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An expert software for multi-layer coatings design in surface engineering

Céline Bondoux[1,a], Christophe Degrandcourt[1], George Ailinca[1], Pierre D'Ans[1,b], Marc Degrez[1,c], Denis Wathelet[2,d], François Barthelemy[2,e], Julie Anciaux[2,f], Gustavo Ospina[2,g], Jean-Marie Jacquet[2,h]

[1] CREA-SURF team, Department of Matter and Materials, Applied Sciences Faculty, Université Libre de Bruxelles (ULB), Belgium

[2] Institute of Computer Science, Faculté Notre-Dame de la Paix (FUNDP), Namur, Belgium

[a]cbondoux@ulb.ac.be, [b]pdans@ulb.ac.be, [c]mdegrez@admin.ulb.ac.be, [d]dwa@info.fundp.ac.be, [e]fba@info.fundp.ac.be,[f]jan@info.fundp.ac.be, [g]gos@info.fundp.ac.be, [h]jmj@info.fundp.ac.be

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Abstract. For the first time, a unique expert system able to give assistance to designers in surface engineering has been built. Not only is this software able to provide multi-layer coating solutions, but it is also able to rank different solutions according to their technico-economical interest. In addition to its ability to solve corrosion and wear concerns, it is also able to deal with surface finishing properties (like brightness, weldability, electrical conductivity, biocompatibility, …). This paper describes the structure of this expert system together with its main operation principles and future developments.

Introduction

The design of parts often requires the use of surface treatment at the final stage of the material processing in order to add necessary surface properties that the bulk material doesn't own intrinsically. Nevertheless, adequate selection of surface treatment has become more and more difficult : owing to environmental restrictions on processing as well as ever growing demand for multiple functionalities, these more and more stringent requirements are seldom matched with a single surface treatment (single coating). This is why surface engineering field is attracting much interest for several years, in order to develop multi-layer coating stacks and surface treatment sequences that bring ever more functionalities to the substrate materials.

Despite their strong interest for surface engineering, industrial designers rarely use innovative multi-layer treatment, owing to the complexity of multiple criteria selection to build a multi-layer stack. Indeed, selection criteria can vary quite widely depending on the application field and there's currently a lack of reliable references, standards or guide, that would give an overview of how to approach any kind of surface engineering issues. Many industrial sectors (automobile, aeronautics, naval, optics, machining tools…) and application fields (corrosion resistance, wear resistance, optical, electrical properties…) are concerned by this issue. This is why there is a strong request from industrial designers for an expert system able to help them to define surface treatment sequences (multi-layer coatings) that meet both surface properties requirements and treatment integration onto their production units (i.e: ease of integration).

To our knowledge, there's lack of a software system that combines both surface engineering and a decision-making aid algorithm that would cover a wide field of applications. As a matter of fact, present-day commercially available software [1, 2] only offer single surface treatment solutions, and deal mainly with corrosion [3-4] or tribological [5-7] protection problems. These tools are basically relying on the search of the desired properties in a materials library included within the software, with poor criteria for decision-making aid. A few decision-making aid software do exist, but are dedicated to a specific coating process technology like painting [8] or plasma spray [9]. Therefore there is clearly a lack of an expert system in surface engineering, that is to say, a software able to think like an expert would do, able to advise and explain solution, and able to take into account users' preference (in terms of process availability, cost or performance…).

This paper reports on our attempt to build such kind of unique expert system able to give assistance to designers in surface engineering : a software able to provide multi-layer coating solutions, able to rank different solutions according to their technico-economical interest, able to solve a wide range of surface functionalities, including, in addition to corrosion and wear, surface finishing properties like brightness, weldability, electrical conductivity, biocompatibility... A General overview of the software architecture and operation principles is described hereafter.

Architecture of the Expert System

Our expert system is made up of several processors. Its operation relies on the linking of these distinct units. Each processor encloses sub-units, which will be described with more details in a future publication. Thus, the main modules composing the expert system are :

- a *questionnaire*
- a *stacking unit*
- a *layer selection unit*
- a *materials database*
- a *ranking unit*
- an *explaining unit*

A schematic representation of the expert system shows these different modules composing the software in Fig. 1.

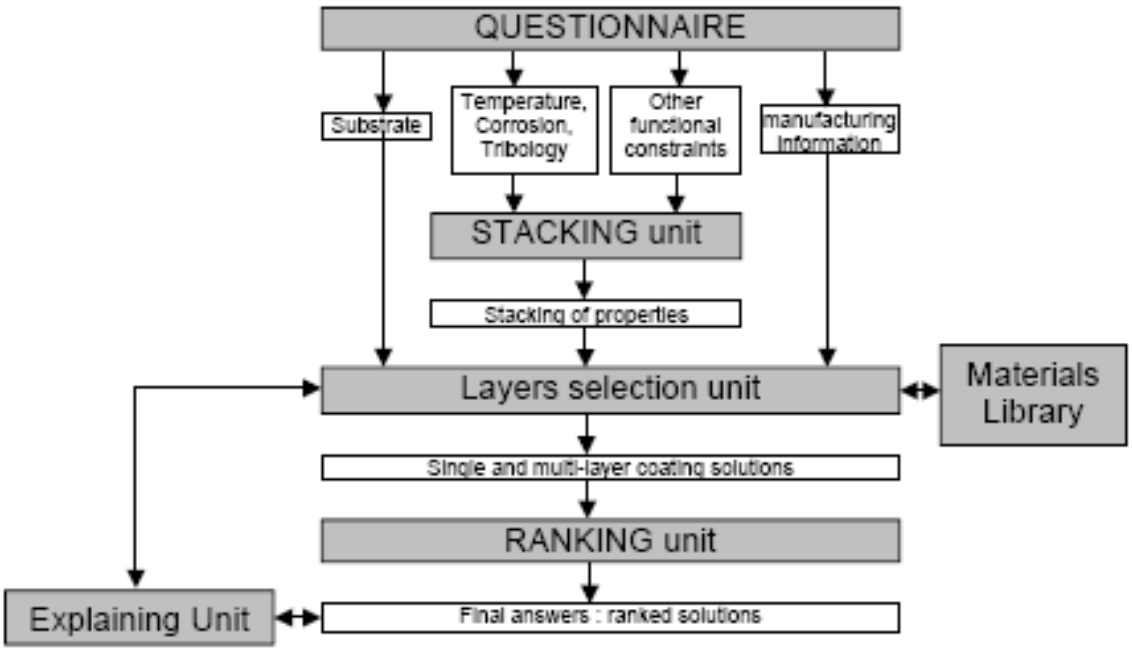

Fig. 1. schematic representation of the expert system with its different modules

Questionnaire. A series of questions are asked to the user about his intended engineering application. The questioning is divided into four parts:

- *Substrate description* (Fig. 2a) : geometric features (shape, size, roughness, presence of holes, threads…) and nature (material composition), pre-treatment of the substrate (thermal treatment, welding, sticking, mechanical assembly), manufacturing process (cold-rolling, powder metallurgy, moulding…)
- *Working conditions* (Fig. 2b) : exposition to temperature, corrosive medium (hot gazes, immersion in water or specific chemicals, molten medium …), tribological solicitations (presence of a counter-body and description of the movement…)
- *Specific constraints* (Fig. 2c) : foreseen post-operations (welding, mechanical working), overall multi-coating thickness tolerance, on-site processing (i.e. mobile equipment), area-selective coating process (i.e. only a part of the substrate surface must be treated).
- *Additional properties request* (Fig.s 2d) : specific demands like weldability, brightness, biocompatibility, fatigue, hardness, thermal conductivity…

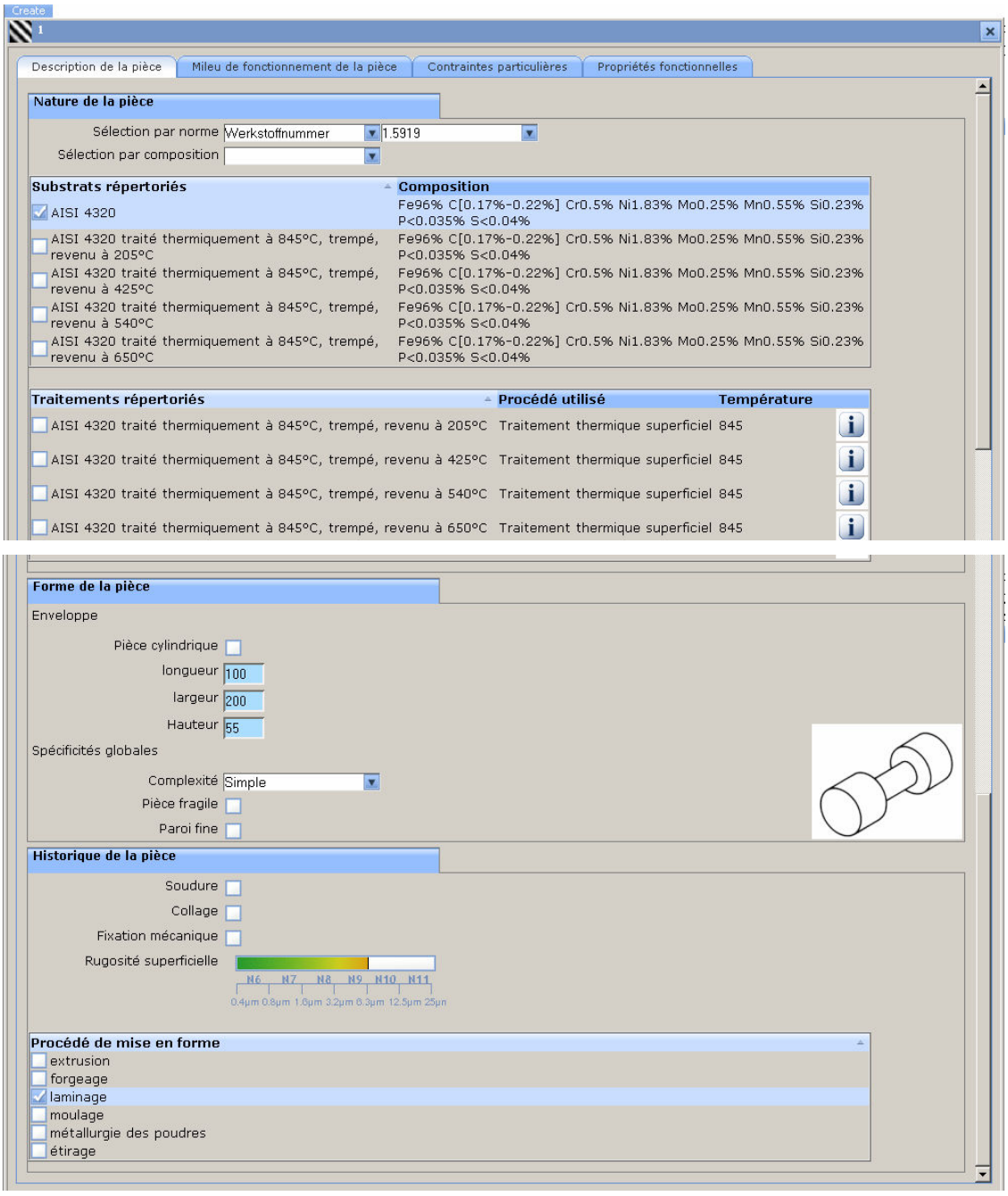

Fig. 2a. Questionnaire : description of the part to be coated

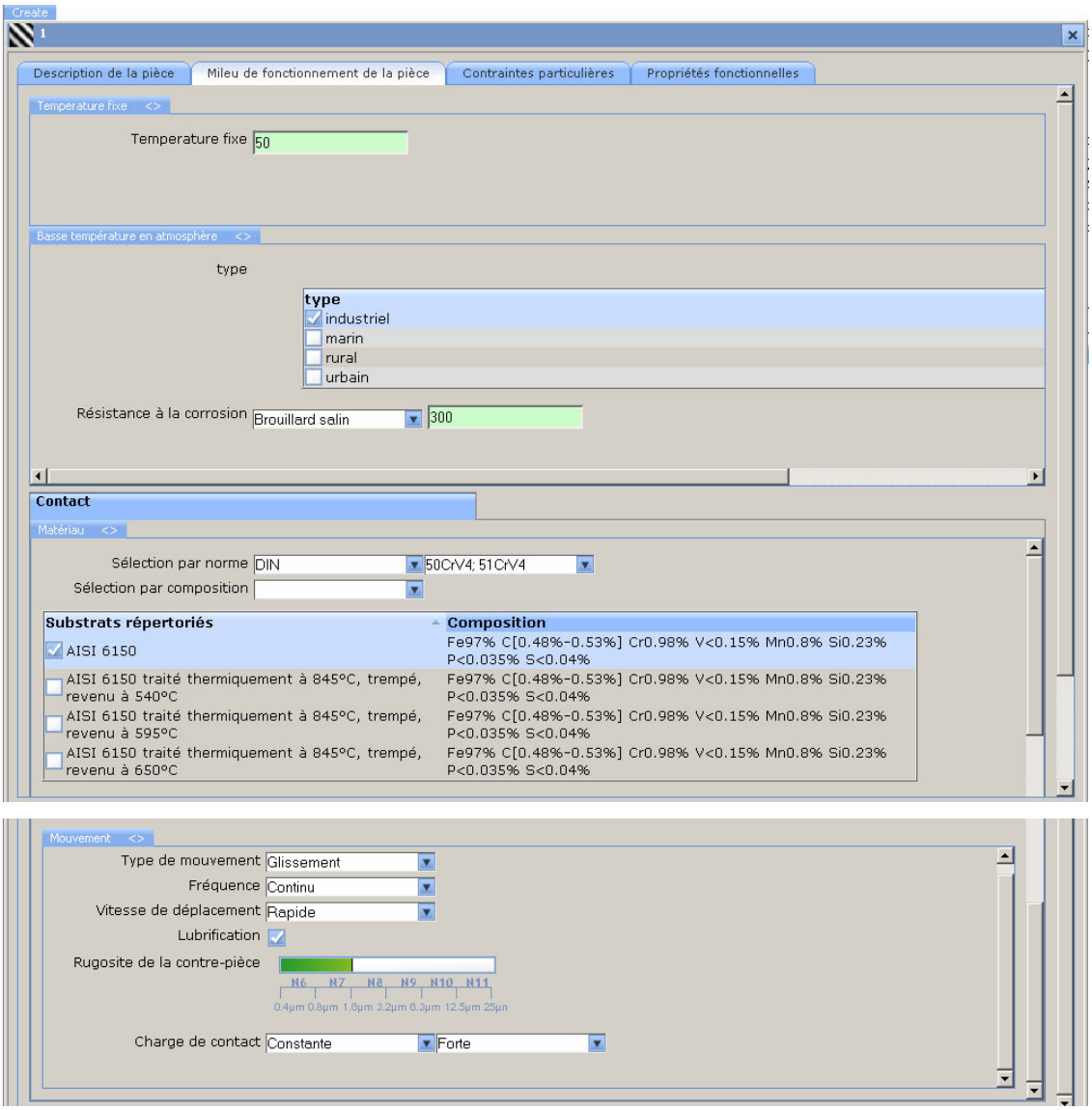

Fig. 2b. Questionnaire - description of the environment of use

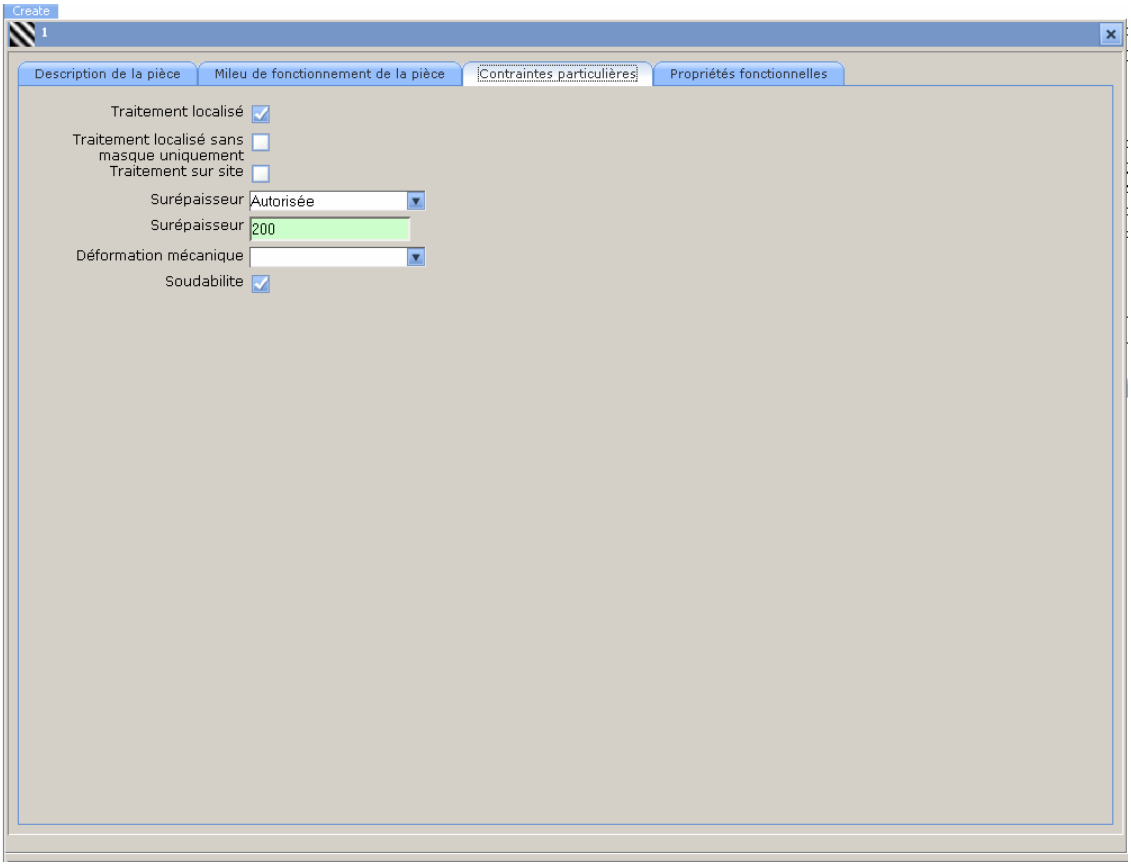

Fig. 2c. Questionnaire - specific constraints

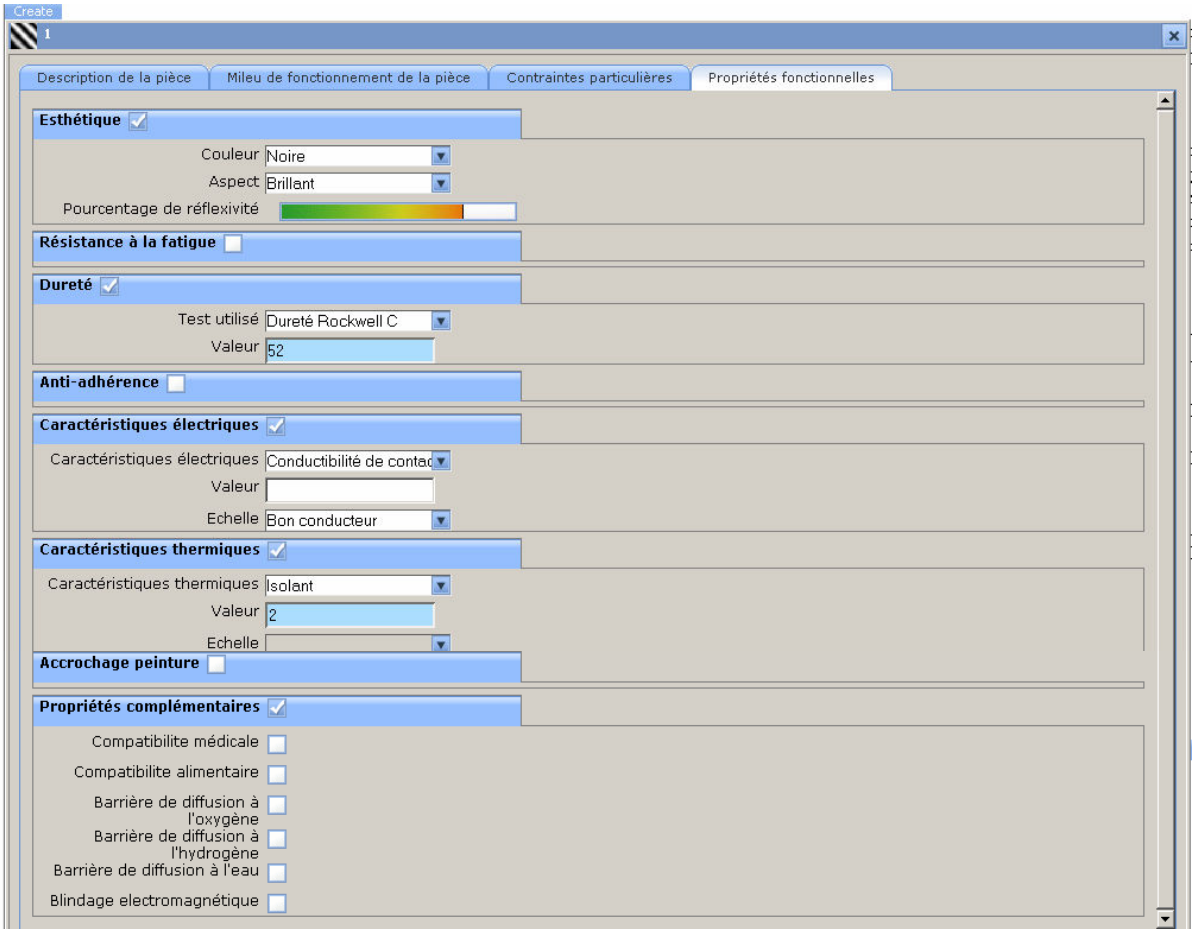

Fig. 2d. Questionnaire - request for other specific functionalities

The information filled in by the user are then sorted into 4 categories :

- the *substrate* : identification according to the Werkstoffnummer standard and associated intrinsic properties.
- *implied functionalities* : necessary properties derived from the working conditions (corrosion resistance, wear resistance, thermal stability…)
- *specific functionalities* : requested properties other than those induced by the working environment.
- information about the *manufacturing of the substrate* : gathering of the information about the substrate manufacturing history from the *substrate description* sheet and information from the *specific restrictions* sheet. This information will impact on the surface treatment processes selection (i.e. elimination of incompatible processes).

These four types of information are then handled by the stacking unit.

Stacking unit. The role of this unit consists in :

- identifying the nature and severity of degradation risks (thermal shock and fatigue, corrosion or high temperature oxidation, adhesive and/or abrasive wear, erosion)
- determining which materials properties and performance levels are necessary to protect the substrate from these identified degradations
- ranking the desired properties to form a stacking sequence of surface treatments to be applied onto the substrate.

The stacking unit is thus able to suggest several different stacking sequences of properties to answer a given problem. The resulting properties stacking sequences are then transmitted to the layer selection unit.

Layer selection unit. Following the properties stacking sequences defined by the stacking unit, the task of this module consists in selecting, from the materials database enclosed to the software (see description in the following sub-section), each individual layers that match the requested properties of the stacking, together with the associated deposition processes of the material layer.

The selection procedure is able to take into account materials or process incompatibilities (with regard to interactions between adjacent materials like interdiffusion, or otherwise, for example, too small substrate size to use a given coating process) and, if necessary, the identified incompatibility may be solved by choosing an alternative coating process or introducing an additional intermediate coating within the stack.

Materials Database. The materials database attached to the software contains a library of materials data sheets for both the substrates and layers. Each data sheet is a kind of material ID-card : it gives the intrinsic properties of the material as well as the surface treatment processes that can be used to produce a coating from the material. Both categories of surface treatments are taken into account :

- coatings processes (PVD, CVD, electrochemical deposition, thermal spray, …)

– surface modification processes, such as conversion coatings, thermochemical diffusion (nitriding, boriding, hot dip galvanizing…), mechanical treatments (shot peening…), thermal surface treatment (induction, laser, plasma…).

The substrates are referenced according to the Werkstoffnummer or DIN standards, as well as elements composition and contents.

Specific information sheets about interactions between 2 given materials and/or processes are also included in the database. This information is a record of the galvanic corrosion compatibility, interdiffusion, friction coefficient, adherence incompatibility, deposition process incompatibility…

Ranking unit. This unit is aimed at ranking the possible solutions answering to a given problem. The following ranking criteria are considered :

– cost (materials and process)
– coherence of two successive processes
– ease of process control
– availability of the process (user's preferences)
– total number of layers
– ratio of the number of intermediate layers (i.e layers used to solve an incompatibility and not to bring a property) to the total number of layers

Let us explain what is behind the criteria named as "coherence of two successive processes". This is a criterion to convey the disadvantages of using successively very different coating processes to build the stacking. Indeed, it is obvious that, from a practical viewpoint, it is less interesting to deposit, for example, one layer with a wet process and then the next layer with a vacuum process, than using wet processes twice successively. Furthermore, the transition direction between two processes is also considered : for example applying a vacuum process after the application of a wet process does not imply the same practical constraints as applying a wet process after the application of a vacuum process. In the first transition direction (wet towards vacuum), careful rinsing and drying of the wet process coated part is required before moving to the vacuum deposition chamber to avoid chamber contamination, whereas no drastic precautions are necessary in the reverse transition direction (vacuum towards wet) between these two processes.

Explaining unit. This module is aimed at giving explanations on the existence or non-existence of specific solutions in the list. This is done upon user's request. The non-existence of a solution can be explained by scanning the solving tracks (solutions tree) and reporting every notch where a failure occurs and the cause of failure. The existence of a given solution is explained by showing which properties are answered by which layer in the stacking.

Conclusions

For the first time, a unique expert system able to give assistance to designers in surface engineering is presented. This tool is aimed at helping the designers to guide their discussions with surface treatment expert subcontractors. Not only is this software able to suggest multi-layer coating

solutions, but also it is able to rank different solutions according to their technico-economical interest. In addition to its ability to solve general corrosion and wear concerns, it is also able to deal with surface finishing properties (like brightness, weldability, electrical conductivity, biocompatibility, …). It is also able to take into account process/materials incompatibilities. This software can also be useful as a R&D support to suggest innovative multilayer coating systems routes that should rather be checked, tested or optimised before making a decision. At present, the described expert software is being tested by industrial experts to evaluate and validate its accuracy, soundness and reliability in solving industrial cases.

Naturally this first software version will be further improved with :

- further feeding of the materials and process library
- following to the first demonstrations to several industrial expert audiences, collected suggestions and remarks might involve adjustment and corrections on materials selection and properties stacking rules
- further options in the solution ranking mode : learning of user's favourite processes, solution performance ranking…
- building-up a simplified, didactic, educational version

Acknowledgement

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