Chapter 6
Cork-Based Structures in Energy Absorption Applications

Mohammad Rauf Sheikhi, Zihao Xie, and Jian Li

6.1 Introduction

6.1.1 Energy Absorption in Engineering Structures

The process of transferring kinetic energy into other types of energy like heat, or deformation to lessen impact force and protect the structure or vehicle from damage is energy absorption (EA). EA is critical for engineering structures, particularly those subjected to dynamic loading conditions such as impact and blast pressure (see Fig. 6.1). These incidents can cause catastrophic structural damage or failure, resulting in human deaths, economic losses, or environmental consequences [2, 3]. Therefore, design a structure that can absorb and dissipate impact energy and maintain the integrity of the structure, is essential. There are several ways to achieve EA in engineering structures such as increasing the strength and stiffness of materials, using sacrificial components that deform or fracture plastically, or incorporating devices that dissipate energy through friction, damping [4]. However, these methods often have disadvantages such as increasing the weight and cost of the structure, reducing the performance and useful life of the structure, or requiring complex maintenance and replacement. Therefore, there is a need for alternative solutions that can provide efficient and effective EA with minimal defects. One of these solutions is the use of cellular materials such as foams, honeycombs structures as energy

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M. R. Sheikhi (✉) · Z. Xie · J. Li
The State Key Laboratory of Heavy-duty and Express High-power Electric Locomotive, Central South University, Changsha, China

Key Laboratory of Traffic Safety on Track of Ministry of Education, School of Traffic & Transportation Engineering, Central South University, Changsha, Hunan, China

National & Local Joint Engineering Research Center of Safety Technology for Rail Vehicle, Central South University, Changsha, China
e-mail: mohammadraufsheikhi@csu.edu.cn

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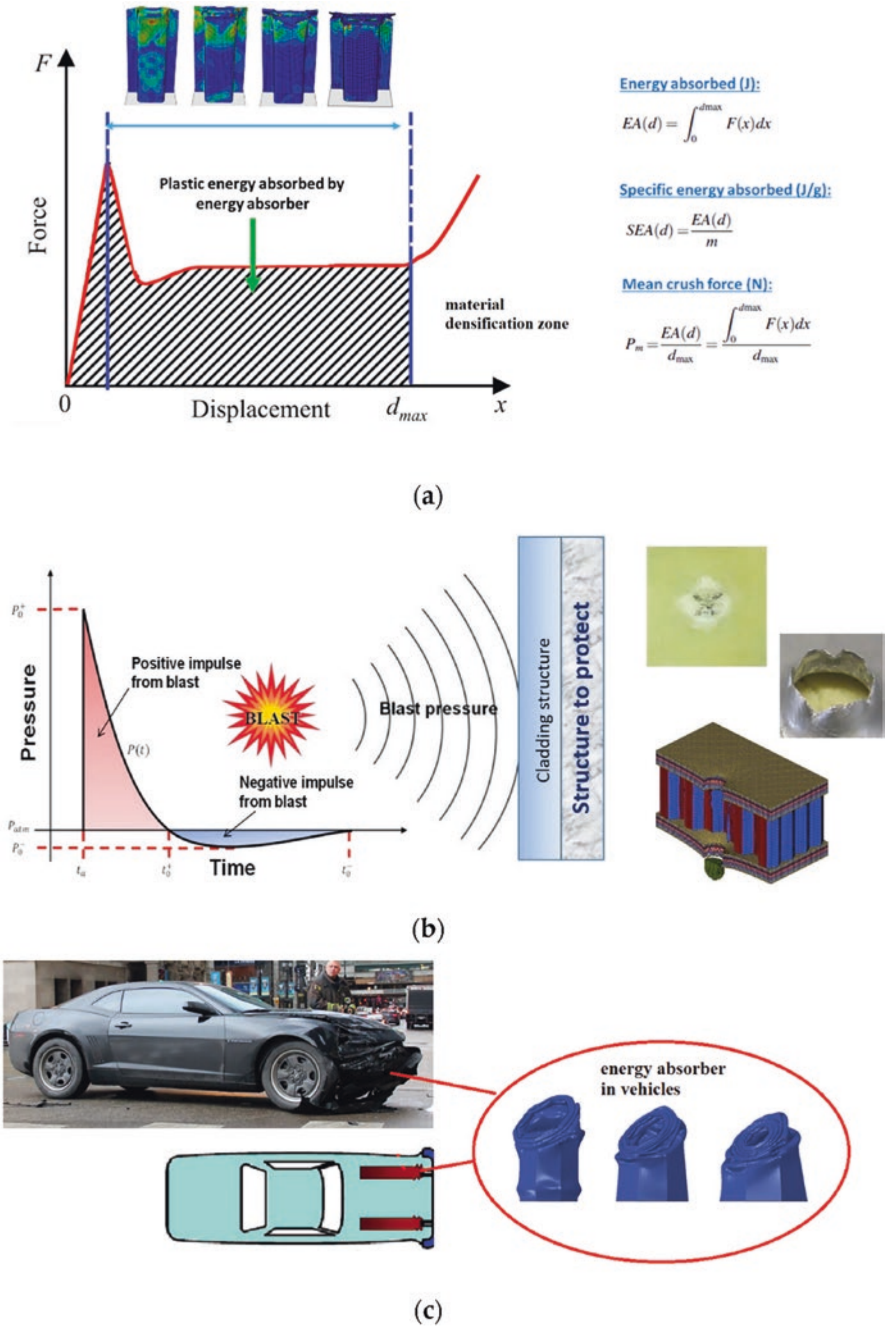


Fig. 6.1 (**a**) EA of thin-walled structures via plastic folding, (**b**) energy absorbers employed as cladding structures for blast resistant applications, (**c**) vehicle safety energy absorbers [1]

absorbers. Cellular materials are porous materials that consist of a network of cells of different shapes and sizes. They have low density and high specific strength and hardness, which makes them suitable for light weight structures. They also have a high specific energy absorption (SEA) capacity, meaning they can absorb a large amount of energy per unit mass. This is because they can undergo large deformation under compressive loading without a significant increase in stress. The deformation mechanism of cellular materials depends on cell geometry and topology, which can be designed to achieve different EA properties [5, 6].

There are two categories of cellular materials which are open-cells and close-cells [7]. First, they can induce large amounts of deformation and energy dissipation without causing high stress levels in the structure. This can reduce the risk of structural failure and increase occupant safety and survival. Second, they can provide tunable and multifunctional properties by changing cell shape, size, density, arrangement, orientation, material composition, or filling medium [8, 9]. This can enable the design of optimal structures that can meet specific requirements for different loading scenarios and applications. Third, they can exhibit self-healing or self-healing capabilities by recovering their shape and properties after deformation. It can increase the service life and reduce the maintenance cost of the structure. Cellular materials have been widely used as energy absorbers in various engineering fields such as aerospace, automotive, civil engineering, medical engineering, sports equipment, packaging industry, and personal protective equipment. Some examples of cellular materials that have been used for EA purposes include metal foams, polymer foams, ceramic foams, composite foams, honeycomb structures, acoustic structures, lattice structures, origami structures, and metamaterials [3, 5].

6.1.2 Cork Definition

Cork is a natural material obtained from the bark of cork oak trees. Cork oak trees are renewable and sustainable, as they can live up to 200 years and regenerate their bark after harvesting [10, 11]. Cork harvesting is a traditional and manual process that does not harm the trees or the environment. The cork is harvested every 9–12 years when the bark reaches a certain thickness and quality. The bark is carefully removed from the trunk and branches of the tree, leaving a thin layer of cork that protects the tree from diseases and insects. The harvested bark is then transported to factories, where it is boiled, cleaned, graded, and made into various cork products [12]. Cork has a unique cellular based structure consisting of closed cells filled with air and surrounded by a thin layer of suberin. Suberin is a hydrophobic substance that makes cork impermeable, buoyant, elastic, and fire resistant. Cork cells are usually pentagonal or hexagonal in shape (as shown in Fig. 6.2c), and their size and density vary depending on the origin and quality of the cork [13, 14]. The cork cell wall consists of a thin middle layer rich in lignin, a thick secondary wall composed of alternating suberin and waxy lamellae, and a thin third wall of polysaccharides (see Fig. 6.2). Early works state that the secondary wall is slippery and

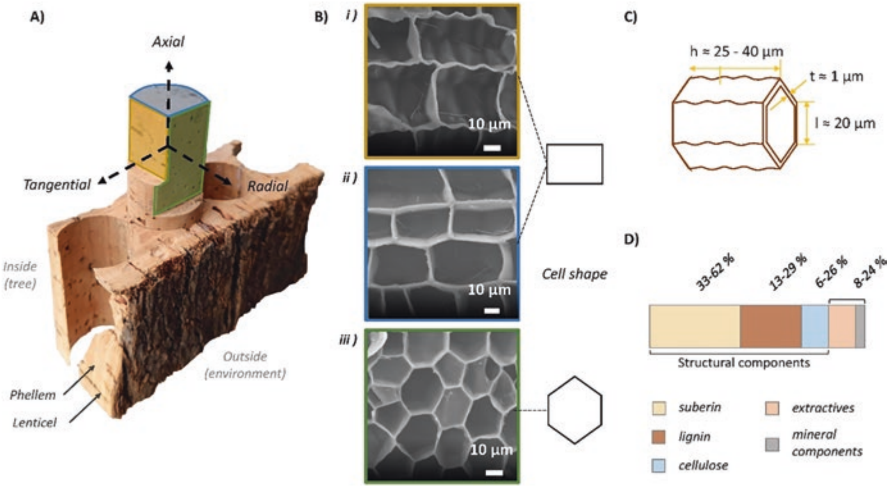


Fig. 6.2 Cork's physical structure and chemical composition: (**a**) a punched bark with a stopper illustrates the macroscopic structure of cork; (**b**) scanning electron microscopy observations from (i) the tangential direction (or radial plane), (ii) the axial direction (or transverse plane), and (iii) the radial direction (or tangential plane); (**c**) the characteristic shape and dimension of a cork cell; (**d**) the percentage of cork's structural components [13, 15–18]

thus may not consist exclusively of suberin and wax. The cork cells are filled with a mixture of gases similar to air, causing them to behave like real "pads," which helps the cork's ability to recover upon compression [19].

Cork has many properties that make it suitable for various applications. Some of the main properties of cork are low density, high compressibility, low thermal conductivity, low sound transmission, high coefficient of friction, high resistance to wear and tear, fire, water, chemicals, and biodegradation. These properties make cork a light, buoyant, elastic, flexible, insulating, durable, fire-resistant, water-resistant [20]. Cork can be classified into two types: origin cork and composite cork. Original cork is natural cork obtained directly from the bark of the cork oak tree. This cork can be used to make wine stoppers, coasters, bulletin boards, floor tiles, and other products that require the natural look and properties of cork. Composite cork obtained by mixing granulated cork with synthetic resins or rubber. Composite cork can be used to make gaskets, seals, pads, sheets, rolls, and other products that require enhanced mechanical and chemical properties of cork [21, 22].

6.1.3 Cork Applications

Cork materials used as insulation component, which effectively regulates temperature and sound, improves indoor comfort, and reduces energy consumption. Also, it can be used on the roof, wall, and floor of different buildings. It is also popular for flooring, where it offers durability and comfort [23]. Origin cork can be combined with other materials to create lightweight composites that increase their structural integrity and acoustic properties. These composites are used in facade, roof, and interior design elements and create stable and beautiful spaces. It can also decorate walls, ceilings, and room dividers with panels and tiles that add sound and heat insulation to different environments [22].

Cork-based structures have transcended traditional applications and are now at the forefront of innovation in the automotive, transportation, and aerospace industries, offering many possibilities [24]. Cork composites, are being explored for automotive interiors, providing aesthetic appeal and durability (for example used in Mazda MX-30). These composites, when used for dashboards, door panels, and seat frames, reduce overall vehicle weight, increase fuel efficiency, and reduce carbon emissions and at the same time they have good looking in interior of the cabin [21]. P50 and P45 sheets of cork materials have been used in the thermal protection system (TPS) of spacecrafts for a long time. The combination of different polymers and cork granulates creates a diverse range of materials for vibration control and acoustic insulation. Cork is a natural material candidate for the sustainable energy sector for example electric mobility and power industry because of its low thermal conductivity, sealing capacity, durability to severe temperatures, and excellent damping capacity. Additionally, cork is utilized in underlayment accessories and a flooring system that includes a top layer, inlay, core layer, and pre-attached underlayment. Furthermore, because of its special qualities, cork is utilized to make sports surfaces, shock pads, shoes, toys, and interior decor for houses and offices. Cork is still being studied and tested for use in other applications [25–29].

6.2 Literature Review on Energy Absorption in Cork Structures

In this section, we will review several studies conducted on the use of cork materials in engineering structures. Paulino et al. [30] present a novel application of cork derivatives in energy absorption and crashworthiness systems for passive automotive safety. They compare the performance of agglomerated cork (AC) with other cellular materials such as polyurethane foam, aluminum foam, and impact polypropylene in terms of EA, penetration, and peak acceleration. They developed a numerical model of a side crash test using LS-DYNA and simulated the effects of placing a AC pad inside the side door of a vehicle. They found that AC has a significant improvement over other materials in terms of reducing impact loads, increasing EA by the structure, reducing penetration levels, and reducing peak acceleration values. Tai et al. [31] conducted a study on the effect of different cellular materials on increasing the crashworthiness of a vehicle during a side impact. They used a finite element (FE) model of a sedan with different types of cellular materials sandwiched between the door panels. They simulated side impacts and measured penetration,

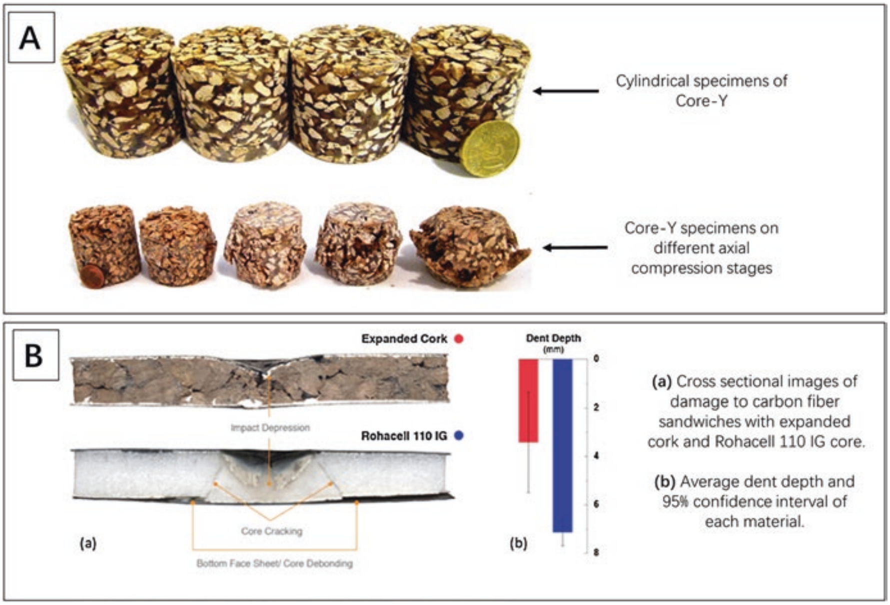


Fig. 6.3 (**a**) Combination of granular cork and an epoxy resin; (**b**) cork core–carbon fiber sandwich composite [32, 33]

internal acceleration, and EA of cellular materials. They found that the inclusion of cellular material significantly reduced passenger compartment penetration and vehicle deceleration by at least 30%.

Alcantara et al. [32] presented an innovative composite, Core-Y, made of cork granular and epoxy resin (as shown in Fig. 6.3a) and investigated its potential applications in structural elements exposed to impact. They describe the Core-Y manufacturing process and perform quasi-static axial compression tests on cylindrical specimens to determine its mechanical properties. They also developed a numerical model based on experimental results to simulate the EA of metallic tubular structures with Core-Y. They concluded that Core-Y has a huge capacity for crushing and is a good candidate for various applications in the automotive industry. In another study, Walsh et al. [33] conducted a study to compare the performance of expanded cork with a synthetic foam (Rohacell), as core materials in sandwich structures with carbon fiber-based face sheets (see Fig. 6.3b). They conducted various tests to measure the bending stiffness, sound and vibration damping, and impact resistance of the composites. They found that expanded cork has lower flexural stiffness than Rohacell but significantly higher sound and vibration damping and impact resistance. They concluded that expanded cork can be a good alternative to synthetic foams for sandwich composites because of better EA and environmental benefits.

Furthermore, Miralbes et al. [34] carried out a study to compare the mechanical properties of cork and AC with expanded polystyrene (EPS) foam under compressive loads. Using energy and yield diagrams, they selected the most suitable material based on the required EA or the maximum stress that should not be exceeded. They also considered certain properties per unit mass, which are more relevant for applications where weight is critical. They found that natural cork had the highest nonspecific and specific properties among cotton products but reached density earlier. EPS had better nonspecific and specific properties than AC due to its low density and larger plateau area. The efficiency graphs showed that EPS has the highest efficiency, followed by natural cork, and the efficiency is related to the compression point.

Serra et al. [35] conducted a study on the impact resistance of hybrid composites made of cork and other materials containing shear thickening fluid (STF) for head protection devices used in micro mobility (see Fig. 6.4a). They tested different combinations of cork sheets, polymers, fabric, and STF under different impact energies. They compared the peak acceleration, strain energy density, strain and impact duration of the composites. They found that two types of composites performed well: (1) one with STF sandwiched between cork and thermoplastic polyurethane (TPU), which reduced peak acceleration and increased deformation levels; (2) fabric with cork and fabric impregnated with STF, which had the highest amount of strain and duration of impact and the lowest density. They concluded that these composites are good candidates for using in helmets. In a subsequent study, Le Barbenchon et al. [36] studied the microstructure and mechanical behavior of AC, made from natural cork granules and bio resin (see Fig. 6.4b). They used optical and scanning electron microscopy (SEM) and X-ray computed tomography to investigate the surface and

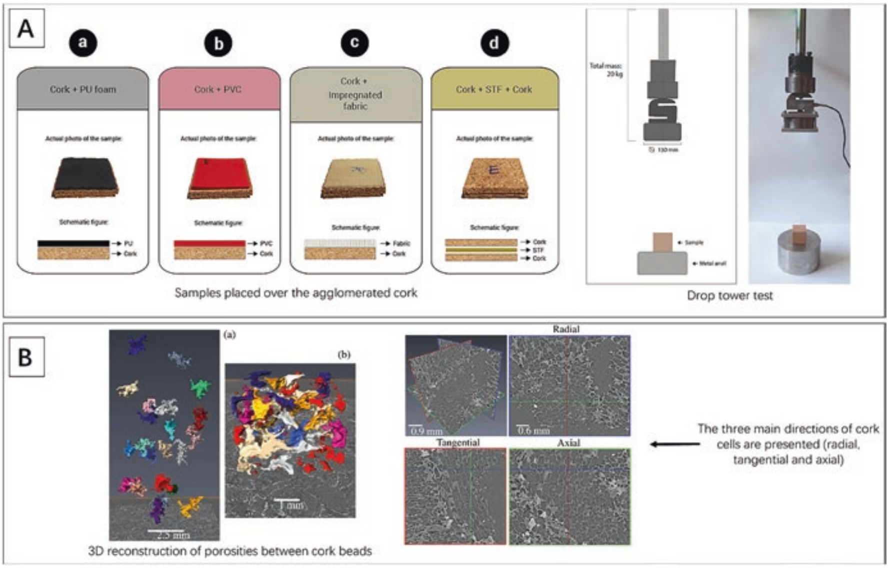


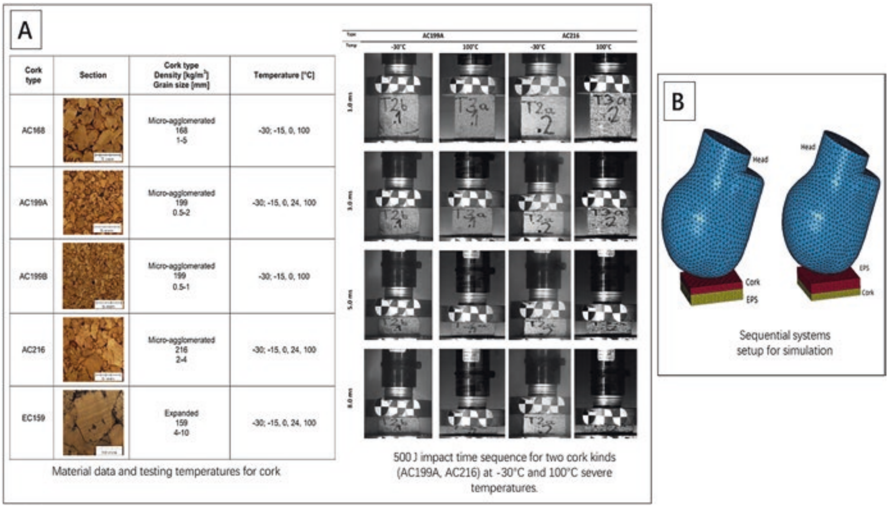
Fig. 6.4 (**a**) The authors made different sandwich samples from Polyanswer and cork; (**b**) 3D reconstruction of porosities between cork beads [35, 36]

spatial arrangement of cork grains and cells. They found that the material has a transversely anisotropic geometry and structure, which affects its mechanical properties under pressure. They performed quasi-static compression tests and used digital image correlation (DIC) to measure the strain and EA of the material. They observed that the material has different stiffness, density, and viscoelastic recovery in different directions. They also identified high strain inhomogeneities and localization bands on the surface of the material. They suggested that their findings could be used to develop better models for AC and understand their behavior at higher strain rates.

Paulino et al. [37] performed a numerical study on the impact behavior of four cellular materials: polyurethane foam, IMPAXX™ 300, aluminum foam, and AC. They used analytical and FE models to compare the energy-absorbing capability, performance index, and peak acceleration of each material under different initial impact kinetic energies. They found that aluminum foam had the highest EA capacity, followed by cork, while IMPAXX™ had the highest specific energy absorption (SEA), followed by AC. They also found that AC and aluminum foam had the lowest peak acceleration values, indicating better crashworthiness. They concluded that AC is the most beneficial material for low kinetic energy values, while aluminum foam is better for larger kinetic energies.

In a separate study, Coelho et al. [38] investigated the potential of cork as a material to absorb impact energy, especially in comparison to expanded polystyrene (EPS), which is commonly used in safety systems such as helmets (see Fig. 6.5b). They simulated compression tests and double impacts on different configurations of hybrid layers consisting of AC and EPS. They found that EPS performed better on the first impact, but lacked spring return and lost EA capacity on the second impact. On the other hand, the AC had a good level of EA with almost full spring return. They also observed that parallel systems, where the AC and EPS layers alternated, had higher accelerations and shorter impact durations than sequential systems, where the AC and EPS layers were separated. They concluded that there is no clear optimal arrangement for hybrid layers, but suggested some possible candidates that balance thickness reduction, deceleration, and weight reduction. Moving on to the next study, Kaczynski et al. [39] conducted a study on the impact behavior of AC under different temperature conditions. They tested five types of AC with different densities and grain sizes and subjected them to impact tests at temperatures from −30 to 100 °C (see Fig. 6.5a). They measured the amount of absorbed EA by cork samples during impact and developed a material model to describe the relationship between temperature, density, and EA. They found that temperature had a significant effect on the performance of AC, especially for high-energy impacts.

Sánchez-Saez et al. [40] performed an experimental study on the dynamic crushing behavior of AC (see Fig. 6.6a), which can be used as a substitute for polymer foams for impact absorbing elements in vehicles. They investigated how the sample thickness affects the energy-absorbing capability, contact force, and strain of cork under dynamic compressive loads. They performed weight loss tests with samples of four different thicknesses and measured the variables mentioned above. They found that the maximum contact force and strain increased with the impact to



Cork type	Section	Cork type Density [kg/m³] Grain size [mm]	Temperature [°C]
AC168		Micro-agglomerated 168 1-5	-30; -15, 0, 100
AC199A		Micro-agglomerated 199 0.5-2	-30; -15, 0, 24, 100
AC199B		Micro-agglomerated 199 0.5-1	-30; -15, 0, 100
AC216		Micro-agglomerated 216 2-4	-30; -15, 0, 24, 100
EC159		Expanded 159 4-10	-30; -15, 0, 24, 100

Material data and testing temperatures for cork

500 J impact time sequence for two cork kinds (AC199A, AC216) at -30°C and 100°C severe temperatures.

Sequential systems setup for simulation

Fig. 6.5 (**a**) The authors made five sandwich samples from Polyanswer and cork; (**b**) 3D reconstruction of porosities between cork beads [38, 39]

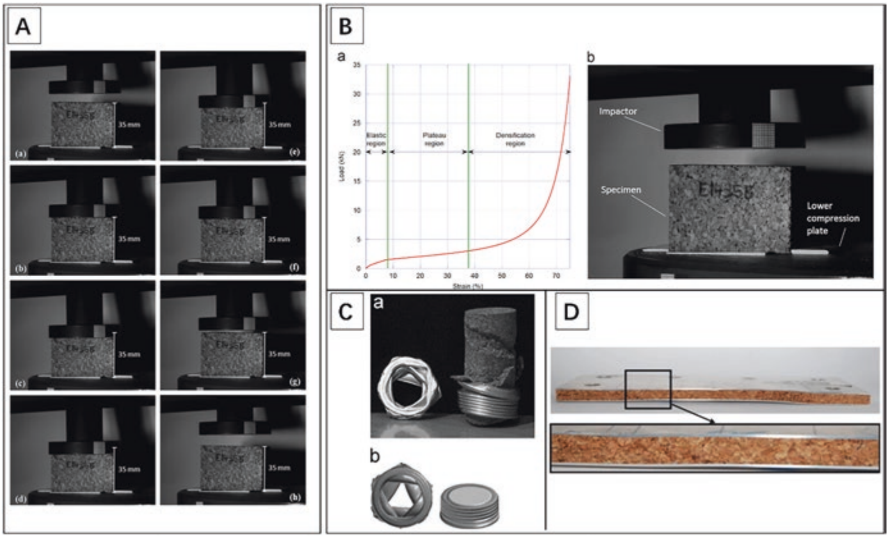


Fig. 6.6 (**a**) Dynamic crushing test impactor and AC specimen displacement; (**b**) (a) NL-10 AC compression load—strain curve and (b) 35 mm thick specimen low-velocity impact test; (**c**) experimental and numerical shape histories of empty and cork-filled tubes in drop-weight device; (**d**) sandwich structure based on cork [40–43]

energy/thickness ratio, while the energy absorbed by the cork was independent of the sample thickness. They concluded that AC has great potential for EA applications, but it also has a large scatter in results due to its natural origin and diversity of properties. In another study, Sánchez-Saez et al. [41] conducted an experimental investigation on the multi-impact behavior of AC (see Fig. 6.6b). They tested specimens with various thicknesses and two impact energy levels using a low velocity impact tower and measured the maximum contact force, maximum strain, and EA in each test. They found that AC cork agglomerates have great EA capability, as the energy absorbed is independent of the number of impacts. They also observed that the maximum contact force and maximum strain were affected by the sample thickness and impact energy level, and they related these variables to the load–strain curve of AC under pressure. They concluded that AC can be a good alternative for some engineering applications subject to multiple impacts.

Shifting focus to another study, Gamiro et al. [42] conducted a study on the use of fine AC as filler inside aluminum tubes to increase their EA during impact loading (see Fig. 6.6c). They performed dynamic experimental tests and numerical simulations with LS-DYNATM software to compare the load-deformation properties, energy-absorbing characteristics, and collapse mode transition of empty and cork-filled tubes with different diameters, thicknesses, and lengths. They found that the percentage increase in absorbed EA by cork-filled tubes depends on the slenderness ratio of the tubes, which is defined by the diameter-to-thickness ratio and the length-to-diameter ratio. They observed that the percentage increase in absorbed energy increases with increasing diameter-to-thickness ratio and decreasing length-to-diameter ratio.

Continuing the exploration, Souza-Martinez et al. [43] conducted an experimental study on the burst response of sandwich structures with AC composite cores and aluminum alloy sheets (see Fig. 6.6d). They tested different core thicknesses and densities under a constant blast load and measured the transmitted impulse and deflection of the faceplates. They also analyzed the internal deformation and damage of the core material and the bond between the core and face plates. They found that core thickness and density have a significant effect on the structural response of sandwich specimens. They also observed that the core material exhibits an almost constant stress region for increasing strains until solidification, allowing it to absorb significant amounts of energy by crushing. Le Barbenchon et al. [44] investigated the effects of temperature and strain rate on the compressive behavior of AC. They performed quasi-static and dynamic tests at different temperatures and strain rates and measured stress–strain curves and foam material parameters. They found that temperature and strain rate both have significant effects on the mechanical behavior of the foam, but with opposing effects. They attributed this to the viscoelastic nature of cork, one of the foam's constituents. They also observed different failure mechanisms under different loading conditions. They developed a specific experimental setup for performing high strain rate experiments at temperature and demonstrated its feasibility by testing the foam at −20 °C in the dynamic regime.

Sheikhi and Gürgen [45] conducted a study on the deceleration behavior of multilayer composites made of AC and STF for protective applications. They aim to exploit the advantages of AC as an eco-friendly material with high EA and STF as a smart material that changes its viscosity under loading. They designed different configurations of AC, foam, and STF layers and tested their performance under impact loading. They found that encapsulation of STF-impregnated foam layers in the composites reduced the peak velocity and increased the time period of velocity deceleration with increased shear thickening formation. They proposed that their eco-friendly smart composites could be used to coat internal components in sensitive systems such as electronic systems, robotic devices, and unmanned aerial vehicles (UAVs). An experimental study of multilayer composites made of AC and warp-knitted spacer fabrics (WKSF) for anti-impact applications was carried out by Sheikhi et al. [46]. They designed and created eight different configurations of composites (see Fig. 6.7b – bottom) with a laser cutting machine and tested their EA capacity using a low-velocity impact machine. They also calculated the life cycle assessment (LCA) of the composites to evaluate their environmentally friendly properties. They found that the structures composed of AC and WKSF layers provide great performance for protective applications, but the position of the components in the multilayer structures affects the EA (see Fig. 6.7b – top). They also found that AC has lower carbon emissions than WKSF and dominates the LCA criteria. In a contrasting study, Sheikhi and Gürgen [47] investigated the EA of STF-enhanced multilayer composites under low energy impact test. They used AC, WKSF, and foam as the main components of the composite and filled STF in the foam layers (see Fig. 6.7a). They compared the performance of composites with and without STF in terms of maximum reaction forces (RF), EA, and SEA. They found that the inclusion of STF improved the anti-impact properties of the composites by increasing the viscosity and dissipating the impact energy over a larger area. They also found that the most effective design was Config-12, which had one layer of coarse-grained AC, one layer of foam, and one layer of WKSF.

Sánchez-Saez et al. [48] investigated the effect of AC on the high-velocity impact behavior of thin aluminum plates. They performed impact-perforation tests on three types of samples: neat AC, pure aluminum plates, and aluminum plates with a AC core (see Fig. 6.8a). They measured the ballistic limit, residual velocity, and EA of each sample. They found that AC has a lower ballistic limit and absorbs less energy than aluminum plates. However, when the cork was utilized as a core material between two aluminum plates, it increased the ballistic limit and absorbed more energy than pure aluminum plates. They concluded that the AC core did not change the failure mechanism of the aluminum plates but improved their ballistic performance.

Moving to another investigation, Fernandes et al. [49] compared the mechanical performance of AC and synthetic materials (EPS and EPP) as shock energy absorbers. They performed quasi-static compression tests, guided drop tests (see Fig. 6.8b), and finite element analysis to evaluate the energy storage capacity, stress–strain behavior, and multiple dynamic loading response of the materials. They found that AC is an excellent alternative to synthetic materials because it is a natural, stable, and resilient material that can withstand significant impact

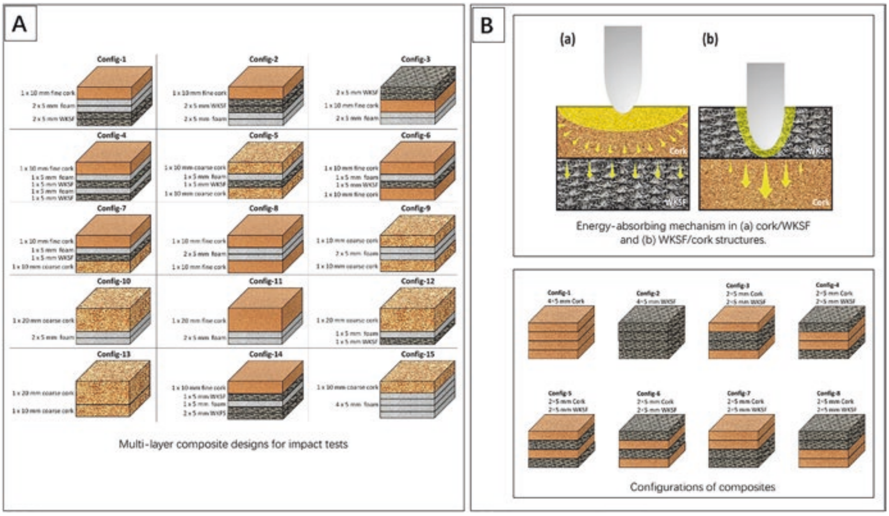


Fig. 6.7 (**a**) Anti-impact design of AC-based multilayer composites enhanced by shear thickening fluid; (**b**) energy-absorbing properties of AC and WKSF-based composites [46, 47]

energies and retain some of its original properties after loading. They also developed a reliable framework for simulating the mechanical response of natural and synthetic cellular materials. They concluded that replacing synthetic foams with natural foams is an acceptable and better solution for protective liners. Shifting our focus to a separate research, Fernandes et al. [50] investigated the application of AC as a cushioning material in helmets (see Fig. 6.8c), as a sustainable alternative to EPS. They developed a finite element model of a motorcycle helmet and compared the performance of AC and EPS liners under impact scenarios. They also created a generic helmet model with different thicknesses and sections of AC liners and assessed their head injury risk using another finite element head model. They found that AC liners have excellent impactability properties and can be recovered after compression, making them suitable for multi-impact applications. They also suggested that thinner helmets with AC liners are possible and that AC could be used in other types of helmets.

The effect of low-velocity impact damage on the ballistic performance of composite sandwich panels with AC core and integrated sheets was investigated by Ivañez et al. [51]. They compared the impact behavior of both types of samples at two impact energies of 25 and 40 J and measured the peak load, force–displacement curves, impact bending stiffness, absorbed energy, impact indentation ratio, and ballistic limit in surface density. They found that low-velocity impact damage did not significantly affect the sandwich panels but reduced the ballistic resistance of the panels. They concluded that the AC core improved the impact resistance of previously damaged composite structures.

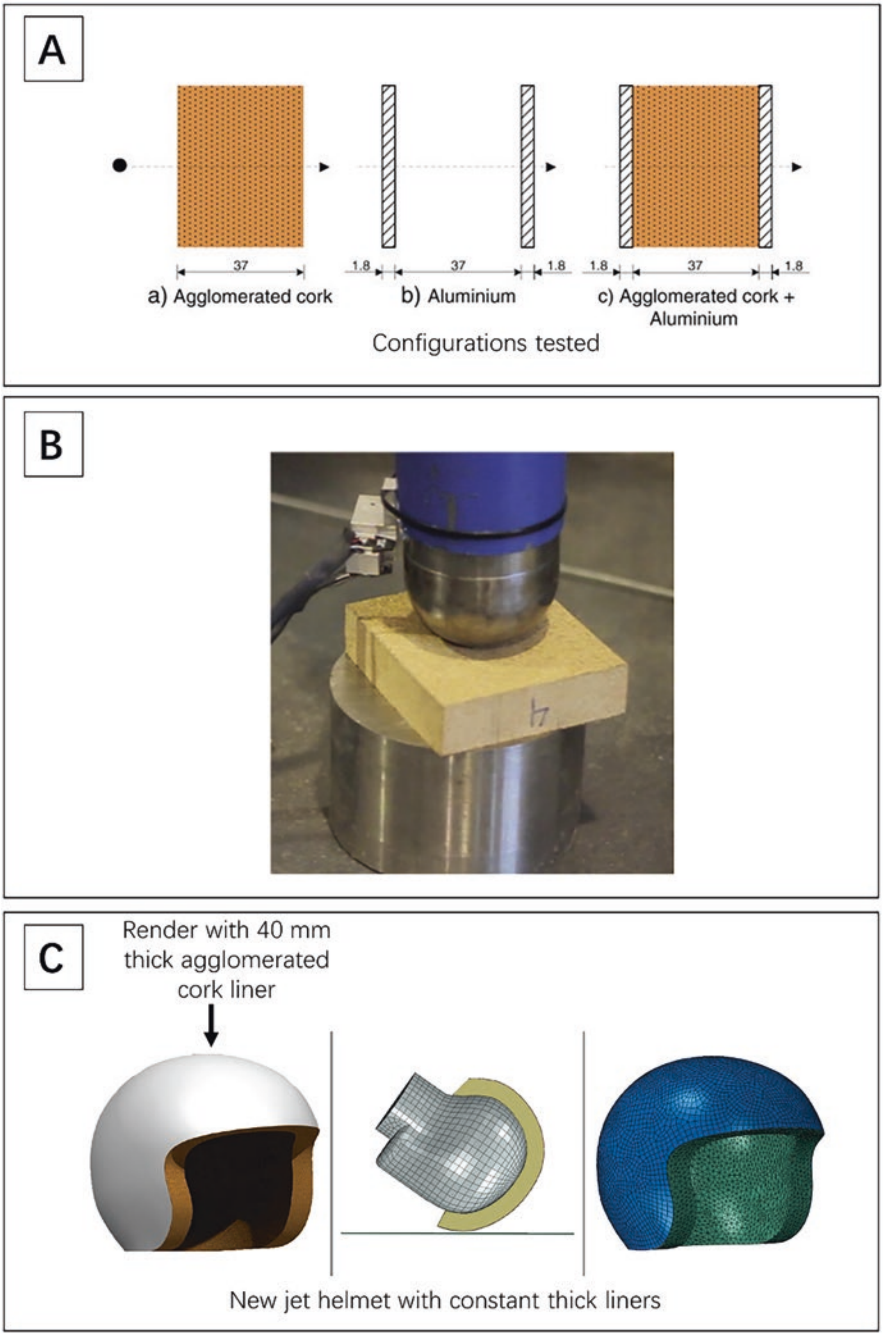


Fig. 6.8 (**a**) Configuration tests for AC-cored structures subjected to ballistic impacts; (**b**) drop tower-based impact test designed by the authors; (**c**) new helmet design [48–50]

6.3 Energy Absorption Performance of Agglomerated Cork Composites: A Case Study

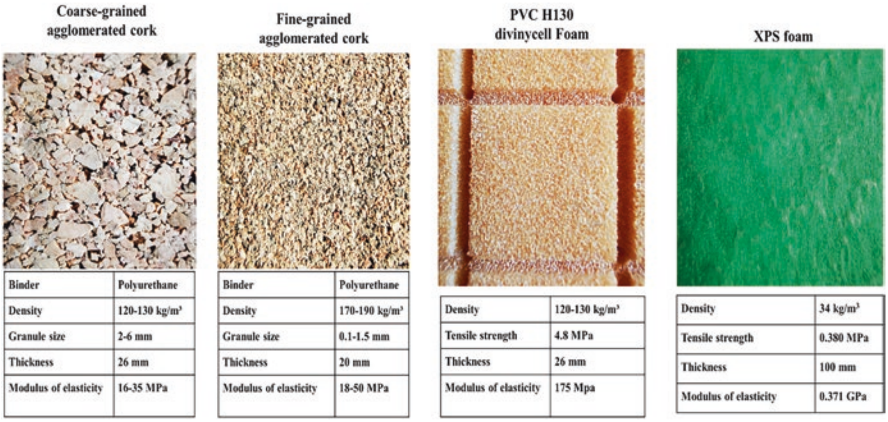
6.3.1 *Materials and Method*

To investigate the energy absorption properties of cork materials, we selected four materials with different densities: XPS foam (34 kg/m^3), PVC foam (130 kg/m^3), fine-grained agglomerated cork (180 kg/m^3), and coarse-grained agglomerated cork (130 kg/m^3). We prepared samples with dimensions of 80 × 80 mm^2 and adjusted their thickness according to their density to guarantee the same weight for all samples. The thicknesses were 100 mm for XPS foam, 26 mm for coarse-grained cork and PVC foam, and 20 mm for fine-grained agglomerated cork. We performed a low-velocity impact test on the samples using a drop tower device. The impactor had a hemispherical shape with a diameter of 15 mm and a mass of 1.02 kg. We dropped the impactor from a height of 1 m corresponding to an energy level of 10.3 J and measured the impact force damping using a dynamometer placed under the samples. We calculated the EA of the samples from the potential energy difference between the first and second impact of the impactor on the samples. The specifications of the component are detailed in Fig. 6.9. The materials and testing apparatus are illustrated in Fig. 6.10.

6.3.2 *Results and Discussion*

6.3.2.1 Maximum Reaction Forces

The curves for the selected materials' impact responses are given in Fig. 6.11 and Fig. 6.12 indicates the highest reaction forces (RFs). XPS foam demonstrates a maximum RF of 1398 N which is the least among others while fine cork has 1500 N, coarse cork at 1622 N, and PVC foam with 1690 N. The peak force of the energy-absorbing structures or materials under impact must be kept below the threshold that would cause damage, while still providing a sufficient total EA capacity in the large deformation process. The RF should remain constant or nearly constant to avoid an excessively high rate of retardation. XPS foam is a closed-cell polymer foam with high compression strength and low density. It has a high initial modulus allowing it to deform elastically at lower stresses than other cells but can deform plastically at larger stress levels resulting in greater deformation and high EA. Fine cork has low density and high porosity which enables it to be soft yet strong enough when compressed as well as exhibiting low stiffness. Moreover, although it can undergo elastic and plastic deformation, its deformation is smaller, and EA is less than that for XPS foam. According to the results, fine cork is suitable for anti-impact applications because of the reduced RF as compared to PVC foam and coarse cork. Similarly, coarse cork has a higher RF in comparison to fine cork thereby



Coarse-grained agglomerated cork

Binder	Polyurethane
Density	120-130 kg/m³
Granule size	2-6 mm
Thickness	26 mm
Modulus of elasticity	16-35 MPa

Fine-grained agglomerated cork

Binder	Polyurethane
Density	170-190 kg/m³
Granule size	0.1-1.5 mm
Thickness	20 mm
Modulus of elasticity	18-50 MPa

PVC H130 divinycell Foam

Density	120-130 kg/m³
Tensile strength	4.8 MPa
Thickness	26 mm
Modulus of elasticity	175 Mpa

XPS foam

Density	34 kg/m³
Tensile strength	0.380 MPa
Thickness	100 mm
Modulus of elasticity	0.371 GPa

Fig. 6.9 Details of the components

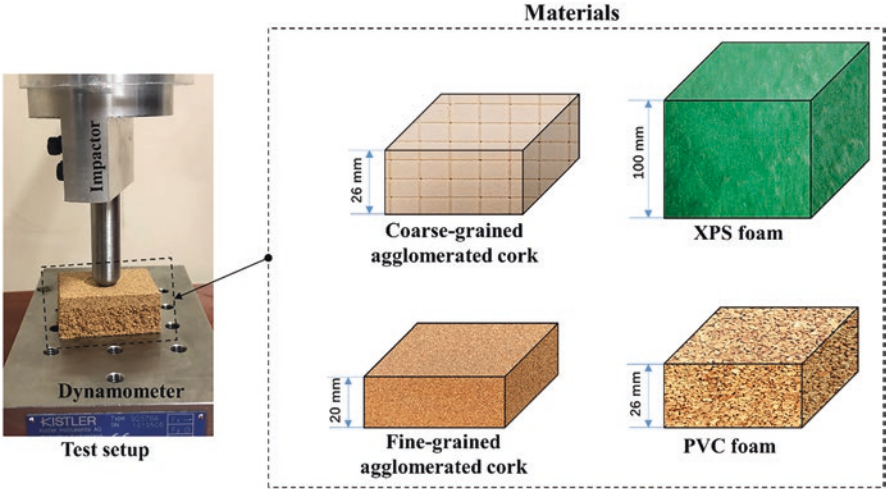


Fig. 6.10 Experimental test setup and specimens

compromising its protective capability. Among the chosen materials, PVC foam has the highest RF.

6.3.2.2 Energy Absorptions

As seen from Fig. 6.13 which shows the EA capacities of selected materials. XPS foam has the best performance in absorbing energy (9.07 J). Then fine cork absorbed more energy (8.04) after XPS foam and this was obtained while it was less thick than PVC foam. Fine cork has smaller grains and high porosity, and this makes it easier to deform after impact and absorb more energy through elastic and plastic

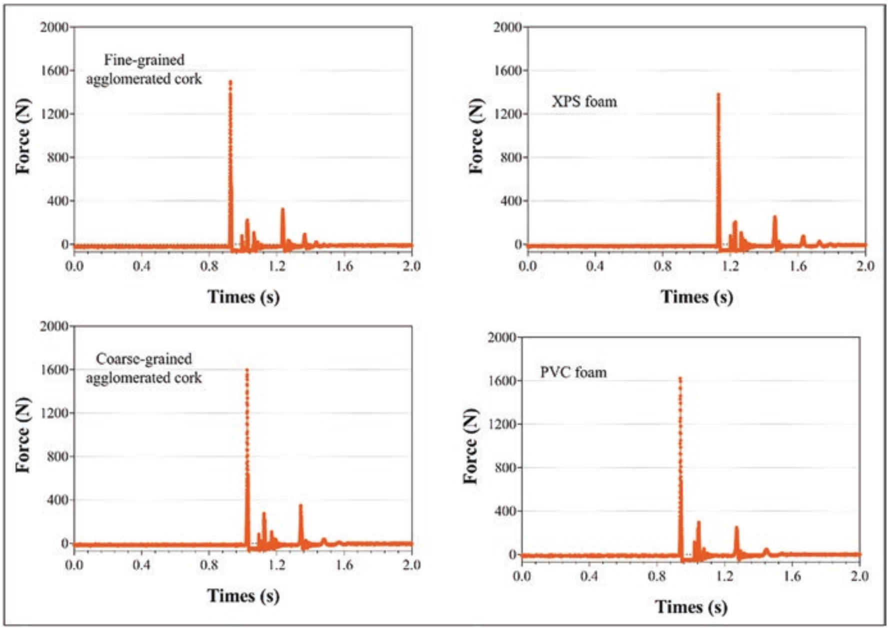


Fig. 6.11 Reaction force curves for the specimens

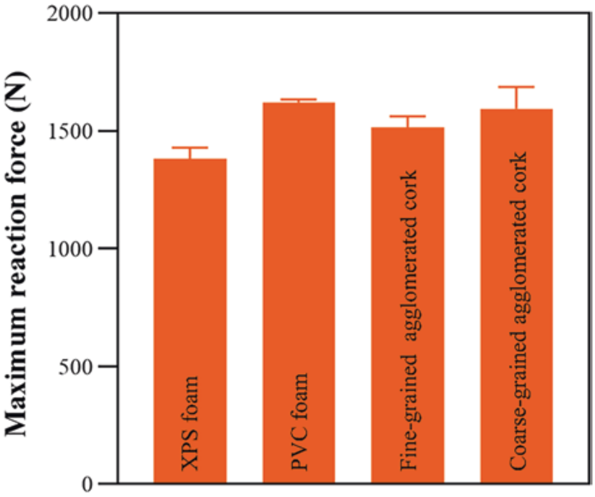


Fig. 6.12 Maximum reaction forces for the specimens

deformation. Coarse cork has larger grains and less porosity, which makes it more resistant to deformation than fine cork. Coarse cork can withstand more loads before failure but absorbs less energy from a sudden impact.

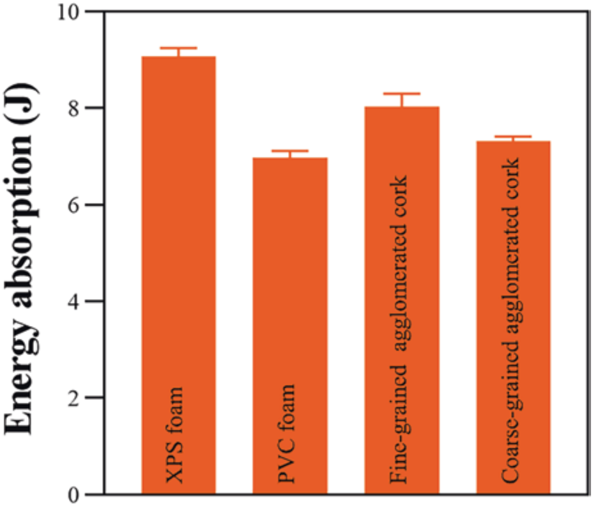


Fig. 6.13 Absorbed energy by the specimens

6.4 Conclusions

In this chapter, we investigated the energy absorption (EA) properties of cork materials. First, the studies conducted by researchers were reviewed, and it was shown how they used cork materials in different structures for anti-impact and energy-absorbing purposes. The review of their studies showed that although cork materials cannot be used alone in most applications due to their poor mechanical properties, by their high EA capabilities, they can be used as an auxiliary part of the main structure to absorb energy. In the second part of the chapter, the energy-absorbing capacity of two types of cork composites (fine and coarse agglomerated cork) is compared with two types of synthetic PVC and XPS foam. All were subjected to an impact test device, and their EA values were calculated. The results demonstrated that, despite having less thickness, fine cork has better performance than PVC foam, which shows that the impact resistance of cork material is inherently high. With smaller grains and higher porosity, fine cork can deform easily upon impact and absorb less energy in impact time. The results of the second part of the chapter indicated that cork materials are promising candidates for use in energy absorption structures, and fine cork can perform better results than coarse cork. The energy-absorbing structure should be light, possessing a high specific energy absorption (SEA) capacity, which is vital important for vehicles energy absorber components and personal safety devices. Since cork has a cellular structure, it has a low weight, and this has made it a high SEA.

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