NOVEL LIGHTWEIGHT COMPOSITE GRIPPER CONCEPTS FOR AUTOMOTIVE MANUFACTURING

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Abstract
A novel approach to valuate concepts for supporting structures made of fiber-reinforced composites, as a main constituent of gripper tooling in the range of handling operations for automotive fabrication, is presented. Increased production costs related to composite materials can be compensated by the benefits of reduced gripper masses, when they enable a reduction of cycle times, power consumption and robotic investments. The large amount of divergent handling operations involves a variety of mechanical requirements. The plurality of influencing variables and the counteraction of application specific requirements complicates a valuation of potential composite concepts. In order to overview the diversity of automotive handling operations, requirements are derived and structured clusters according to commonalities are defined. On this basis assessment criteria are expressed, which allow an allocation of potential composite concepts to the different clusters. Economical and operational aspects are additionally taken into account to enable an overall valuation. The compiled methodology enables the assessment of novel composite gripper concepts. Weight optimized solutions can be located and assigned to suitable automotive handling implementations in order to optimize potential weight reductions. Hereby characteristics of the mechanics of composite materials can be transferred to direct benefits for the operators.

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1. Introduction

The production process of automobiles requires the handling of manifold automotive components. Such handling processes are to be found throughout all crafts of vehicle manufacturing. The manipulation is commonly performed by robots or manual handling devices. In order to enable the grasping of the automotive parts, ranging from small to large-scale, gripper tools have to be attached to the handling devices. The mass inertia of both, the gripper and the manipulated vehicle part, influence the performance of the robotic handling cell. Decreasing moved mass improves the energy balance, increases the productivity as consequence of higher allowable tool movement rates and decreases the robotic investment of such implementations. In the context of manual handling devices, the decrease of inertia is connected to an improvement of the ergonomics.

One possibility to obtain weight reductions is the utilization of the advantageous mechanical properties of fiber-reinforced composites for supporting structures [1]. In this context, an evaluation of new potential concepts is complicated by the variety of automotive handling operations and the altered material properties. Besides the application-oriented aspects, counteracting monetary and operational demands have to be taken into account and additionally impede the assessment of composite concepts.
Detailed analyses with regard to the requirements of automotive handling implementations and the derivation of an assessment methodology could support users with the evaluation of concepts for gripper made of fiber-reinforced composites.
The topology of the presented work is as follows: The state of the art is stated in section 2. The scientific approach behind this work is depicted in section 3. An analysis of automotive handling implementations is presented in section 4. Section 5 introduces an assessment methodology for composite concepts, which is validated in Section 6. Section 7 presents the results, which are discussed in section 8. Section 9 outlines the conclusions made and indicates future fields of research.

2. State of the art

Recent automotive gripper tooling is commonly based on modular tool boxes. The supporting structures are built out of standardized metal elements such as profiles. The actual grasping function is accomplished by attaching function elements (e.g. pneumatic suckers) to the metal frames. This modular setup enables a flexible adaption of the structural gripper geometry to different applications and their corresponding requirements [2]. The metallic processing and material properties play an important role in this context, since stiffness and strength decreases can be prevented or minimized by the application of appropriate joints, without large increases in the mass.
New structural concepts for handling gripper based on fiber-reinforced composites have been developed by different institutions with the intention of reducing gripper masses [3–5]. An assessment of the lightweight potential of composite concepts is however complicated by the altered material properties, the corresponding change of jointing technologies and the wide range of divergent application specific requirements. The weight saving potential is conditioned by the geometrical and mechanical (stiffness and strength) requirements of the particular implementation and is therefore case-dependent. A characterization of the requirements is necessary to enable a proper evaluation of gripper concepts made of fiber-reinforced composites and promotes the development of case-oriented, weight optimized solutions.
Different approaches to structure existing automotive handling gripper applications do exist. Bilsing Automation, for example, organizes automotive implementations according to the different crafts into press and body shop. The body shop grippers are subdivided into "handling", "process" and "geometry gripper" [6]:

- "Handling gripper": simple transportation of components from point A to point B.
- "Process gripper": feeding or positioning of components for processing with increased demands.
- "Geometry gripper": handling, fixation and installation of components during joining process with high demands.
- Special case: tool combination of welding tongs and process gripper

The Euro-Gripper-Tooling manual, which was developed with the participation of diverse German car manufacturers, proposes the same classification [7].
Various publications on methods exist that support the selection of robot grippers. The content is however focused on the choice of appropriate grasping and releasing principles and thus mainly influences the

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selection of the function elements [8, 9].
The mentioned state of the art outlines the lack of detailed analyses of automotive handling applications with regard to their structural requirements. The described classifications do not provide enough details concerning the mechanical and geometrical specifications of the applications. Therefore, they are not sufficient for evaluating or creating weight optimized composite solutions. For modular tool boxes based on metal profiles, this level of detail is not mandatory, since metal jointing technologies allow a flexible adaption to geometry and loading case. Accordingly a general assessment methodology for composite concepts does not exist yet.

3. Method

An analysis of the handling implementations along an exemplary automotive production line is performed in order to derive application-specific requirements for gripper supporting structures. On this basis the applications are structured according to commonalities and clusters are formed. Accordingly geometrical and mechanical assessment criteria are derived, which allows an allocation of weight optimized concepts to appropriate applications. Further assessment criteria concerning monetary and operational aspects are determined in dialog with expert equipment engineers.

4. Automotive handling gripper

Automotive handling grippers are commonly custom-made products for particular tasks. Correspondingly, hardly any implementation looks like the other. In order to make this diversity manageable, handling grippers along an exemplary production line are analyzed. Since it would be very time-consuming to collect the theoretical specifications for every application, a visual inspection of the implementations is performed. The analysis criteria must allow conclusions on the requirements of the application and provide the necessary data for creating an assessment methodology. For this purpose, the theoretical main duties of a handling gripper structure are phrased: the gripper structure must provide the geometry for the connection of the function elements, must bear the induced loads at a certain stiffness and must comply with process-specific tolerances. The three tasks are depicted in Figure 1 and linked to correlating application-specific influencing factors. Economical and operational considerations are neglected for now and associated subsequently.

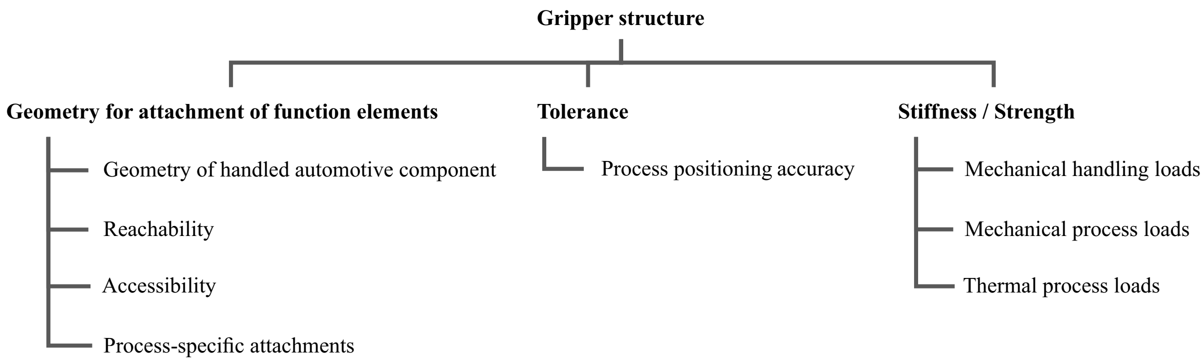

Figure 1. Systematology: gripper structure

Besides the general influencing factors, additional information concerning the amount and location of attachments and force transmissions promotes an assessment of composite structure concepts. Accordingly, the geometric constraints have to be also analyzed. In summary, the following analysis criteria is defined and depicted in Table 1.

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Table 1. Analysis criteria

Automotive part		Current Gripper				Process
Type	Geometry	Build-up	Geometry	No. function elements	Reachability/Accessibility	Application/Task

The geometry of the grippers is depicted in pseudo-3D abstractions across the analysis, in order to reduce the complexity of the visualizations to the required minimum. Function elements and robotic flange are only displayed in 2D for sake of clarity and simplicity, resulting in a non-consideration of their actual orientation. Figure 2 demonstrates an exemplary derivation of such an abstraction.

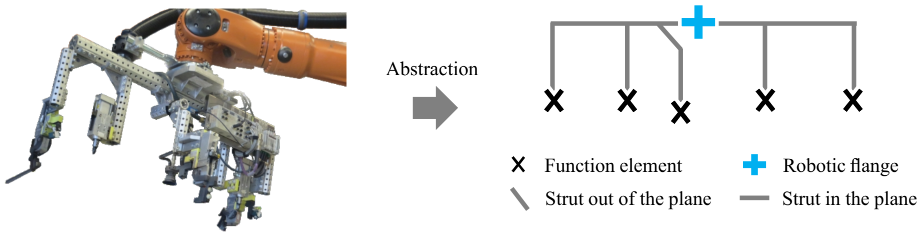

Figure 2. Abstraction of the gripper structure geometry

4.1. Analysis of automotive handling implementations

In the course of this work, 130 applications throughout the body shop and the main assembly were investigated. Some handling applications, which do not comply with common handling gripper designs due to their special characteristics, are neglected in this work. An example are applications, comprising only one special shaped function element such as seat or battery installation. Since it is not possible to depict every investigated implementation, some samples are presented in Table 2.

4.2. Derivation of commonalities

The geometric design of gripper structures has no limitation. Almost every implementation distinguishes from the other and is a unique product. In order to limit the geometric diversity, commonalities and correlations are analyzed and investigated. Since the geometry of the automotive component influences the arrangement of the function elements, different structural gripper set-ups are linked to certain geometric characteristics of the manipulated part. The manipulated components are divided, according to their dimensional characteristics and shapes into: quasi-1D, quasi-2D and 3D components. The quasi-2D and 3D components are additionally subdivided into extensively shaped and irregularly shaped parts. The allocation of different automotive components to the clusters will clarify the breakdown. A typical gripper geometry with an exemplary arrangement of the function elements is allocated to each cluster. This classification is depicted in Figure 3.
Exceptions from this classification arise from accessibility and reachability constraints and can cause switches of the gripper structure appearance from quasi-1D to 2D (or from quasi-2D to 3D). The arrangement of the function elements is commonly oriented towards the outside contour of the manipulated component. This is why the function elements for extensive quasi-2D and 3D parts are typically arranged along circumferential frames. Irregularly shaped components however have a disordered function element layout following the part geometry.
The investigated applications range from simple handling over component processing to installation pro-

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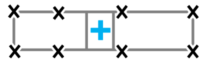
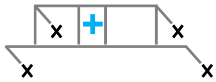
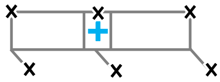
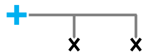
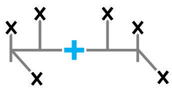
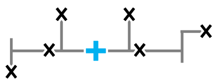
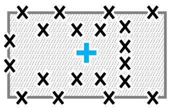
Table 2. Samples of analyzed gripper applications

Automotive Component		Current Gripper				Process
Type	Geometry	Construction elements	Geometry	No. function elements	Reachability/ Accessibility	Application/ Task
Roof	Quasi-2D extensive	Euro-Gripper-Tooling		low	None	Handling
Reinforcing plate	Quasi-2D extensive	Euro-Gripper-Tooling		low	Accessibility	Handling
Side plate	3D extensive	Euro-Gripper-Tooling		low	None	Handling
Cross member	Quasi-1D	Euro-Gripper-Tooling		low	Reachability	Handling
Cross member	Quasi-1D	Euro-Gripper-Tooling		low	None	Handling
Top cross member	Quasi-1D	Euro-Gripper-Tooling		low	Accessibility	Handling
Rear ground	3D irregular	Euro-Gripper-Tooling		low	None	Handling
Rear ground	Quasi-2D irregular	Euro-Gripper-Tooling		low	None	Handling
Panorama roof	Quasi-2D extensive	Milled panel		high	None	Installation

cedures. Accordingly, the requirements with regard to accuracy and stability of the gripper vary strongly. The classification approach of Euro-Gripper-Tooling and Bilsing Automation enables a useful structuring according the level of requirement. Besides varying demands regarding the gripper structure, a correlation of the gripper task and the amount of function elements is detected. Increased accuracy demands affect the tolerance requirements of the structure, but are also accompanied by an increase of attachments, such as measuring systems, centering devices and component fixations. Additionally, the size, shape and weight of the handled component slightly influences the number of function elements. The increased stability requirements result from mechanical or thermal process loads, occurring during the processing steps. The heat flow during welding works does usually not directly affect the gripper structure and is thus being neglected.

5. Evaluation methodology

The evaluation methodology works interactively with the user. The systematology of the methodology is depicted in Figure 4. The user is asked to rate the concept qualitatively with regard to ten different

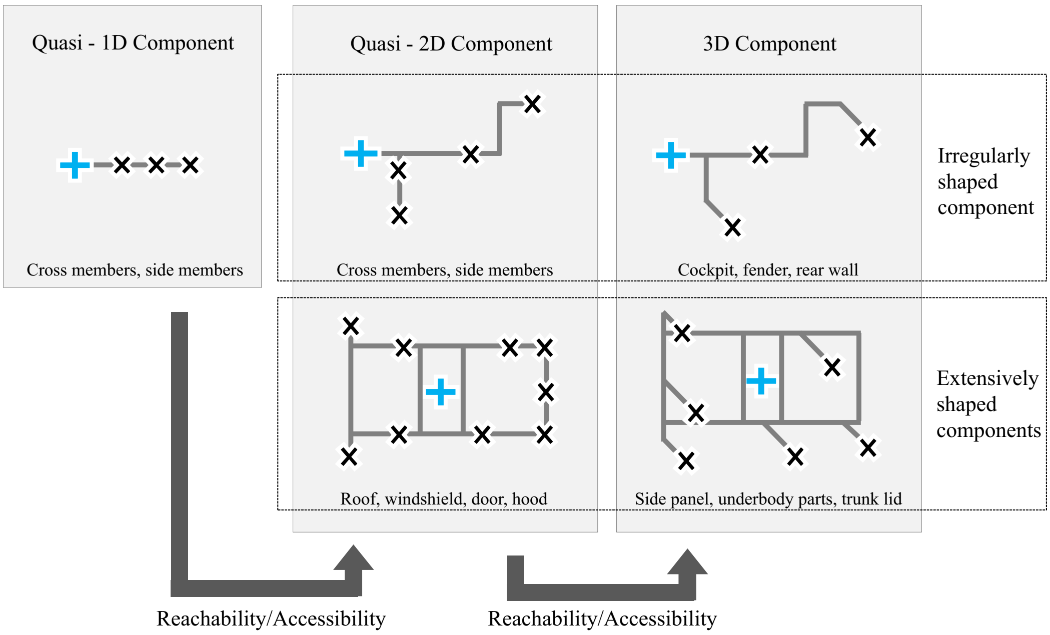


Figure 3. Correlation between component geometry and gripper appearance

characteristics. The characteristics are subdivided into mechanical and economical aspects. Criteria one until four are intended to determine the economic efficiency of the composite concepts, neglecting potential efficiency improvements as a consequence of weight reductions. The mechanical criteria ranging from five to ten, enable an assessment of the lightweight potential of composite concepts. Furthermore, they allow an allocation of concepts to appropriate fields of application.
The geometric flexibility is determined by selecting which of the five geometric clusters are feasible with the considered concept. According to the number of chosen clusters, the flexibility is rated high (4-5), medium (2-3) or low (1-2). Unfeasible geometric clusters are excluded. The weight balance of attachment joints determines whether the concept is suitable for "handling grippers" with low amounts of function elements, "process grippers" with medium amounts and "geometry grippers" with high amounts. Disadvantageous gripper types are excluded. The tolerances of the manufacturing process do also affect the selection of suitable gripper types. Unfeasible gripper types are excluded.

6. Validation

For the validation of the methodology, a composite concept based on pullwinded profiles and aluminum clamps is evaluated [3]. Profile and clamps are detachable, if no adhesives were applied and are therefore highly maintainable. Pullwinded carbon profiles and aluminum clamps are mass-produced components. Correspondingly, the profiles are comparatively low-priced for a composite product and highly available. Since standard construction elements are employed, the construction costs are low. Profile and clamps are flexible construction elements and are arrangeable in many ways. Accordingly, the sample geometries of all clusters are feasible. The weight balance of aluminum clamps is bad. Accordingly every attached function element lowers the weight saving potential of the composite gripper. As a consequence, "process" and "geometry gripper" are excluded. Pullwinded profiles possess an advantageous shape and fiber orientation for bearing bending and torsion loads in general. The topology is however restricted by the tubular components. Criterion seven is therefore rated medium. Profiles require a joint at every intersection and have therefore a low ability of minimizing fiber disruptions. Available sizes and thicknesses of profiles are regulated by the market. Accordingly, the adaptability to the load case is low.

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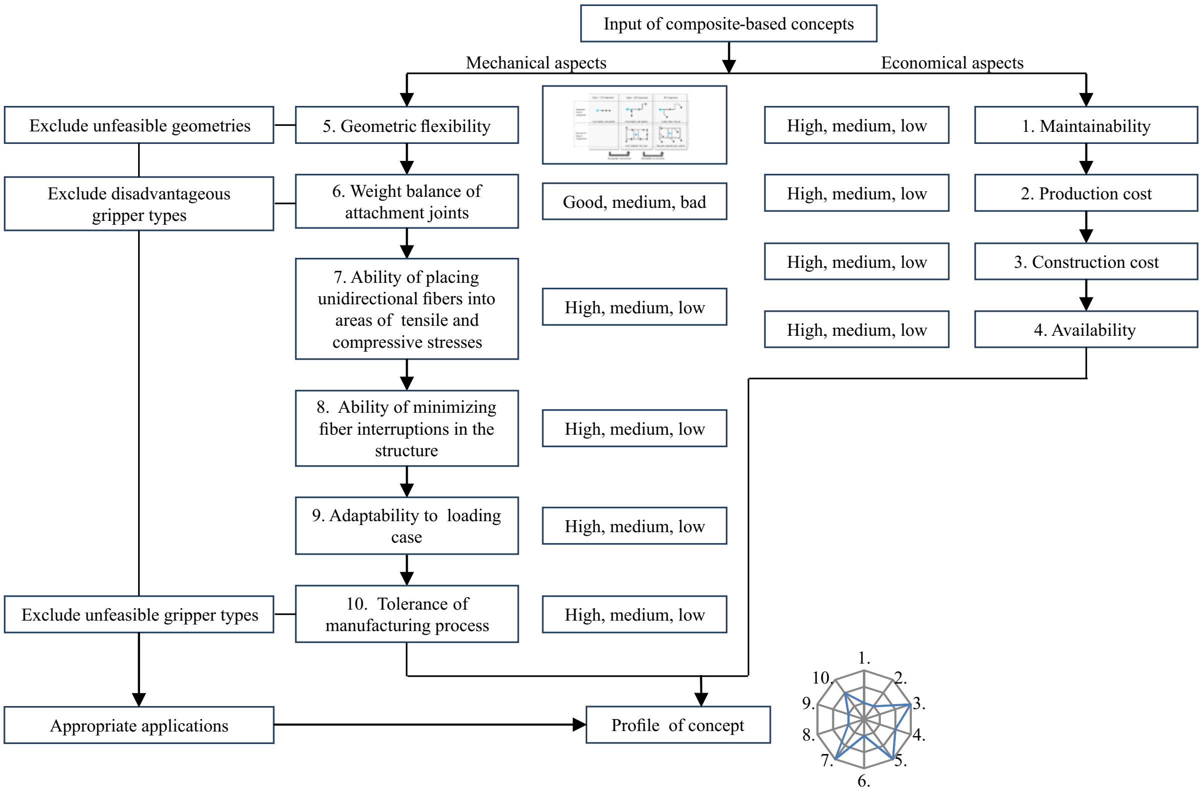

Figure 4. Evaluation methodology

The production tolerance of the concept is small, since the profiles have to be joined manually without any reference points in the structure.

7. Results

The analysis of 130 implementations enabled the derivation of different correlations between application and gripper. Several gripper appearances were allocated to particular automotive components and divided into geometric clusters. Pursuant to the nature of body shop components, the majority of automotive handling applications concerns extensively shaped quasi-2D and 3D components. With regard to the joint issue of composite materials, a correlation between the amount of attachments and the gripper task was pointed out. This correlation was associated with existing classifications for handling gripper applications. Based on this, an assessment methodology was presented, which enables a qualitative overall assessment of composite gripper concepts and their allocation to particular automotive applications.

8. Discussion

The diversity of handling gripper appearances, resulting from varying component geometries and applications, complicates potential classification approaches. The determined geometric clusters enable a differentiation of automotive components and gripper appearances. However, a limited set of borderline cases was encountered, where an explicit assignment to the geometric clusters was not possible. This is also why absolute numbers of applications within the different clusters were not presented.
Within the framework of the methodology, the amount of attached function elements was connected to the gripper task. This correlation is however disturbed by minor influences of the component size,

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shape and weight on the amount of attachments. These circumstances may lead to a false exclusion of borderline cases in the course of the methodology.

9. Conclusion and outlook

The presented work makes the diversity of automotive handling applications more manageable, by introducing component and application-specific clusters. The assessment methodology, based on the classifications, enhances the evaluation of potential composite concepts through allocating them to appropriate fields of application. Thereby, application-oriented composite solutions can maximize the weight saving potential along automotive production lines. The consideration of economical and operational aspects enables an overall assessment.
In order to simplify the entire design process of equipment engineers with regard to composite gripper implementations in the future, the assessment methodology could be extended to a design methodology. The user has to be able to input an intended application as well as personal preferences and the methodology needs to allocate an appropriate solution. Additionally, existing concepts could be evaluated and deficits derived. These deficits could be used for the development of advantageous concepts.

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