# MIE498H1: Research Thesis 2026-2027

| | |
|---|---|
| **Supervisor** | Prof. Patrick C. Lee |
| **Supervisor email** | patrickc.lee@utoronto.ca |
| **Number of Positions** | 2 |
| **Open to** | Undergraduate Mechanical Engineering Students |
| **Term Offered** | Full-year |
| **Research Area** | Materials |
| **Research Topic** | Bio-Inspired Hybrid Composites for Synergistic High-Performance Multi-Functional Applications |

**Project Description**

This research addresses hurdles in the longevity and material redundancy in current thermoplastic-based automotive composites using a hybrid composite approach, through a thorough investigation of process-structure-property relation of such composites. Conventional biphasic automotive composites, mostly polypropylene- (PP) and polyamide 6- (PA6) based, are often reinforced with high loadings of glass fibres (GFs) to achieve the ultra-high strengths required for stringent safety standards. However, the high GF loadings pose an issue of high brittleness, low impact strength, and high densities and thereby reduce fuel efficiency. In addition, due to the sole use of GFs, there is a need for additional additives to impart functional properties (e.g., heat dissipation) to final parts.

In this research, multifunctional nanofillers, such as graphene nanoplatelets (GnPs) and halloysite nanotubes (HNTs), are introduced as secondary reinforcements to create bio-inspired, hierarchically structured architectures in these composites (**Error! Reference source not found.**). The addition of such nanofillers alone in PP or PA6 promotes the crystallisation of tougher polymorphs in these composites. However, in combination with GFs, these nanofillers localize at the fiber surfaces, effectively functionalising the fibers via possible combinations of covalent bonds, hydrogen bonds, and/or electrostatic attractions, creating hierarchical hybrid fillers. These hybrid fillers encourage epitaxial trans-crystallisation in polymers such as PP and PA6, fully encapsulating the fillers by forming a gradient interphase between the hybrid fillers and the bulk polymer matrix, which has a higher stiffness than bulk crystalline phases, as revealed by nanomechanical characterisation. On the microscopic level, the trans-crystallization results in superior filler-matrix compatibility and more efficient stress transfer under load, which ultimately translate to heightened macroscopic mechanical performance. These composites were designed by drawing inspiration from living organisms, emulating specific internal material architectures (see Figure 1), leading to a similar balance of mechanical performance and density as is obtained by natural material analogues.

This approach yields an 84% improvement in impact strength, 27% increase in specific tensile strength, and 56% increase in tensile toughness, all while reducing the composite density by 18% compared to currently used industrial baselines. In addition to enhancements in mechanical performance, the hybrid fillers also promote the multifunctionality of composites. These include improved processibility due to self-lubrication, and tailorable thermal management capabilities; future work includes improving the fire retardancy, colourability, as well as the fatigue resistance of these automotive structural composites.

Overall, this research aims to address the hurdles faced by current GF-reinforced thermoplastic automotive structural composites through the tailoring of hybrid fillers and careful microstructural control. These considerations are applied directly in current streamlined injection processes with little-to-no adjustments in processing needed, addressing sustainability targets by developing lightweight multifunctional materials with a facile manufacturing pathway.

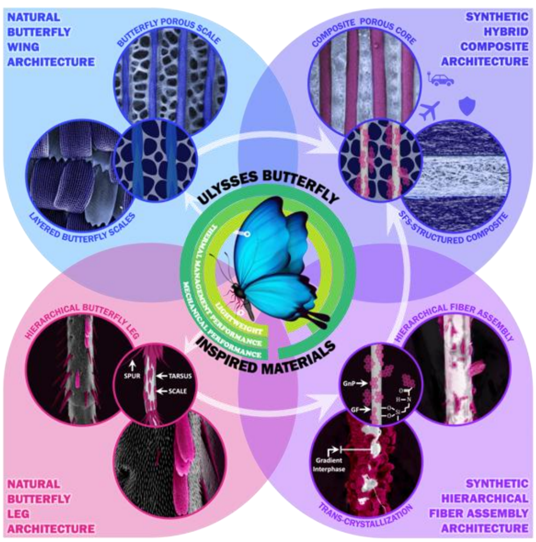


**Figure 1**: Schematic illustrating examples of bio-inspiration for hybrid composite design.

**Additional Information** N/A

**Application Instructions** Please submit CV and unofficial transcript to Prof. Patrick Lee (patrickc.lee@utoronto.ca)