Powder-based processing of highly-loaded platelet-reinforced composites

Maximizing the volume fraction of reinforcing platelets in polymer composites is a current scientific and technological challenge as it can potentially enable the fabrication of high-performance materials inspired by unusual biological materials like nacre. The fabrication of these highly-loaded composites usually requires the infiltration of liquid monomers into a porous scaffold that are subsequently consolidated into a continuous polymer matrix. Such infiltration process often limits the choices of polymers and leads to long processing times and restrictions in size and geometry of the final part. In this work, we demonstrate the fabrication of highly-loaded platelet-reinforced composites using a new infiltration-less route that consists in the directed-assembly of polymer particles and ceramic platelets.

Sara T. R. Velasquez, Justin-Aurel Ulbrich, Marco R. Binelli, Kunal Masania, **Rafael Libanori***, André R. Studart*
Laboratory for Complex Materials, Department of Materials, ETH Zurich, 8093 Zurich, Switzerland.
e-mail: libanori@mat.ethz.ch

Materials & Methods

Soft phase: polyimine vitrimer

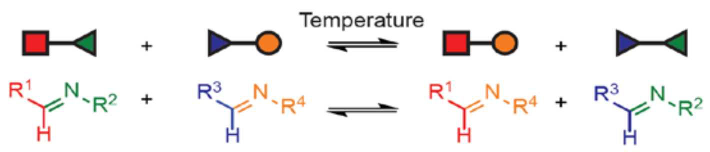

Fig. 1. Dynamic imine chemistry: metathesis reaction leads to the exchange of the R groups between two different imines. [1]

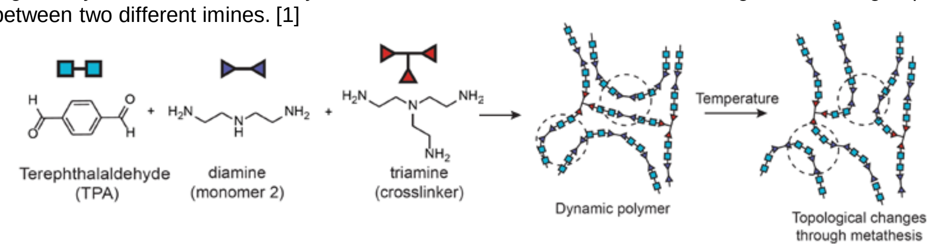

Fig. 2. Typical temperature-induced topological changes in cross-linked vitrimers through metathesis of imine groups.

Reinforcing phase: ceramic microplatelets

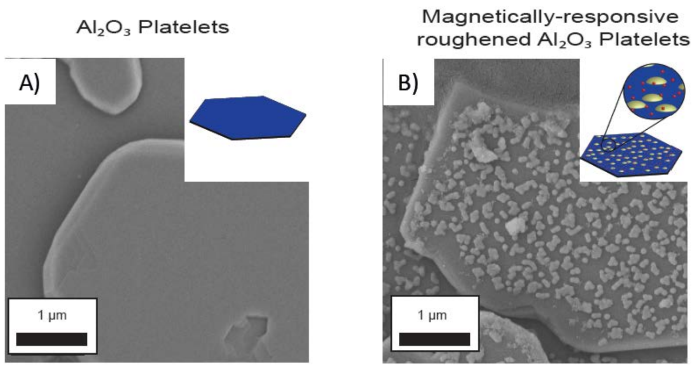

Fig 3. Reinforcing ceramic platelets used in the fabrication of highly-loaded composites . A) Flat Al_2O_3 platelets. B) Magnetized Al_2O_3 platelets.containing nanoasperities [2].

Reinforcing phase: ceramic microplatelets

Fig 4. Synthesis of polyimines and fabrication of polymer particles through cryo-milling. Monomers: Terephthalaldehyde (TPA), Diethylenetriamine (DETA) and Tris (2-aminoethyl) amine (TAEA). Solvent: Ethyl Acetate (EtAc).

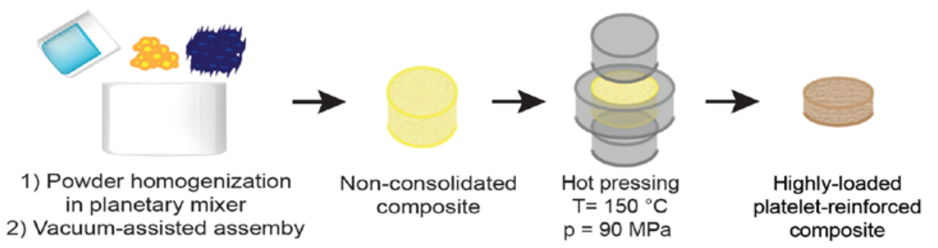

Fig 5. Powder-based processing of composites using vacuum-assisted magnetic assembly followed by hot-pressing at low temperatures. [3]

Results

Powder morphology and size

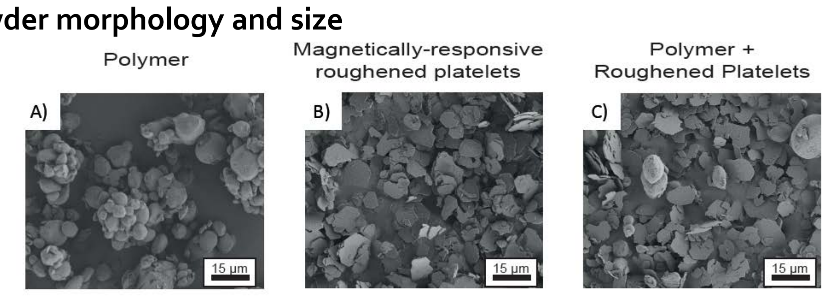

Fig. 6. A) Polymer powder obtained after cryo-milling (soft phase). B) Magnetically-responsive roughened platelets (reinforcing phase). C) Powder mixture obtained after homogenization in the planetary mixer.

Composite microstructure

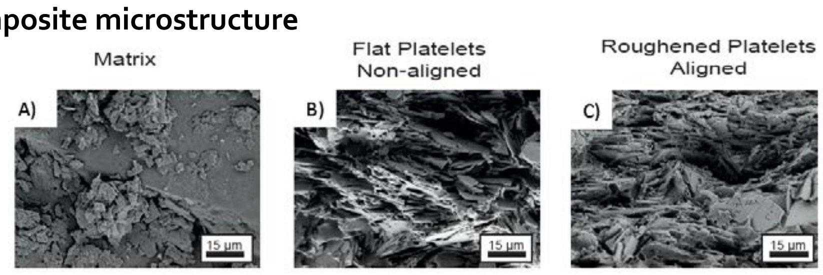

Fig. 7. SEM images of fractured surfaces tested in flexural mode. A) Pure polymer matrix. B) Composite reinforced with 50 vol% of flat, non-aligned platelets. C) Composite reinforced with 50 vol% of roughened, magnetic field aligned platelets

Mechanical performance

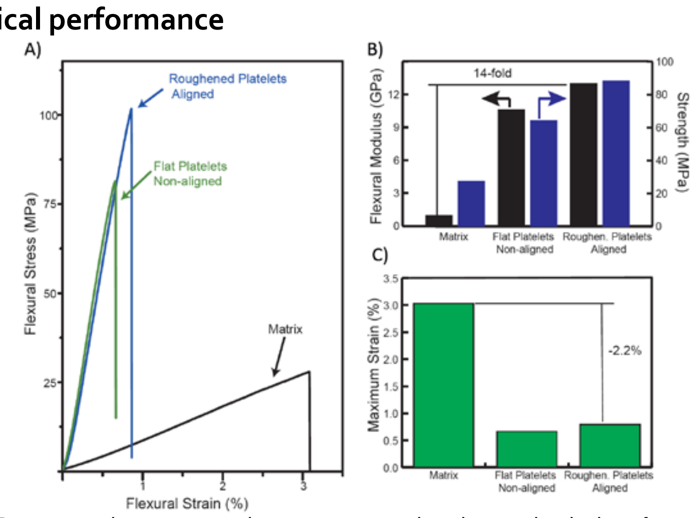

Fig. 7. A) Representative stress-strain curves comparing the mechanical performance in flexural mode for the composites fabricated in this study. B) Flexural modulus and maximum flexural strength for the pure matrix and composites. C) Strain at rupture for pure matrix and composites

Conclusions and expected impact

The infiltration-less process developed in this study simplifies significantly the fabrication of platelet-reinforced composites containing high volume fraction of reinforcing particles. The use of a cross-linked polymer matrix containing dynamic covalent bonds allows for successful densification of the composite during uniaxial hot pressing as the rearrangement of polymer chains is activated at relatively low temperatures (140 oC). Incorporation of aligned reinforcing platelets within the polymeric material increases the flexural modulus and strength of the composite by 14-fold and 3-fold as compared to the pure polymer matrix, respectively. Stiffer and stronger composites can be obtained by incorporating nanoasperities on the surface of the reinforcing platelets. Flexural modulus and strength are further increased by 20% and 27%, respectively, when compared to flat, non-aligned platelets, while keeping comparable strain at rupture. The powder-based strategy developed in this study is a promising route to fabricate lightweight composite exhibiting superior mechanical performance and can ultimately lead to a significant reduction in fuel consumption of transportation vehicles.

References

[1] Belowich M.E. et al., Chem. Soc. Rev., 2012, 41, 2003–2024
[2] Libanori, R. et al. Bioinspiration & Biomimetics, 2016, 11 (3), 036004.
[3] Grossman M. et al., Adv. Mater. 2017, 29, 1605039.

Partners

EMS