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Data-Driven Ballistic Property Prediction of Ceramic Armor Materials for Advanced Protection Systems

M S Rishav Subhin[a]*, Naveen Josh S[b], Mungara John Silvister Raju[c]

[a]Department of Electronics and Communication Engineering, [b]Department of Computer Science and Engineering,
[c]Department of Mechanical & Automobile Engineering, School of Engineering & Technology, Christ University, Bangalore

Introduction and Objective

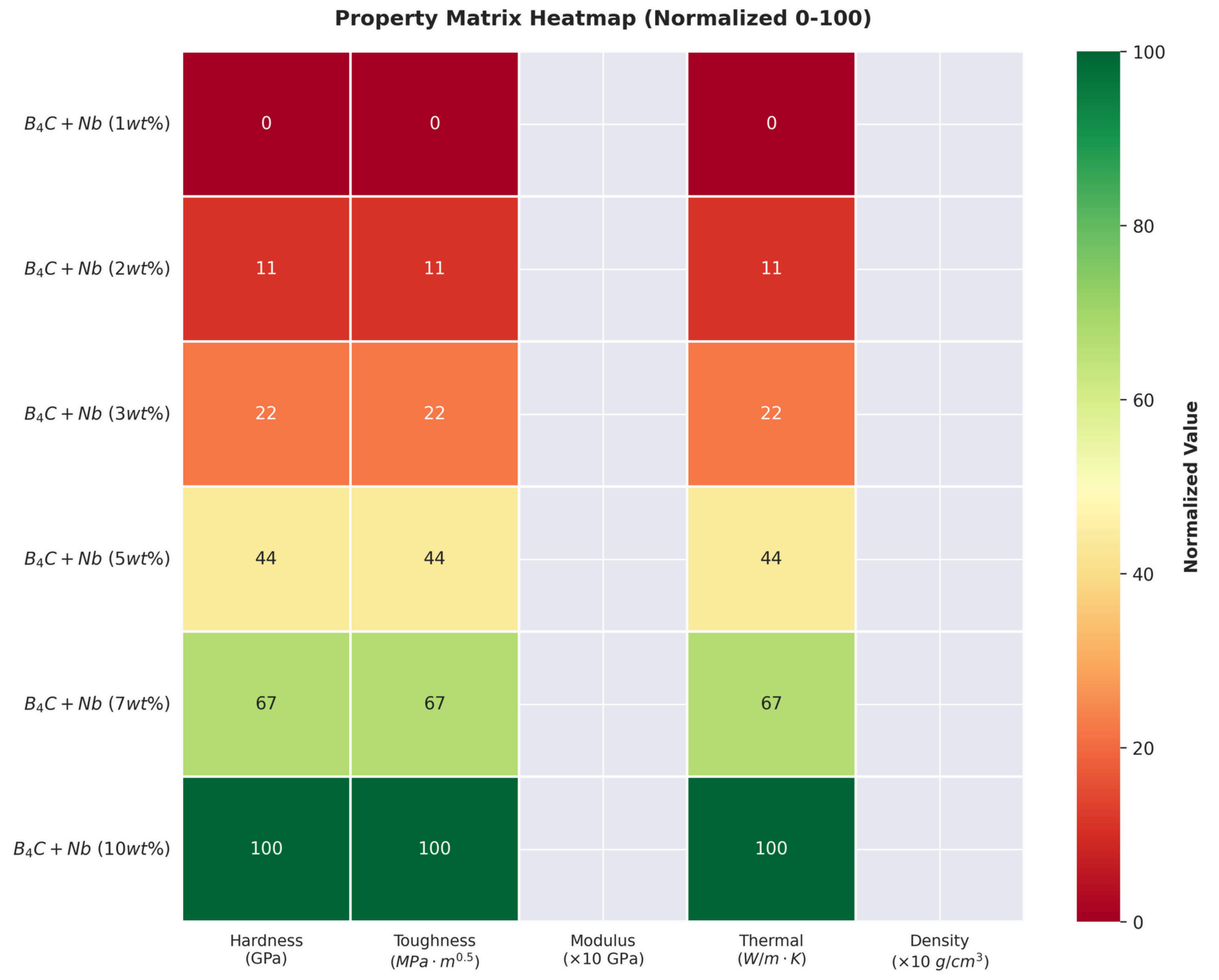
Ceramic armor selection still depends heavily on firing trials and destructive testing, which slows innovation and fails to systematically explore composition microstructure–performance relationships. This work develops a machine learning–driven prediction system integrating crystallographic, mechanical, and thermal descriptors to forecast ballistic-relevant properties, enabling rapid screening of candidate armor ceramics.

To develop an ML framework capable of:

- Predicting mechanical & ballistic performance of ceramics with high accuracy
- Optimizing ceramic compositions for lightweight, high-protection armor
- Reducing experimental screening effort for defense materials discovery

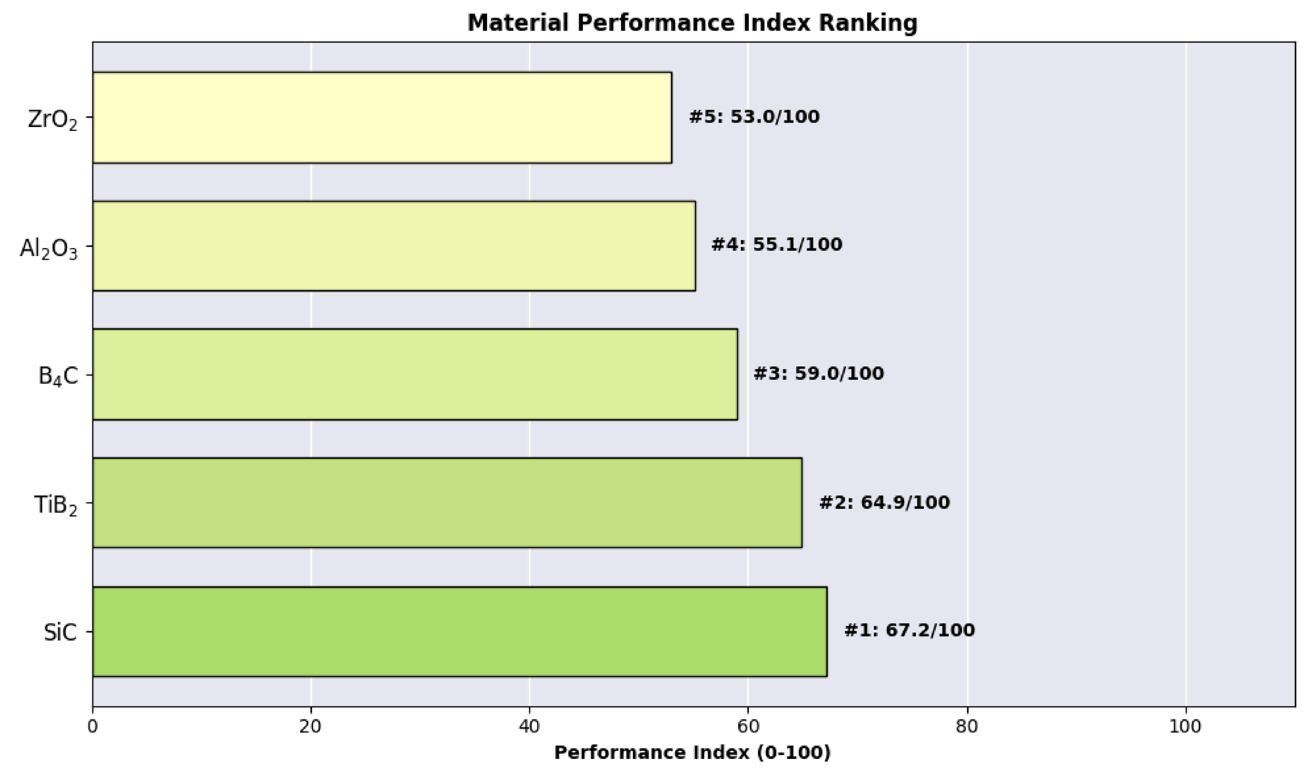
Methodology: The ML Pipeline

- Data Sources: Integrated repository combining the Materials Project, NIST Ceramics Database, and ballistic datasets for SiC, B_4C, WC, TiC, and Al_2O_3.
- Feature Engineering: Optimization performed on key ballistic indicators: Fracture Toughness, Hardness, Density, and Penetration Resistance.
- Algorithm Performance: The predictor achieves $R^2 > 0.85$ for mechanical properties and $R^2 > 0.80$ for ballistic indices.

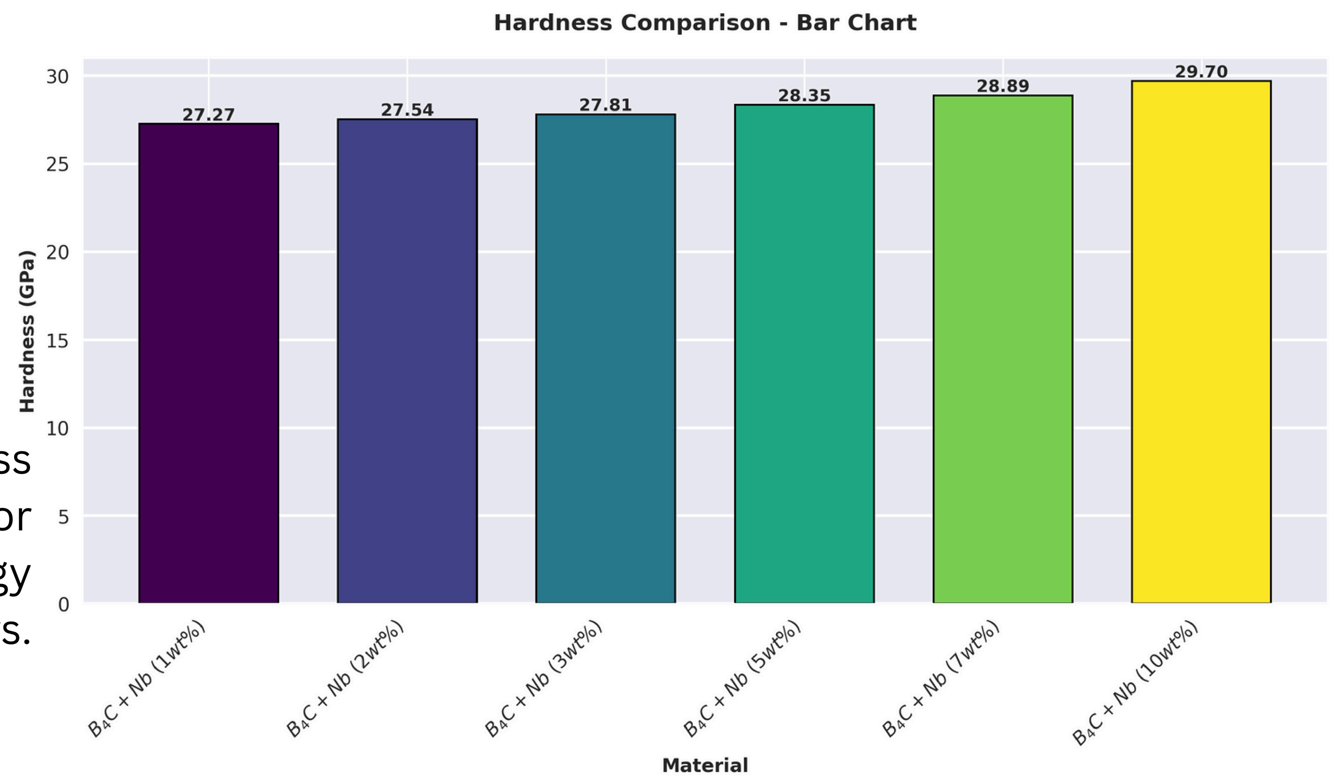


Normalized input dataset visualizing the property distribution across material classes used to train the ML predictor.

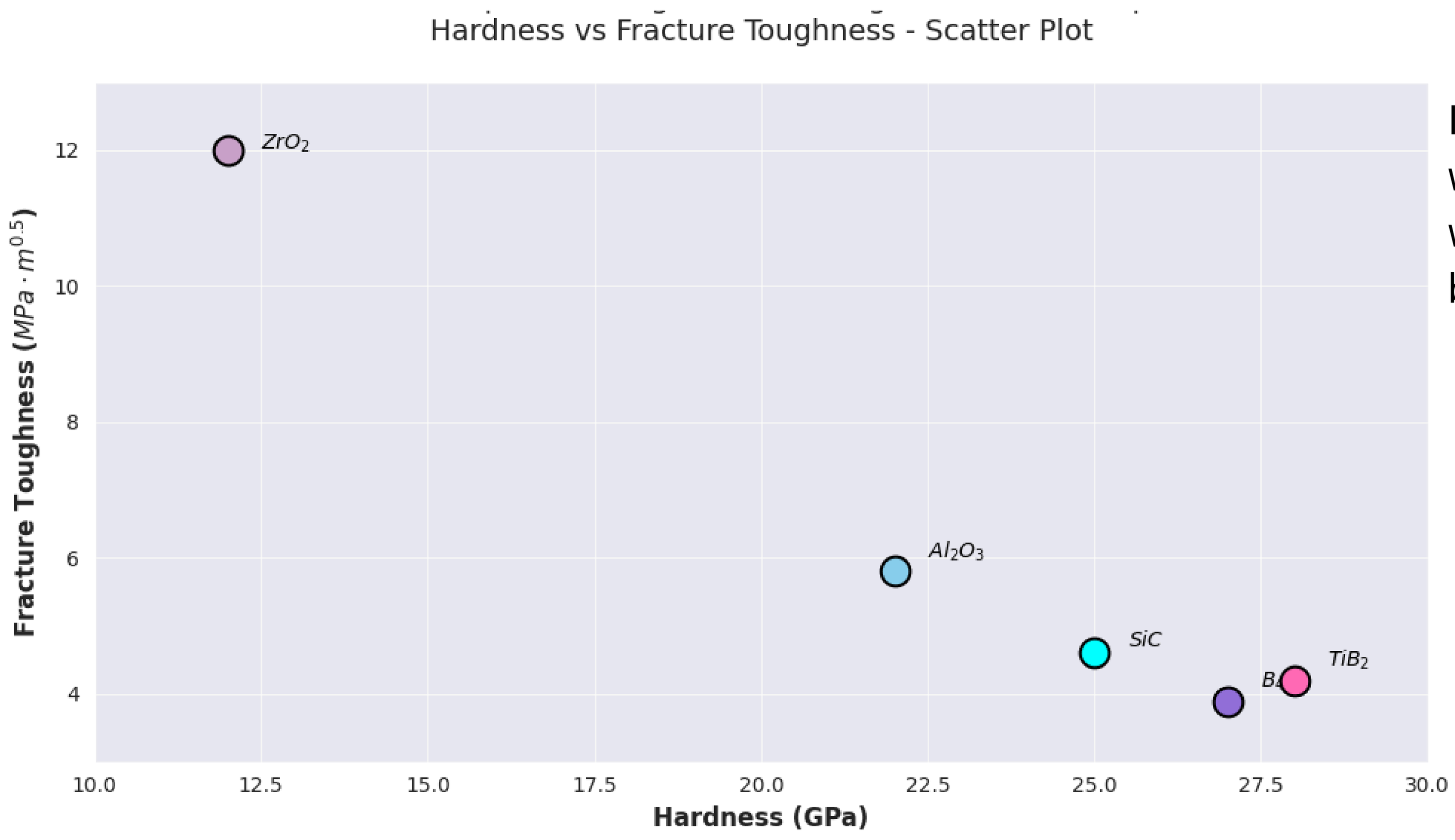
Results & Discussions



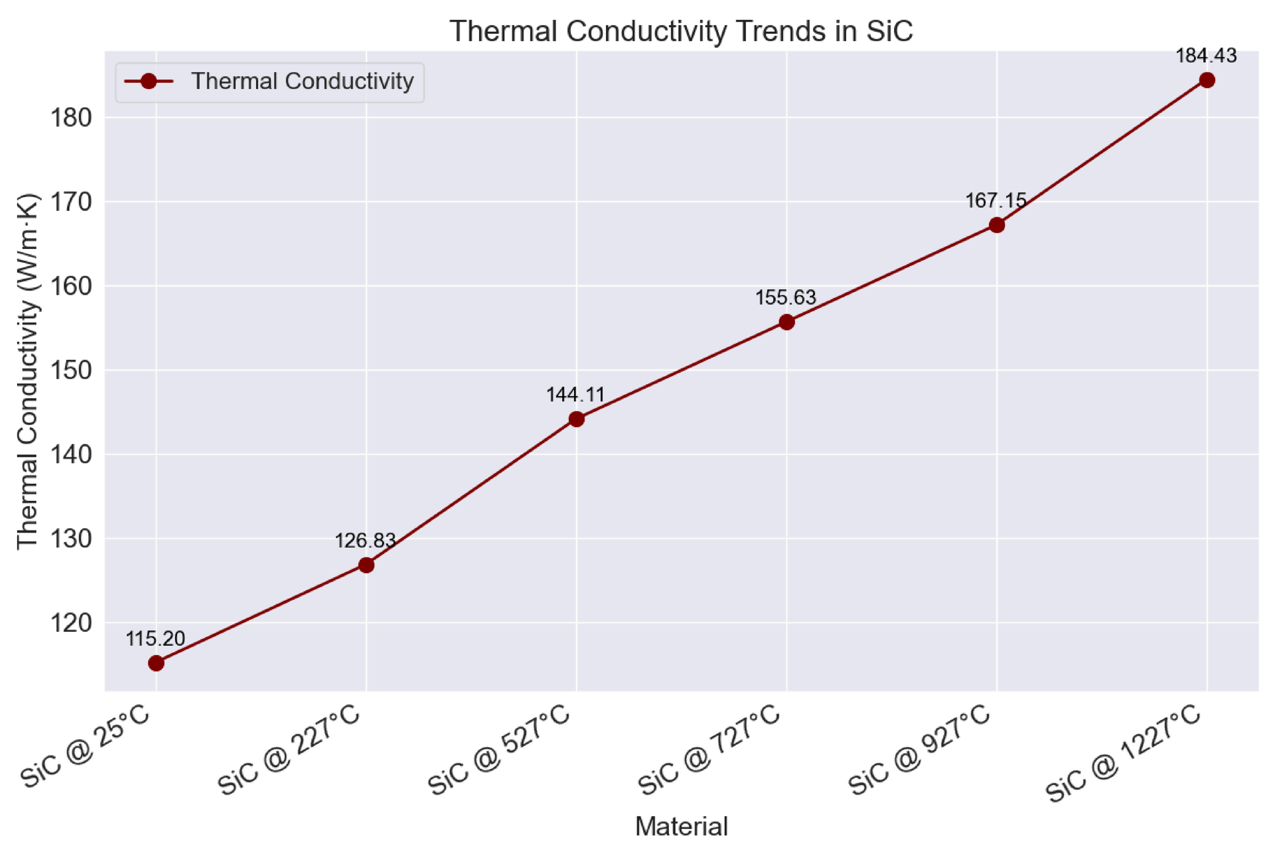
SiC achieves the highest composite score **(67.2/100)**, offering the optimal balance of weight, thermal, and mechanical properties.



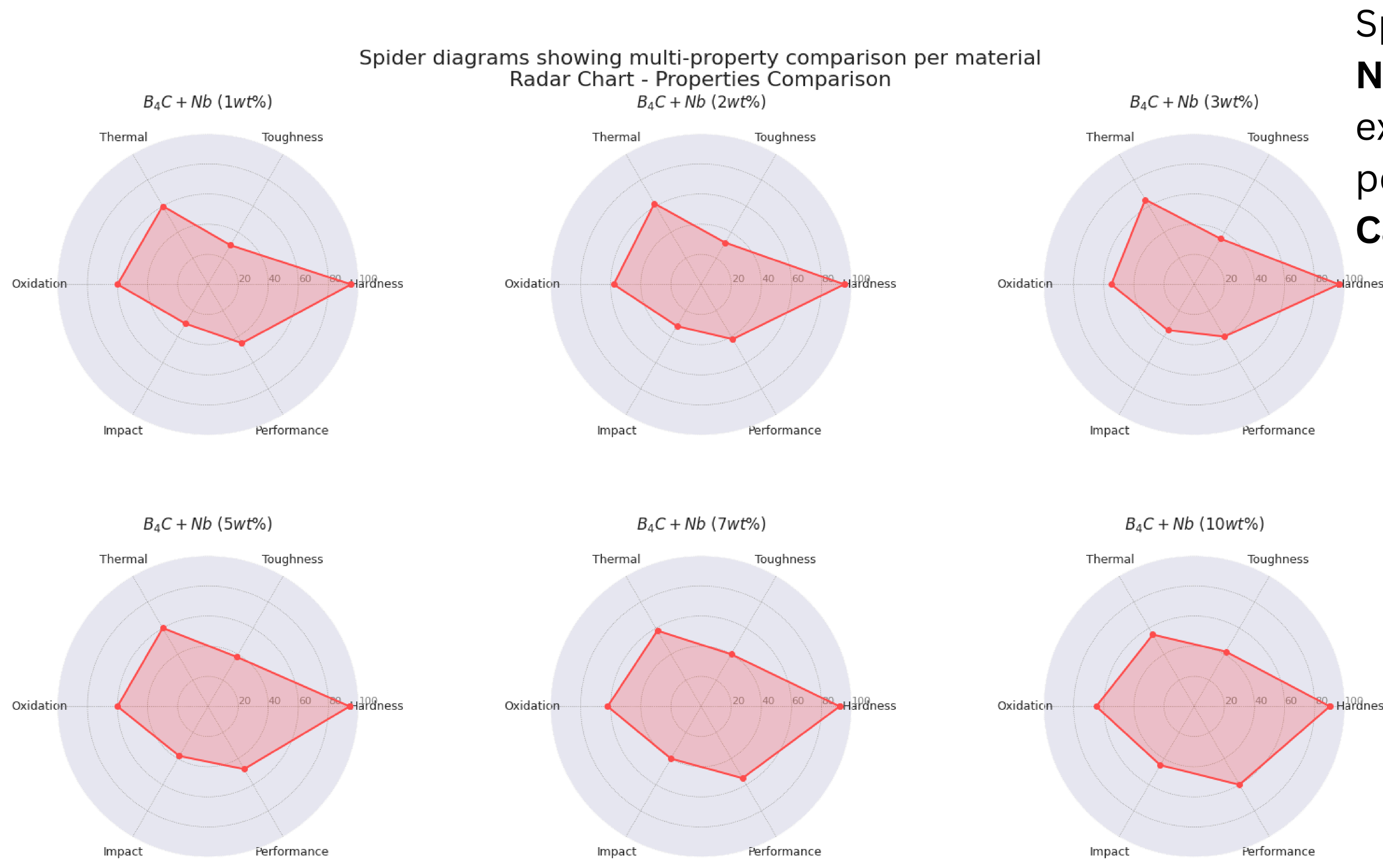
TiB_2 leads with a maximum hardness of **28.0 GPa**, providing superior resistance against kinetic energy penetrators.



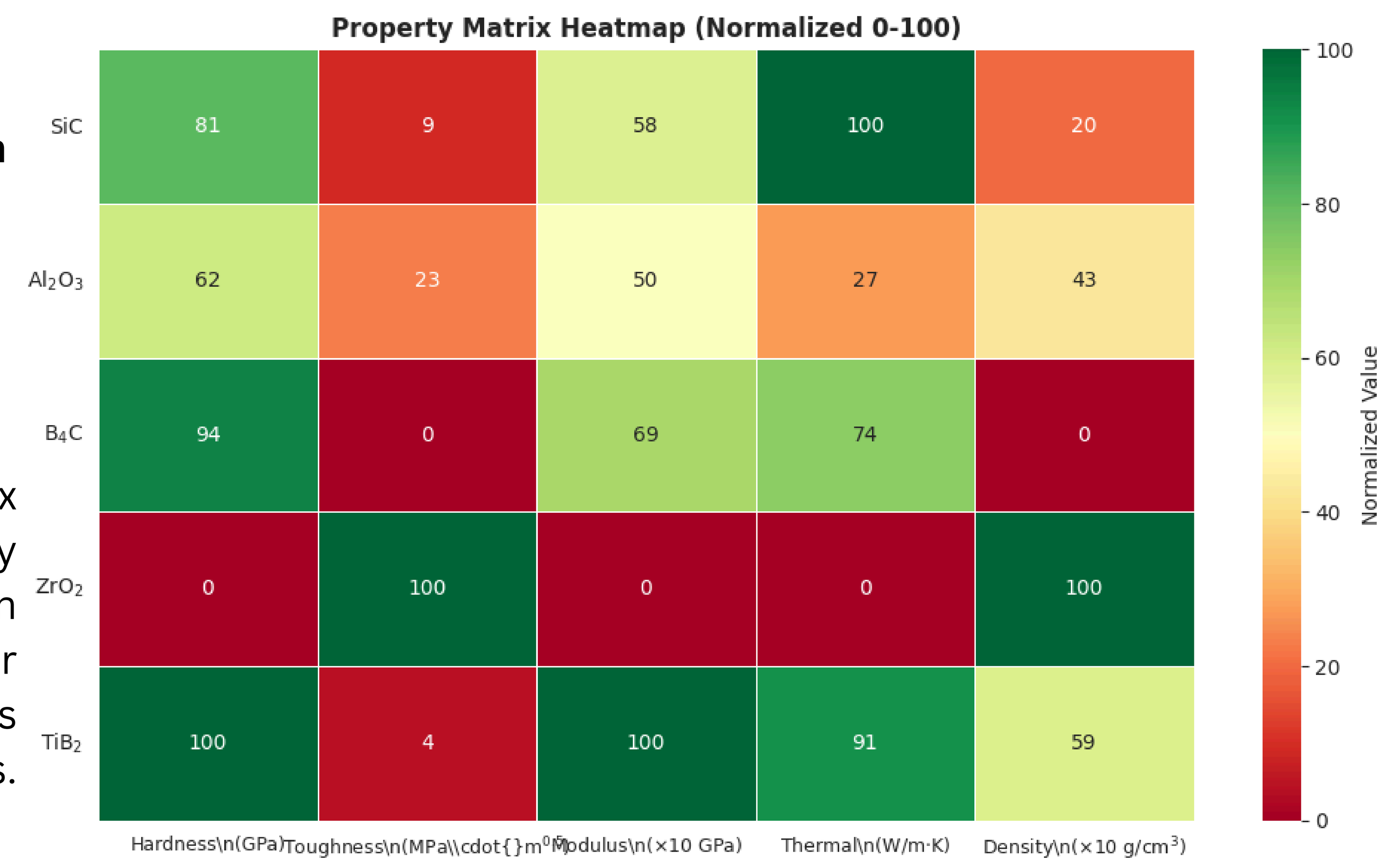
Illustrates the inverse relationship where **ZrO_2** maximizes toughness, whereas **SiC** and **TiB_2** prioritize ballistic hardness.



Line analysis showing the increase in **SiC** thermal conductivity at elevated temperatures, critical for dissipating impact energy.



Spider diagrams revealing how **Niobium** doping systematically expands the multi-property performance envelope of **Boron Carbide**.



Normalized matrix highlighting optimal property clusters, with green indicating superior performance across standardized metrics.

Conclusions

- ML achieves R^2>0.80 ballistic; NSGA-II optimizes 3x faster.
- B_4C+Nb(10wt%): Top perf (61.9/100)—hardness 29.7 GPa, density 2.52 g/cm³.
- Framework extensible to composites for defense-energy sustainability.

For our detail, please scan

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