

RECENT TRENDS IN RESEARCH ON SLAGS

R. Boom^{a)}, K. C. Mills^{b)} and S. Riaz^{b)}

a): Corus Research, Development & Technology, P O Box 10.000, 1970 CA IJmuiden, and NIMR/Department of Materials Science and Technology, Delft University of Technology, 2628 AL Delft, the Netherlands;

b): Department of Materials, Imperial College, London, SW7 2BP, UK.

ABSTRACT

In a previous review we looked at slag-related research from the period between the first and fifth international slag conferences (1980-1997). In this paper we have extended the review from 1996 to 2000 to determine (among other things) whether the economic slump in South-East-Asia has had a significant impact on the publication of slag-related papers like the disintegration of the USSR had.

We concluded from the review presented here:

- (i) that if there has been a decrease in slag-related publications, it is a small one (10%);
- (ii) that most surprisingly, the Russian contribution to slag-related research has increased markedly to reach levels higher than that in 1987;
- (iii) that if the economic slump in south East Asia has resulted in a decrease in slag-related research, it is a small one;
- (iv) that more than 30% of slag-related publications deal with plant investigations and process modelling and there has been an increase in industrially-related studies reported at recent slag conferences;
- (v) there has been a significant increase in studies on recycling of slags and their environmental problems, and these topics are now the focus of 1 out of every 8 publications.

1 INTRODUCTION

Four years ago we reviewed the progress of slag-related research, from the First International Slag Conference in 1980 to the Fifth Conference held in early 1997 [1]. We concluded that annual output of slag-related research publications had stayed approximately constant at 350 per annum but there had been some marked changes in the contributions.

- (i) There had been a marked decrease in the major contributions from the Russian establishments that probably reflected the upheavals of industry that accompanied the disintegration of the USSR.
- (ii) There had been a marked drop in slag-related publications originating from both USA and the EEC countries and it was speculated that this might be associated with the decrease in the teaching of Metallurgy as a university course in these countries.
- (iii) The decrease in EEC and USA contributions was offset by an increase in slag-related publications (in Japan, China, Korea and Australia)
- (iv) Although the nature of the research activity and the type of the slag studied had remained remarkably constant, it was apparent that newer interests such as recycling of slags and environmental problems, slag foaming and smelting reduction, and mould fluxes for continuous casting had all attracted increasing interest in more recent years.
- (v) The Sixth International Conference on Molten Slags, Fluxes and Salts will take place in Stockholm, 12-15 June 2000, and in Helsinki, 16-17 June 2000. Between the Fifth and Sixth Conferences, there has been a major jolt to the economies of the South East Asian countries. So, to see if this had had any impact on slag-related publications it was decided to carry out a further survey of slag-related publications.

2 PROCEDURE ADOPTED

A literature survey was produced using the Metadex CD-ROM system using slags as a descriptor or as part of the title. The abstracts of these papers were then used to identify the nature of the research investigations and the

slags studied and the geographical nature of the research group, as far as possible. The research was carried out in the year preceding the slags conference to avoid distortion of the annual output through the publications of a large number of papers at the conference. To maintain consistency in the papers classifying the geographical origin it should be noted that (i) the EEC refers to countries comprising the European Union in 1996 and (ii) Russia refers to all states originally constituting the USSR.

In order to study the trends in the last four years, Metadex searches were carried out for slag-related publications in 1997 and 1999. The slags conference proceedings for the 1997 meeting in Sydney and the abstracts submitted for the Stockholm/Helsinki conference in 2000 were also investigated.

3 REVIEW OF METADEX CITATION

3.1 Annual Citation

The total number of citations for a slag-related research is given in Table 1 and Figure 1.

Table 1: The total number of citations of slag-related papers.

<u>Year</u>	1980	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90
Number of citations	357	321	335	376	393	389	433	382	388	405	327
<u>Year</u>	1991	'92	'93	'94	'95	'96	'97	'98	'99		
Number of citations	329	359	339	269	250	291	327		160*		

**These totals may be incomplete since translated papers are not cited for 2 or 3 years after the year of publication.*

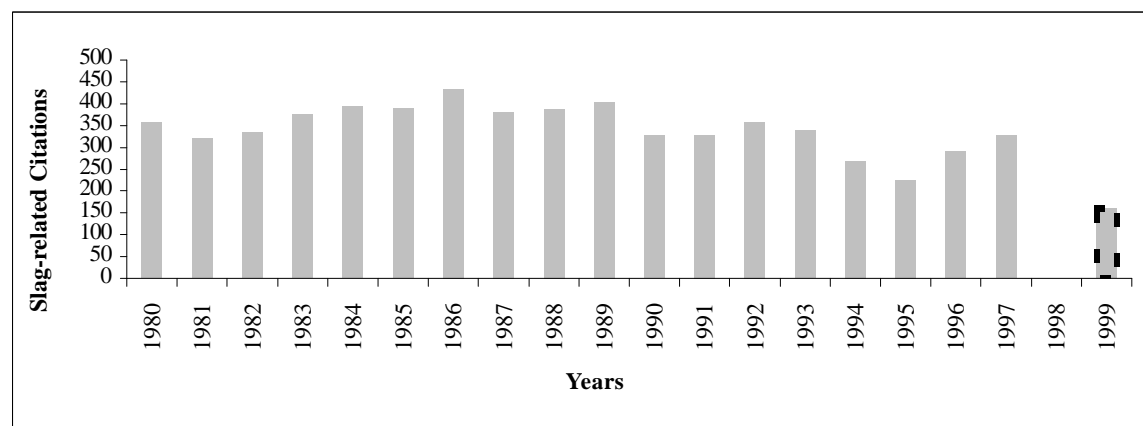


Figure 1: Annual number of publications of slag-related papers 1980 to 1999.

It can be seen that the annual citations for 1996 and 1997 were both higher than those for 1994. The annual citations for 1999 were low, but this is due to the fact that all the citations had not worked the way through the system yet because some translations may take up to 2 years to appear. Note: the citations for 1995 were also down substantially at the time of the last review.

3.2 Geographical Origin of Research

The results with respect to the geographical origin of the slag publications are given in Table 2 and Figure 2.

Table 2: Geographical origin of research on slags (%).

Country	Slag Research (%)				
	1979	1987	1995 (1993)	1997	1999
USA	15.3	8.4	15.4 (7.5)	8	10
Canada	4.7	3.2	10.6 (6.5)	4	4.3
Japan	12.2	17.1	13.2 (21.5)	12.4	14.3
EEC	23.7	21.8	10.1 (12.4)	13.8	13.1
Russia	29.8	25.3	16.3 (15.4)	30.5	31.3
Eastern Europe	5.4	8.4	3.1 (4.0)	3.2	3.7
China	2	8.7	15 (13.9)	16.4	9.4
Korea	0	0.5	5.7 (4.0)	1.5	5.3
India	1	1.7	2.6 (2.0)	4.3	0.6
Australia	1.4	1	4 (3)	2	1.6
South America	2	1.5	0.5 (1.5)	0.7	2.5
South Africa	1.7	0.5	1.3 (5.7)	0.7	1.2
Others	0.8	1.9	2.2 (3.5)	2.6	3.7

() indicates values for 1993, values for 1995 may be affected by time lag for translations.

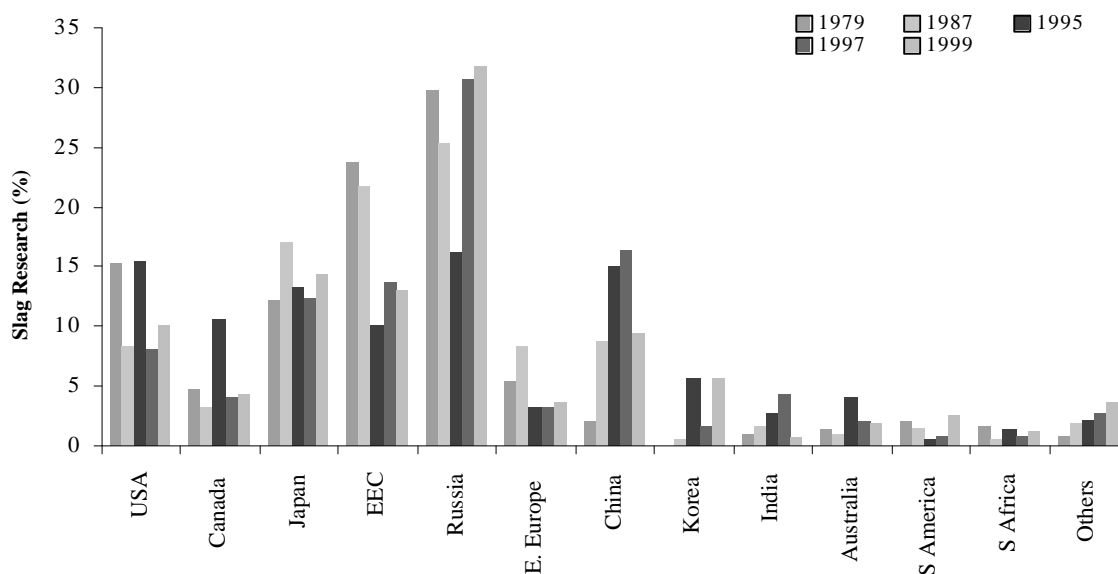


Figure 2: Geographical origin of slag-related publications (%) in 1979, 1987, 1995 and 1999.

It can be seen that:

- (i) most remarkably, the number of Russian publications has risen about the level it attained before the disintegration of the USSR (many of these publications are on industrially-oriented topics);
- (ii) the citations emanating from the EEC and the USA have managed to stay constant;
- (iii) there has been a drop in citations of slag-related papers emanating from Japan since the high point of 1993 but citations of work coming out of China, Korea and India has remained fairly constant.

3.3 Nature of Research Activity

The results of the statistics on nature of research activities as published in the papers on slags are shown in Table 3 and Figure 3.

Table 3: Distribution of slag related research activities (%).

Activity	Slag Research(%)				
	1979	1987	1995	1997	1999
Phase/Mineralogical Equilibria	6.7	2.1	3.4	5.2	9.4

Thermodynamics	9.8	9	11.3	7.6	9.4
Kinetics	6.3	5.6	4.4	4.3	8.0
Physical Properties	11.6	8.2	13.5	11.2	12.5
Slag/Metal Equilibria	19.2	19	26	10.4	8.1
Plant data/Process Modelling	38.4	43.2	20.7	40.6	30.4
Refractory Erosion	4	7.9	3.4	4.6	6.5
Recycling/Environmental	4	5	11.3	14.5	12.1
Foaming/Smelting Reduction	0	0	6	1.7	2.5

It can be seen that:

- (i) in general, the activities of slag-related research over the years have remained at a remarkably constant level;
- (ii) the level in slag/metal equilibria has tended to decrease in more recent years;
- (iii) there has been a considerable increase in the activities associated with recycling waste products and environmental concerns, such that this now constitutes around 13-15% of the total projects.

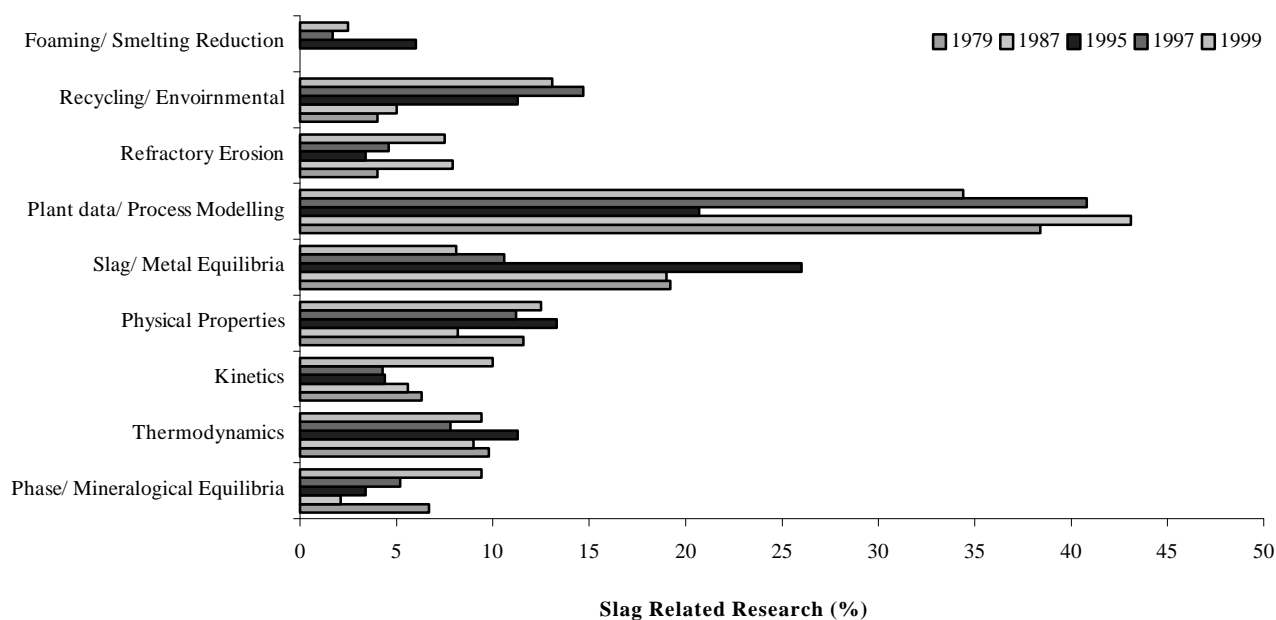


Figure 3: Research activities of slags (%) investigated in 1979, 1987, 1995, 1997 and 1999.

3.4 Types of Slags Studied

The results in terms of types of slags are shown in Table 4 and Figure 4.

Table 4: Types of slags investigated.

Type of Slag	Slag Research(%)				
	1979	1987	1995	1997	1999
Ironmaking	17.3	10.1	9.2	16.4	10.0
Steelmaking	20.3	23.7	14.6	19.8	22.5
Ladle/Refining	8.2	15.4	8.4	10.3	9.3
Mould Flux	4.8	5.9	13.6	6.3	6.2
Ferroalloys	3.9	---	1.5	2.6	3.7
Coal	0.5	0.3	0.5	0.6	0.0
Welding Flux	0.9	1.2	1.5	2.8	2.5
Non-Ferrous	10.4	16.6	9.5	12.9	14.3
Mattes	14.7	10.2	10.7	9.7	10.0
Synthetic	19	16.6	30.6	12.9	16.1
Wastes	0	0	0	5.5	5.6

Inspection of these results indicate:

- that the type of slags studied has remained remarkably constant over the years;
- that there has been a growing interest in using waste material as sustainability consciousness and environmental legislation gets progressively tougher.

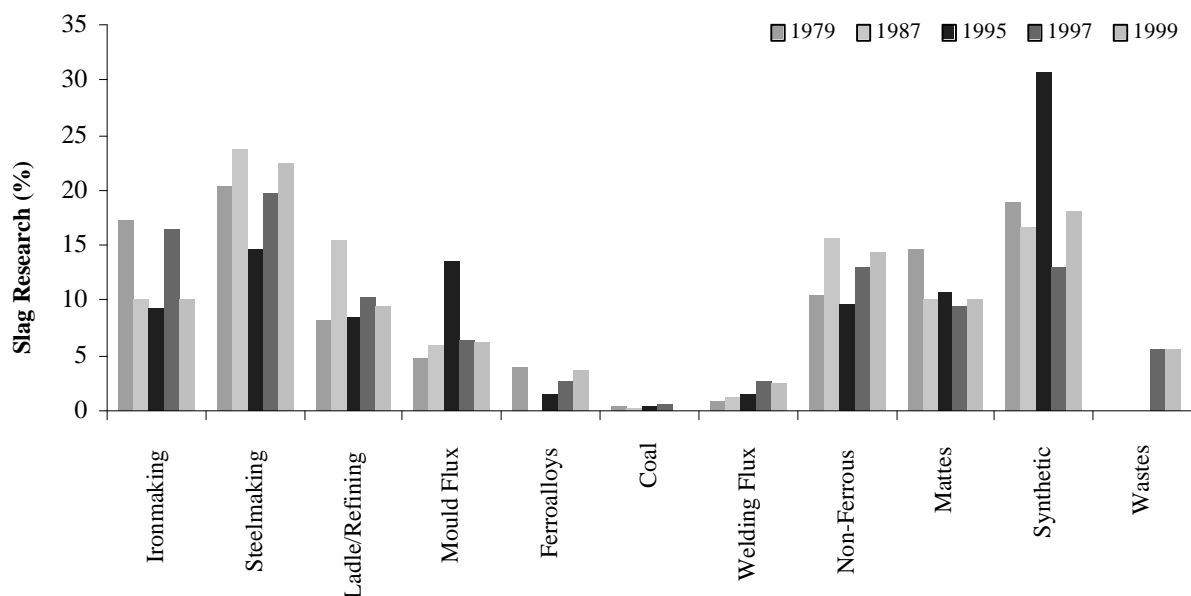


Figure 4: Types of slags studied in 1979, 1987, 1995, 1997 and 1999 (as %).

4 REVIEW OF CONFERENCE PROCEEDINGS

The previous review [1] showed that the conference proceeding publications are not a true reflection of the research activity on a global basis since the statistics of the proceeding papers are influenced by geographical and economic factors. For instance, Russian research publications on slags constituted 25% of the total in 1988 but there were no Russian papers in the proceedings of the slags conference of that year.

4.1 Geographical Origin

It should be pointed out that the abstracts for the 2000 conference did not contain the affiliations of the participants and the attribution was based solely on the ethnic origin of the name, where the participant was unknown to the authors of this article. Consequently, the geographical origin for the 2000 conference may be subject to considerable error. The results presented in Table (5) and Figure (5) show that:

- (i) there is a marked distortion in attendance for the host country and neighbouring countries;
- (ii) Japanese participation in the conference continues at a high level.

Table 5: Geographical origin of papers published in Conference Proceedings (%).

Country	Slag Research (%)					
	1980	1984	1988	1992	1997	2000
USA	13.0	28.6*	10.1	4.8	8.6	5.6
Canada	24.0*	14.3	7.6	3.2	2.0	0.9
Japan	20.4	26.0	34.4	50.8*	34.3	16.9
EEC	29.6	15.6	36.9*	17.7	12.5	30.5*
Russia	5.6	0.0	0.0	7.4	2.5	13.4
E. Europe	0.0	1.3	0.0	1.6	0.0	4.6

China	1.9	2.6	0.0	6.5	4.9	11.6
Korea	0.0	0.0	0.0	4.0	4.9	3.0
India	1.7	1.3	1.3	0.0	0.0	2.0
Australia	1.9	5.1	5.2	3.2	22.5*	5.2
S America	0.0	5.2	5.2	0.0	2.0	3.5
S Africa	1.9	0.0	0.0	0.8	4.9	2.2
Others	0.0	0.0	0.0	0.0	1.0	0.7

* Slag conference held in this country or area

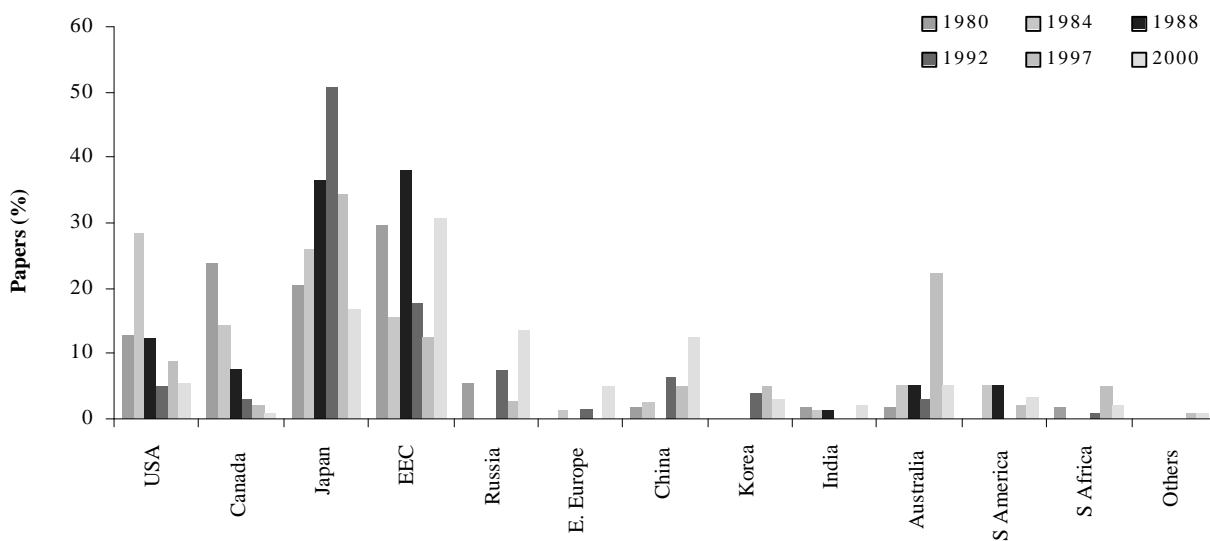


Figure 5: Geographical origin of papers published in Slags Conferences Proceedings held in 1980, 1984, 1988, 1992, 1997 and 2000.

4.2 Nature of Research Activity

The results of the distribution for the slag research activity are summarised in Table 6 and are shown in Figure 6.

Table 6: Nature of research on slags published in Conference Proceedings (%).

Activity	Slag Research (%)					
	1980	1984	1988	1992	1997	2000
Structure	8.3	3.8	5.0	5.6		
Phase/Mineralogical Equilibria	3.2	6.9	3.0	1.5	8.8	12.3
Thermodynamics	29.5	18.2	17.6	14.3	21.3	11.0
Kinetics	14.8	10.6	6.4	8.5	5.3	5.2
Physical Properties	21.3	20.5	18.6	24.3	29.4	32.3
Slag/Metal Equilibria	9.8	28.0	37.5	28.2	18.6	5.4
Plant data/Process Modelling	8.2	4.5	2.0	5.1	10.8	18.4
Refractory Erosion	1.6	2.2	2.0	2.8	2.9	5.6
Recycling/Environmental	3.3	0.0	2.0	1.1	0.0	6.3
Foaming/Smelting Reduction	0.0	1.5	0.0	6.8	2.9	3.5
Optical Basicity	0.0	3.8	5.9	1.7	0.0	0.0

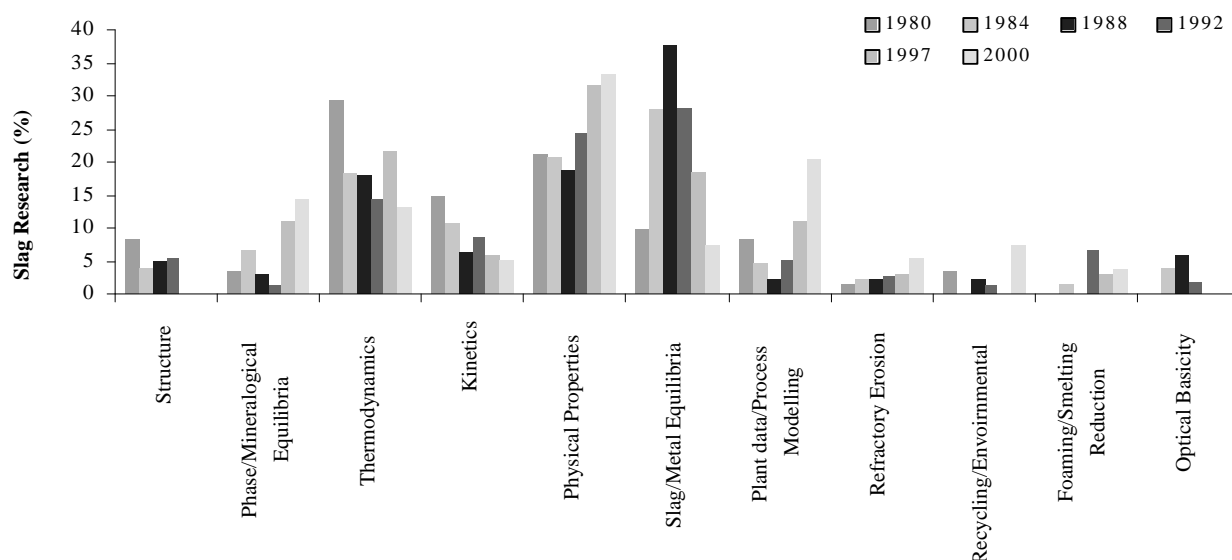


Figure 6: Nature of research activity in papers published in Slag Conference Proceedings.

Inspection of the table shows that the trends in research activities tend to be very similar to those cited for the Metadex search, viz,

- activities are remarkably consistent over the years;
- there has been a decrease in slag/metal equilibria research in recent years;
- an increase in the recycling of slag materials and environmental concerns;

- (iv) interest in foaming/smelting reduction seems to have decreased a little.

However, it is notable that there is a significantly higher percentage of slag-related papers in the category plant data/process modelling than in any previous conference and this may be a result of the conference organisers desire to make the conference more industrially related by attaching workshops on industrial problems.

4.3 Types of Slags Studied

The results on types of slags studied are summarised in Table 7 and it can be seen:

- (i) that there has been a marked decrease in the work carried out on synthetic slags which may be a reflection of the conference organisers of the 1997 and 2000 meetings to make the conference more industrially-relevant;
- (ii) that mould fluxes and ladle and tundish slags have become a major source of research interest which probably reflects the current global drive to improve alloy purity;
- (iii) that research on non-ferrous slags makes up significant fractions of the work covered in the Sydney and Stockholm/Helsinki conferences; it is likely that fluctuations in the levels of papers on non-ferrous slag are strongly influenced by geographical position of the conference.

Table 7: Types of slags studied for publication in Conference Proceedings (%).

Type of Slag	Slag Research(%)					
	1980	1984	1988	1992	1997	2000
Ironmaking	0.0	3.0	3.3	4.3	14.7	4.8
Steelmaking	10.0	3.0	5.2	4.3	5.9	11.8
Ladle/Refining	2.0	0.0	1.1	0.8	4.9	12.9
Mould Flux	8.0	1.0	2.2	4.3	12.7	10.4
Ferroalloys	2.0	3.0	5.3	6.0	4.9	3
Coal	0.0	1.0	1.1	0.0	1.0	1.3
Welding Flux	0.0	2.5	1.1	0.0	0.0	0.4

Non-Ferrous	14.0	10.2	2.2	5.1	18.3	16.9
Mattes	6.0	2.0	2.2	4.3	3.5	1.3
Synthetic	58.0	74.3	76.3	70.9	34.1	29.4
Borates/Enamel	0.0	0.0	0.0	0.0	0.0	1.2
Wastes	0.0	0.0	0.0	0.0	0.0	4.6

5 DISCUSSION

From the analysis of Metadex data as well as from the slag conferences data a Russian recovery in the field of research on slags and fluxes can be noted. This makes Russia the favourite candidate to host the Seventh International Conference on Molten Slags, Fluxes and Salts.

The South East Asia economic depression does not seem to have had a large effect on the Japanese and Korean participation neither in slag research publications nor in attendance of international slag conferences.

A distinct move towards more industrially related topics has been distilled from the literature data. One possible explanation is that a better understanding of slag phenomena is absolutely needed to shift the limits of the processes as applied in industry. A second explanation is that universities and institutes have better relationships with industry than ever before. Industry is moving fundamental research problems to universities and institutes, where no longer industrial work is considered poisoned or sub-scientific standard or not done. On the contrary, the industrially oriented fundamental type of research is found to create a great challenge for scientists and students. Furthermore, the industrial money is very welcome to enforce the infrastructure and appeal of the universities.

In the special case of the Stockholm/Helsinki conference the organisation of focused workshops on mould fluxes related problems, aluminium production technology and slag/metal/refractory interactions and their influence on steel quality, certainly has attracted industry researchers not only to attend but also to contribute.

The driver of sustainability generates more and more research on recyclability and on the environmental impact of secondary materials. Slags and fluxes are

outspoken examples of this category of materials, which explains the increased in research activity on recycling and environmental topic has reached about 12% of the total research on slags.

6 REFERENCES

[1]: R Boom and K C Mills; Proc. 5th International Conferences on Molten slags, Fluxes and Salts held in Sydney, Australia, Jan. 1997, pub. ISI, Warrendale, PA, USA pp. 3-9.

ACKNOWLEDGEMENT

We thank Professor S Seetharaman (KTH) for his encouragement and pursuance for us to write this article.