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Toward a Method for Evaluating the Applicability of Aluminum Foam Sandwich

P. Hommel ✉, D. Roth, H. Binz and M. Kreimeyer
University of Stuttgart, Germany
✉ patrick.hommel@iktd.uni-stuttgart.de

Abstract
Aluminum foam sandwich (AFS) is an innovative material for lightweight structures due to its various advantages (e.g. low specific mass). Today, many material properties (e.g. strength) are still not well researched, which is why AFS is not yet considered in current material selection processes. Therefore, AFS has rarely been used in the past and its application potential remains unused. This paper presents an approach toward an appropriate method for considering AFS in material selection processes to assist designers in evaluating whether the use of AFS in an application is profitable.

Keywords: lightweight design, design for x (DfX), design methods, material selection, aluminum foam sandwich

1. Introduction and motivation

The aim of reducing mass and conserving resources can be achieved with the aid of lightweight designs. If there is less moving mass, there is lower energy consumption and therefore also fewer emissions (Friedrich, 2013). The realization of lightweight designs is a major challenge, however, with different materials and different design methods now of great importance in this regard. Sandwich structures can complement common integral or differential design as they combine different lightweight design strategies in one material (Kopp et al., 2009). Aluminum foam sandwich (AFS), which is shown in Figure 1, is an innovative material combination for lightweight structures (Banhart et al., 2019; Binz et al., 2018; Sviridov, 2011). Typically, the core and the face sheets are made of aluminum alloys. Homogeneous aluminum plates are used for the face sheets and the core is a porous foam structure created by heating the raw material. The characteristic powder metallurgical manufacturing process creates a metallic bond between the face sheets and the core; as this does not require any adhesives, it therefore has a high recycling quality (Seeliger, 2011).

Figure 1. Aluminum foam sandwich in different thicknesses

Because of its many advantages, such as high bending stiffness at low density, good damping behavior and beneficial mechanical energy absorption, AFS has a wide range of possible applications (Banhart et al., 2019; Hommel et al., 2021; Sviridov, 2011). Components made of AFS can prove particularly profitable in mechanical and plant engineering, for example in load-bearing structures within machine tools (Hipke et al., 2007), and in the automotive industry, such as in battery boxes for electric vehicles or crash-relevant components (Banhart et al., 2019). An overview of suitable applications has been summarized by Hommel et al. (2021).

2. Problem clarification and goal

AFS has many advantages as well as numerous potential applications. Yet, the usage of the material remains limited for reasons such as a lack of design knowledge, a lack of reference applications and above all the high manufacturing costs of the material (Hommel et al., 2020). Given this lack of design knowledge and reference applications, designers do not know about the possibilities for designing with AFS and using it in a beneficial way. Innovative materials such as AFS can only be used in situations where they are cost-effective or when various advantages are combined to achieve additional benefits. However, a study (Hommel et al., 2020) has shown that AFS is often not even considered before the focus turns to matters of economic feasibility. A relevant aspect in this context is the correlation between familiarity with the material and its consideration in the material selection process. The study showed that almost 90% of respondents were aware of the material, but less than half considered it as a possibility within the development process. Of all respondents, only 26% had already used the material. The main reason for excluding AFS before examining added value and costs is that the designers are not familiar with the material – and often don't know it at all. Due to a lack of experience with AFS, they prefer to use a proven and better-known material in the interest of simplicity and risk minimization. In addition, it has been discovered that designers are frequently unable to judge whether an application is fundamentally suitable for the use of AFS (Hommel et al., 2020). And as certain material characteristics of AFS are not available, it is not possible to perform quantitative comparison and selection within existing selection methods. The fact that AFS is not included in common methods is also due to the fact that AFS is a material and a construction method at the same time.

If AFS is excluded from the material selection process without any evaluation of its suitability for use, the potential of AFS may remain untapped and another material may be selected even though AFS would be more suitable. Since there is not yet any support for the selection of AFS use cases, this gap has to be closed. The aim of this paper is to develop approaches toward a method for identifying the targeted use of AFS. With the help of such a method, the designer should be supported in evaluating if the use of AFS is reasonable for a given application. Therefore, the main research question of this paper is:

How can a designer be assisted in deciding whether it is appropriate to use aluminum foam sandwich instead of a reference material in an application?

3. Structure of this paper

In the following section, the state of the art regarding the reasons for using AFS is described along with basic aspects of material selection. Section 5 defines the requirements for the method to be developed, while Section 6 describes various possible ways of implementing the method. The most suitable type is then presented in Section 7 by discussing an approach toward the method for evaluating the applicability of AFS. The article concludes with a summary of the findings and provides an outlook on further activities.

4. State of the art

This section describes the state of the art, beginning with the motivators and corresponding advantageous applications of aluminum foam sandwich. The discussion then moves on to an overview of the basic methodology of selection and evaluation methods, including a detailed explanation of systematic material selection according to Ashby (2005).

4.1. Motivators for the use of aluminum foam sandwich

A systematic literature review by Hommel et al. (2021) served to investigate where AFS has been used or could be used and which advantages arise from the use of AFS. These results were then used to develop a set of motivators for the use of AFS, which will support the designer in evaluating its potential

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use. The final motivators, which are the reasons for the use of AFS, are summarized in the following (order according to descending frequency of references in literature): high energy absorption capacity, mass reduction due to lower density, high mechanical properties, sound insulation, optimized heat transfer, vibration damping, non-inflammability and heat resistance, lower thermal conductivity, radiation protection, recyclability, corrosion resistance, reduction of costs due to fewer individual parts, tune vibration frequency, appealing optical design and integration of functions.

4.2. Methods for selection and evaluation

Product development methods in general are a planned and rule-based approach for achieving a specific goal (Ehrlenspiel and Meerkamm, 2017; Lindemann, 2009). A variety of basic literature explains the methods and their application in detail, with fundamental works in design methodology including Ehrlenspiel and Meerkamm (2017), Gausemeier et al. (2001), Lindemann (2009) and Pahl et al. (2007). In Honold et al. (2019), a method map is presented that clearly shows the multitude and variety of product development methods. This subchapter will focus on selection and on the evaluation methods in particular, as these form the basis of the method to be developed.

Selection and evaluation according to technical/economic and general criteria (e.g., functional aims, cost aims and safety) help to determine the most suitable solutions from a multitude of ideas (VDI, 1993). Evaluation methods are applicable within the different phases of the product development process (Wartzack, 2021). In order to evaluate the suitability of a solution with respect to the target system that has been created, common evaluation criteria have to be defined: These can be assigned with values and compared as sums (Breiing and Knosala, 1997). Several methods are available for this purpose, such as basic evaluation for pre-selection with the help of advantage-disadvantage comparisons, selection lists, comparisons of pairs or simple point rating systems (Ehrlenspiel and Meerkamm, 2007; Pahl et al., 2007). If more intensive selection is necessary, then a weighted point rating system, the technical/economic evaluation according to VDI (1998) or Kesselring (1951), or benefit analysis (Zangemeister, 2014) can be used. What all these methods have in common is that an evaluation can only lead to a decision if at least two real solution variants are available, if the evaluation criteria are defined in relation to objectives and if there is a possibility of assessing and ranking the variants according to the degree to which they fulfill the criteria (Haberfellner et al., 2019).

4.3. Systematic material selection

There are various reasons for changing the materials used, such as increasing technical performance, reducing manufacturing costs, changing customer requirements, quality problems with existing products, modifications to legal requirements or even social responsibility for the environment (Reuter, 2014). In order to select the right material for an application, the conditions of use have to be analyzed and the tasks of the component must be recorded in a requirements profile. On the one hand, the functional requirements must be fulfilled; on the other hand, the material must also be suitable for the corresponding manufacturing and joining processes (Ashby, 2005). Existing literature highlights many different procedures for the systematic identification of a suitable material (Kaiser, 2017). Procedures for material selection are based on the generally formulated problem-solving cycle according to Haberfellner et al. (2019) and can be started at different points in the product development process, with systematic material selection usually taking place during the conceptual design phase (Reuter, 2014).

An established procedure for selecting a suitable material is that of systematic material selection according to Ashby (2005). Initially, all materials are considered so as not to exclude any material prematurely. Then the relevant material properties are derived from the design requirements and compared with the characteristics of the materials. During this screening, materials that don't fit the requirements are excluded. The remaining materials are ranked and the final material choice can be made with the help of supporting information. (Ashby, 2005)

While the entire procedure, and in particular Ashby's well-known material diagrams, can be used manually, it can alternatively be combined with software such as Granta's CES (Ashby, 2005) in order to find the best possible solution via optimizable parameters (e.g., cost and weight reduction).

Since this work deals specifically with sandwich materials, it should be added that the procedure described is aimed at solid materials and the comparison with sandwich materials therefore requires an

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additional step. Ashby (2005) states that a hybrid, such as a sandwich composite, is seen as a “material” in the sense that the properties of the individual components are merged (ranging from the least of both to the best of both). In the case of density, the calculation of the composite density is obvious as the densities of the individual materials can be weighted according to their ratio. For other mechanical properties such as strength, rules of mixtures must be applied. With this simplification, designers are enabled to use existing methods.

5. Requirements for the method to be developed

Having this in mind, there is currently no selection method in which AFS is already integrated, possibly because it is simply too recent a development. As described above, AFS can be integrated into Ashby's material diagrams. But since only a few material properties are known for AFS, however, this means that comprehensive material selection with AFS is not possible. Material studies to clarify further material properties of AFS are relatively expensive and will require a lot of time. For this reason, the development of a qualitative method is more suitable.

The method to be developed for assessing the suitability of AFS in various applications must meet several requirements relating to lightweight design and the use of the material. In order to assess whether a method does in fact provide support to designers, it is necessary to define essential requirements that must be met. Keller and Binz (2009) have developed an overview of general requirements for methods and classified them according to the following eight groups: revisability, practical relevance and competitiveness, scientific soundness, comprehensibility, usefulness, problem specificity, structure and compatibility, and flexibility. The most important groups for the present work are discussed in more detail below by presenting specific requirements for the method being developed.

Usefulness is evaluated in terms of the effectiveness and efficiency of a method (Keller and Binz, 2009). The aim is to ensure that the method is as simple to use as possible. While product knowledge increases during the product development process, the freedom of design decreases (Pahl et al., 2007). Therefore, a suitability analysis for AFS should be undertaken in the early phases so as to make appropriate use of this design freedom. It is important to achieve a helpful result quickly. The amount of time needed must correspond to the usefulness and complexity of the task. In addition, a new method should not require expensive software applications.

Flexibility is provided to the designer by creating degrees of freedom and choices. The methodology should not restrict the designer in the choices to be made and should also allow for the combination of methods, for example (Keller and Binz, 2009). In terms of the method for AFS, such freedom means that the method must be usable for previous applications as well as for future applications. In addition, there should not yet be any limitation on whether the method should be used to compare AFS to a reference material or whether the method should generally be used to determine if AFS is at all suitable for an application. Accordingly, it must be possible to apply the method at different times within the product development process. It must also be applicable to different products and not limited to one product category or industry.

Comprehensibility indicates an understandable method which is simple to apply. The procedure should be easy to learn or intuitive in application and should not require any major explanations. The results should be transparent and repeatable when applied by other users with the same level of knowledge. As a consequence, the decisions made using the method must be comprehensible (Wartzack, 2021).

Since the selection of suitable applications for AFS is a challenge, the selection method is developed with the aim of evaluating the usefulness of AFS in a particular application. Economic factors must be considered when selecting a material in order to ensure its success on the market. Usually, all costs incurred in the product life cycle must be considered and not only the material costs themselves. However, taking these total costs into account is difficult – especially in the concept phase – because there are still too many inaccuracies and a lack of knowledge about the product. Furthermore, the general data availability of AFS as described above represents an additional challenge that further complicates the cost estimation. For this reason, it is advisable to develop a method that is more qualitative than quantitative in order to reflect the circumstances and provide a realistic assessment. In any event, properties that are available for AFS, such as density or Young's modulus, should also be considered in the method.

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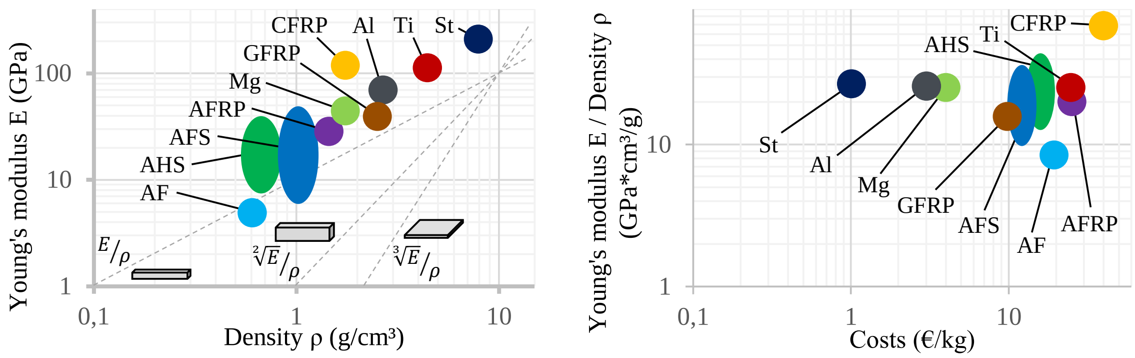
6. Potential approaches toward the method for evaluating the applicability of AFS

Where the previous section discussed the requirements relating to a method, this section will look at the different options of the method and the theoretically possible options in this case. A description of a procedure analogous to Ashby's material selection (Section 6.1) will be followed by a substitution analysis comparing two materials (Section 6.2) and the presentation of a procedure intended to verify the general suitability of AFS (Section 6.3). These options will then be evaluated and a justification given regarding the most appropriate type of method for AFS.

6.1. Integration of AFS into the material selection process according to Ashby

In systematic material selection according to Ashby (2005), all materials are initially considered without bias and the best materials are then identified with the aid of a four-step procedure. A typical objective in the context of lightweight design is to search for the lowest component weight while fulfilling a specified minimum stiffness, which corresponds to a classical approach using free search. However, AFS has not been included in Ashby's material diagrams thus far. These diagrams include metallic materials such as aluminum alloys and steels as well as various foams (mainly made of plastic).

It is generally possible to integrate AFS into the different diagrams as described in Section 4.3, i.e. aluminum and aluminum foam can be plotted and then the composite for AFS can be determined depending on the fundamental load type. This task can be performed quite well for density, although there is already a wide range of foam densities. The first difficulties arise when it comes to the various stiffnesses/strengths. It is impossible to specify an exact value of the Young's modulus for AFS, for example: Not only does this depends on the sandwich configuration (i.e. the different ratios of the layer thicknesses), the material parameters also depend on the loading. For instance, the effective modulus of elasticity is greater under bending than under compressive stress. This behavior naturally also applies to other sandwich materials such as honeycomb sandwiches, with the specific adjustment of the honeycomb sizes allowing the wide ranges of density and Young's modulus. These two schematic diagrams (see Figure 2) show how such material diagrams could look with AFS added to them (shape of an ellipse due to variations and load types). In this case, an aluminum foam density of 0.6 g/cm³ and a Young's modulus of 5 GPa were selected for the configuration of AFS. While the left-hand chart plots the relationship between the Young's modulus and density of different materials, the right-hand chart plots the ratio of the two properties against costs (values according to Klein and Gänsicke, 2019 – costs varies greatly depending on the quantity required). Similar to the portfolio technique, the corners represent different areas and the materials in the top left box have the best rating. As a result, the diagram on the left shows that AFS as a plate is more suitable than aluminum alloys and comparable to carbon fiber-reinforced plastic (CFRP) in terms of stiffness-weight behavior under bending stress (parallel shift of the $\sqrt[3]{E}/\rho$ line). The materials presented always include whole groups or families of different materials. Similarly, for materials with alloys an average value of different alloys is used to describe the whole group, so that for example the term aluminum represents the whole group of aluminum alloys.



AF = Aluminum foam; AFRP = Aramid fibre-reinforced plastic; AFS = Aluminum foam sandwich; AHS = Aluminum honeycomb sandwich; Al = Aluminum; CFRP = Carbon fibre-reinforced plastic; GFRP = Glass fibre-reinforced plastic; Mg = Magnesium; St = Steel; Ti = Titanium

Figure 2. Schematic material diagrams plotted for Young's modulus versus density (left) and a density-based Young's modulus versus costs (right)

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6.2. Evaluation of the substitution potential of AFS

In this approach, the initial situation is a component made of a material such as steel or aluminum alloy. However, this use leads to certain disadvantages, which means that a change of material must be considered. Whether the substitutional use of AFS offers added value in this case can be examined by comparing the reference material with AFS. The method must show which advantages and disadvantages would result from a substitution with AFS. A questionnaire-based approach according to Ashby et al. (2004) is therefore suitable for this purpose and based on the evaluation of various material properties shown as an example in Table 1.

Table 1. Comparison of the fulfillment of different criteria for various materials

0 = Not fulfilled; 1 = Rather not fulfilled; 2 = Partly fulfilled; 3 = Rather fulfilled; 4 = Fulfilled

		Materials/Alloys					
		AFS	*Aluminum*	*Steel*	*Copper*	*Co…*	*Titanium*
Evaluation criteria	*High energy absorption capacity*	4	2	1	2	3	1
	Low density	3	2	0	0	3	1
	High mechanical properties	2	3	4	2	[illegible]	4
	Sound insulation	4	1	1	1		1
	Optimized heat transfer	3	3	2	4		2
	…on protection						
	Recyclability	3	3	4	4	[illegible]	0
	Corrosion resistance	3	3	2	3	3	4

When using this strategy, the designer will be asked a comprehensive set of specific questions to obtain answers about the application in order to proceed with the material selection. Based on the individual answers, scores are assigned to the materials according to their characteristics (e.g., a low density means a high score) and this makes it possible to state which material has more overall benefits. Moreover, it can be shown where the strengths and weaknesses are in each case. The user is guided systematically through a series of decisions, such as selecting possible materials and defining requirements for the application. This step-by-step and predefined procedure allows the user to focus on answering the individual questions, making this approach highly relevant in practice.

6.3. Verification of the fundamental suitability of AFS

This approach toward evaluating the suitability of AFS is a methodical tool that can be used to assess whether the use of AFS at a specific location or in a particular product is reasonable. Since this approach is highly analogous to the procedure in Section 6.2, it can be carried out with similar conditions – however, reference materials are irrelevant in this regard as the focus is solely on AFS. A questionnaire or a checklist with different items is once again used. With the help of a defined threshold value, a final decision can be made on whether the use of AFS is possible in principle and whether it also makes sense. This variant is a simple application that enables a quick procedure and is helpful for an initial evaluation. If it is concluded that AFS is reasonably suitable, its use must then be investigated in more detail.

6.4. Evaluation of the different approaches

As explained in the previous sections, there are different approaches for checking whether a component can be made from AFS. The implementation described in Section 6.1 would be well suited and a great support if the data availability of AFS allowed for its integration into the diagrams. The aforementioned material properties such as Young's modulus are already discussed in the literature, but with significant differences. If other material properties such as thermal conductivity are added, the challenge of identifying a material on a reliable basis becomes even greater. In the selection process described above and based on Ashby, the material charts are too extensive for the data availability of AFS and a selection process including AFS cannot be founded on this method alone. Nevertheless, the diagrams in Figure 2 offer great added value and can be used as an overview, since it is possible to clearly identify which

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material is more suitable than others (with regard to the specified properties). These simplified diagrams are therefore useful for the variant described below, as well as for the overall methodology when it comes to providing a quick initial classification of the materials.

Since the two variants from Sections 6.2 (substitution) and 6.3 (fundamental suitability) only differ in terms of whether a reference material is included while the methods themselves are structured in a similar way, these variants are considered in combination in the following. The disadvantages of the first variant (Section 6.1) lie in the quantitative specification of the properties and the associated lack of data availability for AFS. The two other possibilities described for the conversion of a method have their strengths in this aspect, since they do not depend on exact values and instead describe the characteristics in a qualitative manner. The advantage of these implementation lies in the fact that the materials are compared on a lower but similar level of accuracy, making it possible to weigh up the positive and negative consequences of the respective materials. The method represents a simple catalog of questions about reasons for using the materials that is not yet specifically directed at material parameters and is thus well suited to AFS. This questionnaire can be understood as a kind of checklist that Roth (1994) considers highly suitable at the functional and principle design stage. For the reasons mentioned above, a questionnaire in the form of a checklist is to be chosen as a suitable method for supporting the evaluation of the use of materials. In addition, the requirements mentioned in Section 5 can be fulfilled by such an approach.

7. Approach toward the method for evaluating the applicability of AFS

This section describes the development of the selected method, starting with an explanation of the basic procedure and structure of the method. The supporting information is then presented by means of an example and the results are subsequently discussed.

7.1. Concept and structure of the method

The initial situation for the application of the developed method is as follows: A material is used for a specific component, which leads to disadvantages or defects that need to be optimized in the future. These disadvantages may be caused, for example, by the use of unsuitable materials (e.g., insufficient properties, changes in legal requirements) or by an unsuitable design. The chosen method of substitution evaluation focuses on the first aspect and checks the suitability of AFS as a substitute material via a systematic procedure. In order to verify the suitability, a table (see Table 2) is prepared with various criteria in the first column and the materials to be compared in the first row. Since AFS is the focus of the investigation, the set of criteria presented in Section 4.1 can be taken as a basis and eventually complemented by additional criteria. The individual cells of the table are pre-filled with points from 0 to 4 in such a way that the degree of fulfillment of the respective criterion is indicated for the corresponding material. For this purpose, it is necessary that the material characteristics and other properties are sufficiently known and automatically converted into the number of points in order to be able to compare the materials with each other. By adding the points together, a ranking of the materials can be determined at the end.

The designer (user of the method) receives the table and starts by specifying the materials to be compared (reference material and AFS), after which the requirements to be considered for the application can be checked off. The structure is similar to a checklist for identifying material requirements of a product (Collins et al., 2010), where the different questions can be answered with “yes”, “no” or “possibly”. For improved guidance, the individual requirements are divided into main groups (e.g., mechanical material characteristics, thermal properties) and questions are asked ranging from a rough to a fine level of detail. The marked criteria and the materials are then considered in the comparison table and the evaluation process can be started. This provides a rating in the form of a total score, thereby indicating which material is more suitable on the basis of the selected criteria. The table can also be used to show whether AFS is suitable in principle on the basis of the points achieved in percentage terms and according to a defined threshold value.

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7.2. Application of the method demonstrated by a case study

The approach developed for the method will be illustrated by an example application. In this context, an extendable step of a train (see Figure 3, left) has to be optimized by saving mass in order to reduce energy and wear costs. It must be examined whether the steps should be made of another material instead of the previous aluminum material – and whether AFS in particular is suitable for these steps.

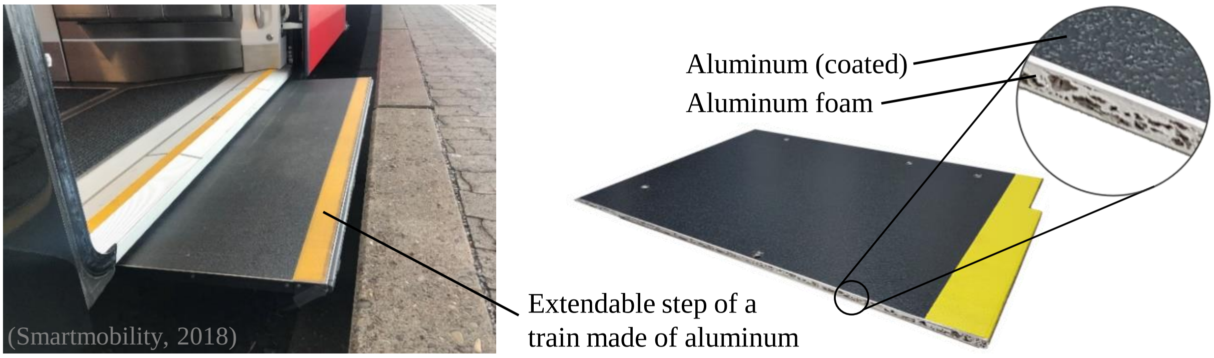

Figure 3. Potential use of AFS as an extendable step of a train

The table, an excerpt of which is shown in Table 2, is first pre-filled with the materials to be compared (in this case aluminum and AFS) and a selection of the criteria to be considered. Corresponding questions are answered with “yes”, such as whether moving masses are present, whether there is a bending load that demands an increased bending stiffness, and whether the application has to fulfill certain fire protection requirements. The point classification, which is available as a database, can be activated after this pre-selection phase and ranges from 0 points (not fulfilled) to 4 points (completely fulfilled). If necessary, the designer can change the points at their discretion or add and evaluate further requirements. After the selected requirements are filled in, the scoring can be completed and the individual point scores are added up so that a statement can be made about the benefit of changing the material. The result can be read in the last line of Table 2. For the present example, a rating of 24 points would be obtained for aluminum versus 27 points for AFS. Therefore, AFS is potentially suitable for the application and even offers certain advantages over this reference material, which was also validated by manufacturers of AFS. Thus, a first application of this step was prototyped (see Figure 3, right).

Table 2. Excerpt of a completed checklist for evaluating the applicability of the materials in the application example

0 = Not fulfilled 1 = Rather not fulfilled	2 = Partly fulfilled 3 = Rather fulfilled 4 = Fulfilled	Reference material	Substitute material
Relevant?	Application requirements	*Aluminum*	*Aluminum foam sandwich*
☒	High energy absorption capacity	2	4
☒	Low density	2	3
☒	High mechanical properties	3	2
☒	Good joinability	4	2
☐	Sound insulation	2	4
☒	Fire resistance	4	4
	Total	24	27

7.3. Discussion

The approach toward the method presented here can support designers in deciding whether or not AFS is a suitable material for a given application. One advantage is the simple and intuitive application that guides the designer through the process (*Usefulness* and *Comprehensibility*), while another is that no expert knowledge of the materials is required. The designer only needs to define requirements and materials in order to quickly obtain a result, since the questions and evaluations already exist. Of course, the user can add criteria and adapt the template accordingly. In addition, the designer is free to choose

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whether to compare only two materials or to evaluate several materials against each other (*Flexibility*). This method is a cost-effective solution compared to professional software, which is often expensive. In this way, the requirements defined in Section 5 are all fulfilled with the presented approach.

Since the application of such evaluation methods can lead to varying degrees of error in the result, the outcome should always be critically examined afterwards. Not only must the criteria to be defined be unambiguous, they must also be provided with accurate values. Should a comparison of points produce a result that is not significantly different, it is important to avoid drawing hasty conclusions – certain fluctuations are obvious due to the uncertainties in the points. If AFS's number of points is only 90% of the reference, for example, this does not necessarily mean that AFS is unsuitable and it is still worth reviewing the details. When finalizing the method, it is also important to consider whether it makes sense to weight the individual requirements or whether this might excessively influence the result.

The aforementioned disadvantage of possible fluctuations in the points means that the validity of the results must be verified in several studies. In contrast to detailed selection processes such as Ashby's (2005), which are of course more extensive and more precise, the method presented here does not make any claim to represent holistic material selection as it is based on limited data; the method should rather be understood as an initial assessment. Since costs cannot be considered to such an extent at the respective phase, the assessment must always be concluded by a separate cost-benefit analysis.

8. Conclusion and outlook

As aluminum foam sandwich is less familiar than other materials and therefore has a higher product risk, a selection method provides a helpful means of support. On the one hand, this need for a selection method arose from a survey; on the other hand, a method for selecting AFS is also necessary because AFS is both a material and a design method – and this combination is not sufficiently considered in previous selection methods. Due to data availability, a comprehensive material selection was not possible to date. The aim of this paper was to show how a designer can be supported in deciding whether AFS can be used appropriately instead of another material. For this purpose, different support options were presented and a promising approach was selected and described in more detail. The selected method is an evaluation table, which is a questionnaire in the form of a checklist and serves to assess which material is best suited based on requirements to be defined for the corresponding use case.

As this method must be fully developed and implemented in the future, it is necessary for the database to be reliably compiled with background information and the corresponding points in order to be able to make meaningful decisions. Questions in the catalog must be evaluated with regard to their meaningfulness and, if necessary, expanded so that the true goal of the method can be achieved. Furthermore, the threshold value, which indicates a material's suitability in principle, must also be investigated in the future. One option would be to analyze existing products in terms of the points they may achieve. Technical applicability and the interface must be realized accordingly to ensure the function of the digital method, which can be implemented as a web application. Finally, the method must be evaluated completely by numerous applications to assess its usefulness and applicability. In the future, this method should ensure that AFS is no longer excluded in the material selection. This could lead to an increasing use of AFS in the industry and thus to more reference applications, which in turn improve the design knowledge.

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