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SINTERING - THEORY AND PRACTICE

PROCEEDINGS OF THE 5TH INTERNATIONAL ROUND TABLE CONFERENCE ON SINTERING, 1981

Edited by

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PREFACE

This volume constitutes the Proceedings of the 5th International Round Table Conference on Sintering. The conference, the latest of a series started in 1969, was held at Portorož, Yugoslavia, between September 7th and 10th, 1981.

The themes of the 5th IRTCS were the recent progress in theory and practice of sintering processes. Contributions were also invited dealing with properties of sintered materials influenced by the sintering process. Papers were divided into the following sessions:

- Sintering: Theories and Kinetic
- Sintering in heterogeneous systems
- Microstructural aspects of sintering
- The influence of powder characteristics, atmosphere and other parameters on sintering
- Sintering and properties of sintered materials
- Special techniques.

Every session was introduced by invited papers and concluded by a report and general discussion concerning the contributed papers given as posters. The presentation of all contributed papers as posters, an innovation in the series of IRTCS meeting, proved to be a good opportunity for free and informal discussions during the conference, particularly between scientists working at universities, in research and industrial laboratories. Each paper was displayed during the whole duration of the conference to allow for all the material to be digested.

An evening session was devoted to panel discussion on the relevance of theoretical approaches to practical systems. To the astonishment of local hosts, the participants gathered for this session at 9 pm and finished informal discussions in the early morning hours.

The conference attracted some 140 participants from various European countries, USA, India, Japan and China.

The organizers were fortunate in having considerable cooperation and assistance from the members of the International Advisory Committee, session chairmans, referees, invited speakers, contributing authors and conference staff. To all of them we extend our grateful thanks.

On behalf of the participants and the ceramics community, we gratefully acknowledge the financial support provided by the Research Council of Slovenia,

the Committee for Coordination of Science and Technology in SFR Yugoslavia and J. Stefan Institute in Ljubljana.

The organizing committee is also grateful to the following organizations which financially assisted the conference:

- Iskra, Electrical Industry, Ljubljana
- Industry "Prvi Partizan", Sintered Metals and Cemented Carbides Factories, Titovo Užice
- Zorka, The Non-metallic Minerals and Construction Materials Plant, Šabac
- Institute of Technical Science of SASA, Beograd
- Center for Multidisciplinary Studies, Belgrade University
- Sintal, Sinter Metals and Tools Factory, Zagreb
- Rade Končar, Electrochemical Institute, Zagreb
- Exoterm-Cgemical Industry, Kranj
- Termika-Industrial and fitting enterprise for insulation, Ljubljana

Last but not least, we are grateful to the members of J. Stefan Ceramic laboratory for smoothly conducting the conference.

Drago Kolar
Stane Pejovnik
Momčilo M. Ristić

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CONTEMPORARY DEVELOPMENT OF THE SCIENCE OF SINTERING

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ABSTRACT

In a great number of recently published papers, the process of sintering is regarded from the atomic point of view. Fundamental investigations of the process of sintering, started by Ya.I.Frenkel, B.Ya.Pines and G.C.Kuczynski, are based on the study of atomic models. The contemporary contributions mainly represent further development of their assumptions. The study of kinetics of sintering of real materials is based principally on a phenomenological description of the macrochanges during the process itself.

However, the research on the electronic theory of the solid state is worthy of attention from the point of view of further development of the theory of sintering. Its further stages can be explained from the point of view of G.V.Samsonov's configuration model of the solid state.

INTRODUCTION

Indisputable is the fact that in the dialectic development of the science of sintering, the papers of Ya.I.Frenkel [1], B.Ya. Pines [2] and G.C.Kuczynski [3] contributed considerably to a sudden and stimulating rise from a microstructural towards an atomistic conception of this process in the middle of this century. At the same time, a phenomenological theory established by V.A. Ivensen [4] appeared.

Theoretical principles of the science of sintering ascertained by the above-mentioned authors have been considered, even up to the present day, as a firm basis for further development of this science and have also been used very often in the interpretation of results obtained during investigations of real materials sintering. If ob-

served from a general point of view, it can be said that today, in order to explain the sintering process, the following approaches exist: idealized models, reological, statistical and phenomenological (empirical) approaches.

Further to this, no less attention should be paid to the contribution of Ya.E.Geguzin and his book "Physics of Sintering" [5], which has already become a classic. In this book, the author discusses in a critical and universal way the science of sintering from an atomistic point of view. A similar attempt, although more descriptive, has recently been made by H.E.Exner who wrote the book "Principles of Single Phase Sintering" [6]. After all, detailed analyses of scientific papers published till these days show that an atomistic approach to the problem, even in the modern science of sintering, is used for an explanation of phenomena and properties, only. In this light, this is the field where, among other things an explanation concerning the statement of M.H.Tikkanen [7], as quoted: "The fact is that basic research in powder metallurgy has long been in a state of crisis" should be sought.

This, however, should not be comprehended one-sidedly, as the development of the science of sintering depends, to a considerable degree, on progress both in the physics and the chemistry of the solid state. Modern solid state physics is mainly based on the atomistic structure of solids. It is the electronic structure of solids that is considered responsible for its properties and consequently for processes taking place in the solid state. Within this, for example, a diffusion mechanism can also be determined by the electronic structure of a crystal. Having this in mind, it is logical to expect that the science of sintering as a multidisciplinary science, will further develop, as well, in accordance with progress in solid state physics and chemistry.

A critical analysis of some papers which, according to our opinion, can give in a certain way, a general review of the modern state of the science of sintering, is presented in our paper. This analysis comprises the papers dealing with the problem of solid state sintering, principally published from 1977 on, thus giving a modern level survey of this field of science.

Sintering Models

Following the methods of modern solid state physics and chemistry, the science of sintering, from its very beginning, based its fundamental investigations on very idealized models. Apart from

this, interpretation of the results obtained during experimental studies of real materials sintering is very often simplified so much so that a polydisperse powder is presented as a system of ideal spheres of the same size. Not wishing to analyse the absurdity of these manipulations on a macroscopic level, we shall focus our attention on presenting an interpretation of the sintering process on a microscopic level.

G.V.Samsonov [8-11] was the first to point out the unity that existed between the sintering and the pressing process. In the most recent papers of E.Y.Gutmans and his collaborators [12,13], the pressing process is treated as "cold sintering". By the term "cold", they consider that the temperature under which the process is being performed is lower then Tm/2, where Tm is the melting point of the material (absolute temperature). Having analysed a series of materials that were cold sintered, they showed that plastic flow of the powder particles in gradients of high pressure leads to cold sintering in many materials. High mechanical properties of the cold-sintered samples were observed for materials with high melting points ($Tm/2 \geq 300$). This indicates that diffusion dependent processes play, at most, a secondary role in cold sintering processes [14], making for better adhesion through enhanced surface diffusion and pipe diffusion in heavily deformed regions, or through recrystallization at grain boundaries.

It is obvious that to consider the pressing process as cold sintering, even at the atomistic level, is fully justified. D.Stefanović and M.M.Ristić have investigated this process in a series of papers [15-17], taking into account the electronic structure of materials (Fig. 1). They indisputably proved that when the work function of a material (measured by thermoelectric force - TEMF) in certain stages of the process is known, the occurences described recently by following the changes in macro-characteristics of a system can be substantially explained in a satisfactory way from a unique point of view.

K.I.Euler, together with his collaborators, investigated the thermoelectric effect that exists during the copper pressing process [18]. The results obtained show that such measurements can be reasonable only if the investigations are carried out on metal powders, the surfaces of which are not oxidized. In the normal case, when metal surfaces are oxidized, investigations of the influence of the pressing pressure are carried out on a metal-semi-