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Comprehensive analyses between acoustic comfort and materials used in vehicles

A data driven literature review of acoustic comfort in vehicles

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***Abstract* — Several factors have contributed to the increased interest in assessing the acoustic comfort experienced by passengers in the vehicle cabin. Due to increased mobility, the time people spend in cars has increased substantially. Also, another factor that led to increased interest is strictly related to marketing, as the differentiation between models in the same market segment is becoming more and more difficult to stabilize through performance or aesthetic criteria. Evaluating the level of acoustic comfort in automobiles involves both knowledge in the field of physics and a minimum of knowledge in the sphere of the human body. In order to achieve the goal of noise reduction researchers and Noise Vibration Harshness - NVH engineers have done a lot of research work on noise control. This study is an effort to present research trends on noise control in motor vehicles. The analysis of the Web of Science, Scopus and Google Scholar databases and the comparison of the obtained results indicate that the most used method to combat noise is the use of materials with sound-absorbing properties. The diversity of results obtained from databases is attributed to the wide range of journals and the coverage of topics in each journal. VOSviewer software was used to visualize the results obtained from the Scopus database. Using VOSviewer bibliometric data analysis software, publication trends were analyzed using term analysis, keyword co-occurrence and author collaboration. These steps can be used as a starting point both in research and innovation and in the search for complete solutions.**

Keywords—acoustic comfort; noise control; materials; sound absorbing materials; database analysis, VosViewer analysis.

I. INTRODUCTION (*Heading 1*)

Noise, vibration and harshness (NVH) are synonymous with quality factor in automotive engineering, according to studies in 2013 [1]. This quality factor is influenced by internal noise, such as engine noise, and external noise, such as aerodynamic noise and tire noise from the road. While many studies have been done to identify noise sources and reduce noise and vibration transmission from engine and aerodynamic sources to the passenger compartment, reducing tire-road noise outside the compartment still remains a challenge [1]. In 1995, researchers discovered that most plastic components inside cars play an effective role in reducing sound emissions, ensuring interior acoustic comfort for passengers. Studies on the acoustic comfort inside cars, since 2006, indicate that the solutions addressed in combating noise indicate the introduction of increasingly higher percentages of composites in the car industry, especially in their interiors. There is a trend towards the development of new thermoplastic composites with improved acoustic and mechanical performance for use in car interiors. According to research conducted by Enamul Hague and Dan Asbury in 2006, it was concluded that thermoplastic composites offer several advantages over existing polyurethane substrate materials for use in lining applications, exhibiting improved acoustic performance. It also provides excellent dimensional stability over the full range of vehicle interior temperatures. In addition to providing greater stiffness, thermoplastic composites allow for greater modeling flexibility with a smaller bend radius moldability [2]. As part of the MFERD (Magnésium Front End Research and Development) project, in 2010, another approach to noise reduction is noted, in the framework of research into the development of technologies that would allow the use of magnesium alloys as the main structural material in the construction of motor vehicles (in mainly made of steel, which is four times heavier than magnesium) in the sense of reducing the total mass and from reasons of environmental protection. This approach is based on the principle of manufacturing dashboards from magnesium alloys (instead of the traditional ones from steel and aluminum with the same mass density), as this plays a critical role in insulating the passenger compartment of the vehicle, by separating the engine compartment from the interior of the cabin [3]. In 2011, there is an interest in sound-absorbing materials in vehicles, used to provide comfort to passengers by reducing noise while driving. Researchers are analyzing the development of PET (polyethylene terephthalate) hollow fiber sound-absorbing materials to achieve light weight and high sound absorption performance, the results of experimental tests showing that such

products are more performant than conventional ones [4].

Part of the research in the field finds solutions to combat noise in vehicles, starting from the generating source. Thus, in 2014, the thermo-acoustic encapsulation of the engine block is proposed, capable of significantly reducing the radiated sound and, in addition, increasing the heat storage capacity, at the same time increasing the efficiency of the engine. Consequently, exhaust emissions are reduced by avoiding so-called cold starts [5]. Also in 2016, part of the studies focused on improving acoustic and thermal comfort, by using materials with the potential to reduce noise and thermal insulation (glued by needle punching, glass wool, jute and waste - jute, cotton, polyester and polypropylene), for the interior of cars [6]. There are also studies, from the year 2017, in which the use of green materials (by-products of oil processing) is proposed for acoustic insulation in the automotive and construction industry, and these studies will also be carried out in the aviation sector, regarding the use of green materials for non-structural components of airplanes [7]. In 2020, an IoT architecture is proposed for the real-time monitoring of noise pollution and the correct assessment of acoustic comfort composed of a hardware prototype for the collection of ambient data, the identification of disturbing sounds and the planning of ways to avoid them. The obtained results are promising, representing a significant contribution to IoT-based noise monitoring systems [8]. IoT systems are expected not only to contribute to the improvement of living environments, but also to be an integral part of daily routine [9]. Researchers have found that internal noise is an important factor in vehicle design. In the future, interest in this topic is expected to increase due to the concern for health and acoustic comfort issues closely related to the emergence of autonomous vehicles and new modern applications. Although there is a vast literature on this topic, most of the work focuses on the study of the noise contribution of specific vehicle components in controlled environments such as test laboratories and from the perspective of psychoacoustics. Currently researchers are focusing on developing sound processing applications and collecting sounds from inside vehicles in real time in real traffic scenarios using IoT technology [10].

II. TRENDS IN THE USE OF MATERIALS IN THE AUTOMOTIVE INDUSTRY

A. Materials used in autombiles industry

The materials used to make automobiles have seen continuous improvements and their weight has changed over time in favor of materials that ensure superior performance, which creating lighter, more durable parts, with sound-absorbing and vibro-absorbing properties, cheaper and with possibilities of recycle. Sound-absorbing materials can. The percentage of use of plastic materials in the composition of automobiles has increased recently by 5-6 times.

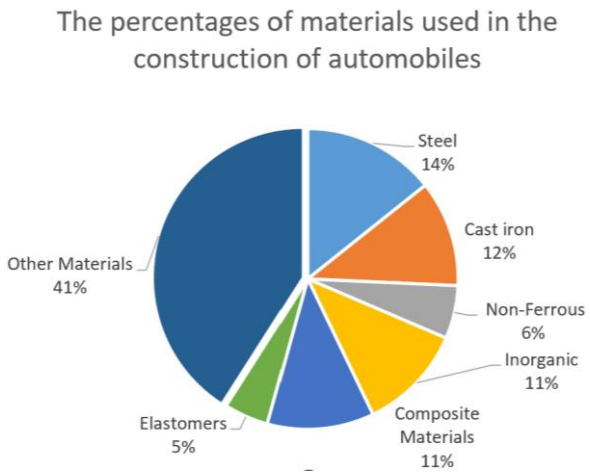

Figure 1: Materials used in automobiles.

Composite materials are the strategy used by major car manufacturing companies, in the last 30 years, to reduce car noise by up to 10 dB, to ensure acoustic comfort, they are recyclable, they lead to important cost reductions and, due to their low weight, they participate in the achievement of the CAFE - *Corporate objective Average Fuel Economy* standards imposed by European manufacturers to reduce consumption and thereby carbon dioxide emissions.

B. Classification of acoustic materials

Noise can be reduced and controlled by using different types of materials that have the property of reduces sound pressure by absorption sound waves. Sound-absorbing materials are used to reduce noise in homes, from residential complexes, on construction sites, on highways, ports, airports, railway stations, halls industrial, automotive industry, etc. For the best possible yield of sound-absorbing materials must we take into account both the characteristics of each type of material as well as the characteristics of the noise where we want to use that material.

There are currently several types of both synthetic sound - absorbing materials (foam polyurethane, expanded polyurethane, etc.) as well as natural materials (made from: cork, wood waste, cellulose, sheep 's wool, fleece and straw, hemp, coconut fiber, glass waste, etc.). Materials that reduce the acoustic energy of a sound wave as the wave passes through it by the phenomenon of absorption are called sound absorptive materials. They are commonly used to soften the acoustic environment of a closed volume by reducing the amplitude of the reflected waves. Absorptive materials are generally resistive in nature, either fibrous, porous or in rather special cases reactive resonators [11]. Classic examples of resistive material are nonwovens, fibrous glass, mineral wools, felt and foams. Porous materials used for noise control are generally categorized as fibrous medium or porous foam. Fibrous media usually consists of glass, rock wool or polyester fibers and have high acoustic absorption. Sometimes resistant fibers are also used in making acoustical products. An absorber, when backed by a barrier, reduces the energy in a sound wave by converting the mechanical motion of the air particles into low-grade heat. This action prevents a

buildup of sound in enclosed spaces and reduces the strength of reflected noise [11].

III. MATERIAL AND METHODS

In order to conduct this study, a qualitative tool that preserves past research, describes the immediate trends and future purpose of study on a particular topic. In the VOSViewer bibliometric data analysis software, it was determined that the most used method of controlling and reducing interior noise in cars is the use of materials with sound-absorbing properties. A strong connection between the acoustic comfort and the materials was also determined. It could be discovered which sub-topic has been well explored and the scope of other related fields through such a study. Bibliometric analysis provides an excellent platform for researchers who want to explore new and complex topics. Three databases were chosen namely Web of Science, Scopus and Google Scholar. The VOSViewer library was created with the database obtained from Scopus, as it is the largest literature abstracts and citations database and provides a comprehensive overview of research carried out in all fields of science. The WOS and Scopus databases also provided data on the researchers' country of origin. Research on the use of acoustic materials to ensure acoustic comfort in automobiles was carried out in 36 countries. In the analysis of the trends of materials used in the fight against noise was considered the country that has more than 5 publications. Author affiliation searches are not possible in GS.

A. Building the database from WOS, Scopus and GS.

In order to determine research trends on acoustic comfort in automobiles, three databases were analyzed: WOS, Scopus and GS. The first step was to search by key terms for articles that aimed to research acoustic comfort in automobiles. The trend in the use of acoustic materials as been determined, since 1987 until now [12]. Subsequently, a preliminary selection was made by analysis and only journal and conference articles indicating conclusive results were considered. For example, an article that contained a result without explaining its origin was not taken into account. Subsequently, a current stage of research in the field of acoustic comfort could be outlined and also the strong connection between acoustic comfort and materials, indispensable elements in its assurance, could be determined.

B. Bibliographic information

Figure 2: The country of origin of the research.

The United States has the largest number of researches, based on the analysis of the three databases WOS, Scopus and GS. France, China and India are the other important generators of research in the field.

C. Term analisys

The VOSViewer maps were built using data from Scopus, where most research in this field has been recorded. Cluster size represents the relative strength of the results. Analysis of key terms gives an idea of the heads on which the mentioned research is based extract terms based on their occurrence in a publication. Minimum number of appearances the term is set to 10, which gives 5078 results. The most relevant terms were chosen based on the default choice, which is 60% of the most relevant terms. Therefore, 81 terms were selected that fall into eight main groups. Cluster one (noted as red), two (green), three (blue), four (yellow), five (purple), six (light blue), seven (orange) and eight (brown) have 23, 12, 10, 9, 9, 7, 6 and 5 terms and is represented in figure 3.

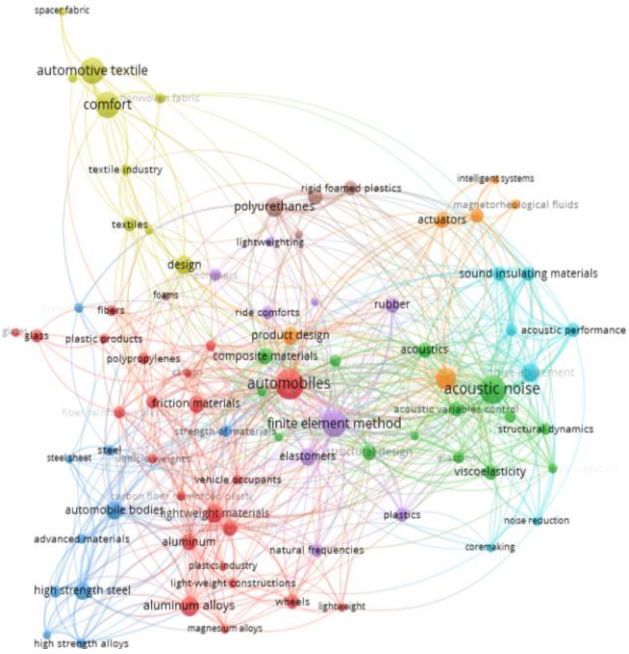

Figure 3: Scientific map in VOSViewer - the terms being grouped into eight clusters.

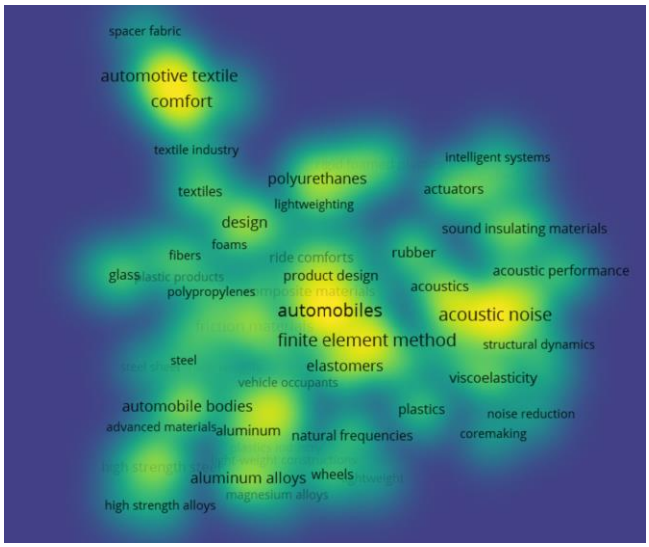

Figure 4: Scientific map in VOSViewer - the density of occurrence of key terms.

The first cluster contains information on ensuring acoustic comfort through the use of lightweight materials (glass, fibrous materials, carbon fibers, plastics) as well as composite materials. The second group talks about the parameters (related to the propagation of acoustic waves) and properties (porosity, elasticity) that acoustic materials possess. The use of composites is reflected in terms of the automotive industry. The third cluster groups the heavy type materials (steel alloys), the fourth groups the terms related to the design of vehicles, architecture and aesthetics, textile materials are also found in this category. The fifth cluster contains the elastomers, the sixth the sound insulation materials, the seventh is related to the sensors in noise detection and intelligent systems to combat them and the last cluster contains the foam and multilayer materials.

D. Co-authorship-country analysis

The distribution of research according to the author's affiliation, using the scope database, is represented in figure 5. In the analysis, the maximum number of countries per document was chosen to be five. The minimum number of citations of a country was set to one which returns 21 results. The largest set of linked articles had 21 articles containing 5 groups. The biggest the cluster contains 5 countries.

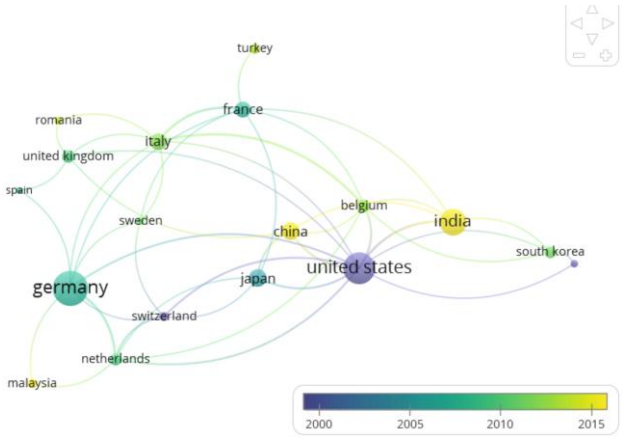

Figure 5: Scientific map in VosViewer representing coauthor-country relationship, Scopus database.

The United States is represented by the first group (purple) and stands first by publishing the most papers in the field of acoustic comfort in automobiles. Germany and India are the places with the most publications after the United States.

IV. CONCLUSIONS

This study reviewed works from specialized literature that presents practical ways to improve and preserve the acoustic comfort in the passenger compartment of a motor vehicles and the trends in its insurance. Journal articles and conference papers were searched in the WOS, Scopus, GS databases and analyzed in the VOSviewer software. The analyzes papers showed clear trends both in the analysis of acoustic comfort and in strategies to improve it.

This systematic literature review guide is accurate, quick in terms of reference selection and can be applied to any field of study.

These steps can be used as a starting point for research and innovation as well as for the search for complete solutions. VOSViewer database analysis software can be used to determine any correlations between key terms.

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