SEVENTH CONFERENCE OF THE INTERNATIONAL SOCIETY FOR SCIENTOMETRICS AND INFORMETRICS

PROCEEDINGS – 1999

Colima, México, July 5-8, 1999

Sponsored by

Universidad de Colima

México

Edited by

César A. Macías-Chapula

ISSI UNIVERSIDAD DE COLIMA

Mapping Knowledge Through Co-Occurrence of Keywords – The Case of Surface Treatment

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Abstract

The Metadex database is a useful and widely employed tool for materials engineers. It provides a comprehensive coverage of international literature on metallic materials. The Metadex keywords are necessarily contained within the Thesaurus of Metallurgical Terms, which includes a list of modifying terms that may be linked to primary terms, narrowing the their scope. All modifying terms fit one of four categories: processes, properties, effects or forms. The reformating of Metadex Descriptors field was made creating new fields considering all the modifying terms categories. This approach aims to improve the potential of bibliometric information analysis in the field of materials technology. An automated bibliometric treatment of recovered records was accomplished using keyword occurrence and co-occurrence counting. This treatment has generated important information for materials enginneers about structure-properties-processes relationship on surface treatment.

Introduction

A component must have a shape that is suited to the tasks it is expected to perform during its lifetime. The materials engineer meets this requirement by taking advantage of a complex three-part relationship between the material's structure, the processing steps the material is subjected to, and the material's properties. When the materials engineer changes any aspect of this relationship, either or both of the others also change [1,2].

Thus, knowledge of the relationship between structure, properties and processing is very important in the field of materials technology. This applies to research on surface treatment, which consists of processes carried out to alter the properties of materials only on their surface layers. The surface treatment may or may not include the deposition of new material on the surface of the original material. The final properties of materials depend, among other factors, on the process employed, the materials' initial properties and the forms of the material deposited, as well as on the effects of process variables.

The Metadex bibliographic database is a very useful information source in materials technology and surface treatment. It is produced by ASM International and by The Institute of Materials and provides a comprehensive coverage of the international literature on metals. The Metadex Descriptors field presents the keywords used to describe the indexed documents. Only terms included in The Thesaurus of Metallurgical Terms, also provided by ASM International and by The Institute of Materials, are used as keywords in the Metadex.

The Thesaurus of Metallurgical Terms contains a comprehensive and controlled list of terms employed in Metallurgy and Materials Science. These terms, called Primary Terms, can be of six types: materials, processes, properties, products, forms or influencing factors. There is also a short list of terms called Modifying Terms, which are used in association with the Primary Terms [3]. All the modifying terms fit one of four categories: processes, properties, effects (of influencing factors), or forms. By focusing on a specific aspect of the concept represented by a primary term, the use of modifying terms provides an important way of narrowing the scope of a search.

The general rules for the use of primary and modifying terms are as follows: "processes" and "properties" modifying terms are associated to primary terms representing materials, forms and, occasionally, products (e.g. "copper, extraction"; "coatings, physical properties"). "Effects" modifying terms are used to modify "processes" or "properties" primary terms (e.g. "oxidation resistance, coating effects"). "Forms" modifying terms are used to modify "materials" primary terms (e.g."stainless steels, castings). All modifying terms are also valid primary terms and this is particularly useful when the topic of the search is very broad.

The 1992 edition of the Thesaurus of Metallurgical Terms contains more than 6,570 primary terms and 117 modifying terms. Despite the fact that they belong to different categories, Metadex presents all the keywords in only one field. The keywords attributed to a paper or conference paper with the aim of describing it are linked to each other due to the fact that they are in the same record. On the other hand, the subdivision of these descriptors in new fields, based on the use of modifying terms, broadens the possibility of analysis since one can analyze the keywords linked to one class of modifying terms and also to analyze co-occurrences of keywords linked to two classes of modifying terms, as shown in Table 1.

The increasing volume of information available in the field of materials technology and surface treatment has led to the development of methodologies to accomplish information analysis and synthesis. Among these is the methodology that includes the

Table 1. Keyword co-occurrence possibilities in the subdivision of Metadex descriptors field

	POSSIBILITIES OF KEYWORD CO-OCCURRENCE
BEFORE REFORMATTING	1. Descriptors – Descriptors
AFTER REFORMATTING	1. Processes – Properties
	2. Processes – Effects
	3. Processes – Forms
	4. Processes – Solitaries
	5. Properties – Effects
	6. Properties – Forms
	7. Properties – Solitaries
	8. Effects – Forms
	9. Effects – Solitaries
	10. Forms – Solitaries

use of software for automated information treatment, which is often based on bibliometry. The use of bibliometric analysis allows one to classify, separate and add value to the collected data [4,5]. Automated treatment of information extracted from the Metadex database has been used in materials engineering work with the purpose of identifying materials and raw materials used in specific products through the study of the descriptors field [6].

This work aims to enhance the use of the Metadex database, using its structure to extract information that is relevant for the materials engineer. The subdivision of modifying terms related to properties, processes, effects and forms of the Metadex Descriptors field provides broadened possibilities in the bibliometric analysis of information on materials.

The association of the modifying terms to each other and to primary terms is studied, focusing on the subject of surface treatment.

Methods

This work was done in four steps: the collection of data from the Metadex database, reformatting of saved records with the purpose of creating new fields, automated bibliometric treatment and the construction of tables and graphs to present the information.

The records covering surface treatment from 1990 to 1997 were taken from the Metadex database available in KR Ondisc's CD-ROM. The search strategy about surface treatment led to the recovery of 5,917 records.

Since Metadex was built for documentation purposes, we have had to reformat the saved records using the Infotrans software [7,8]. The main alteration in the records' structure consisted of creating 5 fields from the original Descriptors field.

The new created fields are:

PROCESSES- containing all "processes" modifying terms and associated primary terms

PROPERTIES- containing all "properties" modifying terms and associated primary terms

EFFECTS- containing all "effects" modifying terms and associated primary terms

FORMS- containing all "forms" modifying terms and associated primary terms

SOLITARIES- containing primary terms not associated to any modifying term

The automated bibliometric treatment was accomplished by counting the occurrences and co-occurrences of several keyword combinations. Lists and matrixes were produced showing the frequency of occurrence and co-occurrence of keywords. The Dataview software was used in this phase [9].

Based on the lists of keyword occurrences and co-occurrences generated by the Dataview software, several tables were produced to present the results.

The Statistica software enabled us to carry out a correspondence analysis with the matrixes generated by the Dataview software[10.11].

Results and discussion

The bibliometric treatment that was conducted defined the frequency of occurrences (number of records in which a given word occurs) and co-occurrences (number of records in which two given words occur) of keywords, allowing for the transformation of text data into numerical data.

Table 2 presents the frequency of "processes" or "properties" primary terms associated to "effects" modifying terms. The fact that the term "wear resistance" appears at the beginning of the table, where the higher frequencies are located, indicates that wear resistance is strongly associated to surface treatment. The high frequency of association between the "properties" primary term "wear resistance" and several "effects" modifying terms shows that in surface treatment studies there is a tendency to explore the relations between the wear resistance of materials and changes of coating, heating and composition, among others.

Table 3 shows the frequency of the "materials" primary terms most closely associated to "forms" modifying terms. An analysis of the "Forms" column indicates that the main types of materials involved in surface treatment are coatings and composite mate-

Table 2. Frequency of "processes" and "properties" primary terms associated to "effects" modifying terms.

Keywords		Frequency
Processes or Properties	**"Effects" modifying terms**	
Wear Resistance	Coating Effects	941
Wear Resistance	Heating Effects	757
Wear Resistance	Alloying Effects	261
Wear Resistance	Composition Effects	230
Corrosion Resistance	Coating Effects	196
Hardness	Heating Effects	161
Wear Resistance	Radiation Effects	129
Corrosion Resistance	Heating Effects	104
Surface Hardness	Heating Effects	67
Service Life	Heating Effects	64
Microhardness	Heating Effects	59
Hardness	Coating Effects	59
Hardness	Alloying Effects	59
Microstructure	Heating Effects	55
Tool Life	Coating Effects	51
Impact Strength	Heating Effects	51
Fatigue Strength	Heating Effects	51
Wear Resistance	Deformation Effects	50
Friction	Coating Effects	44
Surface Structure	Heating Effects	43
Wear Resistance	Environmental Effects	37
Corrosion Resistance	Alloying Effects	37
Case Depth	Heating Effects	35
Wear Resistance	Stress Effects	34
Hardness	Composition Effects	34
Toughness	Heating Effects	33
Wear Resistance	Temperature Effects	32
Microhardness	Coating Effects	31
Wear Resistance	Welding Effects	29
Sliding Friction	Coating Effects	29
Friction	Heating Effects	29
Tensile Strength	Alloying Effects	26
Microstructure	Alloying Effects	25
Diamond Pyramid Hardness	Heating Effects	25
Frictional Wear	Coating Effects	23
Tensile Strength	Heating Effects	21
Service Life	Coating Effects	21
Impact Strength	Alloying Effects	21
Corrosion Resistance	Radiation Effects	21

rials. Several primary materials terms associated to the "form" modifying term "coating" were noticed, showing that there is a great diversity of materials (a total of 198 materials in the 826 lines of the complete table) being tested for use as coatings.

Table 4 presents the frequency of "materials", "forms" or "products" primary terms most closely associated to "processes" modifying terms. An analysis of the "processes" column indicates that coating and heat treatment are the main surface treatment

Table 3. Frequency of " materials" primary terms associated to "forms" modifying terms.

Keywords		
Materials	**"Forms" modifying terms**	**Frequency**
Titanium Nitride	Coatings	241
Aluminum Base Alloys	Composite Materials	214
Silicon Carbide	Composite Materials	179
Nickel Base Alloys	Coatings	154
Aluminum Oxide	Composite Materials	122
Cemented Carbides	Coatings	104
Titanium Carbide	Coatings	92
Composite Materials	Coatings	81
Nitrides	Coatings	71
Nickel Base Alloys	Composite Materials	67
Nickel	Composite Materials	66
Titanium Carbide	Composite Materials	65
Aluminum Oxide	Coatings	62
Nickel	Coatings	58
Chromium	Alloying Elements	57
Chromium	Coatings	57
Tungsten Carbide	Composite Materials	55
Vanadium	Alloying Elements	54
Silicon	Alloying Elements	54
Particulate Composites	Coatings	52
Ferrous Alloys	Coatings	49
Aluminum	Composite Materials	48
Tungsten Carbide	Coatings	46
Chromium Compounds	Coatings	45
Carbides	Coatings	45
Copper	Alloying Elements	44
Aluminum	Alloying Elements	44
Cobalt	Composite Materials	44
Nitrogen	Dopants	43
Cobalt Base Alloys	Coatings	42
Nickel	Alloying Elements	39
Molybdenum	Alloying Elements	36
Titanium Compounds	Coatings	36
Boron	Alloying Elements	34
Titanium	Alloying Elements	33
Carbon	Coatings	33
Phosphorus	Alloying Elements	30
Manganese	Alloying Elements	30
Copper	Composite Materials	30
Borides	Composite Materials	30
Cermets	Coatings	29
Chromium Carbide	Coatings	28
Graphite	Composite Materials	28
Silicon Carbide	Coatings	26
Aluminum Compounds	Coatings	26

processes that metallic materials are subjected to. An analysis of the "materials, forms or products" column indicates that steel is the material most commonly subjected to surface treatment.

Table 5 presents the frequency of "materials", "forms" or "products" primary terms most closely associated to "properties" modifying terms. An analysis of the "properties" column indicates that, generally speaking, the major goal of surface treatments is the improvement of mechanical properties.

Table 5. Frequency of primary terms for materials, forms or products associated to "properties" modifying terms.

Keywords		
Materials, Forms Or Products	**"Properties" Modifying Terms**	**Frequency**
Sprayed Coatings	Mechanical Properties	162
Particulate Composites	Mechanical Properties	158
Coatings	Mechanical Properties	147
Protective Coatings	Mechanical Properties	132
Ceramic Coatings	Mechanical Properties	120
Chromium Steels	Mechanical Properties	106
Cast Iron	Mechanical Properties	104
Aluminum Base Alloys	Mechanical Properties	98
Powder Metallurgy Parts	Mechanical Properties	87
Bearing Steels	Mechanical Properties	86
Cemented Carbides	Mechanical Properties	78
Tool Steels	Mechanical Properties	75
Austenitic Stainless Steels	Mechanical Properties	74
Medium Carbon Steels	Mechanical Properties	73
High Speed Tool Steels	Mechanical Properties	70
Carbon Steels	Mechanical Properties	66
Castings	Mechanical Properties	64
Steels	Mechanical Properties	63
Vapor Deposited Coatings	Mechanical Properties	61
Titanium Base Alloys	Mechanical Properties	61
Nodular Iron	Mechanical Properties	59
Surface Layer	Mechanical Properties	58
Sintered Compacts	Mechanical Properties	58
Manganese Steels	Mechanical Properties	57
Low Carbon Steels	Mechanical Properties	53
Fiber Composites	Mechanical Properties	53
Chromium Molybdenum Steels	Mechanical Properties	48
High Carbon Steels	Mechanical Properties	46
Ferrous Alloys	Mechanical Properties	46
Nickel Base Alloys	Mechanical Properties	45
Nickel Chromium Molybdenum Steels	Mechanical Properties	44
Cobalt Base Alloys	Mechanical Properties	42
White Iron	Mechanical Properties	41
Gray Iron	Mechanical Properties	39
Bronzes	Mechanical Properties	39
Stainless Steels	Mechanical Properties	37
Composite Materials	Mechanical Properties	37
Electroplates	Mechanical Properties	36
Cutting Tools	Mechanical Properties	34
Whisker Composites	Mechanical Properties	33
Weld Deposited Coatings	Mechanical Properties	32
Superalloys	Mechanical Properties	32
Chromium Iron	Mechanical Properties	32
Low Alloy Steels	Mechanical Properties	31
Copper Base Alloys	Mechanical Properties	31

i.e., steels, cutting tools and others. An analysis of the coatings column indicates the materials used as coatings, e.g., titanium nitride, nickel base alloys and cemented carbides. The substrate – coating pair that appears most often is cutting tools – titanium nitride

It is interesting to note that the categories of modifying terms used in Metadex allow comparisons to be made between materials processing ("processes" modifying

terms), materials properties, materials structure ("forms" modifying terms) and parameter variation effects such as temperature, composition and vibration, among others ("effects" modifying terms). This distribution meets the needs of materials scientists and engineers to compare information concerning materials structures, processing and properties.

Table 6. Co-occurrence frequency of substrates and coatings.

Keywords		Frequency
Substrates	**Coatings**	
Cutting Tools	Titanium Nitride	18
Carbon Steels	Nickel Base Alloys	16
Tool Steels	Titanium Nitride	14
Carbon Steels	Cemented Carbides	14
Steels	Titanium Nitride	11
Medium Carbon Steels	Nickel Base Alloys	11
Low Carbon Steels	Nickel Base Alloys	11
Low Carbon Steels	Cemented Carbides	10
Cutting Tools	Nitrides	10
Cemented Carbides	Titanium Nitride	10
Carbon Steels	Aluminum Oxide	10
Titanium Base Alloys	Titanium Nitride	8
Cutting Tools	Titanium Carbide	8
Chromium Steels	Titanium Nitride	8
Titanium	Titanium Nitride	7
Steels	Composite Materials	7
Stainless Steels	Titanium Nitride	7
Die Steels	Titanium Nitride	7
Cemented Carbides	Titanium Carbide	7
Tool Steels	Nitrides	6
Steels	Nickel Base Alloys	6
Low Carbon Steels	Titanium Carbide	6
Low Carbon Steels	Aluminum Oxide	6
Dies	Titanium Nitride	6
Cutting Tools	Carbides	6
Cutting Tools	Aluminum Compounds	6
Carbon Steels	Titanium Carbide	6
Carbon Steels	Composite Materials	6
Aluminum Base Alloys	Titanium Nitride	6
Aluminum Base Alloys	Titanium Carbide	6

The connections between primary terms and modifying terms can be obtained through a correspondence analysis of co-occurrence matrixes, with the co-occurrence frequency considered as a measure of association. Figure 1 shows the nonhierarchical classification of primary terms representing the alloys that can be used in surface treatments, related to modifying terms that indicate the forms in which the alloys are applied. Aluminum and magnesium base alloys are used preferentially as composites, while cobalt base alloys are associated to the use of dopants. Nickel, chromium and lead alloys are used as coatings. None of the studied alloys are clearly associated to the application of thin films or claddings.

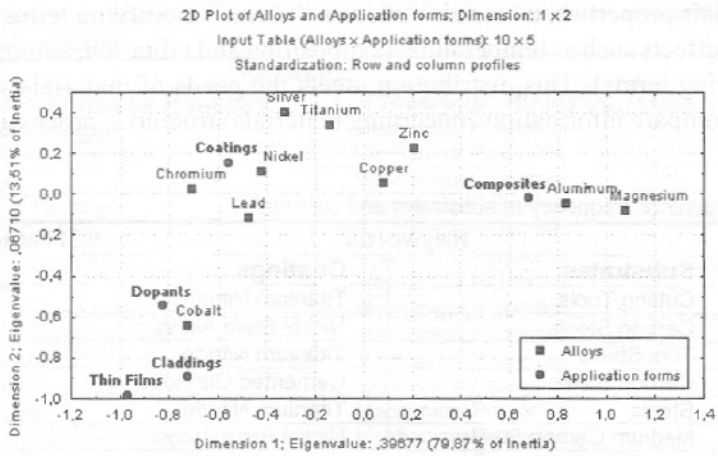

Figure 1. Nonhierarchical classifications of alloys in relation to application forms

Figure 2 presents the nonhierarchical classification of primary terms representing carbides of several elements used in surface treatment, related to modifying terms that indicate the form in which theses carbides are used.

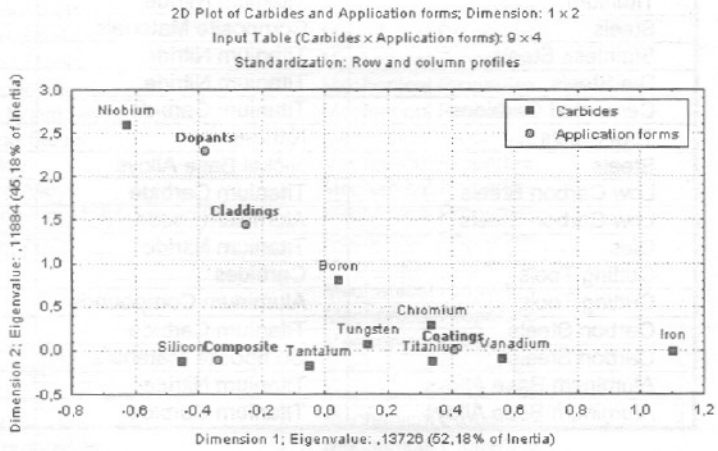

Figure 2. Nonhierarchical classifications of carbides in relation to application forms

Niobium carbide is associated to the use of dopants, while silicon carbide is used as a composite. Titanium, vanadium and chromium carbides are used as coatings. There is no co-occurrence between carbides and the thin film modifying term. None of the studied carbides are clearly associated to cladding applications.

Reformatting of records extracted from the Metadex database with the purpose of creating specific fields from descriptors field allows new forms of association and analysis that result in more detailed and structured information on surface treatment. Other

combinations of primary and modifying terms can be made, according to the needs of the materials scientist and engineer for information related to the subject in question. Within this context, automated information analysis is an important tool to synthesize formal information in the field of materials technology.

Conclusion

The results of this work led to the following conclusions:

- The structure of the Metadex database allows reformatting of its descriptors field, with a coherent creation of 5 new fields, i.e., processes, properties, effects, forms and isolated descriptors;
- The reformatting of records broadens the associative possibilities and data analyses, increasing the value of the information;
- There is a trend toward increasing research to study the relation of materials wear resistance to variables such as coating alterations, heating and alloy composition.
- A large variety of materials (198 materials) is being tested for use as coatings;
- The main surface treatment processes for metallic materials are coating and heating treatments. Steel is the material that is most frequently subjected to surface treatment.
- The main purpose of surface treatments is the improvement of mechanical properties
- The substrate – coating pair that appears most often is cutting tools – titanium nitride;
- Materials are generally used in specific forms of application for surface treatments, i.e., aluminum and magnesium alloys and silicon carbides are used as composites, cobalt alloys are used with dopants, nickel, chrome and lead alloys and titanium, vanadium and chrome carbides are used as coatings.

Acknowledgements:

The authors gratefully acknowledge the support of the Brazilian financing institutions FAPESP and CNPq/PADCT-TIB.

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