6] studied the influence of oxide contents of electrolytic copper powder on the sintering processes. They have carried out some dilatometric studies on the shrinkage behaviour of powder compacts during non-isothermal heat-up period. No attempts, however, was made by these investigators to relate quantitatively the results of non-isothermal sintering to theories of sintering in general and mechanisms involved during sintering in particular.