IMPERIAL LAIDLAW SCHOLARS

Bio-Inspired Polyborosiloxane–Alumina Composites with Dynamic Covalent Cross-Links for Seismic Shock Mitigation

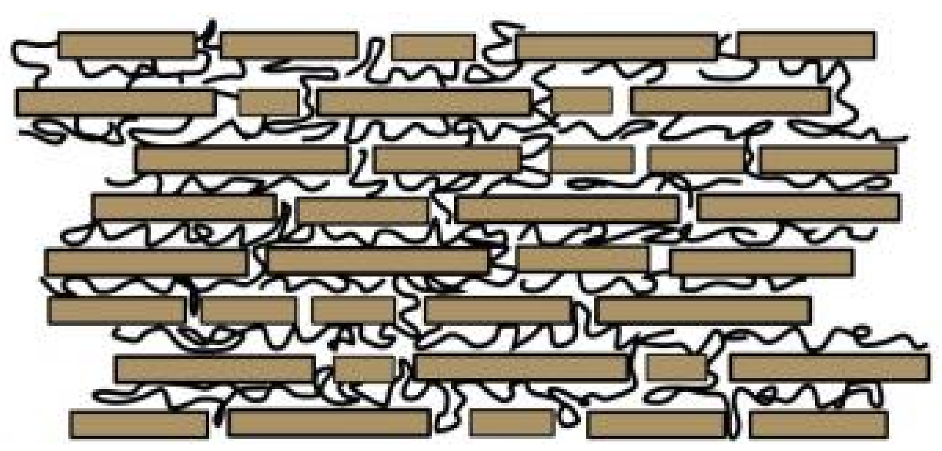
Mr Ahmet Tanrikulu,
Dr Eleonora D'Elia,
Dr Florian Bouville

1. Motivation & Context

Earthquake swarms subject critical civil infrastructure to repetitive seismic shocks. Conventional high-strength structural ceramics suffer catastrophic brittle failure during primary shocks, eliminating structural integrity prior to subsequent ground tremors.

"Developing bio-inspired composites capable of autonomous self-healing between seismic shocks to absorb subsequent ground motions and prevent cumulative failure."

This research engineers a nacre-mimetic architecture combining rigid **alumina platelets** (Al_2O_3) embedded in an energy-dissipating dynamic **polyborosiloxane** (PBS) matrix, synergising structural stiffness with autonomous mechanical recovery.



Dynamic Borosiloxane Chemistry

The polymer matrix incorporates dynamic coordinate covalent $B \leftarrow O$ and dynamic covalent $B - O$ bonds synthesised via the polycondensation of hydroxyl-terminated polydimethylsiloxane (PDMS) with boric acid (BA):

$$\text{PDMS} + \text{B(OH)}_3 \xrightarrow[\text{cond.}]{200^\circ\text{C}} \text{PBS Network} + \text{H}_2\text{O} \uparrow$$

Reversible cross-link exchange allows chain re-engagement across severed fracture planes. Platelet pull-out and polymer relaxation dissipate transient seismic shock energy.

2. Fabrication & Processing

Stoichiometric Cross-Linking Ratios PDMS and boric acid were reacted at 200°C. Strict thermal control was critical: reactions exceeding 200°C caused irreversible thermal decomposition and polymer discoloration.

Five stoichiometric PBS:BA cross-linking formulations were synthesised for evaluation: **1:40, 1:43, 1:46, 1:50, and 1:52**.

Mould Design	Observed Failure Mode
3D Open Mould on Porous Cast	Severe tearing during razor separation from substrate.
Open Mould with 3D Plunger	Viscous composite slurry leaked through mould clearances.
Closed Silicone & Glass Wells	High demoulding shear stresses caused edge cracking.
Greased Circular Dish + Razor Cut	**Uniform defect-free film; precise dog-bone contouring.**

Formulation: 25 vol% vs 50 vol% Alumina Initial casting trials incorporating 50 vol% alumina platelets produced an excessively brittle composite prone to macroscopic drying fractures. Decreasing the mineral loading to **25 vol%** delivered an optimal mechanical compromise: preserving structural elastic modulus while retaining polymer chain mobility essential for crack self-healing.

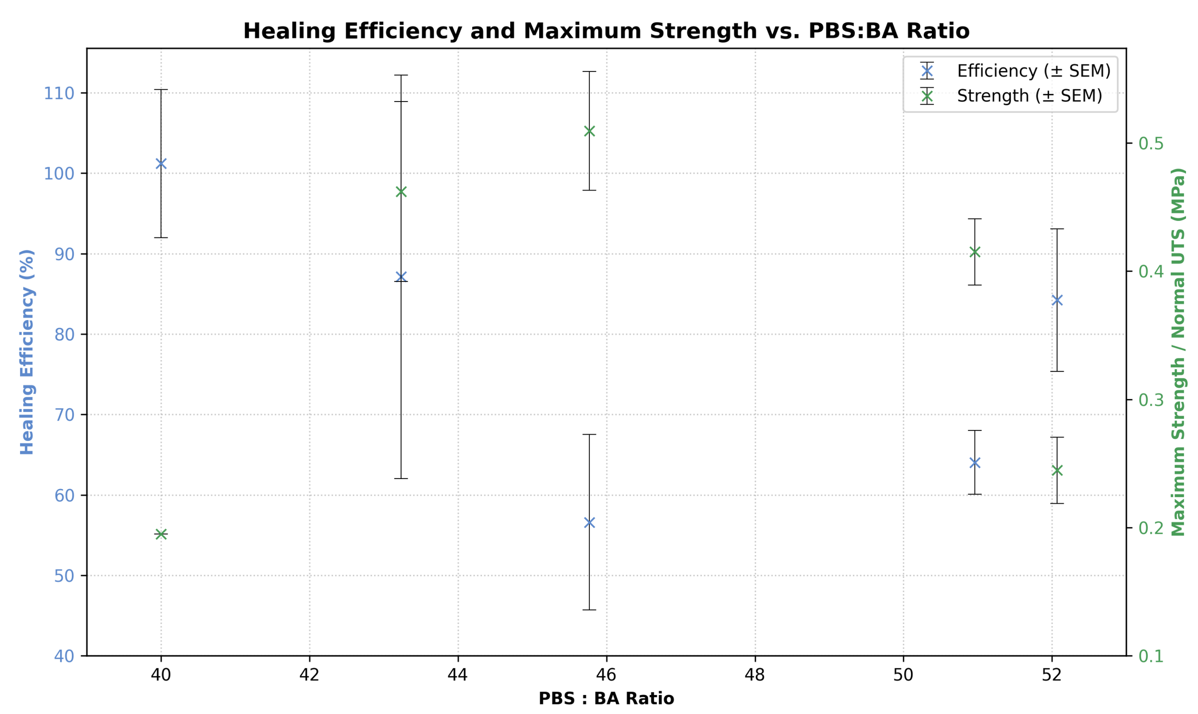
Demoulding Optimization: Developing defect-free, reproducible dog-bone specimens required over 30 iterative casting and demoulding trials:

3. Mechanical Testing & Data

Uniaxial tensile testing was performed on a Zwick/Roell universal testing machine using testXpert data acquisition. Tensile crosshead displacement speed was held strictly constant across all samples to isolate chemical cross-linking variations from intrinsic strain-rate-dependent shear-stiffening effects.

Specimens were bisected across the gauge length with a razor blade. The halves were realigned under light compressive contact on a greased glass plate and annealed at **100°C for 12 hours**.

$$\text{Healing Efficiency } (\eta) = \frac{\sigma_{\text{UTS, healed}}}{\sigma_{\text{UTS, pristine}}} \times 100\%$$



4. Key Findings & Impact

The self healing efficiency results ranged from

65-95%

Optimal Cross-Link Density (1:46): The 1:46 PBS:BA formulation yielded peak tensile strength (**0.53 MPa**), providing adequate network rigidity without restricting polymer chain reorientation.

High Autonomous Recovery: Healing efficiencies between **65% and 95%** confirm autonomous interface restoration under mild thermal contact without external cross-linkers.

Rate-Dependent Shear-Stiffening: Faster tensile testing rates yielded elevated UTS, verifying viscoelastic rate sensitivity advantageous for seismic energy absorption.

PBS:BA = 1:46 Delivers the Optimal Trade-off Between Structural Strength and Healing Efficiency

The shear-stiffening ensures that high-velocity seismic shocks trigger rapid matrix stiffening, dissipating kinetic tremor energy through reversible bond dissociation. The healing allows subsequent tremors to be absorbed without cumulative degradation prevent catastrophic failure in earthquake-prone zones