A SENSORIAL AND INSTRUMENTAL INVESTIGATION ON THE PERFORMANCE OF BIO-BASED MATERIAL VERSUS SYNTHETIC MATERIAL

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This paper examines whether the physical properties of materials can be useful predictors of material sensory properties. In this study, sensory methods were used to investigate the relationship between measured surface roughness and the perceptual qualities for a varied set of materials (flax, glass). A significant connection was observed between the physical and tactile perceptual properties of the materials that determine the sensory profile. Furthermore, based on sample semantics, this study investigated how the tactile attributes of natural material and synthetic material are perceived and interpreted semantically. However, the research shows that there is lack of studies on the aesthetic and sensory aspects of materials, despite the fact that these traits are essential in the creation of a product interface.

Keywords: sensory methods, bio-based material, synthetic material, instrumental, environment

1. Introduction

Material selection is a mature discipline where physical parameters such as surface types are used as predictors of a material performance in the design of new product. In particular, this paper aims to highlight and enhance the capabilities of the suggested method for an individual-centred design. It is therefore a question of showing how this tactile sensory evaluation method should evolve in order to favor a better integration of the human being very early in the product design process, making it possible to predict their perceived quality based on an evaluation of surface characteristics [1 – 2].

Thus, the study related to our theme is generally linked to Engineering Sciences via Materials Science and Industrial Engineering, or on a deeper level, to Human Sciences via Psychology for sensory evaluation and Art Sciences for the aesthetic part of sensory industrial design.

The current study addresses the question of whether physical properties of materials can be useful indicators for sensory properties of materials. During this research, sensory methods were used to investigate the relationship between

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measured surface roughness and its perceptual qualities for a diverse range of materials (bio-based material - linen, synthetic material - glass).

2. The state of the art

Within the framework of this study, and in accordance with the industrial and research context, we follow a model of human-centric sensory based analysis, where the aim is to indicate the place of the human being and its role as a perceived quality control agent. The industrial designer and the mechanical designer are regarded as specialized co-designers in their discipline.

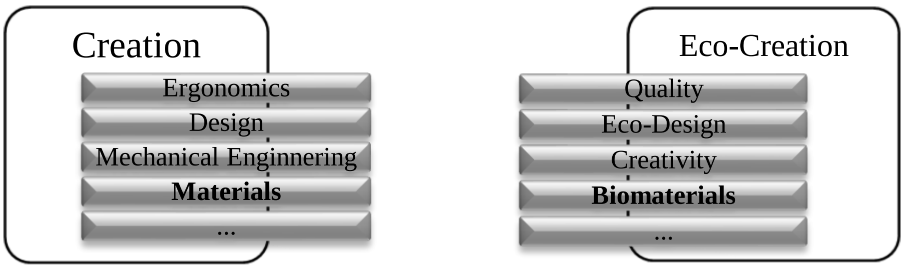

Fig. 1. Stages of the design / eco-design process

In a context of increased competition, a company must gradually and consistently integrate the design and production phases as well as other later stages of the product life cycle (after-sales, recycling or destruction of materials). As a result, the development process becomes the result of interactions and iterations between several activity processes [3 – 5]. As a consequence, important organizational changes are taking place in companies ever more often, reflecting in particular a shift from the traditional product design process to a collective, simultaneous and even integrated process [5 – 8].

We have noted that the industrial context no longer allows companies to rely on the design of products that only fulfils technical functions. As a matter of fact, the consideration of this function of assessing the materials is now becoming essential in the race for innovation. However, in the field related literature, we also noticed that there is little or no research on their sensory features. We can go as far as to say that there is a real lack of protocols regarding their sensory evaluation [8 – 9].

It is in this context that we position our study in a user-centric sensory evaluation approach which attempts to integrate human factors, through sensory metrology. To position our research in the framework of a human-centric design, our research theme is focused on the areas of quality control for the estimation function, or even design based on an evaluation of sensory characteristics.

2.1. Sensory design

Designers base their work on fundamental aesthetic principles, but these are usually abstract and do not form an explicit guideline for product design. The designer also has tools at his disposal to help him become familiar with consumer preferences. This is the case of trend boards, for example. The results of a trend board are highly dependent on the designer's subjective interpretation [10 – 12]. In this way, the designer's work remains essentially a matter of personal expertise [7 – 8].

The designer's intervention can often be perceived as restrictive if it comes late in the design process causing to reconsider the technological, functional or aesthetic choices that have already been developed over a long period of time by the manufacturers' design teams. We have sought to develop a methodology that provide an objective foundation for the designer's choices, in order to give additional weight to his recommendations when confronted the other actors in the design process [7 – 10].

This tool must be able to guide the improvement of the sensory characteristics of existing products, but also facilitate the development and validation, according to sensory criteria, of new materials.

However, today it cannot be left to the sole responsibility of the designer, whose creative role is totally indispensable, to represent the perceptual and social values of the material. Sensory metrology, in the same way as technical engineering for technical characteristics, will contribute to the design of the perceptual and social aspects of the material [10].

2.2. The innovative materials

At the heart of business of the activity of companies is the creation of new products based on innovative materials. Nowadays, the design process plays an important role in the competitiveness of companies, as we have seen in the previous sections [5].

All companies, whether traditional or modern, take advantage of this in order to advance in their business, in search of added value and increased competitiveness of their products [10 – 11]. It is not enough to think about the material, it is also necessary to foresee the needs related to the implementation of the material and a sensory evaluation for the acceptance of a product by its consumers [10].

For the introduction of new materials, for their development as part of the product design, it is necessary to think about the needs/expectations of consumers, and it can happen that some choices are blocked [11 – 12]. These are the constant questions and challenges that drive companies to modernize. And the modernization of companies today, which are increasingly competitive, is moving towards the replacement of old (more polluting) materials with new bio-based (eco-friendly) materials [9].

The new bio-based materials have very complex technical and physical characteristics that easily allow the replacement of old materials. In other words, in a product design, complexity should only be a way to make it easier to use and even to be build, it should be adapted to the needs of consumers [5 – 9]. We specifically focus on composed bio-based materials made from natural flax fibers as they are materials with a great potential in terms of applicability within the context of a rising sustainability context.

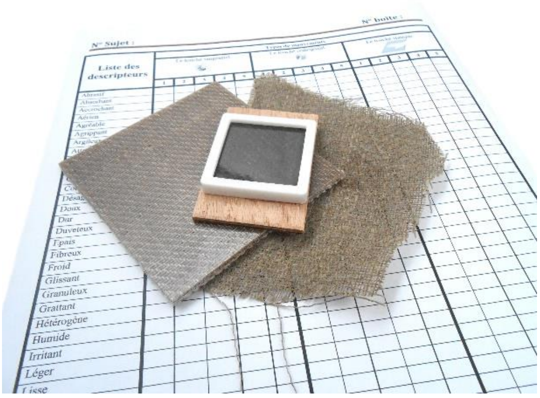

Fig. 2. Bio-based materials – case of flax fiber

Composite materials with plant fiber reinforcement are currently the subject of much research due to their environmental benefits and their ability to replace reinforced glass fiber composites [5].

Strict environmental legislation and consumer interest in ecological issues are accelerating the transition to sustainable development models, thus opening up great opportunities for the natural fiber markets [13 – 15]. From an ecological point of view, the cultivation requirements for flax are convenient. It is a renewable resource of the future, with no adverse environmental or health consequences, Fig. 2. Numerous studies have demonstrated the potential of flax fibers as a reinforcement in a matrix compared to glass fibers [5 – 7].

3. Material and methods

We made samples (6 x 4 cm) for our experiments to facilitate the tests. A composite is the result of a mixture of fibers (linen/glass) and a matrix (a resin) during the manufacturing process. The orientation of the fiber is a determining factor in the result of the composite properties of the composite. Two groups of semi-finished products are distinguished: unidirectional and twill. Unidirectional is defined as a web fiber oriented always the same direction.

The roughness measurements were carried out with an inductive profilometer. The profilometer examines the surface and immediately indicates the corresponding value at the pre-selected wavelength limit. The profilometer allows the exact measurement of the degree of roughness of the bio-based materials and the synthetic materials chosen for our study. The roughness of a material is a characteristic of the surface condition of a hard material.

The core of the profilometer is a very fine diamond tip that reads the altitude as it is moved along the surface. Variations in the voltages generated are detected by the sensor and then converted into different roughness parameters by the tool electronics [16]. In this way, it is possible to quickly obtain a detailed profile of the surface. The measurements would be made five times per sample and the results will be presented after the average. The measurement is carried out in a temperate environment. The output of the profilometer allows data to be transmitted to a PC using a program (ALTISURF 500 – acquire a measurement). It is also possible to perform measurements, visualize parameters and present the profile graphs in a various option. The processing of the results will be done with the help of ALTIMAP software.

On a macroscopic scale, a surface appears smooth or rough to us by simply moving a finger over it. In the same way, a profilometer (or roughness meter) is equipped with a probe that moves over the surface. The vertical movement of the probe tip is digitally analyzed to determine the previously defined roughness. The measurements should provide us with the arithmetic average deviation of the roughness profile.

3.1. The subjects

The discussion on the choice of the subject factor as a random factor has long been debated in sensory analysis [6 – 7]. For our study the subject factor was chosen as a random factor because the subjects of the panel were randomly selected among the EDIM department (Ergonomics Design and Mechanical Engineering) students of the UTBM (University of Technology Belfort Montbéliard) in the same age group, socio-cultural level. When the subject effect is random, the product*subject interaction automatically becomes a random variable. The latter also depends on the product factor, and the variability due to the interaction is taken into account in the expression of the average square of the product effect. The bibliography suggests that the homogeneous panel makes common differences between the samples.

The subject panel consists of 20 subjects between 21 and 30 years of age, EDIM students. We selected the subjects in order to obtain a homogeneous panel.

3.2. Samples preparation process

Composite materials with plant fiber lining are currently the subject of much research due to their environmental benefits and their ability to replace glass fiber lining composites. For our study, we chose to compare the bio-based material made from natural flax fiber with the synthetic material made from glass fiber through sensory and instrumental means [17].

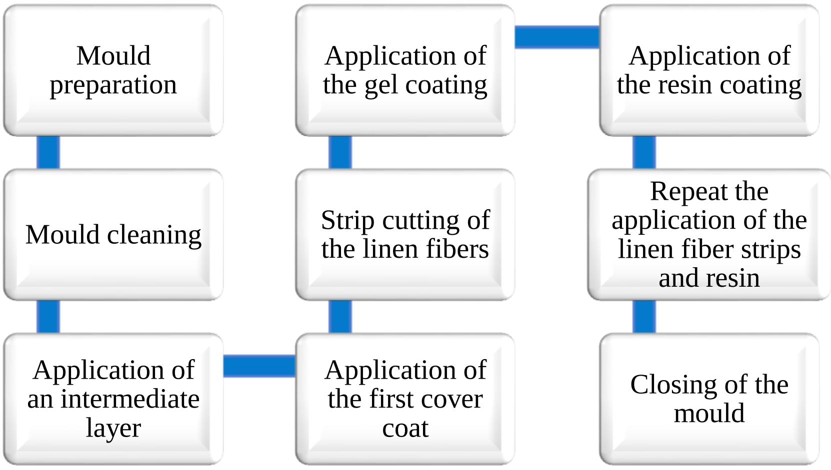

Fig. 3 Sample preparation protocol

The samples were manufactured in the same way for all types of materials (bio-based and synthetic) for sensory and instrumental measurements. The general sample fabrication protocol (Fig. 3) was observed. The choice of materials was guided by two objectives. The first objective was to create samples that would cover the texture of a hard material surface in a homogeneous way. The second objective was to create samples with similar mechanical characteristics to those of a synthetic material made of glass fiber [18 - 21].

We chose to do the sensory evaluation tests blindfolded. To do this, we constructed boxes, Fig. 4.

We evaluated the materials mainly through touch, because the flax fiber has a special smell and a different color than the synthetic one. The experiments are conducted blindfolded to minimize impartiality due to the presence of color and sensory forms. All samples are placed by five in the special box prepared for these experiments where the code of the samples was always different.

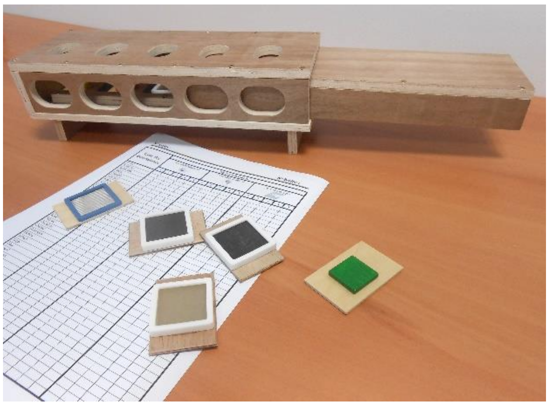

Fig. 4. Test boxes / samples

For example, we recapitulate the products space chosen for our study:

- Bio-based material samples:
  - Number of samples: 10 pieces;
  - Number of sample types: 2 types: 1 unidirectional (flax); 1 twill (flax);
  - Number of surface variations: 1 characteristic: on roughness;
  - Number of surface state variations: 10 variations: 5 for the unidirectional material; 5 for the twill material;
  - Size of sample: 6 cm x 4 cm.
- Synthetic material samples:
  - Number of samples: 5 pieces;
  - Number of sample types: 1 type: 1 fiberglass (synthetic);
  - Number of surface variations: 1 characteristic: on roughness;
  - Number of surface variations: 5 variations;
  - Size of the sample: 6 cm x 4 cm.

3.3. Descriptors

A descriptor is a term that describes a sensation and is defined as precisely as possible so that can be understood in the same way by all subjects. For our study, we took as a starting point a list of 10 descriptors from the specialized literature. The list of descriptors was constructed based on work [1, 3, 6 – 7]. In order to correlate the sensory and instrumental measurements, we chose the rough descriptor in our further research.

4. Experimental part

The participant has to express his or her feelings about the touching of the samples through a given list of descriptors and at the same time the participant has the possibility to freely verbalise his or her feelings about the samples. The participant has no time limit to name the descriptors related to his or her feeling about the samples according to the different types of movements that will be classified into three distinct categories that the participant must respect: tangential (fingers move in parallel along the surface), orthogonal (press on the surface), and static (the hand rests passively on the surface).

For each type of movement, the participant must use only the index, middle and ring fingers and the first two phalanges of each finger of the dominant hand. The participant was asked to make three assessments on each sample. We recorded the choice made by the participants in writing. We chose not to record the responses of the subjects participating in the experiments (such as audio or video recording) in order not to interfere with the spontaneity of the subjects.

5. Results

The correlation between the instrumental data and the sensory data of the panel subjects for roughness are presented in Figs. 4, 5 and 6 for each type of material. The data (intensity scores / roughness measurements) are acquired directly on the ALTISURF 500 program and processed with the ALTIMAP program. The correlation test allowed us to identify significant relationships between the sensory descriptors of the panel and the instrumental variables measured. In particular, it was recognized that the change in the variation of the surface state, as in our case, variation of the surface state according to the roughness (we recall here that we varied each type of material 5 times), are phenomena to be taken into account in order to better predict the mechanical properties of a biobased material and a synthetic material.

From a theoretical point of view, a correlation test measures the strength of a link between two sets of data. If the correlation relationship is perfect, then all numerical changes in one variable should be reflected in a parallel and proportional change in the data for the second variable. In this case, knowing the value of one variable absolutely predicts the associated value of the other variable. The correlation measures the “degree” of relationship that exists between two sets of data (in our case sensory data for the perceived feeling for the descriptor “rough” and instrumental data for the roughness of a surface), but it also gives the meaning of the relationship. If the relationship is positive, an increase in the values of one variable results in an increase in the values of the other variable. If the relationship is negative, an increase in the values of one variable results in a parallel decrease in the values of the other variable [6 – 7].

In a similar way, twenty subjects took part in experiments consisting firstly in evaluating the intensity perceived when touching a biobased material from flax fiber and a synthetic material from glass fiber. In a second phase, instrumental measurements were carried out on the roughness. This series of experiments allowed us to establish a significant connection between the sensory variables and the instrumental variables.

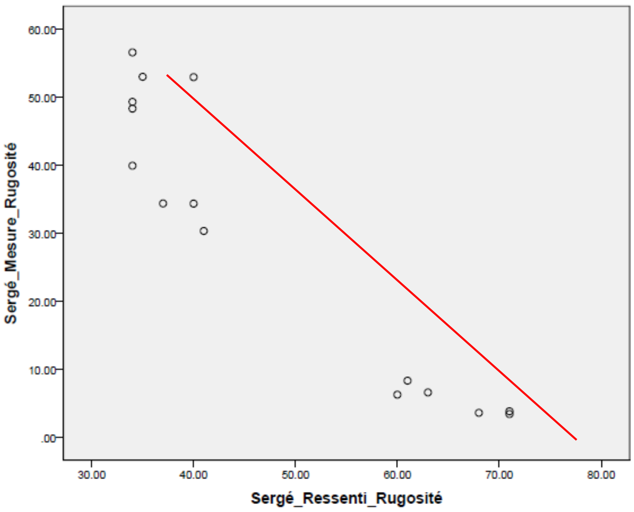

Fig. 5 Correlation between sensory data and instrumental data - twill

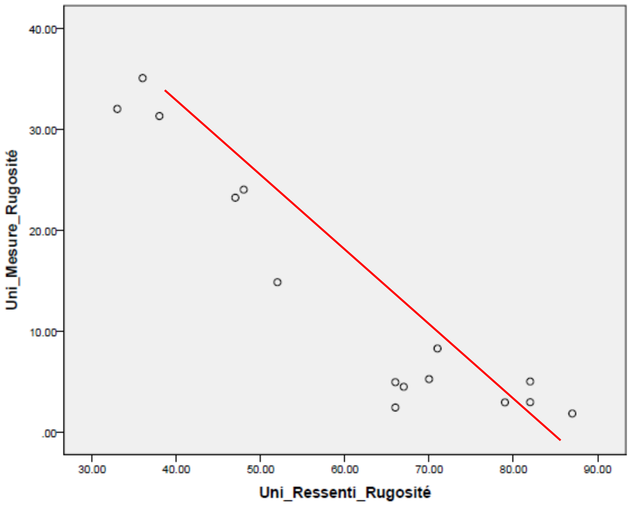

Fig. 6 Correlation between sensory data and instrumental data – unidirectional

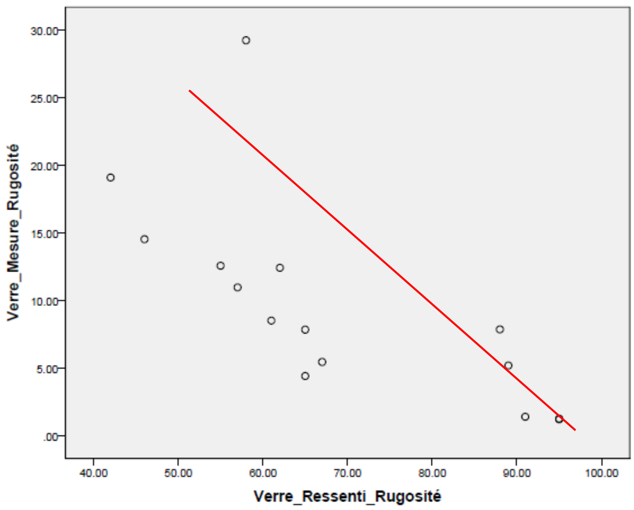

Fig. 7 Correlation between sensory data and instrumental data –glass

The calculation of the correlation coefficient (in our case, the Pearson correlation), is used here to know if the sensory measurements can be correlated with the instrumental measurements. We found a good correlation between the roughness perceived by subjects and the instrumental measures, the coefficient values are revised downwards. For the descriptor “roughness”, the measurements correspond to the means of the values obtained by the profilometer. Through these experiments, we found that there is a good correlation between the subjective and objective measurements. The results show a correlation between the two sensory and instrumental variables.

In this section we present the experiments done on twill and unidirectional biobased materials and synthetic materials in their raw state. The results obtained in this research helped us to set up another series of experiments to find out to which intensity the selected descriptor - rough - is perceived by the participating subjects. In this study, we also discussed the main results of studies that have established correlations between sensory and instrumental measurements of a bio-based material and a synthetic material.

6. Conclusions

In conclusion, we present a new methodology for tactile sensory evaluation that uses the Human as a measuring tool, allowing the consumer's perception to be taken into account, based on an evaluation of the sensory and instrumental characteristics of the surface of a bio-based material.

Several points emerge from the literature review. Bio-based materials (flax fiber) are potentially an interesting product space, both for the sensory part and for the sensory and instrumental correlation part. The challenges of this task are multiple: to develop a methodical approach (protocol) by placing man at the heart of the method; to search for a minimum of descriptors that will give the maximum information on the sensory properties of the assessed product; to measure the intensity of the perceived sensation for each of the chosen descriptors; to construct, with the help of all the quantified descriptors, the profile of the product; to check whether untrained consumers can talk about the sensations in a way that is useful and coherent for the designer.

In order to predict the sensory perception of biobased/synthetic materials, we have implemented contrasting instrumental methods. The experiments we carried out in the EDIM department of UTBM, France, allowed us to test and validate our proposed methodology. The mechanical roughness measurements are correlated with the perception measurements. More precisely, through this approach, we have demonstrated how the biobased material is perceived compared to the synthetic material. The Pearson's correlation coefficient between the scores of the samples of a biobased material and a synthetic material rejects the research issue according to which biobased materials can easily replace synthetic materials for the descriptor “roughness”.

7. Future work

The results obtained for the correlation between sensory measurements and instrumental measurements for the descriptor “rough” try to foster further research. It seems that the “rough” descriptor is interesting to search for correlations with instrumental parameters from various instrumental methods. We would like to illustrate that the bio-based material is similar in perceived tactile properties to the synthetic material in its raw state.

In further research, an important question is whether it is possible to transfer sensory descriptors between subjects from different cultures (France and Romania). Another question is what are the differences and similarities in sensory descriptions between groups of subjects with different languages and cultures backgrounds.

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