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Lightweight components for light electric vehicles based on textile exterior

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Summary

Most important requirements for light electric vehicles are a small size and low weight. Regarding the market implementation, the urban environment provides the highest usage potential for this vehicle class. With respect to weight saving measures, textiles as exterior material of light electric vehicles offer a promising approach. This paper clarifies the definition of requirements and explains the identification of appropriate textiles through a market analysis as well as how to evaluate them. The construction of a demonstrator allowed several tests under real conditions and additionally served the identification of suitable textiles for the use in vehicle exterior.

Keywords: materials, light vehicles, research, sustainability

1 Introduction

The vehicle industry is on the threshold of the greatest change in history. The megatrend of electric mobility takes hold in vehicle development and spreads rapidly. [1] This shift from a combustion to an electric engine provides the opportunity of adjusted as well as novel mobility concepts, such as micro mobility. Due to restrictions related to particular matter, traffic congestion and the lack of sufficient parking space, the urban and suburban areas are enhancing the attractiveness of using light electric vehicles (LEV), such as the Renault Twizy. [2] Even the first and last mile issue involves this kind of vehicle class. [3] However, the problem regarding the weight of batteries is not only affecting electric passenger cars but also vehicles within this small size. Even the most advanced versions of battery cells come with high weight and packing size. Combatting this issue, light electric vehicles enable the reduction of the entire vehicle weight to a reasonable level. LEVs, which are reaching a maximum speed up to 80 km/h and are mainly designed for urban and suburban areas, are intended for recent concepts in lightweight without forfeiting tremendous levels of passenger safety. This research project focusses on the usage of fabrics in the area of vehicle exterior as a lightweight application. Therefore, appropriate textiles replace materials as sheet metal and plastic cladding. The chassis entails wide potential for possible savings, as it covers 35% to 45% of the entire vehicle weight of common cars. [4] Furthermore, an appropriate substructure offers the advantage of individual adjusting of textile coating to the vehicle design. Through the large variability, textiles do not only differ in color, but also regarding technical characteristics, handling and maintenance. As the market shows great variety of textiles being suitable for diverse applications, this research paper aims to identify fabrics that qualify for the usage in exterior of electric lightweight vehicles. The determination of such textiles is realized with the help of evaluating as well as weighting methods.

Fabrics are primary known from the area of the textile industry. The field of application of technical textiles has developed beyond and leads from agricultural or construction technic even to medical engineering. When it comes to vehicle construction, fabrics are generally used in the area of interior. However, EDAG Light Cocoon emphasized the potential to utilize textiles for vehicle exterior as well. [5] Although the showcar demonstrated the opportunity of using it as a lightweight component in vehicle exterior, it does not succumb with any application-orientated requirements. Thereby the focus does not lie on roof areas of convertibles, but concentrates on the front, rear and lateral faces of vehicles. There is still a research gap regarding the examination of the technical fabrics use in the area of vehicle exterior, although it provides a high potential. Those fabrics underlie different mechanical as well as weather-related influences. Moreover, the requirements for the textile usage in automotive applications are significantly higher. Due to that, this study developed a suitable method identifying appropriate fabrics in the area of exterior of lightweight vehicles.

2 Method to evaluate the usage of textiles in vehicle exterior

The methodological approach contains several stages related within a multiphase process (**Fehler! Verweisquelle konnte nicht gefunden werden.**). As an initial step follows the definition of the requirements that are necessary for the textile implementation. All framework conditions, influences and specifications are transferred into requirement characteristics. Thereby, differentiation is made between fixed and desired requirements. Subsequently, the defined specifications are collected within a requirement list. In order to gain an overview about the variety of available textiles, a market research analysis follows as a second step. Having a comprehensive understanding of all the existing types of textiles as well as their individual specifications plays a major role. The identification of appropriate textile starts with defining a search field in order to simplify a structured searching process. The evaluation of the identified fabrics is conducted with the help of the cost-benefit analysis. Subsequently, those requirements defined in the first process step are aggregated into evaluation criteria. The characteristics are determined in the form of a valuation list and submitted to a weighting by means of the method of pair-by-pair comparison. After the weighting follows the actual evaluation of the criteria within a rating matrix. Doing so, the individual fabrics are evaluated based on the assessment criteria as well as the weighting. As a final step of the third methodological stage follows a sensitive analysis in order to examine the robustness of the demonstrated cost-benefit analysis. This procedure analyses fluctuations within single input values and its influences on the result. An extensive number of textiles is running this valuation process, which results in the final selection of respective textiles. Only the four best-evaluated fabrics qualify for a test under approximately real life conditions. In order to provide as realistic vehicle conditions as possible, the tests were gathered with the help of a demonstrator.

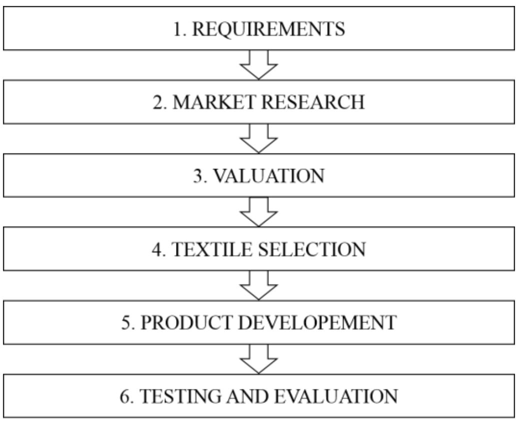

Figure 1: Methodology of the project

This was built in the style of a light electric vehicle as this category offers the highest potential for exterior textile usage. A Renault Twizy was used as demonstrator with the plastic doors being replaced by the implementation of textile components. The modification of the light electric vehicle was supported by the method of the morphological box and the systematic product development (VDI 2221). [6] As soon as the demonstrator construction was accomplished, real-time tests were gathered. Especially long-term testing in a wind tunnel provided further insights regarding the textile usage in vehicles. Figure 1 offers a short summary over the multiphase process.

2.1 Requirement definition

In order to develop a demonstrator analysing the potential of respective textiles for the usage in vehicle exterior, it is highly important to understand what kind of requirements the fabrics need to meet. This aspect especially matters in the area of the automotive industry as the usage of textile is still something rather unexplored and therefore should be sensibly defined. By defining requirement framework conditions, factors like weather influences, legislation and authorization (crash and safety) as well as restrictions need to be taken into account. As already mentioned, the specifications are collected and documented in a requirement list. It contains several areas enabling a specific documentation of the requirements. The areas are described by the following dimensions:

- description of requirement
- characteristic of requirement
- type of requirement
- priority of requirement.

In order to provide a common understanding and limit space for interpretation, the description of the requirements needs to be phrased as clear and comprehensive as possible. Considering the dimension of the requirements' characteristic, it also needs to be clarified that they can show a qualitative as well as quantitative character. At best case, the requirements are defined through quantitative values such as number, size or other measurable variables. The dimension of the requirements' type differs from functional requirements, general conditions as well as non-functional requirements. Functional requirements focus on the description of features the textile should demonstrate. The requirements' prioritization according to its importance as well as determined or desired character follows as a last step. While desired requirements of a textile are rather optional, determined specifics need to be fulfilled, otherwise it won't be considered in any of the following steps. [7]

The creation of the requirements is a very important aspect and needs to follow a clear structure. A common procedure is the scenario technique, which helps to define certain requirements within all product areas by analysing various scenarios of the product-life-cycle. Those scenarios cover positive functions, such as product functionality, as well as negative aspects focussing for example on safety issues and failure. Proven W-Questions (What, who, where, when, what for and how) help to identify important use-cases for the vehicle exterior textile usage. This particular case shows special relevance regarding human-product-requirements. Thereby, individual feelings, views, the touch as well as smell has to be considered. By applying the scenario technique, relevant requirements are identified and collected in the final requirement list already mentioned. Figure 2 provides a review regarding the methodological procedure for the development of the requirement list. [8]

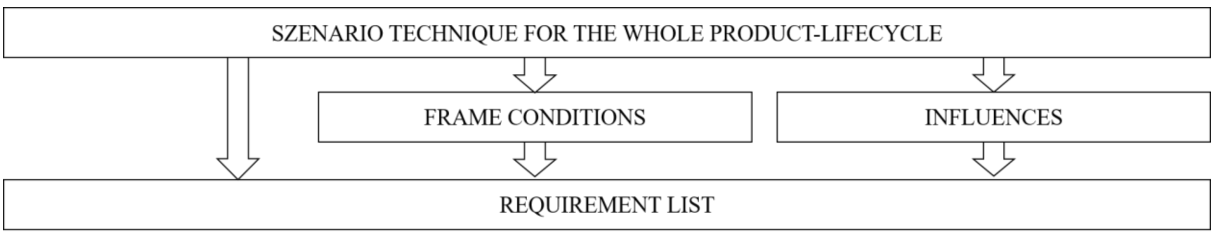

Figure 2: Methodology for developing requirement list

2.2 Market research

After having defined, described and collected all relevant requirements that need to be fulfilled by the fabrics, the actual task of identifying suitable textiles begins. In order to pursue a structured process, the method of semantic-based search is used. As a first step follows the definition of respective search and application fields, e.g. research only focusses on textiles that are applicable for outdoor usage and are already implemented in the market. Analogical to innovation management, search fields enable focussing on specific information, which are also needed for later valuation. [9] Within this study, the search fields are represented by the different application areas of textiles, with outdoor usage being most important search field. In order to narrow the search field as well as provide better results, the main-search field is divided into several sub-search fields. This division increases the chance of identifying comparable approaches as well as already gathered information regarding the external textile usage in the automotive industry. As the construction of the search field highly depends on the search term, a semantic based search is conducted in order to identify suitable results regarding the textiles. Within this methodological technique, the focus lies clearly on the search term. From a linguistic point of view, semantic describes the education of importance and meaning of the language. [10] Ontology-creation as well as –search enables the semantic search in order to identify relevant information, structure the data and emphasizes their correlations. The internet provides a huge choice of semantic search engines, however, search engines usually generate limited satisfactory results as they usually work with structured data provided by public lexical resources. Because of this reason, unstructured ontological knowledge cannot be understood or found and consequently a semantic-based search was performed. During the search request, search terms as well as recordings of the associated ontological facts are analysed more detailed. Within this paper, the semantic search is realized as a manually detection of ontologically related search terms. The semantic based search request, based on ontologically related search terms, is applied on structured and non-structured data sources. Sources for structured data is represented through a textile data base, whereas the non-structured data is provided by a web-based content analysis of publications. The market analysis results in the identification of textiles with high levels of information density. Figure 3 shows the methodology of the market research step.

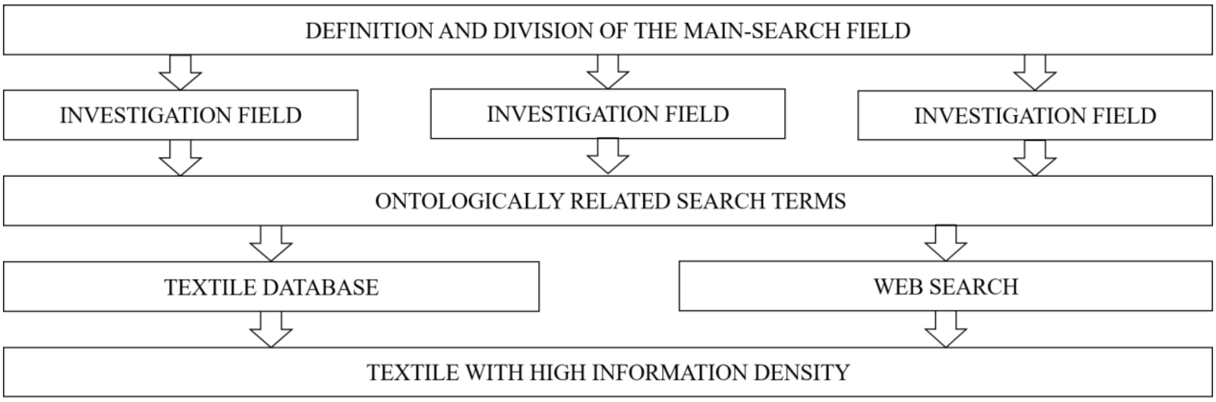

Figure 3: Methodology of the market research

2.3 Textile evaluation

Subsequently, prior results of the requirements' definition process as well as the semantic search for appropriate textiles need to be evaluated. Regarding the evaluation process, only textiles that are meeting the predefined requirements are taken into account, whereas fabrics that are failing the requests are not further considered. Within this step, a methodological approach inspired by the VDI 2225-3 was used for the technical evaluation. [11] The approach's most dominant advantage lies in the description of evaluation criteria based on indicators. Those indicators are also able to consider more than one function of respective textiles. Basis of this approach forms the further developed requirement list, whereas the evaluation criteria is based only on desired requirements that are fulfilled by the textile. It is highly important to take all of the desired requirements into account, as each textile property has to assign to one of the evaluation criteria. If several requirements show the same evaluation criteria, they can be summarized to a higher level. The following example should increase the understanding: the requirements *high variety of colours* and *high quality appearance* can be summarized within the evaluation criteria *Optics.*

The next section pays attention to the rating scale used within the evaluation process. The scale identified to what extend the respective textile property fulfils the evaluation criteria. Depending on the type of property the criteria is either demonstrated through quantitative or qualitative aspects. E.g. applying the scale to the requirement *high variety of colours,* the rating starts with the option of *one colour,* continues with *two colours* and so forth, finally resulting with the last option *four or more colours*. Each of those options refers to fixed p_n values (e.g. *one colour=1*, *two colours=2,* and so on.). The VDI 2225-3 recommends using a scale with five point values with a high value representing a high degree of fulfilment. Within this paper, the value *four* demonstrates the best degree of fulfilment (4 = *very good*), value *three* indicates a good fit (3 = *good),* value two describes a sufficient level of fulfilment (2 = *sufficient)* whereas value *one* reveals a barely reached level of fulfilment (1 = *barely achieved).* The value *zero* was used when the textile did not meet the evaluation criteria at all. If multiple textile properties could be assigned to a rating criterion, every single property had to be ranked on the scale. The ranking concludes in a total score of certain textile properties, which was calculated through the arithmetic mean for equally large meaning proportions.

Before finishing the valuation process, the evaluation criteria has to be weighted which works best by using the paired-comparison. Each evaluation criteria is transferred into a matrix and each row is compared with each column, which leads to the direct comparison of each evaluation. The following instructions are important when using the paired-comparison method:

- Each evaluation criterion is compared with every other evaluation criterion in direct comparison from line to column
- If the evaluation criterion in the row is more important than the one in the column, the value of 2 is entered at the intersection of row and column
- If both criteria are equally important, a 1 is entered
- If the evaluation criterion from the column is more important than the one from the line, a 0 is entered.

Table 1 shows an example of the paired-comparison-matrix:

Table 1: Example of the paired-comparison-matrix

	Evaluation critera 1	Evaluation critera 2	Evaluation critera 3	Evaluation critera 4	…	Σ	Weighting [%] (g_n)
Evaluation critera 1	x	1	1	0	1	3	15
Evaluation critera 2	1	x	2	0	1	4	20
Evaluation critera 3	1	0	x	0	0	1	5
Evaluation critera 4	2	2	2	x	2	8	40
…	1	1	2	0	x	4	20
						20	100

The lines are summed up and entered in the preference matrix. Next, the relative ratio between the value of an evaluation criteria noted in the lines and the sum of all values in the lines is calculated and further documented as the weighting in percent shown in the respective column. The sum of all weighting factors adds up to 100 percent. [7]

After executing the weighting of the evaluation criteria, follows the next step within the evaluation process of the textile which is demonstrated by the detection of the technical valence x_n. The textiles identified with the help of the market search are rated with the weighted evaluation criteria by means of the determined rating scale. This scale represent the connection to the textile properties. The technical valence is calculated with the following formula [12]:

$$x_n = \frac{\Sigma g_n * p_n}{\Sigma g_n * p_{max}} = \frac{(g_1 * p_1) + (g_2 * p_2) + (g_3 * p_3) + \cdots + (g_n * p_n)}{(g_1 * p_{max}) + (g_2 * p_{max}) + (g_3 * p_{max}) + \cdots + (g_n * p_{max})} \quad (1)$$

$g_n = Weighting\ factor\ of\ each\ criteria\ (n)$

$p_n = \ Value\ of\ the\ rating\ scale\ of\ each\ criteria\ (n)$

$p_{max} =$ Maximum achievable value of the rating scale

The technical valence, according to formula 1, represents the weighting degree of fulfilment in relation to the maximum degree of fulfilment of the requirements of a textile. This means in effect that if the technical valence of a textile gets the value *one*, the textile satisfies all requirements to 100%. Therefore, the values of the technical valence are be classified as follows:

- $x_n = 1 \rightarrow ideal\ value$
- $x_n > 0{,}8 \rightarrow ivery\ good\ value$
- $x_n = 0{,}7 \rightarrow good\ value$
- $x_n < 0{,}6 \rightarrow dissatisfying\ value$

The value of the technical valence provides an estimation regarding the degree of applicability of certain textiles for the exterior of vehicles. According to these results, the textiles are chosen and procured for a practical construction and real tests. Figure 4 shows the whole methodology of the textile evaluation process.

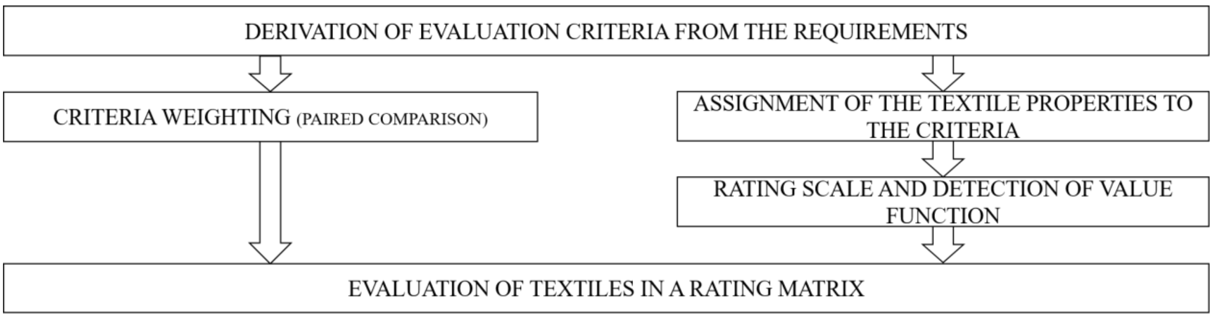

Figure 4: Methodology of the evaluation of textiles

2.4 Demonstrator development and testing

After the theoretical determination of suitable textiles the general functionality needs to be tested under real conditions in order to evaluate if the textile stands the test for the exterior usage. In order to do so, a demonstrator has been built serving as a test environment which approximately represents a real use case. As the demonstrator basically functions as a prototype, the construction needed to be fast and at low cost. The demonstrators' main purpose is the examination of the textile usage in the area of vehicle exterior and if the fabrics perform under real conditions such as wind, different weather circumstances or mechanical load. Realizing the construction under the aspect of rapidity and low investment, an existing light vehicle as well as consisting manufacturing processes were used.

In order to construct the demonstrator and follow a structured as well as systematic approach, the method of *VDI 2221- Construction methodology - methodical development of solution principles* was used. [6] However, one issue needs to be handled prior to the final demonstrator development: the clarification regarding which light vehicle component may be replaced by textile. It turns out that the doors of a light electric vehicle provide high potential as they are standalone as well as simple components providing a large, straight surface. The size of the surface also enables the testing of aspects like fluttering or noise generation.

Right after accomplishing the demonstrator construction follows the proper testing phase in order to evaluate the usability of textiles as vehicle exterior. The tests include noise-vibration-harshness-tests (NVH) which measure the quality of the textile with the help of optical photogrammetry. In order to realize a systematic test procedure of the NVH testing, experimental parameters need to be defined first. The parameters are defined on the basis of the requirements which were determined at earlier stage. The experimental parameters of the individual experiments are summarized as follows:

- Determination of vibrations (particularly their intensity)
- Determination of the distribution of vibrations
- Noise detection

Vibration and noise are measured camera based in order to enable the recording during as well as after the test. Therefore, the camera position is highly important and needs to be well adjusted in order to get reliable results. The different test scenarios are divided into:

- Tests in a wind tunnel
- Test drives on the road
- Textile behaviour in special conditions

In order to analyse and evaluate the camera recordings of test test-drives, the optical image measurement plays a major role. Therefore, the approach of photogrammetry is used which enables drawing conclusions from the depicted reality of the image recordings. [13]

The image measurement used in this project context is based on the following successive steps:

- Calibration of the camera
- Equalization of the image
- Camera vibration and noise reduction
- Pixel measuring

The comprehensive analysis of the different test scenarios results in the final conclusion regarding the eligibility of certain textile for exterior usage in the area of light electric vehicles.

3 Results

This section presents all results that were gathered within the evaluation process, the demonstrator construction as well as the different tests under real-world conditions in order to evaluate the applicability of textiles as vehicle exterior of light electric vehicles. Prior to data analysis follows the definition of requirements. The requirement list included textile specific as well as demonstrator requirements which were divided into technical-physical, manufactural, economical, human-product and advanced requirements. The development of the list took place under the constant consideration of every kind of influences, frame conditions and functional requirements. As the final requirement lists counts 93 positions, the demonstration within this paper would go beyond the scope.

As already mentioned in the previous chapter, the narrowing of the market search field is highly important to focus on relevant products only. Within this research, the search fields are based on the application area of textile usage in the outdoor sector that provide comparable implementations as vehicle exterior. The following list shoes the analysed search fields:

- Automotive applications
- Architectural textiles
- Sailing and paragliding textiles
- Sunscreen textiles
- Parachutes, hang gliders and ballooning
- Textiles for protection/coverage
- Sports- and leisure wear
- Camping and tent textiles
- Water sports as windsurfing and sailing
- technical textiles (unwoven material, membranes)

After having defined and structured the search fields, the semantic-based search within several databases followed as a next step. As an initial step occurs the development of ontological related search terms enabling a specific search in databases. Especially journals and online publications at techfinder [14] of the WTI and SpringerLink [15] generated valuable results. Additionally, the specific search among identified brands and manufacturer helped gathering more detailed information. The comprehensive market analysis resulted in the following textiles with all meeting the fixed requirements:

- Textile-laminate of Sympatex [16]
- Textile-laminate of Goretex [17]

- Textile-laminate of Texapore [18]
- Tyvek Hardstructure [19]
- Tyvek softstructure [19]
- Textile for architecture (Polyester)
- Awning (Polyester)
- Canvas (Polyester)
- Soft top
- Cotton wool
- Filter foil (PVC)
- Tarpaulin (PVC)
- Nylon-balloon-textile (Polyamid)

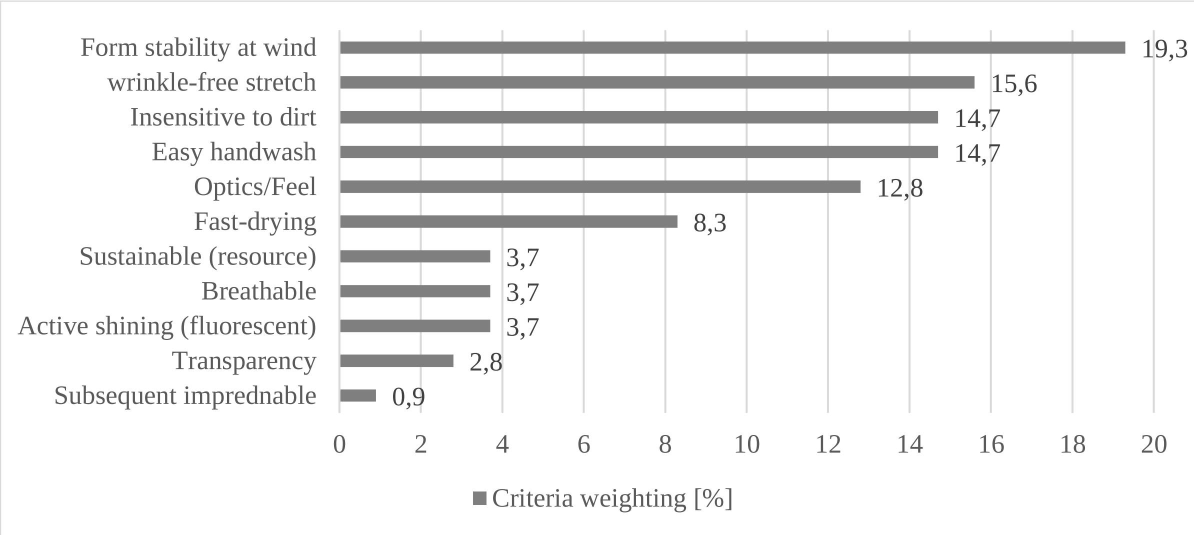

Figure 5: Results of the criteria weighting

Subsequently the evaluation criteria was defined on basis of the desired requirements. A pair-comparison of these criteria was conducted afterwards, however, due to reasons of complexity the single results cannot explicitly shown in this paper. Therefore, only the Top Three criteria will be demonstrated: *stability at wind* (19,3%) is at the first rank, *winkle-free stretch* of the textiles is ranked on the second position (15,6%) and *insensitive to dirt* (14,7%) as well as the ability for *easy hand wash* (14,7%) share the third place. An overview of the summarised results of the weighted criteria is provided in Figure 5.

Within a next step the properties of the textiles were allocated to the criteria, which is decisive for generating the rating scale and technical valence. The result of the technical valence are shown in Figure 6.

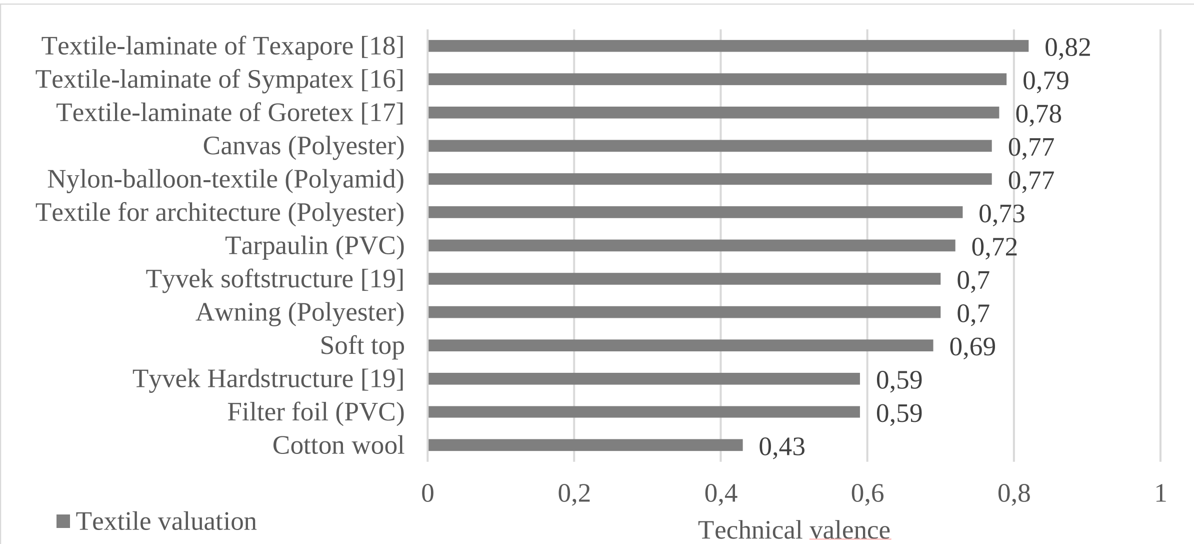

Figure 6: Results of the Textile valuation

According to the evaluation process, the following textiles were selected to test with the demonstrator:

- 2-Layer laminate (navy blue)
- Nylon, PU-coated
- Polyester, silicon coated
- Tyvek soft structure (1442R)
- Polyvinylchloride coated textile

After having selected and procured respective textiles, the development of the demonstrator based on the VDI 2221 started. A Renault Twizy served as basis construction with the doors being removed and replaced through textile doors equipped with frames of aluminium square profiles. All constructional work has been planned by 3D-CAD software, however, the curves of the frame could not be realised with aluminium profiles and therefore were built with the help of manufacturing (3D-Printing). Figure 7 demonstrates the construction of the aluminium frames on the left while the picture on the right side shows the final demonstrator equipped with textile doors. Compared to the other construction steps, the development of the textile doors was rather uncomplicated. Only the rounding of the doors led to slight difficulties when fixing the seam of the textile, however the general construction process faced no challenge and was quite easy to realise. A highly important aspect is the textiles value of strain, as there are different levels depending on the type of textile. Especially stretchable textiles have to be strained equally strong.

Figure 7: Left: Demonstrator with aluminium frame. Right: Finalized Demonstrator with textile doors.

As soon as the demonstrator was applicable, a high number of tests were conducted. The measurement of vibration was examined in a wind tunnel demonstrated in Figure 8. One of the most important advantages is represented through the stationary setup which enabled a direct measurement at the inside of the textile door with a scale.

Figure 8: Test setup in the wind tunnel

The selected textiles were tested at large as well as small surfaces. However, the Tyvek textile with its polyvinylchloride coat could not be mounted at the aluminium frame and therefore was only tested at the large surface. Unfortunately, the loud noises generated by the wind turbine made it impossible to conduct any acoustic tests in the wind tunnel. Therefore, those tests were executed at additional test drives. Figure 9 demonstrates the rise of the amplitude with increasing speed of the wind very well. It turns out, that the Nylon (PU-Coated) provides the best performance which is characterised through the shortest amplitude. In this case, a short amplitude is directly linked to little vibration in the wind test. Generally, all of the textiles' amplitudes were rather low.

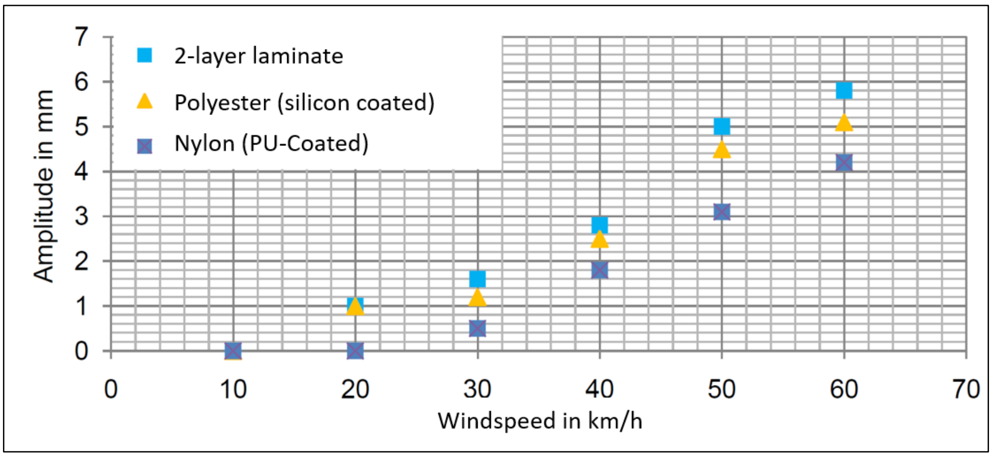

Figure 9: Result of the vibration test in the wind tunnel (large surface)

It is logical to assume that the intensity of vibrations becomes larger at higher velocities. Figure 10 concentrated on the results referring to the small surfaces. Shorter amplitudes implicate that smaller surfaces enable less textile vibrations. As demonstrated in Figure 10 the vibrations are fewer at small surfaces compared to the large ones, with the Nylon (PU-Coated) showing the best vibration results again.

As the results indicate, the Nylon (PU-Coated) provides the best characteristics and performance as textile for vehicle exterior usage. In this context, the clamping force presents a highly influencing parameter. The clamping force needs to be high enough in order to keep the surface stable. However, the performance is always dependant on the specific textile. Another important aspect is the parameter of aerodynamic. The gap size leads to a windstorm inside the textile which results in the inflation of the textile from the inside to the outside.

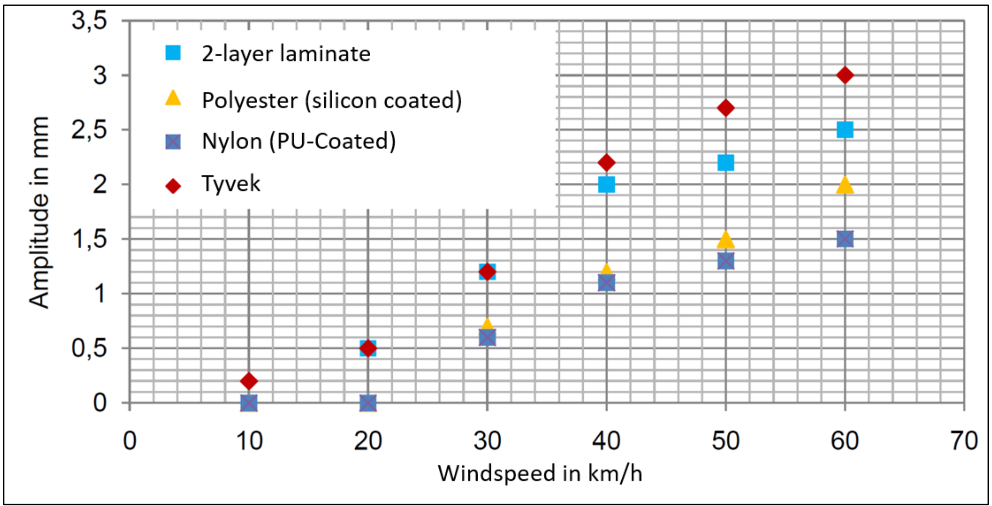

Figure 10: Result of the vibration test in the wind tunnel (small surface)

To verify the results gathered in the wind tunnel, additional driving tests followed as a next step. In order to generate as realistic street conditions as possible, influencing factors such as lane vibrations, crosswinds, splashes and contamination of the surfaces were integrated within the test as they are affecting the performance of the textile. All of the fabrics offered surfaces that are easy to clean in case of dirt or pollution, only the 2-layer laminate showed small white dots caused by salt. All of the textiles are waterproof, especially the laminate convinces through its high hydrophobic properties which provide the best performance within water and dirt repellence. The Tyvek textile also comes with properties like hydrophilic as well as dirt sensitivity, especially demonstrated by the following test: In order to simulate stone chipping, a 200g wooden block was dragged from a height of one meter with the results showing no visible traces on the textile. Another examination regarding quality check and resilience of the materials is demonstrated by the burning test. The results show a range of different burning level depending on the material. Nylon for example was very slow burning and showed high resistance whereas the 2-layer laminate inflamed very fast. The burning character of the Tyvek can be compared to a lit candle. In general, the Polyvinylchlorid coated textile showed the best results within the burning test followed by Nylon (PU-Coated). All textiles coped with the exposure of thorns and claws, except the polyester (silicone) and Tyvek fabrics, which were damaged.

4 Conclusion

Recent times demand for new and innovative approaches as new mobility concepts such as micro mobility or light electric vehicles also come with a change of vehicle components. Therefore, this study focused on the analysis of textile as vehicle exterior in order to provide new possibilities and insights regarding the implementation of fabrics within light electric vehicles.

This paper tries to illustrate a structured procedure explaining how to define specific requirements of textiles and summarize them into a requirement list, identify suitable textile with the help of a market analysis as well as valuate them by means of a weighting and evaluation method. One of the most beneficial contribution of this article lies in the construction of a real demonstrator, which enabled the testing of selected textiles under approximately real conditions. Therefore, assessments regarding the suitability of respective textiles as vehicle exterior are more valid and reliable.

When reflecting the results, the Nylon textile with a PU-Coating provides the highest usage potential as well as the best performance of vibration behavior. The vibration measurement revealed a slight amplitude of 4.2mm at 60km/h, which is highly satisfying. Further, its hydrophobic properties, the resistance towards thorns and claws as well as its low burning potential clearly speak in favor of the sustainable use of this material as vehicle exterior.

This paper clearly proves that textiles can be used as exterior material for light electric vehicles. As the study shows, there are already suitable textiles implemented on the market, which meet a high number of demanded requirements. However, in order to provide a perfect realization and suitability, the development of new or adjusted textiles that fulfill all relevant requirements is on paramount importance.

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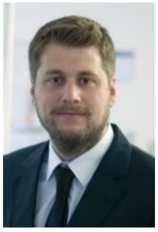

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