# A BIBLIOMETRIC ANALYSIS OF THE GLOBAL LITERATURE IN THE CORROSION FIELD FROM 1992 TO 2007

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## ABSTRACT

The corrosion field experienced a rapid growth in knowledge and innovations in the last decade. In this paper, a bibliometric analysis was applied to evaluate the global scientific production of corrosion papers (46,384 pieces) from 1992 to 2007 in all journals of all the subject categories of the Science Citation Index Expanded (SCIE) compiled by the Institute for Scientific Information (ISI), Philadelphia, USA. The analysis of the published outputs showed that research on corrosion increased steadily over the past 16 years and the researchers from the EU, the USA and China contributed greatly to the rise in publications. Synthetically analyzing the information including international cooperation, subject category, distribution of journals, document type, document language and author keywords, the development of corrosion

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research over the past 16 years has been visualized and several key findings were provided. This bibliometric method can help relevant researchers realize the panorama of global corrosion research, and establish the further research direction.

**Keywords:** Corrosion; Bibliometrics; Research trends

## 1. INTRODUCTION

It is generally thought that, from the late 1920s into the early 1940s, the foundation of corrosion science was established owing to the significant work of a group of scholars, of whom U.R. Evans, A. Frumkin and C. Wagner are the outstanding representatives [1]. Since then the detrimental effects of corrosion on economy, safety and the environment became evident and many efforts were dedicated to the fundamental and applied research of corrosion. Nowadays, "corrosion" has become a conventional subject with a history of nearly 100 years, consisting of corrosion science and corrosion engineering & technology. The corrosion researchers have broadened their interest from the traditional metallic material to more general materials, such as polymers [2], inorganic and composite materials [3]. The research on corrosion and its prevention has experienced a constant increase in the literature with all aspects of corrosion. The scientific production every year has grown from the early amount of less than 100 papers [4] to more than 4,000 papers. However, despite the long history and productiveness of corrosion research, there have been few attempts at gathering systematic data on the international scientific production of corrosion research except for Hugh S. Isaacs, who analyzed the contribution of corrosion to the publication of the electrochemical society [1]. As a good tool to deal with the large amount of literature information, the bibliometric method has already been widely applied for the scientific production and research status in many disciplines of science and engineering [5]. Through the flexible using of bibliometric analysis, the researchers can make effective use of the potential information contained in bibliometric documents, thus finding the clues of future research orientation and rethinking their current work.

The Science Citation Index Expanded (SCIE) database, provided by

the Institute for Scientific Information (ISI), is the most important and frequently used source of-scientific and technological achievements in all areas of science, engineering and technology. Based on this database, bibliometric methods are used to characterize the development of corrosion research quantitatively. Conventionally, bibliometric methods were used to evaluate the research state by investigating the publication outputs, quantities of citation. For example, Lufrano and Staiti evaluated the publication contribution of different countries on the supercapacitor research [6]. Chiu and Ho analyzed the citation situation of the publications in homeopathy research field [7]. However, focusing only on the changes of the these bibliometric items may be inadequate to provide a clear description of the development of a research field.

The aim of the present study is to carry out in-depth analysis of the literatures associated with corrosion and its prevention, trying to visualize the research state and trends of corrosion research through some improved bibliometric methods, in which the bibliometric information such as international cooperation, author keywords, subject category and document type were introduced. This study may facilitate the discussion of the future developing trends of corrosion research, therefore guiding researchers in their specific fields of science.

## 2. DATA AND METHODOLOGY

SCIE, published by ISI, is a general citation index covering complete scientific and technical fields. It is the major tool in the world for bibliometric and scientometric studies. From 1900 to 2006, SCIE included 172 subject categories and 6,166 journals. The bibliometric data of publications in the corrosion field were obtained from the online version of SCIE database (ISI Web of Knowledge), and based on which, 'corrosion' was used as a keyword for searching in topics, namely in titles, abstracts or keywords. The search resulted in the bibliometric information of 46,384 published papers related to corrosion from 1992 to 2007. It should be pointed out that personal judgment, experience and interests are definitely factors that influenced the counting of the papers related to the corrosion field, so the present study just faithfully acquired the raw data from SCIE database without adding any selection logic.

Moreover, for the convenience of discussion, the literatures obtained by searching "corrosion" in topics are expressed as "corrosion-related" papers.

In this work, the publications originating from England, Scotland, Northern Ireland, and Wales were situated under the UK heading. All papers were classified according to their titles so as to remove any overlaps. The impact factor is the most important indicator for evaluating the performance of a journal, and all the impact factors of journals in this study were obtained from the Journal Citation Reports (JCR) in the year 2007 ISI.

## 3. RESULTS AND DISCUSSION

### 3.1. Growth of publication

Figure 1 shows the trend in the number of the global corrosion-related SCIE articles. The figure indicates a steady increase in the number of articles over the past 16 years; further calculation shows the annual average growth rate is approximately 6.8%. Following this trend, it is expected that the number of papers in the corrosion field will exceed 5500 in 2010 and experience a constant growth.

Regarding the distribution of the annual publication outputs from different countries within Europe, Figure 2(A) shows that researchers in Germany and France are more prolific as compared to other European countries. When the most contributive six European countries are combined into a union to compare with other countries, it becomes the top-scoring one with 1,025 articles in 2007, followed by China with 760 and USA with 641, as shown in Figure 2(B).

In the case of China, we find a distinct increase in the number of SCIE articles since 2000, which doubled every five years, thus implying that a tremendous development of corrosion research was achieved in China during the last decade. The annual average growth rate on the number of articles is about 18%, which is quite different from the growth rate in other countries.

In order to evaluate the research quality in different countries, the index of "times cited per paper" of each country was calculated. Figure 3 shows the ranking of the most-cited 11 countries for the times cited per

paper, which clearly demonstrates a fact that papers from Russia, India and China are less cited by researchers. On the other hand, papers from the USA and the UK are more popular and more influential in the corrosion field. So it can be concluded that the developed countries, such as the USA, the UK, Italy and France, are still the leading countries in corrosion research despite the fact that the annual publication outputs in these countries are gradually being surpassed by China and India.

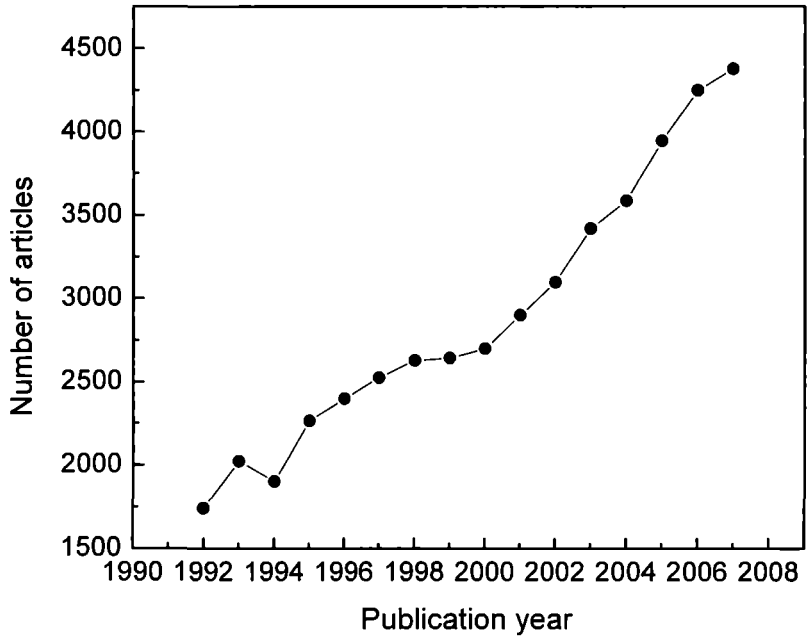


**Fig. 1:** Trend in the annual number of corrosion-related SCIE articles over the world

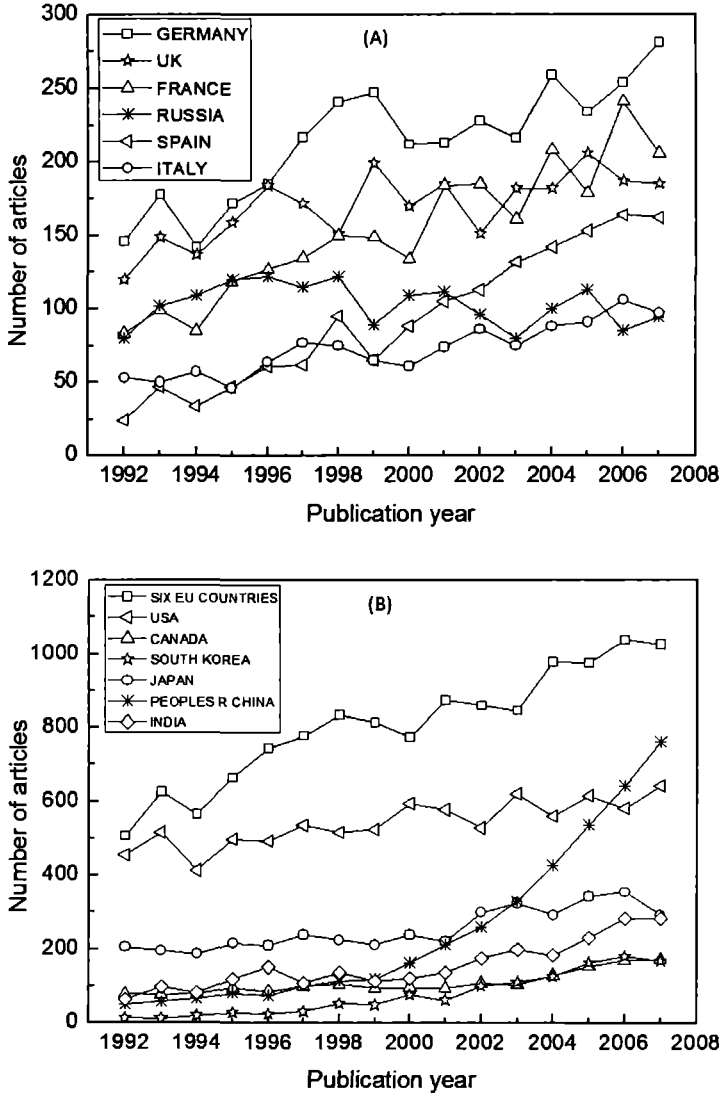


**Fig. 2:** Distribution of articles from different countries vs. the publication year: (A) most contributive 6 countries in Europe, (B) Six European countries and other most contributive 6 countries

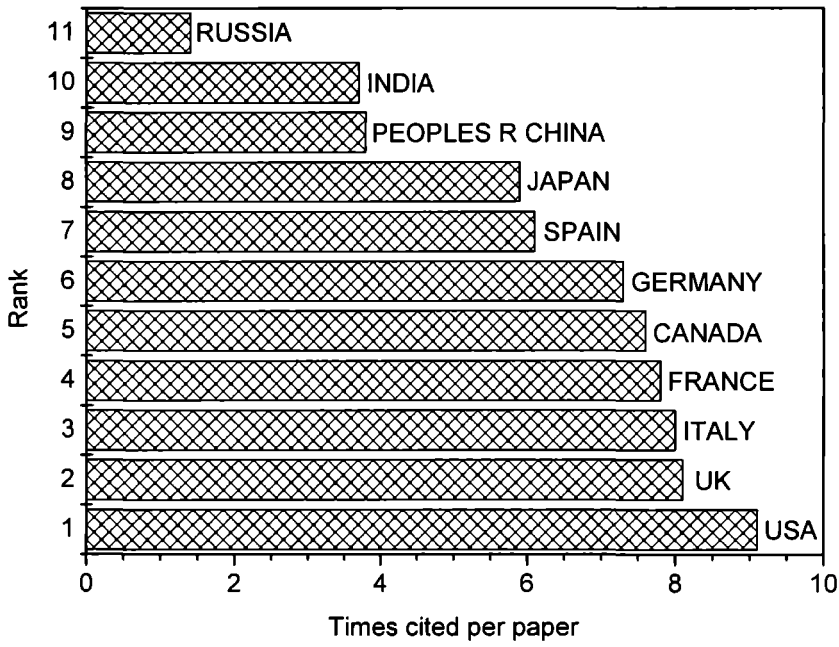


**Fig. 3:** Ranking of the most-cited 11 countries 11 countries for times cited per paper

## 3.2. Distribution of document type and language

Table 1 shows the distribution of document type of publications related to corrosion from 1992 to 2007. There were 16 document types involving a total of 46384 papers. Among them, 43,004 were original articles, distantly followed by review papers with 1084, editorial material with 826, meeting abstracts with 434 and others.

As is shown in Table 2, 93.7% of papers were published in the English language. English is distinctly the dominant language for international scientific communication. The results suggest that authors from Germany, Japan, China, France and some other countries mainly submit their papers to English journals. Some native non-English SCIE journals are becoming less popular for the reason that papers published in these journals are seldom available or understood by foreign researchers. Editors of Chinese journals have realized this issue, so more and more SCIE journals in China only accept English manuscripts.

**Table 1**
Distribution of document types of the articles published from 1992 to 2007

| DT | P | DT | P |
|---|---|---|---|
| Article | 43004 | Reprint | 49 |
| Review | 1084 | Correction, Addition | 27 |
| Editorial Material | 826 | Discussion | 26 |
| Meeting Abstract | 404 | Software Review | 6 |
| News Item | 337 | Biographical-Item | 3 |
| Note | 269 | Book Review | 2 |
| Letter | 268 | Bibliography | 1 |
| Correction | 77 | Item About an Individual | 1 |

DT: document type; P: number of publications.

### 3.3. Publication activity and international collaboration

Of the 46,384 SCIE publications published from 1992 to 2007, 5,239 publications (11.3%) were international collaboration papers and 39,020 (84.1%) were single country publications. These publications covered 125 different countries or territories (Hong Kong, Taiwan). Publication activity of countries and institutes worldwide participating in the corrosion research from 1992 to 2007 can be noted in Tables 3 and 4, which depict the top 15 countries and institutes ranked by number of publications, including the number of single country publications and internationally collaborated publications. Eight countries with the 10 highest Country GDP (the USA, Japan, Germany, China, the UK, France, Italy, and Canada) also ranked as the 10 most productive countries which published papers related to corrosion research. Moreover, the eight countries are also productive in independent papers, including 22,447 (57.5%) of all independent papers. Of the 15 most prolific institutions shown in Table 4, seven are from Asia, three are from western Europe, two from the USA, two from eastern Europe and one from South America. Nine are universities, and the remaining institutions are research institutes.

**Table 2**
Distribution of language of the articles published from 1992 to 2007

| Language | P | Language | P |
|---|---|---|---|
| English | 43466 | Korean | 13 |
| German | 782 | Croatian | 10 |
| Japanese | 629 | Swedish | 9 |

**Table 2** (continued)

| Language | P | Language | P |
|---|---|---|---|
| Chinese | 531 | Ukrainian | 8 |
| French | 277 | Finnish | 5 |
| Spanish | 230 | Slovene | 3 |
| Rumanian | 157 | Slovak | 3 |
| Russian | 147 | Italian | 2 |
| Portuguese | 38 | Estonian | 1 |
| Czech | 25 | Dutch | 1 |
| Polish | 25 | Serbo-Croatian | 1 |
| Hungarian | 21 | | |

The USA showed the greatest numbers of world publications, being followed distantly by other countries. It also had the most frequent partners, accounting for 13% of the international collaborative articles. It would be reasonable to assume that more international collaboration would lead to more publication outputs due to the sharing of ideas and workloads. In general, international co-authorship (ICA) papers were more prevalent in recent years than in earlier years, and the increasing trend of ICA share of world publications was somewhat in accordance with the trend of the number of countries or institutes. International cooperation, which playing an ever-growing role in contemporary scientific research, can usually manifest itself in ICA papers tracked by bibliometric tool [8].

Using 4-year intervals to minimize the year-to-year fluctuations, the percentages of articles with ICA were 4%, 9%, 14% and 19% for the periods of 1992–1995, 1996–1999, 2000–2003 and 2004–2007,

respectively. It indicated that the corrosion research was being more globally connected and the increased case of communication in a technologically connected world contributed to the increasing collaboration.

**Table 3**

Publication activity of countries or territories from 1992 to 2007

| Country/ Territory | TP | R (%) | SP | R (%) | CP | R (%) |
|---|---|---|---|---|---|---|
| USA | 8665 | 1(20.5) | 7248 | 1(19) | 1417 | 1(13) |
| Japan | 4044 | 2(9.5) | 3479 | 2(8.9) | 565 | 5(5.2) |
| Peoples R China | 3970 | 3(8.2) | 3426 | 3(8.8) | 544 | 6(5.0) |
| Germany | 3425 | 4(7.9) | 2519 | 4(6.5) | 906 | 2(8.4) |
| UK | 2719 | 5(6.4) | 1924 | 6(4.9) | 795 | 3(7.3) |
| India | 2466 | 6(5.6) | 2294 | 5(5.9) | 170 | 16(1.6) |
| France | 2445 | 7(5.3) | 1749 | 7(4.5) | 696 | 4(6.4) |
| Canada | 1726 | 8(4.0) | 1304 | 9(3.3) | 422 | 8(3.9) |
| Russia | 1648 | 9(3.4) | 1453 | 8(3.7) | 195 | 15(1.8) |
| Spain | 1494 | 10(3.3) | 1030 | 10(2.6) | 464 | 7(4.3) |
| South Korea | 1202 | 11(2.7) | 956 | 11(2.5) | 246 | 10(2.3) |
| Italy | 1165 | 12(2.6) | 798 | 12(2.0) | 367 | 9(3.4) |
| Egypt | 860 | 13(1.9) | 696 | 14(1.8) | 164 | 17(1.5) |
| Brazil | 851 | 14(1.9) | 656 | 15(1.7) | 195 | 14(1.8) |
| Taiwan | 833 | 15(1.8) | 774 | 13(2.0) | 59 | 35(0.55) |

TP: total publication output; SP: single country publication output; CP: international collaboration publication output; R (%): the rank and percentage of the country in the study field.

**Table 4**

*Publication activity of institutes from 1992 to 2007*

| Institute | TP | R (%) | SP | R (%) | CP | R (%) |
|---|---|---|---|---|---|---|
| Chinese Academy Science | 1478 | 1(1.4) | 1418 | 1(1.5) | 60 | 6(0.74) |
| Russian Academy Science | 833 | 2(0.79) | 705 | 4(0.72) | 128 | 1(1.6) |
| Tohoku University | 818 | 3(0.77) | 715 | 3(0.73) | 108 | 2(1.3) |
| Spanish National Council for Research | 789 | 4(0.75) | 751 | 2(0.77) | 38 | 10(0.47) |
| Indian Institutes of Technology | 666 | 5(0.63) | 600 | 5(0.61) | 66 | 5(0.81) |
| Central Electrochemical Research Institute | 606 | 6(0.57) | 515 | 6(0.53) | 91 | 3(1.1) |
| Pennsylvania State University | 436 | 7(0.41) | 389 | 8(0.40) | 47 | 8(0.58) |
| Tsing Hua University | 427 | 8(0.40) | 421 | 7(0.43) | 6 | 297(0.074) |
| Ohio State University | 393 | 9(0.37) | 361 | 9(0.37) | 32 | 17(0.39) |
| University of Manchester | 385 | 10(0.36) | 329 | 11(0.34) | 56 | 7(0.56) |
| Beijing University of Science & Technology | 370 | 11(0.35) | 351 | 10(0.36) | 19 | 54(0.23) |
| Ukrainian Academy Science | 365 | 12(0.34) | 275 | 22(0.28) | 90 | 4(1.1) |
| Indira Gandhi Centre for Atomic Research | 343 | 13(0.32) | 306 | 18(0.31) | 37 | 12(0.45) |
| University of Paris 06 | 341 | 14(0.32) | 315 | 15(0.32) | 26 | 28(0.32) |
| University of Sao Paulo | 331 | 15(0.31) | 322 | 12(0.33) | 9 | 171(0.11) |

### 3.4. Distribution of journals and subject category

In total, 46,384 SCIE publications referring to corrosion were published in a diverse variety of 2,604 journals, within which about 35.3% journals contained only 1 article and 14.0% journals contained 2 articles. On the contrary, approximately 32.5% of the total articles on corrosion research were published in the 15 core journals showed in Figure 4, whereas the remainder were published in the other 2,589 journals. The bibliometric result shows that the international journal of *Corrosion Science* ranked first with 2,577 (5.56%) published papers, *Corrosion* ranked second with 1,620 (3.49%) published papers and *Surface & Coatings Technology* ranked third with 1,551 (3.34%) publications, respectively.

It is worth pointing out that the international journal of *Corrosion Engineering Science and Technology* (ranked 38$^{th}$ with 194 published papers) is formerly *British Corrosion Journal* (ranked 21$^{st}$ with 303 published papers), and their Print ISSN are 1478-422X and 0007-0599, respectively. In our analysis, we classify journals based on the Print ISSN, not the Online ISSN, so we did not put them in Figure 4 for their ranks. However, if we classify journals based on the Online ISSN (they share the same Online ISSN: 1743-2782), the journal of *Corrosion Engineering Science and Technology* will rank 12$^{th}$ with 497 (1.07%) published papers.

The bibliometric analysis of publications in the corrosion field showed 173 subject categories identified by ISI during the past 16 years, and Figure 5 shows the distribution of the top 8 subject categories on corrosion from 1992 to 2007. The most common categories were *Material Sciences, Multidisciplinary* and *Metallurgy & Metallurgical Engineering*, followed by *Material Sciences, Coatings & Films* and *Electrochemistry*. It can be concluded from the results described above that "corrosion" was mostly present in the subject category of *Metallurgy* and *Material Sciences* related fields. These results provided a current view of the research emphasis of the topic of corrosion since the use of statistics in any scientific discipline can be considered a key element in evaluating its degree of maturity [9]. Additionally, the proportion of scientific articles per category exhibited small variation during the time period covered.

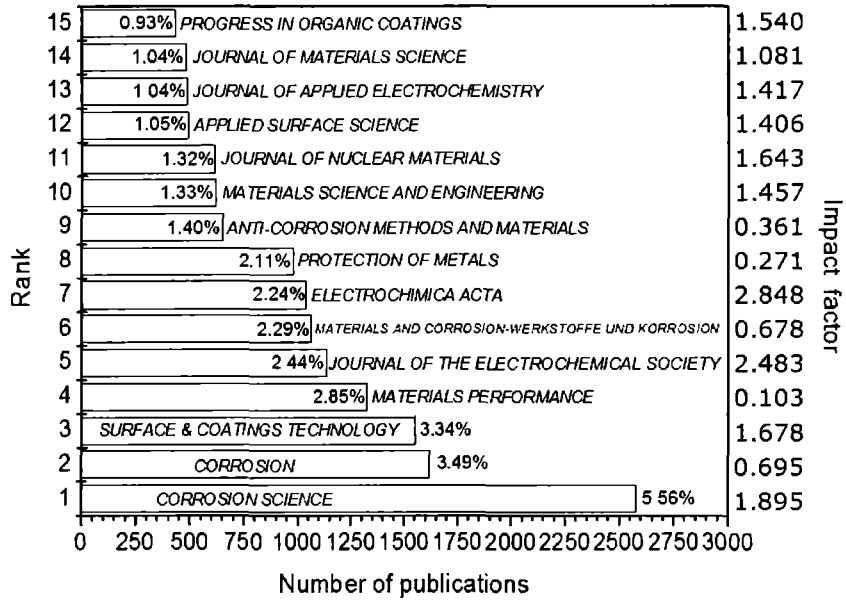


**Fig. 4:** The 15 most active journals on corrosion field from 1992 to 2007.

## 3.5. Author keywords

The top 20 author keywords that appeared in the articles published from 1992 to 2007 are shown in Table 5 based on a 4-year-interval method. Of the entire 42,783 author keywords, 31,262 (73%) keywords appeared only once, 5,072 (12%) keywords appeared twice and 2,011 (4.7%) keywords appeared three times. The large number of author keywords used only once or twice probably indicates a lack of continuity in research or a wide disparity in research focuses. The most frequently used keyword for all periods was "corrosion" which was also a keyword used for searching in this study. Besides the common terms frequently used in corrosion research, the top 20 author keywords cover a wide range of specific topics such as corrosion process ("stress corrosion cracking", "oxidation", "pitting corrosion"," atmospheric corrosion"), material categories ("stainless steel", "steel", "copper", "iron", "mild steel", "titanium", "aluminium", , "concrete"), testing methods ("EIS", "electrochemical impedance spectroscopy", "XPS" ) and corrosion control("coatings").

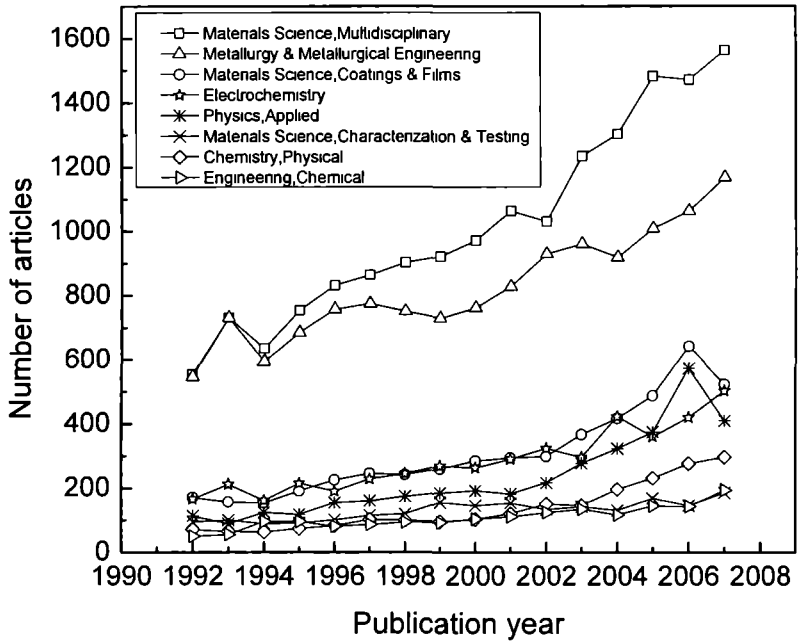


**Fig. 5:** Distribution of subject categories on corrosion field from 1992 to 2007

During the entire study period, "corrosion resistance", "steel" and "copper" are always the frequently adopted author keywords, thus indicating that these topics are invariable hotspots in the corrosion research. It is also noteworthy from Table 5 that "aluminium", "mild steel", and the testing methods of "EIS" (Electrochemical Impedance Spectroscopy), "XPS" (X-Ray Photoelectron Spectroscopy) were seldom used as keywords in earlier years, but they were frequently used in recent years. Additionally, the ranks of "microstructure", "coatings" and "atmospheric corrosion" have increased drastically from 17 to 5, 19 to 14 and 100 to 16, respectively. This means the research articles on these topics have notably increased and these keywords may be the potential focuses in the future. On the other hand, it is surprising to find that there are several popular topics in the past such as "stress corrosion cracking", "iron" and "oxidation" are becoming gradually less significant as noted during our study period.

## 4. CONCLUSIONS

In the present study, the evolution and quality of global corrosion research from 1992 to 2007 have been analyzed quantitatively using bibliometric methods. Some key findings were provided for the first time. In total, 46,384 articles were published in 2,604 journals listed in 173 subject categories established by ISI. The corrosion research presented an upward trend as the production of papers increased steadily in the last 16 years, and the annual production of papers in 2007 was more than twice that in 1992. It is reasonable to assume that the number of global scientific papers on the topic of corrosion will exceed 5500 in 2010. The analysis on country distribution of research publications showed that, in the last 16 years, the number of countries worldwide participating in corrosion research greatly increased. It was also notable that the USA, contributing the most independent and international collaborative articles, had the most frequent international partners. Meanwhile, China demonstrated a constant and quick increase in the number of annual publications since 2000. As the flagship journal of the corrosion related field, *Corrosion Science* published the most articles. Approximately 32.5% of the articles associated with corrosion were published in the 15 core journals, whereas the remaining articles were published in the other 2,589 journals.

According to the author keywords analysis, "corrosion resistance", "steel" and "copper" seem the invariable hotspots of corrosion research in the study period of 16 years. Several author keywords such as "microstructure", "coatings" and "atmospheric corrosion", which dramatically increased in ranking in recent years, might become hotspots in the near future.

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**Table 5**
The 20 most popular author keywords in corrosion-related literatures from 1992 to 2007

| Author Keywords | Total (P) | R (P) | | | |
|---|---|---|---|---|---|
| | 1992-2007 | 1992-1995 | 1996-1999 | 2000-2003 | 2004-2007 |
| corrosion | 5532 | 1(448) | 1(1027) | 1(1562) | 1(2495) |
| corrosion resistance | 1294 | 2(110) | 3(216) | 2(330) | 2(638) |
| stainless steel | 1004 | 3(88) | 2(246) | 3(270) | 3(400) |
| steel | 728 | 11(53) | 4(175) | 4(193) | 6(307) |
| copper | 659 | 6(62) | 5(170) | 7(161) | 7(266) |
| stress corrosion cracking | 647 | 4(84) | 8(130) | 5(188) | 9(245) |
| oxidation | 633 | 5(65) | 6(150) | 6(180) | 10(238) |
| microstructure | 576 | 17(42) | 16(84) | 10(141) | 5(309) |
| pitting corrosion | 572 | 28(30) | 7(146) | 12(133) | 8(263) |
| EIS | 525 | - (0) | 20(79) | 13(129) | 4(317) |
| coatings | 481 | 19(37) | 10(117) | 9(142) | 14(185) |
| electrochemical impedance spectroscopy | 474 | - (0) | 24(68) | 8(150) | 11(221) |
| iron | 457 | 12(49) | 9(118) | 17(112) | 17(178) |
| mild steel | 432 | 121(11) | 14(86) | 11(135) | 12(200) |
| titanium | 410 | 43(22) | 18(82) | 15(122) | 15(184) |
| polarization | 399 | 36(26) | 11(111) | 26(92) | 22(170) |
| aluminium | 390 | 897(2) | 12(108) | 27(92) | 13(188) |
| concrete | 376 | 35(26) | 19(81) | 14(128) | 26(141) |
| atmospheric corrosion | 371 | 100(13) | 31(62) | 16(117) | 16(179) |
| XPS | 368 | 196(7) | 17(84) | 18(101) | 18(176) |

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