Progress in NanoSPD research through scientometric analysis

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Abstract. In this paper, we use the scientometric approach based on the Web of Science Core Collection to analyze the data on publication activity in the area of nanostructured materials processed by severe plastic deformation (SPD) techniques on the following three main topics: ultrafine-grained materials, severe plastic deformation and bulk nanostructured materials. The results marked early 1990s as the starting period for first publications in question as well as their fast development. Pioneer works by Prof. Valiev and his laboratory at that time and their role in the growth of nanoSPD-related research were outlined.

1. Introduction

NanoSPD research, that is the study of nanostructured materials produced by severe plastic deformation techniques, has been attracting growing interest in the scientific community all over the world and this phenomenon only tends to progress over the recent decade due to fundamental findings and considerable innovation potential. This is easily demonstrated by the vast number of international nanospd-related events held worldwide. In recent years the development of nanoSPD topics has become one the most attractive research directions in materials science, as materials nanostructuring can provide new and unusual properties for a wide range of metals and alloys [1]. With new research comes growing publication activity, in addition there is interest towards the very origin and history of first discoveries in the field and the analysis of future trends; the latter is possible by means of a separate field of study that deals with measuring and analyzing scientific literature, i.e. scientometrics. Its major research issues include the measurement of the impact of research papers and academic journals, the understanding of scientific citations, and the use of such measurements in policy and management contexts [2]. Modern scientometrics is mostly based on the work of Derek J. de Solla Price and Eugene Garfield. The latter created the Science Citation Index, which in turn led to the Web of Science (which is an online subscription-based scientific citation indexing service originally produced by the Institute for Scientific Information (ISI), later maintained by Clarivate Analytics) [3].

Citations in science serve to link similar research items and help to locate publications having most significant impact in a particular field. It also helps to assess current trends and emerging fields of
research. In this case, it is of particular interest to apply such approach to the analysis of nano SPD-related topics so as to follow the development of this field and see its future tendencies.

2. Materials and methods
For the purpose of this research we were using Web of Science Core Collection, including the Emerging Sources Citation Index. To analyze the research output in the topics as a measure of scholarly interest to nano SPD, we have made topical searches for three main nano SPD-related topics: “Ultrafine-grained materials”, “Severe plastic deformation” and “Bulk nanostructured materials”, which effectively returns records containing those words combinations in the paper titles, abstracts, or keywords.

To analyze the most important research outcomes in this topic, we were using the measure of total citation counts according to Web of Science Core Collection. Modern bibliometricians try to refrain from using total citation counts and instead prefer to compare counts for papers of similar age, document type, and in comparable fields. Although, as Van Noorden, Maher and Nuzzo pointed out in [4] the old-fashioned hall of fame based on total citation counts still has value.

3. Results and discussions
In the framework of the present work the following three nano SPD-related topics [5,6] served as the focus of analysis:

1. Ultrafine-grained materials, i.e. polycrystalline materials having grain size less than 1 micron and mostly high-angle grain boundaries;
2. Severe plastic deformation, i.e. heavy straining under high imposed pressure, which is a metal forming procedure for producing ultrafine-grained and nanostructured materials;
3. Bulk nanostructured materials, that is UFG materials having various nanostructural features – nanoparticles, nanoclusters, segregations at grain boundaries, etc.

The topics were applied to conduct the quantitative analysis of publications published between 1900 and 2019 indexed within Web of Science Core Collection. The obtained results are presented in the graphs clearly demonstrating that active publications in these areas started in early 1990s.

![Figure 1](image-url)

**Figure 1.** Showing 4,155 records for topic “ultrafine-grained materials”. The record count in each column is the total number of articles published in the selected year. The count includes Early Access articles that are fully peer-reviewed, citable, and published but have not been assigned a volume/issue/page number.

As is seen, although first publications for the topic “ultrafine-grained materials” had appeared in 1977 and 1980 (one publication per year) [7], “real” publication activity started only in the early 1990s (with 10-12 papers per year) with steady growth until about 2000 when this number experienced a sudden increase, and then another leap can be observed in 2008.
However, the content analysis for the early works published before 1990 (for examples, see [7]) demonstrated that despite the presence of a specific term “ultrafine grains” in the title or abstract or keywords, the paper text was in fact dealing with grain sizes exceeding 1 micron, i.e. considerably larger than included in the present-day definition of ultrafine-grained materials. Yet at the same time the publications of early 1990s include the pioneer research by R.Z. Valiev with co-authors [8-10] as well as a number of international papers [11, 12] authored by T.G. Langdon and Z. Horita and having high citation numbers.

The analytic analysis of the topic “severe plastic deformation” (figure 2) traces the start of publications back to 1964 with 1-2 papers appearing per year until 1991 and 2000 (the number boosted to 14 and 113 accordingly). Over the years, publication activity on this topic has experienced steady and quick growth (+about 100 publications a year), now reaching and maintaining a very high level of productivity such as over 900 publications per year (in 2017 and 2018).

Figure 2. Showing 11,321 records for topic “Severe plastic deformation”.
The analysis of total citations for “severe plastic deformation” provides the following top 5:

| Publication                                         | Times cited |
|-----------------------------------------------------|-------------|
| Valiev, Islamgaliev, Alexandrov, 2000 [13]          | 4,640       |
| Valiev, Langdon, 2006 [14]                          | 2,675       |
| Meyers, Mishra, Benson, 2006 [15]                   | 2,596       |
| Zhilyaev, Langdon, 2008 [16]                        | 1,664       |
| Kumar, Swygenhoven, Suresh 2003 [17]                | 1,055       |

Obviously, the topic of “bulk nanostructured materials” is rather “young” in contrast to other subjects with first publications appearing in the early 1990s with steady growth until 2009 when the number suddenly increased to 269 and keeps at about the same level up until today (figure 3). The analysis of paper citations provides the following top 5:

| Publication                                         | Times cited |
|-----------------------------------------------------|-------------|
| Valiev, Islamgaliev, Alexandrov, 2000 [13]          | 4,640       |
| Poudel, Hao, Ma al, 2008 [18]                       | 3,096       |
| Hochbaum, Chen, Delgado, et al [19]                 | 2,860       |
| Valiev, Langdon, 2006 [14]                          | 2,675       |
| Meyers, Mishra, Benson, 2006 [15]                   | 2,596       |

Thus, the scientometric analysis of publications for topics “ultrafine-grained materials” and “severe plastic deformation” showed that their origin and increase in the total number per year over the study period can be contributed to the articles of early 1990s by the Ufa group of authors from the laboratory of Prof. R.Z. Valiev and to the series of international publications launched by Profs. T.G. Langdon (UK) and Z. Horita (Japan). Further, “bulk nanostructured materials” appeared as a new and exciting topic and has been steadily becoming an essential and integral part of active studies in the field of nanotechnologies and nanomaterials (http://nanospd.asso.univ-lorraine.fr/). Here it is important to note that the most popular devices for imposing large and severe plastic strains were introduced in scientific literature even earlier; that is by Prof. P. Bridgman in 1935 for high pressure torsion [20] and by Prof. V.M. Segal and colleagues in 1981 for equal channel angular pressing/extrusion (ECAP/ECAE) [21]. It was only in the end of 1980s-beginning of 1990s that the implementation of SPD approaches for producing UFG materials and increasing their properties took place, which served as the start of nanoSPD research [22]. Here, a particular publication [12] should be noted that introduced pioneer results of first studies – thus playing a crucial role in forming the entire nanoSPD subject - and outlined new tasks and challenges for further research; the number of its citation presently heads towards 5000, which is among record performance in modern materials science.
Figure 3. Showing 3,435 records for topic “bulk nanostructured materials”.

4. Conclusions
The analysis of nanoSPD research, that is the development of bulk nanostructured materials produced by severe plastic deformation, conducted in the present work shows that scientometric analysis may be an efficient tool to study the history behind the development of a scientific trend as well as to anticipate its further growth and priority tasks. In particular, the analysis reveals the key role of pioneer research by Prof. Ruslan Valiev and his colleagues in the early 1990s in the formation of this subject.

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