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Highly cited publications output by India in materials science published during 2003–2012: A scientometric assessment

B. M. Gupta*, S. M. Dhawan[1], Ritu Gupta[2]

National Institute of Science Technology and Development Studies, [1]National Physical Laboratory, New Delhi, [2]Shri Venkateswar University, Tirupati, Andhra Pradesh, India

ABSTRACT

The main objective of this research was to identify highly cited papers in materials science and to analyze their publication and citation data to study their citation characteristics and to understand what role contributing authors, research organizations, as well as international collaborative players play in Indian materials science research. Indian materials science articles published from 2003 to 2012 were screened and highly cited papers, with at least 100 citations since publication, were identified and selected for a bibliometric analysis. The total number of papers, authorship, and collaboration statistics are presented for authors, institutions, foreign countries. To assess contributions, a new indicator, and the major contributor index (MCI) were used. Citation trends for all papers, as well as for top papers, are presented. A total of 396 highly cited articles, constituting 2.59% world share and 2.96% country share, were published by India in materials science output during 2003–2012. This study covered only those papers that received at least 100 citations since publication. In recent years, top-cited articles have reached their citation peak in the early years of their citation life cycle but have shown a more rapid decreasing trend compared to top-cited articles from the past decades. These 396 articles have received 68,668 citations, with an average citation per paper being 173.40. The leading Indian organizations participating in highly cited research were IISc-Bangalore (49 papers), NCL-Pune (29 papers), Jawaharlal Nehru Centre for Advanced Research-Bangalore (25 papers), Indian Institute of Technology (IIT)-Delhi and IIT-Kharagpur (16 papers each), Indian Institute of Chemical Technology-Hyderabad (15 papers), etc. The leading authors were C.N.R. Rao (20 papers), M. Sastry and V.K. Gupta (9 papers each), A. Govindaraj (8 papers), and A. Ahmad, V. Thomas, and C.D. Lokhande (6 papers each). The leading international collaborative countries were the USA (49 papers), Japan (27 papers), Germany (23 papers), South Korea (12 papers), and France (9 papers). MCI varied among leading institutions, as well as among individual authors. An indicator like the MCI can provide a proxy for the contributions made by an individual or institution. It reflects the independent research ability and leadership. In future evaluations of the institution or individual performances, the MCI should be included, together with the number of total papers, to provide a better profile of research performance.

Keywords: Article life, authors, highly cited, india, international collaboration, major contributed organizations, material science research, scientometrics, scopus

INTRODUCTION

Innovations in information technology, biotechnology, and materials science and engineering are considered to be the major driving forces that have been instrumental in catalyzing the emergence of a new industrial paradigm. In the materials industry, it is the knowledge inputs, as opposed to inputs of materials and energy that drive the creation of new and advanced materials to meet the specific demands in leading a better quality of life. Preexisting materials have either been adapted or changed (e.g., alloys) to meet the emerging requirements. New materials are critically important to the industry in energy savings, pollution control, safe packaging, etc., or to the human beings in improving their quality of life. Materials science research today has become one of the major driving forces for global competitiveness in this modern world. All of the major countries are investing heavily in R and D, with the hope to

***Address for correspondence:**
E-mail: bmgupta1@gmail.com

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generate new industrial opportunities. Over the years, India has also invested in a major way in R and D in materials science. It has since undertaken major research programs in materials science involving a large number of academic and research bodies including institutes of national importance, research institutes, universities and colleges, engineering colleges, etc. India has entered into collaboration with many of the leading organizations from developed countries in many of its sponsored programs. Many of such collaborative programs in materials science are being funded and monitored by major scientific agencies in the country such as Department of Science and Technology, Council of Scientific and Industrial Research, Defense Research and Development Organization, Department of Scientific and Industrial Research, University Grants Commission (UGC), etc. Among developing countries, India has an edge in R and D in materials science in terms of a number of research organizations, research facilities, and the number of researchers.[1]

Literature Review

At the international level, Adam and Pendlebury[2] examined the changing landscape of materials science, by focusing on the origin and nature of materials science, reviewed its growth globally, and identified the key players in terms of publications output in the materials science research. It selectively looks at some of its hot topics, such as graphene, metal-organic frameworks, and nanofibrous scaffolds used for tissue engineering. Surwas *et al*.[3] also examined world literature in materials science during 2006–2010, in terms of publication output and citations. It particularly focuses on the growth of publications and citations, continent-wise distribution of publications and citations, country-wise distribution of publications, domain-wise distribution of publications and citations, extent of international collaboration, identification of highly cited publications and highly preferred journals, etc.

At the national level, few scientometric studies on India's materials science research have been undertaken in the past. Among such studies, Gupta *et al*.[4] examined Indian materials science publications, as indexed in Scopus database during 2001–2010. They focused on several parameters such as publication growth and rank, country-wise contribution, material-wise contribution, share of international collaborative linkages and leading collaborating countries, the most productive Indian institutions and authors, and characteristics of highly cited papers. Kademani *et al*.[5] made a scientometric assessment of 14,849 Indian publications in materials science during 1999–2008, with a focus on metrics such as the growth of publications and citations, relative growth rate and doubling time, domain-wise distribution of publications and citations, national and international collaboration, highly productive institutions, highly productive authors, highly preferred journals, and highly cited publications. Walke *et al*.[6] made a quantitative assessment of Indian Materials Science output (9545 papers) during 1993–2001 and assessed publication size and growth, media of communication, strength and weakness in the areas of research, research quality, nature of collaboration, and institutional productivity. Mohan *et al*.[1] examined 2587 international collaborative publications in India's materials science research published during 1995–1999. They indicated that materials science research in India is a very broad one and covers most of the important sub-areas. Most of the work involved bilateral research rather than multilateral collaboration. The top collaborating countries were the USA, Germany, France, UK, and Japan. The top 10 Indian institutions contributed 50% of the collaborative publications. The major areas of collaboration were theoretical studies, metals and alloys, electronic materials, and superconducting materials. Among the analysis of highly cited publications, Yuh-Shan[7] identified and analyzed the characteristics of the 14,044 highly cited articles in global materials science research during 1900–2010. These highly cited publications were assessed regarding their distribution in the indexed journals. The citation lives of the highly cited articles depending on citations in the publication year, recent years, and years after publication were applied for the impact of articles. A new indicator, the major contributor index (MCI), was applied to assess publication quality and the characteristics of contribution to articles.

METHODOLOGY

The study derived highly cited articles data from the Scopus, an international multidisciplinary bibliographical and citation database on 28 November 2014 and covered the period from 2003 to 2012. A highly cited article (TC2014 ≥100) was defined, as an article registering at least 100 citations since its publication up to 29 November 2014. In total, 396 India's highly cited articles in materials science (2.59% of the world output of 15,274 articles) received at least 100 citations since publication. The impact factor (IF) of a journal was based on the Journal Citation Report 2013.

The study organized publication and citation data into groups such as: (i) First author publications (FP), (ii) corresponding author publications (RP), (iii) the number of citations since

publication to 2014 is referred as C2014, (iv) citations received in the year of publications (C0), (v) citations in the first year after publication (C1), (vi) the number of citations received in the year 2014 is referred as C2014, (vii) national and international collaborative publications, (viii) most productive journals, etc.

The data were analyzed to assess the quantum of research under various groups, its global share, research quality, life cycle of research publications, contributions of different types of Indian authors, and organizations in materials science. Indian organizations have been classified into groups such as: (i) Institutes of national importance, (ii) research institutes, (iii) universities, (iv) colleges, (v) engineering colleges, (vi) medical and allied colleges, (vii) industrial enterprises, and (viii) nonprofit institutions.

The collaboration type was determined by the addresses of the authors. An article could be either a single-country article, in which all authors' addresses were from the same country, or bilateral or multilateral international collaborative article, which was co-authored by researchers from two or more countries.

In a single-author article where authorship is unspecified, the single author is both the first author and corresponding author. Similarly, in a singly institutional article, the institution is classified as the first author institution and the corresponding author institution. In addition, only the first affiliation of corresponding author was considered when the author had multiple affiliations.

At the individual level, a nonalphabetical name order sends a clear signal to the market that the author who is listed first actually contributed more. The first author is the person who contributed most to the work and writing of the article.[8] The corresponding author is perceived as the author contributing significantly to the article independent of the author position.[9] The corresponding author supervised the planning and execution of the study and the writing of the paper.[10] It is generally assumed that the first author and the corresponding author played significant roles and they are the major contributors in producing a research paper. Thus, in this research, a newly developed indicator as suggested by Chuang and Ho,[11] the MCI, was used to assess the extent a researcher or an institution contributed to publishing an article. The MCI is calculated as the sum of first-author articles and corresponding articles divided by two times the total number of articles. It implies the percentage of instances one takes on the leadership role (first author or corresponding author) out of the total possible available opportunities. The equation is:

$$MCI = (FP - RP)/2TP,$$

Where FP is the number of first-author articles, RP is the number of corresponding author articles, and TP is the number of total articles. When MCI = 0, there is no first- or corresponding-author article. When MCI = 1, all articles are either first- or corresponding-author articles. MCI has two implications. First, it probably indicates a higher capability or productivity in conducting independent research. Second, it could, as well, indicate a more prominent role in collaborations. On the contrary, a low MCI is probably a sign of heavy reliance on collaboration, as well as relying on others to provide a leadership role in conducting research.[11]

OBJECTIVES

Citations are assumed to be a reflection of research articles use and impact. The main objective of this publication is to examine the characteristics of highly cited Indian publications in materials science published during the 10 years between 2003 and 2012. The study, in particular, will assess: (i) The annual distribution of Indian contribution, its research quality and its global share, (ii) the contribution made by authors and organizations from different types of Indian organizations, (iii) institutional participation measured in terms of single institution publications and collaborating institution publications; (iv) nature of international collaboration (bilateral or multilateral), and (v) media for communication of publications and characteristics of top 15 publications.

ANALYSIS, DISCUSSION AND RESULTS

As per data sourced from SCOPUS database, the world output of all highly cited publications in materials science published during 2003–2012, and cited at least 100 times since publication, stood at 15,274 papers. India published 396 highly cited papers during this period. Its global publication share of highly cited papers in materials science averaged at 2.59%. India was ranked at tenth position among the top 15 world countries on its global publication share of highly cited papers. The USA topped in this ranking; its global publication share averaged at 39.8% relative to India's 2.59% share of highly cited papers.

India was ranked as the 8th most productive country in the world on the basis of its total national output in materials

science publications (75,540 papers including even highly cited papers). China topped in this ranking. Its total national output in materials science publications was 367,338 papers relative to India's 75,540 papers during 2003–2012.

India was ranked as the third least productive country in the world on the basis of its national publication share of highly cited papers (0.52%) in the total publication output of the country in materials science during 2003–2012. China was ranked as the fourth least productive country in the world on this ranking. Its national publication share was 0.63% relative to India's 0.52% share. The top five nations that topped in this ranking are the USA, Australia, UK, Canada, and Germany. Their national publication share of highly cited papers in the country output in materials science publications varied in the range 1.18–2.05% [Table 1 and Figure 1].

Both India and the world witnessed a negative growth rate in the annual output of highly cited papers during 2003–2012. India averaged the growth rate of 23.33% (annual output dropping from 57 in 2003 to 4 in 2012) compared to 18.29% in the annual output of the world. The whole world annual output dropped from 2200 to 292 highly cited papers during the corresponding years. India's world share of highly cited papers in 10 years averaged to 2.59%. The citations per paper in respect of highly cited papers by India in materials science is wide varying between 100 and 1033 citations per paper with an average of 173.40 citations per paper. Of the total 396 publications, 11 received 100 citations each in 10 years [Table 2].

The citation window for citation count of highly cited papers in this study was not fixed. The citation count was done on total citation counts since paper publication till November 2015. Citation count of highly cited papers was, therefore, time-dependent varying from 1 to 12 citation per year (2003 to November 2014).

To enable comparative citation performance of highly cited papers on an annual basis, differences in citation window periods were normalized, and citation impact calculated on citation density indicator. Citation density

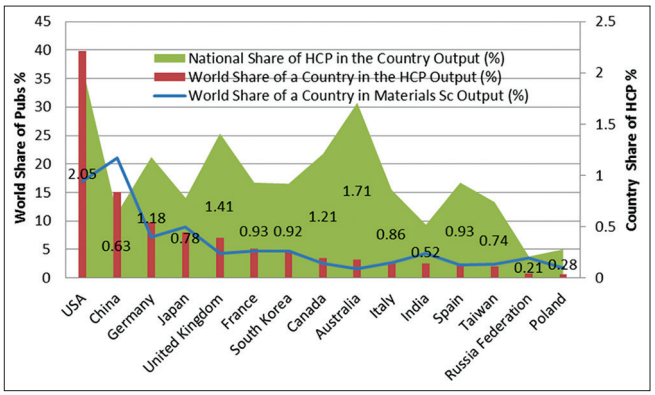

Figure 1: Comparative performance of the top 15 most productive countries in material science on three select indicators 2003-2012

Table 1: Distribution of world publication output, HCP world output, and HCP country share of the top 15 most productive countries in material science: 2003-2012

Country	Country output of TP			Country output of HCP			Share of HCP in the country output	
	Publication count	Share	Rank	Publication count	Share	Rank	Share	Rank
China	367,338	21.02	1	2308	15.1	2	0.63	12
USA	297,246	17.01	2	6080	39.8	1	2.05	1
Japan	156,131	8.93	3	1221	8.0	4	0.78	10
Germany	125,377	7.17	4	1476	9.7	3	1.18	5
France	83,012	4.75	5	772	5.1	6	0.93	6
South Korea	81,799	4.68	6	750	4.9	7	0.92	8
UK	76,386	4.37	7	1078	7.1	5	1.41	3
India	75,540	4.32	8	396	2.59	10	0.52	13
Russia Federal	60,459	3.46	9	124	0.8	14	0.21	15
Italy	45,783	2.62	10	396	2.6	11	0.86	9
Canada	43,653	2.50	11	528	3.5	8	1.21	4
Taiwan	42,494	2.43	12	313	2.0	13	0.74	11
Spain	40,656	2.33	13	378	2.5	12	0.93	7
Poland	30,527	1.75	14	85	0.6	15	0.28	14
Australia	28,788	1.65	15	492	3.2	9	1.71	2
World	1,747,905			15,274				

HCP=Highly cited papers, TP=Total papers

Table 2: Annual output of HCP by India and the world in materials science and their citations since publication: 2003-2012

Year	World	India				
	Number of publications	Number of publications	Number of citations	CPP	Citation density	Share in world output
2003	2200	57	11,240	197.19	1124	2.59
2004	1951	50	5355	107.10	595	2.56
2005	2010	57	10,034	176.03	1254	2.84
2006	1801	44	6386	145.14	912	2.44
2007	1737	38	7805	205.39	1301	2.19
2008	1602	42	8584	204.38	1717	2.62
2009	1603	49	9949	203.04	2487	3.06
2010	1336	41	6726	164.05	2242	3.07
2011	742	14	1900	135.71	950	1.89
2012	292	4	689	172.25	689	1.37
Total	15,274	396	68,668	173.40		2.59
CAGR (%)	18.29	23.33	Average CPP			

HCP=Highly cited papers, CPP=Citation per paper, CAGR=Compound annual growth rate

measures citations per paper per citation window-year (i.e., the number of citations/year since paper publication) [Table 2 and Figure 2].[12] Citations since publication were counted till November 2014. For instance, papers published in 2004 had 11-year citation window. Their citation density averaged to 9.7 citations per paper per citation window-year (5335/11)/50 = 9.7. Papers published in 2012 had nearly 2-year citation window. Their citation density averaged to 57.4 citations per paper per citation window-year. Contrary to expectations, citation density for papers published in the most recent year (2012) was the highest relative to citation density for papers published in the earlier years 2003–2011. Citation density data of highly cited papers have shown a consistent increase from 16.4 in 2003 to 33.9 in 2011. But the increase in citation density has been the steepest from 33.9 in 2011 to 57.4 in 2012.

Even as the annual output of highly cited papers has shown negative growth, their citation density per paper per citation window-year has shown a consistent increase. Compared to citations per paper, citation density data reveal a clearer and better picture of the citation impact of highly cited papers published by India in materials science. It reveals that India made significant gains in terms of visibility and citation impact of highly cited papers in materials science published during 2003–2012 [Figure 2].

Of all the 396 highly cited Indian publications, 313 (79.04%) appeared as articles, 69 (17.42%) as reviews, and 14 (3.54%) as conference papers. As expected, reviews registered the highest citation impact per paper (244.93), followed by articles (159.59) and conference papers (129.64). Except one, all other conference papers were later published in journals [Table 3].

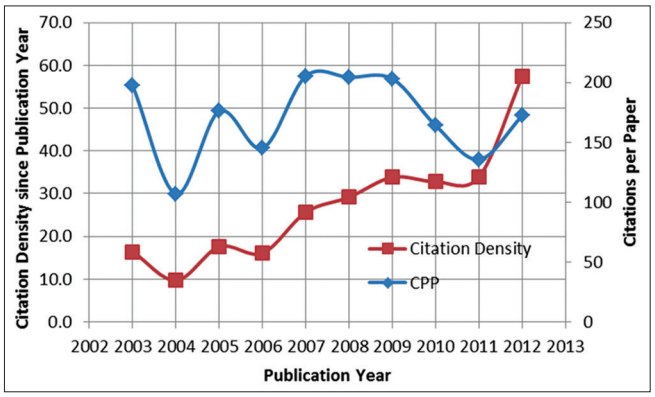

Figure 2: Comparative citation impact of India's highly cited papers in materials science measured on citation density indicator and citations per paper : 2003-2012

Citation distribution of highly cited papers is much skewed. Very few highly cited papers (0.25%) relatively received high-end citations (1000–1033) and accounted for 1.43% share of the total 68,668 citations received during 2003–2014. Nearly 4.3% of papers received citations in the citation frequency range (400–999) and accounted for 10.81% citations share. The bulk of highly cited papers (79%) received citations in the frequency range (100–199) and accounted for a substantial citation share of 61.6%. Nearly 17% of papers received citations in the frequency range (200–399) and accounted for 24.65% of citations share [Table 4, Figures 3 and 4].

Contribution of Authors

In all, there were 1214 authors to 396 highly cited Indian publications in materials science. Of these, 820 were Indian authors and 394 were foreign authors. Amongst

the 1214 authors, 166 (13.67%) had along with them only corresponding-author articles, 211 (17.38%) had only first -author articles, and 198 (16.39%) had both first author and corresponding author articles. Among the 820 Indian authors, 128 (15.61%) had along with them only corresponding-author articles, 181 (22.07%) had only first-author articles, and 148 (18.05%) had both first author and corresponding author articles. Among the 394 foreign authors, 38 (9.64%) had only corresponding-author articles, 30 (7.61%) had only first-author articles, and 42 (10.66%) had both first author and corresponding author articles.

Of the 820 Indian authors of highly cited papers, 85% belonged to major leading organizations in the country. In particular, 357 authors were affiliated to research institutions, 200 to institutes of national importance, and 145 to universities. The remaining 15% of authors belonged to relatively lesser known smaller organizations. Of these, 51 authors belonged to engineering colleges, 15 to medical colleges, 29 to colleges, 20 to industrial enterprises, and 3 to nonprofit organizations. This sort of distribution implies that excellence in materials science research has started emerging as well from smaller institutions that currently lie outside the research space occupied and dominated traditionally by high-end research institutions and universities in the country.

Table 3: Distribution of highly cited publications contributed by India by type of publication, 2003-2012

Type of publication	TP	TC	CPP
Articles	313	49,953	159.59
Reviews	69	16,900	244.93
Conference paper	14	1815	129.64
Total	396	68,668	173.4

TP=Total papers, TC=Total citations, CPP=Citation per paper

Table 4: Distribution of highly cited Indian publications in materials science by citations range, 2003-2012

Citation range	Number of publications	Total citations	Publications share	Citations share
100-199	312	42,298	78.79	61.6
200-299	52	12,147	13.13	17.69
300-399	15	4783	3.79	6.96
400-499	7	2891	1.77	4.21
500-599	6	3010	1.51	4.38
700-799	2	1524	0.50	2.22
900-999	1	982	0.25	1.43
1000-1099	1	1033	0.25	1.50
Total	396	68,668	100	100

The authorship per paper varied widely from 1 to 30 authors. The average number of authors per paper was seen as 3.95 and the largest number of authors per paper was 30 [Table 5 and Figure 4].

The study discovers the inverse relationship between "number of authors per paper" and "productivity of highly cited papers" (Pearson's $r = -0.589$). As the authors per paper go up in numbers, the productivity of highly cited papers witnesses a corresponding decline. For instance, the authorship by 1–5 authors per paper published 84% highly cited papers in materials science. In contrast, the authorship by 10–30 authors per paper published merely 2% highly cited papers. Table 5 and Figure 4, respectively, provide comparative data and graphics on publication productivity, citations received per paper vis-à-vis number of authors per paper.

Indian authors contributed highly cited papers in the frequency range from 1 in 10 years to 20 papers in 10 years. Of the 820 Indian authors, 720 were least productive ones; each author contributed one publication each in 10 years; 67 authors contributed two publications each; 16 authors contributed three publications each; 5 authors contributed four publications each. In another set of 5 authors, each author contributed five publications each. In a set of 3 authors, each author contributed six publications each. Of the 820 authors, only 4 were seen as prolific ones. Of these, 1 author contributed 8 publications in 10 years, 2

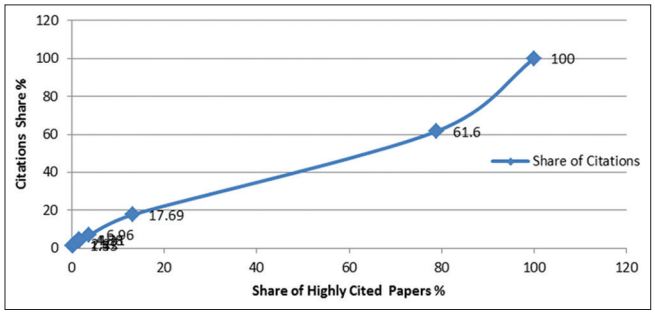

Figure 3: Distribution of highly cited papers in materials science by citations share size

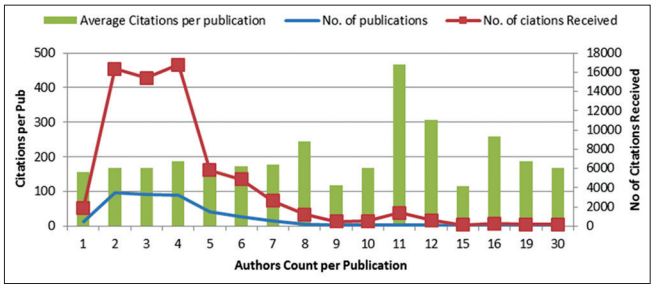

Figure 4: Distribution of highly cited papers by authors per paper: 2003-12

had contributed 9 publications each, and another 1 author had contributed 20 publications.

Table 6 presents a list of top 33 authors each having contributed at least 3 highly cited publications. The list is arranged by the decreasing number of highly cited papers contributed, the author with the highest number of papers on the top. In addition, each entry lists total contribution, the number of papers as the first author and/or corresponding author papers during 2003–2012. Upon studying and analyzing citation performance of these 33 authors, it was found that the 2 authors, namely B. Das of Indian Institute of Chemical Technology (IICT)-Hyderabad and R.S. Sonawane of Center of Materials of Electronic Technology (C-MET)-Pune have registered the highest value (1 each) of MCI, in spite of their being ranked at 24th and 25th positions in the author ranked list of highly cited papers. In contrast, 4 authors namely A. Govindaraj of JNCSR-Bangalore, J. Mittal of MANIT-Bhopal, U.V. Waghmare of Jawaharlal Nehru Centre for Advanced Research (JNCASR)-Bangalore, and A. Malviya of MANIT-Bhopal have received 0 value of MCI, in spite of their being ranked at 4th, 12th, 16th, and 28th positions in the authors ranked list of highly cited papers. All other 27 authors have received MCI value varying from 0.17 to 0.83, with the third highest rank being given to N.M. Vigneshwaran of Central Institute of Research on Cotton Technology (CIRCT)-Mumbai (MCI = 0.88, author rank list = 17), followed by V.K. Gupta of Indian Institute of Technology (IIT)-Roorkee (MCI = 0.87, author rank list = 3), P.K. Maiti of IISc-Bangalore (MCI = 0.67, author rank list = 19), M. Joshi of IIT-Delhi (MCI = 0.67, author rank list = 23), C.N.R. Rao of JNCASR-Bangalore (MCI = 0.63, author rank list = 1), B. Smitha of IICT-Hyderabad (MCI = 0.50, author rank list = 13), A.A. Khan of IICT-Hyderabad (MCI = 0.50, author rank list = 14), S. Ramprabhu of IIT-Madras (MCI = 0.50, author rank list = 15), R.P. Singh

Table 5: Publication productivity in materials science by number of authors per paper: 2003-2012

Number of authors per publication	Number of publication	Number of citations	Average citation per publication
1	12	1875	156.25
2	97	16,368	168.74
3	92	15,395	167.34
4	90	16,772	186.36
5	41	5812	141.76
6	28	4866	173.79
7	15	2647	176.47
8	5	1219	243.8
9	4	472	118.00
10	3	502	167.33
11	3	1398	466
12	2	611	305.5
15	1	116	116
16	1	258	258
19	1	188	188
30	1	169	169
Total	396	68,668	173.4

Table 6: Top 33 highly cited authors from India each with three or more publications in materials science during 2003-2012

Name of the author	Affiliation	TP	FP	RP	MCI
C.N.R. Rao	JNCASR-Bangalore	20	8	17	0.63
M. Sastry	NCL-Pune	9	0	4	0.22
V.K. Gupta	IIT-Roorkee	9	6	9	0.83
A. Govindaraj	JNCASR-Bangalore	8	0	0	0.00
A. Ahmad	NCL-Pune	6	1	4	0.42
V. Thomas	M.G. University-Kottayam	6	0	5	0.42
C.D. Lokhande	Shivaji University-Kolhapur	6	0	5	0.42
S. Sridhar	IICT-Hyderabad	5	0	2	0.20
U. Ramamurthy	IISc-Bangalore	5	1	3	0.40
K.S. Subramanayam	JNCASR-Bangalore	5	1	1	0.20
A. Mittal	MANIT-Bhopal	5	3	0	0.30
J. Mittal	MANIT-Bhopal	5	0	0	0.00
B. Smitha	IICT-Hyderabad	4	4	0	0.50
A.A. Khan	IICT-Hyderabad	4	0	4	0.50
S. Ramprabhu	IIT-Madras	4	0	4	0.50
U.V. Waghmare	JNCASR-Bangalore	4	0	0	0.00
N.M. Vigneshwaran	CIRCT-Mumbai	4	3	4	0.88
N. Munichandraiah	IISc-Bangalore	3	0	1	0.17
P.K. Maiti	IISc-Bangalore	3	3	1	0.67
L.S. Panchkarla	JNCASR-Bangalore	3	0	1	0.17
R.P. Singh	NCL-Pune	3	0	3	0.50
M.K. Dongare	NCL-Pune	3	0	1	0.17
M. Joshi	IIT-New Delhi	3	2	2	0.67
B. Das	IICT-Hyderabad	3	3	3	1.00
R.S. Sonawane	C-MET-Pune	3	3	3	1.00
V. Murugesan	Anna University-Chennai	3	0	1	0.17
M.A. Quraishi	IT-BHU	3	0	3	0.50
A. Malviya	MANIT-Bhopal	3	0	0	0.00
A.N. Banerjee	Jadavpur University-Kolkata	3	0	3	0.50
S.K. Sahoo	ILS-Bhubaneswar	3	1	2	0.50
V.R. Shinde	Shivaji University-Kolhapur	3	3	0	0.50
A.A. Kathe	CIRCT-Mumbai	3	0	0	0.00
A. Nangia	University of Hyderabad	3	0	3	0.50

TP=Total Papers, FP=Number of first-author top cited articles, RP=Number of corresponding top-cited articles, MCI=Major contributor index, IISc=Indian Institute of Science, NCL=National Chemical Laboratory, JNCASR=Jawaharlal Nehru Centre for Advanced Research, IIT=Indian Institute of Technology, C-MET=Center of Materials of Electronic Technology, IT-BHU=Institute of Technology-Banaras Hindu University, MANIT=Maulana Azad National Institute of Technology, ILS=Institute of Life Sciences, CIRCT=Central Institute of Research on Cotton Technology, IICT=Indian Institute of Chemical Technology

of NCL-Pune (MCI = 0.50, Author Rank list = 21), M.A. Quraishi of Institute of Technology (IT)-Banaras Hindu University (BHU) (MCI = 0.50, author rank list = 27), A.N. Banerjee of Jadavpur Univ-Kolkata (MCI = 0.50, author rank list = 29), S.K. Sahoo of Institute of Life Sciences (ILS)-Bhubaneshwar (MCI = 0.50, author rank list = 30), A. Nangia of University of Hyderabad (MCI = 0.50, author rank list = 33), etc.

Contribution of Organizations

In all, 269 organizations (163 Indian and 106 foreign) had participated in materials science research in India during 2003–2012. Of the 163 Indian research organizations, only 10 were seen as most productive since each had published 10–48 highly cited papers in materials science in 10 years during 2003–2012. The other 153 organizations were not seen as highly productive since each contributed 1–6 publications. For instance, 111 had contributed 1 publication each in 10 years; 20 had contributed 2 publications each, 8 contributed 3 publications each, 9 contributed 4 publications each, 5 contributed 5 publications each, 4 contributed 6 publications each, and 4 contributed 8 publications each.

Research institutions in the S and T sector dominate in research publications in materials science. Their share of highly cited papers in materials science was the largest (46.21%, 183 papers), followed by institutes of national importance (34.59% share, 137 papers), universities (23.99% share, 95 papers), engineering colleges (8.58% share, 34 papers), colleges (4.80% share, 19 papers), industrial enterprises (2.78% share, 11 papers), medical and allied colleges (2% share, 8 papers), and nonprofit organizations (0.50% share, 2 papers) during 2003–2012 [Table 7].

The performance of the Indian organizations measured in terms of MCI also confirms that research institutes contributed the largest share. They registered the highest MCI value (0.71) with first rank in the number of highly cited publications, followed by institute of national importance (MCI = 66, publication rank = 2), medical and allied colleges (MCI = 0.63, publication rank = 7), universities (MCI = 0.63, publication rank = 4), colleges (MCI = 0.47, publication rank = 5), engineering colleges (MCI = 0.35, publication rank = 4), and industrial enterprises (MCI = 0.18, publication rank = 6). If MCI is > 0.500, it is indicative of the higher capability of an institution to conduct research independently or contribute to research productivity significantly. It also indicates

Table 7: Distribution of HCP across different types of Indian organizations: 2003-2012

Type of organization	TP	FP	RP	MCI
Research institutes	183	135	131	0.71
Institutes of national importance	137	89	92	0.66
Universities	95	58	60	0.62
Engineering colleges	34	15	9	0.35
Colleges	19	12	6	0.47
Industrial enterprises	11	2	2	0.18
Medical and allied colleges	8	5	5	0.63
Nonprofit organizations	2	0	0	0.00
Total	396			

FP=Number of papers with first authors, RP=Number of papers with corresponding authors, TP=Total papers, MCI=Major Contribution Index, HCP=Highly cited papers

a more prominent role of the institution in research collaboration. On the contrary, if the MCI is low, it is a sign of heavy reliance on others to play a leadership role in conducting research or in research collaboration.

Table 8 presents a list of top 33 organizations, each with a minimum of 3 contributions. The organizations are ranked by the number of highly cited papers contributed along with their total contributions and the number of contributions, as first author and/or corresponding author. Upon studying their performance, it was found that only 4 Indian organizations, namely University of Hyderabad, ILS, Bhubaneshwar, CIRCT, Mumbai and National Aerospace Laboratories (NAL), Bangalore have registered the highest value (1) of MCI, in spite of being ranked at 24, 28, 29, and 30 in the organization ranked list of highly cited papers. These four organizations have been followed by IIT, Kharagpur (MCI = 0.91, organization rank list = 5), Central Salt and Marine Chemical Research Institute, Bhavnagar (MCI = 0.88, organization rank list = 13), Naval Materials Research Center, Thane (MCI = 0.88, organization rank list = 27), IICT, Hyderabad (MCI = 0.87, organization rank list = 6), Shivaji University, Kolhapur, Annamalai University, Annamalainagar, IIT, Guwahati (MCI = 0.83 each, organization rank list = 17, 18 and 20), IIT, Madras (MCI = 0.81, organization rank list = 9), JNCASR, Bangalore (MCI = 0.78, organization rank list = 3), Indian Association for Cultivation of Science (IACS), Kolkata (MCI = 0.75, organization rank list = 14), IIT, Roorkee (MCI = 0.73, organization rank list = 7), C-MET-Pune, and IT-BHU, Varanasi (MCI = 0.71, organization rank list = 10 and 21), and other organizations have their value of MCI <0.70.

Of the 163 Indian participating organizations, 50 were research institutions from the S and T sector. They accounted for the largest share of participation 30.67%,

Table 8: Thirty-three leading Indian organizations who contributed HCP in materials science research, 2003-2012

Name of the organization	TP	FP	RP	MCI
IISc, Bangalore	49	28	26	0.55
NCL, Pune	29	18	19	0.64
JNCASR, Bangalore	25	19	20	0.78
IIT, Delhi	16	11	11	0.69
IIT, Kharagpur	16	15	14	0.91
IICT, Hyderabad	15	13	13	0.87
IIT, Roorkee	13	8	11	0.73
National Institute of Interdisciplinary Science and Technology, Thiruvanthapuram	12	9	7	0.67
IIT, Madras	13	10	11	0.81
C-MET, Pune	10	7	7	0.7
IIT, Kanpur	10	7	6	0.65
IIT, Bombay	8	3	3	0.38
Central Salt and Marine Chemical Research. Institute, Bhavnagar	8	7	7	0.88
IACS, Kolkata	8	6	6	0.75
Mahatma Gandhi University, Kottayam	8	3	7	0.63
Anna University, Chennai	8	3	2	0.31
Shivaji University, Kolhapur	6	6	4	0.83
Annamalai University, Annamalainagar	6	5	5	0.83
National Physical Laboratory, New Delhi	6	4	4	0.67
IIT, Guwahati	6	5	5	0.83
IT-BHU, Varanasi	5	3	4	0.7
BHU, Varanasi	5	1	1	0.2
MANIT, Bhopal	5	3	0	0.3
University of Hyderabad	5	5	5	1.0
Jadavpur University, Kolkata	5	3	2	0.5
Bhabha Atomic Research Centre, Mumbai	5	3	2	0.5
Naval Material Research Center, Thane	4	4	3	0.88
ILS, Bhubaneshwar	4	4	4	1.0
CIRCT, Mumbai	4	4	4	1.0
NAL, Bangalore	4	4	4	1.0
Tata Institute of Fundamental Research, Mumbai	4	1	1	0.5
University of Delhi	4	1	1	0.5
University of Madras	4	1	1	0.5

TP=Total Papers, FP=Number of first-author top cited articles, RP=Number of corresponding top-cited articles, IISc=Indian Institute of Science, NCL=National Chemical Laboratory, JNCASR=Jawaharlal Nehru Centre for Advanced Research, IIT=Indian Institute of Technology, IICT=Indian Institute of Chemical Technology, C-MET=Center of Materials of Electronic Technology, IACS=Indian Association for Cultivation of Science, IT-BHU=Institute of Technology-Banaras Hindu University, BHU=Banaras Hindu University, MANIT=Maulana Azad National Institute of Technology, ILS=Institute of Life Sciences, CIRCT=Central Institute of Research on Cotton Technology, NAL=National Aerospace Laboratories, HCP=Highly cited papers, MCI=Major contributor index

followed by 38 universities accounting for 23.31% share, 24 engineering colleges 14.72% share, 17 universities with 10.43% share, 15 institutes of national importance 9.20% share, 10 industrial enterprises 6.13% share, 7 medical and allied colleges 4.29% share, and 2 nonprofit organizations with 1.23% share of participation during 2003–2012.

Among the 396 highly cited publications, 178 papers had the participation of 1 organization each, 138 papers with 2 organizations each, 41 papers with 3 organizations each, 21 papers with 4 organizations each, 9 papers with 5 organizations each, 3 papers with 6 organizations each, 2 papers with 7 and 10 organizations each, and 1 paper with 11 and 20 organizations each. The average number of organizations per paper was 1.99 [Table 9 and Figure 6]. It was also observed that there is no systemic increase or decrease in terms of average citations per paper, as the number of organizations per paper increases.

Single Organization Versus Multiple Organizations in Highly Cited Papers

All the 396 highly cited publications in materials science research were classified into the following three categories: (i) Publications wherein only single Indian organization had participated (178 publications); (ii) publications wherein 2 or more Indian organizations had participated (labeled as national collaborative publications, 83 publications); and (iii) publications wherein 2 or more Indian and foreign organizations had participated (labeled as international collaborative publications, 135 publications) [Table 10].

Further, it was seen that internationally collaborative publications averaged higher citations per publication (191.17) compared to national collaborative publications (168.71) or single institution publications (162.12) [Table 10].

Single Organization Publications

In total, of the 178 papers, each had seen the participation only one organization in their publication. Their share in highly cited publications in materials science was 44.95%. Seventy-four unique Indian organizations had participated in these 178 publications. Of these, 9 were institutes of national importance (with 53 publications), 27 were research institutes (with 79 publications), 24 were universities (with 32 publications), 8 were engineering colleges (with 8 publications), 4 were colleges (with 5 publications), 1 was medical and allied college (with 1 publication), and 1 was industrial enterprise (with 1 publication).

IISc-Bangalore contributed to the largest number of publications (18), followed by NCL-Pune (13 publications), IICT-Hyderabad (12 publications), IIT-Madras (8 publications), JNCASR-Bangalore (6 publications), IIT-Delhi and IIT-Guwhati (5 publications each), NIIST-Thiruvanthapuram (5 publications), IIT-Kanpur, CIRCT-Mumbai, and Annamalai University (4 publications

each), IACS-Kolkata and NAL-Bangalore (3 publications each), 13 institutions (2 each publications), and the rest with 1 publication.

In terms of the number of authors per publication, 12 publications had authorship by 1 author each, 66 publications had 2 authors each, followed by 45 publications with 3 authors each, 33 publications had 4 authors each, 13 publications had 5 authors each, 5 publications had 6 authors each, 2 publications had 7 authors each, and 1 publication each had 8 and 9 authors. The average number of authors per publication was 3.02.

Table 9: Distribution of HCP by author organizations per publications during 2003-2012

Author organizations per publication	Total publications output	Total citations	Average citations per publication
1	178	28,857	162.22
2	138	24,122	174.80
3	41	7908	192.88
4	21	3914	186.38
5	9	1504	167.11
6	3	620	206.67
7	2	743	371.5
10	2	616	308.00
11	1	181	181.00
20	1	203	203.00
Total	396	68,668	173.40

HCP=Highly cited papers

Table 10: Citation performance of highly cited publications by type of collaboration: 2003-2012

Type of collaboration	Total publications	Total citations	Average citations per publication
Co-authors from within a single institution	178	28,857	162.12
National Collaborative Institutions	83	14,003	168.71
International Collaborative Institutions	135	25,808	191.17
Total	396	68,668	163.22

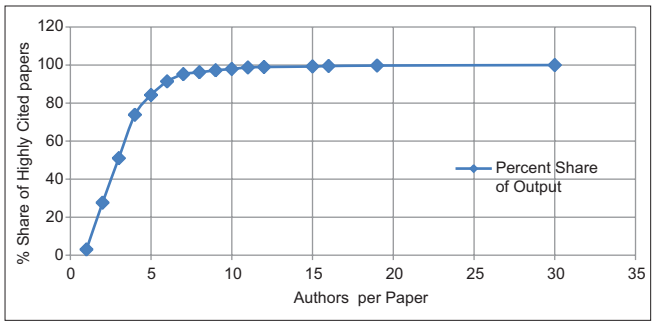

Figure 5: Distribution of highly cited papers by number of authors per paper

Multiple Organizations Publications – National Collaboration

In all, there were 83 nationally collaborative publications and each had the participation of two or more Indian organizations. Their share of highly cited publications in materials science was 20.96%. In these 83 publications, 9 institutes of national importance had participated in 40 publications, 34 research institutes in 50 publications, 21 universities in 25 publications, 17 engineering colleges in 21 publications, 10 colleges in 7 publications, 5 medical and allied colleges in 4 publications, 5 industrial enterprises in 4 publications, and 1 nonprofit organization in 1 publication.

IISc-Bangalore had participated in the largest number of publications (20) in this category, followed by JNCASR-Bangalore (14 publications), IIT-Roorkee (10 publications), NCL-Pune (7 publications), C-MET-Pune (6 publications), Maulana Azad NIT-Bhopal (5 publications), IT-BHU (4 publications), IIT-Madras and NIIST-Thiruvanathapuram (3 publications each), etc.

In terms of organizations per publication, 70 publications had the participation of 2 organizations each, 10 publications had 3 organizations each, and another 3 publications had 4 organizations each. The average number of organizations per paper was 2.19.

In terms of distribution of authors, 28 publications had participation of 4 authors each, followed by 21 publications with 3 authors each, 15 publications with 2 authors each, 7 publications each with 5 and 6 authors, and 5 publications with 7 authors. The average number of authors per publication was 3.82.

Of the 83 national collaborative publications, 40 were those publications wherein authorship was specified both as the first author and corresponding author, 43 publications had specified authorship as the first author, and another 43 publications specified authorship as the corresponding author.

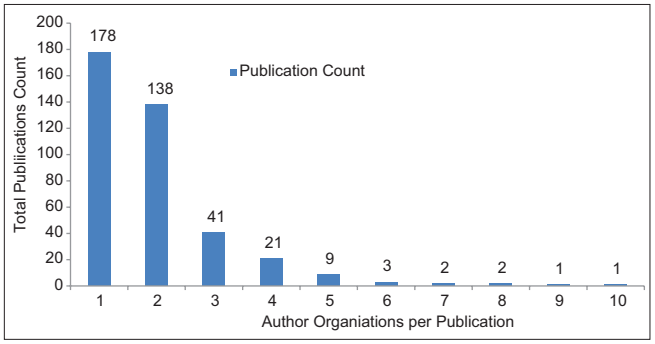

Figure 6: Distribution of highly cited papers by author affiliated organizations per publication in materials science: 2003-13

Table 11 illustrates collaborative linkages of various Indian organizations. The institutes of national importance received the largest number of collaborative linkages (29), followed by research institutes (27), universities (14), engineering colleges (11), industrial enterprises (5), medical colleges (5), etc.

Multiple Organizations Publications – International Collaboration

In all, there were 135 internationally collaborative publications. Each had the participation of two or more Indian and foreign organizations. These 135 papers accounted for 34.09% total share of highly cited publications in materials science. These 135 international collaborative publications were the outcome of nearly 10 institutes of national importance that participated in 42 publications, 27 research institutes in 55 publications, 22 universities in 36 publications, 6 colleges in 7 publications, 4 engineering colleges in 5 publications, 4 industrial enterprises in 5 publications, 2 medical and allied colleges in 3 publications, and 2 nonprofit organizations in two publications.

IISc-Bangalore participated in the largest number of publications (12), followed by IIT-Delhi and NCL-Pune (7 publications each), IIT-Bombay, Anna University (6 publications each), IIT-Kharagpur and JNCASR-Bangalore (5 publications each), IIT-Kanpur, NIIST-Thiruvanathapuram and IACS-Kolkata (4 publications each), etc.

In terms of organizations per publication, it was found that 2 organizations each had participated in 67 publications, 3 organizations each participated in 31 publications, 5 organizations each participated in 9 publications, 6 organizations each participated in 3 publications, 2 publications each 7 organizations, 10 organizations each participated in 2 publications, and 11 organizations participated in 1 publication, and 20 organizations participated in 1 publication. The average number of organizations per publication was 3.06.

In terms of the number of authors per publication, 29 publications each had 4 authors, 26 publications each 3 authors, 16 publications each 2 and 6 authors, 8 publications each 7 authors, 4 publications each 8 authors, 3 publications each with 9, 10, and 11 authors, 2 publications each 12 authors, and 1 publication each with 15, 16, 19, and 30 authors. The average number of authors per publication was 5.30.

Of the 135 international collaborative publications, 104 had bilateral collaboration (involving 1 organization from at least India and one country abroad) and 31 had multilateral collaboration (involving organizations from India and more than one country abroad).

Of the 31 multilateral collaborative publications, 22 had participation from 3 foreign countries, 5 publications had from 4 countries, 4 publications had from 5 countries, and 1 publication each had participation from 7 and 9 countries.

In all, collaborating organizations and collaborating authors belonging to 30 countries had participated in these 135 highly cited materials science publications. The USA participated in the largest number of collaborative publications (49), followed by Japan (27), Germany (23), South Korea (12), France (9), UK (6), Australia and Belgium (5 each), Italy, Hong Kong, China, Singapore and Sweden (4 each), Canada, the Netherlands, South Africa and Spain (2 each), and Brazil, Finland, Poland, Portugal, Taiwan, Turkey, Ghana, Malaysia, Mexico, Russia, New Zealand, Switzerland, and Austria (1 each).

In bilateral cooperation, the USA collaborated in the largest number of publications (31), followed by Japan (18),

Table 11: National collaborative publications - 2003-2012: Collaborative linkages of author organizations

Organization type	Total publications	Total collaborative, linkages	Number of collaborative linkages							
			Institutes of national importance	Research institutes	Universities	Engineering colleges	Colleges	Medical colleges	Industrial enterprises	Nonprofitable organizations
Research institutes	37	43	19	13	5	3	0	1	1	1
Institutes of national importance	13	13	2	7	0	2	2	0	0	0
Universities	15	21	2	5	4	1	5	1	3	0
Colleges	2	5	1	0	2	0	2	0	0	0
Engineering colleges	14	14	5	1	3	4	0	0	1	0
Medical colleges	2	3	0	1	0	1	0	1	0	0
Total	83	99	29	27	14	11	9	3	5	1

Germany (13), UK (5), Australia and Belgium (4 each), Sweden (3), France and Hong Kong (2 each), and 13 countries (1 each).

In multilateral collaboration, the USA participated in the largest number of collaborative publications (18), followed by Germany (10), France (7), China, Italy, Singapore, Switzerland and South Korea (3 each), and Hong Kong and Russia.

In these 135 international collaborative publications, 70 authors contributed both as the first author and corresponding author, 64 participated as a first author only, and 66 participated as the corresponding author. Besides, 28 foreign authors participated both as the first author and corresponding author, 34 as a first author only, and 28 as the corresponding author only. From India, 28 authors participated both as the first author and corresponding author, 34 as the first author, and 28 as the corresponding author only. The relative contribution of various foreign countries in terms of first author and corresponding author publications are shown in Table 12.

In all, 394 foreign authors representing 106 foreign institutions contributed in the publication of 135 internationally collaborative papers. The list of foreign institutions that contributed to more than 2 highly cited publications in materials science research is shown in Table 13. National Institute of Material Science, Tsukuba, contributed to the largest number of publications (7), followed by Catholic University of Leuven, Belgium (5 publications), Rice University, USA, Cambridge University, UK and Texas A.M. University, USA (4 publications each), Rensselaer Polytechnic Institute, USA, Northwestern University, Los Alamos National Laboratory, USA, Korea Research Institute of Chemical Technology, Daejon, South Korea and University of New South Wales, Sydney, Australia (3 publications each), etc.

Table 12: Contribution of foreign collaborating countries in HCP in materials science during 2003-2012

Country	Number of publications with			
	Total	Both FP and RP	FP	RP
USA	49	14	13	13
Japan	27	8	2	3
Germany	23	10	3	6
South Korea	12	0	3	4
France	9	0	5	5
UK	6	0	1	1
Australia	5	0	0	1
Belgium	5	0	1	1
Italy	4	2	0	0
Hong Kong	4	1	0	0
China	4	0	1	1
Singapore	4	1	1	1
Sweden	4	1	0	0
Canada	2	0	0	0
The Netherlands	2	0	0	0
South Africa	2	0	0	0
Spain	2	1	0	1
Turkey	1	1	0	0
Taiwan	1	1	0	0
Russia	1	1	0	0
New Zealand	1	1	0	0
Finland	1	0	0	1
Total		42	30	38

FP=Number of first-author top cited articles, RP=Number of corresponding top-cited articles, HCP=Highly cited papers

MEDIUM OF COMMUNICATION

Journals play an important role in the communication structure of science. Of the 396 highly cited publications in Indian materials science, 395 were published in peer-reviewed journals, and one as a conference proceedings. The 395 highly cited publications were published in 103 journals related to materials science.

Of the 103 journals, 39 journals (34.51%) reported one highly cited publication each, 18 (15.94%) journals reported two publications each, 10 (8.85%) journals published three publications each, 8 (7.08%) journals contained four publications each, 2 (1.77%) journals contained five publications each, and 26 (25.24%) journals published more than five publications each. Table 14 lists the top 64 journals which published 2 or more highly cited publications. *Journal of Material Chemistry* published the largest number of the highly cited publications (19 papers, 4.81% share), followed by *Progress in Polymer Science* (Oxford) and *Journal of Physical Chemistry C* (18 publications, 4.56% share each), *Chemistry of Material* (16 publications, 4.05%), *Journal of Molecular Catalysis A: Chemical and Material Chemistry and Physics* (11 publications, 2.78% share), *Journal of Colloid and Interface Science* and *Nanomedicine: Nanotechnology, Biology, and Medicine* (10 publications each, 2.53% share each), etc., In Table 15, highly cited articles were classified both by the number of citations range as well as by the IF range. But, there is no correlation between the number of citations and the IF.

TOP 15 HIGHLY CITED ARTICLES

Table 16 shows the 15 leading articles in materials science with a TC2014 >322. Both citation numbers

Table 13: List of foreign organizations contributing minimum two highly cited publications, 2003-2012

Country	Name of organization (number of publications)
Japan	National Institute of Material Science, Tsukuba (7)
	Kyoto Institute of Technology (2)
	Tohoku University (2)
	Tokyo Institute of Technology (2)
Belgium	Catholic University of Leuven (5)
UK	Cambridge University (4)
South Korea	Korea Research Institute of Chemical Technology (3)
	Hanyang University, Seoul (2)
Australia	University of New South Wales, Sydney (3)
	Monash University (2)
Singapore	National University of Singapore (2)
	Institute of Material Research and Engineering (2)
Hong Kong	University of Hong Kong (2)
	City University of Hong Kong (2)
Germany	Max Plank Institute of Colloids Interfaces, Potsdam (2)
	Muenchen (2)
	Ludwig-Maximilians-Universitat, Muenchen (2)
	Kaiserslautern University of Technology (2)
	Institute of Polymer Research, Dresden (2)
	Institute for Material Processing in Energy Systems, Julich (2)
Sweden	Royal Institute of Technology (2)
USA	Rice University (4)
	Texas A & M University (4)
	Rensselaer Polytechnic Institute (3)
	Northwestern University (3)
	Los Alamos National Laboratory (3)
	Georgia Institute of Technology (2)
	Michigan State University (2)
	California Institute of Technology, Pasadena, CA (2)
	Pennsylvania State University (2)
	University of Navada (2)
	MIT (2)

and ranking for the TC2014 are displayed. The top most article - "Mechanical behavior of amorphous alloys"[12] - was published by Schuh *et al*., in *Acta Materialia* in 2007 and had TC2014 of 1033. Of these 15 articles, 8 were published from 2003 to 2007 and 7 from 2008 to 2012. Journals which published these articles were: *Nature Materials* (IF = 36.40), *Nature Nanotechnology* (IF = 33.265), *Progress in Polymer Science* (Oxford) (IF = 26.854) (with 4 papers each), *Progress in Materials Science* (IF = 25.87) (with 2 papers each), *Journal of Materials Chemistry* (IF = 6.626), *Biomacromolecules* (IF = 5.788), *Solar Energy Materials and Solar Cell* (IF = 5.03), *Journal of Membrane Science* (IF = 4.908), *Advanced Materials* (IF = 4.438), *Acta Materialia* (IF = 3.94), and *Progress in Solid State Chemistry* (IF = 1.8).

Table 14: List of journals publishing two or more high cited papers

Name of the Journal	TP	IF 2013
Journal of Materials Chemistry	19	6.626
Progress in Polymer Science (Oxford)	18	26.854
Journal of Physical Chemistry C	18	4.835
Chemistry of Material	16	8.535
Journal of Molecular Catalysis A: Chemical	11	2.786
Materials Chemistry and Physics	11	2.129
Journal of Colloid and Interface Science	10	3.552
Nanomedicine: Nanotechnology, Biology, and Medicine	10	3.672
Acta Materialia	9	3.94
Advanced Materials	9	4.438
Composites Science and Technology	9	3.633
Industrial and Engineering Chemistry Research	9	2.235
Nano Letters	9	12.94
Corrosion Science	8	3.686
Journal of Membrane Science	8	4.908
Solar Energy Materials and Solar cells	8	5.03
Chemical Communications	7	6.718
Journal of Materials Science	7	2.305
Materials Science and Engineering A	7	2.409
Nanotechnology	7	3.672
Polymer	7	3.766
Journal of Power Sources	7	5.211
Biomaterials	6	8.312
Bulletin of Materials Science	6	0.87
Crystal Growth and Design	6	4.558
Macromolecules	6	5.927
Journal of Materials Processing Technology	5	2.041
Journal of Nanoscience and Nanotechnology	5	1.339
Advanced Functional Materials	4	10.40
Applied Surface Science	4	2.538
Biomacromolecules	4	5.788
Materials Letters	4	2.269
Nature Nanotechnology	4	33.265
Progress in Materials Science	4	25.87
Surface and Coatings Technology	4	2.199
Thin Solid Films	4	1.867
ACS Nano	3	12.033
Carbon	3	6.16
Composites Part A: Applied Science and Manufacturing	3	3.012
European Polymer Journal	3	3.242
International Materials Reviews	3	6.55
Journal of Alloys and Compounds	3	2.726
Journal of Physical Chemistry	3	4.835
Polymer Degradation and Stability	3	2.633
Sensors and Actuators, B: Chemical	3	3.84
Progress in Crystal Growth and Characterization of Materials	3	1.476
Acta Biomaterialia	2	5.684
Carbohydrate Polymers	2	3.916
Composite Structures	2	3.12
Current Applied Physics	2	2.026

Contd...

Table 14: Contd...

Name of the Journal	TP	IF 2013
Journal of Applied Polymer Science	2	1.640
Journal of Macromolecular Science - Polymer Reviews	2	6.593
Journal of Physics Condensed Matter	2	2.223
Langmuir	2	4.384
Microporous and Mesoporous Materials	2	3.209
Nature Materials	2	36.40
Physica E: Low-Dimensional Systems and Nanostructures	2	1.856
Progress in Crystal Growth and Characterization of Materials	2	1.476
Reactive and Functional Polymers	2	2.822
Science and Technology of Advanced Materials	2	2.613
Scripta Materialia	2	2.968
Small	2	7.514
Solar Energy	2	3.541
Superconductor Science and Technology	2	2.796

TP=Total papers, IF=Impact factor

Table 15: Distribution of HCP by citation range and IF range

IF range	Range of citations					
	100-199	200-299	300-499	500-699	700 and more	Total
30 and more	4		1		1	6
20.1-30.0	11	2	6	2	0	21
10.1-20.0	12	5	1	0	0	18
8.01-9.00	17	4	1	1	0	23
7.01-8.00	3	1	0	0	0	4
6.01-7.00	28	6	0	1	0	35
5.01-6.00	21	3	1	1	1	27
4.01-5.00	34	4	4	1		43
3.01-4.00	69	12	1	0	1	83
2.01-3.00	66	10	7	0	1	84
1.01-2.00	36	5	0	0	0	41
0.01-1.00	10				0	10
Total	311	52	22	6	4	395

HCP=Highly cited papers, IF=Impact factor

Effect of Time on Citations

The citation of an article usually follows a time course, as citations to a particular paper vary with time. The lifespan of an article demonstrates its influence on scientific research. The citation rank of an article (achieved highest in a year) was studied annually for the top-cited articles in materials science.

Figures 7 and 8 show the citation life cycles of articles published in the time period 2003–2007 and 2008–2012. Two distinct patterns are observed. Articles published in 2003–2007 had the lower citation start in the publication year (0–13 citations, but mostly 0–2 citations) but gradually citation peaks were reached in 5–10 years (to be precise, 1 paper reached its citation peak in 5 years, 2 papers in 7 years, 3 papers in 9 years, and 1 paper in 10 years) and then citations followed a decreasing trend.

On the contrary, articles published in 2008–2012 had the higher citation start in the publication year (0–24 citations, but mostly 7–24 citations) and then followed rapid increasing trend and reached citation peak in 4–6 years (2 papers in 4 years, 2 papers in 5 years, and 3 papers in 6 years) and then followed rapid decreasing trend. Overall, articles published in later years had a more rapid increase in citation numbers, needed relatively fewer years to reach their citation peak, but after reaching their citation peak had a rapid drop in citation numbers. If such a trend continues in future, it is expected that top-cited articles will follow even steeper citation increase and reach their citation peaks faster within a shorter time, but will also follow more rapid decline.

SUMMARY AND CONCLUSION

This study obtained publications and citations data from Scopus database pertaining to 396 highly cited papers in materials science that India had published during 2003–2012. The study covered only those papers that have received 100 or more citations till 28 November 2014. The high number of citations is perceived as an acknowledgement of intellectual debt and scientific progress. Highly cited papers are typically considered as high-quality science. They constitute an important category of journal papers. Measuring the citation impact of publications with high percentiles is a useful tool to ensure quality assessment of authors, institutions as key (most influential) contributors to science and technology.

The study sought to highlight the citation characteristics of highly cited papers including their citation life cycles. The study revealed that 396 highly cited articles were reported in 103 Indian and foreign journals; the IF of these journals varied widely from 0.87 to 36.4. The most productive journals in materials science of interest to India are: *Journal of Materials Chemistry* (19 papers), followed by *Progress in Polymer Science* (Oxford) (18 papers), *Journal of Physical Chemistry C* (18 papers), *Chemistry of Materials* (16 papers), *Journal of Molecular Catalysis A: Chemical* (111 papers), *Materials Chemistry and Physics* (11 papers), *Journal of Colloid and Interface Science* (10 papers), and *Nanomedicine: Nanotechnology, Biology, and Medicine* (10 papers). The IF of

Table 16: Fifteen most frequently cited Indian articles in material science research (TC2011>430)

Rank (TC2014)	Rank (C2014)	Top cited article information	Journal	Year	IF	Reference
1 (1033)	3 (174)	Schuh CA, Hufnagel TC, Ramamurty U. Mechanical behavior of amorphous alloys	Acta Materialia	2007	3.94	[12]
2 (982)	2 (198)	Das A, Pisana S, Chakraborty B, Piscanec S, Saha SK, Waghmare, UV, Novoselov, KS, Krishnamurthy HR, Geim AK, Ferrari AC, Sood AK Monitoring dopants by Raman scattering in an electrochemically top-gated graphene transistor	Nature Nanotechnology	2008	33.265	[13]
3 (773)	9 (85)	Albertsson AC, Varma IK. Recent developments in ring opening polymerization of lactones for biomedical applications	Biomacromolecules	2003	5.788	[14]
4 (751)	1 (214)	Geetha M, Singh AKb, Asokamani R, Gogia AK. Ti based biomaterials, the ultimate choice for orthopaedic implants - A review	Progress in Materials Science	2009	25.87	[15]
5 (598)	15 (26)	Rao CNR, Deepak FL, Gundiah G, Govindaraj A. Inorganic nanowires	Progress in Solid State Chemistry	2003	1.8	[16]
6 (576)	8 (93)	Sakthivel S, Neppolian B, Shankar MV, Arabindoo B, Palanichamy M, Murugesan V. Solar photocatalytic degradation of azo dye: Comparison of photocatalytic efficiency of ZnO and TiO_2	Solar Energy Materials and Solar Cells	2003	5.03	[17]
7 (558)	13 (60)	Adhikari, B., Majumdar, S. Polymers in sensor applications	Progress in Polymer Science (Oxford)	2004	26.854	[18]
8 (526)	14 (50)	Smitha B, Sridhar S, Khan AA. Solid polymer electrolyte membranes for fuel cell applications - A review	Journal of Membrane Science	2005	4.908	[19]
9 (502)	11 (83)	Besra L, Liu M. A review on fundamentals and applications of electrophoretic deposition (EPD)	Progress in Materials Science	2007	25.87	[20]
10 (500)	12 (62)	Fratzl P, Gupta HS, Paschalis EP, Roschger P. Structure and mechanical quality of the collagen-mineral nano-composite in bone	Journal of Materials Chemistry	2004	6.626	[21]
11 (485)	5 (134)	Ci L, Song L, Jin C, Jariwala D, Wu D, Li Y, Srivastava A, Wang ZF, Storr K, Balicas Le, Liu F, Ajayan, PM. Atomic layers of hybridized boron nitride and graphene domains	Nature Materials	2010	36.40	[22]
12 (477)	4 (140)	Panchakarla LS, Subrahmanyam KS, Saha SK, Govindaraj A, Krishnamurthy HR, Waghmare UV, Rao CNR. Synthesis, structure, and properties of boron- and nitrogen-doped grapheme	Advanced Materials	2009	4.438	[23]
13 (463)	7 (107)	Bhadra S, Khastgir D, Singha NK, Lee JH. Progress in preparation, processing and applications of polyaniline	Progress in Polymer Science (Oxford)	2009	26.854	[24]
14 (453)	6 (114)	Pillai CKS, Paul W, Sharma CP. Chitin and chitosan polymers: Chemistry, solubility and fiber formation	Progress in Polymer Science (Oxford)	2009	26.854	[25]
15 (431)	10 (83)	Bajpai AK, Shukla SK, Bhanu S, Kankane S. Responsive polymers in controlled drug delivery	Progress in Polymer Science (Oxford)	2008	26.854	[26]

IF=Impact factor

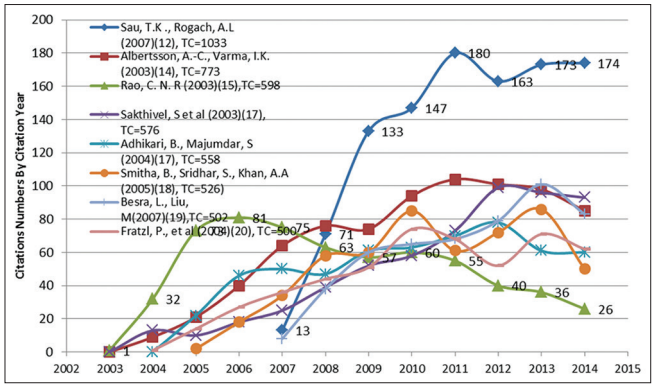

Figure 7: Citation life cycle of eight out of top 15 highly cited articles published during 2003-07

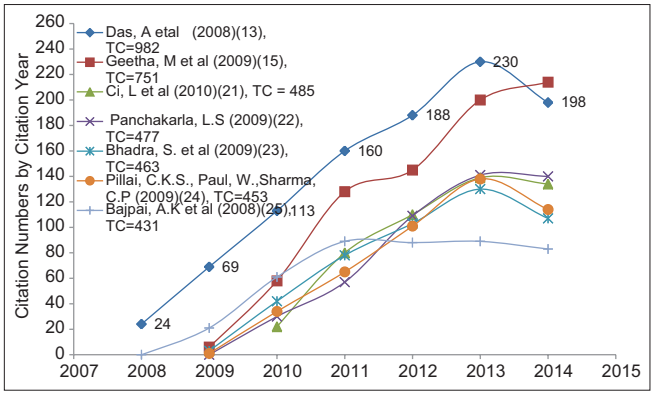

Figure 8: Citation life cycle seven out of top 15 articles published from 2008 to 2012

these journals varied between 2.129 and 6.626, except for *Progress in Polymer Science* (Oxford) (IF 26.854).

These 396 highly cited articles have received a total of 68,668 citations in 12 years, with an average citation per paper of 173.40. The leading organizations from India that had participated in highly cited research were IISc-Bangalore (49 papers), NCL-Pune (29 papers), JNCASR-Bangalore (25 papers), IIT-Delhi and IIT-Kharagpur (16 papers each), IICT-Hyderabad (15 papers), etc. The leading authors were C.N.R. Rao (20 papers), M. Sastry and V.K. Gupta (9 papers each), A. Govindaraj (8 papers), and A. Ahmad,

V. Thomas, and C.D. Lokhande (6 papers each). The leading international collaborative countries were the USA (49 papers), Japan (27 papers), Germany (23 papers), South Korea (12 papers), and France (9 papers). MCI varied among leading institutions, as well as among individual authors.

High-quality research in materials science in India is fast declining. This is evident from the fact that the publication output of highly cited papers has witnessed a negative publication growth at - 23.33% per annum in contrast to a negative growth rate of 18.29% by the world during 2003–2012. The negative growth rate of highly cited papers by India and the world is a matter of grave concern.

Citation density data reveal that citation visibility and the impact of highly cited Indian papers in materials science are gradually increasing over time. It increased from 16.4 citations in 2003 to 33.9 in 2011 and was the highest with 57.4 citations in 2012. Citation density measures citations per paper per citation window-year (no of citations/year since paper publication).

Two distinct patterns are observed with respect to citation life cycles of highly cited papers that India had published in materials science. Articles published in later years had a more rapid increase in citation numbers and needed relatively fewer years to reach their citation peak, but after reaching their citation peak, they follow a path of rapid fall in their citation numbers. If such a trend is to continue in future, it is expected that high-percentile articles will follow even steeper citation increase and reach their citation peaks faster within a shorter time since publication, but thereafter will see a more rapid fall in their citation numbers.

Nearly 16% of Indian authors featured as corresponding authors, 22% as first author articles, and 18% as both first author and corresponding authors. Nearly 9.64% of foreign authors featured as corresponding authors, 7.61% as first authors, and 10.66% as both first author and corresponding author of articles.

The USA dominates the global leadership in materials science with its world publication share of 39.8%, followed by China (15.1%), Germany (9.7%), Japan (8.0%), the UK (7.1%), France (5.1%), and South Korea (4.9%). India lags behind world trend in research productivity materials science research. Its global publication share is stagnating at 2.59%. If India is to emerge, as one of the top global leaders in materials science, it must seek to accelerate its publication growth in materials science research significantly and couple this trend with a large number of high-percentile citation papers. Till 2014, India could publish merely 8% (32) of its output in the top citation range (300–1300).

International collaboration seems to be the key to generate highly cited papers in materials science. This approach is an indispensable requirement to produce highly cited papers. This study observes that internationally collaborated papers averaged higher citation rate per paper (191.17) relative to nationally collaborated papers (168.71).

India has enough scope to engage in international collaboration efforts when as many as 55% of its highly cited papers out of 396 are made exclusively with Indian authorship either through national collaboration mode or single-institution participation mode. Internationally, collaborated papers are still in the minority. For promoting international collaboration in the country, India must take initiatives to reinforce its efforts for a meaningful dialog seeking collaboration with top global leaders in materials science research such as the USA. Thus far, the USA has remained the leading partner for international collaboration with India. Quest for excellence must be international.

High-quality materials science research within India is still confined to select few top-end organizations/institutions belonging to research sector and higher education sector in the country. Though their performance rating in terms of MCI is relatively higher, a gradual decline in materials science research is indicative of their changing research priorities or of growing dearth of high-profile, productive scientists or of scientific institutions in the country. The challenge before the top science leadership in country is how to bridge such a capability building gap in materials science research.

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