BOOM, R., RIAZ, S. and MILLS, K.C. Slags and fluxes entering the new millennium: an analysis of recent trends in research and development. *VII International Conference on Molten Slags Fluxes and Salts,* The South African Institute of Mining and Metallurgy, 2004.

Slags and fluxes entering the new millennium: an analysis of recent trends in research and development

R. BOOM*, S. RIAZ† and K.C. MILLS‡

*Corus Research, Development and Technology, Ijmuiden Technology Centre, Ijmuiden, The Netherlands

†Corus Research, Development and Technology, Teesside Technology Centre, Middlesbrough, United Kingdom

‡Imperial College, Department of Materials, London, United Kingdom

This paper details the recent trends in slag-related research from 1999 to 2003. The trends in the following are outlined:

- Annual publication rate
- Geographical origin of the work
- Nature of the research (e.g. thermodynamics, kinetics)
- Nature of the slag studied.

This study has revealed that slag research in the USA and Europe has decreased to about a half over the last 20 years and that there has been a significant decrease in Japanese research in this area in recent years. However, these decreases have been offset by significant increases in Chinese and Korean research activity. There has been a significant increase in the amount of work carried out on the recycling and environmental aspects of slags in recent years.

Introduction

In a previous paper[1] we reviewed papers on slags and fluxes published in the period from the First (1980) to the Fifth (1997) International Conference on Molten Slags and Fluxes. On the occasion of the 6th International Conference on Molten Slags, Fluxes and Salts, held in Stockholm and Helsinki in June 2000, we analysed further the developments from 1996 to 2000[2,3]. In this paper we have used the same methodology to detect the trend in research on slags and fluxes entering the new millennium. The results for the years 1999–2002 were studied following the established methodology. Data available for 2003, by definition incomplete, were analysed. The contributions to the VII International Conference on Molten Slags, Fluxes and Salts, scheduled for 25–28 January 2004 at Cape Town, South Africa, were analysed based upon the titles available from the preliminary programme.

In general the geographical distribution was allocated to the prime establishments—participation was credited to both establishments if in different geographical areas.

With topics, some papers were accredited to two categories where they fall square, into these categories, but in general only one accreditation was allocated to each paper.

Methodology

Based upon the METADEX reference source for metals a literature survey was produced using the key words ‘slag’, ‘mould flux’, ‘casting powder’ and ‘matte’ as descriptors. We did not use the descriptor ‘salts’ to be able to compare the results of the actual study with the earlier published work. METADEX is a comprehensive source for information on metals and alloys, including properties, manufacturing, applications, and development, containing over 950 000 references. Information from over 2 000 journals, plus patents, dissertations, government reports, conference proceedings and books are indexed by expert editors from Cambridge Scientific Abstracts.

The abstracts of the papers as a result of this query were then used to identify the nature of the research investigation, the type of slags studied, and the geographical origin of the research groups involved.

In Table I the total number of abstracts per year are collected identified by the query performed in 2000, as well as the results achieved in the present study.

In Figure 1 the two data sets are compared. It is clear that the Metadex reference source has been updated with historical material over the last three years. From the 2000 search an average annual production of 348 papers was found, a number that increased to 387 from the 2003 search. One can conclude that the worldwide publication rate for papers on slags, fluxes and mattes equals about 1 per day.

Geographical origin

The geographical origin is classified according to the following global partition: United States of America (USA), Canada, Japan, European Union (boundaries as defined in 2003), Russia, Eastern Europe, China, Korea, India, Australia, Central and South America, South Africa and Others. The percentage of papers per geographical area is collected in Table II and presented in Figure 2.

The picture is remarkably stable over the years: Russia stays by far the most productive country in slag-related publications with about a quarter of the total every year. However, compared to earlier periods (1980–1999) where the average Russian contribution was 30 per cent, this is a reduction. In comparison with earlier work, Russia in this study is confined to the country with the 2003 (post USSR)

Table I
Annual number of slag-related papers from the Metadex reference source 1980 to 2003

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Citations in 2000 [2-3]	357	321	335	376	393	389	433	382	388	405
Citations this work	356	338	367	394	409	444	460	428	459	431

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Citations in 2000 [2-3]	327	329	359	339	269	250	291	327		160
Citations this work	347	367	393	410	350	330	312	339	347	371

Year	2000	2001	2002	2003
Citations this work	454	425	408	48*

* incomplete data

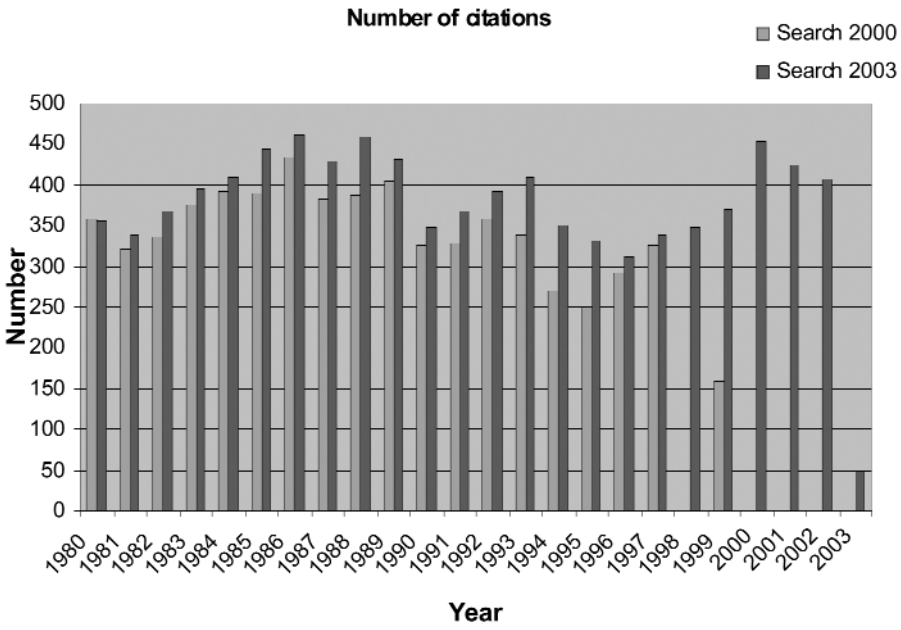

Figure 1. Number of slag-related publications in Metadex resulted from searches in 2000 and 2003

borders, whereas earlier the Soviet Union was referred to as Russia. In the present study publications from some of the former Soviet Union republics are allocated to Eastern Europe, indeed showing an increase as compared to the earlier results[2,3]. The output of Japanese slag research is reduced dramatically from the 20 per cent range in the 1980s and 1990s to the actual 11 to 13 per cent. China's share of publications on slags and fluxes increased from a few percent in the 1980s to the actual range of 12 to 19 per cent, in accordance with the ultra-fast growth of the metallurgical industry in China, especially the iron and steel industry[4].

Nature of research activities

The nature of the research activities on slags, fluxes and mattes are divided into: phase equilibrium or mineralogical studies, thermodynamics, kinetics, physical properties, slag/metal equilibrium, the combination of plant data and process modelling, refractory erosion, foaming and smelting reduction, modified oxygen steelmaking, slag splashing, and the combination of environmental and recycling studies. The percentages are collected in Table III and presented in Figure 3.

From the statistics it can be concluded that the distribution of different research activities in the field of slags is remarkably constant. The overwhelming majority of published works (about 40 per cent) is devoted to plant data and/or process modelling, much of it emanating from Russia and China. The decreasing trend in number of slag/metal equilibria studies, noted previously, seems to be turned around in 2002. The percentage of publications on slag foaming and smelting reduction continues to increase in the new millennium. The relative number of slag studies focused on recycling and environmental concerns has maintained its high level (about 15 per cent) and may be actually increasing, which reflects the increasing awareness of sustainable production and environmentally friendly processes.

Types of slags studied

The results of the analysis, in terms of types of slags studied, are presented in Table IV and Figure 4. About a quarter of all slags studied is directly related to the steelmaking process. If we add to that the ironmaking slags (on average 11 per cent), the ladle/refining slags (around 10 per cent) and the mould fluxes for continuous casting of

Table II
Geographical origin of research on slags (%), data for 1979-1997 from[2;3]

	1979	1987	1993	1997	1999	2000	2001	2002	2003
USA	15.3	8.4	7.5	8.0	8.9	8.1	7.0	8.7	2.1
Canada	4.7	3.2	6.5	4.0	3.9	5.1	4.4	3.9	4.3
Japan	12.2	17.1	21.5	12.4	10.2	11.2	14.0	13.1	6.4
European Union	23.7	21.8	12.4	13.8	12.7	7.4	11.4	9.0	12.8
Russia	29.8	25.3	15.4	30.5	31.3	28.9	24.9	24.9	40.4
Eastern Europe	5.4	8.4	4.0	3.2	4.4	4.7	5.8	6.4	2.1
China	2.0	8.7	13.9	16.4	11.9	19.0	17.1	11.8	8.5
Korea	0.0	0.5	4.0	1.5	5.3	3.8	3.6	6.9	4.3
India	1.0	1.7	2.0	4.3	1.9	1.8	2.2	1.5	8.5
Australia	1.4	1.0	3.0	2.0	1.9	4.0	3.9	4.9	4.3
Central &South America	2.0	1.5	1.5	0.7	4.7	2.9	4.3	4.1	4.3
South Africa	1.7	0.5	5.7	0.7	1.4	1.6	0.5	2.6	0.0
Others	0.8	1.9	3.5	2.6	1.4	1.6	1.0	2.1	2.1

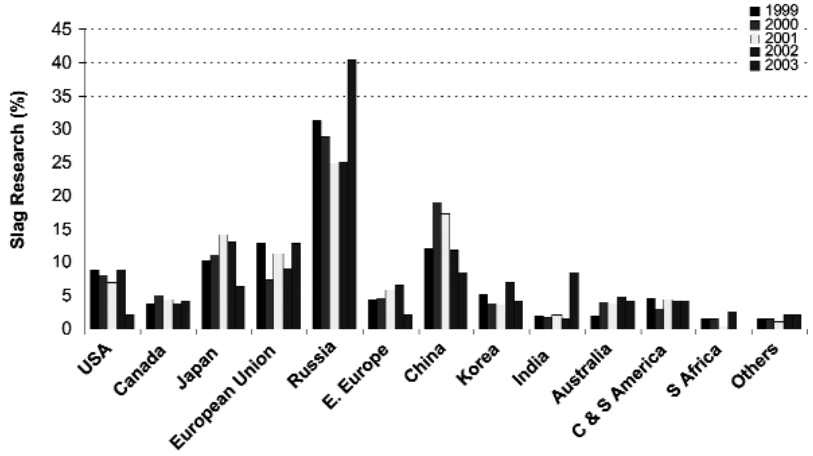

Figure 2. Geographical origin of slag-related papers in period 1999 to 2003

Table III
Distribution of slag-related research activities (%), data for 1979–1997[2;3]

	1979	1987	1995	1997	1999	2000	2001	2002	2003
Phase equilibrium/mineralogical	6.7	2.1	3.4	5.2	5.4	4.6	4.1	4.5	2.3
Thermodynamics	9.8	9.0	11.3	7.6	5.4	8.4	6.9	7.5	2.3
Kinetics	6.3	5.6	4.4	4.3	7.6	7.9	3.7	4.3	4.5
Physical properties	11.6	8.2	13.5	11.2	9.5	11.5	9.7	9.0	2.3
Slag/metal equilibrium	19.2	19.0	26.0	10.4	14.1	8.4	8.3	12.3	20.5
Plant data/process modelling	38.4	43.2	20.7	40.6	37.8	38.6	44.1	37.6	34.1
Refractory erosion	4.0	7.9	3.4	4.6	2.4	1.8	3.0	3.3	2.3
Foaming/smelting reduction	0.0	0.0	6.0	1.7	4.6	4.9	3.7	3.3	2.3
Modified oxygen steelmaking	-	-	-	-	0.3	0.4	0.2	0.3	0.0
Slag splashing	-	-	-	-	1.6	2.9	1.6	1.5	2.3
Recycling/environmental	4.0	5.0	11.3	14.5	11.1	10.4	14.7	16.5	27.3

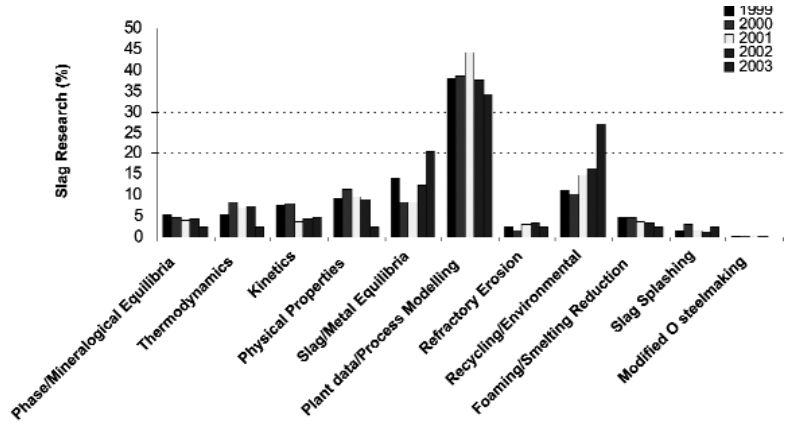

Figure 3. Research activities of slags investigated in the period 1999–2003

Table IV
Type of slags and fluxes investigated (%), data for 1979–1997[2;3]

	1979	1987	1995	1997	1999	2000	2001	2002	2003
Ironmaking	17.3	10.1	9.2	16.4	9.1	12.6	12.2	11.1	15.9
Steelmaking	20.3	23.7	14.6	19.8	25.3	20.3	22.0	28.1	22.7
Ladle/refining	8.2	15.4	8.4	10.3	8.0	7.7	13.6	10.1	6.8
Mould fluxes	4.8	5.9	13.6	6.3	6.6	7.0	6.8	3.7	0.0
Welding fluxes	0.9	1.2	1.5	2.8	1.1	1.3	0.9	0.5	2.3
Non-ferrous	10.4	16.6	9.5	12.9	12.1	15.4	13.1	18.5	36.4
Mattes	14.7	10.2	10.7	9.7	13.2	10.1	9.8	7.9	4.5
Synthetic	19.0	16.6	30.6	12.9	17.9	18.7	14.5	11.1	6.8
Ferro alloys	3.9	0.0	1.5	2.6	3.8	3.3	1.4	3.0	4.5
Wastes	-	-	-	5.5	3.0	3.5	5.6	6.2	0.0
Coal	0.5	0.3	0.5	0.6	-	-	-	-	-

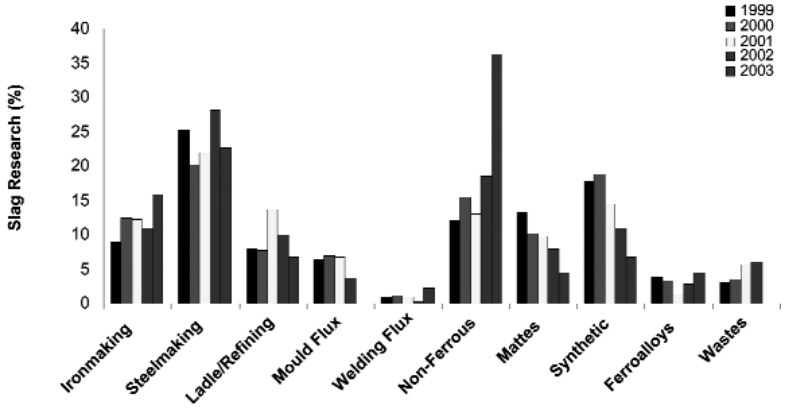

Figure 4. Types of slags studied in the period 1999 to 2003

steel (7 per cent), we can conclude that more than 50 per cent of slags studied are directly related to industrial iron- and steelmaking. Compared to the relative importance of iron and steel in the international metals world[5] this fraction should be much higher. Given the long human experience with iron (more than an iron age or 3 000 years) the knowledge of iron- and steelmaking slags will eventually come to certain saturation. The knowledge on processing of the 'new' non-ferrous metals, on the other hand, needs to be extended and deepened, which explains the steady increase in non-ferrous slag studies. The increase in the reuse of waste slags, as indicated here for 2002 and 2003, is in line with the expectation of the importance of waste minimization or reuse.

Review of conference proceedings and programmes

Previous reviews[1-3] showed that the conference proceeding publications are not a true reflection of the research activity on a global basis. It is obvious that the statistics of the papers in the conference proceedings are influenced by both geographical and economic factors. For instance, Russian research publications on slags constituted 25 to 30 per cent of the total in 1979 to 1987, but there were no Russian papers in the proceedings of the slags conferences of 1984 and 1988.

The results presented in Table V and Figure 5 show that there is a marked distortion in attendance for the host country and neighbouring countries. Japanese participation in the conference continues at a high level up to 2000. For the VII International Conference on Slags, Fluxes and Salts ,we can conclude that indeed the host country South Africa is far better represented than the percentage of published literature would indicate. The Japanese contribution to this conference dropped dramatically as compared to the first five slag conferences, thereby continuing a tendency that started with the Stockholm/Helsinki conference. The Cape Town figure of 8.8 per cent Japanese contributions is far below the Japanese average percentage of published papers on slags and fluxes. The gradual decrease in the number of papers from the USA and Canada over the years can be clearly seen in Table V, whereas EU participation has been held at a remarkably high level despite the decrease in EU publication rate over the same time period.

Conclusions

From our literature review based on Metadex data covering the period 1980–2003 we can conclude that:

- The publication rate of slag-related research papers remains remarkably constant at about 360 per year, equivalent to, on average, one publication on slags and fluxes per day.
- Over the last 20 years the contributions from the USA and the European Union have decreased to about half of the total.
- The publications from Japan have decreased significantly in recent years.
- There has been a significant increase in the slag-related research activities in China and Korea.
- There has been a significant increase in recycling and environmentally-orientated projects in the last few years.

Table V
Geographical origin of papers published in conference proceedings or programmes (%), data for 1979–1997[2;3]

	1980	1984	1988	1992	1997	2000	2003
USA	13.0	*28.6	10.1	4.8	8.6	5.6	4.1
Canada	*24.0	14.3	7.6	3.2	2.0	0.9	5.4
Japan	20.4	26.0	34.4	*50.8	34.3	16.9	8.8
European Union	29.6	15.6	*36.9	17.7	12.5	*30.5	36.4
Russia	5.6	0.0	0.0	7.4	2.5	13.4	2.7
Eastern Europe	0.0	1.3	0.0	1.6	0.0	4.6	2.7
China	1.9	2.6	0.0	6.5	4.9	11.6	5.4
Korea	0.0	0.0	0.0	4.0	4.9	3.0	5.4
India	1.7	1.3	1.3	0.0	0.0	2.0	2.0
Australia	1.9	5.1	5.2	3.2	*22.5	5.2	14.9
Central &South America	0.0	5.2	5.2	0.0	2.0	3.5	3.4
South Africa	1.9	0.0	0.0	0.8	4.9	2.2	*7.4
Others	0.0	0.0	0.0	0.0	1.0	0.7	1.4
Place slag conference	Halifax	Lake Tahoe	Glasgow	Sendai	Sydney	Stockholm Helsinki	Cape Town°

* Slag conference held in this country or area
° Based upon preliminary programme

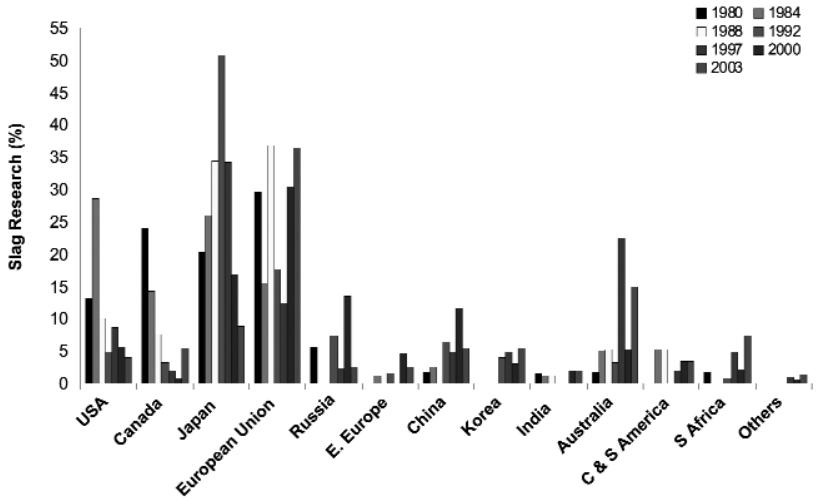

Figure 5. Geographical distribution of papers presented at the slags and fluxes conference series in the period 1980 to 2003

Acknowledgements

We thank Guus Docen of the Library and Information Services of Corus Research, Development and Technology for performing the literature search on the Metadex database.

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