EPJ Web of Conferences **140**, 16006 (2017) DOI: 10.1051/epjconf/201714016006
Powders & Grains 2017

Some statistics about research on granular materials during the last decade

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Abstract. In this work we present several statistical analyses about research on the subject of granular materials during the last ten years. These statistics are based on the set of articles published in the Granular Materials section of *Physical Review E* during this period, comprising roughly 1000 documents (including rapid communications). We estimate the degree of contribution of countries, academic institutions, authors, and articles, in terms of the frequency of appearance on the articles' affiliations and the number of citations. On the first hand, these analyses serve as a recognition to researchers and research communities that have notably contributed to the development of knowledge on granular materials. On the second hand, the presented statistics allow for identifying countries and institutions where research in granular materials is the most developed, and also places where it can be developed in the future. Finally, these analyses allow for highlighting which cooperations amongst countries have been the most active during the last decade, which in turn allows for identifying potential links to be created and developed across this research network.

1 Description of the data set of articles

The set of articles that was analyzed was composed of all papers published in the Granular Materials section of *Physical Review E*, which was chosen as one of the possible reference titles in the research field of granular materials. The set comprised 951 articles, published between January 27 2006 (i.e., Vol. 73, Issue 1) and September 2 2016 (i.e., Vol. 94 Issue 3), with more than 1600 authors in total. From the results openly available on the internet, the following information was recorded for each article: publication date, volume, issue, title, DOI, number of citations, abstract, authors, and affiliations.

2 Countries and international cooperation

Figure 1 shows a world map in which countries have been assigned a color scale indicating the number of times each country appears on the authors' affiliations [1]. It can be seen that the number of appearances for each country varies strongly, from one to several hundreds. A strong concentration of appearances can be observed in a few countries. Table 1 shows the twenty top countries, ranked according to the number N of appearances. It can be seen that more than 50% of appearances correspond to the three countries on top of the list.

Table 1. Top twenty countries, ranked according to the number N of times that each country appears on the authors' affiliations.

Country	N (-)	(%)
USA	851	27.2
France	437	14.0
Germany	271	8.7
Spain	191	6.1
China	162	5.2
United Kingdom	147	4.7
Netherlands	146	4.7
Australia	87	2.8
Switzerland	69	2.2
Norway	64	2.0
India	63	2.0
Chile	61	1.9
Japan	60	1.9
Belgium	55	1.7
Taiwan	54	1.7
Italy	49	1.6
Argentina	45	1.4
Mexico	45	1.4
Israel	40	1.3
Hungary	32	1.0

Figure 2 shows the network of scientific cooperation links found in the set. Each time that two countries appeared on the authors' affiliations of a given article, a link was counted. Again, it can be seen that the number of links in which each country takes part varies strongly, from zero to more than a hundred. A strong concentration of link ends can be observed in a few countries. Table 2 shows

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[1] It must be noted that the numbers reported on Fig. 1 do not represent the number of papers in which at least one of the authors is affiliated to an institution in the corresponding country, since a given country can appear several times in a single article

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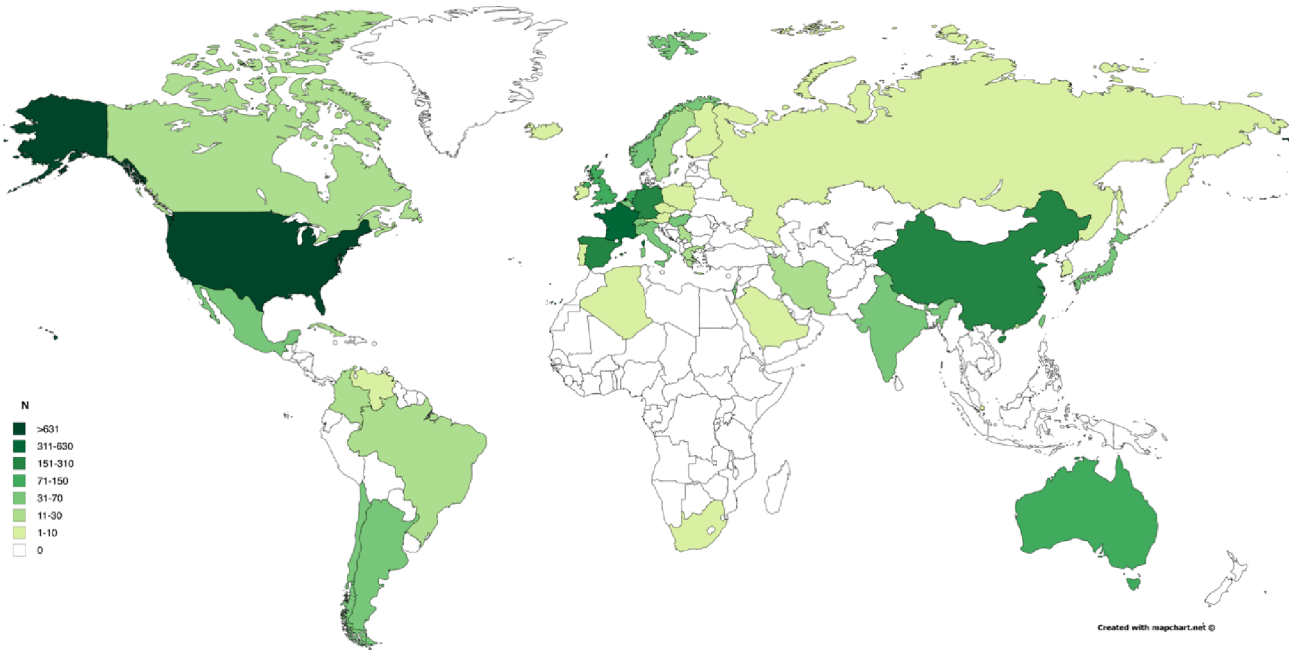

Figure 1. World map in which countries have been assigned a color scale indicating the number of times each country appears on the authors' affiliations.

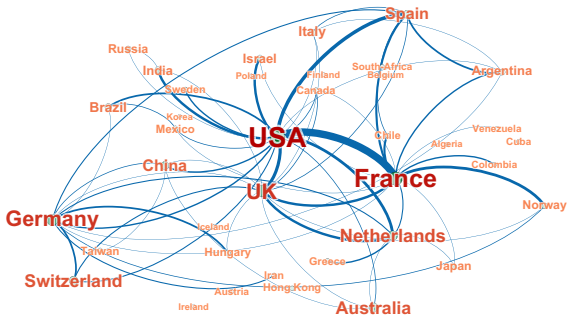

Figure 2. Network of scientific cooperation links found in the set. Thicker links represent more collaborations established.

the twenty top countries, ranked according to the number *N* of links in which each of them takes part. It can be seen that the five countries on top of the list take part in more than 50% of the total number of links.

3 Research institutions

The data set was used to assess the degree of contribution of research institutions, quantified by means of the number of times that each institution appears on the authors' affiliations [2] [3]. Table 3 shows the twenty top institutions, ranked according to the number *N* of appearances.

Table 2. Top twenty countries, ranked according to the number *N* of times that each country takes part in an international cooperation link.

Country	*N* (-)	(%)
USA	116	18.4
France	87	13.8
United Kingdom	54	8.6
Germany	48	7.6
Netherlands	40	6.4
Spain	34	5.4
Switzerland	23	3.7
China	19	3.0
Argentina	18	2.9
Australia	17	2.7
Norway	16	2.5
Brazil	15	2.4
India	15	2.4
Israel	14	2.2
Italy	12	1.9
Chile	11	1.7
Hungary	10	1.6
Mexico	9	1.4
Canada	8	1.3
Greece	7	1.1

[2] Again, it must be noted that these frequencies do not represent the number of papers on which at least one of the authors is affiliated to the corresponding institution, since a given institution can appear several times in a single article

[3] In our analyses, when a given author reported to be affiliated to several institutions, only the first of them was taken into account.

Table 3. Top twenty research institutions, ranked according to the number N of times that each institution appears on the authors' affiliations.

Institution	N (-)	(%)
Universidad de Sevilla (Spain)	72	4.8
University of Twente (Netherlands)	68	4.5
Université de Montpellier (France)	65	4.3
Princeton University (USA)	55	3.7
Université de Liège (Belgium)	54	3.6
University of Oslo (Norway)	52	3.5
Northwestern University (USA)	51	3.4
University of California (USA)	48	3.2
Universidad de Navarra (Spain)	46	3.1
Friedrich-Alexander Universität Erlangen-Nürenberg (Germany)	45	3.0
University of Pennsylvania (USA)	42	2.8
Université de Lyon (France)	41	2.7
Universidad de Extremadura (Spain)	41	2.7
Max Planck Institute for Dynamics and Self Organization (Germany)	40	2.7
Yale University (USA)	39	2.6
University of Chicago (USA)	39	2.6
Université de Rennes (France)	38	2.5
Universität Bayreuth (Germany)	37	2.5
Université Pierre et Marie Curie (France)	34	2.3
Université Paris Diderot (France)	31	2.1

4 Researchers

The data set was used to assess the degree of contribution of researchers, in terms of two indicators: the number of articles that each researcher authored, and the number of citations to articles that the researcher authored. Table 4 shows the twenty one top researchers, ranked according to the number N_a of articles that the researcher authored. This measure can be compared to the mean value for all authors in the data set: $\langle N_a \rangle = 2.1$.

Table 5 shows the twenty top researchers, ranked according to the number N_c of citations to articles that the researcher authored. This measure can be compared to the mean value for all authors in the data set: $\langle N_c \rangle = 17.2$.

5 Articles

Finally, the data set was used to asses the relevance of the articles, in terms of the number N_c of citations to these articles. Table 6 shows the twenty top articles, ranked according to N_c, as well as the citation rate $\dot{N}_c$, estimated as the number of citations divided by the article's age in years. These measures can be compared to the mean values for all articles in the data set: $\langle N_c \rangle = 8.6$ and $\langle \dot{N}_c \rangle = 1.4$ yr^{-1}.

6 Final comments

In this work we have performed several statistical analyses related to the research of granular materials for the last ten

Table 4. Top twenty one researchers, ranked according to the number N_a of articles that the researcher authored.

Researcher	N_a (-)
J. Javier Brey	24
Farhang Radjaï	21
Vicente Garzó	19
Salvatore Torquato	17
Hans J. Herrmann	16
Thorsten Pöschel	16
Nicolas Vandewalle	16
Iker Zuriguel	16
Emilien Azéma	14
Julio M. Ottino	14
Luis A. Pugnaloni	14
Douglas J. Durian	13
Jean-Christophe Géminard	13
Robert P. Berhinger	12
María Isabel García de Soria	12
Hisao Hayakawa	12
Richard M. Lueptow	12
Pablo Maynar	12
Diego Maza	12
Jean-Noël Roux	12
Renaud Toussaint	12
Average for the data set: $\langle N_a \rangle = 2.1$	

Table 5. Top twenty researchers, ranked according to the number N_c of citations to articles that the researcher authored.

Researcher	N_c (-)
Farhang Radjaï	384
Salvatore Torquato	380
Jean-Noël Roux	282
Martin van Hecke	256
Frank H. Stillinger	245
Emilien Azéma	219
Yang Jiao	211
Hans J. Herrmann	203
Vicente Garzó	189
Iker Zuriguel	182
Luis A. Pugnaloni	181
Julio M. Ottino	171
Wim van Saarloos	169
J. Javier Brey	162
Gary S. Grest	162
Diego Maza	158
Sidney R. Nagel	154
Thorsten Pöschel	151
Andrea J. Liu	149
Leonardo E. Silbert	145
Average for the data set: $\langle N_c \rangle = 17.2$	

Table 6. Top twenty articles from *Physical Review E*, ranked according to the number N_c of citations.

Article	N_c (-)	$\dot{N}_c$ (yr^{-1})
- C.H. Rycroft, G.S. Grest, J.W. Landry, and M.Z. Bazant. *Analysis of granular flow in a pebble-bed nuclear reactor*. 74(2), 2006.	96	9.5
- A. Donev, R. Connelly, F.H. Stillinger, and S. Torquato. *Underconstrained jammed packings of nonspherical hard particles: Ellipses and ellipsoids*. 75(5), 2007.	88	9.4
- A. Tordesillas, D.M. Walker, and Q. Lin. *Force cycles and force chains*. 81(1), 2010.	72	10.8
- E. Somfai, M. van Hecke, W.G. Ellenbroek, K. Shundyak, and W. van Saarloos. *Critical and noncritical jamming of frictional grains*. 75(2), 2007.	71	7.4
- S. Henkes, Y. Fily, and M.C. Marchetti. *Active jamming: Self-propelled soft particles at high density*. 84(4), 2011.	68	13.8
- M. Schröter, S. Ulrich, J. Kreft, J.B. Swift, and H.L. Swinney. *Mechanisms in the size segregation of a binary granular mixture*. 74(1), 2006.	68	6.7
- L.E. Silbert, A.J. Liu, and S.R. Nagel. *Structural signatures of the unjamming transition at zero temperature*. 73(4), 2006.	66	6.3
- V. Richefeu, M.S. El Youssoufi, and F. Radjaï. *Shear strength properties of wet granular materials*. 73(5), 2006.	64	6.2
- F. Alonso-Marroquín, I. Vardoulakis, H. J. Herrmann, D. Weatherley, and P. Mora. *Effect of rolling on dissipation in fault gouges*. 74(3), 2006.	62	6.2
- D.I. Goldman and P. Umbanhowar. *Scaling and dynamics of sphere and disk impact into granular media*. 77(2), 2008.	60	7.0
- T. Aste and T. Di Matteo. *Emergence of Gamma distributions in granular materials and packing models*. 77(2), 2008.	58	6.8
- A.R. Abate and D.J. Durian. *Approach to jamming in an air-fluidized granular bed*. 74(3), 2006.	57	5.7
- I. Agnolin and J.-N. Roux. *Internal states of model isotropic granular packings. I. Assembling process, geometry, and contact networks*. 76(6), 2007.	54	6.2
- Y. Jiao, F.H. Stillinger, and S. Torquato. *Optimal packings of superballs*. 79(4), 2009.	53	7.1
- P.-E. Peyneau and J.-N. Roux. *Frictionless bead packs have macroscopic friction, but no dilatancy*. 78(1), 2008.	53	6.5
- N.V. Brilliantov, N. Albers, F. Spahn, and T. Pöschel. *Collision dynamics of granular particles with adhesion*. 76(5), 2007.	51	5.8
- E. Azéma, F. Radjaï, R. Peyroux, and G. Saussine. *Force transmission in a packing of pentagonal particles*. 76(1), 2007.	49	5.3
- V. Vitelli, N. Xu, M. Wyart, A.J. Liu, and S.R. Nagel. *Heat transport in model jammed solids*. 81(2), 2010.	46	7.0
- V. Garzó, J.W. Dufty, and C.M. Hrenya. *Enskog theory for polydisperse granular mixtures. I. Navier-Stokes order transport*. 76(3), 2007.	46	5.1
- S. Henkes and B. Chakraborty. *Statistical mechanics framework for static granular matter*. 79(6), 2009.	45	6.2
Averages for the data set: $\langle N_c \rangle = 8.6$ and $\langle \dot{N}_c \rangle = 1.4$ yr^{-1}		

years. The data set was obtained from the openly available data of the journal *Physical Review E*, section Granular Physics (including Rapid Communications), which includes roughly 1000 documents and more than 1600 authors.

On the one hand, we found that the top five countries, ranked by the total number of articles published inside the time window, make more than 50% of the total of publications. This reflects a strong research network centered around these countries, something also reflected on the international collaborations.

On the other hand, the most published and cited authors show that the top authors publish and/or get cited much more than the average on each case. Some of the most published authors are also amongst the most cited authors, highlighting the relevance and broad impact of their research.

Finally, it should be noted that the presented analysis does not pretend to be an objective and complete overview of research on the field of granular materials, since it only included one section of one journal. This analysis should be understood as a proposal to look at our research community from a new perspective. In the future, it would be great to extend these analysis including journals such as *Physical Review Letters*, *Granular Matter*, *Europhysics Letters*, etc., or even the set of researchers that have attended the Powders and Grains conference.