Sintering 2000: Conference Report

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The presentations made during Sintering 2000 (7th International Conference on Sintering), organised under the auspices of the International Institute for the Science of Sintering (IISS), Belgrade, are reviewed here. The conference was divided into 15 Technical Sessions for the invited and contributed papers. The sessions were grouped as: Fundamentals; Advanced Processing Methods; Ferrous Materials; Non-Ferrous/Intermetallic Materials; Oxide Ceramics; Non oxide Ceramics; Cermets; Ceramics Matrix Compounds; and, Electronic Materials.

Sintering 2000 (7th International Conference on Sintering), organised under the auspices of the International Institute for the Science of Sintering (IISS), Belgrade, was held in New Delhi, India, from 22-25 February 2000. Since 1975, IISS has been periodically organising international conferences in different countries, e.g. Yugoslavia (1975), Poland (1979), India (1983), Canada (1991) and China (1995). The current Conference is first in the 21st century and in the new millennium. It is not surprising that it has been held in India, which has to its credit the biggest ancient man-made sintered artifact, the famous iron pillar of Delhi not hitherto manufactured anywhere. Like earlier conferences, the thrust was not much on the number of delegates but on the quality of deliberations. The conference attracted about 100 participants from 16 countries. From overseas, the registrants were as follows: Israel (7); Japan (5); USA (4); UK and Germany (3 each); Sweden and France (2 each); and, Australia, Austria, Canada, South Korea, Taiwan, South Africa, Yugoslavia, Brazil and Spain (1 each).

In all, there were 72 technical papers, out of which a few could not be presented. Luckily, their places were taken by alternate papers. Scheduling of the program and its strict monitoring by the Session Chairmen were done in such a fashion that the participants either from metal or ceramic sector found enough store of information. Invited papers were each allotted 25 minutes while the contributed ones 15 minutes each.

In the brief Inaugural Session, welcome address by Prof. G S Upadhyaya was followed by those by Dr. Ashok Mohan, President of Powder Metallurgy Association of India, Prof. S Somiya (Japan) (Hon. Member, IISS), Prof. I R Harris (U.K.) and finally a message from the Secretary-General of the IISS, M M Ristic. The recently published book by Prof. G S Upadhyaya, entitled ‘Sintered metallic and ceramic materials (John Wiley, U.K.)’ was released by Prof. Somiya.

After the brief inaugural session, the keynote lecture was delivered by Prof. Rex Harris of the School of Metallurgy and Materials, University of Birmingham (U.K.). He masterly reviewed various sintered rare earth permanent magnets, particularly NdFeB. For better properties, there is need for the composition to move towards stoichiometry. This presents difficulties with regard to their sintering process since there is a corresponding fall in the properties of grain boundary liquid phase and this necessitates very careful control by the oxygen content during production. At the end, he highlighted future scenario aimed at reducing production costs and improving performance.

Session on Fundamentals

Professor G S Upadhyaya opened the session with his invited paper entitled ‘Some issues in sintering science and technology’. He particularly emphasized on the role of additives in changing the sintering kinetics. A need for bridging the gap between sintering theory and practice was also demonstrated. He pin-pointed the limitations of various models, which severely depended on morphological features, ignoring the very basic chemical nature of the materials concerned. Professor Yuri Kornyshev (Israel), in his invited paper ‘Inhomogeneously distributed defects in solids’ proposed a concept of inhomogeneous locally random distribution of microdefects in crystalline solids. He correlated such defects with properties like electric conductivity, Hall
effect and magnetoresistance. During his invited presentation ‘Three-dimensional computer modelling of grain growth and pore shrinkage during sintering’, Professor G Tomandl (Germany) showed very instructive computer simulated pictures for three cases; pores at grain corners, pores at grain boundaries and pores within grains. Individual grains were allowed to change their positions within these three cases. In the absence of Prof. R M German (USA), his earlier colleague and co-author Dr Anish Upadhyaya (India) described the results of liquid phase sintering heavy alloys aboard the space shuttle Columbia as a part of the International Microgravity Lab (IML-2) and Microgravity Space Lab (MSL-1 and MSL-1R) while discussing the invited paper ‘Gravitational effect on compact shaping and microstructural evolution during liquid phase sintering’. It was concluded that liquid phase sintering was allowed over a wide range of solid-liquid ratios than possible on earth. Prof. T R Ram Mohan (India) discussed the role of point defects in the sintering behaviour of high purity alumina ceramics, particularly the role of niobia on sintering. The sequence during sintering was necking, clustering of grains, faceting, abnormal grain growth, pore formation, pore growth, and nucleation, growth and separation of second phase. Another invited paper ‘Computer-aided control of the evolution of microstructure during sintering’ was presented by Prof. P C Kapur (India), in which he elaborately described the effect of particle size distribution and time temperature cycle on the evolution of microstructure of alumina-zirconia ceramics. Dr Peter Morgan (USA), in his invited presentation ‘Does bulk diffusion ever control sintering of ceramic materials?’ very lucidly propounded that the boundary phenomena are almost always rate controlling.

Advanced Processing Methods

The opening invited paper in this technical session was by Prof. D K Agrawal (USA), describing ‘Microwave processing of ceramics, cermets, powdered metals and transparent ceramics: Recent developments’. He vigorously advocated the utilization of this technology for almost all materials and claimed the achievement of properties at much lower sintering temperatures and time. The participants were equally sceptical in mass production of commercial products like structural parts by this process and their dimensional tolerances. The other invited presentation was by Prof. Mats Nygren (Sweden) on spark plasma sintering, confirming the rapid material transport and densification at lower temperatures and short holding times by the process. He gave an example of fully dense pseudobinary system Al2O3-Y2O3-Al2O3, obtained by heating appropriate powder mixtures to 1573 K at the rate of 600 deg/min with no holding time at all.

Mr D R Sahu, in his contributed paper ‘Sintering of Al-Zr based oxide ceramics by thermal plasma’, highlighted the significance of residual porosity, microstructure, grain size and grain boundaries of the material in achieving the resultant properties.

Ferrous Materials

Prof. Paul Beiss (Germany) opened this session by his invited presentation ‘Structure properties relationships of porous sintered steels’. He masterly demonstrated how average pore characteristics are unsuited to be correlated with mechanical performances. Fatigue fractures for instance are initiated only at large irregular pores, never at small round pores. He also presented some new results on the fully reversed flat bending fatigue data of sintered steels. Dr H Danninger Austria), in his invited presentation ‘Processes in P/M steel compacts during the initial stages of sintering’ described in depth the desorption of gases, reduction of surface oxides, neck formation and dissolution of carbon and other alloying elements in steels. He discussed that the formation of stable necks in steel-graphite is retarded until dissolution of graphite has occurred to a significant extent. Prof. J M Torralba (Spain), contributed the paper ‘Microstructural evolution in HSS parts obtained by a modified MIM process’, in which the subtle differences between M2 and T15 high speed steels were highlighted.

Dr K S Narasimhan (USA), in his masterly presented invited paper ‘Transient liquid phase sintering application and commercial practice’, made an overview of the whole ferrous alloy systems. Prof. J M Torralba (Spain), in another invited presentation studied the sinterability of the bronze and phosphorus bronze steels. Detailed dilatometric studies were presented and the sintering temperature of 910°C was found to be sufficient to achieve the end results. Other two invited papers in this session were from Japan and India, respectively. Dr. Akira Fujiki (Japan), described in detail the present status and the future prospects of P/M parts application for automotive industries. Mr S R Sundaram reviewed the sintered component production in Asia-Oceania. In another contributed paper of Dr Danninger, ‘Dissolution of
different graphite grades during sintering of P/M steels, the investigations related to Fe-0.8% C steel. It was concluded that the selection of graphite grade is important especially for presintering prior to further treatment. The dissolution of graphite increases hardness and improves particle strength. Prof. M Hamidi (India), in his paper 'Machinability of sintered heat treated steels' examined the role of additives, microstructural modification, proper selection of cutting tools, etc. on machinability.

Non-ferrous/Intermetallic Materials
Dr Graham Schaffer (Australia), in his invited paper, discussed liquid phase sintering of various aluminium alloys. The presence of magnesium reduces the surface oxide on aluminium particles, thus facilitating wetting and diffusion. Prof. M C Chaturvedi (Canada), in his invited paper discussed the thermal barrier coatings of Ni-based Superalloys via combustion synthesis/sintering of powders. Two other invited papers in this category were from Prof. K S Hwang (Taiwan) on sintering of molybdenum with nickel and copper additives and Dr Anish Upadhyaya (India) on processing strategies for consolidating tungsten heavy alloys for ordnance applications. Dr P Ghosal (India) discussed on TEM investigations of liquid phase sintered W-Ni-Co system and did not notice any intermetallic phase at interface even at a very high magnification. Dr T P Bagchi (India), in his contribution discussed a case study on sintering of tungsten heavy alloy using various statistical problem solving tools.

Oxide Ceramics
J Lechelle (France), in his lucid presentation discussed the mechanism-based approach for the sintering of MOX nuclear fuel. The numerical schemes of resolution of the problem were conceived in a 2-D case. Dr D K Chatterjee (USA), in his invited paper discussed sintering behaviour and microstructure development of aluminia, zirconia and its composites formed using chelated additives in the binder coagulation casting process. Among the contributed papers, B P Saha (India) spoke on the thermal anisotropy in sintered cordierite monoliths. Dr T D Senguttuvan (India), talked on sintering behaviour of alumina rich cordierite porous ceramics.

Non-Oxide Ceramics
The opening invited lecture in this technical session was of Prof. S Somiya (Japan), who spoke on hydrothermal corrosion of nitride and carbide of silicon. The reaction between Si₃N₄ and/or SiC with water vapour is important for application to engine parts. Prof. F Thevenot (France), in his invited paper entitled 'Liquid phase sintering of silicon carbide: Microstructure design' emphasized the seeding of sintering powder in order to control microstructural features. The system was SiC-3 wt% eutectic composition (60% Al₂O₃-40% Y₂O₃). Dr S K Biswas (India) described the gas pressure sintering of silicon nitride and expressed that the microstructure of the final product is very much dependent on the method of incorporation of additive of the sintering powders. Dr J Mukherji (India) at length discussed the friction and wear aspects of nitrogen based ceramics. Composting dense silicon nitride, with boron nitride and titanium carbide improved wear properties, the maximum improvement being with 15% TiC addition. Dr Rixecker (Germany) of Max Planck Institut für Metallforschung, Stuttgart, presented the invited paper which was to be presented by his co-author Prof. F Aldinger. The title of the paper was 'Microstructure-property relationships in silicon carbide ceramics liquid phase sintered with oxynitride additives'. By starting from a β SiCα SiC mixture and by performing dedicated heat treatments, a platelet-reinforced microstructure was obtained, which gives rise to high values of fracture toughness. Prof. M P Dariel (Israel), in his invited paper 'Graded ceramic preforms: Various processing approaches' described different approaches aimed at generating ceramic preform with the in-built porosity gradient. Some of these approaches rely on the variations of the sinterability of stacked powder layers, e.g., as a function of the carbon content in TiC; of the TiC/TiB₂ ratio and of particle size in B₄C preforms. Mr O.P. Chakraborti (India) highlighted the growth of SiC particles in reaction sintered SiC. Dr S Bandopadhyay (India) discussed the reaction sequences which occurred during sintering of different SIALON compositions in which the author took into account the entire concentration plane Si₃N₄-Al₂O₃-AlN-Y₂O₃-AlN of the system Y-Si-Al-O-N. The last contributed presentation in this group of papers was from Dr A K Jha (India), who spoke on 'Wear behaviour of sintered ceramic matrix composites containing SIALON'.

Cermets
Since the number of presentations in this group were more, these spanned in two sessions. The first invited paper was by Prof. S Kang (Korea) who spoke
on B$_4$C-Al composites. Prof. H O Andre, Chalmers University (Sweden), in the invited paper 'Microstructure development during sintering and heat-treatment of cemented carbides and cerments', described in detail how microscopic techniques like SEM, TEM, including energy filtered TEM were successful in detailed structures studies of both hard and binder phases. In another paper from the group of Prof. Andre, Mr. Robert Frykholm spoke on development of the microstructure during gradient sintering of WC-TiC (C$_3$N)-Co based cemented carbide. The material was sintered in nitrogen free atmosphere, resulting in an outward diffusion of nitrogen. Prof. S Luyckx (S. Africa) reviewed the work done at the University of Witwatersrand on the effect of VC in WC-CO in amounts varying from 0.4 wt% to 10 wt%. When added in amounts larger than 1 wt%, it was found that VC is useful substitute for WC. Dr Ken-ichi Takagi (Japan), in his invited paper 'High tough boride based cerments produced by reaction sintering', described how by enhancing the reaction kinetics the formation of the brittle third phase is prevented. Dr S Banerjee (India), in his invited paper 'Net-shape forming of Bi-continuous Al$_2$O$_3$ compositions by displacement reaction', although not strictly falling in the domain of sintering, described a product with 74 vol% Al$_2$O$_3$-26 vol% Al($\text{Si}$) composition. The special feature was more or less isotropic linear shrinkage. Prof. A N Tiwari (India), spoke on compaction and sintering behaviour of glass-alumina composites. Alumina was found to exert a strong inhibiting influence on the densification as it increases the activation energy for sintering from 67 to 123 kcal/mol. Mr Pradyot Datta (India) presented an interesting paper on the effect of CrB addition on sintering of 316L/434L stainless steel - 10 v/o Cr$_3$C$_2$ composites. The study also included mechanical, magnetic and corrosion properties of these cerments. Prof. G S Upadhyaya (India), in the paper 'Sintered porous cerments based on TiB$_2$ and TiB$_2$-TiC-Mo$_2$C', showed that the maximum volume of transverse rupture strength was found for TiB$_2$-TiC-Mo$_2$C-40 wt% Ni/Mn cermet.

Ceramic Matrix Composites

Dr T Watanabe of Kyushu National Industrial Research Institute (Japan) described a new multi-layer composite with super-plastic layer, a hard layer and a weak interface. Such multi-layer composites were prepared by tape casting in the Al$_2$O$_3$/TiC/MoSi$_2$ - Mo$_2$B$_3$ systems. Dr K G K Warrier (India), in another invited paper 'Densification of mullite-SiC nanocomposite sol-gel precursors by pressureless sintering', showed that seeded mullite had interesting features like low temperature phase transformation at ~1250°C and densification at a lower temperature of 1350°C resulting in finer grained (~3 nm) microstructure. Ms S Mohanty (India), in her presentation spoke on the influence of sintering characteristics close to melting temperature on magnetic and transport properties of lanthanum based calcium manganate CNR composites.

Electronic Materials

Prof. B D Stojanovic (Brazil), in her invited paper 'Synthesis and characterisation of 9.5/65/35 PLZT prepared by the polymeric precursor method', compared the processing and end properties of the PLZT ceramics prepared by Pechini and partial oxalate methods, respectively. Mr B E Davis of the University of Birmingham (U.K.), discussed recent developments in the sintering of NdFeB. The effect of composition on the densification kinetics was described using a powder blending technique to vary the composition prior to sintering. Dr. Chandra Prakash (India) reported on the influence of Mn-substitution on densification and dielectric properties of modified PZT. Dr L Mancic (Yugoslavia) talked on the sintering of Bi-based superconducting powders through the freeze drying. The synthesized sintered agglomerate powder had irregular shape, smooth surface with an area of 2.5 m$^2$/g and the mean crystallite size of 231 nm. Mr Manoj Kumar in his contribution on synthesis, characterisation and properties of [Re$_x$I$_y$]NbTiO$_6$ ceramics for dielectric resonators in microwave circuits.

Valedictory Session

In the valedictory session of Sintering 2000, representatives of different continents presented their impressions on the Conference. They were unanimous that Sintering 2000 was a trend-setter in the new Century and hoped that the future conferences will also maintain the standards set by this conference. The Chief Guest, Prof. S K Joshi, ex-DG, CSIR, emphasized on the multidisciplinary approach of sintering studies. Prof. G S Upadhyaya gave the vote of thanks and announced that the published proceedings of this conference are to be dedicated to the memory of late D Kolar, a member of the Conference International Committee, who died recently. The next International Conference 'Sintering 2004' is likely to be organized in Israel.