Metallic glass fracture: Mechanisms, design, performance.

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Introduction

Amorphous alloys, particularly Bulk Metallic Glasses (BMGs), present a unique class of materials with intriguing mechanical properties, yet their application is often hindered by a tendency towards brittle fracture. Understanding and overcoming this brittleness is a central theme in contemporary materials science. A comprehensive review of current understanding emphasizes fracture mechanisms and toughness in these alloys, underscoring the critical roles of shear band formation, propagation, and their interaction with various microstructural features [1].

This foundational work provides insights into fundamental factors governing ductility and brittleness, guiding approaches to enhance toughness through compositional design and microstructural engineering.

Expanding on these foundational concepts, researchers have explored innovative processing techniques to optimize BMG properties. One notable advancement involves additive manufacturing, which has been shown to yield exceptional fracture toughness and strength in bulk metallic glasses [2].

This tailored processing method can overcome traditional size limitations and property trade-offs, opening doors for materials with superior mechanical performance, particularly valuable for structural applications demanding high damage tolerance. The ability to manipulate material structure at this level offers a promising pathway for BMG utilization in demanding environments.

Beyond basic fracture, the long-term performance under cyclic loading is crucial. Investigations into the fatigue crack propagation behavior of Zr-based BMGs at both ambient and elevated temperatures reveal how thermal conditions significantly influence crack growth rates and underlying mechanisms [3].

This research is vital for assessing the material's potential in applications where component longevity under varying thermal and cyclic stress is a key consideration. The complex interplay of temperature and mechanical stress dictates component reliability.

The core mechanism of deformation and failure in BMGs often revolves around shear bands. The critical role of shear band evolution during tensile fracture of BMGs is meticulously studied, illustrating how the formation, multiplication, and interaction of these bands dictate overall ductility and the eventual failure mode [4].

This deeper understanding of microstructural events leading to macroscopic fracture provides essential insights into improving BMG performance. Such detailed analyses are paramount for predictive modeling and material design.

Compositional modifications represent another potent strategy for property enhancement. Researchers have demonstrated enhanced fracture toughness and ductility in high-entropy BMGs through the minor addition of Niobium (Nb) [5].

This specific compositional tuning strategy offers a promising route to mitigate the inherent brittleness of many metallic glasses, thereby facilitating the design of more robust and damage-tolerant amorphous alloys for a wider range of structural applications. This approach leverages the synergistic effects of multiple principal elements.

Furthermore, dynamic loading conditions introduce another layer of complexity to BMG behavior. Studies examining the fracture behavior of BMGs under dynamic loading emphasize the crucial role of shear band propagation and their interactions during rapid deformation [6].

This work reveals that the rapid initiation and complex interplay of shear bands govern the material's response to high strain rates, providing insights into impact resistance and dynamic failure mechanisms. Understanding these transient processes is critical for applications involving sudden impacts or high-speed deformation.

A critical review synthesizes current understanding of brittle fracture mechanisms in metallic glasses, meticulously analyzing various theoretical models and experimental observations [7].

This comprehensive overview of factors contributing to inherent brittleness offers valuable guidance for future research, aiming to improve the toughness and reliability of these materials. Such reviews are indispensable for consolidating knowledge and identify-

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ing research gaps.

Beyond compositional tuning, microstructural design through composite formation also shows promise. Research details how introducing in-situ formed ductile phases can significantly improve the fracture toughness of Zr-based BMG composites [8].

These ductile phases act as effective crack blunting and bridging agents, thereby increasing the energy required for crack propagation and enhancing the material's resistance to catastrophic failure. This composite approach provides a pathway to overcome the limitations of monolithic BMGs.

The influence of external design parameters, such as specimen geometry, also impacts fracture characteristics. Investigations into the fracture behavior and energy absorption of Zr-based BMGs with varying specimen geometries demonstrate the crucial role of specimen design in influencing observed fracture patterns and the material's capacity to absorb energy before failure [9].

These practical insights are vital for optimizing component design in real-world applications.

Finally, the thermal stability and deformation mechanisms under extreme conditions are explored through studies on high-temperature fracture behavior of Zr-based BMGs. A fascinating transition from brittle to ductile fracture is observed as temperature increases [10].

This work provides valuable information on the thermal stability and deformation mechanisms of these materials, crucial for their application in high-temperature environments, expanding their potential utility.

Conclusion

This collection of studies extensively explores the fracture behavior, toughness, and ductility of amorphous alloys and Bulk Metallic Glasses (BMGs). Key investigations focus on understanding the fundamental mechanisms governing these materials' response to various loading and environmental conditions. Several articles delve into the critical role of shear band evolution, from their formation and propagation to their complex interactions with microstructural features, in dictating tensile fracture, dynamic failure, and overall ductility [1, 4, 6]. Researchers highlight that the ability to control these shear band dynamics is paramount for enhancing mechanical performance.

Significant efforts are dedicated to improving the inherent brittleness often observed in metallic glasses. Strategies explored include compositional design, such as minor Nb addition in high-entropy BMGs to boost fracture toughness and ductility [5]. Another promising avenue is microstructural engineering, exemplified by the in-situ formation of ductile phases in Zr-based BMG composites, which act as crack blunting and bridging agents, thereby increasing fracture resistance [8]. Additive manufacturing techniques are also shown to overcome traditional size limitations, leading to BMGs with exceptional fracture toughness and strength, suitable for high damage tolerance applications [2].

Furthermore, the impact of external factors like temperature and loading conditions is thoroughly examined. Studies reveal how temperature influences fatigue crack propagation rates and mechanisms [3], and how high temperatures can even induce a fascinating brittle-to-ductile fracture transition in Zr-based BMGs [10]. The dynamic loading response of BMGs is also analyzed, underscoring the rapid initiation and interplay of shear bands during impact [6]. The influence of specimen geometry on fracture behavior and energy absorption is also noted, providing practical insights for design optimization [9]. Collectively, these papers provide a comprehensive view of the challenges and opportunities in engineering robust amorphous materials, synthesizing theoretical models with experimental observations to guide future research in this unique class of materials [7].

References

1. Qun W, M.Q. J, *S.X. M. Toughness and fracture mechanisms of amorphous alloys. Prog Mater Sci.* 2020;111:100650.
2. Jianan L, Y. C, *S. J. Exceptional fracture toughness and strength in an additive manufactured bulk metallic glass. Acta Mater.* 2021;211:116843.
3. Dongdong C, X.Q. L, Q.H. Z. Fatigue crack propagation behavior of a Zr-based bulk metallic glass at ambient and elevated temperatures. *J Alloys Compd.* 2022;919:165842.
4. Yong-Jie H, S.H. C, *S.K. L. The critical role of shear band evolution on tensile fracture of bulk metallic glass. Mater Sci Eng A.* 2019;767:138384.
5. Hao-Yu L, R.J. Z, C. H. Enhanced fracture toughness and ductility in high-entropy bulk metallic glasses through minor *Nb addition. Scripta Mater.* 2023;225:115206.
6. Jinhu F, H.L. L, X.J. W. Fracture behavior of a bulk metallic glass under dynamic loading: *Role of shear band propagation and interaction. J Mater Sci Technol.* 2020;59:169-178.
7. P.K. R, D.J. S, G.J. F. Mechanisms of brittle fracture in metallic glasses: *A critical review. J Mater Sci Technol.* 2021;67:1-13.
8. Hao S, J. M, Y. H. Improved fracture toughness in Zr-based bulk metallic glass composites via in-situ formation of ductile phases. J Non-Cryst *Solids.* 2022;585:121542.

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9. Xinqiang L, D.D. C, Q.H. Z. Fracture behavior and energy absorption of Zr-based bulk metallic glasses with varying specimen geometries. *Intermetallics.* 2023;153:107775.

10. Y.B. H, Y.H. L, J.F. L. High-temperature fracture behavior of Zr-based bulk metallic glasses: *From brittle to ductile transition. J Mater Res Technol.* 2020;9(4):8820-8829.

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