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Review

Advances in implant for surface modification to enhance the interfacial bonding of shape memory alloy wires in composite resins

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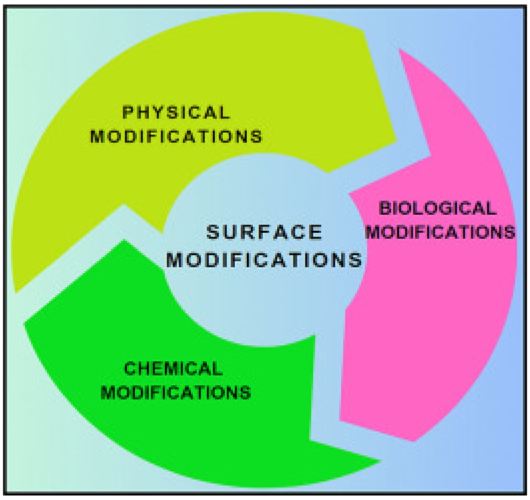
Highlights

- Current developments in methods for surface modification to increase the interfacial bonding of shape memory alloy (SMA) wires and composite resins are reviewed in this article.
- In this review work, the interfacial bonding of SMA wires and resin composites is evaluated with an in-depth review of the experimental methods utilized.
- Viscoelastic characteristics of SMA-resin interfaces can be studied with a precise tip to evaluate materials surface profiles.
- The most promising surface modification methods are critically described in the conclusion of the article, as well as potential advances and prospects for the field of SMA composites.

Abstract

Shape memory alloys (SMAs) are gaining traction in aerospace, automotive, and energy sectors due to their roles as actuators, sensors, and energy converters at high temperatures. Their unique benefits have led to widespread commercial use, supported by extensive research. However, engineered metallics often face deformation and strength issues. Efforts are underway to bolster the bond between SMA wires and composite resins through advanced surface modifications. This review delves into recent surface modification techniques, challenges in SMA composite adhesion, and analytical tools like X-ray photoelectron spectroscopy (XPS) and atomic force microscopy (AFM). The study concludes with insights on promising modification strategies and the future of enhanced bonding in SMA composites.

Graphical abstract



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Introduction

Shape memory alloys (SMAs), a remarkable class of metallic materials, are distinguished by their unique ability to revert to their original configuration in response to specific stimuli like temperature fluctuations, mechanical stress, or magnetic fields. This fascinating property, termed the shape memory effect, originates from the reversible phase transition between two distinct crystalline structures [1]. These alloys are celebrated for their exceptional robustness, flexibility, and resistance to wear and tear, making them invaluable in a multitude of sectors. In addition to their signature shape memory characteristics, some SMAs exhibit an extraordinary feature known as superelasticity, which empowers them to withstand substantial deformations without sustaining lasting damage [2]. Their versatile applications span across several industries. In the realm of aerospace, SMAs are crucial in the construction of intricate components such as wing mechanisms, landing gear, and propulsion systems. Within the automotive sector, their utilization in smart sensing devices, movement inducers, and shock absorbers is noteworthy, contributing significantly to vehicle performance and safety. In the medical field, SMAs are revolutionizing patient care through their use in advanced medical devices, including vascular stents and orthodontic appliances, benefiting from their biocompatibility and shape adaptability [3].

The unparalleled properties of SMAs have spurred their adoption in enhancing composite materials, notably in applications demanding enhanced durability, stiffness, and resilience. SMA wires, when embedded within polymer-based composites, play a pivotal role in augmenting structural integrity [4], while their incorporation into cementitious materials is instrumental in improving ductility and energy absorption, critical in construction and civil engineering applications [5]. Despite these advantages, a significant challenge is the adhesion between SMA wires and the resin matrix within these composites. This bonding issue is crucial as insufficient adhesion can lead to reduced composite efficacy, manifesting as layer separation, fractures, and compromised structural integrity [[6], [7], [8]].

Addressing this critical concern, recent literature has extensively explored interface dynamics in SMA-composite systems. Studies like those by Mohit et al. [9] have examined the mechanics of bonding and its impact on composite longevity, while research teams like Jin et al. [10] have focused on surface treatment methods to enhance fiber-matrix adhesion. Investigations into mechanical dynamics by researchers such as Rogers et al. [11] and Osfouri et al. [12] have provided insights into the structural behaviour of composites incorporating SMA, particularly under various stress conditions. These studies collectively underscore the paramount importance of bond strength in ensuring the functional success of SMA-based composites.

In this review, we systematically explore the forefront of advancements in surface modification techniques designed to strengthen the interfacial bond between SMA strands and resin matrices. Drawing from a rich collection of recent scholarly contributions, we classify surface modification strategies into three broad categories: physical interventions, chemical treatments, and biological processes. Each category, while distinct, converges on the common goal of enhancing bond strength, albeit through different mechanisms and approaches. Our aim is to provide an in-depth analysis of these cutting-edge methods, elucidating their mechanisms of action, effectiveness, and potential limitations [13,14,15]. We also emphasize the need for tailored approaches that consider the unique attributes of SMAs, thereby enabling the development of composites optimized for specific applications.

The synthesis of this knowledge has the potential to catalyse the development of advanced materials, especially in fields where mechanical performance is paramount, such as aerospace engineering, medical device technology, and infrastructure development. By highlighting the latest innovations in SMA surface modification, we envision a new era of materials science where the interfacial bond strength is no longer a limiting factor but a leveraged feature, propelling SMAs to broader industrial applications and technological breakthroughs. The various surface modification methods and their role in enhancing interfacial bonding in SMA composites are systematically illustrated in Fig. 1.

Section snippets

Transition boundary development in composite materials

The development of a transition boundary between SMA and resin layers is a critical technique for enhancing the mechanical properties of composite materials [16]. This process requires meticulous control over the interfacial layer, both physically and chemically, to positively impact the composite's overall characteristics [17]. Research in this area, notably by Parasuram (2023) and his team, underscores the significance of fine-tuning interfacial properties, particularly in composites with …

Interfacial bonding evaluation techniques

The experimental study on interfacial bonding is presented in Fig. 9. In order to evaluate the strength of interfacial bonding between Shape Memory Alloy (SMA) resin and wires matrices, various experimental methods have been employed. These methods typically involve subjecting composite materials to different tests and measuring the resulting bond strength 84. The most commonly used experimental method for evaluating interfacial bonding strength is listed here. Interfacial strength and …

Utilizing molecular dynamics simulations in assessing interfacial dynamics

The realm of Molecular Dynamics (MD) simulations has emerged as a linchpin in understanding and forecasting the interfacial dynamics between Shape Memory Alloy (SMA) wires and resin structures in SMA-focused composites. By dissecting molecular actions and interactions at infinitesimal scales, MD simulations unveil the core mechanisms presiding over interfacial links. When paired with hands-on experiments, MD simulations provide a richer, more layered understanding of interfacial dynamics across …

Cutting-edge techniques for interfacial property analysis

This segment delves into state-of-the-art methods for analysing interfacial attributes in SMA-based composite materials. Harnessing these techniques is paramount to refine the interfacial binding and understand the nuances of surface chemistry and structure. …

Conclusions and future perspectives

In recent times, the prominence of Shape Memory Alloy (SMA) wires has surged, primarily because of their unparalleled capability to revert to their pre-deformed state upon reaching a specific temperature threshold. Their applications span across diverse domains, from healthcare to structural engineering. A pivotal aspect that impacts the efficacy and mechanical attributes of composite materials incorporating SMA wires is their bond with resins. In our exploration, we delved into a myriad of …

CRediT authorship contribution statement

T. Gopalakrishnan: Conceptualization, Investigation, Writing – original draft. **Raja Venkatesan:** Conceptualization, Formal analysis, Investigation, Writing – original draft. **M. Chandrasekaran:** Data curation, Formal analysis. **Simon Deepa:** Formal analysis, Writing – review & editing. **Seong-Cheol Kim:** Funding acquisition, Project administration, Supervision, Writing – review & editing. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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