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A numerical study on the crashworthiness of corrugated conical tubes: energy absorption and impact performance

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ABSTRACT

The crashworthiness of structures refers to their ability to protect occupants during an impact by absorbing and dissipating the energy generated during a collision. One of the most critical design considerations in safety engineering, especially in automotive and aerospace industries, is to ensure that energy absorption during a crash is maximized while minimizing damage to the occupants. Among the various energy-absorbing structures, corrugated tubes have emerged as an effective solution due to their enhanced performance in crash scenarios. This article delves into a numerical study on the crashworthiness of corrugated conical tubes, focusing on their energy absorption capabilities, deformation modes, and overall performance during an impact.

KEYWORDS

Crashworthiness; Corrugated conical tube; Finite element analysis; Energy absorption enhancement; Crumple zone; Energy dissipation

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Introduction

Crashworthiness plays a key role in ensuring the safety of vehicles and structures during accidents or collisions. The primary objective is to design materials and structures that can absorb the kinetic energy from an impact, thereby reducing the forces transmitted to the occupants or surrounding environment. Energy absorption is a critical aspect in crashworthiness design, and various types of energy-absorbing structures have been explored, including crumple zones, bumpers, and tubes [1]. Tubular structures are particularly attractive because of their ability to deform in a controlled manner during an impact, thus absorbing large amounts of energy while keeping the forces on the occupants manageable. Corrugated tubes have become an increasingly popular choice in crashworthiness design due to their unique geometric structure. These tubes exhibit a high level of energy absorption due to their ability to deform progressively and absorb energy through plastic deformation, folding, and crumpling [2].

Corrugated Conical Tubes: Design and Structure

A corrugated conical tube is a type of tubular structure characterized by its conical shape and the presence of corrugations along the tube's surface. The cone shape allows for a gradual tapering in diameter, which can be tailored to absorb varying amounts of energy depending on the specific application [3]. The corrugated structure refers to the tube's surface being ridged or wavy, rather than smooth. This design increases the tube's local buckling strength, allowing it to deform in a more controlled manner during an impact [4]. The unique combination of conical geometry and corrugation enhances the tube's energy absorption capabilities compared to regular cylindrical tubes [5].

In terms of crashworthiness, the use of these corrugated conical tubes offers multiple benefits like improved energy dissipation during impact, progressive deformation that absorbs a greater amount of kinetic energy, increased strength-to-weight ratio, which is critical in automotive and aerospace industries, the flexibility to design these tubes for specific energy absorption requirements by adjusting the angle of the cone and the shape of the corrugations [3].

Numerical Simulation of Crashworthiness

Numerical studies are invaluable in understanding the crashworthiness of structures like corrugated conical tubes. By using advanced computational techniques, engineers can simulate various crash scenarios and evaluate how the tubes respond to different impact conditions. Finite Element Analysis (FEA) is one of these studies most commonly used numerical methods, allowing for detailed simulations of complex materials and geometries [6].

A typical numerical study on the crashworthiness of corrugated conical tubes involves modelling the geometry of the conical tube, including the corrugations and material properties, defining boundary conditions to simulate real-world impact situations, such as collisions with rigid barriers or other structures, applying impact forces that simulate crash conditions, including varying velocities, angles, and energy levels, evaluating the deformation modes of the tube, including bending, buckling, and crumpling [7].

Assessing the energy absorption characteristics of the structure, which are vital to ensuring that the tube can dissipate the required amount of kinetic energy while limiting the forces on the surrounding structure or occupant.

Results of the Numerical Study

In a typical numerical study of crashworthiness, the results may include several key findings:

Energy absorption efficiency

The primary goal of the study is to assess how efficiently the corrugated conical tube absorbs the impact energy. Generally, these tubes show excellent performance, with high energy absorption rates due to their progressive collapse and controlled

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deformation. The conical shape helps distribute the impact load more evenly across the structure, reducing peak forces and increasing overall energy dissipation [2].

Deformation modes

The deformation of the tube during impact is closely analyzed. The numerical models typically show that the corrugated conical tube deforms in a progressive folding or crumpling manner, which ensures that energy is absorbed uniformly along the length of the tube. The corrugations facilitate this process by providing localized areas of strength and ensuring that the deformation is gradual [8].

Effect of geometry

The study may also investigate how variations in the tube's geometry (such as the angle of the cone or the size and shape of the corrugations) affect crashworthiness. For instance, a larger corrugation depth or a steeper cone angle may increase the tube's ability to absorb energy but might also affect the structural integrity and buckling behavior. Optimizing the geometry is a key part of improving the crashworthiness of these tubes [9].

Comparison with Other tubular structures

The numerical results often include a comparison of the corrugated conical tube's performance with that of other standard crashworthy structures, such as simple cylindrical tubes. In many cases, corrugated conical tubes outperform traditional designs in terms of energy absorption, structural stability, and overall performance under crash conditions [10].

Applications of Corrugated Conical Tubes in Crashworthiness Design

Crashworthiness refers to a vehicle's ability to protect its occupants during an impact, a critical aspect of vehicle design that ensures safety during accidents. In this context, corrugated conical tubes have emerged as a vital component for enhancing energy absorption and improving the structural integrity of vehicles in crash situations [11].

Energy absorption enhancement

Energy Absorption Enhancement one of the most significant applications of corrugated conical tubes in crashworthiness design is their exceptional ability to absorb and dissipate impact energy during a crash. The unique shape of these tubes, with a conical and corrugated structure, allows them to deform in a controlled manner during a collision. When a vehicle experiences a crash, the corrugated conical tubes undergo progressive buckling, which distributes and absorbs the impact energy [12]. This minimizes the force transmitted to the vehicle occupants, reducing the likelihood of severe injuries.

The conical shape helps to progressively collapse under impact, and the corrugated surface adds further resistance to deformation, offering a well-controlled energy dissipation mechanism. This is crucial in protecting the vehicle's structural integrity and enhancing the overall safety performance [13].

Lightweight design with high strength

Corrugated conical tubes offer a lightweight yet strong solution, which is particularly beneficial in automotive crashworthiness design. The material used in these tubes is typically lightweight metal alloys such as aluminum or advanced composite materials, which ensure the vehicle remains fuel-efficient while maintaining a high level of strength [14]. The combination of strength and lightweight properties allows the tubes to absorb energy without adding excessive weight, which is essential for meeting safety regulations without compromising vehicle performance [15].

By integrating these tubes into areas of the vehicle that are most prone to crash forces, such as the front or rear crumple zones, engineers can optimize the vehicle's structural design to ensure maximum safety with minimal weight penalty. Improved impact behavior in front-end and side-impact collisions

Corrugated conical tubes are particularly beneficial in the design of crumple zones, especially for front-end and side-impact collisions. In a front-end collision, the front part of the vehicle is designed to crumple in a controlled manner, reducing the impact forces transferred to the occupants. The corrugated conical tubes help in managing the deformation by progressively absorbing energy through the controlled folding of the tube [16].

In side-impact collisions, where the force distribution may not be as evenly spread out, the tubes provide localized energy absorption in the areas where the impact is most intense. The conical geometry ensures that the force from the collision is spread across a larger area, further improving energy dissipation and reducing the likelihood of severe injury.

Conclusions

The crashworthiness of structures, especially in applications that require energy absorption and impact resistance, is a crucial area of engineering research. The numerical study on the crashworthiness of corrugated conical tubes has revealed their potential as effective energy absorbers capable of enhancing safety in automotive, aerospace, and civil engineering applications. Their unique design, combining the benefits of conical geometry and corrugated surfaces, allows for superior performance in terms of energy dissipation, progressive deformation, and overall structural stability under impact conditions.

As this area of study progresses, further optimization of tube geometry and material selection, along with the development of more advanced numerical models, will continue to improve the effectiveness of corrugated conical tubes in real-world crash scenarios. The future of crashworthiness design is increasingly focusing on maximizing energy absorption while minimizing structural damage, and corrugated conical tubes are well-positioned to play a significant role in achieving these goals.

Disclosure statement

No potential conflict of interest was reported by the author.

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