SUITABILITY ASSESSMENTS FOR COMPOSITE-METAL-HYBRID MATERIAL SYSTEMS FOR AUTOMOTIVE CRASH STRUCTURES

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Abstract

Current material selection methods significantly employ subjective user decisions and thus often lack the appropriate objectivity. The proposed methodology for suitability assessments for composite-metal-hybrid material systems in automotive crash structural applications is based solely on physical quantities to support and replace subjective aspects in decision-making. It analyses the structural loading from several crash load cases, such as frontal barrier crashes or pole side impacts, simultaneously using specifically defined suitability criteria. One is based on the anisotropy of loading and a second one comprises the global structural plastic deformation of all load cases. These criteria are then evaluated systematically in order to reach a transparent and reproducible process for suitability assessments for hybrid material systems in automotive structural applications. With the input from numerical crash simulations, experimental studies and the definition of applicable suitability criteria the methodology is an efficient and employable tool, which will support material selection processes providing a high level of method objectivity. Furthermore, the analysis and visualization of superimposed data for a multitude of crash load cases is a new approach to the assessment and reveals new aspects of structural loading. The methodology itself is expandable through the definition of new criteria and may be transferred to other functional domains or material spectrums.

1. Introduction and Current State of Research

Stringent EU-regulations for CO_2-emissions of vehicles [1] and growingly demanding crash safety requirements lead to an increased exploration of novel body-in-white (*BIW*) materials. Using hybrid material systems consisting of advanced composites and metals in automotive structures subjected to crash loads are one solution to benefit from significant weight saving potentials inherent to composites (carbon or glass fiber reinforced plastics, CFRPs or GFRPs) [2–4] and stable, well studied crashworthiness characteristics of metals at competitive costs. Furthermore, entirely new loading and damage mechanisms particularly characteristic to a hybrid material system ("hybrid mechanisms") might be identified and utilized in a respective structural application [5, 6]. As a matter of course, a profound knowledge about the materials' behavior and mechanisms as well as an understanding of the loading situation and mechanical performance requirements are necessary to successfully apply such new hybrid material systems in a vehicle structure.

A continuously growing diversification of *BIW*-materials [7] necessitates well-structured approaches in order to establish logical, transparent and reproducible processes of material selection in structural design. This decision making process can usually be formulated as a conversion of a set of input data (e.g. structural requirements) into a set of output data (e.g. relevant material systems and related manufacturing processes). In the majority of cases, there is a multitude of – maybe even contradicting - criteria to be considered.

A number of authors have proposed methods to solve such multicriteria selection problems in the domain of structural design and material selection. One example are the graphic representations of materials or material classes with respect to particular properties, as proposed by Ashby et al. [8, 9]. Theses charts and the introduction of "performance lines" help to identify materials that might suit a particular set of performance requirements in an application. The resulting set of materials is then narrowed down in a sequence of further selection steps with an increasing number of criteria, higher minimum threshold values or additional boundary conditions, as schematically depicted in Figure 1.

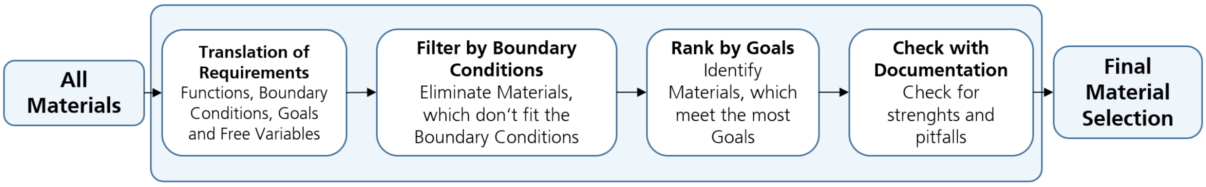

Figure 1. The four-leveled process of strategic material selection (reprod. from [8]).

Other authors, such as Chiner [10], Reuter [11], Farag [12] or Sahr [13] have proposed similar processes, with the latter putting a particular focus on multi-material solutions for automotive structural applications. The main shortcoming of these methods however, lies in the – partly intensive – inclusion of user or "expert" knowledge. This rather subjective component is mostly introduced at particularly sensitive steps in the process such as the definition of requirements or material properties. This generally leads to a significant reduction of objectivity and transparency of those methods.
Other approaches propose processes with higher levels of abstraction in order to increase transparency and to rule out subjective aspects in decision-making. Farag [14] has introduced the weighted properties method, which is an alternation of the classic benefit-analysis. Following equation (1) every material system is assigned a certain performance value N, which equals the sum of considered normalized properties P individually weighted with a factor α.

$$N_j = \sum_{i=1}^{n}\left(\alpha_i \cdot P_{ij}\right), \; \sum_{i=1}^{n}(\alpha_i) = 1 \tag{1}$$

Although this generally leads to a more transparent evaluation process, the values of the weighing factors again are chosen by the user depending on his assessment of the structural application. This means a strong limitation of the method objectivity and reproducibility. Saaty [15, 16] proposes a more comprehensive approach to a multicriteria decision making problem named the analytical hierarchy process (AHP). After defining a decision goal, the user designs a hierarchical structure which graphically depicts the goal, various criteria and subcriteria, alternatives (material systems) and their mutual relations, see Figure 2.

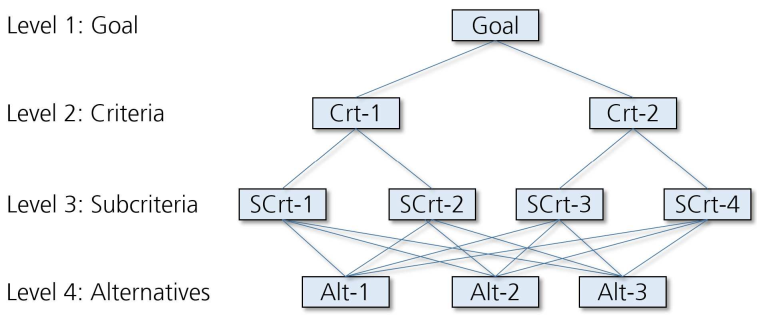

Figure 2. Schematic depiction of the different levels in the AHP (reprod. from [17]).

Based on pairwise comparisons, all elements in this structure are assigned certain priorities, which are then assembled into matrices. These are then mathematically processed and lead to a final prioritization of the alternatives. Next to a clear decomposition into rather simple sub-problems and a precise calculation of priorities, the method even provides metrics to assess the quality and inconsistencies of a decision. However, the overall process is relatively complex and the pairwise comparisons also mainly rely on subjective decisions taken by the user, which again results in a limited method objectivity in a real application [17, 18].
One important aspect to consider when checking for the suitability of advanced composite materials is their anisotropy. Their advantages with high specific material properties over conventional *BIW*-materials can only be exploited if the anisotropy is properly used in a structural application. This motivates a suitability analysis based on the structural loading using objective suitability criteria. One approach concerning the material anisotropy was proposed by Durst [19]. He calculates a component's loading anisotropy *K* over a multitude of crash load cases using finite element analysis and equation (2).

$$K_{\mathrm{Component}} = \frac{1}{n}\sum_{j=1}^{n} K_{\mathrm{Element,\,j}} = \frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{m}\left[a_{j,i}\cdot b_{j,i}\cdot g_{j,i}\right], \qquad (2)$$

Here, *a* is an anisotropy factor based on the relation of the absolute values of the principal stress in a finite shell element for a particular load case. *b* is an orientation factor describing the similarity of main loading directions in an element for the various load cases and *g* is a weighting factor for individual load cases based on their relative level of stress. *m* and *n* describe the number of load cases and elements in the component, respectively. This value of loading anisotropy *K* can then be used to quantify the component's suitability for the application of anisotropic FRPs. Although Durst's work is an important step towards suitability assessments using objective criteria based on the structure's physical loading situation, some major shortcomings inhibit a real application of his original method. These shortcomings mainly result from averaging element values while calculating the component's K-value and will be addressed at the respective parts in the main chapter of this paper.
The aims of this work can be derived from the methods described above and can be stated as follows:

- A transparent methodology for reproducible suitability assessments for hybrid composite-metal-material systems in automotive structural applications
- Objective and physically based suitability criteria
- A simultaneous consideration of multiple crash load cases from FEM simulations
- Integration into an expandable and transferrable framework for general material selection

2. Methodology Framework

This chapter describes the overall framework with its logical flow of information and its technical implementation using *Python scripting*.

2.1. Overview

As in most established methods or processes, the center core of a suitability assessment lies in the comparison (conversion) between requirements or "loading profiles" of the relevant structures and the property profiles of the available material systems (Mat). This is represented by the "systematic evaluation"-step at the bottom of the schematic depiction of the methodology framework in Figure 3. The critical part of this step are the suitability criteria (C), which can be considered as communication channels and may have to be defined with respect to the load cases and material systems of the specific task. The framework has three major inputs: The result files from full vehicle crash FE-simulations of the relevant load cases, results from experimental investigations and characterizations with the material systems and the respective suitability criteria. These inputs are obviously connected through mutual relationships, which refer to the load cases and type of structural performance considered.

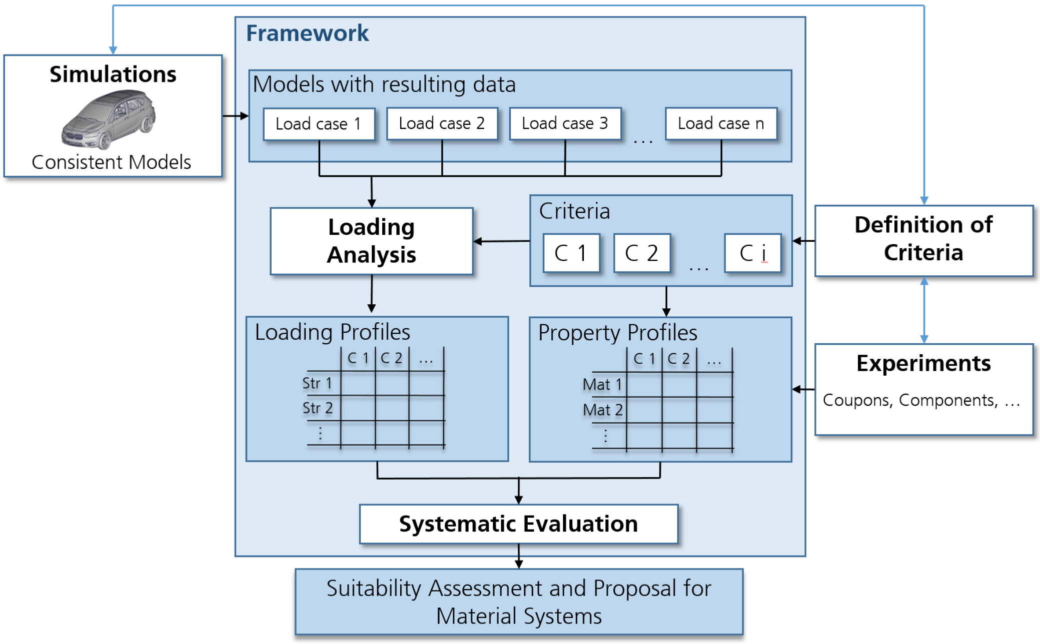

Figure 3. Schematic depiction of the methodology framework and the flow of information.

The main loading analysis can be performed using the simulation data and the suitability criteria. This results in in loading profiles for the structural applications (Str) considered, which in turn can then be compared to property profiles resulting from the experimental data. The systematic evaluation in the first step ensures a reproducible process of decision making in order to reach final suitability assessments and proposals of material systems. Of course, the quality of this comparison is mainly dictated by the quality of the defined criteria and their implantation in the loading analysis.

2.1. Technical Implementation and Visualization

As stated above, the loading profile of an automotive structure as used here is based on physical data stored in full vehicle FE-simulation models. The software used to model and run the full vehicle crash simulation is *Abaqus/Explicit* by *Simulia* (*Dassault Systèmes*). The simulation of each load case yields one result file called output database file (.odb-file), which contains the model geometry and all requested field and history outputs such as the stress or strain information. These .odb-files can be accessed and modified using *Python* scripts. The information flow while superimposing the relevant load cases for a loading profile is schematically depicted in Figure 4.

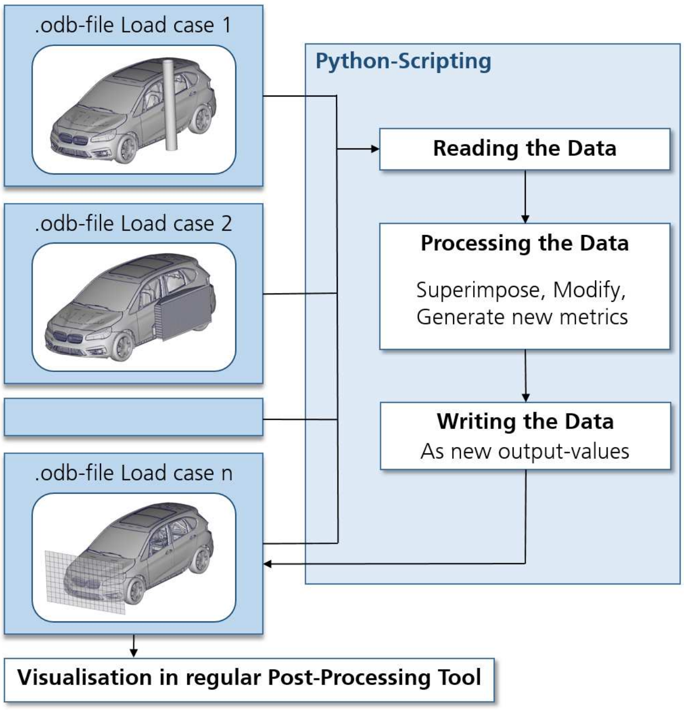

Figure 4. Schematic depiction of the technical workflow of the loading analysis.

All .odb-files are consecutively accessed by *Python scripting* for the relevant data to be read and extracted. The data of all load cases is then temporarily stored and processed in the *Python* script before being written back into one of the .odb-files as new outputs which in turn can then be conveniently visualized using common post-processing software, such as the *Abaqus Viewer* [20].

3. Suitability Criteria

As derived earlier, the suitability criteria are essential to the quality of the entire methodology and must be defined according to the considered functional performance of the structure (e.g. energy absorption) and the material systems available. In the following sections, two criteria for the application of hybrid composite-metal material systems in automotive crash structures will be proposed in detail and further criteria will be briefly introduced.

3.1. Loading Anisotropy

The definition of the new anisotropy criterion follows the basic concept of Durst's method of using the loading anisotropy as a suitability criterion for FRPs and will be introduced with reference to the respective formulations, where applicable. Loading anisotropy is present, when there is a predominant direction of force, strain or stress in the element. The classic approach to determine loading anisotropy is based on evaluating the principal stresses and their relative magnitude. Using the principal stresses is particularly interesting in combination with FRPs since the principal directions may then be used as primary directions of fiber orientation since they are free of shear stresses, which have a diminishing effect on the composite material's performance.
After computing the principal stresses (σ_1, σ_2) and their directions in a plane state of stress (shell elements) following traditional continuum mechanics theory (e.g. Gross [21]), one can quantify the level of anisotropy by relating their absolute values using equation (3).

$$PSF = \frac{max\ (|\sigma_1|,|\sigma_2|) - min\ (|\sigma_1|,|\sigma_2|)}{max\ (|\sigma_1|,|\sigma_2|)} \tag{3}$$

In contrast to Durst's formulation, the new principal stress factor *PSF* has a linear relation to the absolute magnitudes of the principal stresses, which allows for a more intuitive conclusion to the real state of stress and its direct representation in the *PSF*-value. The difference is depicted in Figure 5, where the PSF is plotted over the normalized principal stresses σ_1 and σ_2.

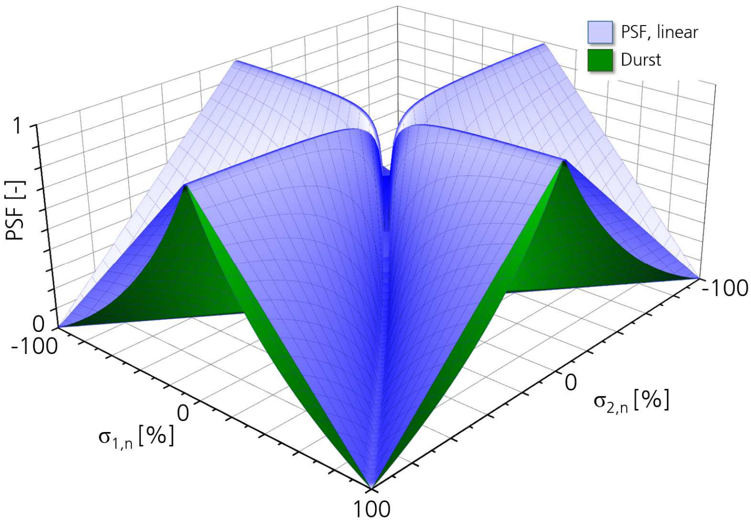

Figure 5. Principal stress factor PSF over normalized principal stresses in a shell element compared to Durst's anisotropy value.

Further significant advances have been achieved when superimposing load cases for a global loading anisotropy quantification. The new approach does not consider every single load case individually to calculate a predominant direction and absolute state of stress, which are then averaged arithmetically over all load cases to get the orientation factor *b* and are transformed into weighing factors *g*, respectively. Here, the direct addition of the plane stress tensors reduces the number and complexity of mathematical operations, makes any weighting factor obsolete and yields a significantly more reliable computation of a resulting predominant loading direction than using the arithmetic mean. This is schematically depicted in Figure 6, where three load cases with principal loading angles of 0°, 90°, and 10° are considered.

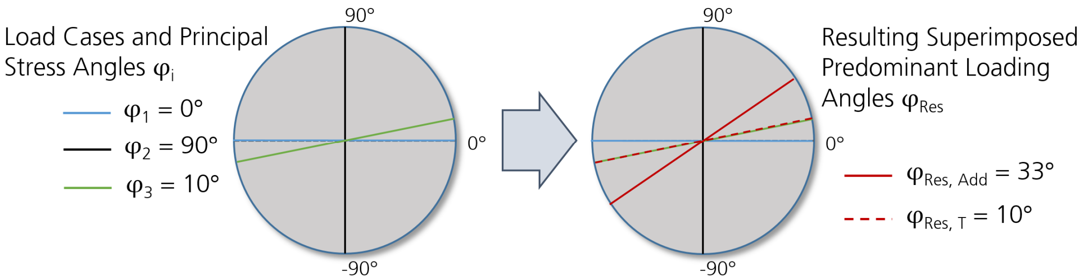

Figure 6. Comparison of the resulting loading directions for superimposed load cases from computing the arithmetic mean and from applying the proposed tensor addition technique.

Computing the arithmetic mean will result in an angle of 33°, which does not represent the desired value. Since the first two load cases share a 90° angle, their principal coordinate system is not defined and thus they have no resulting predominant direction. It is merely defined through the third load case with an angle of 10°, which is exactly the result of the tensor addition method.
In order to avoid a mutual elimination of tensile and pressure loads, we transform the stress tensors into their principal coordinate systems and calculate the absolute values of the principal stresses in the tensors' traces. After back-transforming, the tensors and adding them up, the principal stresses are calculated from the resulting superimposed tensor. It is noted that – in accordance to a wide agreement (see e.g. Meng [22], Cheng and Kikuchi [23] and Ihle [24] for hybrid systems) – there is no

differentiation between tensile and pressure loads in the elastic regime when computing principal stresses.

The most relevant enhancements however, have been achieved in computing a component anisotropy metric. Obviously, the user will lose information when integrating element values to component values due to the reduction of spatial information resolution, but - particularly on full vehicle level - it can be quite useful to identify components with a single overall metric. Where Durst again uses the arithmetic mean of the element values to calculate a component value – irrespective of the single elements resulting predominant loading direction - the authors propose a new uniformity index, which quantifies the level of uniformity of the individual elements' resulting loading directions with respect to one global direction. The left graphic in Figure 7 emphasizes the need for a component-wide uniformity index showing an elementwise plot of the *PSF* in a doorsill section with resulting predominant loading directions. It can be seen, that simply computing an arithmetic mean cannot account for the local distribution of loading directions and their overall level of uniformity.

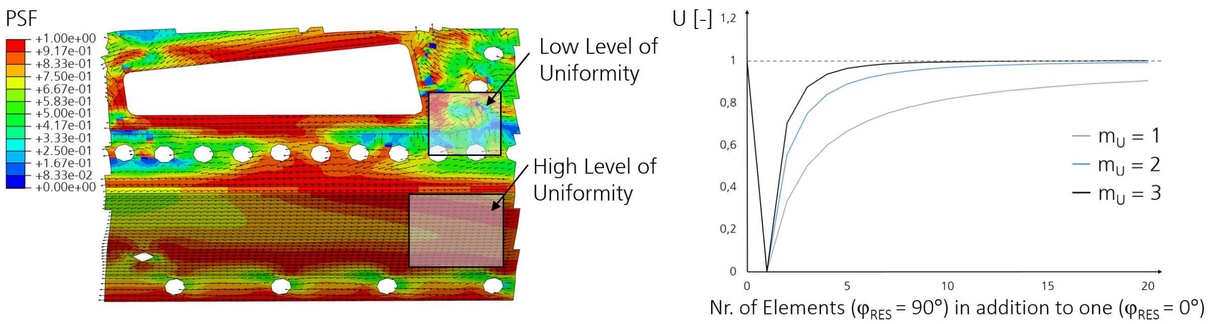

Figure 7. Elementwise plot of the *PSF* in a door sill section with resulting predominant loading directions showing areas of high and low levels of directional uniformity (left) and effect of the exponent m_U on the convergence of the uniformity index *U* with respect to the distribution of local resulting loading directions (right).

For a component consisting of n_E elements with their individual resulting loading directions $\varphi_{\mathrm{RES,\,i}}$ the uniformity index *U* can be calculated using the following equation

$$U = \max_{0° \leq \alpha_{REF} < 180°} \left[1 - \left(\frac{\sum_{i=1}^{n_E} |\alpha_{\mathrm{REF}} - \varphi_{\mathrm{RES,i}}|}{45° \cdot n_E} \right)^{m_U} \right], \quad (4)$$

where a global reference angle α_{REF} between 0° and 180° is defined, which minimizes the normalized sum of deviations in the single elements and thus maximizes the value of *U*. As depicted in the right graph of Figure 7, the exponent m_U allows the user to adjust the level of convergence of *U* towards its maximum value of 1– or sensitivity - with an increasing uniformity of loading directions in the component. This can be used to account for varying numbers of elements or component sizes.

Since both metrics the *PSF* and *U* are essential to a component's overall suitability for the application of composite materials the component's anisotropy index *AnIso* is calculated using equation (5).

$$AnIso = \frac{\sum_{i=1}^{n_E} PSF_i}{n_E} \cdot U(\alpha_{REF}) \quad (5)$$

The value range of *AnIso* lies – just as the ones for the *PSF* and *U* – between 0 and 1 and accounts for the anisotropy of loading in the individual elements and the uniformity of resulting loading directions over the entire component and can thus be considered an index for the suitability of composite-intensive or rather metal-intensive hybrid material systems. With the works of Volk [25], it can also be used to calculate the layup and the cross-sectional share of FRP within a hybrid system.

A visualization of both the *PSF* and the *AnIso* for a section of the automotive *BIW* based on the superposition of a frontal barrier crash and a pole side impact is shown in Figure 8.

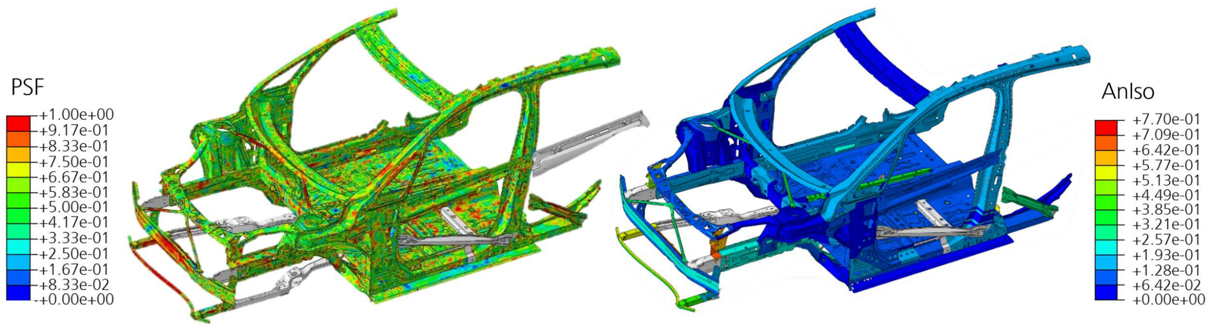

Figure 8. Plot of the element-wise *PSF* (left) and the component-wise *AnIso* (right) for a section of the automotive *BIW* based on the superposition of a full overlap frontal barrier crash and a pole side impact.

The comparison in Figure 8 shows, that the identification of components is much simpler using the component-wise plot of the *AnIso*-metric with a lower level of information density. However, looking at the PSF of single components we can also see, that the distribution of anisotropy can be strongly heterogeneous, which might be important for further design and material selection decisions. Furthermore, it is obvious that struts and structural members feature higher *AnIso*-values than, say, rather planar sheet components, which indicates their functional role as classic load path structures.

3.1. Plastic Deformation and Energy Absorption

For working with crash structural applications, the level of plastic deformation of a component may indicate its role in energy absorption for the crash management of the vehicle. For conventional *BIW*-materials, the level of plastic deformation is directly linked to the energy absorbed through deformation work, local metal plastification and adiabatic heating. On the other hand, the hybrid material systems investigated by the authors mainly feature significantly higher specific energy absorption values than conventional *BIW*-materials, which makes the energy absorption a second suitability criterion.
The simulation output data used to assess the plastic deformation is an "equivalent plastic strain" labelled *PEEQ* in the *Abaqus Analysis User's Guide* [26], which is a scalar equivalent variable for the plastic share in the total state of strain (analogous to the von Mises-stress). *PEEQMAX* is a variable containing the maximum *PEEQ*-value of all integration points in a shell-element. This variable is read for the considered structures and load cases in the last time frame and the largest value of all k load cases is written back as a new output PDE_{Res} into the element, as stated in equation (6).

$$PDE_{Res} = max\ (\ PEEQMAX_1, \dots , PEEQMAX_k\ ) \tag{6}$$

As derived for the anisotropy criterion it may be helpful to reduce the information density in order to identify relevant structures on a full vehicle level. The component-wide index for the plastic deformation PDB_{Res} is calculated from the element index PDE_{Res} as follows:

$$PDB_{Res} = \frac{\sum_{i=1}^{n_E} PDE_{Res,\, i}}{n_E}. \tag{7}$$

The PDB_{Res} index thus equals the arithmetic mean of all n_E elements in a component. Plots of both indices are shown in Figure 9 for a *BIW* and two frontal crash load cases - one with 40% and the other with 100% overlap with the deformable barrier.
Based on the visualizations in Figure 9, it is possible to identify areas of significant plastic deformation, such as structural hinges in folding members or designated energy absorption structures such as the crash boxes in the front. Just as seen for the anisotropy visualization, the component-wise resolution helps to identify relevant components more easily.

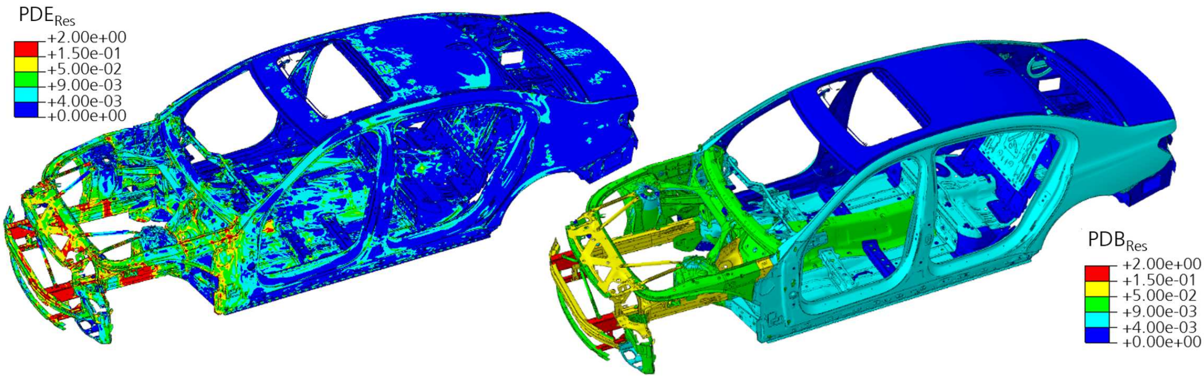

Figure 9. Plot of the element-wise PDE_{Res} (left) and the component-wise PDB_{Res} (right) indices for the superimposed maximum plastic deformation for two frontal crash load cases with different overlap.

However – maybe even more strikingly – it is obvious, that the lower information on the right resolution might lead to misinterpretations and must be complemented by the element-wise depiction. Particularly the vehicle side frame shows an extremely heterogeneous distribution of plastic deformation, which must be considered when taking design and material application decisions.

3.1. Further Criteria

In order to support the material selection process based on the two criteria presented and to demonstrate the methodology's flexibility and expandability, the following criteria, which are not limited to hybrid material systems or crash applications, are introduced.
A major shortcoming of the methods discussed in chapter 1 is the extensive use of subjective user knowledge. This is particularly true when qualifying the loading type (axial compression or bending) of a structure (see Sahr [13] or Kellner [27]). Especially for crash applications, this distinction is of major importance for structural design and material selection, since this usually also implies an entirely different set of functional requirements. The approach to base this decision on clear mechanical indicators takes into account the states of stress on the upside and the downside of a finite shell element. Based on the relationships of first principal stresses on the upside $\sigma_{1,u}$ and downside $\sigma_{1,d}$, as schematically depicted in Figure 10, it is possible to calculate a ratio bending load R_B following equation (8)

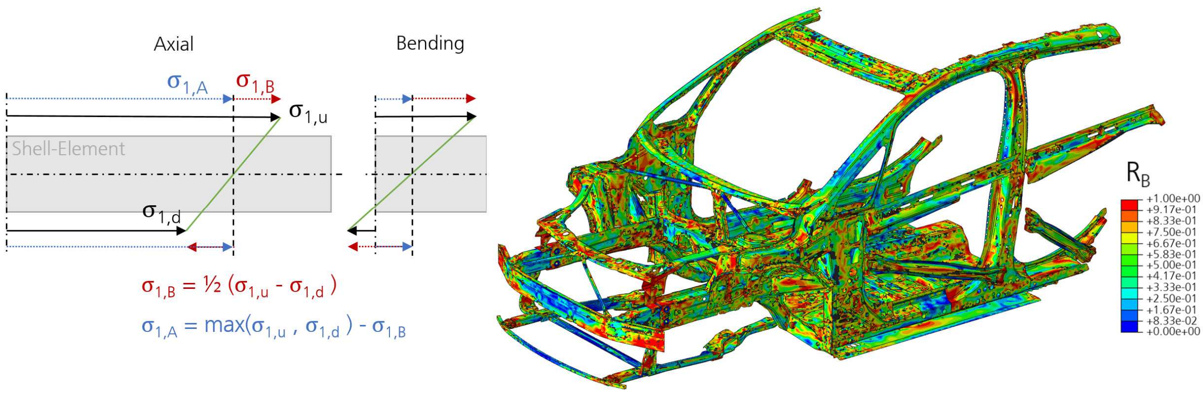

Figure 10. Relation of the first principal stresses on the upside and downside of shell element for a rather axially an rather transversely loaded case (left) and the evaluation of the ratio of bending load R_B in the *BIW* for a frontal barrier crash with 40 % overlap (right).

$$R_B = \frac{\sigma_{1,B}+\sigma_{2,B}}{\sigma_{1,A}+\sigma_{2,A}+\sigma_{1,B}+\sigma_{2,B}}, \quad (8)$$

where $\sigma_{i,A}$ and $\sigma_{i,B}$ are the axial (*A*, tension and compression) and bending (*B*) shares of stress, respectively. These result from the comparison of both principal stresses ($i = 1$ and $i = 2$) on the upside (*u*) and the downside (*d*) of the shell element. One precondition is a satisfactory co-alignment of the principal directions on the upside and downside, which is met in a vast majority of elements of the models studied (grey elements in right picture of Figure 10). The same picture also shows, that struts and load path structures exhibit a rather low share of bending load. On the other hand, one can see, that a typical bending member, such as the frontal lateral member, also features quite low bending shares in the component center. This adds value to the analysis and is in accordance with the user's expectations, but also points out a characteristic challenge: the differentiation between local and "global" or component variables. The loading type of a component – or its stiffness(es) as another example – is impossible to assess with local element-type variables only. The additional consideration of global characteristics, such as component axes or particular types of distribution of values, can enhance these analyses and help to expand the presented methodology.
As a further criterion the position of a structural application in the vehicle's *BIW* can be linked to two important functional aspects. The structural integrity requirements is the first one and particularly relevant for a structure's crash functionality. In order to provide a safe survival space in a crash the passenger compartment needs to fulfill several requirements, one of which concerns the integrity of the surrounding structural components in order to ensure safety in subsequent collisions and to avoid sharp edges. Since there are major differences in the failure behavior of materials – particularly of CFRP- and GFRP-hybrids – and the resulting structural integrity, the proximity to the passenger compartment can be used as a suitability criterion for the hybrid material systems studied. A second functional aspect refers to costs. As depicted in Figure 11, in order to reach a balanced weight distribution in the vehicle (e.g. low and central center of gravity), there is a characteristic distribution of the efficiency of lightweight design measure and the corresponding cost tolerance limit.

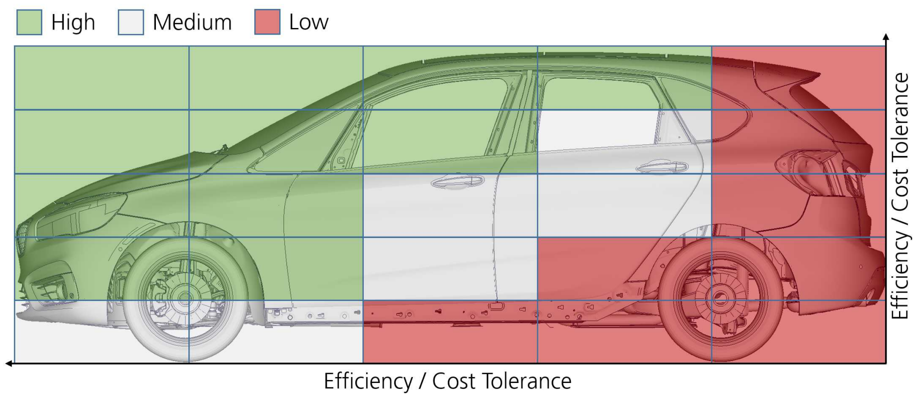

Figure 11. Qualitative distribution of the efficiency of lightweight design measures and related cost tolerance along the longitudinal and vertical axes of a vehicle with a front engine (reprod. from [28]).

Since there are significant differences in the cost specific performance of CFRP- and GFRP-hybrids, the position of a structural application can indicate the suitability based on the cost tolerance. It might thus be functionally and economically correct to apply a CFRP-hybrid in a roof structure, whereas a doorsill might better be designed using a rather low-priced GFRP-hybrid.
Additional criteria to extend the method might also refer to manufacturing processes and incorporate the geometric complexity or to surface quality requirements, for example.

4. Systematic Evaluation Process

In order to evaluate the presented criteria to reach a suitability assessment for a material system or a proposal for a certain structural application, a systematic process needs to be defined, which ensures both transparency and reproducibility. It is noted, that this process is directly linked to the structures, functionalities, material systems and thus also the criteria considered. This means, that it must be designed accordingly and that the version presented here, may only apply to the boundary conditions of this project. The base structure of the process is derived from the characteristic mechanical behavior of the composite-metal-hybrid material systems studied in a tensile test. It is composed of four characteristic sections as depicted in Figure 12 and was previously discussed by the authors in Dlugosch et al. [29, 30].

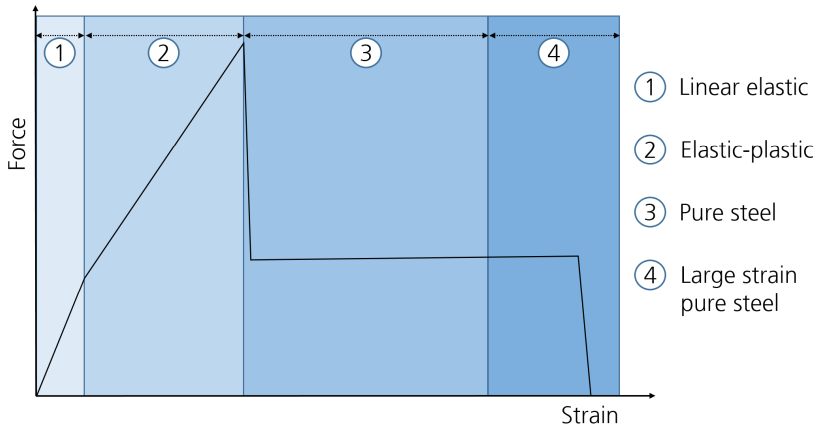

Figure 12. Schematic depiction of the force-strain-behavior of composite-metal-hybrid material systems in a tensile test.

After the first section, the steel phase starts to yield causing the kink in the curve at the transition to the "elastic-plastic" regime, where the FRP-phase deforms elastically until complete failure at the end of section two. Subsequently, the steel phase undergoes a section of moderate plastic deformation and a section of large plastic strains until necking and failure. The same regions are found in the structure of the systematic evaluation procedure depicted in Figure 13.

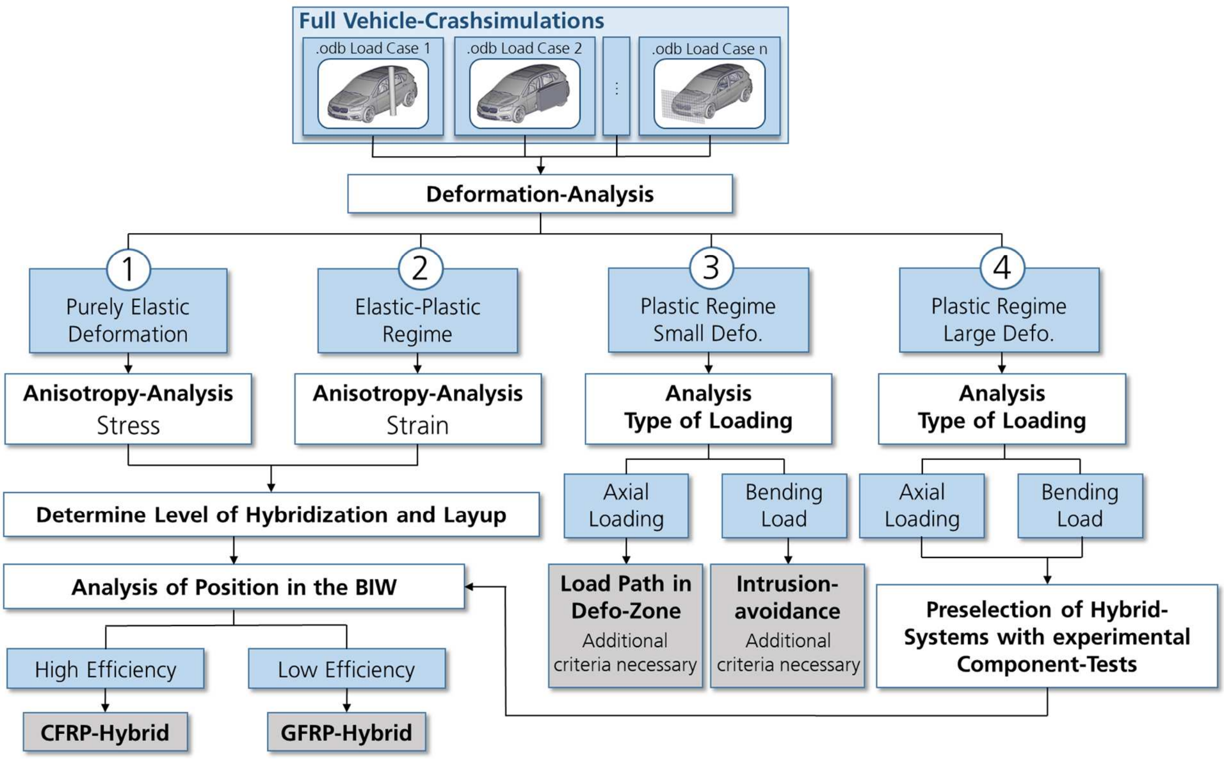

Figure 13. Systematic evaluation process to assess the suitability of composite-metal-hybrid materials systems based on the criteria proposed.

Based on the level of deformation or strain four paths referring to the sections in the material systems's behavior are defined in the process. If a critical amount of elements stays in the elastic regime, an anisotropy analysis based on the principal stresses leads to the determination of the level of hybridization and the FRP-layup (as described in Volk [25]). Taking into account the position of structure in the BIW, the process will result in an efficiency evaluation of the measure leading to a decision for a rather CFRP- or GFRP-hybrid solution. In the second path, a critical amount of elements has reached the plastic deformation regime. In this case, there is no distinct relation between stress and strain, which causes the shift to the analysis based on strain values. This works analogous to the otherwise more reliable analysis based on the stresses [23]. Mainly load path structures are expected to lie within the evaluation paths one and two. The third path comprises structures, which feature a significant amount of plastic deformation but cannot be qualified as classical energy absorbing structures. Since the defined criteria do not allow for a clear decision on the respective structures' functional role, further criteria are necessary to fully assess material system's suitability. Structures undergoing a massive plastic deformation lie within path four and can be considered classical energy absorbing structures. After evaluating the type of loading, the results from the respective experimental studies help to define a preselection of suitable material systems. Another efficiency or structural integrity evaluation will then lead to a final proposal.
As stated above, the proposed systematic evaluation process is strongly dependent on the case of application and must be considered a first draft with several possibilities for extensions, adjustments and improvements. Particularly the definition of thresholds between the decision branches need to be defined through continued application reasonable judgement with a clear documentation.

5. Conclusions and Outlook

The proposed new methodology with its criteria and systematic evaluation allows for suitability analyses of composite-metal-hybrid material systems in automotive crash structural applications based on clear physical quantities without taking into account subjective user decisions. The flexible and transferrable framework is realized using *Python scripting* and can analyze 70 % of a modern *BIW*-FE-model (ca. 800000 elements) for two crash load cases in 15 minutes on a regular desktop pc. The new anisotropy criterion is a significant enhancement to Durst's original idea regarding several essential aspects. The analysis and visualization of superimposed plastic deformation data for a multitude of crash load cases resembles a new approach to the assessment and reveals new aspects of structural loading and further criteria indicated the possibilities to enhance and expand the proposed methodology.
Clearly, the general idea of loading analysis in order to take design decisions bears the risk of circular reasoning. However, this method is meant as first step and assisting tool in the transition from conventional *BIW*-materials towards novel material systems and keeping the latter risk in mind will help to avoid incorrect decisions. Furthermore, this methodology could be used as an input to optimization processes in structural design and material selection when closing the feedback loop.

Ongoing work focusses on the enhanced analysis of characteristic profiles loading of criteria for particular structural roles in the automotive crash management. The reliable, automated identification of structural roles could bring new insights into classical vehicle body design for passive safety. Furthermore, it could enable the transition to entirely new structural concepts for alternatively propulsed or autonomously driving vehicles.

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