Multi-dimensional build planning of FGMs

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Functionally graded materials (FGMs) are composite materials that enable components with varying properties across their volume. Their key characteristic—a continuous change in material composition—balances opposing material properties while avoiding limitations associated with conventional composites that have distinct interfaces. This makes them appealing to industries such as aerospace, automotive, and biomedical. A major challenge in building FGMs is identifying the layer-wise material composition. This challenge arises from the multitude of available materials and the complexity of navigating the multi-material design space under thermodynamic equilibrium constraints given required material properties. For instance, an FGM consisting of two materials with very different coefficients of thermal expansion can jeopardize component reliability under extreme heat conditions. Therefore, selecting compatible material compositions remains a significant challenge. We formulate the problem of finding compatible material compositions as an optimization problem, given thermodynamic equilibrium and material properties for a set of materials and number of layers. We developed a suite of gradient-based and gradient-free algorithms that output a layer-by-layer material composition. To increase computational efficiency, we leverage the shortest path on an n-dimensional grid of material compositions, with each dimension corresponding to a material used in manufacturing. To evaluate this framework, we emulate the process of building FGMs through the Direct Energy Deposit (DED) method. In DED metal additive manufacturing, non-homogeneous mixing in the transition layers is determined by the melted ratio of the previous and current layer, known as dilution. We incorporate the dilution effect in our algorithms to ensure both as-designed and as-built components avoid undesirable material phases. We demonstrate the application of our algorithms for different ternary systems and scale it to solve multi-ternary build problems. This research aims to provide researchers and practitioners with tools to rapidly explore and identify material composition for individual layers considering chemical and manufacturing constraints.