Short-Time Sintering for Cost-Efficient Production and Material Development

Abstract

This article discusses the advantages of reduced sintering times, deducing the motivation for the development of new short-time sintering techniques in line with the conventional sintering methods. An introduction is given into various short-time sintering techniques highlighting their benefits and possibilities as well as their limitations. Finally the most important development trends are presented, which are expected to facilitate further progress in terms of cost and resource efficient production and material development.

Active Principle	Conventional	Short - Time
TEMPERATURE	PRESSURELESS SINTERING	FAST-Sint®
TEMPERATURE + GAS PRESSURE	GAS PRESSURE SINTERING SINTER-HIP	G-FAST-Sint
TEMPERATURE + MECH. PRESS.	HOT PRESSING	FAST-SPS

Fig. 1 Conventional sintering methods and equivalent short-time sintering techniques by active principle

Introduction

Powder metallurgical as well as ceramic technologies include the process step "consolidation", which transforms a powder compact to a solid part. This is done mainly by "sintering" (also called "burning"), whereas alternative consolidation methods, e.g. "infiltration" or "reaction binding" are used comparatively seldom. Sintering is a thermal processing method (sometimes assisted by mechanical pressure) and therefore the most energy consuming processing step of the process chain in nearly all cases [1]. Moreover the sintering parameters (e.g. the time) can influence the properties of the sintered material significantly [2,3]. Both aspects show, that modern sintering methods with greatly reduced time consumption offer new possibilities regarding the combination of cost efficiency and material quality.

Motivation for Short-Time Sintering Methods

The most important sintering methods are listed in Fig. 1 according to the respective active principle: If only thermal energy is used for consolidation, the method is called "Pressureless Sintering", whereas during "Gas Pressure Sintering" or "Sinter-HIP" an isostatically acting gas pressure assists the consolidation. If the pressure is transferred by uniaxial working punches, the method is called "Hot Pressing". The state-of-the-art of these sintering methods and the respective kiln technology is well developed and works very successful in production and material development.

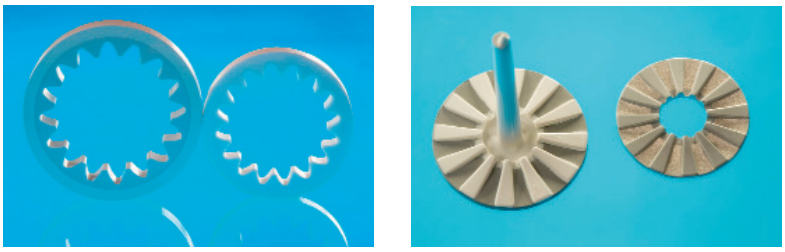

Fig. 2 Typical PIM (powder injection moulding) components for FAST-Sint®, approx.: 20 mm diameter

(source: IKTS; left: 2C gear wheel, design: Robert Bosch GmbH); right: thread stopper made of steel and zirconia, design: Rauschert Heinersdorf-Pressig GmbH)

But sintering is a very cost intensive process step, as well due to the high energy consumption as due to the required high-sophisticated kiln systems [1]. Because "energy" is "power" multiplied by "time", a shortening of the sintering cycle time leads directly to lower energy costs. Together with the simultaneously improved production capacity of the kiln system a significantly increased cost as well as resource efficiency can be realized, if the conventional sintering is substituted by a short-time sintering method.

Moreover not only sintering temperature, atmosphere and pressure, but especially sintering time has a significant influence on the properties of the sintered material and consequently on the quality of the sintered component. Some materials or big parts really need long sintering periods, but in many cases the time consuming conventional methods are only causing unwelcome processes like grain growth, decomposition, phase transformations etc. Especially due to the advancing nano technologies the demand for an optimal and homogeneous consolidation in a minimal time period is increasing [4].

These aspects are the motivation for the development of the new short-time sintering techniques which are in line with the proven conventional methods and listed in the third column of Fig. 1. These new techniques offer the above mentioned advantages for the production of powder metallurgical and ceramic parts as well as for the development of powder metallurgical and ceramic materials. In the following the vari-

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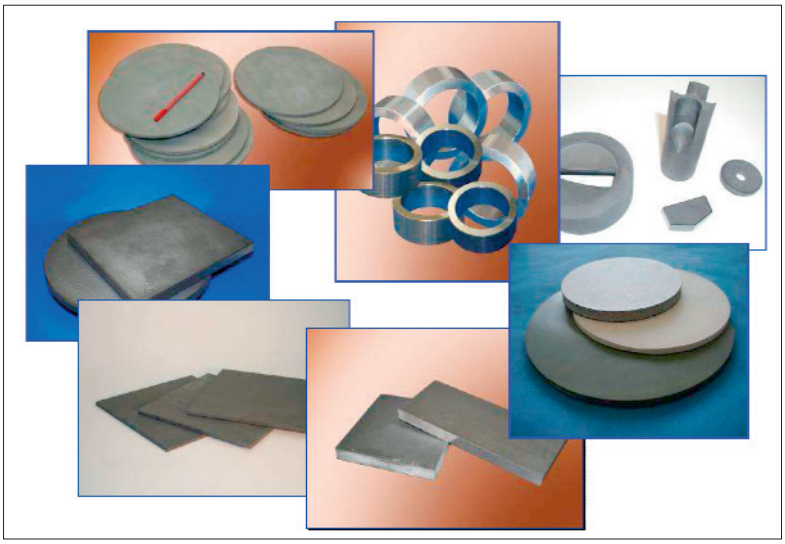

Fig. 3
Typical components for FAST/SPS

Fig. 4
Advancements of the FAST/SPS sintering technique

ous short-time sintering techniques will be explained together with application examples:

FAST-Sint® Rapid Sintering Technology

Equivalent to the "Pressureless Sintering", the "Gas Pressure Sintering" and the "Sinter-HIP" the new "FAST-Sint®" rapid sintering technology was developed [5], especially suitable for smallish dry pressed or powder injection moulded parts (Fig. 2), which can not be made in a FAST/SPS pressing tool due to their complex geometry. FAST-Sint® is a fully automated sintering machine with a heating cell specially tailored to the respective single sintering part. Due to this adaptation and an extremely low thermal inertia very precise heating processes are possible with heating rates of more than 1000 K/min. Depending on part size, thermal conductivity and sintering behaviour cycle times below one minute can be realized, offering completely new possibilities in terms of material properties (e.g. nanostructures, metastable structures etc.) and cost efficiency.

FAST/SPS

Equally to the conventional „Hot-Pressing" the FAST/SPS method consolidates the powder in the die using uniaxial pressure generated by punches, giving limitations regarding the complexity of geometry on one hand (Fig. 3), but saving the effort of a preceding forming operation on the other hand. The higher possible pressure offers further chances for material improvement, especially in combination with the drastically reduced time consumption of FAST/SPS compared with conventional hot pressing [6]. FAST/SPS works with an electrical field ("FAST" = Field Assisted Sintering Technique) which generates a current travelling directly through the part, whereby processes in the micro scale („SPS" = Spark Plasma Sintering) can activate and assist the consolidation process [7]. The direct heating of the part and pressing tool systems, which is specially tailored to the part geometry and material, allows the fabrication of high quality and homogeneous parts in very short time periods. FAST/SPS sintering machines with 50 to 2500 kN maximum pressing force are already in the field of material development, pilot and small series production for several years very successfully. Now they are used more and more for real production purposes [4,8], triggering continuous and targeted enhancements for further improved cost efficiency and part quality. Three important development directions are listed in Fig. 4 and will be explained in the following:

Hybrid Heating:

This method is especially suitable for the rapid sintering of large-area components. By application of a well-directed, additional heating of the FAST/SPS pressing tool system from the outside the temperature gradients already minimised by an optimized design can be further reduced significantly and a continuing improvement of the heating rate becomes possible. The above mentioned optimization of the pressing tool as well as of the hybrid heating can be conducted by finite-element-simulation [9–12] (Fig. 5). The important influence of an optimally designed pressing tool on the temperature homogeneity of the component and the further improvement due to hybrid heating technology is presented in Fig. 6. In practice the excellent temperature homogeneity during the complete heating and sintering process leads to a sintering interval, which is much narrower and runs at significant lower temperatures (Fig. 7). This makes further time and energy savings possible. Additionally the sintered component shows optimal, homogeneous material properties.

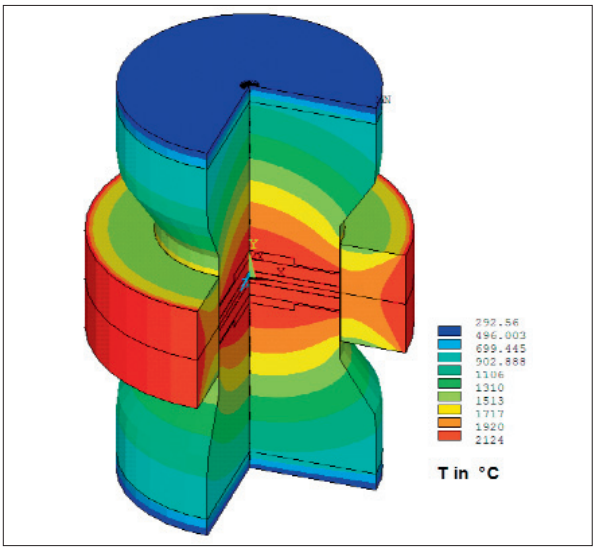

Fig. 5
Temperature distribution in a FAST/SPS pressing tool system during sintering of a binderless tungsten carbide disc 200 mm Ø × 10 mm 100 K/min up to 2100 °C (finite element simulation)

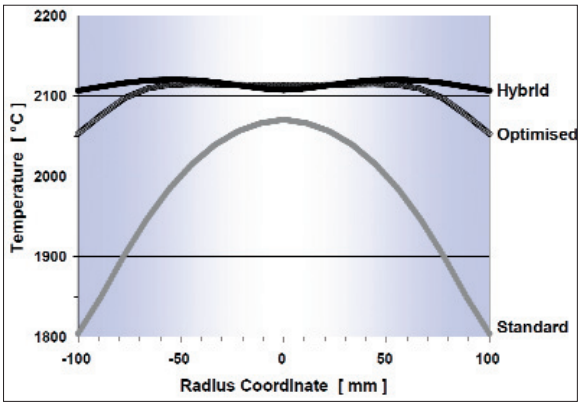

Fig. 6 Homogenisation of the temperature distribution of the component of Fig. 5 by optimisation of pressing tool and hybrid heating (finite element simulation)

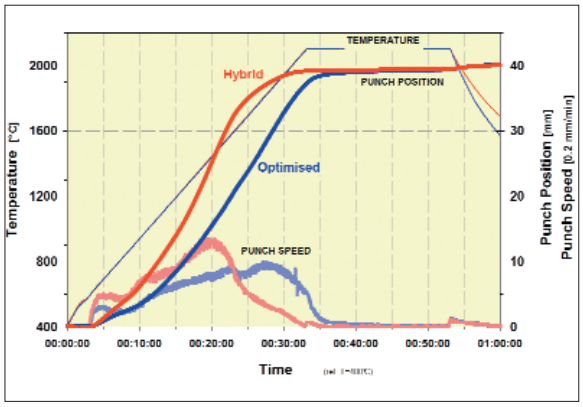

Fig. 7 Improvement of the sintering behaviour of binderless tungsten carbide discs 200 mm Ø × 10 mm by hybrid heating (comparison of real sintering cycles)

Semi-Continuous Sintering Cycle

Semi-continuous FAST/SPS systems are working with multiple process chambers, which enable a decoupling of the actual sintering procedure from the – especially for larger components time consuming – cooling process and possibly the pre-heating procedure too. This results in a multiplication of the production capacity of the sintering system. Fig. 8 explains this principle by means of temperature curves, again for the former example of a 200 mm Ø x 10 mm tungsten carbide disc: already with a relatively simple two-chamber semi-continuous system the timing cycle can be reduced from 85 minutes to only 36 minutes.

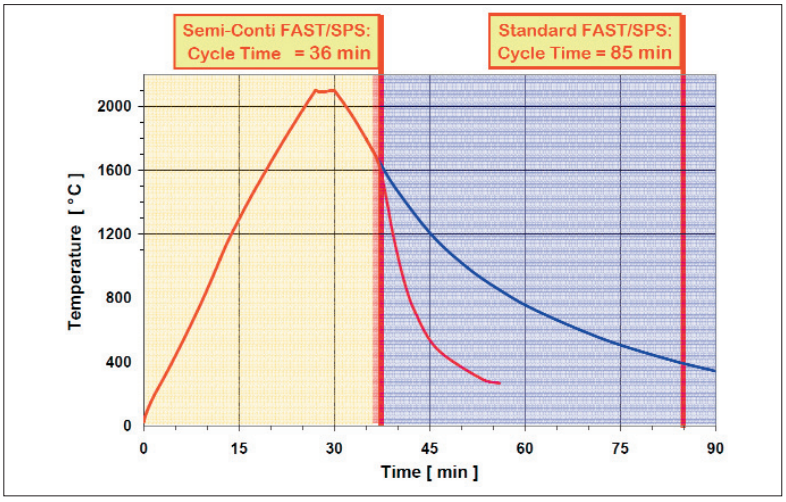

Fig. 8: Shortening of timing cycle by decoupling of sintering and cooling procedure of binderless tungsten carbide discs Ø200x10 mm

Ultra-fast FAST/SPS-Technology „FAST²"

The development of „FAST²" systems was inspired by the vision of a dry powder press system, producing not only powder compacts, but completely sintered components. Accordingly the procedure is similar to a conventional powder pressing process with the steps of „filling" – „covering" – „pressing" – „ejecting", but completed by the sintering step (after the pressing step), using a specialized integrated pressing tool system with associated power supply and measurement & control systems and realising heating rates of thousands of degree per minute. „FAST²" is especially suitable for large volume production of smallish components with relatively simple geometry.

Outlook

The above presented development directions of short-time sintering technology are showing a trend, which will be enforced more clearly in the future, namely the well directed advancements of short-time sintering systems, triggered by the requirements of the user. This will be done precisely tailored for special application fields, materials or even definite components, with the aim and the result of a significant improvement of the cost and resource efficiency of the fabrication of powder metallurgical and ceramic high-quality components. An example is the newly developed 250 kN FAST/SPS system, shown in Fig. 9.

Fig. 9 Newly developed 250 kN FAST/SPS system

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