Potential use of nonwoven for acoustic absorption

Uso potencial de não-tecidos para absorção acústica

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ABSTRACT
The use of nonwoven for technical implementation has increased considerably in recent years in most areas, not as a simple replacement for other materials, but as a product with specific properties which can be used for various purposes. It's specific structure, resulting from the interaction between the raw materials and the manufacturing process, has been successful in several applications, providing, in according to the field, resistance, comfort, acoustic absorption and structure lightness. Therefore, from a brief review of the literature, the objective of this paper is to present the main techniques of web bonding and web forming for the production of nonwoven and present its potential for application in acoustic absorption when applied in civil area.

Keywords: forming; bonding, polyester, technical textile, civil construction.

RESUMO
O uso de não-tecidos para implementação técnica aumentou consideravelmente nos últimos anos na maioria das áreas, não como uma simples substituição para outros materiais, mas como um produto com propriedades específicas que pode ser usado para vários fins. Sua estrutura específica, resultante da interação entre a matéria prima e o

processo de fabricação, tem tido sucesso em diversas aplicações, proporcionando, de acordo com o campo, resistência, conforto, absorção acústica e leveza da estrutura. Portanto, a partir de uma breve revisão da literatura, o objetivo deste trabalho é apresentar as principais técnicas de colagem e formação de trama para a produção de não-tecidos e apresentar seu potencial de aplicação em absorção acústica quando aplicado na área civil.

Palavras-chave: conformação, colagem, poliéster, têxteis técnicos, construção civil.

1 INTRODUCTION

Most textile materials have properties in common, resulting from fiber, fabric and finishing manipulation, as well as comprehension of the interaction and the behavior in different combinations and environment (Horrocks and Anand, 2000).

The term technical textile can be defined as textile materials and products produced due to its technical properties and performance, to the detriment of its aesthetic or decorative attributes (Horrocks and Anand, 2000), (Iqbal, 2009). As a consequence, the technical textiles are continually overcoming barriers between the traditional use as home textile, and other materials such as paper, plastic, film, membranes, metals, ceramics, glass among others for new products and solutions.

According to the main international technical textile fair, which takes place in Germany, a *Techtextil Messe* Frankfurt, technical textile may be applied in 12 main segments (Iqbal, 2009), according to Table 1.

Table 1. Technical textiles segments and applications.

Segment	Applications
Agrotech	Agriculture, aquiculture, fruit farming and forestry applying materials
Buildtech	Civil construction
Clothtech	Specific technical components performance for shoes and garment
Geotech	Geotextile and applications in civil construction (highways, slope protections) and environmental engineering (landfields)
Indutech	Filtration, transport, cleaning and others industrial uses
Hometech	Technical components for furnishing, home textile and coatings
Medtech	Medicine and personal hygiene applying materials
Mobiltech	Automobile, maritime shipping, railways and Aerospace transport applications
Oekotech	Environmental protection

Packtech	Most diverse packages used for agriculture, industry among others
Protech	Personal and patrimonial protection
Sportech	Sports and leisure materials and products

2 METHODOLOGY

The methodology used in this review was based on a scientific literature research from Google Scholar of terms related to nonwoven, such as: technical textile; acoustic isolation; acoustic nonwovens; polyester acoustic insulation; technical fabrics; technical nonwovens; acoustical insulations for building.

Also, it was used data from other sources such as books, technical catalogues, handbooks and congress annals.

3 NONWOVEN DEFINITION

Among several substrates used in the textile area the nonwoven fabric stands out. It can be affirmed that from the development of nonwoven there was an expansion in the use of technical textile for some specific types of products, providing, depending on the application, an increase of properties of technical textile, presenting durable, breathable, water repellent, fire retardant and antimicrobial products, among others (Iqbal, 2009).

There are different definitions that can be found in the literature for the term nonwoven. Initially it was defined as a term used for structures that doesn't present the same behavior as those obtained in the traditional textile industry.

There is also a definition for nonwoven as a planar structure, produced from the compression of fibers and yarns. The Association of Nonwoven Industry (INDA) defines nonwoven as structures formed by webs consolidated for the entanglement of fibers or filament yarn by mechanical, thermal or chemical process (Chen, 2015).

The Brazilian Association of Technical Standards (ABNT) defines nonwoven as a plane, flexible and porous structure, constituted by webs from fibers or yarns, oriented targeting or randomly, consolidated by mechanical (friction) and/or chemical (adhesion) and/or thermal (cohesion), or by the combination of them (ABNT NBR 13370:2017). Furthermore, there is a wide variation of treatments that involve the processes of nonwoven finishing. The purpose may be the improvement of the touch, liquid absorption, water and dirt repellency, fire retardant, UV resistance and mechanical finishing. The application of products made from nonwoven is very comprehensive, including mainly, the following fields: filtration; automotive; medical; geotextile; construction industry; battery separator; thermal and acoustic insulator; hygienic products and development of composites.

Nonwoven may present solutions relative to engineering, that can be optimized, customized and made to measure. The Figure 1 illustrates the main segments of the application for nonwoven, with its respective field's sizes in percentage.

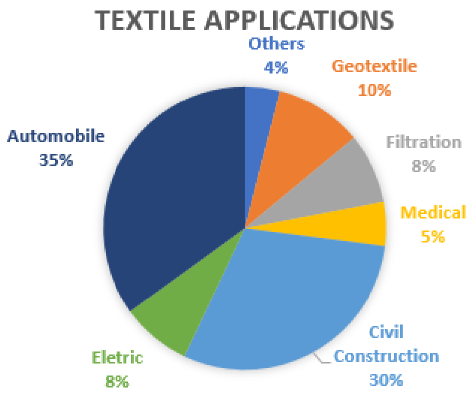


Figure 1. Main nonwoven applications (adapted from Kellie, 2016).

The use of nanofibers for nonwoven manufacture also stands out. It's noteworthy, that even when compared to other conventional textile materials, nonwoven fabrics that have positive environment characteristics, because of their light weight. In other words, making a product using a few amounts of material, affects in many benefits, as cost and reduction of carbon gas emission (Kellie, 2016). Furthermore, for its manufacture, recycled polymer, bioplastics, natural and sustainable materials can be used. The use of these materials has the objective of reducing the environmental impacts.

For the technical application of nonwoven, the use is predominantly made of fibers made of synthetic polymers, due to its versatility and resistance.

Raw materials are one of the most important factors in determining the properties of nonwoven. The chemical properties of the fibers determine the acid, base and solvent resistance; the physical properties determine the reaction to the mechanical strength, humidity, heat among others (Russel, 2007).

The development of nonwoven has mainly two stages: web forming and web bonding. Moreover, it is possible to classify the nonwoven accordingly to its raw material used, final application and consequently properties. The most common classification method is the production method (Albrecht et al., 2003).

Therefore, the objective of this present paper is to make a brief literature review about the different nonwoven classification, namely: weight; forming process; bonding process; and about its raw materials. Besides that, it will be presented the great potential of these materials' application on the widest range; namely: nonwoven on medicine/hygiene; household nonwoven; and mostly on absorption and isolation for acoustic use in civil construction.

4 CLASSIFICATION IN TERMS OF WEIGHT

According to Laerte et al. (1999), nonwoven can be classified according to its weight. Table 2 shows the classification.

Table 2. Classification in terms of weight

Weight [g/m²]	Classification
Less than 25	Light
Between 26 and 70	Medium
Between 71 and 150	Heavy
Above 150	Top-Heavy

The web, already structured but not consolidated yet, is formed by one or more layers of web made from fibers or filament obtained by three forming processes: dry laid; wet laid; and polymer laid process (Albrecht et al., 2003).

5 DRY LAID FORMING METHOD

On the dry laid forming process, the nonwoven is formed by carding machine (Carded) and by air jet (*Air Laid)* (Russel, 2007).

In the carded process, the fibers are parallelized by cylinders covered with "teeth", that form mainly anisotropic webs. Those webs may be produced in cross lapper. Figure 2 illustrates a conventional carding machine. This equipment is used on the production of web to be filling for quilts, pillows, jackets and thermal and acoustic isolation.

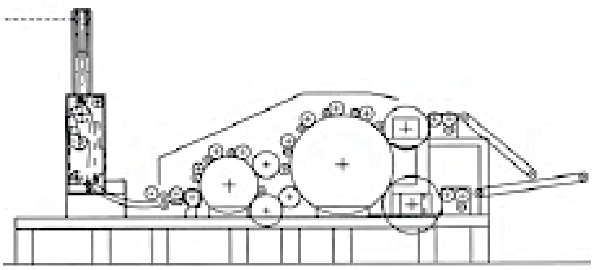


Figure 2. Conventional carding machine (adapted from AUTEFA).

Figure 3 illustrates the aerodynamic process, where the fibers are suspended by an air flow and then are collected by a netting forming a web.

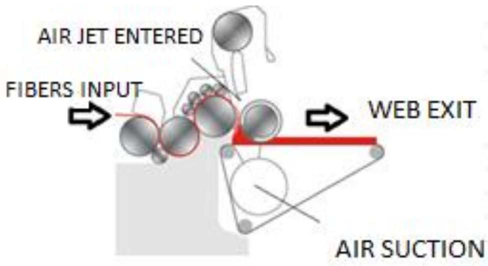


Figure 3. Aerodynamic forming method (adapted from AUTEFA).

6 WET LAID FORMING PROCESS

In the wet laid forming process, the fibers are suspended in an aqueous medium and then collected by bulkhead filtration, forming the web (Laerte et al., 1999). This process is similar to paper industry; however, the size of the fibers is slightly bigger.

7 POLYMER LAID FORMING PROCESS

Nonwoven is included in the molten process, produced by blowing spinning (Meltblown) and by continuous spinning (Spunbonded). These processes use polymer as raw materials (Laerte et al., 1999).

At Meltblown the polymer is melted by spinners with very small diameter holes and immediately a cold air flow quickly solidifies the mass in fibers that are blown in high velocity to a collecting netting forming the web (Figure 4).

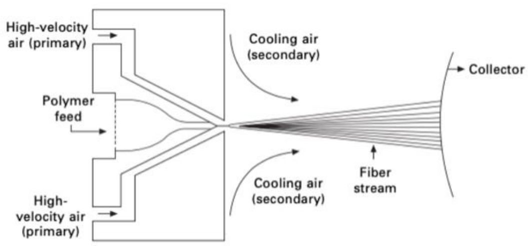


Figure 4. Meltblown forming method (adapted from Russel, 2007).

Figure 5 illustrates the spunbonded forming process. The polymer is molten through the spinneret, cooled and stretched, and later deposited on a conveyor belt shaped as a web.

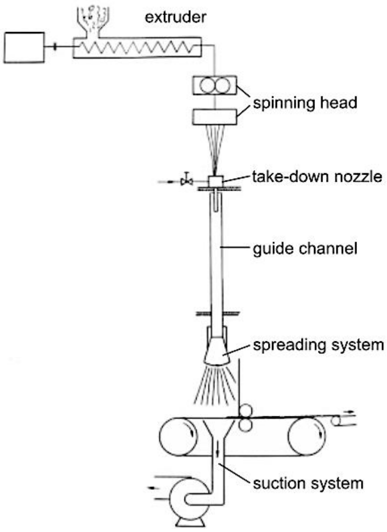


Figura 5. Spunbonded forming (adapted from Albrecht et al., 2003).

The Spunbonded and Meltblown processes when combined, can be used on the nonwoven production, for the medical area as surgical clothing and protection face masks. This combined process is usually known as SMS (Spunbonded + Meltblown + Spunbonded).

8 CLASSIFICATION IN TERMS OF BONDING PROCESS

After the formation of the web it is necessary to make its bonding (union of the fibers or filaments) to ensure resistance to the nonwoven. The finishing required for the final product is also granted (Laerte et al., 1999). There are three basic methods for bonding of nonwoven that also may be combined between each other: mechanical bonding (friction); chemical bonding (adhesion) and thermal (cohesion).

9 MECHANICAL BONDING BY NEEDLEPUNCH

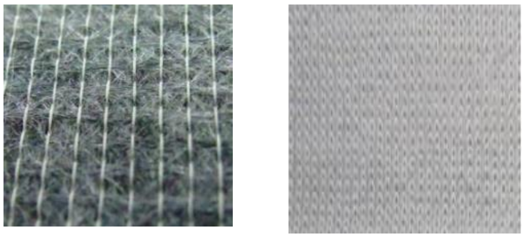
The fibers or filaments are intertwined through the alternate penetration of barbed needles. This process is used on the obtainment of thick nonwoven used in the production of artificial leather, carpet, automotive felts, filters and products of acoustic and thermal isolation (Russel, 2007).

10 MECHANICAL BONDING BY HYDROENTANGLED PROCESS (SPUNLACE)

The intertwining of the fibers or filaments is made by the penetration on the web by high pressure water jets (Laerte et al., 1999). Due to the use of fine and short fibers in this process, the result is nonwoven used in personal hygiene such as tissues, sanitary pads, and materials for disposable diapers.

11 MECHANICAL BONDING BY STITCH BONDING

The process of bonding or finishing by stitch bonding can be divided into two big groups: with the introduction of the yarns, that literally sew the nonwoven, called Maliwatt (Figure 6-a); or without the use of the yarns, which from the own fibers of the nonwoven, occurs the bonding of the material, called Malivlies (Figure 6-b).



a b

Figure 6. Stitchbonding: Maliwatt (a) and Malivlies (b).

12 CHEMICAL BONDING

The chemical binders make the union of the fibers or the filaments of nonwoven. There are several techniques to apply the chemical bonding: by impregnation; by foam; by pulverization and by the method of impression. Each process presents its particularities and consequently specific properties on the final product.

13 THERMAL BONDING

The thermal bonding of fibers or filaments from the nonwoven is made by the heat to the melting temperature of the constituent thermoplastic fibers followed by cooling to solidify the bonding area. Two methods stand out: the warmed calendering and through warm air flow.

The nonwoven produced by warmed calendering has a different characteristic, due pattern engraved surface on the embossed calendar roller. Consequently, they are materials that don’t present untangled fibers or filaments on its surface. Usually, they are not so thick, and its touch is similar to the paper (Figure 7) (Albrecht et al., 2003).

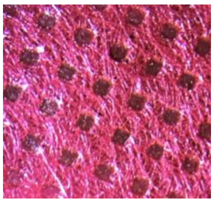


Figure 7. Nonwoven calendered by cylinder

When the bonding process uses the passage of warm air, normally it is used an oven where the nonwoven is laid above a perforated conveyor belt where the warmed air flows through the fibers.

14 CLASSIFICATION IN TERMS OF RAW MATERIALS

In most cases, the fibers/filaments represent the main raw materials used on nonwoven manufacturing. Its proportion in the final products varies between 30% to 100%. It is essential the nominal and percentage indication of the raw materials of the composition (Laerte et al.,1999).

The properties of the raw materials added to the supplied by the process of forming/bonding define the final characteristics of the nonwoven and also its performance. Therefore, the raw materials most used are:

- Artificial: viscose, glass fiber, acetate;
- Natural: wool, cotton, coconut, sisal, cashmere, asbestos;
- Synthetic: polyester, polypropylene, polyamide, polyacrylonitrile, polyethylene, polycarbonate.

15 NOWOVEN APLICATION AS ACOUSTIC INSULATING

Among several nonwoven technical applications, one that has more notoriety is referred to the use as acoustic absorbent materials.

In this regard, acoustic is defined as a science that studies the sound, including effects such as reflection, refraction, absorption, diffraction and interference. The sound can be considered as a physical phenomenon. The sound wave is longitudinal while the particles are temporarily displaced in a parallel direction to the energy transport and then return to their original position (Kannan, 2005).

The vibration of particles and their displacement in relatively dense waves, alternating to lower densities, result in the usual vibration of the environment, which is perceived by the auditory system. An acoustic wave might be described as a term of its variables such as: amplitude, frequency length, time period and intensity (Kannan, 2005).

- Amplitude: it refers to the height between the peak and the wave valley, in other words, maximum and minimum pressure;
- Frequency: it is determined by the number of maximum and minimum of the wave that the sound produces in a unit of time, usually measured in Hertz (Hz);
- Wavelength: it is the distance that the wave travels to make a complete cycle, which means, two peaks or two valleys;
- Time period: it is defined as the time that a wave performs a complete cycle;
- Intensity: it is defined as the average rate of acoustic energy that is transmitted through a unit of area.

The speed of the sound is determined by the quickness that the disturb is propagated from one particle to another one. In normal conditions of pressure and humidity at sea level, the sound travels in a rate of 344 m/s (Kannan, 2005).

The sound absorption is the result of the dissipation of the acoustic energy transformed in heat. The mechanism of dissipation happens when the sound penetrates the pores of the materials due to the pressure of the air. The oscillating air molecules interacts with the materials according to the frequency of the sound. This oscillation results in loss by friction (Kannan, 2005).

For this reason, fibrous materials are great acoustic absorption agents. Among several substrates, the nonwoven fabrics stands out. As it was verified, the nonwoven can be classified according to the raw materials used. So, there are some fiber parameters that may influence on the nonwoven forming and bonding process (Narang,1995):

- Fiber length;
- Fiber diameter;
- Fiber transversal section (round, trilobal, among others);
- Fiber count number;
- Crimp presence and type on the fiber (spiral or serrated)

Besides that, there are also parameters intrinsically related to the nonwoven forming and bonding method, such as the web disposition (parallel or crossed), density of the final product, air permeability, weight and thickness of the product (Narang, 1995).

All these properties are obtained from the synergy between the mechanical parameters, relative to the process, and the parameters of the own used material, granting a wide range of possibilities and solutions in most different areas.

16 STRUCTURAL PARAMETERS INFLUENCE OF THE FIBERS AND NONWOVEN TO ACOUSTIC ISOLATION/ ABSORPTION

Specifically, in the absorption/sound insulation segment, two very important properties intrinsic to the raw materials must be considered

Specifically, in the segment of acoustic absorption/isolation, it must be considered the shape of the fiber's transverse section (Figure 8). According to Figure 9, fibers with a tortuous transverse section (in black, 4GD) produce a higher resistance to the airflow (in blue and red, respectively trilobal and round), therefore they show more acoustic absorption (Mevlut; Edward, 2008).

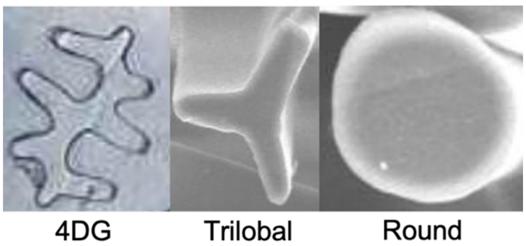


Figure 8. Fibers transversal section (adapted from Mevlut; Edward, 2008).

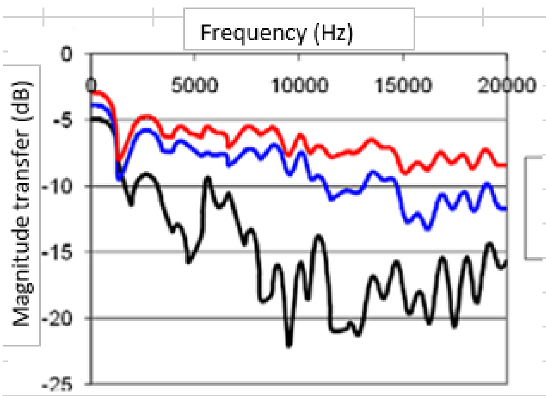


Figure 9. Influence of the fiber's transversal section on acoustic absorption (adapted from Mevlut; Edward, 2008).

In addition, the fiber's linear density also influences absorption. Fibers with lower linear density (considering direct count number) form nonwoven with a greater number of filaments by volume unit, providing the development of nonwoven of bigger density, analyzing the same fiber or a specific mixture. On the Figure 10, the fibers used present round cross section. In blue color indicates a fiber with 3 Denier and in red color a fiber with 15 Denier (Dilan; Osman, 2017) (Lee; Joo, 2013) (Mevlut; Edward, 2008) (Shahani, 2014).

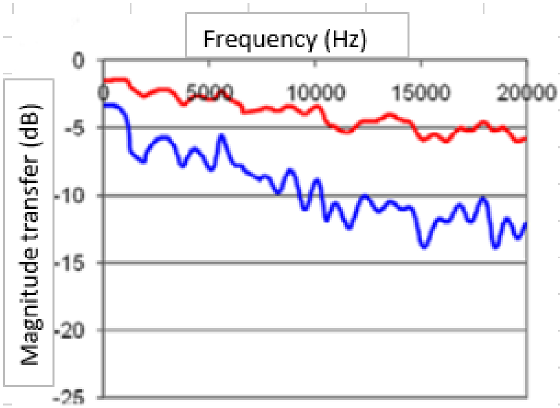


Figure 10. Influence of the fiber's count number on acoustic absorption (adapted from Mevlut; Edward, 2008)

Comparing the same fiber, materials with higher density result in more acoustic absorption, as it's shown in Figure 11, where in red the fiber shows 0,07 of density; in blue 0,16; in green 0,28; in brown 0,43 and in black 1.15 (Mevlut; Edward, 2008).

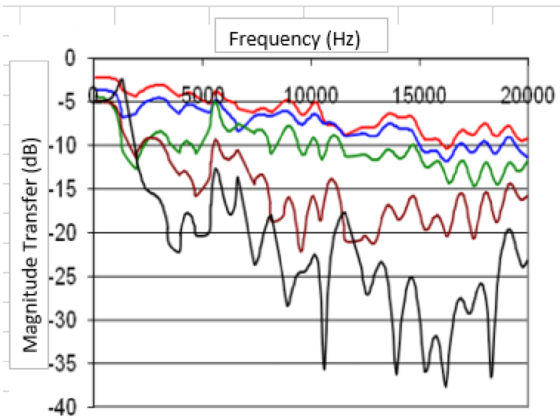


Figure 11. Influence of the nonwoven density on acoustic absorption (adapted from Mevlut; Edward, 2008).

For porous and fibrous materials, the acoustic performance is defined by a set of constants: absorption and reflection coefficient, acoustic impedance, propagation constant and transmission loss and reduction coefficient. In special case, the material's performance of the sound's absorption is evaluated by the absorption of the sound coefficient (α) (Kannan, 2005).

The coefficient of sound absorption (α) is defined as a measure of the acoustic energy absorbed by the material and it is usually expressed as a decimal variation between 0 and 1,0. If 55% of the sound energy incident is absorbed, the absorption coefficient of the material is 0,55. A material that absorbs all the sound waves incidents will have a absorption coefficient of 1 (Kannan, 2005).

This coefficient depends of the angle that the sound wave collides over the material and the frequency of the sound. It is usually found in the frequency standard of 125, 250, 500, 1000 and 2000 Hz. (Kannan, 2005) (Hoda, 2009).

Other acoustic important parameters that need to be considered while studying the acoustic absorption properties are (Hoda, 2009):

- Sound reflection coefficient: ratio of the sound intensity reflected amount and the total sound incident intensity.
- Sound impedance: ration between the sound pressure that acts on the sample surface and the speed of the particle normal to the surface.

Comparing sound absorbent materials to noise control, the coefficient of noise reduction (NRC) is normally used. It is intended for use as a unique index or number that defines the efficiency of one absorbent material. The values of NRC supply a quantification of how well the surface will absorb the human voice spectrum (Hoda, 2009), (Pedroso et al., 2017).

Therefore, the NRC is defined as the arithmetic average between the performance of the acoustic absorption of the material in 4 frequencies (250, 500, 1000 e 2000Hz). It must be used with caution because it doesn't represent the whole performance of the material (Pedroso et al., 2017). The Equation 1 illustrates the noise reduction coefficient.

$$NRC = \frac{\alpha_{250}+\alpha_{500}+\alpha_{1000}+\alpha_{2000}}{4} \qquad (1)$$

The use of nonwoven as acoustic insulating on civil construction has providing the development of thinner and lighter walls when compared to conventional walls, that are made by ceramic blocks, for the same acoustic development (Luca, 2018) (Figure 12).

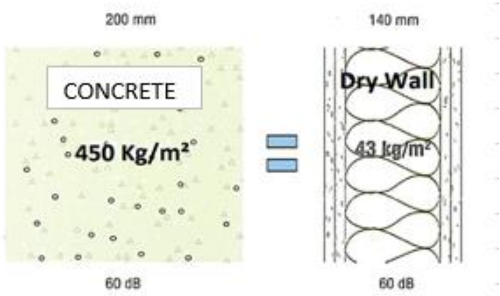


Figure 12. Comparation between a conventional wall and a drywall using nonwoven as inner insulating (adapted from Luca, 2018).

According to COMAT (2012), the drywall is a system used in the construction of walls and linings for inner and outsider environment, constituted by sheets of plaster screwed in galvanized steel, with high mechanical and absorption acoustic.

So, comparing a drywall with 70mm of thickness without the presence of nonwoven inside the cavity with a drywall filled with nonwoven (both walls with standards sheets of 12,5mm of plaster on each side, totalizing a 95mm width), the wall with nonwoven presents and average isolation gain of approximately 8 dB (Figure 13). This gain is significant, since the increase to 3 dB on the acoustic scale should double the station's source, meaning a three-fold reduction between the station and recipient source (Holtz and Frias, 2015) (Luca, 2018).

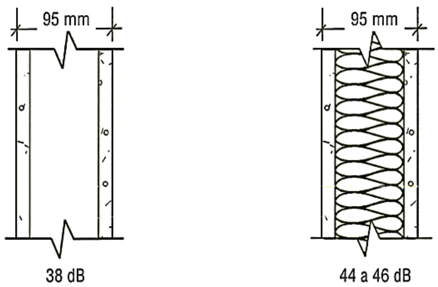


Figure 13. Comparative between drywall with and without nonwoven filling as internal insulating (adapted from Luca, 2018).

To module-based lining the use of nonwoven is analogous to the walls, giving the structure lightness as shown in Table 3, which compares a mineral nonwoven from ARMSTRONG Company with a polyester nonwoven from ECOFIBER brand, both of the same thickness.

Table 3. Comparation between the mineral lining and the polyester nonwoven lining.

Material	NRC	Weight [g/m²]	Thickness [mm]
Mineral	0,50	3.660	15
Polyester nonwoven	0,49	830	15

According to Table 3, it is shown that the difference in the NRC is 1dB for materials of the same thickness. However, the lining produced by the polyester nonwoven is 4.4 lighter than the mineral, relieving the structural load, reducing the number of anchor points that support the lining in the concrete ceiling.

Table 4 demonstrates the elevated index of the NRC and α to nonwoven with relativity lower weight, used in civil construction.

Table 4. Sound absorption of nonwoven polyester.

Thickness [mm]	Weight [g/m²]	NRC	α
50	1000	0,70	0,75
50	1250	0,75	0,75
50	1500	0,75	0,75
50	1750	0,80	0,80
100	2000	0,85	0,90
100	2500	0,85	0,90

17 CONCLUSION

It is noticed that there are many used ways to classify the nonwoven fabric, since the production method (forming and bonding), as well as the intrinsic parameters from the ram material used. The synergy between the involved variables will provide the characteristics to the final product, allowing the use of nonwoven on most several technical areas.

It is also noticed that the use of nonwoven, in specific application, such as acoustic absorption/ insulating used mostly in civil construction, has been gaining notoriety, due to its presented performance.

Matters as safety, weight reduction and versatility of application are also factors that add up to the success of nonwoven to the technical segment, combining knowledge in the areas of textile and civil engineering.

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