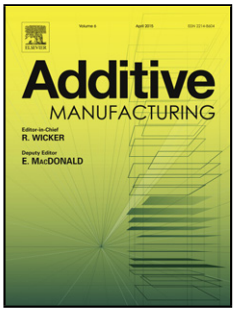

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# Algorithm-driven design of fracture resistant composite materials realized through additive manufacturing

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## ABSTRACT

Fracture, the breakdown of materials as cracks advance, is one of the most intriguing materials phenomena; it can happen even to very tough biological tissues including tendons, skin, bone and teeth, materials whose critical physiological functions can be compromised by structural irregularities. It has been suggested that creating composites by mixing heterogeneous constituents of contrasting material properties can yield designs that can better adapt to stress concentration, leading to synthetic materials with higher toughness than their constituents. Here, an optimization algorithm is used to assess material fracture resistance in the presence of a crack. The analysis is further extended through experiments that involve the use of additive manufacturing. Optimal solutions are composed solely of soft and stiff material elements, and are compared to various benchmarks. Multi-material three-dimensional-printing (3D-printing) is used to create material samples. Experimental results and mechanical testing show that an algorithmic design coupled with 3D-printing technology can generate morphologies of composites more than 20 times tougher than the stiffest base material, and more than twice as strong as the strongest base material. Direct comparison of strain fields around cracks shows excellent agreement between simulation and experiment. The results suggest that the systematic use of microstructure optimization to generate enhanced fracture resistance constitutes a new materials design paradigm.

**Keywords**: 3D-printing, heterogeneous design, mechanical testing, optimization, fracture, finite element modeling

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## 1. INTRODUCTION

One tissue engineering strategy to treat bone loss due to impact or disease is designing reliable scaffolds that are made of synthetic materials with desired mechanical functions and properties [1, 2]. Current classes of scaffolds use materials such as hydroxyapatite, alumina, and calcium phosphates, all of which have low resistance to fracture and high brittleness [3, 4]. Cracks that originate in these structures can quickly propagate and cause catastrophic material failure due to the high stress and strain concentration around the crack tip. Using homogeneous synthetic