Chapter 3
Cork Agglomerates in Acoustic Insulation

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3.1 Introduction

Sound control and effective acoustic insulation are vital considerations across numerous industries, encompassing construction, automotive, aerospace, and entertainment. As concerns about noise pollution grow and the demand for improved sound management escalates, researchers and engineers continually seek innovative materials to achieve optimal acoustic insulation solutions.

To comprehend the principles of acoustic insulation, it is imperative to first grasp the nature of sound and its propagation through different materials. Sound is a form of mechanical energy that travels in the form of waves, generated by the vibration of a source, such as a loudspeaker or human vocal cords. These sound waves consist of alternating compressions and rarefactions of air particles, propagating outward in all directions from the source. When sound encounters a surface, a portion of the energy is reflected, while the rest is transmitted or absorbed [1]. The ability of a material to reduce the transmission of sound waves is known as sound insulation or soundproofing. Materials with effective sound insulation properties can significantly attenuate noise transmission, thereby creating quieter environments [2].

Acoustic insulation is the process of minimizing sound transmission between spaces or materials. It plays a critical role in controlling noise and achieving acoustic comfort in various settings, ranging from residential and commercial buildings

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to transportation vehicles and industrial facilities. One of the primary objectives of acoustic insulation is to reduce noise transmission from external sources to indoor spaces, providing a peaceful and undisturbed environment for occupants. Another one is minimizing noise transmission between different areas within a building or vehicle, ensuring privacy and acoustic separation. We can also count in enhancing the acoustic performance of products and structures, contributing to a higher quality of sound reproduction and clarity. Effective acoustic insulation is crucial in numerous applications, including home theaters, recording studios, concert halls, classrooms, hospitals, and offices. It also holds immense significance in the automotive and aerospace industries, where it helps mitigate road or engine noise, leading to a more comfortable and enjoyable experience for passengers [2–4].

Cork agglomerates are engineered materials created from the natural bark of the cork oak tree (*Quercus suber L.*). The unique cellular structure of cork, consisting of tiny air-filled chambers enclosed by a flexible cell wall, is a defining characteristic that contributes to its remarkable acoustic insulation properties. The composition of cork agglomerates typically involves granulated cork particles that are carefully processed and bonded together using a binding agent. The granules vary in size and may be mixed with other additives to achieve specific properties and performance characteristics. This flexibility in composition allows cork agglomerates to be tailored for various acoustic insulation applications. When sound waves interact with cork agglomerates, the air trapped within their cellular structure causes sound energy to be absorbed and transformed into heat. Additionally, the flexibility and viscoelasticity of cork cells enable them to convert some of the sound energy into mechanical vibrations, further dissipating the acoustic energy [5]. The combination of these mechanisms results in a material that effectively attenuates sound waves, making cork agglomerates highly effective for acoustic insulation purposes. The intrinsic properties of cork, such as its low density, non-toxicity, and resistance to moisture, also contribute to its suitability for a wide range of applications in sound control and acoustic engineering [6, 7]. Figure 3.1 shows the microstructural views of cork agglomerates.

The manufacturing of cork agglomerates involves several essential steps, each crucial in determining the final material's properties. The first step is harvesting and preparing the cork bark. Cork is sustainably harvested from the cork oak tree's outer bark, ensuring minimal impact on the tree's health. After harvesting, the cork bark is left to dry and age for several months, during which it undergoes natural changes that enhance its properties. The dried cork bark is then crushed or granulated into small pieces of varying sizes. The size of the granules can be tailored to achieve specific acoustic insulation properties. To create cork agglomerates, a binder is added to the cork granules. The binder serves as an adhesive, bonding the granules together to form cohesive blocks or sheets of cork agglomerates. The mixture of cork granules and binder is then placed into molds, where it undergoes compression to form the desired shape and density. The compression process allows for the

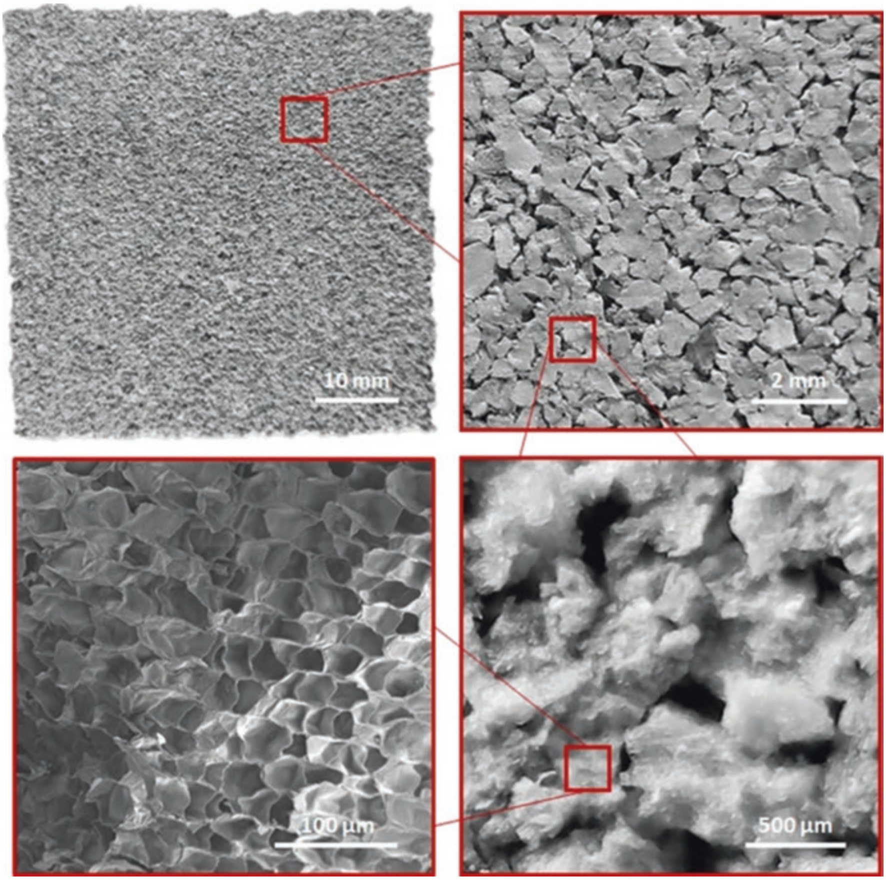

Fig. 3.1 Microstructural views of cork agglomerates [8]

formation of a cohesive and uniform structure. After molding, the cork agglomerates undergo a curing process to allow the binder to set and strengthen the material. This step is essential to ensure the integrity and stability of the final product. Following curing, the cork agglomerates are conditioned in controlled environments to achieve the desired moisture content and acoustic properties. Depending on the application and desired characteristics, the surface of cork agglomerates may undergo additional surface treatment. Surface treatments can include coatings, laminations, or texturing to further enhance acoustic performance or improve aesthetics. The manufacturing process is designed to produce cork agglomerates with consistent properties and reliable acoustic insulation capabilities. The versatility of the material allows for various forms such as cork boards, panels, sheets, or granulated cork, making it adaptable to different installation requirements and applications [9, 10].

3.2 Factors Affecting Acoustic Insulation

The acoustic insulation performance of cork agglomerates is influenced by various factors that engineers and researchers must consider when designing and implementing acoustic solutions. Understanding these factors is essential to optimize the material's effectiveness in different applications. One of the key factors is material density. The density of cork agglomerates plays a significant role in their acoustic performance. Higher density materials generally exhibit better sound insulation capabilities due to increased mass and reduced sound transmission. However, there is an optimal density range for specific applications, as excessively high density may affect the material's flexibility and sound absorption characteristics. Material thickness is another important factor on the acoustic insulation performance. The thickness of cork agglomerates directly impacts their sound absorption and sound insulation properties. Thicker materials can provide higher sound transmission loss and enhanced sound absorption at lower frequencies. For applications requiring effective sound blocking, a thicker layer of cork agglomerates may be necessary to achieve desired results. On the other hand, surface treatments, such as coatings or laminations, can modify the acoustic properties of cork agglomerates. They can enhance sound absorption, reduce sound reflection, and improve durability. Different surface treatments may be applied based on specific application requirements, allowing for a more tailored acoustic solution [6]. Air content in the material is also determinant on the acoustic properties. When using cork agglomerates as part of a partition or sound barrier, the presence of an air gap can significantly impact sound transmission. Air gaps act as additional barriers to sound energy, contributing to higher sound insulation performance. The size and configuration of the air gap relative to the cork agglomerates should be carefully considered to optimize acoustic performance [11, 12]. Temperature and humidity are other factors affecting the mechanical properties of cork agglomerates, potentially influencing their acoustic performance. Extreme temperature fluctuations or high humidity levels might alter the material's dimensions and stiffness, which, in turn, can affect its sound absorption and insulation capabilities [13]. The structural integrity of cork agglomerates is crucial for long-term acoustic performance. Any damages or defects in the material can reduce its effectiveness in sound insulation and absorption. Proper handling, installation, and maintenance are essential to preserve the material's integrity over time. The acoustic properties of cork agglomerates can vary across different frequency ranges. Understanding how the material behaves at various frequencies is essential for matching its performance to specific noise control requirements. The material's ability to absorb sound may be more effective at certain frequencies, while its sound-blocking capabilities may excel at others. Carefully considering these factors and conducting thorough testing and characterization, engineers can optimize cork agglomerates for specific acoustic insulation applications [14]. The interplay of these factors allows for versatile applications, from reducing external noise in buildings to enhancing sound quality in musical or audio environments.

3.3 Position of Cork Agglomerates Among Acoustic Insulating Materials

To evaluate the acoustic insulation capabilities of cork agglomerates effectively, it is essential to compare them with other traditional and innovative materials commonly used for sound control. Each material possesses unique properties that influence its performance in various acoustic conditions. Fiberglass insulation is a widely used material for soundproofing in construction applications. It offers good sound absorption properties due to its fibrous structure, which traps sound energy. However, compared to cork agglomerates, fiberglass can be more challenging to work with due to potential skin irritation during installation and its susceptibility to moisture damage [15, 16]. Cork agglomerates, on the other hand, are naturally resistant to moisture and offer the additional benefits of sustainability and eco-friendliness. Foam insulation materials, such as polyurethane foam, are known for their versatility and ease of installation [17, 18]. While they can offer good sound absorption properties, they may not be as effective as cork agglomerates in blocking sound transmission. Cork's unique cellular structure allows it to excel in both sound absorption and transmission loss, making it a well-rounded option for various acoustic insulation applications. Mass-loaded vinyl (MLV) is a dense, flexible material commonly used for soundproofing [19]. It is highly effective in blocking sound transmission and is often employed in combination with other materials. MLV's strength lies in its ability to add mass to partitions or barriers, but it may not have the same sound absorption capabilities as cork agglomerates. Utilizing cork agglomerates alongside MLV can provide a comprehensive acoustic solution that addresses both absorption and transmission loss. Soundproof drywall incorporates materials such as gypsum and viscoelastic polymers to enhance sound insulation. While soundproof drywall can offer excellent sound-blocking properties, it might lack the sound absorption capabilities of cork agglomerates. Combining soundproof drywall with cork agglomerates can create a balanced approach to achieve optimal sound control in various applications.

In comparison to synthetic or mineral-based materials, cork agglomerates stand out as an eco-friendly and renewable choice for acoustic insulation. Materials such as cork demonstrate low embodied energy, meaning they require minimal energy during production, contributing to a lower carbon footprint. Choosing cork agglomerates aligns with sustainable building practices and environmental consciousness [8, 24]. It is essential to consider specific application requirements when selecting acoustic insulation materials. While cork agglomerates excel in numerous scenarios, the choice of material depends on factors such as the desired acoustic performance, budget constraints, environmental impact, and ease of installation. Cork agglomerates offer a compelling combination of sound absorption and sound insulation capabilities, making them an attractive option for various acoustic challenges. Their eco-friendly nature, low toxicity, and unique cellular structure set them apart

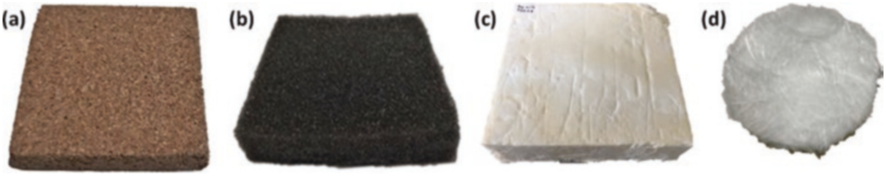

Fig. 3.2 Various insulation materials: (**a**) cork agglomerates [20], (**b**) polyester foam [21], (**c**) polyurethane foam [22], and (**d**) fiberglass [23]

from conventional insulation materials. By carefully assessing project-specific needs and considering material advantages and limitations, designers and engineers can leverage cork agglomerates to create quieter, more comfortable, and environmentally sustainable spaces [25, 26]. Figure 3.2 shows various acoustic insulation materials used in the applications.

3.4 Acoustic Insulation Applications with Cork Agglomerates

The exceptional acoustic insulation properties and eco-friendly nature of cork agglomerates make them highly versatile and well-suited for various applications across different industries. Building and construction sector is one of the biggest application areas for cork agglomerates. In the construction industry, cork agglomerates find extensive use in creating quieter and more comfortable living and working spaces. They are utilized as wall and ceiling panels, flooring underlayment, and acoustic insulation in partition walls. Sound absorption capabilities of cork agglomerates contribute to reducing noise reverberation and improving speech intelligibility, making them valuable additions in classrooms, offices, conference rooms, auditoriums, and entertainment venues [27]. Automotive and transportation are other sectors using cork agglomerates as acoustic insulators. Cork agglomerates play a vital role in these sectors, where noise control is essential for passenger comfort. They are used as insulating materials in vehicle interiors, reducing road and engine noise. By installing cork agglomerates in areas such as door panels, floors, and engine compartments, automotive manufacturers can create quieter and more pleasant driving experiences [28]. In the music and entertainment industry, sound quality and acoustic performance are paramount. Cork agglomerates contribute to creating acoustic environments with enhanced sound clarity and reduced echoes. They are utilized in recording studios, music practice rooms, home theaters, and concert halls to optimize sound absorption and eliminate unwanted reflections, ultimately delivering a superior auditory experience. Industrial facilities often generate significant noise levels from machinery and equipment. Cork agglomerates serve as effective noise barriers and absorbers in these environments, helping to control

Fig. 3.3 Cork-based acoustic panels with different designs [29]

noise pollution and protect workers' hearing health. They are commonly applied to equipment enclosures, machine guards, and plant partitions to mitigate noise transmission. Figure 3.3 shows cork-based acoustic panels with different designs.

Cork agglomerates are utilized in heating, ventilation, and air conditioning (HVAC) systems to reduce the transmission of mechanical noise and vibrations. By incorporating cork agglomerates in HVAC ducts and enclosures, unwanted noise levels can be minimized, ensuring a quieter and more pleasant indoor environment for occupants. In marine and aerospace applications, where space and weight are critical considerations, cork agglomerates offer a lightweight and efficient solution for sound control. They are used in boat and yacht interiors, as well as aircraft cabin components, to achieve effective acoustic insulation without adding unnecessary weight [30]. Cork agglomerates are increasingly finding applications in the renewable energy sector. They are employed as insulating materials in wind turbine components to reduce noise emissions during operation. Additionally, cork agglomerates may be utilized in solar panels to enhance soundproofing and reduce the impact of environmental noise.

3.5 Environmental Impact and Sustainability of Cork Agglomerates

The use of cork agglomerates for acoustic insulation aligns perfectly with the principles of environmental conservation and sustainable practices. As an eco-friendly material, cork agglomerates offer significant advantages that contribute to green building initiatives and sustainable development. Cork agglomerates are derived from the bark of the cork oak tree, which can be harvested without harming the tree. The cork oak tree has a unique ability to regenerate its bark after harvesting, allowing for periodic and sustainable cork extraction. This renewability ensures a continuous supply of raw material without depleting natural resources. Furthermore, cork oak forests serve as valuable carbon sinks, actively sequestering carbon dioxide from the atmosphere. The process of bark regeneration leads to increased carbon absorption, contributing to the mitigation of greenhouse gas emissions. By supporting the use of cork agglomerates, we indirectly support the preservation and expansion of these vital cork oak ecosystems [9, 11, 31].

The production of cork agglomerates requires minimal energy compared to many conventional insulation materials. Low embodied energy refers to the reduced energy consumption during the material's extraction, processing, and manufacturing stages. As a result, cork agglomerates have a lower carbon footprint and are considered a more sustainable option for acoustic insulation. Cork agglomerates can also be recycled and reused for other applications at the end of their life cycle. Recycling cork waste from manufacturing processes or old cork-based products contributes to a circular economy and reduces waste. This recycling capability further enhances the sustainability credentials of cork agglomerates.

Cork agglomerates are biodegradable, meaning they naturally break down over time without causing harm to the environment. When disposed of properly, cork agglomerates do not contribute to pollution or landfill waste, making them an environmentally responsible choice. In addition, cork agglomerates are nontoxic and hypoallergenic, posing no health risks to occupants or installers. Unlike some synthetic insulation materials, cork does not emit harmful chemicals or volatile organic compounds. This ensures a safe and healthy indoor environment, especially in residential and healthcare settings [9]. The environmental benefits of cork agglomerates align with the requirements of various green building certification systems, such as Leadership in Energy and Environmental Design (LEED) by the US Green Building Council. Using cork agglomerates in construction projects can earn credits toward LEED certification, further promoting sustainable building practices. Cork agglomerates exemplify the harmony between acoustic performance and environmental sustainability. As a renewable, carbon-sequestering, low-energy material, cork agglomerates contribute to eco-conscious construction and sustainable development practices. Embracing cork agglomerates for acoustic insulation projects not only enhances sound control and comfort but also supports efforts to protect the planet's natural resources and combat climate change.

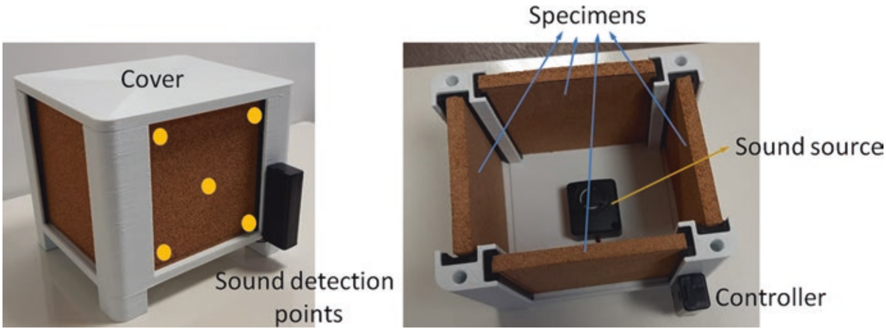

Fig. 3.4 Sound insulation test setup

3.6 A Case of Acoustic Insulation: Comparison of Insulators

3.6.1 Experimental Details

To demonstrate the acoustic insulation performance of cork agglomerates, a set of acoustic insulation materials were investigated by using an in-house test setup as shown in Fig. 3.4. As shown in the figure, a sound source is located at the center of test frame while covering the four sides with the specimens. After closing the cover, the sound is enabled by using the controller unit. The sound source produces a sound with the intensity of 110 dB based on the measurements inside the test system. To investigate the acoustic insulation performances with the specimens, a sound meter was used to measure the insulated sound levels at five sound detection points on each face. The averages of the sound levels were calculated and compared to discuss the acoustic insulation performance of the specimens.

In this study, four materials such as cork agglomerates, AA6061, extruded polystyrene (XPS), and polyurethane (PU) were investigated. The results were compared to each other to understand the position of cork agglomerates among the engineering materials in terms of acoustic insulation performance. The specimens were sized into 120 × 120 mm^2 panels for using them in the test system. The thickness of the specimens was kept at 10 mm. Table 3.1 gives the details of the specimens.

3.6.2 Results and Discussion

Figure 3.5 shows the sound intensity after insulating the sound source with the investigated materials. According to the sound measurements upon cork insulation, the intensity of 110 dB at the sound source reduces to 86.8 dB, which gives the lowest sound intensity among the investigated insulation materials. On the other hand, AA6061 plate shows the lowest performance with the sound intensity of 102.4 dB after insulation. XPS- and PU-based insulators exhibit higher acoustic insulation

Table 3.1 Details of the specimens

Specimen	Properties
Cork agglomerates 	Binder: Polyurethane Granule size: 0.5–1.0 mm Density: 170 kg/m^3
AA6061 plate 	Density: 2670 kg/m^3
XPS layer 	Density: 35 kg/m^3
PU foam 	Density: 40 kg/m^3

performances than AA6061 plate and the sound intensities are measured as 95.1 and 89.9 dB, respectively.

Aluminum alloys do not possess high damping characteristics, which means they do not dissipate sound energy efficiently. Although aluminum alloys may offer some level of sound insulation, they are not the primary choice for acoustic applications. Instead, they are preferred for their mechanical properties and are used in various industries such as aerospace, automotive, construction, and manufacturing. Hence, the lowest performance of AA6061 among the other materials is an expected

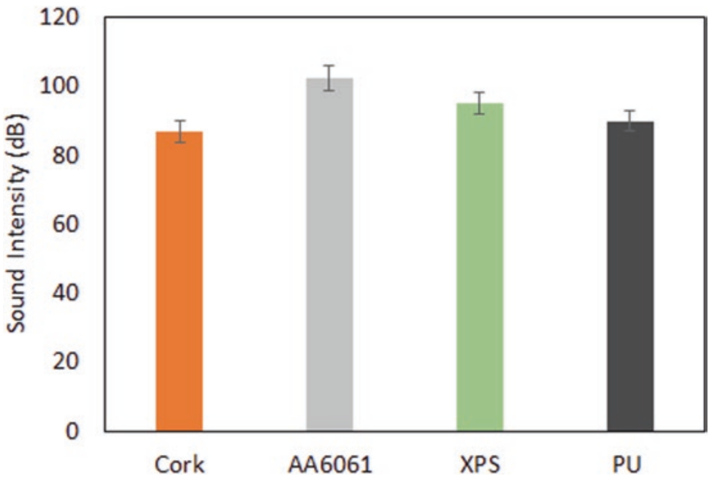

Fig. 3.5 Sound intensity after insulating the sound source

outcome in this work. For acoustic insulation purposes, specialized materials such as cellular structures, acoustic foams, and other dense and porous materials are commonly employed to achieve better soundproofing results. These materials are designed to absorb, block, or dampen sound waves effectively. From this aspect, XPS, PU, and cork agglomerates come to the forefront due to their porous microstructures.

XPS is a type of rigid foam insulation commonly used in construction and building applications. When it comes to acoustic insulation, XPS has some favorable properties that can contribute to reducing sound transmission. XPS has a cellular structure that includes closed cells. These closed cells provide sound absorption properties, helping to reduce the echo and reverberation of sound waves within a space. XPS provides some damping properties that can help reduce the vibration of sound waves passing through it. Therefore, this can contribute to limiting sound transmission. Despite this advantage with XPS, its primary purpose is thermal insulation. On the other hand, PU is a versatile and widely used material known for its excellent insulating properties. Regarding the acoustic insulation, PU-based materials can be effective in certain applications due to its unique characteristics. Due to its porous microstructure, the trapped air in the PU helps dissipate sound energy, making it effective at absorbing and reducing sound reflections and reverberations within a space. It is commonly used in sound-absorbing panels or as an acoustic treatment in studios, theaters, and other spaces where echo and noise control are important. The advantage of cellular structure is also benefitted from cork agglomerates in sound insulation. Air-filled cells within the cork granules allow the material to effectively absorb sound waves and reduce sound reflections and reverberations. In addition, cork-based materials provide sustainable and eco-friendly solutions in engineering applications, which eliminate the side effects of synthetic materials harmful to environment.

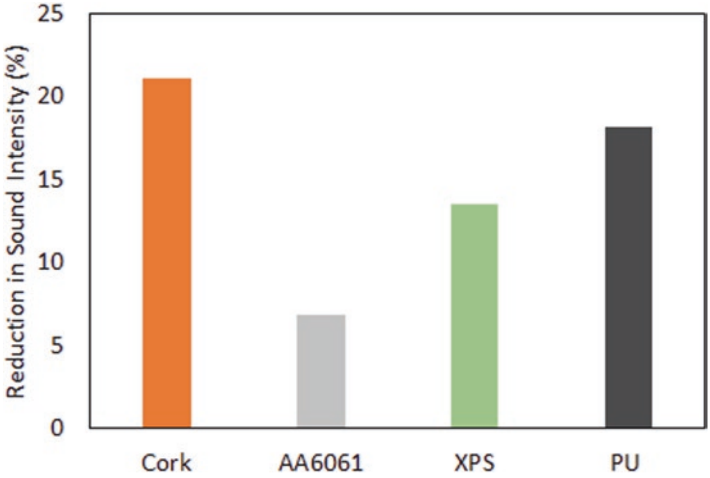

Fig. 3.6 Reduction in sound intensity after insulating the sound source

Figure 3.6 shows the reduction in sound intensity after insulating the sound source. It is clearly seen that AA6061 provides a reduction about 7%, which is quite a low magnitude in sound blocking. On the other hand, the reduction in sound intensity reaches up to 13.5% with XPS insulation. Using PU foam, the reduction in sound intensity jumps higher to the level of 18%. Cork agglomerates enhance the insulation performance and reaching the reduction of 21% in sound intensity. It is also important to note that material density is another key factor in acoustic insulation applications. The density of a material plays a significant role in determining its effectiveness in reducing the transmission of sound waves, and it directly influences the material's sound insulation properties. In this case study, material densities were used as-received and not optimized for better insulation.

3.7 Conclusions

The exploration of acoustic insulation properties by cork agglomerates has unveiled a material that exemplifies the harmonious blend of superior sound control and environmental sustainability. As a renewable resource derived from the bark of the cork oak tree, cork agglomerates offer unique cellular structures that excel in both sound absorption and transmission loss, making them highly effective in creating quieter and more comfortable environments.

Throughout this chapter, we investigated the composition and manufacturing process of cork agglomerates, understanding the factors influencing their acoustic insulation performance. In addition, various applications of cork agglomerates in industries ranging from construction and automotive to music and entertainment were explored to showcase their versatility in addressing diverse sound control challenges. The environmental benefits of cork agglomerates were highlighted, emphasizing their status as a renewable resource, carbon sink, and low-energy material. The eco-friendly nature of cork agglomerates aligns seamlessly with green building practices and sustainable development, contributing to efforts to combat climate change and promote responsible resource management. As we look to the future, the research and development of cork agglomerates are expected to progress, exploring advanced manufacturing techniques, hybrid materials, and smart insulation applications. This ongoing innovation will likely lead to enhanced acoustic performance, further solidifying cork agglomerates' position as a go-to solution for effective sound control.

A case study was carried out to demonstrate the position of cork agglomerates in acoustic insulation applications. In this investigation, cork agglomerates were compared to other engineering materials such as AA6061, XPS, and PU in terms of acoustic insulation performance. The investigation focused on the sound transmission through the materials. According to the results, AA6061 showed the lowest acoustic insulation performance. XPS and PU layers provided enhanced performance in sound insulation due to their porous structures. However, cork agglomerates left behind these materials and provided the highest sound insulation performance in this study. In addition to their promising sound blocking performance, cork agglomerates have demonstrated their merit as a reliable and eco-conscious material in various industries. As engineers, designers, and researchers continue to unlock its full potential, we can anticipate a quieter and more sustainable future, where cork agglomerates play a key role in fostering environments that promote well-being, productivity, and acoustic comfort.

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