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Research Status and Prospect of Energy Absorption Devices

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Keywords: Mine disasters; Energy absorption device; Support of roadway; Intelligent Mine;

Abstract: Energy absorption devices, as an important technology for energy absorption and dissipation, are widely applied in various fields such as automobiles and aerospace, and have demonstrated significant application value in the prevention and control of mine disasters. This paper summarizes the research status of energy absorption devices by different scholars and classifies them into thin-walled type, honeycomb structure type, negative Poisson's ratio type, pre-cracked type and foam aluminum type. It focuses on analyzing the energy absorption characteristics and working principles of various energy absorption devices. Secondly, it discusses the application of energy absorption devices in mine roadway support, especially their roles in improving the impact stability of roadway surrounding rocks, reducing the hazards of impact ground pressure to personnel and equipment, and prolonging the service life of the roadway. Finally, this paper looks forward to the future development directions of energy absorption devices in material optimization, structural design, multi-functionality and intelligence. Research shows that energy absorption devices have significant application value in mine roadway support. With the advancement of materials science and intelligent technology in the future, energy absorption devices will be further optimized and innovated, providing more reliable guarantees for mine safety.

1. Introduction

In mining engineering, rockburst is the main dynamic disaster in coal mining. With the increasing demand for energy, many metal and coal mines have entered a state of deep resource extraction in depth [1-2]. With the gradual development of mineral resource mining towards deeper areas, the stress environment of various underground rock masses is becoming increasingly complex. Phenomena such as high ground stress and rock mass slip are leading to an increasing number of engineering disasters [3-4]. Geological disasters such as mine rockburst and large deformation of soft rocks pose a huge threat to the safe and efficient mining of deep resources. Therefore, scholars have introduced energy absorbing components into mine roadway support.

The initial purpose of introducing energy absorbing components into the support of mine tunnels was to consume some or most of the impact energy of the surrounding rock during the occurrence of rock burst through energy absorbing components, in order to reduce the harm of rock burst to personnel and mining equipment in the tunnels. The working principle of energy absorbing components is to absorb impact energy through deformation, that is, when the energy absorbing component is subjected to external forces, the material will deform, and the energy will be converted into strain energy of the material, thereby consuming and absorbing the energy. At present, energy absorbing components have been widely used in many mines, with good results in reducing the probability of rockburst accidents.

Through in-depth research on the evolution history and working mechanism of energy absorbing components, it was found that the existing energy absorbing components have a single function and only play a role in absorbing and consuming impact energy. So, with the development of science and technology and materials science, in the future, energy absorbing components will move towards multifunctionality and intelligence, and the production materials of energy absorbing components will also be further optimized.

This article summarizes typical energy absorbing components from 2000 to 2025. Starting from the development history of energy absorbing components, the types and characteristics of energy absorbing components were classified and summarized, and their application in mine roadway support was discussed. Finally, the future optimization and innovation directions were discussed. It is of great significance for the development of future mine roadway support.

Development history and classification of energy absorbing components

1.1 Development history of energy absorbing components

In 2002, Wang Fuqi et al.[5] conducted in-depth research on the energy absorption characteristics of multi-layer thin-walled circular tubes through experimental methods. Research has shown that multi-layer thin-walled circular tube energy absorbing components composed of multiple single circular tubes have significant structural characteristics of mutual support due to the significant interaction effects between the tubes. Their load-bearing performance and energy absorption characteristics are significantly better than those of a single circular tube structure. In 2004, Wang Zili et al. [6] developed a new single shell side crashworthy structure. By transforming the side frame into a thin-walled square tube filled with foam plastics, the structural deformation mode was effectively changed, which not only improved the energy absorption efficiency, but also significantly enhanced the ship's crashworthiness. In 2006, Hou Shujuan et al. [7] studied a thin-walled metal energy absorbing component with a circular cross-section at the conical end. The study showed that its energy absorption efficiency is closely related to the conical length and edge diameter. When the conical length is 106.8mm and the edge diameter is 60.76mm, the component can achieve the best energy absorbing performance. In 2007, Long Shuyao et al. [8] found that when using a rectangular cross-section conical thin-walled tube as an energy absorbing element, its specific energy absorption is negatively correlated with the inclination angle of the oblique side, and shows a trend of first increasing and then decreasing with increasing wall thickness. This study provides important theoretical basis for the design of automotive energy absorbing components. In 2007, Yan Haiqi [9] developed a new type of threaded shear energy absorbing component, which achieves free expansion and contraction through an impact guide rod. Thread shear failure is the main energy absorbing mechanism, while the impact guide rod bears the function of force transmission. Its straightness has a critical impact on the performance of the component. In 2008, Chen Bingzhi et al. [10] analyzed the anti-collision performance of metal thin-walled components with different cross-sectional shapes and unit cell forms through finite element simulation. Research has shown that the square single-cell cross-section has the best energy absorption efficiency in the square model; Hexagons perform best in polygon models; Under the condition of equal perimeter, the energy absorption performance of circular cross-section is most prominent. In 2008, Han Qinghua et al. [11] studied the energy absorption characteristics of thin-walled square steel tubes, focusing on the effects of cross-sectional form, thickness, length, and end opening on axial and radial collision performance. Research has shown that during axial collisions, square tubes convert kinetic energy into internal energy through plastic deformation, and their energy absorption capacity is significantly affected by cross-sectional form, length, thickness, and end closure state; During radial collision, although the energy absorption mechanism is similar to that of axial collision, the closed end state has no significant effect on the energy absorption performance. In 2009, Zhao Guangning et al. [12] conducted an optimization study on the energy absorption characteristics of thin-walled circular tubes filled with foam aluminum. The results show that the filled foam aluminum structure can significantly increase the deformation energy and specific energy absorption without increasing the maximum compression force while reducing the mass of the components, thus effectively reducing the damage of the protected objects. In 2009, Zhang Zonghua et al. [13] proposed a novel Kagome honeycomb sandwich cylindrical energy absorbing structure. This structure achieves energy absorption through the synergistic effect of honeycomb cell walls and thin-walled tubes: preferential buckling of honeycomb cell walls triggers local wrinkling of tube walls, expanding the plastic yield zone, while the wrinkled tube walls support further collapse of the honeycomb, significantly improving energy absorption performance compared to traditional thin-walled tubes. In 2009, Tang Zhiliang et al. [14] innovatively designed two types of structures, namely non convex section thin tubes and composite multi cell tubes, based on the study of the influence of the angle between the triangular parts of thin-walled structures on energy absorption characteristics. Research has shown that non convex cross-section thin tubes significantly improve energy absorption performance compared to traditional convex normal deformation thin-walled tubes, while combined multi cell tubes achieve better energy absorption effects. In 2010, Zhang Zonghua [15] proposed a new type of arched reinforced filled beam structure based on the research background of transverse bending of energy absorbing components. By setting arch stiffeners with adjustable section shape in the hollow thin-walled beam, the structure achieves better energy absorption performance than the hollow thin-walled beam and foam filled beam with the same quality. 2011 Song Qiang [16] studied the impact performance of foam metal filled thin-walled cylinder through numerical simulation, and compared the filling effects of single density and gradient density. The research shows that the energy absorption capacity and impact resistance of the thin-walled cylinder are significantly improved by foam metal filling, and the energy absorption increases with the increase of foam metal density. In 2012, Shao Wengang [17] studied the impact energy absorption performance of viscoelastic beam components. By setting elastic damping composite supports at both ends of the elastic beam, the constructed viscoelastic beam component exhibits excellent rapid absorption characteristics of impact stress, significantly improving the beam's support capacity and impact resistance performance. In 2012, Hu Lixiang [18] studied the energy absorption characteristics of square, diamond, and trapezoidal metal circular tube arrays through numerical simulations. Research has shown that trapezoidal arrays have the best stability but lower energy absorption efficiency, while square arrays, although slightly less stable, exhibit the best deformation mode and energy absorption performance. In 2012, Luo Hongzhi [19] studied the performance of corrugated energy absorbing tubes, which are formed into standard segments through material folding and can be longitudinally expanded. Numerical simulations show that the folded structure can effectively reduce the initial peak load and improve energy absorption efficiency, but experiments only verified the reduction of peak load, and the improvement of energy absorption efficiency was not significant. There is a difference between the two results, and further in-depth research is needed. In 2013, Zhang Zhidan [20] optimized the anti-collision design of thin-walled components filled with multiple cells, and compared and studied the honeycomb structures filled with rectangular and ring-shaped circular tubes. Research has shown that the energy absorption performance of a circular distribution is slightly better than that of a rectangular distribution; Among the three kinds of cross section members, the conical section foam filled thin-walled member has the best energy absorption characteristics, followed by the circular section, and the square section has the worst performance.

In summary, before 2014, scholars' research was almost entirely focused on areas such as automotive energy absorption, and did not involve energy absorption support in mining tunnels. After 2014, the application of energy absorbing components in mining disasters began to become popular. Further summarize four typical energy absorbing components for mining after 2014 and discuss them in the future.

1.2 Classification of energy absorbing components

Energy absorbing components can be classified into various types based on their structural form, material properties, and working principles. The following is a detailed introduction to several common types of energy absorbing components and provides detailed examples.

1.2.1 Thin walled energy absorbing components

Thin walled energy absorbing components are one of the earliest studied and applied energy absorbing components. The basic principle is to absorb impact energy through plastic deformation of thin-walled structures. Thin walled structures are usually made of metal materials such as steel, aluminum, etc. According to their appearance, they can be divided into thin-walled circular tubes, thin-walled multi deformation tubes, and pre folded thin-walled tubes.

The main advantages of thin-walled energy absorbing components are simple structure, low cost, and good energy absorption effect.

In 2018, Tang Zhi et al. [21] designed a six-sided thin-walled tube energy absorption and anti-impact component for the top beam of the support. Figure 1 shows the schematic diagram of the six-sided thin-walled tube structure. The energy absorption characteristics of this energy absorption component under different materials, inner edge lengths, thicknesses and lengths were studied through experiments and numerical simulations. The research shows that components of different sizes and materials have stable deformation failure modes and high stroke efficiency, and their performance is less affected by size and material; energy absorption is achieved through plastic deformation, and the energy absorption capacity is linearly related to the compression distance. Figure 2 shows the relationship between the energy absorption capacity and displacement of this energy absorption component. This component is not only applicable to the top beam of the hydraulic support, but also can be extended to be applied in fields such as highway guardrails and automotive anti-collision front beams.

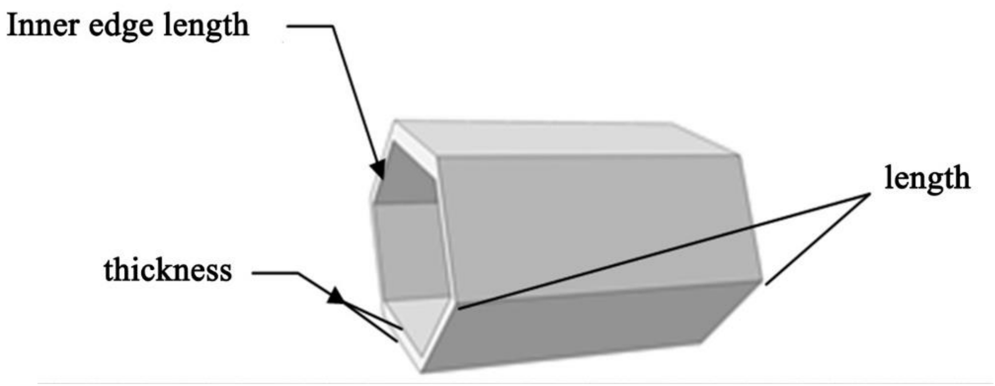

Figure 1: A hexagonal thin-walled square tube energy absorbing and anti impact component

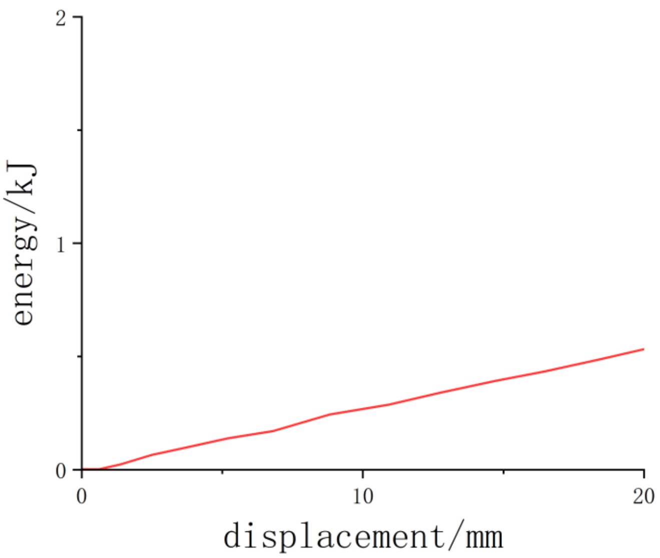

Figure 2: Relationship Diagram between Energy Absorption Capacity and Displacement of Hexagonal Thin-walled Square Tube

In 2024, Zhang Jianzhuo et al. [22] proposed a novel conical thin-walled circular tube energy absorption structure and conducted performance analysis through finite element simulation. Figure 3 shows the schematic diagram of this structure. Figures 4, 5, and 6 are respectively the graphs of energy absorption and displacement relationship with different guide groove radii, different cone angles, and different wall thicknesses. The study shows that: while keeping other parameters unchanged, reducing the diameter of the guide groove or increasing the wall thickness can significantly enhance the initial peak force, total energy absorption, and average counterforce; while increasing the cone angle will reduce the average load. In addition, the conical design effectively solves the problems of tube expansion and mid-section crushing of traditional energy absorption components under compression, ensuring the controllability of deformation.

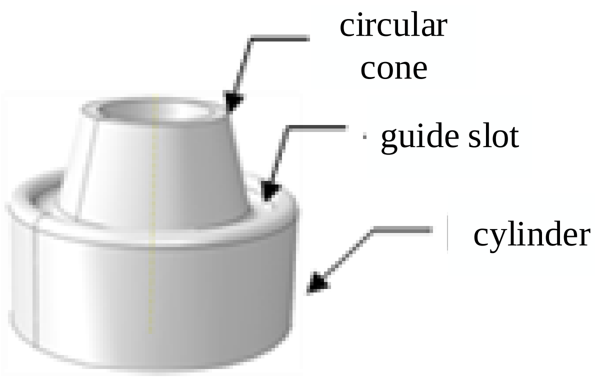

Figure 3: New Cone-shaped Thin-walled Circular Tube Energy Absorption Structure

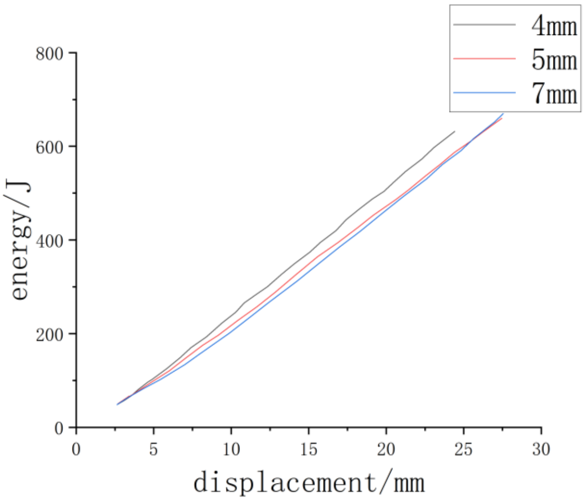

Figure 4: Relationship between energy absorption and displacement of different energy-absorbing components with respect to the radius of the guide groove

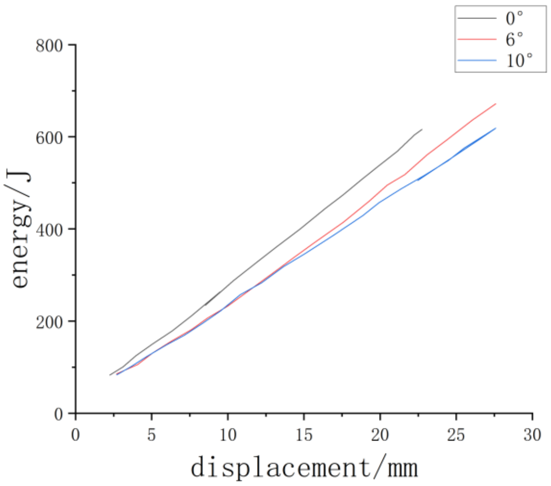

Figure 5: Relationship between the energy absorption capacity and displacement of different energy-absorbing components with tapering shape

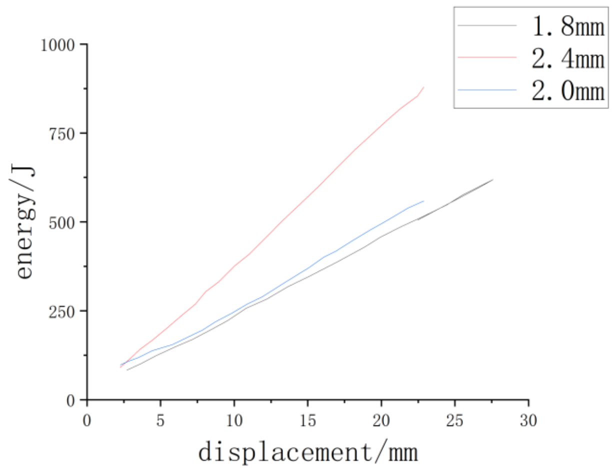

Figure 6: Relationship between energy absorption capacity and displacement of different energy-absorbing components with respect to their wall thicknesses

1.2.2 Honeycomb shaped energy absorbing components

Honeycomb shaped energy absorbing component is a type of energy absorbing component based on honeycomb structure, characterized by high specific strength and stiffness. Divided by material: metal honeycomb structure, composite honeycomb structure. According to shape, it can be divided into hexagonal, triangular, circular, rectangular, irregular and other shapes. Its energy absorption principle is to absorb energy through the bending and folding of the honeycomb wall.

In 2009, Zou et al. [23] investigated the mechanical behavior of two-dimensional hexagonal metal honeycomb structures under dynamic compression, focusing on analyzing the characteristics of shock wave propagation and the energy absorption mechanism. The study revealed that the deformation mode of the honeycomb structure is closely related to the compression speed: when the compression speed exceeds the critical value, shock waves form and propagate with a front thickness of one honeycomb unit thickness, whose thickness is mainly determined by the geometric size and is independent of the compression speed and relative density. One-dimensional shock wave theory can well predict the dynamic compression behavior, but there is a certain error at high compression speeds, and the material model needs to be further optimized. The energy absorption of the honeycomb structure is mainly achieved through the plastic deformation of the honeycomb walls. At low compression speeds, buckling deformation is dominant, while at high compression speeds, local bending and axial compression are dominant. Figure 7 is a schematic diagram of the two-dimensional hexagonal metal honeycomb structure. Figure 8 shows the relationship between the energy absorbed by the energy-absorbing component and the compression speed.

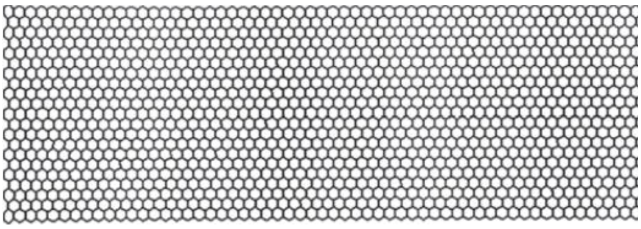

Figure 7: Two-dimensional hexagonal metallic honeycomb structure

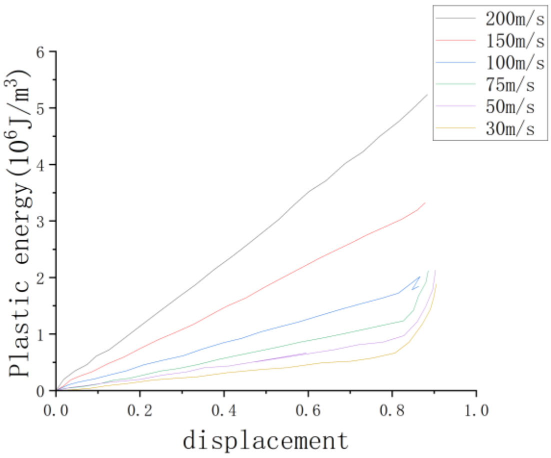

Figure 8: The Influence of Compression Speed on Energy Absorption

In 2018, Zhou Hao et al. [24] based on the Abaqus finite element simulation software, studied the energy characteristics of carbon fiber reinforced composite square honeycomb sandwich structure under the action of underwater explosion shock wave. By establishing simulation models with different relative densities of core materials, they analyzed the impulse transmission characteristics of the structure, the energy absorption process and the energy absorption situation of each component, and compared them with the laminated structures of equal mass. The results showed that the energy absorption of the carbon fiber reinforced composite sandwich structure was closely related to its deformation, failure mode and damage degree, and it was superior to the laminated structures of equal mass in terms of impulse transmission characteristics and energy absorption efficiency. Figure 9 shows the schematic diagram of the carbon fiber reinforced composite square honeycomb sandwich structure, and Figure 10 shows the energy absorption situation of the core materials of the sandwich structure under different conditions.

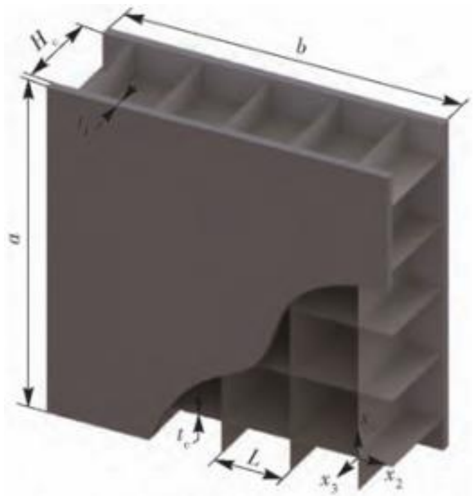

Figure 9: Square honeycomb sandwich structure of carbon fiber reinforced composite material

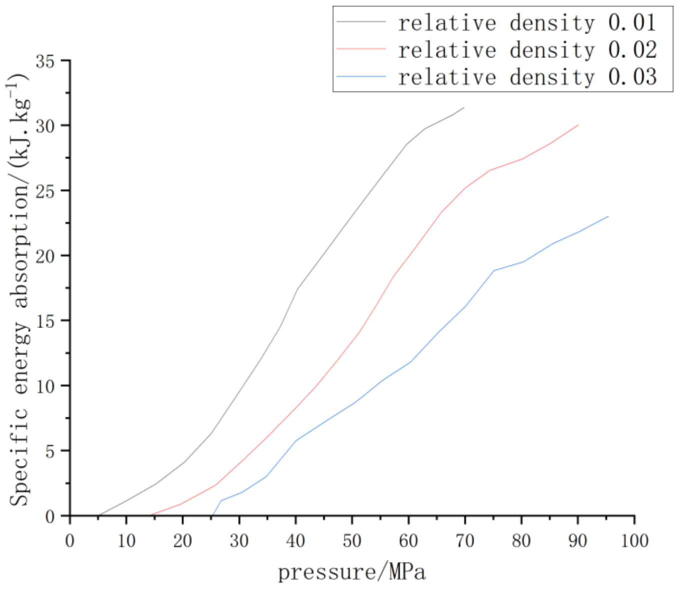

Figure 10: The energy absorption situation of the core materials of the sandwich structure under different conditions.

1.2.3 Pre folded energy absorbing components

Pre folded energy absorbing components absorb energy by pre designing folds (such as ripples, folds, etc.) on the material, so that it can fold and deform in a predetermined way when impacted, thereby absorbing energy. This structure has advantages such as controllable deformation and lightweight. Widely used in fields such as automotive industry, aerospace, and mining roadway support.

In 2014, Tang Zhi et al. [26] proposed a mine-used anti-shock square corrugated thin-walled component. They utilized the finite element software to simulate the energy absorption characteristics of this energy-absorbing component with different wall thicknesses and module quantities, and compared and analyzed the energy absorption characteristics with traditional square thin-walled components. Figure 11 shows the schematic diagrams of a single-module component and multiple-module components, and Figure 12 presents the energy absorption characteristics of the thin-walled components. The research results indicate that the square corrugated thin-walled component has a lower peak crush load and higher total energy absorption and specific energy absorption, with significant anti-shock effect; reducing the wall thickness and increasing the number of modules can effectively lower the peak crush load, but it will also reduce the total energy absorption and specific energy absorption. Finally, based on the simulation results, the appropriate component size was selected, and the correctness of the simulation was verified through experiments.

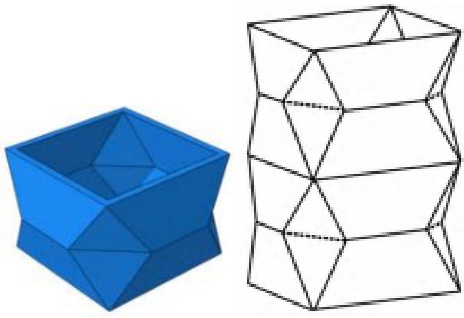

Figure 11:Schematic Diagram of a Single Module Component and Multiple Module Components

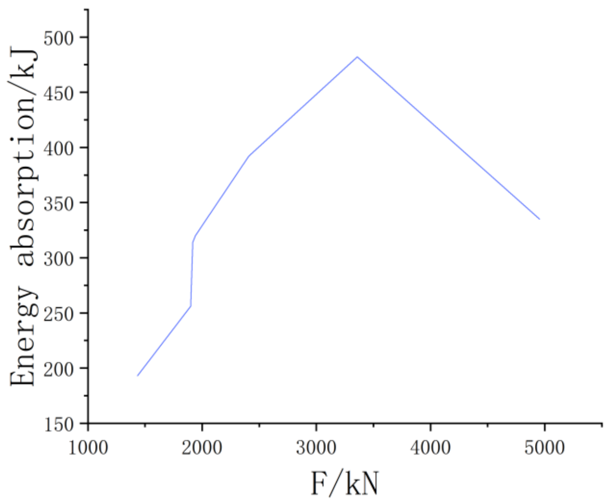

Figure 12: Energy Absorption Characteristics of Thin-walled Components

In 2023, Xu Hailiang et al. [27] proposed a new type of mine-use combined corrugated column component. Figure 13 shows the structural schematic diagram of the energy absorption component, and Figure 14 presents the energy absorption characteristics of the new type of anti-impact energy absorption component with different wall thicknesses. Using the finite element numerical simulation method, the anti-impact energy absorption performance of the new combined corrugated column component and the existing square pre-corrugated component was compared and analyzed, and the influence of different side wall slopes and wall thicknesses on the energy absorption characteristics of the new component was discussed. The research results show that the new combined corrugated column component outperforms the traditional component in terms of peak bearing capacity, average crushing bearing capacity, total energy absorption, and specific energy absorption, and when the side wall slope is 1.2 and the wall thickness is 7mm, the component performance is optimal. The study also found that by balancing the side wall thickness and the friction factor between the component and the rigid plate, the fluctuation of the bearing capacity curve can be further reduced.

Figure 13: New Mining Combination Folded Column Component

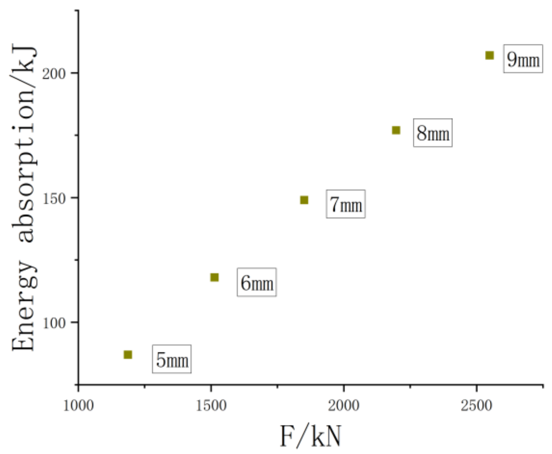

Figure 14 Characteristics of energy absorption of new type anti-impact energy-absorbing components with different wall thicknesses

1.2.4 foam aluminum filled energy absorption component

Foam aluminum energy absorbing component is an energy absorbing component based on foam aluminum material. Foam aluminum is widely used in automotive, aerospace and other fields due to its advantages of light weight, high energy absorption efficiency and so on. The energy absorption principle of foam aluminum energy absorption component is to absorb energy through the compression deformation of foam aluminum. The most typical foam aluminum energy absorption component is foam aluminum filled thin-walled tube.

Foam aluminum filled thin-walled tube: When foam aluminum filled thin-walled tube is subjected to axial impact, foam aluminum will compress and deform, thus absorbing energy. The energy absorption efficiency is related to the density of foam aluminum and the geometric shape of thin-walled tubes.

In 2022, Chen Junhong et al. [28] conducted a study on the impact energy absorption characteristics of thin-walled metal tube structures filled with foamed aluminum. Through quasi-static compression experiments using a material testing machine and dynamic compression experiments with the Taylor-Hopkinson specimen, they compared and analyzed the performance of three different density specimens. Figure 15 shows the structure of the foamed aluminum-filled thin-walled metal tube, and Figure 16 presents the relationship curve between the energy absorption capacity and mass of the energy absorption device. The study indicates that under quasi-static compression conditions, foamed aluminum filling can significantly enhance the energy absorption capacity of the structure; however, under dynamic compression conditions, only when the density of the foamed aluminum exceeds the critical value can the energy absorption performance of the structure be effectively improved.

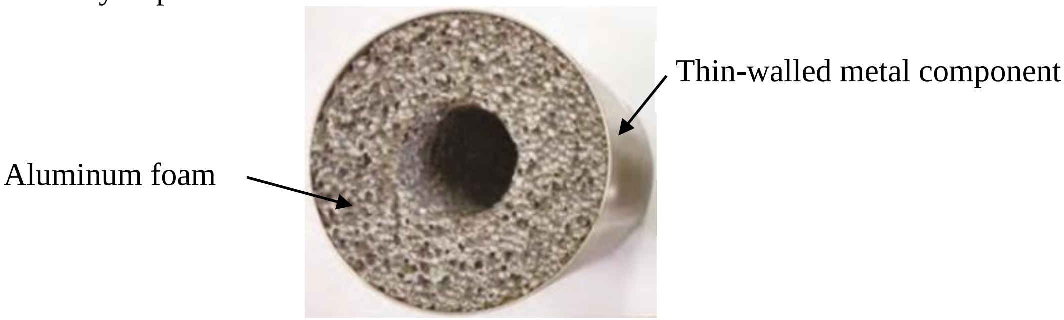

Figure 15: Structure of foam aluminum filled thin-walled metal tube

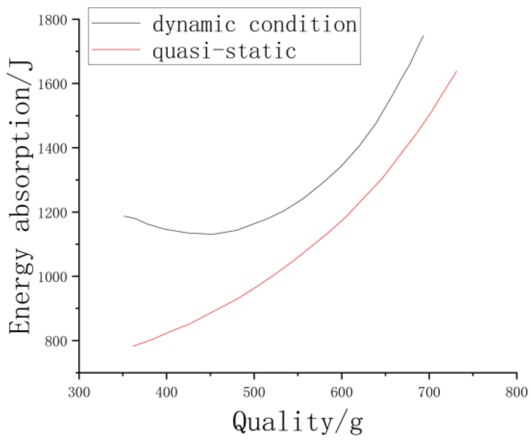

Figure 16: The curve of the relationship between the energy absorbed by the energy-absorbing device and its massr

In 2007, Zhang Tao et al. [29] conducted a comparative study on the energy absorption characteristics of tubular thin-walled structures filled with foam aluminum with four cross-sectional forms: single cap, double cap, circular, and regular hexagonal. The impact buckling process of the structure was numerically simulated using explicit dynamic analysis software, with a focus on analyzing the energy absorption characteristics and impact reaction forces. Figure 17 shows the schematic diagram of the foam aluminum-filled tubular thin-walled structure, and Figure 18 presents the curves of energy absorption and axial compression displacement for the four cross-sectional models[30]. The research results indicate that the double-cap and circular cross-sectional models have more stable energy absorption processes and better energy absorption effects. Meanwhile, the material parameters of the shell and the density of the foam aluminum have significant influences on the energy absorption characteristics of the structure. This study provides important references for the optimization design of impact-resistant structures.

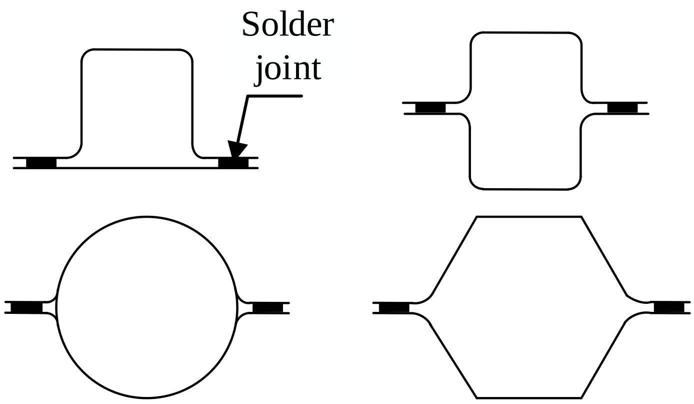

Figure 17: Section Diagram of Tubular Thin wall Structure Filled with foam Aluminum

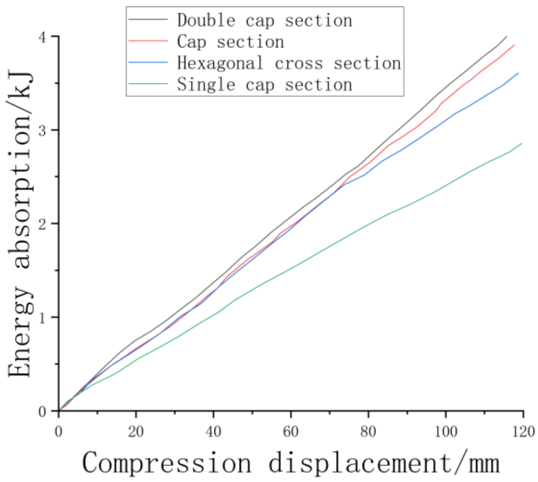

Figure 18: shows the curves of the absorbed energy versus axial compression displacement for four cross-sectional models.

2. Application of Energy Absorbing Components in Mine Tunnel Supportt

With the increase of mining depth, the frequency and intensity of geological disasters such as rockburst are also increasing. Rock burst is a dynamic phenomenon that occurs during the mining process of coal mines. It is influenced by factors such as coal and rock properties, geological structure, mining layout, and coal pillar placement. Under the action of original rock stress and mining induced stress, the accumulated elastic energy of the coal and rock volume around the roadway or working face is instantly released, resulting in severe damage. Energy absorbing components, as an effective energy absorption and dissipation technology, are gradually being introduced into mine roadway support. The application of energy absorbing components in mine roadway support is mainly reflected in the following aspects. Table 1 shows the provinces and specific coal mines in China that use energy absorbing components.

2.1 Improving the Impact Stability of Surrounding Rock in Roadways

Energy absorbing components can effectively reduce the impact of ground pressure on the surrounding rock of tunnels by absorbing and dissipating impact energy, thereby improving the stability of tunnels. Energy absorbing components are usually installed in the support structures of tunnels, such as anchor rods, brackets, etc. Tang Zhi et al. [31] proposed a mining anti impact square corrugated thin-walled component. When impact ground pressure occurs, the energy absorbing component can effectively absorb the impact energy and provide sufficient energy release space for coal and rock through the crushing space. From the above analysis, it can be concluded that regardless of the type or material of energy absorbing components, their core mechanism is to absorb energy through plastic deformation, effectively reducing the destructive effect of impact energy on the protected object.

2.2 Reduce the harm of impact ground pressure to personnel and equipment

The hazards of rockburst are multifaceted. In terms of personnel safety, it may cause serious casualties. For example, in the event of a strong impact, the sudden ejection or collapse of coal and rock masses may bury or directly impact workers, posing a significant threat to their safety [32]. Therefore, in the roadway support of coal mines

2.3 Extending the service life of tunnels

Entering energy absorbing components can effectively reduce the harm of impact ground pressure to personnel and equipment in the tunnel. When rockburst occurs, energy absorbing components can absorb most of the impact energy, reducing the direct impact of shock waves on personnel and equipment in the tunnel, thereby improving the safety of the mine. Energy absorbing components absorb and dissipate impact energy, thereby reducing the damage of impact ground pressure to tunnel support structures and extending the service life of tunnels. Table 1 lists the comparison of the service life of tunnels after using energy absorbing components in five typical coal mines. The application of energy absorbing components can effectively reduce the maintenance cost of tunnels and improve the economic benefits of mines.

Table 1: Comparison of coal mine service life before and after the introduction of energy absorbing components

Coal mine name	Pre introduction service life	Service life after introduction	Lifting effect
Shanxi Tashan Coal Mine	6-12 months	2-3 years	Extend by 2-3 times
Shaanxi Hongliulin Coal Mine	8-10 months	More than 2 years	Extend by 2-3 times
Burtai Coal Mine in Inner Mongolia	4-6 months	1.5-2 years	Extend 3-4 times
Shandong New Julong Coal Mine	10-12 months	Over 2.5 years	Over 2.5 years
Guizhou Shanshanshu Coal Mine	6-8 months	1.5-2 years	Extend by 2-3 times

Optimization and Innovation of Three Energy Absorbing Components

With the advancement of technology and the development of materials science, the optimization and innovation of energy absorbing components are constantly advancing. In the future, intelligent materials and AI driven material design will lead the way. The following are some prospects for optimizing and innovating energy absorbing components.

3.1 Material optimization

The material selection of energy absorbing components has a significant impact on their energy absorption efficiency. In the future, with the continuous emergence of new materials such as carbon fiber and nanomaterials, the materials of energy absorbing components will be further optimized. Carbon fiber has the advantages of high strength, lightweight, and impact resistance, making it an ideal material for manufacturing energy absorbing components. Nanomaterials have extremely high strength and toughness, and are widely used in the automotive industry and aerospace fields. But its disadvantages cannot be ignored, such as high preparation costs, complex preparation processes for nanomaterials, high equipment requirements, resulting in high costs. Further research is needed to determine whether nanomaterials can be applied to energy absorbing components. But in the future, carbon fiber composite materials are expected to be widely used in energy absorbing components.

3.2 Structural optimization

The structural design of energy absorbing components has a significant impact on their energy absorption efficiency. In the future, with the development trend of computer simulation and optimization algorithms moving towards high precision, intelligence, distribution, and interdisciplinary integration, these technologies will play a more important role in scientific research, engineering design, and industrial production, providing powerful tools for solving complex problems, and the structural design of energy absorbing components will also be further optimized. By optimizing the geometric shape, wall thickness, cross-sectional form, and other parameters of the energy absorbing component, its energy absorption efficiency can be effectively improved.

3.3 Multifunctionality

Future energy absorbing components will not be limited to a single function of energy absorption. With the development of science and technology, energy absorbing components will also have other functions, such as monitoring and early warning. In the future, integrated sensors and intelligent control systems can be installed in energy absorbing components to monitor the stress state and occurrence of ground pressure in tunnels in real time, thereby achieving early warning and timely response to mining disasters.

3.4 Intelligence

With the rapid development of artificial intelligence and IoT technology, and their deep integration in multiple fields. So the energy absorbing components will gradually achieve intelligence. Future energy absorbing components will be able to provide feedback based on the stress state of the tunnel and the occurrence of impact ground pressure, automatically adjust their energy absorbing characteristics, and achieve optimal absorption and dissipation of impact energy, ensuring the safety of personnel and equipment in the tunnel.

4 Conclusion

As an effective energy absorption and dissipation technology, energy absorbing components are currently the only energy consuming components in mine roadway support, and therefore have important application value in mine roadway support. Through the research and application of energy absorbing components, the impact stability of tunnels can be effectively improved, the harm of impact ground pressure to personnel and equipment can be reduced, and the service life of tunnels can be extended. In the future, with the development of materials science, structural design, and intelligent technology, energy absorbing components will be further optimized and innovated, providing more reliable guarantees for mine safety.

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