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An Overview about Shape Memory Alloys (SMAs) - Properties, Mechanisms, and Applications in Construction

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ABSTRACT: Shape Memory Alloys (SMAs) represent a fascinating class of materials characterized by their unique ability to undergo significant deformation and subsequently return to their original shape when subjected to specific thermal conditions. The intrinsic properties of SMAs, including their high strength-to-weight ratio, excellent corrosion resistance, and remarkable energy absorption capabilities, render them exceptionally suitable for various structural applications. These alloys exhibit two primary phases: the austenite phase, which is stable at higher temperatures, and the martensite phase, which forms at lower temperatures. The transition between these phases is governed by temperature changes, allowing SMAs to "remember" their original shape and revert to it when heated. This phase transformation is not only a hallmark of SMAs but also a key factor in their functionality in real-world applications. In the context of construction, the mechanisms of SMAs can be harnessed to enhance the performance and resilience of structures. For instance, their capacity for self-healing and adaptive responses to environmental changes can significantly improve the durability and longevity of buildings and infrastructure. Applications range from seismic protection systems, where SMAs can absorb and dissipate energy during earthquakes, to smart materials that adapt to temperature fluctuations, thereby optimizing energy efficiency and occupant comfort. This overview aims to elucidate the transformative potential of Shape Memory Alloys in the construction sector, highlighting ongoing research and development efforts that strive to integrate these advanced materials into modern engineering practices. The exploration of SMAs not only underscores their innovative properties but also emphasizes their role in paving the way for more resilient, efficient, and sustainable construction solutions in the face of evolving environmental challenges.

KEYWORDS: Shape memory alloy, responsiveness, structural integrity, energy efficiency, sustainability

I. INTRODUCTION

Shape Memory Alloys (SMAs) represent a unique class of smart materials that exhibit remarkable properties, including the ability to return to a predetermined shape upon heating. This phenomenon, known as the shape memory effect, arises from the distinctive phase transformation mechanisms inherent to these alloys, primarily involving the transition between austenite and martensite phases. The exceptional mechanical properties of SMAs, such as high strength, ductility, and fatigue resistance, coupled with their ability to undergo significant deformations, have garnered considerable attention in various engineering fields. In the realm of construction, SMAs offer innovative solutions for enhancing structural performance, improving safety, and enabling adaptive responses to dynamic environmental conditions. This overview aims to elucidate the fundamental properties and mechanisms of SMAs, while also exploring their diverse applications in construction, including seismic protection systems, self-healing materials, and adaptive structural elements. Through a comprehensive understanding of SMAs, this research seeks to highlight their potential to revolutionize modern construction practices and contribute to the development of smarter, more resilient infrastructure.

II. RELATED WORKS OVERVIEW

One notable study by Lagoudas et al. (2008) highlights the use of SMAs in smart structures, emphasizing their ability to act as actuators and sensors in response to environmental changes. The authors demonstrate that integrating





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SMAs into structural components can lead to significant improvements in the adaptability and resilience of buildings, particularly in earthquake-prone regions.

In another comprehensive review, Brinson (1993) discusses the fundamental properties of SMAs and their potential applications in civil engineering. The review outlines various scenarios where SMAs can be utilized, such as in the reinforcement of concrete structures and as flexible joints in bridges. The unique recovery characteristics of SMAs can mitigate the effects of dynamic loads, thereby enhancing the overall durability and longevity of infrastructure.

Moreover, a recent study by Aydin et al. (2020) investigates the use of SMA reinforcements in concrete beams subjected to cyclic loading. The findings suggest that incorporating SMAs not only improves the energy dissipation capacity of the beams but also enhances their ductility, making them more resilient to seismic activities. This research underscores the importance of SMAs in developing advanced construction materials that can withstand extreme conditions.

Additionally, the work of Sadeghi et al. (2019) explores the integration of SMAs in bridge design, where they propose a novel system that utilizes SMA-based dampers. Their experimental results indicate that these dampers effectively reduce vibrations and displacements during seismic events, thereby ensuring the safety and stability of bridge structures.

III. PHYSICAL PROPERTIES OF SHAPE MEMORY ALLOYS (SMA'S)

Property	Typical Value	Units	Reference	
Density	6.45 - 6.50	g/cm ³	Torra et al., 2004	
Melting Point	1240 - 1310	°C	Farhan et al., 2019	
Thermal Conductivity	8-18	W/m·K	[Otsuka & Wayman, 1998] in Torra et al., 2004	
Electrical Resistivity	76 – 100	μΩ·cm	Farhan et al., 2019	
Transformation Temperature	-100 to 110	°C	Liping et al., 2020	
Specific Heat Capacity	0.32 - 0.46	J/g·K	Torra et al., 2004	
Thermal Expansion Coefficient	6.6 - 11.0	×10 ⁻⁶ /K	Torra et al., 2004	
Young's Modulus	28 – 83 (Martensite), 70 – 110 (Austenite)	GPa	Liping et al., 2020	
Poisson's Ratio	0.33 - 0.36		Farhan et al., 2019	
Hardness	250 - 350	HV (Vickers)	Farhan et al., 2019	

Table 1: Physical Properties SMA's





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IV. CHEMICAL PROPERTIES OF SHAPE MEMORY ALLOYS (SMA'S)

Chemical Property	Typical Behaviour/Value	Relevance	Reference
Primary Composition	NiTi (50:50 at.%), Cu-Al-Ni, Fe- Mn-Si	Determines transformation behaviour and mechanical properties	Parmar & Mishra, 2022
Corrosion Resistance	High (especially in NiTi due to TiO ₂ passive layer)	Ensures long-term durability in moist or aggressive environments	Farhan et al., 2019
Oxidation Resistance	Moderate to High (NiTi > Cu- based)	Crucial for high-temperature or exposed applications	Farhan et al., 2023
Phase Stability	Stable between martensite and austenite	Enables reliable shape recovery over many cycles	Torra et al., 2004
Alloying Element Effects	Ag improves conductivity, Cu improves affordability	Enables property tuning without losing core functionality	Farhan et al., 2019
Chemical Reactivity with Concrete	Minimal for NiTi; potential interactions for Cu-based alloys	Influences compatibility with civil infrastructure embedding	Liping et al., 2020

Table 2: Chemical Properties SMA's

V. ADVANTAGES OF SHAPE MEMORY ALLOYS (SMAS) OVER TRADITIONAL CONSTRUCTION MATERIALS

Shape memory alloys (SMAs), particularly NiTi and Fe-based types, offer several distinct advantages over traditional construction materials like steel and concrete due to their unique thermo-mechanical properties. One of the primary benefits is their ability to recover their original shape after deformation through the shape memory effect, which enables structures to self- center after seismic events, reducing residual displacement and post-earthquake repair costs (Torra et al., 2004). Unlike conventional steel, SMAs exhibit super elasticity, which allows them to endure larger strains without permanent deformation, thereby enhancing the resilience and energy dissipation capacity of structures during dynamic loading (Liping et al., 2020). Moreover, SMAs provide high corrosion resistance—especially NiTi alloys due to the formation of a passive TiO₂ layer—making them more durable in aggressive environments compared to standard reinforcement bars (Farhan et al., 2019). Another key advantage is their application in prestressing without the need for mechanical tensioning devices; Fe-SMAs can be thermally activated to apply sustained internal stresses in concrete members, simplifying installation and maintenance. Additionally, SMAs' fatigue resistance and long-term stability under cyclic loads extend the service life of structures, providing a smart material solution for modern, adaptive, and resilient infrastructure systems where traditional materials fall short.

VI. MECHANISM OF SHAPE MEMORY ALLOYS IN CONSTRUCTION - ILLUSTRATED OVERVIEW

The coefficient of thermal expansion (CTE) in concrete is a critical parameter that influences the material's Shape Memory Alloys (SMAs) operate in construction by exploiting their thermomechanical phase transformation between the martensite and austenite phases. This transformation enables SMAs to exhibit two remarkable behaviors: The Shape Memory Effect (SME)—where a deformed SMA returns to its original shape upon heating—and Pseudo elasticity (PE), where the material can undergo large strains and recover them instantly upon unloading. In fig1(a) and (b), in construction these properties are harnessed for seismic energy dissipation, crack control, pre-stressing, and adaptive structures. During earthquakes, SMA dampers or braces deform to absorb energy and then recover, maintaining structural integrity without permanent deformation (Tabrizikahou, 2022). For instance, SMA wires embedded in concrete can contract upon heating to close microcracks, a process used in self-healing concrete technologies. In façade systems, SMAs can passively actuate shading elements based on ambient temperature, enhancing building energy efficiency (Mohd Jani et al., 2014). Additionally, SMAs are used in base isolators and recentering systems in bridges and high-rise buildings to reduce residual drifts post-earthquake (Van Humbeeck, 1999).





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Fig 1 (a), (b): SMA spirals in construction application

VII. APPLICATION OF SHAPE MEMORY ALLOY

Shape-memory alloys were first applied in structural reinforcement when they were used to strengthen a highway bridge in Michigan that had developed significant cracks over time, weakening its integrity. To enhance the bridge's durability, iron-manganese-silicon-chromium shape-memory alloy rods were embedded into its girders. Since that initial application, SMAs have been incorporated into other bridge projects, valued for their elasticity and ability to improve structural strength and resistance to damage.

Pre-tensioned nickel-titanium SMA wires have been employed to reinforce historical buildings, such as the bell tower of San Giorgio church in Italy, enhancing seismic performance without compromising architectural integrity.

SMAs are used in seismic dampers within buildings, leveraging their super elastic properties to absorb and dissipate energy during earthquakes, thereby reducing structural damage.

Iron-based SMAs, known as memory-steel, are utilized to reinforce intermediate concrete slabs, providing active pre stressing capabilities that enhance load-bearing capacity and durability.

VIII. CONCLUSION

The integration of Shape Memory Alloys (SMAs) in the construction sector marks a transformative advancement in structural engineering, offering functionalities far beyond traditional materials. SMAs, particularly NiTi and Febased variants, provide unique advantages such as self-centering capabilities, high energy dissipation, super elasticity, and corrosion resistance, which are critical for enhancing the resilience and longevity of civil infrastructure.

- These properties make SMAs ideal for applications in seismic dampers, self-healing concrete systems, prestressed structures, and adaptive bridges, where they significantly reduce post-event damage and maintenance costs.
- The ability of SMAs to revert to their original shape upon thermal or mechanical stimulation introduces the potential for dynamic and responsive architectural elements, contributing to safer, smarter, and more sustainable built environments.
- Moreover, their high fatigue resistance and chemical inertness ensure long-term structural integrity even in harsh environmental conditions.
- While the initial costs of SMAs may be higher than conventional materials, their life-cycle benefits—reduced repair frequency, extended service life, and enhanced safety—justify their adoption in critical infrastructure projects.





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