

The 7th International Conference on Nanomaterials by Severe Plastic Deformation: a report of the International NanoSPD Steering Committee

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Abstract. The 7th International Conference on Nanomaterials by Severe Plastic Deformation (NanoSPD7) is hosted by the University of Sydney (Australia) following a series of earlier conferences: in Moscow (1999), Vienna (2002), Fukuoka (2005), Goslar (2008), Nanjing (2011) and Metz (2014). This introductory paper reports on several major developments in NanoSPD activities as well as on recent NanoSPD citation data which illustrate the growth and expansion of this important research area for the time period following the conference in Metz. Close attention is given to topics of nanostructuring of metals by SPD processing for advanced properties and on new trends in developing SPD techniques for practical applications. A special concern of the committee is the appropriate terminology that is used in this new field of science and engineering as well as the innovation potential of recent applied studies and developments.

1. Introduction

In recent years there has been growing interest in bulk nanostructured materials produced by severe plastic deformation (SPD) processing, as demonstrated by the increasing numbers of publications with high citations as well as numerous specialized conferences, workshops and symposia on the subject (www.nanospd.org). The conferences of the NanoSPD series serve as a live-to-live platform allowing the attendees and contributors to present and share the most cutting-edge research and receive feedback from colleagues, attend numerous exciting sessions and become aware of the innovative studies in particular areas of research. These conferences have been held all over the world, starting in 1999 (Moscow, Russia) and then continuing in 2002 (Vienna, Austria), 2005 (Fukuoka, Japan), 2008 (Goslar, Germany), 2011 (Nanjing, China), 2014 (Metz, France) and now in Sydney, Australia. This latest meeting offers even more stimulus for scientific and applied research and summarizes the important events related to NanoSPD and to the activities of the International NanoSPD Steering Committee.

This introductory report is designed to present a summary of the main results that have occurred in NanoSPD over the last three years since our meeting in Metz, France, in 2014 with its record-breaking 428 participants from 42 different countries and to discuss the important achievements and provide a performance summary. In addition, statistics on publication citation data are presented to illustrate the major impact of NanoSPD within the broad field of Materials Science.

2. Main events and publications as a platform for the exchange of ideas and research in the NanoSPD field

Major NanoSPD related conferences and symposia over the period 2014-2017

The last three years since the 6th International Conference on Nanomaterials by Severe Plastic Deformation (NanoSPD6) in Metz, France, have witnessed extensive and profound research in the NanoSPD area with a number of international conferences and meetings, thus providing a sustainable content for thorough exchange within the research community, industry representatives and emerging experts to bring the ideas from a laboratory scale to the mass production of products as well as to offer the participants an opportunity for networking with new people within the field, cultural activities and receptions to establish new connections and ties. Of the primary events aimed at enhancing research in these areas, the authors would like to emphasize the following:

The 69th ABM International Annual Congress, the annual meeting of the Brazilian Metallurgical Association, was held in Sao Paulo, Brazil, on July 21-24, 2014. Incorporated within the meeting was the Second Pam American Materials Conference co-sponsored by TMS and consisting of several English-language symposia on topics of current interest. One of these symposia was a one-day meeting on Ultrafine-Grained Materials organized by Roberto Figueiredo and Terence Langdon. This symposium was well-attended and contained several presentations of interest to members of the NanoSPD community.

22nd International Conference on Metastable and Nano Materials (ISMANAM) held on July 13-17, 2015 in Paris, France, was a success as a multidisciplinary forum promoting international scientific and technological exchanges on all aspects related to metastable, amorphous and nanostructured materials, in particular, produced by severe plastic deformation.

The 5th International Symposium on Bulk Nanostructured materials: from fundamentals to innovations (BNM-2015) was held on August 26-28, 2015 in Ufa, Russia, by the Institute of Physics of Advanced Materials of Ufa State Aviation Technical University (IPAM USATU). The symposium was dedicated to the 20th anniversary of IPAM USATU, headed by Prof. Ruslan Valiev. The symposium covered the following topics: New trends in SPD, Physical and mechanical properties of BNM, Microstructure evolution and phase transformations, Grain boundary engineering of UFG materials, Computer modeling and texture analysis. The specific feature of this symposium was its special focus on practical applications of nanoSPD materials. That is the reason for organizing a round-table on “Innovation trends and mechanisms & commercialization of BNM”.

International Workshops on Giant Straining Process for Advanced Materials (GSAM 2015, GSAM2016) were held on September 3-6, 2015, and July 28-31, 2016, in Fukuoka, Japan, by the International Research Center on Giant Straining for Advanced Materials (IRC-GSAM) at Kyushu University to discuss the topics from structural properties as well as from functional properties of the SPD-processed materials. The workshop proceedings were published under the title «Exploring SPD Potential: Innovative Approach for Production of High-Performance Materials» and «Promoting Functionality by Severe Plastic Deformation: Significance of Lattice Defects and Phase

Transformation» (The proceedings are available upon request to zenjiorita@gmail.com). As a GSAM series of workshops, GSAM2017 is planned on September 2-5, 2017, in Fukuoka, Japan, to promote exchanging idea of different fields and pursue new emerging research topics (visit <http://irc-gsam.kyushu-u.ac.jp/index-e.html> for more information).

International Conference on Superplasticity in Advanced Materials (ICSAM 2015), including a session on Severe Plastic Deformation was held on September 7-9, 2015, in Tokyo, Japan, with approximately 130 presentations, more than 160 participants and 3 exhibition-making companies from over 20 countries. Many presentations were focused on the superplasticity of ultrafine-grained alloys from SPD processing, their unique behavior and potential for applications.

The 14th International Union of Materials Research Societies-International Conference on Advanced Materials (IUMRS-ICAM 2015) was held on October 25-29, 2015, at the Jeju International Convention Center in Jeju, Korea. IUMRS-ICAM, a bi-annual conference, once again provided great opportunities for scientists, researchers, engineers and business executives from all parts of the world not only to exchange the latest knowledge but to share the state-of-art techniques in the field of material sciences.

During the event, Prof. Ruslan Valiev (Russia) and Prof. Yuntian Zhu (U.S.A.) received the 2015 Somiya Award (presented biennially by the International Union of Materials Research Societies (IUMRS) for the most significant research conducted by an interactive group or team whose members are drawn from at least two continents) for resolving the paradox of superior strength and ductility of ultrafine-grained metals through microstructural design (Fig. 1). This is the second time this award has been given to members of the NanoSPD International Steering Committee because in 2005 the award was presented to Prof. Zenji Horita (Japan) and Prof. Terry Langdon (U.S.A.).



Figure 1. Prof. Valiev receiving the awards on behalf of both recipients presented by General Secretary of IUMRS, Prof. Robert P.H. Chang (center) and the Conference Chair, Prof. Soo Wahn Lee (right).

EUROMAT 2015 including a session on Severe Plastic Deformation and Nanostructuring was held on September 21-24, 2015, in Warsaw, Poland, and hosted by the Warsaw University of Technology, the oldest and the largest technical university in the country. The event witnessed an increased record of bringing together up to 2000 researchers, scientists, trainees, and students from both academia and industry to discuss critical developments and perspectives in the field of materials science and technology and their applications.

In 2015 Warsaw University of Technology celebrated its 100th anniversary of the university and the introduction, 45 years ago, of classes in metallurgy and materials science. In a special award ceremony conducted in the University on September 25, 2015, seven senior professors were presented with Friend of the Faculty Awards to mark their long-term collaborations with the Faculty of Material

Science and Engineering at Warsaw University of Technology. Two of the awardees were Prof. Michael Zehetbauer (University of Vienna) and Prof. Terry Langdon (University of Southampton) who were recognized specifically for their collaborations in the field of NanoSPD.

International Biennial Conference on Ultrafine Grained and Nanostructured Materials (UFGNSM 2015) was held on November 11-12, 2015, in Tehran, Iran, following the success of a series of biennial conferences focused on ultrafine-grained and nanostructured materials. The event was jointly organized by University of Tehran, Iran, and University of Trento, Italy. The conference topics were fully covered in *Procedia Materials Science* with 100 papers devoted to bulk nanostructured materials, advanced characterization techniques, nanobiomaterials, nanoelectronic and magnetic materials, synthesis and nanofabrication, modeling and simulation of UFGNSM, nanocoatings and thin films, and nanocomposites.

2016 TMS Annual Meeting with the 9th International Symposium on Ultrafine Grained Materials (UFG IX) was held on February 14-18, 2016, in Nashville, Tennessee, USA. This symposium, as with previous symposia in the series, attracted a wide audience and many topical papers describing recent developments in NanoSPD.

THERMEC 2016 was held from May 30 to June 3, 2016 in Graz, Austria and covered all aspects of processing, fabrication, structure/property relationships and applications of various metallic materials. In the framework of the conference, Professor Reinhard Pippan of the Erich Schmidt Institute of Materials Science in Leoben, Austria, received a THERMEC Distinguished Award for pioneering research in the field of fatigue/fracture and severe plastic deformation of advanced materials and for leadership in materials education in Austria (Fig. 2).



Figure 2. Professor Reinhard Pippan of the Erich Schmidt Institute of Materials Science in Leoben, Austria (on right) receiving THERMEC Distinguished Award from Terry Langdon (left).

2016 Engineering Mechanics Institute International Conference (2016-EMI-IC), including a mini-symposium on Severe Plastic Deformation was held on October 25-27, 2016 in Metz, France. The symposium was organized by Prof. Laszlo Toth and devoted to priority trends in NanoSPD through 28 lectures.

An Internet discussion forum has been created by the Metz research group on SPD issues:

www.lem3-univ-lorraine.fr/forumspd/phpBB3. After inscription to the forum, one can make questions on research topics which can be answered by others and the dialogue can be followed by the members of the forum.

2017 TMS Annual Meeting was held from February 26 to March 2, 2017, in San Diego, California, USA. This comprehensive annual meeting was dedicated to fostering the exchange of learning and ideas across the entire range of materials science and engineering, from minerals processing and primary metals production, to basic research and the advanced applications of materials and the meeting included the following SPD-related symposia: Nanocrystalline and Ultrafine Grain Materials and Bulk Metallic Glasses, Multiscale Architected Materials (MAMII): Tailoring Mechanical Incompatibility for Superior Properties Mechanical Behavior of Advanced Materials.

Major NanoSPD related reviews, special issues and books on NanoSPD research over 2014-2017

A number of new reviews and special issues on the results of recent NanoSPD materials-related studies and developments were published following the NanoSPD6 conference in Metz, France, in 2014. The authors would like to draw attention to some significant key publications during the period under review and these are now summarized:

Nanofabrication using Nanomaterials, edited by J. Ebothe, W. Ahmed, One Central Press (OCP) 2014, The book consists of seven chapters considering nanofabrication as a technical procedure for the preparation or the synthesis of a nanomaterial as well as a project of building a particular system wherein the nanomaterial plays a significant role.

K. Edalati, Z. Horita, *A review on high-pressure torsion (HPT) from 1935 to 1988*, *Mater Sci Eng A* 652 (2016) 325-352 reviewing the findings of Bridgman and his successors from 1935 to 1988 using the HPT method and summarizing their historical importance in recent advancement of materials, properties, phase transformations and HPT machine designs.

I. Sabirov, N.A. Enikeev, M.Y. Murashkin, R.Z. Valiev, *Bulk nanostructured materials with multifunctional properties*, Series: SpringerBriefs in Materials, Springer, 2015, IX, 161 p written by researchers at the forefront of this new materials design approach, the present volume provides a comprehensive introduction to multifunctional design of bulk nanostructured materials, with applications ranging from hydrogen storage to construction engineering.

R.A. Andrievsky, A.V. Khatchoyan, *Nanomaterials in Extreme Environments: Fundamentals and Applications*, Springer Series in Materials Science, vol. 230, Springer 2016. This book focuses on the behaviour of nanomaterials under extreme conditions of high temperature, irradiation by electron/ions and neutrons as well as in mechanical and corrosion extremes. The theoretical approaches and modeling are presented with numerous results of experimental studies as well as the examples of many applications and some unresolved problems.

R. Z. Valiev, Y. Estrin, Z. Horita, T. G. Langdon, M. J. Zehetbauer, Y.T. Zhu, *Producing bulk ultrafine-grained materials by severe plastic deformation: ten years later*, *JOM*, vol. 68, No. 4 (2016) pp. 1216-1226 to provide, exactly ten years after the first article with a similar title was published in JOM in the issue dated April 2006, an update to the fast-moving and challenging field of the fabrication of bulk ultrafine-grained (UFG) materials through the application of severe plastic deformation (SPD) and to give a description of new developments in the production and properties of UFG materials.

Severe Plastic Deformation Technology, edited by A. Rosochowski, Whittles Publishing, Dunbeath, Scotland, UK, 2016, covering the most popular SPD process of equal-channel angular pressing, ECAP and its incremental version, I-ECAP. A separate chapter is devoted to tooling used in ECAP/IECAP. Another popular SPD process is high-pressure torsion (HPT) which produces very good results in terms of refining grain structure but faces some interesting challenges. A less known SPD process is cyclic extrusion compression (CEC), which is thoroughly explained in the book as is twist extrusion (TE) which is a relatively new process that is showing good potential. Finally, an original SPD process of accumulated roll bonding (ARB), capable of refining grain structure in sheets, is discussed.

Defect Structure and Properties of Nanomaterials, 2nd Ed, J. Gubicza. Elsevier, 2017, provides a detailed overview of processing methods, defect structure, and defect-related mechanical and physical properties of nanomaterials and includes new chapters on recent advances in both processing techniques and methods for the study of lattice defects.

3. Citation statistics for publications in NanoSPD

Over the last years several special articles have been published dealing with the historical background of the NanoSPD research [1,2]. From an historical viewpoint, the processing of metals through the application of severe plastic deformation has a long history dating back to the fabrication of steels in ancient China more than 2000 years ago [3] and the subsequent development of Wootz steel in India [4]. Nevertheless, the first scientific reports of processing by SPD appeared about eighty years ago with the work of Bridgman at Harvard University in the United States [5]. These early reports were devoted exclusively to the mechanical characteristics associated with the processing operation and it was only later, in 1988, that the first reports appeared in the scientific literature documenting the ability to achieve ultrafine-grained (UFG) microstructures through SPD and the consequent exceptional properties that may be attained in these materials [6] using HPT and later by ECAP [7]. This was subsequently followed, in 1993, by the first publication from an international team describing the properties of an aluminum alloy processed by SPD with an emphasis on the flow properties and the dependence on strain rate at elevated temperatures [8]. In practice, these early reports led to further publications from several different laboratories and gradually to the development of a worldwide interest in the processing and properties of UFG metals.

It is apparent from this brief summary that NanoSPD is a relatively new field within Materials Science having a scientific history of less than 25 years. Nevertheless, the impact of NanoSPD has been considerable to the extent that this topic now competes easily with more conventional and well-established topics in Materials Science such as flow behavior and crystalline plasticity, the effects of alloying, phase transformations and traditional subjects such as creep, fracture and fatigue. Three earlier reports examined the impact of NanoSPD using citation data that was current at the time of publication [9-11] and this paper follows this earlier tradition by reporting citation data collected from Thomson Reuters Web of Science in March 2017.

The citation data are collected in five Tables covering five of the major journals currently published in the field of Materials Science. Each journal is contained within a different listing in Tables 1 to 5 and for each journal there is information on the total numbers of papers published to date and the Impact factor (IF) for the journal. Within each Table, papers relevant to the field of NanoSPD are listed where these are the papers contained within the top ten all-time most cited articles appearing in each journal. Thus, Table 1 is for *Progress in Materials Science* - a major review journal devoted exclusively to publishing long review articles on selected topics. Inspection of Table 1 shows that this journal has published a total of 501 papers and the IF is exceptionally high at >36. It is remarkable that four of the all-time top ten papers in this journal are from NanoSPD and this includes the papers

in the 1st, 3rd, 4th and 5th positions. Data for *Acta Materialia* are given in Table 2 where again there are four papers in the top ten and in Table 3 for *Scripta Materialia* with five NanoSPD papers in the top ten, including the papers lying in the 1st, 2nd and 3rd positions. Table 4 lists results for *Materials Science and Engineering A* where there are more than 28,000 published papers and yet four of the top ten are again from the field of NanoSPD. Finally, Table 5 contains data for *JOM* which is a U.S. journal primarily publishing invited papers and distributed as a house magazine to all members of TMS. It is apparent that *JOM* contains two NanoSPD papers within the top ten.

As already noted, the numbers collected in Tables 1-5 correspond to data available on the internet in Web of Science as of March 2017. These numbers will gradually increase with time as more citations become available but the overall trends will remain reasonably unchanged. A good indication of the changes occurring over a long period of time may be gained by comparing these data with those published earlier for the NanoSPD6 conference [11]. The important conclusion from this analysis is that reports on NanoSPD have had a major impact within the field of Materials Science and they account for four or five of the all-time most-cited papers in several major journals.

Table 1. All-time ranking for *Progress in Materials Science* (501 papers; IF = 36.083)

Ranking	Author(s)	Year	No. of citations	Reference
1	Valiev <i>et al.</i>	2000	4157	[12]
3	Gleiter	1989	3102	[13]
4	Valiev and Langdon	2006	2139	[14]
5	Meyers <i>et al.</i>	2006	1976	[15]

Table 2. All-time ranking for *Acta Materialia* (12,518 papers; IF = 5.058)

Ranking	Author(s)	Year	No. of citations	Reference
2	Gleiter	2000	1743	[16]
4	Kumar <i>et al.</i>	2003	1272	[17]
5	Saito <i>et al.</i>	1999	1232	[18]
6	Iwahashi <i>et al.</i>	1998	989	[19]

Table 3. All-time ranking for *Scripta Materialia* (10,863 papers; IF = 3.305)

Ranking	Author(s)	Year	No. of citations	Reference
1	Iwahashi <i>et al.</i>	1996	1426	[20]
2	Saito <i>et al.</i>	1998	810	[21]
3	Tsuji <i>et al.</i>	2002	641	[22]
5	Mukai <i>et al.</i>	2001	586	[23]
8	Nieh and Wadsworth.	1991	443	[24]

Table 4. All-time ranking for *Materials Science and Engineering A* (28,458 papers; IF = 2.647)

Ranking	Author(s)	Year	No. of citations	Reference
2	Segal	1995	1779	[25]
4	Valiev <i>et al.</i>	1993	1016	[26]
5	Furukawa <i>et al.</i>	1998	836	[27]
6	Valiev <i>et al.</i>	1991	798	[7]

Table 5. All-time ranking for *JOM* (1890 papers; IF = 1.05)

Ranking	Authors(s)	Year	No. of citations	Reference
2	Valiev <i>et al.</i>	2006	798	[28]
9	Ma	2006	232	[29]

4. Innovation activity

Over the last few years, studies of bulk nanostructured materials tend to be oriented more toward the development of their advanced and superior properties and in this context the concept of nanostructural design plays an important role. In addition to grain refinement down to the nanometer range, grain boundary structure engineering is also important because boundaries having different structures can exhibit specific transport mechanisms, in terms of deformation and diffusion, and this can be used to control the properties [28,30]. This opens up the potential for developing new ways for improving the properties of various ultrafine-grained materials.

Attention to commercial production of nanostructured metals is being motivated by the increasing maturity of SPD technology and the ever-growing number of published reports on the notable properties achieved in a widening range of alloys. Companies are seeking to evaluate or develop nanostructured alloys to use in existing and prospective new products, often working with the assistance of university labs or research institutes that conduct SPD research. For example, the Ufa State Aviation Technical University established a spin-off company NanoMet Ltd. already in 2009. The company's objective was to organize in Ufa the first in the world pilot-commercial production of semi-products (rods) from nanostructured titanium for medical applications. Since 2010, NanoMeT has been commercially producing semi-products (rods) for nanostructured titanium for medical applications. In 2012 NanoMeT received the international ISO 9001:2008 certificate for its quality management system. To date, NanoMeT has mastered the production of long-length rods (over 2.5 m in length) with a diameter of 3-8 mm. The estimated production capacity is 2 tons per year [31].

The development of commercial production methods is being also systematically addressed at the Nanostructured Metals Manufacturing Testbed facility established in Golden, Colorado, in association with the Colorado School of Mines. This facility has multiple SPD machines networked together to transition research scale SPD processing into pilot scale production. Scale up of production rates and billet sizes have been demonstrated for alloys of magnesium, aluminium, titanium, copper, and iron [32]. Product development effects within this pilot scale manufacturing environment show the roles of enabling technologies such as on-machine process monitoring, design of tooling for high pressure, specialized lubrication schemes, and non-isothermal forming processes.

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