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Selection of manufacturing process in mechanical design

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Abstract

This paper describes a computer aid for the selection of a manufacturing process in design of a single mechanical part. The developed module called Evaluation System for Manufacturing Processes utilizes existing general data on process capabilities, design-for-manufacturability rules and materials processing. The results are expressed in the form of process indices, calculated as fuzzy numbers. The currently available databases of the system contain full information on casting processes. © 1998 Elsevier Science S.A. All rights reserved.

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1. Introduction

Selection of material and manufacturing process is placed in an early stage of the product development procedure, i.e. in the design stage. Typically, designing accounts for 7% of the whole product cost while it is responsible for 65% of its potential decrease [1]. The reason is that the design stage is decisive about the main cost constituents: material and manufacturing. There is however, a basic contradiction here: the product characteristics can be most easily influenced at the product's inception but this is precisely when one knows least about them. It is therefore important to develop designing aids which would assist designers in the selection of materials and manufacturing processes.

A number of computer systems of that kind have been proposed. Earlier works [2–5] presented much more simplified aids of limited applicability. The recent, more advanced ones [6,7], usually require collection of large numbers of appropriate case studies and have been reported to be development in a development stage. An extensive discussion of the above proposals can be found in [8].

2. Current approach

The design aid being developed at Warsaw University of Technology is assumed to utilize the existing, general data on process capabilities, design-for-manufacturability rules and materials processing. The whole target Manufacturing Process Selection System (MPSS) will consist of the two sub-systems:

- Evaluation System for Manufacturing Processes (ESMP)
- Evaluation System for Alternative Designs (ESAD).

The system MPSS, schematically shown in Fig. 1, will be used as follows.

A designer usualy creates a number of versions of his design (may be draft or detailed). The choice of the optimum version is made in two stages:

Stage (1) Each of the design versions is analyzed separately from the point of view of the most favorable manufacturing process in ESMP, by computation of the Process Indices (PI).

Stage (2) All the design versions are compared in ESAD, through computation of the Design Indices; the design version having the best value of that index should be chosen.

At a conceptual phase the designer can start from one version only, defined in very general terms (i.e. without direction to any manufacturing process) and utilize the information obtained in stage (1) to select most suitable processes. A number of more detailed

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versions can be then prepared, each oriented to a single process. Process Indices are calculated for each of these versions. The final selection of the process is made in stage (2), through a selection of the optimum design version (associated with one process only). Other procedures of the usage of the both subsystems are also possible.

The conception of the ESAD subsystem has been briefly described in [10]. Currently, the subsystem ESMP is being developed, schematically shown in Fig. 2. It assumes that the process features are grouped in the following three categories:

- Capability of meeting the user and functional requirements
- Compatibility with design-for-manufacturability rules
- Processability of materials.

The first category of the process features is defined by two quantities: URS and CUR. The URS (user/functional requirement suitability) are expressed verbally, in the form of abbreviations used in some other works and a fuzzy number expressed by a numerical triplet defining preference function is assigned to each of the linguistic values [9]. In this work the triplets reflect expected relative difficulties of meeting requirement of the specified value versus a non-problem one (with the value 'VH'-very high). The triplets values are assigned to the URS verbal values as follows: VH{0, 0, 1/6},..., VL{5/6, 1, 1}. The value 'NA' (not allowed) has another meaning: that the process must not be considered because meeting the specified requirement is not possible. All the URS values, stored in relevant databases, are both process- and requirement-dependent. The requirements can be expressed either in a discrete, verbal form (e.g. surface roughness value can be 'Between 200 and 300 RMS', appearance can be 'Nice') or in a numerical form (e.g. minimum hardness can be equal to 60 HB). Some of the URS values can also depend on the combinations of two quantities; e.g. the achievable complexity of the part can be size-dependent. All the requirements are classified either as material dependent or material independent and are stored in the two corresponding databases.

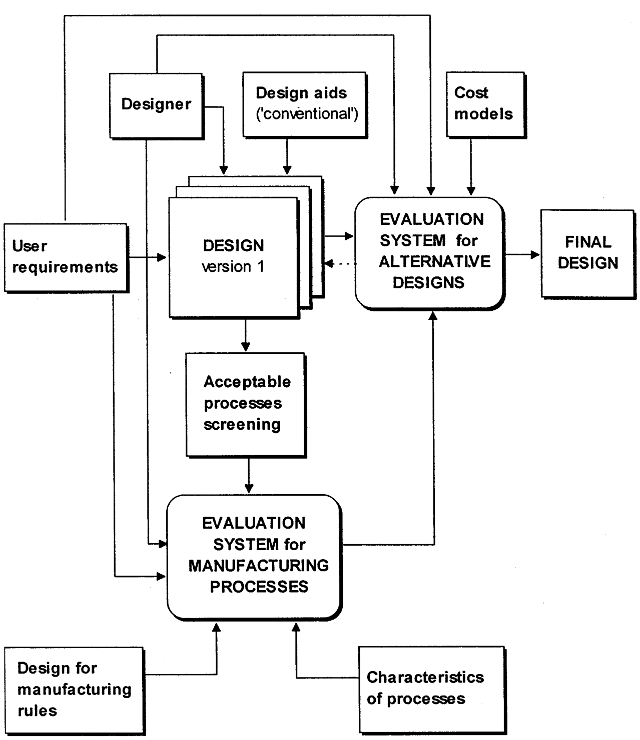

Fig. 1. The manufacturing process selection system chart.

The economical significance of the possible difficulties in meeting the requirements is obtained by multiplying URS by their scaling coefficients CUR (cost-significance of user/functional requirement). Their values, also being triplet-type fuzzy numbers, are assumed to depend on the requirements only and to be equal for all the processes. For example, value 'VH' for a requirement would mean that it is a serious cost driver. The CUR values are stored in the above mentioned two databases, together with the URS values.

The importance of design-for-manufacturability rules is defined by MRS values (manufacturability rule significance), which are expressed in a similar manner as the CUR values above and they reflect the expected increase of the manufacturing cost due to possible violation of the manufacturing rule. A rough estimation of the cost increase due to the violation is related to the verbal values; e.g. 'ML' (middle low) could mean the expected cost increase by 0.1–0.5 of a value for a perfect design (i.e. by 10–50%), with the most probable value 0.3. The designer will be asked to specify whether the rule is fully of partially obeyed for the particular design version and an appropriate value of the fulfilment coefficient f will be determined by the system. For example, if a rule's importance is very high (VH), which would mean that the expected increase of cost due to its most serious violating would be {0.5, 0.9, 1} of the basic cost and the rule is half-obeyed, then $f = 0.5$ and the MRC value for this rule would be {0.25, 0.45, 0.5}. If a rule is not applicable to a given process, it is treated as fully obeyed.

As some manufacturing rules may be less important for some materials, another coefficient d is applied to decrease the resulting MRS values. The values of d, within the range 0–1, are included in the database (value 0 denotes, that the given rule does not apply for the material assumed).

Finally, the overall suitability of a selected material for the processes considered is included in the form of coefficient denoted MS (material suitability). This triplet-type fuzzy number expresses the relative cost increase if less suitable material isused (in a similar way as CUR or MRC), and is assumed for each process and

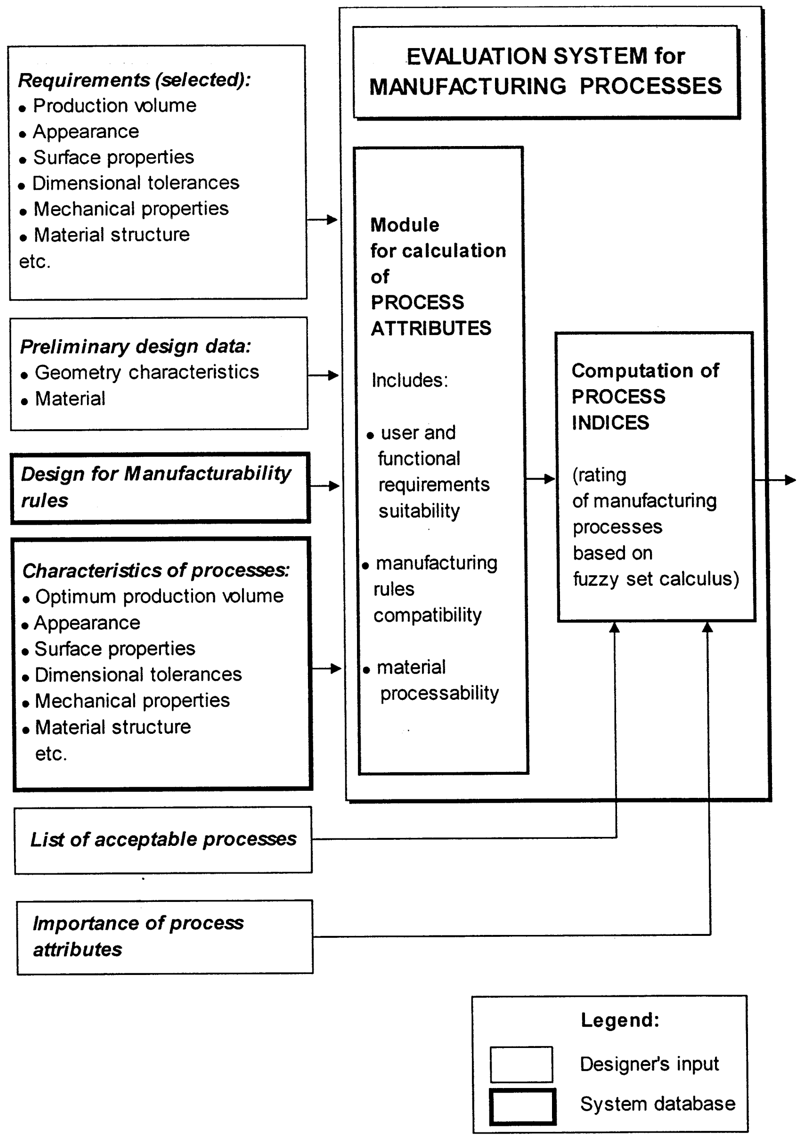

Fig. 2. The evaluation system for manufacturing processes (ESMP) flow chart.

material combination. The scaling factor m is used to the relative importance of the material processability versus the other two features described above.

The Process Index is calculated according to the formula:

$$PI = \sum URS_i \cdot CUR_j + \sum MRS_j \cdot f \cdot d + MS \cdot m \quad (1)$$

where subscripts i and j denote consecutive requirements and rules, respectively. Note, that the PI value is obtained as a triplet-type fuzzy number.

3. Implementation

The first group of processes for which the databases have been completed are casting processes, including sand, shell mould, investment, plaster mould, ceramic mould, evaporative pattern, permanent mould (gravity die), die (high pressure) and centrifugal casting.

The system works in the MS Windows environment. The databases are written in the form of MS Excel spreadsheets which gives large flexibility of their formats. A fragment of the database containing the URS and CUR values is shown in Fig. 3.

The above example demonstrates the case when the process feature called 'size of a part which can be made by the process, kg' may have numerical, continuous values which depend on the parameter called 'complexity' which, in turn, may have discrete values expressed in a verbal form. All the other combinations of the types of process features and their parameters are also possible. The main fields of the database (as shown in the lower right area in Fig. 3) resemble the information

Process:								
No:	1003							
Name:	**Investment c.**							
Feature:								
Number:	1008	Number of values:	6					
Name:	**Size, kg**	Intervals:	Yes					
Significance (CUR):	MH	From:	0	0.001	0.002	1	5	50
		To:	0.001	0.002	1	5	50	10000
Parameter:	Yes							
Number:	1009							
Name:	**Complexity**							
No of records:	5							
Intervals:	No							
	Value:		Suitability values (URS):					
	Very simple		NA	MH	M	ML	ML	NA
	Simple		NA	M	MH	MH	MH	NA
	Medium		NA	ML	VH	VH	VH	NA
	Complex		NA	L	M	L	MH	NA
	Very complex		NA	NA	NA	VL	VL	NA

Fig. 3. An example of a portion of the ESMP database containing information about process capabilities.

charts about applications of different manufacturing processes which can be found in some handbooks [11].

The database with the design-for-manufacturability rules currently contains over 100 items related to different problems appearing in the casting processes. In Fig. 4 an example of user's dialog screen is shown, displaying a rule and the selection bar which facilitates the input of the f values, appearing in Eq. (1).

An example of results obtained from ESMP is shown in Fig. 5. The graph represents the triplet-type fuzzy values of Process Indices for four candidate processes.

The list of processes displayed in the final graphs are determined by a two-step procedure. First the user selects desired processes from the list of the available manufacturing techniques. Second the system excludes those processes, for which values URS = 'NA' were found in a database.

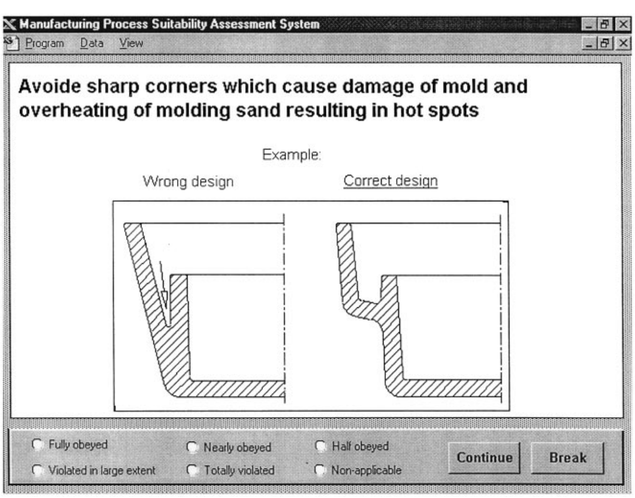

Fig. 4. Example of ESMP dialog screen with a design-for-manufacturability rule.

The 'ideal process' included in the graph is a fictitious one with all the URS and MS values set to 'VH' and all the manufacturability rules fully obeyed. This helps the designer to make his decision: the closer is the candidate process's graph to the graph for 'ideal process', the more suitable is the candidate process for the considered design version.

4. Conclusions and further work

This paper has described the concept, basic components and functioning of the proposed design aid called Manufacturing Process Selection System. The already developed main component: Evaluation System for Manufacturing Processes currently covers most of the casting processes and will be extended to other group of processes, e.g. metal forming.

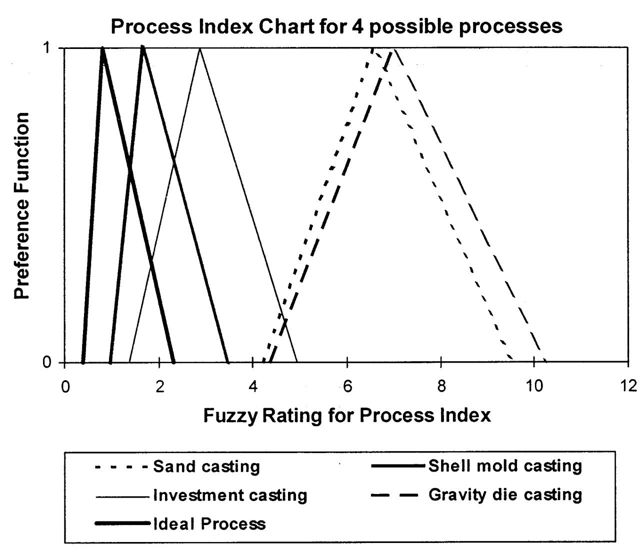

Fig. 5. Example of ESMP results.

The verification of the system is planned by testing it on specially prepared, self-evident data sets as well as on selected case studies, found in the industrial practice.

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