**Impactful Resilient Infrastructure Science and Engineering**

**(IRISE)**

**Summarized Project Scope of Work**

**(FY 2022-23 (IRISE Year 5) Annual Work Program)**

**Project Title:** Developing Lightweight and High-Performance Metamaterial Concrete

**Person Submitting Proposal:** Amir H. Alavi

**Proposed Funding Period:** 10/01/2022 - 09/30/2024

**Project Duration:** 24 months

**Project Title:** Developing Lightweight and High-Performance Metamaterial Concrete

**Project Objectives:**

The overarching goal is to develop a metamaterial lightweight concrete (LWC) technology. This technology will enable fabricating lightweight and high-performance structural elements, with potential applications for pavement systems, bridge decks, and prefabricated bridge elements. A metamaterial LWC specimen can offer superior mechanical properties, such as high strength-to-weight ratio and high stiffness. These properties will be achieved by utilizing mechanical metamaterials in the design of LWC systems.

**Project Scope:**

We propose to develop a suite of metamaterial LWC systems with tunable compressive strength and ductility. The metamaterial LWC design approach may be the next technological revolution in this area, because it enables the creation of LWC with atypical mechanical properties. This goal can be achieved via rational architectural design of the LWC structure and embedded 3D reinforcements, instead of manipulation of the mixture properties.

**Proposed Work:**

The objectives of this project will be realized through the completion of the following tasks:

**Task A – Review of the State-of-the-Art of LWC and MM Research**

The first phase of this task will focus on conducting an extensive literature review to identify recent advances in LWC fabrication techniques, mix designs, and reinforcement techniques. The goal will be to document current LWC practices as a benchmark for evaluating the proposed metamaterial LWC systems. We will then conduct a comprehensive literature search of MM structures with high stiffness and fracture toughness, which can be used as 3D reinforcement lattices in LWC.

**Task B – Characterization, Control, and Optimization of the Mechanical Response of MM Reinforcement Lattices**

The aim of this task will be to conduct numerical and experimental studies to understand the mechanical behavior of a broad range of MMs. The potential designs will be 3D printed in cubic forms with different numbers of unit cells and different polymer types. The 3D printed MM structures will be tested experimentally to determine their load–strain curves. Finite element (FE) simulations will be carried out and will be calibrated using the experimental results.

**Task C – Design and Fabrication of LWC Systems with Embedded 3D Polymeric MM Reinforcement**

The primary objective of this task is to use the knowledge gained in Task B to design, fabricate, and evaluate a suite of metamaterial LWC cubes and beams. This task will involve numerical and experimental study of the LWC specimens created with the two design strategies explained in the project scope. We will select and test MM lattices (up to 5 optimal configurations) with high stiffness and toughness from the lattices we explored during Task B.

**Task D – Design and Fabrication of Composite LWC Systems with Auxetic Structures**

In this task, we propose an alternative second strategy for the rational design of composite LWC systems with auxetic MM-inspired structure and polymeric reinforcement. In this case, the LWC specimens will be fabricated by casting the HPC/UHPC into an auxetic polymeric MM structure. Fatigue tests will be performed on the auxetic LWC beams to evaluate their long-term performance. The results of Tasks C and D will be compared subsequently. Numerical models developed during the previous task will be modified to characterize the response of composite LWC systems with auxetic structure.

**Task E: Development of Recommendations**

The final outcome of this task will be a series of recommendations for solving the technical challenges associated with manufacturing lightweight and high-performance concrete. The cost benefits of the relevant technologies will be discussed throughout the final report.

**Task F: Final Report**

A draft final report will be prepared and distributed to IRISE Steering Committee representatives. The report will include a state-of-the-art review of LWC fabrication techniques, mix designs, and reinforcement techniques; a comprehensive literature review of metamaterial structures with high specific stiffness and fracture toughness, to be used as 3D reinforcements lattices in LWC; and a series of recommendations for the implementation of metamaterial technologies in LWC projects.

**Deliverables:**

* Task A – A literature review summary, to be discussed at a progress review meeting with IRISE Steering Committee representatives, including PennDOT representatives, 3 months from the Notice to Proceed date.
* Task B – A technical memorandum summarizing the optimal designs for the 3D MM reinforcement lattices and the results of the compression testing, to be discussed at a progress review meeting with IRISE Steering Committee representatives, including PennDOT representatives, 12 months from the Notice to Proceed date.
* Task C – A technical memorandum summarizing the optimal reinforcement ratios for LWC structures with embedded 3D polymeric MM reinforcement and the results of the compression and flexural testing, to be discussed at a progress review meeting with IRISE Steering Committee representatives, including PennDOT representatives, 22 months from the Notice to Proceed date.
* Task D – A technical memorandum summarizing the optimal auxetic designs for LWC structures and the results of the compression and flexural testing, to be discussed at a progress review meeting with IRISE Steering Committee representatives, including PennDOT representatives, 22 months from the Notice to Proceed date.
* Task E – The draft list of recommendations, which will be included in the draft final report and discussed with IRISE Steering Committee representatives, including the PennDOT team, as described in Task E.
* Task F – The draft final and final reports, due 23 months from the Notice to Proceed date.

In addition to the deliverables listed above, it is also anticipated that the findings of this research will be published and presented at key technical conferences (e.g. TRB, ASCE Structural Congress, among others) and in journal publications.

**Key Personnel:**

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