

Harmonic heterostructured pure Ti fabricated by laser powder bed fusion for excellent wear resistance

This study provides a manoeuvrable and paradigm route to fabricate Ti with conspicuous strength-plasticity synergy and wear resistance.

CHENGDU, SICHUAN, CHINA, October 23, 2025 /EINPresswire.com/ -- Titanium (Ti) is a promising metal for biomedical implant applications owing to lightweight, superior corrosion resistance and biocompatibility. Unfortunately, Ti is besieged by poor wear resistance owing to inferior plastic shear-resistance and strain-hardening capacity, thus causing premature failure upon joint friction. And conventional strengthening methods inevitably compromise the inherent biocompatibility and safety of pure titanium, which poses a sizable challenge in the manufacturing of wear-resistant Ti orthopedic implants. As described by the Archard law, wear resistance is closely related to both strength and plasticity; however, a trade-off dilemma often exists between strength and plasticity. Therefore, achieving a synergistic enhanced strength-plasticity in pure Ti has become the key breakthrough direction for improving its wear resistance and thereby manufacturing high-performance implants.

Recently, heterostructure inspired by natural materials has been put forward, characterized by heterogeneous zones (including heterogeneity of grains, phases, or compositions, etc.) with dramatically different mechanical, physical or chemical properties. This design strategy leverages the complementary advantages arising from the physicochemical differences between heterogeneous regions, thereby inducing a pronounced synergistic effect in which the integrated

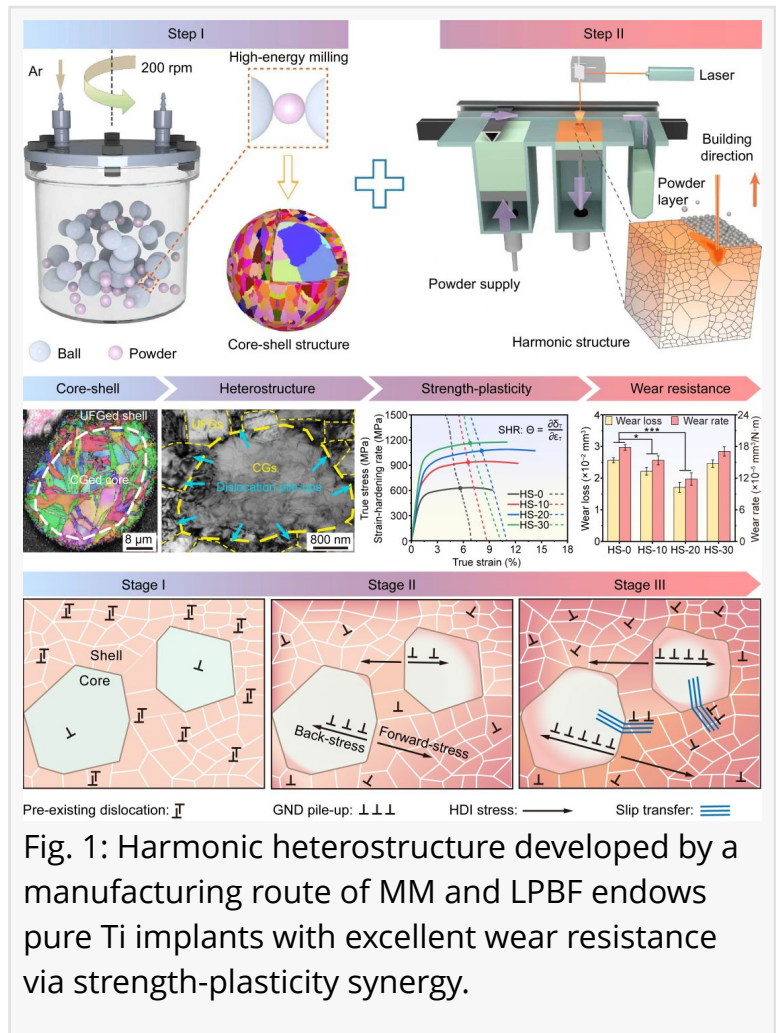


Fig. 1: Harmonic heterostructure developed by a manufacturing route of MM and LPBF endows pure Ti implants with excellent wear resistance via strength-plasticity synergy.

property exceeds the prediction by the rule-of-mixtures. This provides a feasible philosophy to break down conflicting performances, while also opening new avenues for overcoming the strength-plasticity bottleneck in pure Ti implants. However, the challenge facing this strategy lies in efficiently and precisely manipulating the evolution of the size and distribution in heterogeneous regions, thereby achieving the desired [mechanical synergistic effect](#) in pure Ti implants.

For this purpose, the research group of Prof. Shuai Cijun and Gao Chengde at Central South University first proposes a combined technical route integrating mechanical milling (MM) with laser powder bed fusion (LPBF), constructing a highly tunable spatial heterostructure within pure Ti. By leveraging synergistic effects from multi-scale structures, this strategy achieves complementary performance advantages, overcoming the strength-plasticity trade-off bottleneck, thereby endowing pure Ti implants with outstanding wear resistance.

This study of "Harmonic heterostructured pure Ti fabricated by laser powder bed fusion for excellent wear resistance via strength-plasticity synergy" is published in [Opto-Electronic Advances 8, 2025.](#)

Specifically, this research first leverages the controllable energy input of MM pre-treatment process to induce gradient plastic deformation on the surface layer of powder particles, which significantly refines the grain size. This approach enables the preparation of pure Ti powders with a spatial core-shell

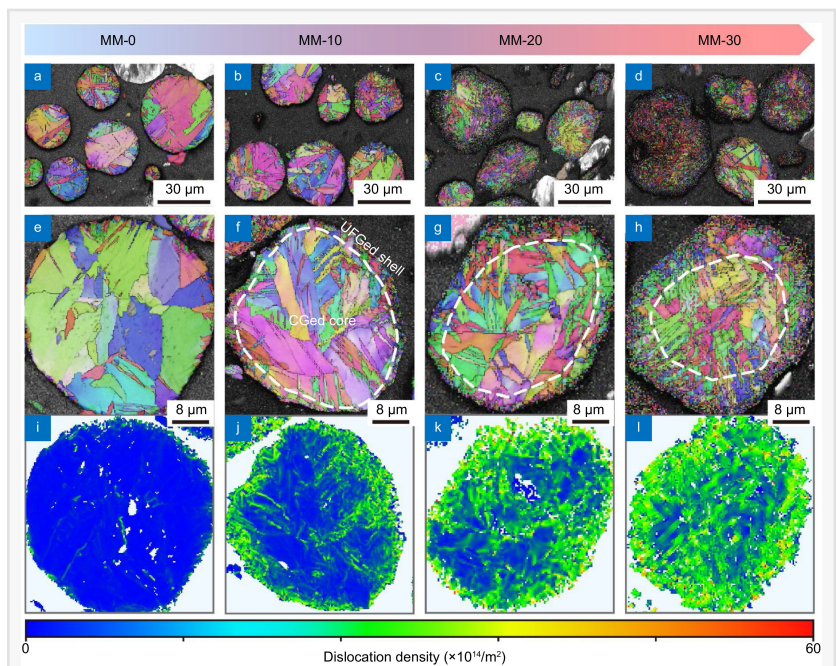


Fig. 2: The cross-section microstructure evolution of pure Ti powders with increasing MM-time (0, 10, 20, and 30 h): (a-d) EBSD orientation maps, (e-h) magnified EBSD orientation maps, and (i-l) KAM maps.

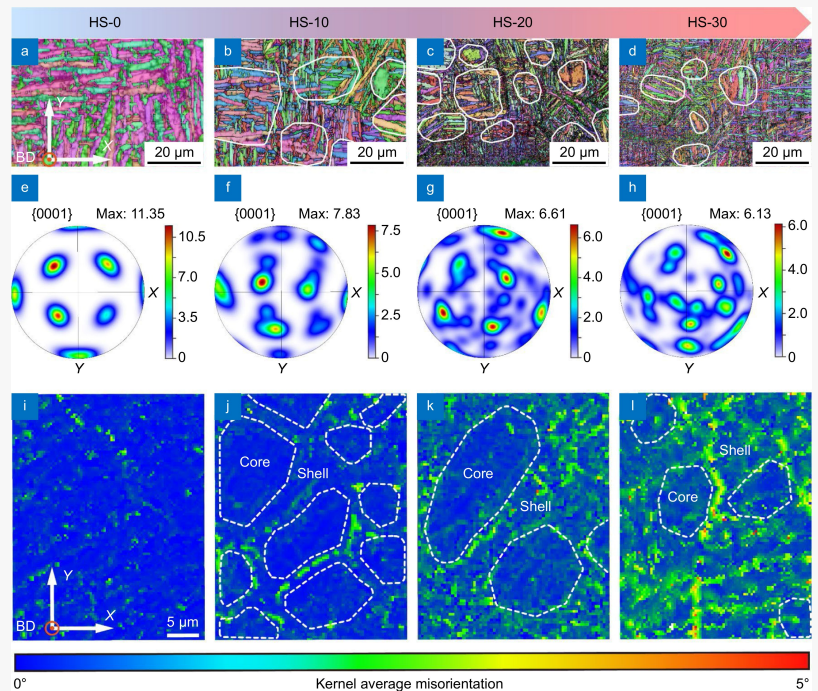


Fig. 3: The microstructure evolution of LPBFed Ti implants upon different MM pre-treatment: (a-d) IPF, (e-h) PF, and (i-l) KAM maps.

structure featuring an ultra-fine-grained (UFGed) shell and coarse-grained (CGed) core, accompanied with pre-existing dislocations. Subsequently, the LPBF process is employed in consolidating the core-shell structured powders into Ti implants.

As a revolutionary intelligent manufacturing technology, LPBF greatly satisfies the integrated manufacturing requirements for high-performance parts through its free-form capability. Notably, the highly transient-melting kinetics and localized nature of LPBF effectively preserve the initial UFGed structure constructed by MM pre-treatment in the powders, hence successfully creating a harmonic heterostructure within consolidated pure Ti. This highly manipulated harmonic heterostructure motivates hetero-deformation-induced (HDI)-strengthening and extra HDI-hardening, thereby achieving a marvelous strength-plastic synergy. Meanwhile, the back-stress induced by geometrical necessary dislocation (GND) pile-up effectively offsets partial wear shear-stress. The concurrent realization of multiple deformation mechanisms endows pure Ti implants with excellent strength-plasticity synergy and wear resistance.

The above findings demonstrate that the enlightening strategy combining MM and LPBF holds significant potential for developing heterostructures and further manipulating structural heterogeneity. This strategy offers novel insights and directions for overcoming wear resistance dilemma and fabricating cutting-edge medical implants. The developed [heterostructured Ti implants](#) in this work exhibit an excellent synergistic effect between strength-plasticity and wear resistance, which is attractive for orthopedic implant applications.

About the Authors:

Cijun Shuai, a professor and doctoral supervisor at Central South University and Jiangxi University of Science and Technology, is a recipient of Changjiang Distinguished Professor, National Thousand Talents Program Leading Talent and National Outstanding Doctoral Dissertation. He focuses on research within the field of biological additive manufacturing and has led over 20 major scientific research projects, including National Natural Science Foundation of China Key Projects, Joint Key Projects, and General Projects. He has published more than 280 SCI-indexed papers with more than 14,000 citations and an H-index of 62, and held over 70 authorized invention patents with some patent rights having been transferred. He has been recognized as a Highly Cited Researcher by Elsevier and ranked among the Top 50 Scientists in Materials Science in the Chinese Mainland, and serves as an associate editor/editorial board member for journals, including International Journal of Extreme Manufacturing and Bio-Design and Manufacturing, etc..

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