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APPLICATION OF RELATIONAL DATABASE CONCERNING PROCESSES AND EFFECTS OF SURFACE LAYERS DEPOSITION

Keywords

Layer deposition process, relational database, nitriding, carburizing, titanizing, PVD, hybrid processes.

Abstract

The article presents the application of a database meant for the collection of information related to technological processes of constituting surface layers. A set-theoretical model of processes and a model-based logical structure of the database are shown. The application to retrieve the information stored in the database in case of multidimensional, variable space of parameters for layer deposition processes is presented. Some functional qualities of application for acquisition, searching and fusion of data regarding nitriding, carburizing, PVD and hybrid processes are described.

Introduction

Issues regarding efficient, computer-aided designing of processes that produce multifunctional materials, including multi-layer coatings, make one of the most modern world trends in the area of material research [5]. To formulate a new technology that would enable producing materials with programmed utilitarian properties of a surface layer, selection of an appropriate foundation is needed, as well as the knowledge regarding diverse parameters values that control the process of layers deposition and chemical and physical phenomena that appear in the process and influence the final result of the process [6]. Mathematical specification of complex, nonlinear or yet unidentified relations between different parameters of layer deposition is often not very precise and in many cases is a simplification of real phenomena that occur in processes of surface layers constitution [3]. Because creating adequate mathematical models may cause difficulties, mainly due to a lack of complete knowledge regarding processes [4], and computational models created for formulated constitutive relations are too expensive in calculations, as a result, reasonable support for the designer while working out the new technology of layer deposition may be databases that contain information regarding obtained results of processes carried on in laboratory or industrial environments. Skilful utilization of recourses of such databases allows discovering analogies as well as contrasts between various processes of layers deposition and can enable a selection of the process's structure or specify values of parameters that are employed during the process's implementation. Databases, with an application of appropriate algorithms, may also provide, statistically significant relationships, rules or formulas that enable inferencing capabilities regarding processes of constitution of surface layers [1]. According to the premises mentioned above, some projects have been started with an utilitarian effect such as the application that contains software and database for acquisition searching and fusion of data regarding processes of surface layers deposition.

1. A set-theoretical model of surface layers deposition processes

For requirements of building database application, the set-theoretical model of layers deposition processes has been formulated. Thermo-chemical and technological diffusive processes of nitriding, carburizing, PVD, processes and hybrid processes were the subject of modelling. The following assumptions have been made:

1. The common property of those processes is the possibility to distinguish sequences of elementary states - technological stages[1] - taking place one

[1] Technological operations.

after the other and possibly linked together with cause-effect relationships (Fig. 1). For instance, in nitriding processes the succeeding stages are: warming up the furnace to the temperature given, obtaining appropriate nitriding potential during the certain time in the temperature obtained in warming up, and cooling down the furnace afterwards.

2. There is a lack of feedbacks in the process, which means that results obtained in the stage *l* do not have any influence on the results obtained in the stage *l*-1 ($1 \le l \le n$). That allows to use the systematic list structure (parameters are its elements) to describe the process of layers deposition (Fig. 1).
3. In each stage, a device with certain parameters (or technical specification) is used.
4. Each process's stage can be described by parameters set. Parameters can refer to technological properties of the process, device's parameters or parameters that have been marked by results of an examination of a layer obtained after the stage termination.

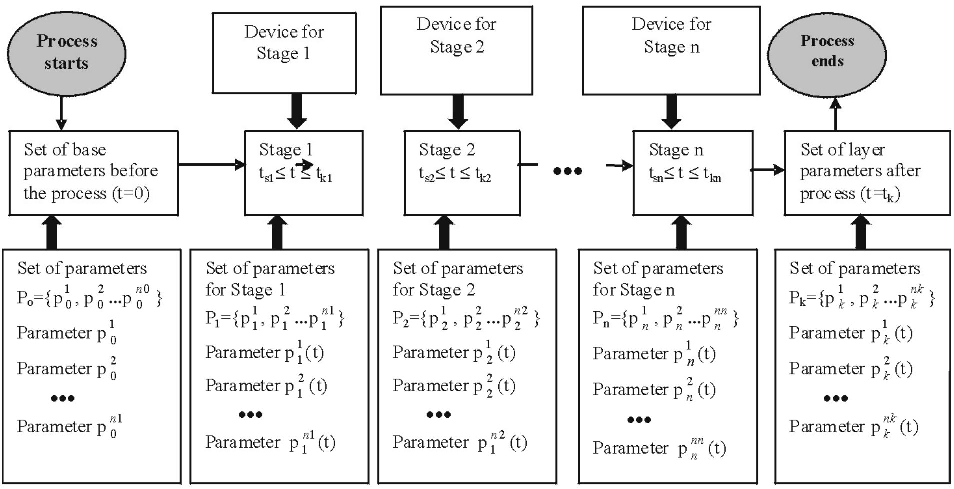

Fig. 1. The structure of thermo-chemical and diffusive processes of surface layer deposition.

The following set-theoretical model, on the basis of formulated assumptions and the process's structure showed in Fig. 1, has been elaborated:

1. The final effect of the process described by the set of parameters P_k is a function of the initial state (set of base parameters before the process) and following stages:

$$P_k = f(P_o, P_1, P_2, \ldots Pn\} \qquad \text{(dependence 1)}$$

2. The next stages of the process create the hierarchy of temporal sequences (Fig. 1):

$$0 \le t_{s1} < t_{k1} \le t_{s2} < t_{k2} \le \bullet\bullet\bullet \le t_{sn} < t_{kn} \le t_k \qquad \text{(dependence 2)}$$

Dependence 2 together with dependence 1 allow to inference about the final result of the process, on the basis of familiarity with values of material parameters before the process and values of parameters in next stages of processes.

3. Sum of all sets of parameters that describe the process forms a countable set:

$$\mathrm{card}(\bigcup_{i}^{n} P_i) = k, \qquad \text{(dependence 3)}$$

where: card(.) – denotes the number of elements (power of a set) of the set (.) and $1 \le k < \infty$

The parameter's space is countable, so that is why mapping of parameter sets in the relational data model is possible.

4. For a given group of thermo-chemical and diffusive processes, for example groups of nitriding processes or groups of carburizing processes, there is a non-empty set of parameters that take a part in succeeding technological operations of the process:

$$\bigcap_{i=1}^{n} P_i \neq \varnothing \qquad \text{(dependence 4)}$$

Dependence 4 enables the elimination of redundancy in the database which collects information related to the layer deposition process.

5. The number of parameters *k* for a given group of parameters depends on employed devices or tests that have been carried out on the material before and after the process. As a result, two PAPVD processes carried out in the same conditions, with the employment of the same devices and that produce layers with the same properties, may contain different set of parameters; because, for instance, in the first process there was wear resistance checked, whereas in the second case, results of corrosive examination were given.

6. Each parameter's domain can be:

- continuous (but limited):

$$\mathrm{DOM(parameter)} \in (w_{min},\ _{max}) \qquad \text{(dependence 5)}$$

where:
DOM – parameter's domain
w_{min} and w_{max} denote an appropriately minimal or maximal value,

- discrete:

$$\mathrm{DOM(parameter)} = \{w_1, w_2, ..w_m\} \qquad \text{(dependence 6)}$$

where
$w_1, w_2, ..w_m$ discrete nominal or disordered values.

Types of data that enable to record numbers, dates and alphanumeric strings must be taken into account in the database.

7. It is possible to specify a subset of parameters, in the following set of the process's parameters $\bigcup_i^n P_i$, that they are not only a time function, but are also functions of other parameters (for example, the hardness of the layer after t-time in a function of distance from the layer surface):

$$p_a = f_1(t, p_b, p_c \ldots) \qquad \text{(dependence 7)}$$

As a result, joint records which describe functional characteristics, for instance diagrams, must be taken into account

8. There are parameters, in the set of the process parameters $\bigcup_i^n P_i$, the values of which are constant within the whole process:

$$p_d(t) = \text{const} \qquad \text{(dependence 8)}$$

2. Logical structure of the database

With employment of dependences 2-7 of a set-theoretic model for describing parameter of the process, a vector $\bar{V}$ has been formulated, whose structure is depicted in Fig. 2.

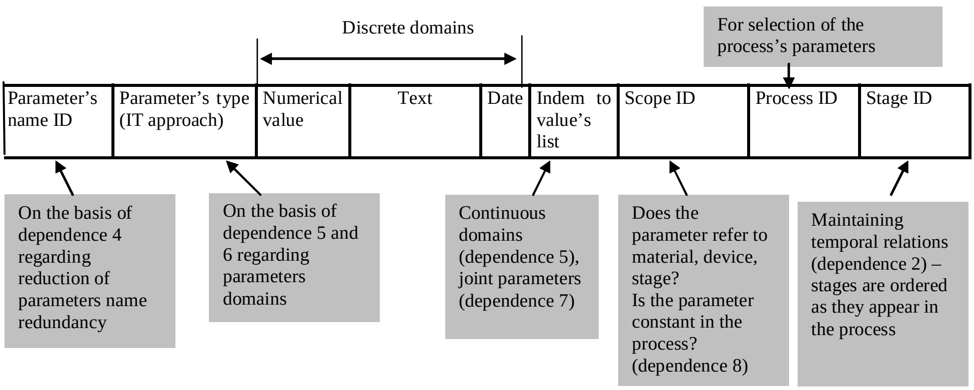

Fig. 2. Vector $\bar{V}$ used to describe the technological deposition process's parameter

In the vector the following system of ‘Parameters type’ coding was used:

- L – number,
- T – text,
- D – date,
- F – joint parameter or parameter with constant domain.

Depending on code’s (called ‘Parameter type’) value, an appropriate vector cells are set to a null value (Fig. 3). In order to divide parameters into subsets adequate for stages, devices, materials (before and after the process terminates) and a subset of parameters with constant for the process values, there is a vector’s element (called ‘Scope ID’) introduced. Coded information regarding the parameter’s location is stored in that cell.

The following coding system has been used:

- O – general data related to the process (constant parameter’s value within the process),
- U – parameter related to devices,
- M – parameter from the set that describes base properties,
- I – parameter that describes a layer,
- E – parameter linked with a stage,

The element of vector ‘Process ID’ enables the selection of all process parameters, whereas the element of ‘Stage ID’ allows the determination of a set of stage parameters.

Fig. 3 presents a mapping a set of parameters of the layer deposition process (described by a set-theoretic model) to computer structure containing vectors showed in Fig. 2.

On the basis of the vector $\overline{V}$ that describes the parameter, the key entity ‘**Process_Parameters**’ has been designed (Fig. 4). The entity contains some data regarding metric units of the parameter. In order to modify the entity contents (for example overwriting the vector’s value or deleting the parameter); and, in order to select lists of values for parameters with constant domains or joint parameters, an additional parameter has been introduced, the value of which for each entity row **Process_Parameters** is unique.

To enable the complete description of the technological layer deposition processes, as well as to make searching more reliable and fusion of data from different databases possible, additional entities containing the following information have been introduced:

1. Identification of the process in the database (**Process** entity).
2. Quick devices (employed within diverse processes) search (**Devices** entity).
3. Process’s stages classification (**Stages** entity) according to ‘Sequence’ attribute in order to keep temporal sequences in the layer deposition process.
4. Quick material search, for which processes are proceeded (**Materials** entity).
5. Reduction of redundant data regarding parameters names and metric units names (entity **Parameters_Names** and entity **Metric_Units**).
6. Collecting data as lists of values for parameters with constant domains or joint parameters (**Joint_Parameters** entity).

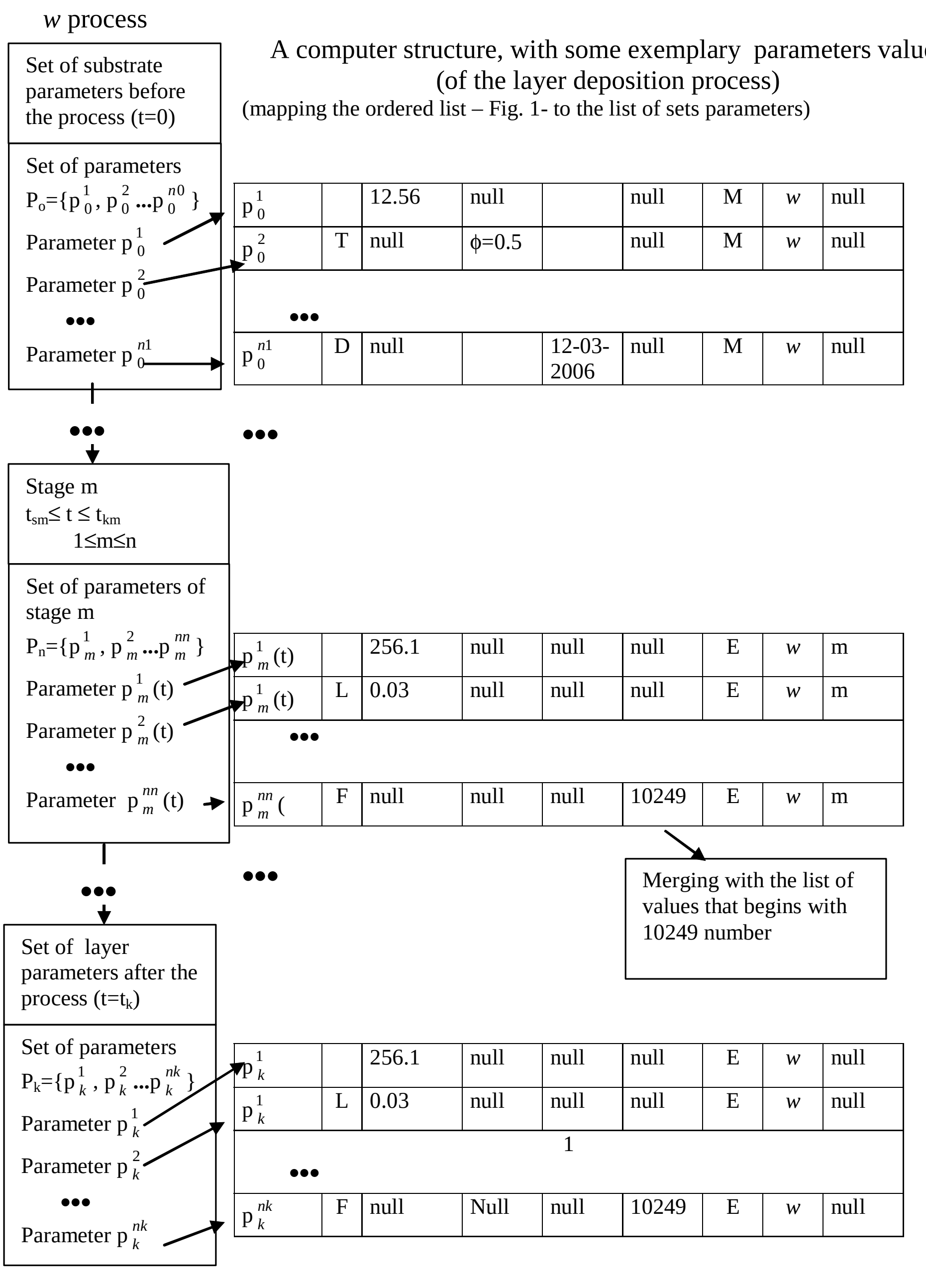

Fig. 3. Mapping a set of parameters of the layer deposition process to computer structure

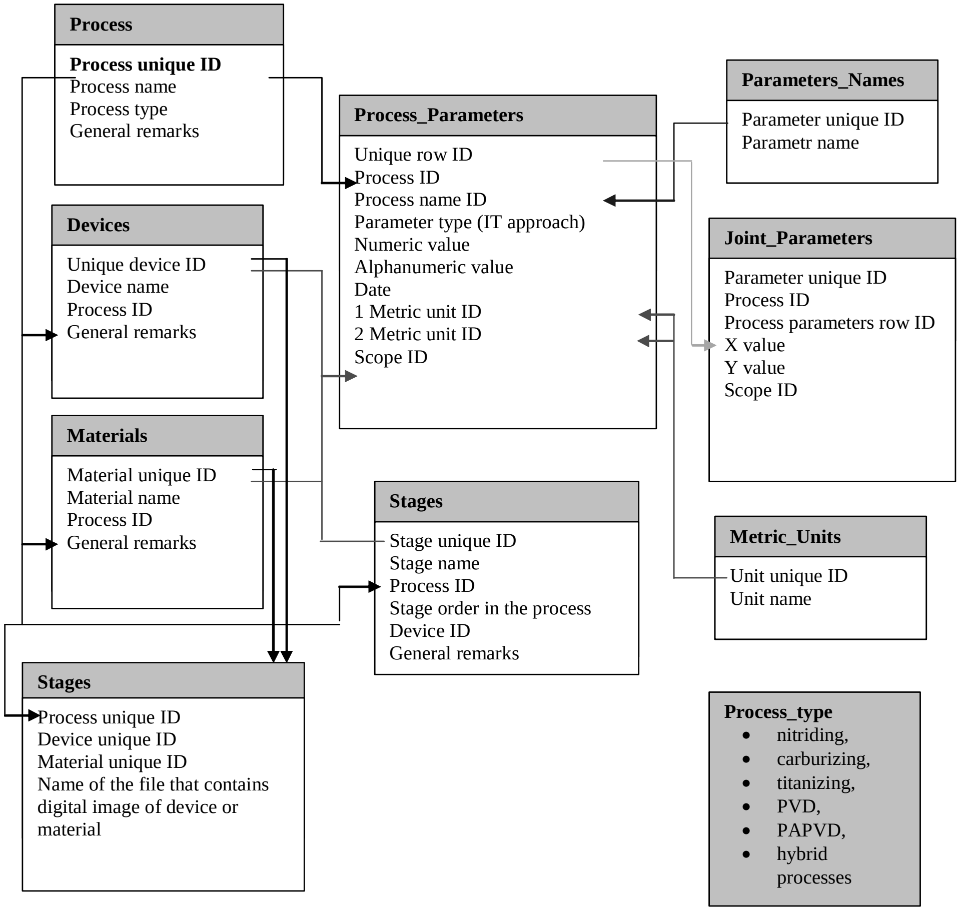

Fig. 4. Logical structure of the database that contains the layer deposition processes information

On the basis of this formulated logical structure, data tables have been implemented. During the implementation, a database standard called Paradox and BDE drivers by Borland [2] have been used.

3. Functional qualities of the database running application

Software for Windows environment (Fig. 5) has been designed, in order to manage the database. The object-orientated programming technique (Delphi) has been used within the implementation process. The software has been equipped with a window-based user interface.

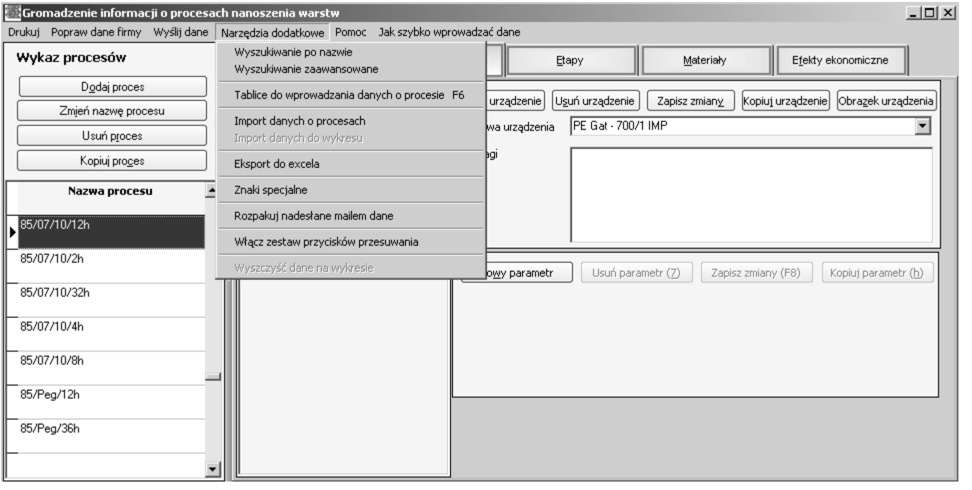

Fig. 5. Database user interface appropriated for gathering of data related to processes of constitution of surface layers

The software has been equipped, inter alia, with the following functional qualities:

1. Registration of a new process consists in defining the process structure and formulating the designer structure into the database.
2. Data modification includes:
   - renaming the process, stage, device or material, changing parameter type or changing parameter values. In case of changing parameters values, changes can be proceeded, not only in the main window of the application, but also with the use of tables. The graphical data are saved as a raster graphics. Saving options for materials includes saving material's images, that describe the substrate before the process as well as obtained layers,
   - deleting information from database on a diverse level, for instance deleting all data that describe the process, deleting data regarding devices, stages, materials,
   - coping data, including coping data referring to the entire process, coping data referring to devices, materials, stages and economic results. Copied data can be 'passed' to another process, another device, stage or material that depends on the selected range of coping activity.
3. Fusion of data from diverse databases (Fig. 6).
4. Data printing: printing all data regarding chosen process or printing already registered processes list.
5. Data searching, which can be proceeded within a simple search (with process name, device name, material name, stage name or parameter name)

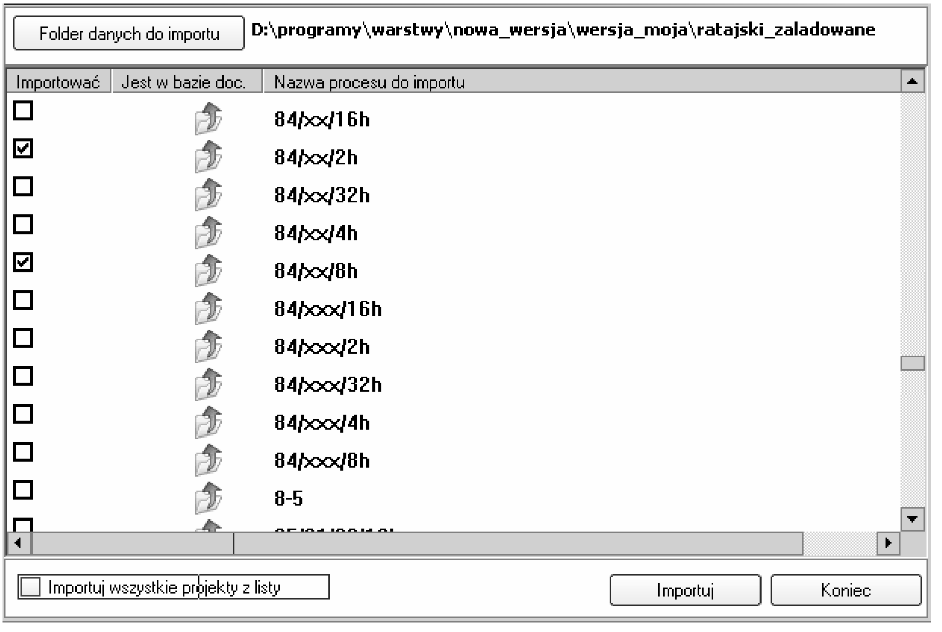

Fig. 6. Form for fusion of data from databases installed on other computers

or advanced search (Fig. 7). Advanced search requires sql query formulation, that consists of criteria which must be fulfilled by searched parameters. It is necessary to give parameters the following: name, relation (=, <=,<,>,>=, consists of character string), value and clauses (and, or) while preparing searching criteria. The algorithm that enables range search can be used in advanced search. An arranged list of processes is the result of range search. Arranging the list is conducted on the basis of a number of process parameters that fulfill searching criteria.

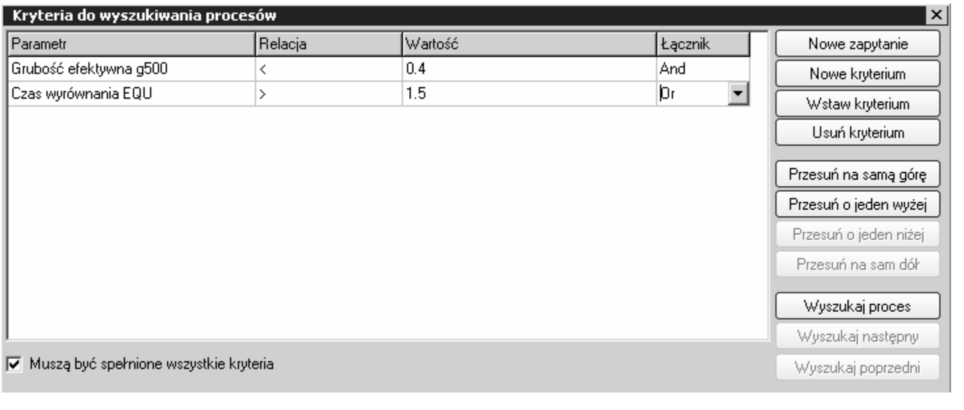

Fig. 7. Form for generating a complex database query

6. Data export – the program enables export of data that describe the process to csv format supported by Microsoft Excel. The user can define the range of exported data.

Designed software enables the user to build the process structure in accordance with the presented set-theoretical model. In order to speed up data input and eliminate errors made within input activities, the software has been equipped with functions such as: data coping and data import, for example data related to joint parameters.

Conclusions

Designed application of relational database has been used in the following research activity: 'Development of intelligent devices for surface modification processes' that has been realized within the framework of The Multi-Year Programme entitled "Development of innovativeness systems of manufacturing and maintenance 2004-2008" for acquisition of data from surface layers deposition processes. Implementation of the application has enabled gathering data regarding 800 nitriding processes and 30 PAPVD processes proceeded with the use of diverse devices (for example: furnaces such as PEGat - 700/1, PEGat - 900/1, Barfield, BAF, HCP, JONIMP, Nitrem) and different grade of steels for layer deposition.

The designed database application has the following properties:

1. Process of layers deposition can be described with the set of different parameters and modified by adding new and deleting those already introduced parameters without a necessity of changes in the database structure (flexibility).
2. The complete process of layers deposition is described with the set of simple computer structures (decompositionality).
3. Rows chosen from the database with SQL queries allow retracing the process of the technological layer deposition (aggregation).
4. There are some relationships fulfilled between entities which allows to coherently describe the process of layer deposition (relation).
5. On the basis of aggregation of information gathered in entities according to diverse criteria, different information sub-sets for example sets of parameters describing layer obtained during the process, etc. can be specified (cumulativeness).
6. The complete set of information gathered in entities creates functional integrity and can be used for supporting of designing processes of layer deposition or forecasting values of parameters that describe layers obtained during different processes (completeness).

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References

1. Dobrodziej J.: Application of database systems – problems and solutions, Maintenance Problems, nr 3, 2003.
2. Resese G.: Java Database. Best Practices. Helion, Gliwice, ISBN 83-7361-260-2, 2003.
3. Walkowicz J.: Fizykochemiczna struktura plazmy a skład chemiczny i fazowy warstw wytwarzanych technikami plazmowej inżynierii powierzchni, Maintenance Problems Library, Radom, ISBN 83-7204-298-5, 2003.
4. Mazurkiewicz A., Ruta R., Trzos M.: Protype research, Maintenance Problems Library, ISBN 83-7204-472-4, 2005.
5. Ratajski. J.: Model of growth kinetics of nitrided layer in the binary Fe-N system. Zeitschrift fur Metallkunde, 95, 2004 p. 9, 23.
6. Ratajski J., Tacikowski J., Somers M.A.J.: Development of compound layer of iron (carbo)nitrides during nitriding of steel, Surface Engineering, Vol. 19, No. 4, 2003, 285.

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Aplikacja relacyjnej bazy danych do gromadzenia informacji o procesach i efektach procesów nanoszenia warstw wierzchnich

Słowa kluczowe

Model procesu nanoszenia warstw, relacyjna baza danych, azotowanie, nawęglanie, tytanowanie, PVD, procesy hybrydowe.

Streszczenie

W artykule zaprezentowano aplikację bazy danych przeznaczoną do gromadzenia informacji o procesach technologicznych konstytuowania się warstw wierzchnich. Przedstawiono model teoriomnogościowy procesów oraz strukturę logiczną bazy danych opracowaną na podstawie modelu. Zaprezentowano aplikację do obsługi bazy danych w przypadku wielowymiarowej, zmiennej przestrzeni parametrów procesów nanoszenia warstw. Omówiono możliwości użytkowe zastosowania opracowanej aplikacji do gromadzenia, przeszukiwania i fuzji danych o procesach azotowania, nawęglania, PVD, PAPVD oraz procesach hybrydowych.