Natural Carbon-enhanced Composite Filaments for Fused Deposition Modeling Applications

The Institute for Sustainable Energy and the Environment (ISEE)
Department of Mechanical Engineering, Ohio University | Athens, Ohio

Logan Veley
Dr. Jason Trembly
Dr. Yahya Al-Majali

OHIO UNIVERSITY 1804
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Introduction

The development of sustainable polymer composites is critical for future manufacturing and construction demands. Reclaimed coal particles provide the opportunity to function as low-cost alternative filler material for composite development. Previous research has shown the benefits of utilizing coal as a filler material [1, 2]. Expanding coal-plastic composites (CPCs) for additive manufacturing applications allows the benefits of the composite to be applied to new end use applications. By compounding thermoplastic resins with bituminous coal particles, 1.75 mm diameter composite filaments can be extruded. The composite filaments can be 3D printed using commercially available fused deposition modeling (FDM) printers. End use parts can be directly printed for composite tooling and fixture applications with practically no waste and without complex equipment. This research develops CPC filaments for FDM applications and characterizes the mechanical and physical properties of the novel materials.

Objectives

- Develop novel 1.75 mm CPC filaments for FDM printing applications.
- Characterize the effect of coal content on the mechanical, physical, and thermal properties of the composite filaments.

Methodology

Thermoplastic pellets are melted and mixed with different weight fractions of coal particles in a batch mixing process, and the compounded material is pelletized. A 3devo Composer 450 single screw filament extruder is used to create 1.75 mm diameter filaments. The filament is air cooled and spooled. The CPC filament is then printed using a Flashforge Creator Pro FDM printer to print end use parts and mechanical testing samples. The microstructure of the CPC filament was investigated using a Keyence VHX digital microscope and the JEOL JSM-6390LV scanning electron microscope. The CPC pellets are also processed via compression molding to create composite sheets. Mechanical and physical test samples are water jet cut from the sheets. Tensile and flexural testing are performed on the Instron 5966 test frame, and Izod impact testing is performed using the Instron CEAST 9050 pendulum impact machine. Thermogravimetric analysis was performed under air to evaluate the thermal stability of the composite materials. Coefficient of thermal expansion (CTE) testing was performed using a convection heated chamber and a one-inch extensometer, and Shore D hardness tested was performed using a handheld durometer.

Figure 1: CPC filament and mechanical test samples.

Methodology

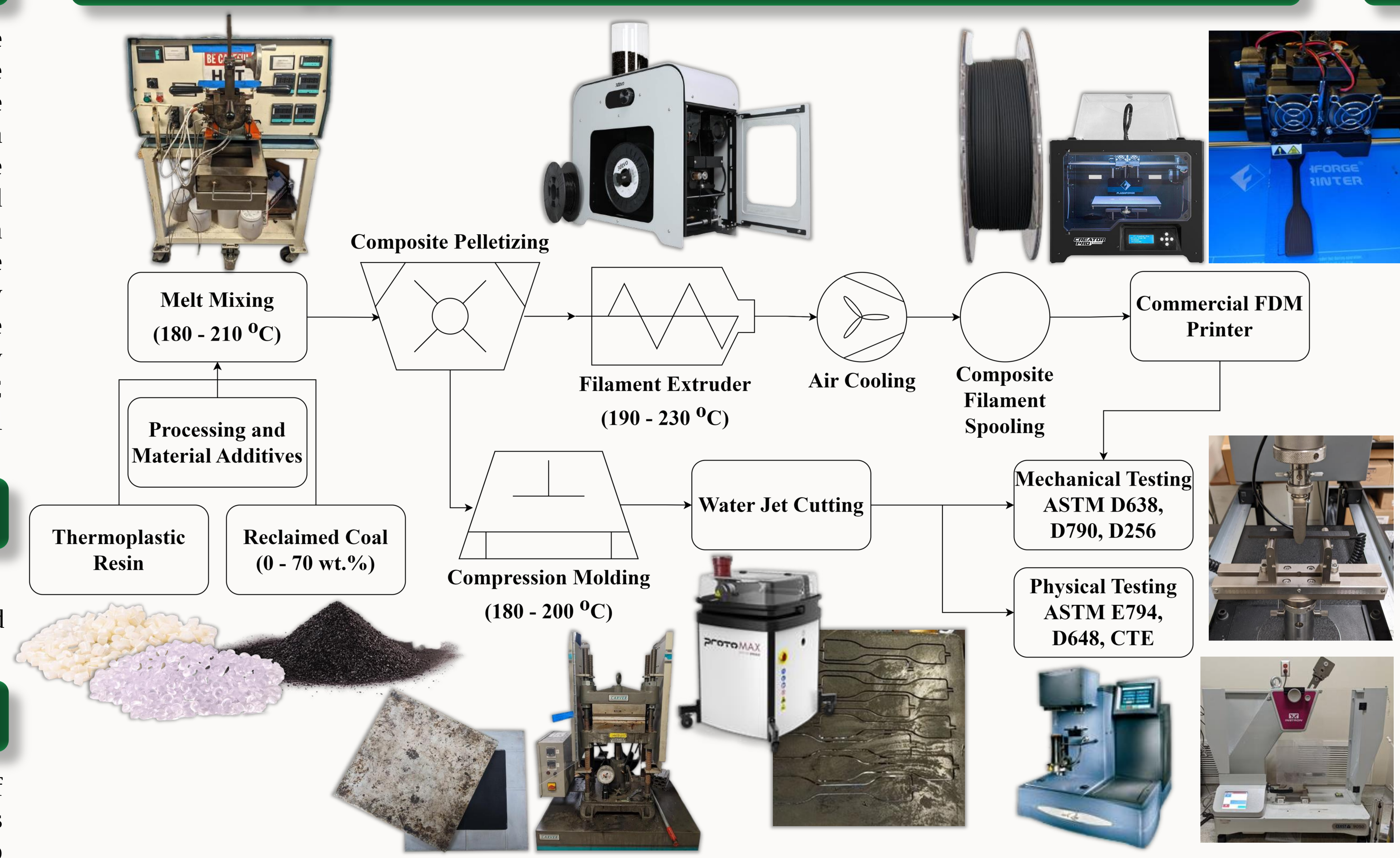

Figure 2: CPC filament and sample production.

Results & Conclusions

- CPC filaments were successfully extruded into 1.75 mm diameter filaments from four different base thermoplastics with varying coal contents.
- The CPC filament microstructures showed even particle dispersion, no large-scale porosity, and favorable particle-matrix interfaces.
- All CPC filaments were successfully 3D printed via commercial printers with nozzle diameter sizes from 0.4 mm to 1.0 mm.
- Some CPC filament formulations exhibited an increase in tensile and flexural strength compared to the neat plastic, and all composites showed an increase in stiffness with increasing coal content.
- All CPCs showed improved or comparable thermal stability in comparison to the neat plastic.
- All CPCs exhibited a decrease in CTE with an increase in coal content which translated to reduced warping in the final printed parts.
- All CPCs demonstrated an increase in hardness with increasing coal loading which improves wearing behavior in printed fixtures or tooling.
- Displacement of polymer resin with coal filler significantly reduces the economic and environmental cost to produce FDM filaments.

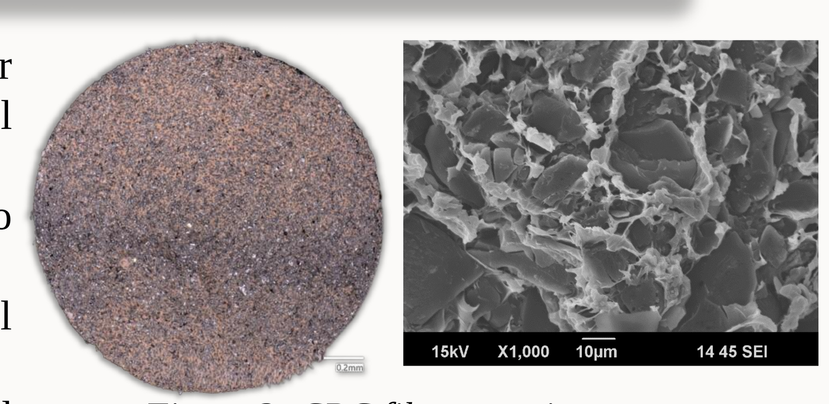

Figure 3: CPC filament microstructure.

Figure 4: CPC printed product.

References

[1] Y. Al-Majali, C. Chirume, E. Marcum, D. Daramola, K. Kappagantula, and J. Trembly, "Coal-Filler-Based Thermoplastic Composites as Construction Materials: A New Sustainable End-Use Application," *ACS Sustainable Chemistry & Engineering*, vol. 7, no. 19, pp. 16870–16878, Sep. 2019, doi: 10.1021/acssuschemeng.9b04453.

[2] Y. Al-Majali, S. Forshey, and J. Trembly, "Effect of natural carbon filler on thermo-oxidative degradation of thermoplastic-based composites," *Thermochimica Acta*, vol. 713, Jul. 2022, doi: https://doi.org/10.1016/j.tca.2022.179226.

Results & Conclusions

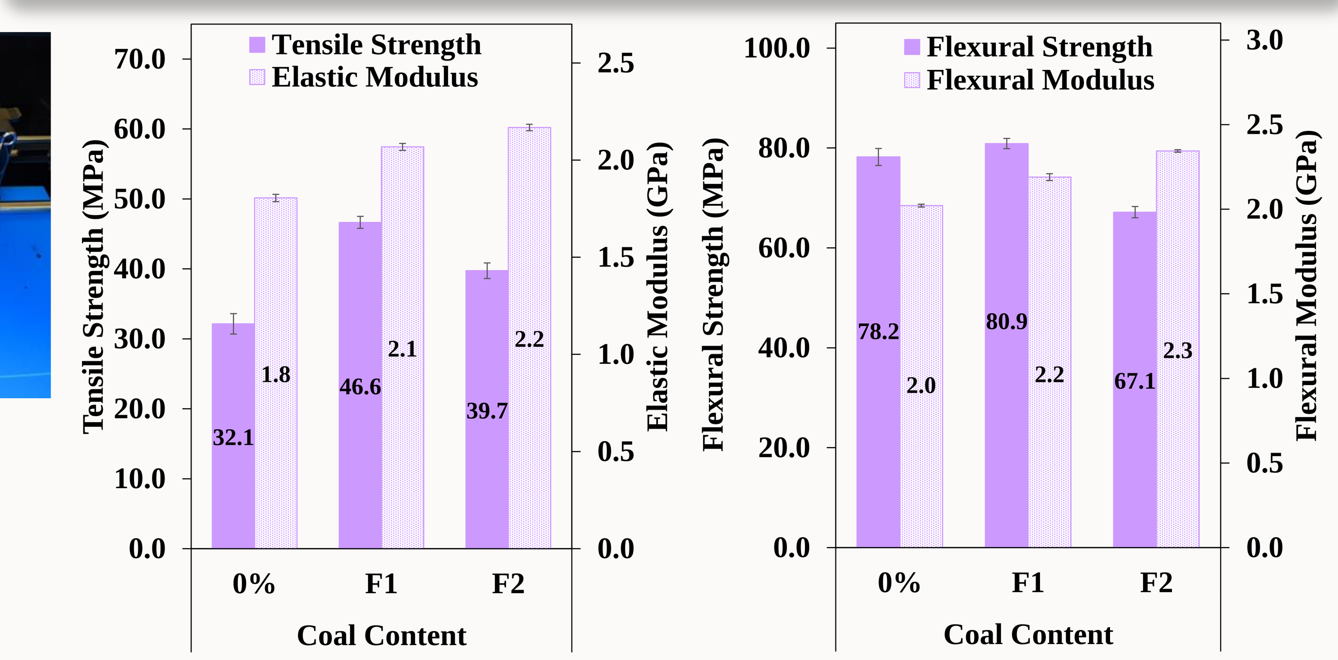

Figure 5: Tensile and flexural properties of Polymer 4 composites.

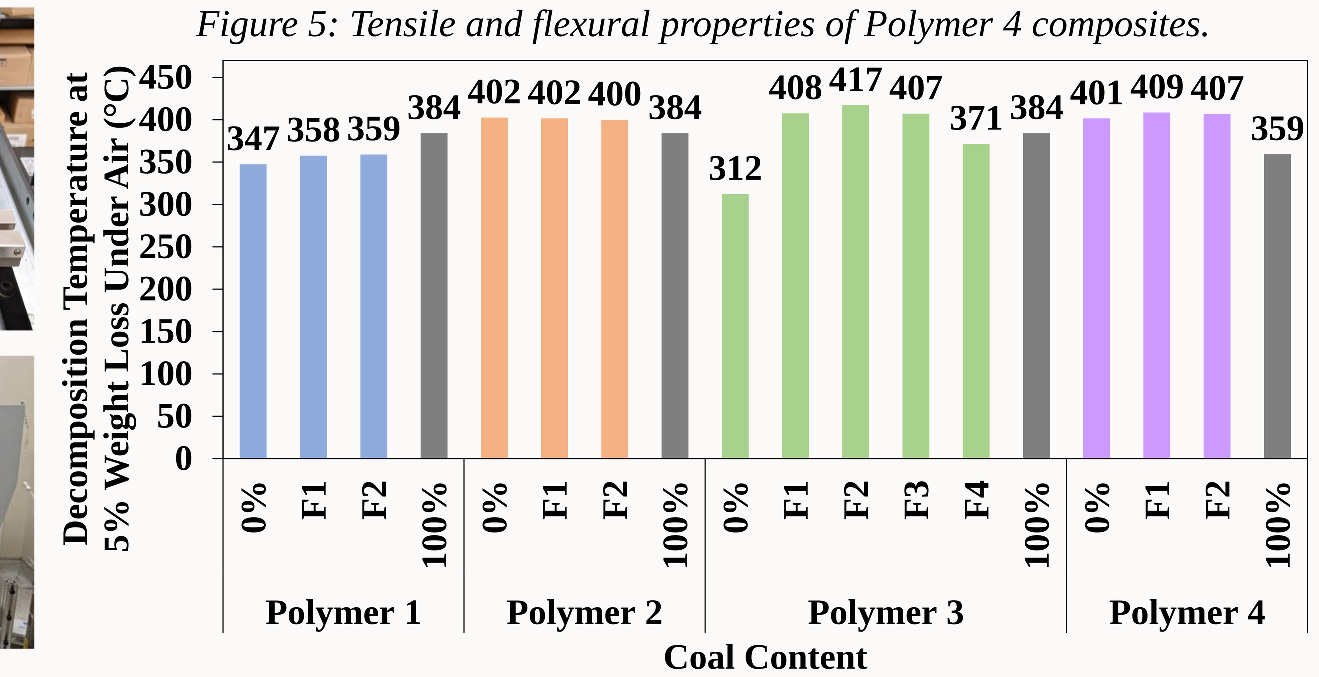

Figure 6: Composite TGA decomposition onset temperatures under air.

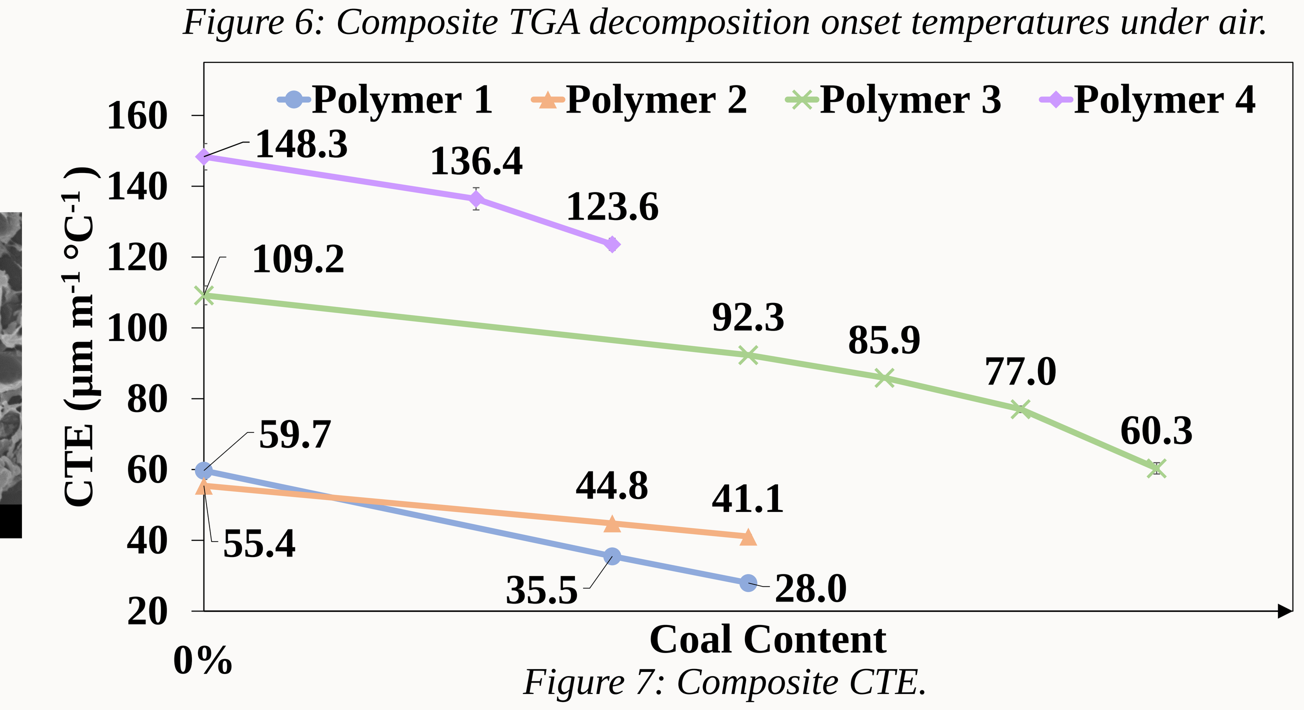

Figure 7: Composite CTE.

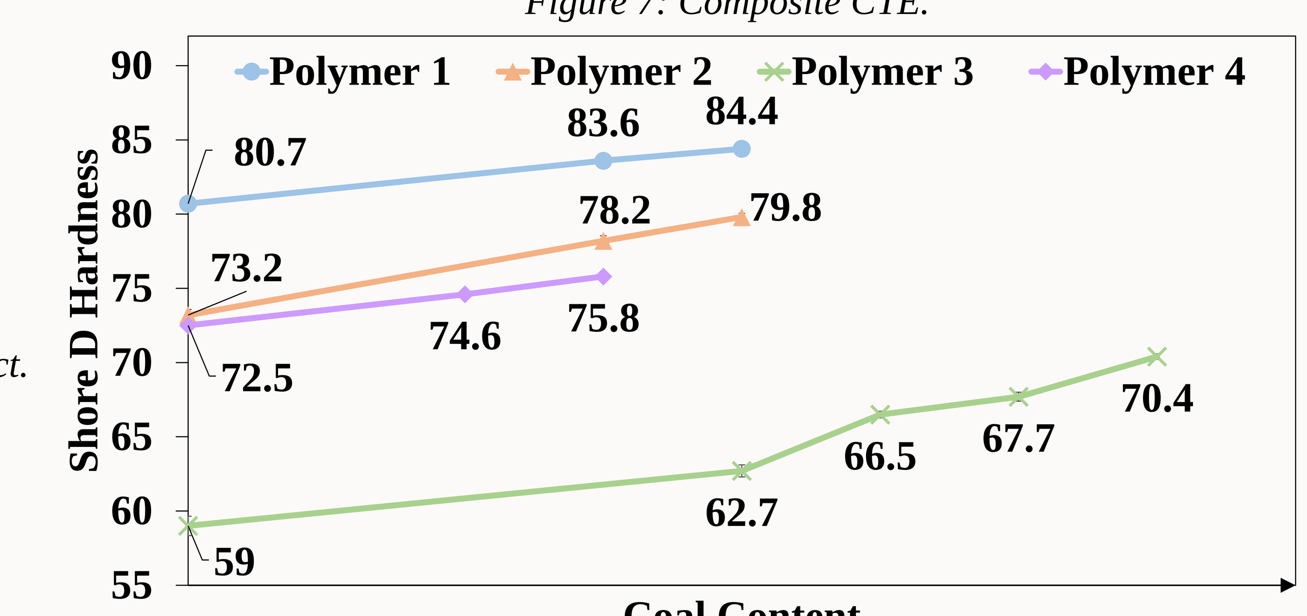

Figure 8: Composite Shore D hardness.

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