Non-isothermal sintering of nanostructured particulate materials: Dream or reality?

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Prof. Valeriy V. Skorokhod, the great scientist and philosopher of sintering, paid special attention to the influence of heating rate on the sintering of particulate bodies. He discussed a lot the development of Dr. V. Ivensen's ideas concerning activation of shrinkage in the case of rapid temperature increase. Initial Ivensen's theory of non-isothermal sintering was grounded on the formal physico-chemical kinetics and treatment of numerous experimental observations just to qualify the activation energies of the shrinkage process at any density. These studies were discussed then in the framework of the rheological theory of sintering by V. Skorokhod within the large topical discussion about the role of defects of the crystal lattice on the densification activity during sintering.

Leading scientists such as Profs. Ya. Geguzin, R. German, E. Olevsky, M. Harmer, Lynn-Johnson, M. Ristich, D. Uskokovich, and many others paid a lot of attention to the non-isothermal stage of sintering and its theoretical justifications using discrete and continual models. Thus, Prof. R. German has modified the model systems of G. Kuczynski's equations for the non-isothermal case. Prof. Lynn-Johnson has proposed the "Master Sintering Curve" method for the analysis of the non-isothermal stage and predicting the best heating regime. Prof. E. Olevsky has developed a continual theory of sintering for the non-isothermal case. Prof. M. Harmer hypothesized a rapid overcoming of the temperature range, where the coalescent growth of grains is dominating over shrinkage and proved its validity experimentally. Prof. H. Palmour III, who proposed a method of rate-controlled sintering, has also grounded on Harmer's hypothesis, and for the first time put the heating rate as a function of the shrinkage rate.

In most of the listed works, the kinetic analyses of sintering were limited to the changes in such macroparameters as shrinkage and porosity without reference to the real structure, primarily the porous and grain structure and their interrelated evolution. Perhaps, H. Palmour III has examined in detail the limitations of the shrinkage rate in relation to the changing morphology of open and closed pores in all porosity ranges.

Ultrafine and nano-sized powders have stimulated further studies of non-isothermal stage of sintering as it turned out that almost 100% densification occurs during heating only under non-linear mode.

All the above achievements preceded the rapid development of modern methods of sintering under the influence of external mechanical, electrical, magnetic, electromagnetic fields: induction, spark-plasma, microwave, laser and flash sintering, in which the duration of sintering was reduced to tens of seconds or minutes. This rapid development is in progress for now, which ensures the creation of the latest materials and competitive technologies in the world. For all these methods, the operating parameters have been established to achieve full density and nanosized grains after sintering for the sake of significantly improved properties of materials due to the size effect.