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Perspective

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Lightweight Design and Manufacturing of Scrapers in Mining Scraper Conveyors: A Perspective

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Abstract: This Perspective emphasizes the potential of topology optimization for advancing lightweight scraper design, while addressing the manufacturing challenges associated with geometrically complex optimized structures. Hybrid investment casting is introduced as a promising approach to bridge innovative design and practical industrial production. The article outlines a forward-looking framework that integrates structural optimization with manufacturing considerations to guide the practical implementation of lightweight and manufacturable scraper designs.

Keywords: Mining scraper conveyor; Lightweight design; Topology optimization; Hybrid investment casting

A mining scraper conveyor is a heavy-duty continuous conveying system widely used in underground mining operations, particularly in longwall coal mining faces [1,2]. It consists of a chain-driven system equipped with scrapers that drag bulk material—such as coal or ore—along the middle trough, as shown in Figure 1. During long-term operation in confined underground environments, the conveyor system is inevitably exposed to complex mechanical and environmental actions, including impact loading, abrasive wear, moisture-induced degradation, and

corrosive conditions, which significantly influence its structural reliability and service life.

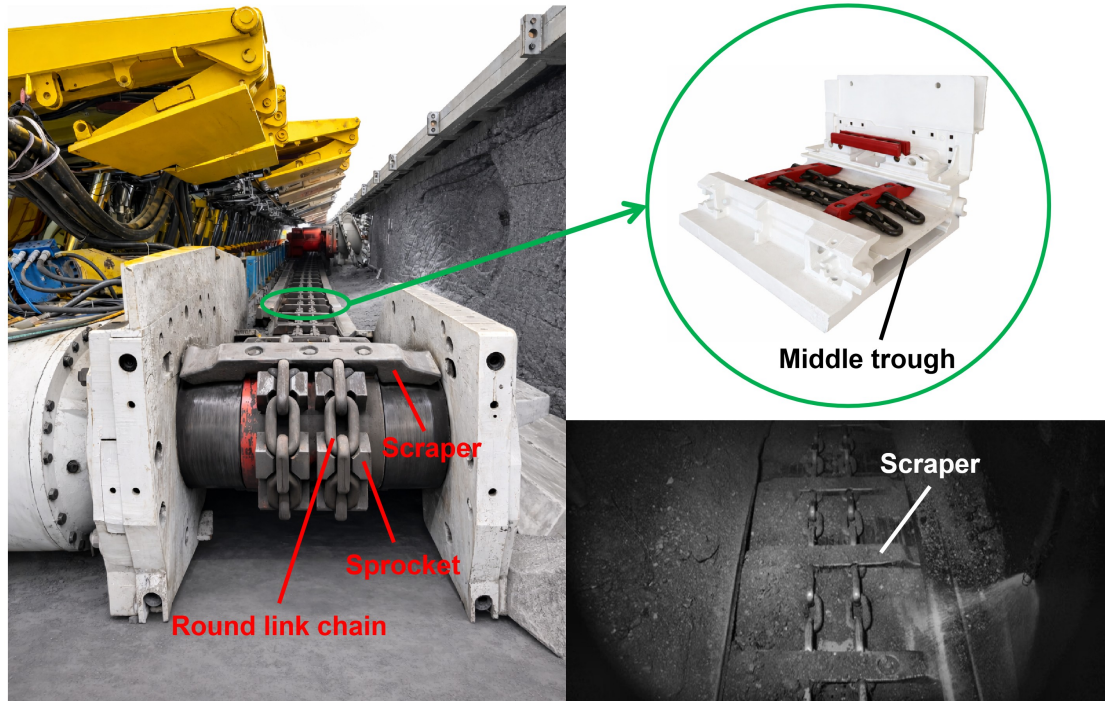


Figure 1: Mining scraper conveyor

Lightweight design of mining equipment has attracted increasing attention in both academia and industry [3,4]. The lightweight design of scrapers plays a key role in the overall performance and stability of a mining scraper conveyor. The mass of scrapers can influence the dynamic behavior of the chain-driven system by affecting inertia, load transfer, and overall mechanical efficiency. Excessive structural weight may increase drive power demand and internal forces within the system, which could potentially reduce operational efficiency and accelerate structural degradation over long-term service. Field observations in mining operations suggest that scrapers generally exhibit relatively lower failure rates compared with several other components in the chain transmission system, indicating that weight reduction may be achievable while maintaining adequate structural strength and operational reliability.

Among existing structural lightweight design strategies, topology optimization is widely recognized as an effective approach for enhancing material utilization and structural performance [5-7]. However, the optimized geometries it generates are typically characterized by considerable geometric complexity [8,9]. Although additive manufacturing offers the geometric flexibility required to fabricate such intricate structures, its high production cost and limited manufacturing efficiency constrain its applicability to large-scale production of heavy-duty mining scrapers. In contrast, conventional casting processes provide superior cost efficiency and industrial maturity, yet they are inherently incapable of directly reproducing highly complex topology-optimized features.

To address this gap, hybrid investment casting offers a practical manufacturing solution [10]. Since the final scraper component is produced through a casting process, casting-related constraints should be incorporated into the topology optimization stage to ensure manufacturability during the design phase. By integrating additive manufacturing with conventional investment casting, the optimized scraper geometry is first translated into a 3D-printed polymer pattern that accurately captures complex internal load paths and hollow lightweight features. The pattern is then embedded in an investment mold and removed through a controlled burnout process, forming a precise casting cavity. During casting, process controls such as mold preheating and inert gas degassing are applied to minimize porosity and stabilize solidification behavior. This integrated workflow bridges design and production, enabling the reliable fabrication of topology-optimized scraper structures while maintaining structural integrity, dimensional accuracy, and practical manufacturability. The workflow of structural lightweight design and manufacturing for heavy-duty mining scrapers is shown in Figure 2.

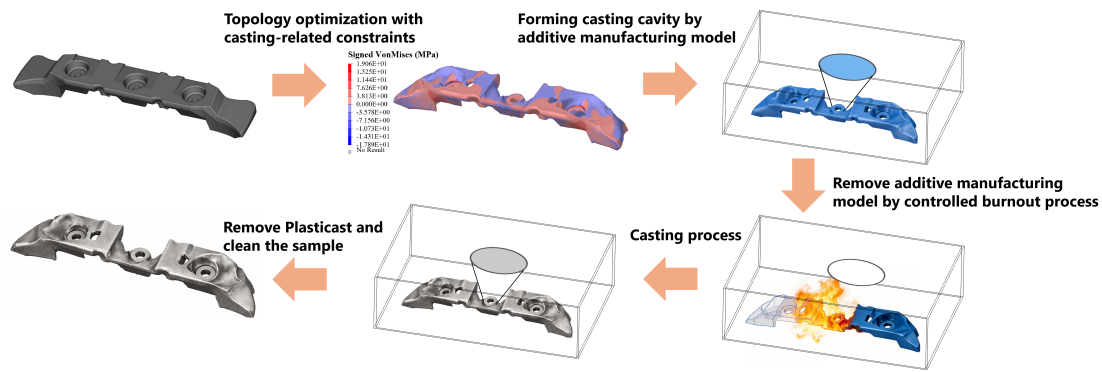


Figure 2: Workflow of lightweight design and manufacturing for scrapers

In summary, lightweight design of mining scrapers requires not only advanced structural optimization methods but also effective integration of scraper geometry design with manufacturing considerations. The integration of topology optimization with casting-oriented constraints, supported by hybrid investment casting, provides a practical pathway for transforming complex optimized scraper geometries into industrially viable and structurally reliable scraper components.

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