Engineered Geopolymer Composites (EGCs) for Sustainable Transportation Infrastructure

Developing ovel Engineered Geopolymer Composites for the repair and new construction of transportation infrastructure

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Engineered Geopolymer (GP) Composites (EGCs) are geopolymer based Engineered cementitious composites (ECCs), which have been recently developed as a more sustainable alternative to ECCs. EGCs are new materials that may find useful application in the repair and new construction of transportation infrastructure due to its high strength and ductility. The objective of this study was to develop novel EGC materials implementing locally available ingredients to produce practical and cost-effective EGCs for the repair and new construction of transportation infrastructure in the region. Variables studied included GP binder composition, fine aggregate type (i.e., locally available river sand and microsilica sand), and PVA fiber content (i.e., 1, 1.5, and 2 vol%). EGCs were thoroughly evaluated to determine physical and mechanical properties.

Background

ECCs are typically composed of Portland cement, supplementary cementitious materials (SCMs), fine aggregate, water, and polymer microfibers. Polyvinyl alcohol (PVA) fibers have been principally used to manufacture ECCs. Since ECCs do not use coarse aggregate, the amount of cement required to manufacture these composites increases relative to conventional concrete. In turn, this increments ECCs environmental impact, as the cement industry consumes vast amounts of energy and produces immense amounts of carbon dioxide (CO2) emissions. As such, there is a significant motivation to find alternative binders that can replace cement in the manufacture of ECC materials without negatively affecting the mechanical properties of these novel composites. Recently, geopolymer (GP) binders have been proposed as a promising and sustainable alternative to cement based binders in the manufacture of ECCs. These composites implementing GP binders are recognized in the literature as strain-hardening geopolymer composites (SHGC) or Engineered Geopolymer Composites (EGCs). Previous studies suggest that GP matrices exhibit comparable compressive strengths to cementitious matrices while exhibiting lower fracture toughness. In turn, EGCs can achieve high tensile ductility at remarkably low fiber contents (i.e., less than 2%).

Geopolymers (GPs) are inorganic aluminosilicate polymers, which can be processed at room temperature from natural sources (e.g., calcined clays, volcanic rocks, etc.) or industrial byproducts (e.g., fly ash, slag, etc.) that provide for a rich source of soluble silicon (Si) and aluminum (Al) species. The formation of GP rigid gels emerges from the geopolymerization of Al and Si species, which occurs through the activation of the GP precursor with an alkaline solution (as shown in Figure 1).

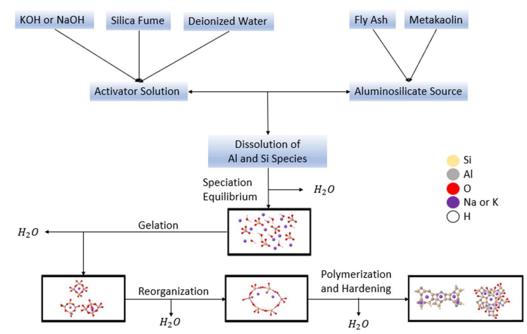


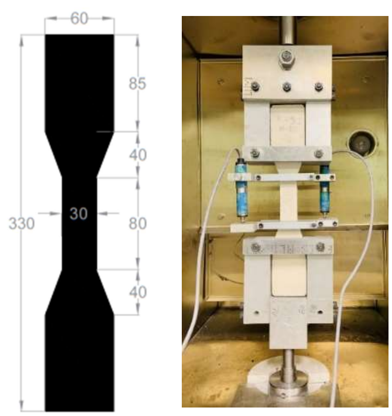
Figure 1 Geopolymerization Process.

Project Summary

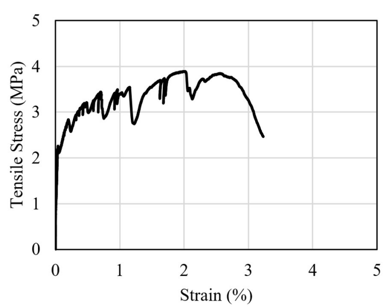
The objective of this study was to develop novel Engineered Geopolymer Composite (EGC) materials implementing locally available ingredients to produce practical and cost-effective EGCs for repair and new construction of transportation infrastructure in the region. To this end, geopolymers (GPs) were synthesized by alkali activation of metakaolin (MK) or a combination of metakaolin and fly ash (MKFA) as GP precursors. MK-GPs were activated using sodium silicate and potassium silicate solutions prepared by dissolving silica fume (SiO2) and KOH or NaOH in deionized water. MKFA-GPs replaced silica fume using fly ash and were activated using only KOH solution. GP binders, GP mortars and fiber-reinforced GP composites (i.e., EGCs) were manufactured and thoroughly evaluated. Properties of GP materials evaluated included water loss, shrinkage, density, setting time, compressive strength, tensile strength and strain capacity, flexural strength and deflection capacity, etc.

Status Update

Based on the experimental findings, it was concluded that MK based GP matrices are promising for the development of EGCs as these GPs produced high mechanical strength at ambient curing conditions and allow for pseudo strain hardening (PSH) behavior to occur when reinforced with low contents of PVA fiber (i.e., 2% volume fraction) as shown in Figure 2. However, robust PSH behavior did not occur. This was attributed to unsatisfactory fiber distribution, as obtaining proper fiber dispersion in MK-GP matrices was challenging due to its rheological characteristics. Future research will be directed towards the optimization of rheological characteristics of the GP matrices and mixing procedures to consistently yield proper fiber distribution.



(a)



(b)

Figure 2 Uniaxial Tensile Test: (a) Test Setup, and (b) PSH Behavior of MK based EGC using 2% PVA fber content (volume fraction).

MKFA GP matrices developed in this study exhibited low mechanical strength and did not produce PSH behavior when reinforced with PVA fibers. Low strengths were associated to the low reactivity of fly ash in contrast to silica fume. Future research will be directed towards evaluating partial replacements of silica fume with fly ash to yield composites exhibiting satisfactory mechanical strength and cost-effectiveness.

Impacts

EGCs are novel sustainable materials exhibiting high mechanical strength and ductility. EGCs have the potential to be successfully implemented as a more reliable alternative for repair and new construction of roads and bridges providing these structures with a significantly superior service life as compared to structures repaired and constructed under current practices. As such, the implementation of EGCs may help to address the durability issues of current and future transportation infrastructure in the region.

Tran-SET

Tran-SET is Region 6’s University Transportation Center. It is a collaborative partnership between 11 institutions (see below) across 5 states (AR, LA, NM, OK, and TX). Tran-SET is led by Louisiana State University. It was established in late November 2016 “to address the accelerated deterioration of transportation infrastructure through the development, evaluation, and implementation of cutting-edge technologies, novel materials, and innovative construction management processes”.

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