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Establishing manufacturing effort models to be used in optimization of extruded aluminum profiles under structural and manufacturing criteria

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Abstract

As the manufacturing effort is often one of the major drivers in structural design, the paper discusses the development and application of a manufacturing effort model (MEM) for aluminum extrusion, representing fuzzy expert knowledge on the process..
The MEM is verified through a comparison with design guidelines for extrusion. The geometrical effects on manufacturing efforts described in the guidelines match with the results generated by the MEM for varying cross-sectional shapes. In order to calculate the input parameters for the MEM, an advanced parameterization method for arbitrary cross-sections is used. Such MEMs can be used as a decision basis for the designer or they can be included into structural optimization in order to find Pareto optimal solutions, representing the experts' preference of structural vs. manufacturing criteria.
The results based on the developed method and its applications show that the interaction between structural and manufacturing aspects can be considered effectively even in early design phases.

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Keywords: manufacturing effort ; manufacturing model ; fuzzy logic ; aluminum extrusion ; cross-section ; contour parameterization ; optimization

1. Introduction

In general, the appropriate consideration of manufacturing efforts during the design process of a product is essential besides functional and structural requirements in order to reach optimal design. One efficient way is the implementation of **M**anufacturing **E**ffort **M**odels (**MEM**) and their integration into the early design process. These MEMs can be used by the design engineer to analyze the manufacturability of the current design with regard to certain design parameters as shown in Figure 1.

Several approaches for manufacturability analysis were developed and can be seen in literature [1]. These models can also be integrated into structural optimization as seen in Figure 2. In the field of optimization a Pareto optimal solution can be found by the integration of the MEM into the objective function representing the interaction between structural and manufacturing aspects as it was demonstrated in [2] and [3]. Results from such an optimization can be seen in Figure 3 for an extruded profile under a bending load and a displacement constrained. The implementation of the used MEM and its validation is explained in detail in this paper. The main goal is not only developing the manufacturability analysis method but also implementing it to the real industrial applications.

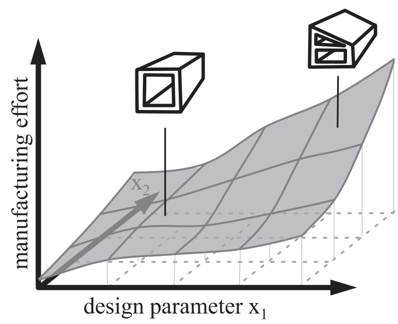

Figure 1: Manufacturing effort of extruded profiles in relation to design parameters

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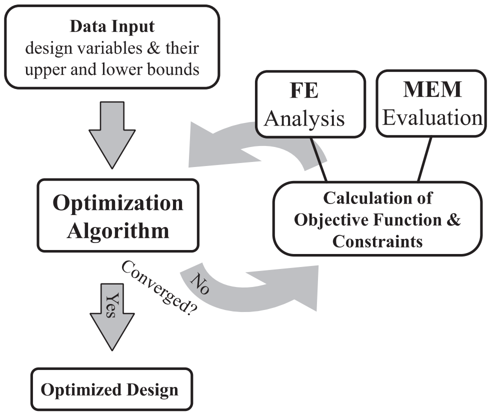

Figure 2: Manufacturing Effort Models (MEM) coupled with Finite Element (FE) models in structural optimization

The implementation is demonstrated by aluminum extrusion case. The algorithm developed and used can parameterize arbitrary cross-sections and extract the values for the effort parameters based on the parameterization automatically. The MEM is built based on techniques for knowledge acquisition and modeling as shown in [3]. These techniques are presented in section 2. The MEM with its corresponding input parameters and response surfaces is described in section 3. The developed algorithms for parameterization and extraction of effort parameters are presented in section 4. In section 5 several cross-sectional designs taken out of design guidelines for extrusion are analyzed. The results of the MEM evaluations are validated by the comparison with the statements of the design guideline on extrusion. Section 6 contains concluding remarks.

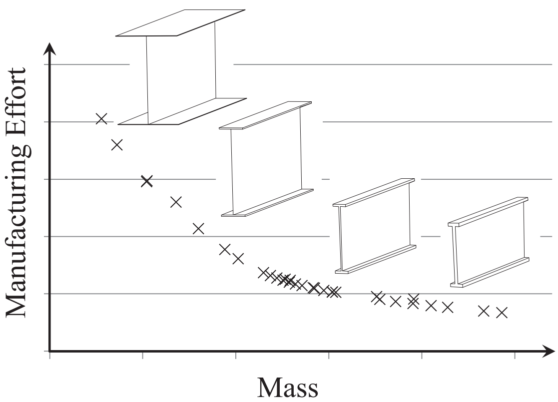

Figure 3: Pareto optimal solutions of an optimized extruded profile under a bending load

2. A method for the implementation of a fuzzy logic based MEM

The modeling of knowledge bases has been investigated over the last decades. One promising approach is the use of fuzzy logic as it was introduced by Zadeh [5], [6]. In section 2.1, the basics of a Fuzzy Rule Based System are described and the corresponding literature is given. In section 2.2 the method developed by the author for the implementation based on knowledge acquisition and its modeling are presented; its application is shown in section 3.

2.1. The basics of a Fuzzy Rule Based System

While in the conventional mathematics quantities are sharply defined, a partial membership of a number to a certain set can be defined by the means of Fuzzy Logic. The use of Fuzzy Logic to develop response-surface-like approximations for expert knowledge was suggested already by Hajela [7]. The fundament of a fuzzy logic system is a set of ‘if…then’ rules, so called Fuzzy Ruled Based System (FRBS) [8]. A detailed description is presented in [4]. Fuzzy approaches were used already in various investigations; one example can be found in [3] where linguistic statements on manufacturing efforts of composite extrusions were modeled.

2.2. Knowledge acquisition and its modeling

An overview of different knowledge acquisition techniques can be found in [9]. In order to model a FRBS, the gained knowledge base has to contain all parameters which can lead manufacturing efficiency and when possible their influences on the manufacturability. The identified parameters are used as inputs of the FRBS. To identify the influence on the manufacturability, the following questions should be clarified for each individual parameter during knowledge acquisition.

- When does the effort increase, when does it decrease?
- How are the slopes during transitions (from low to high production costs and vice versa)?
- Are there any correlations of the process parameters with each other?

The more information is available, the more the approximation model for the effort can be elaborated. Fuzzy sets representing “good", “fair” and “poor" manufacturability are created for the input parameters of the fuzzy model. A rule is created for each input parameter and its corresponding fuzzy set in the form of:

IF Input1 "good" THEN effort is "low"
IF Input1 "fair" THEN effort is "moderate"
IF Input1 "poor" THEN effort is "high"
And so forth for all Inputs

Then, a membership function is selected for each fuzzy set and its course is defined based on the