As Additive Manufacture (AM) and specifically Fused Filament Fabrication (FFF) grows in prevalence and effectiveness for myriad applications, understanding and manipulating bonding conditions and physical stresses during fabrication is essential. The entire market of AM is projected to grow immensely by 2030: growth of the global industry from 2023 to 2030 is estimated to be 432.75% (around 23.3% annually)1. These developments are not surprising, however, as the cost effectiveness and quality of AM materials is improving all the time. FFF specifically is making its way into countless new fields as its capabilities grow. NASA is developing their ability to utilize FFF in high-strain aerospace environments2. AM is also becoming essential in biomedicine, automobile engineering, and micromaterials3. These huge advances show the importance of AM with regard to the development of numerous other sciences and industries.

The conditions of a print impact the properties of the finished product significantly4, so it is crucial to better understand conditions and bonding to better determine and manipulate resultant physical properties, so we can refine our ability to manufacture and implement. Additionally, warping and temperature-related changes to volume can severely impact the effectiveness and strength of the final product, and since high temperature is required in FFF environments for the extrusion of filament, warping can become a significant problem5.

We plan to improve our understanding and tools for AM (specifically FFF) by modeling the temperature and physical changes of a product during printing to characterize bonding conditions, warp-related deviations, and overall product effectiveness. To begin our analysis, we propose a 3-level framework built from the ground up with first principles. The first and most important portion of our methodology aims to model interparticle interactions, which are critical in predicting the structural and physical properties of the finished product. We first focused on modeling the Lennard-Jones potential to characterize non-bonded interactions between filament particles, and we intend to extend modelling using other bonding-type descriptors for qualitatively different temperatures. The second layer of our framework focuses on heat transfer between both adjacent particles and the surrounding atmosphere. This is critical in establishing temperature distributions and future bond quality of printed AM products. To achieve this, our framework will incorporate both conductive and convective heat transfer mechanisms, leveraging Fourier’s law for thermal conduction and Newton’s law of cooling for convective heat loss. Building on this, our final, third layer intends to address the actual mechanical deformative impact of the two previous processes. To this end, we’ll model the stress-strain relationships and distortions we predict to occur as AM prints cool and solidify and/or as more material is added. Using basic continuum mechanics models, we’ll relate thermal energy and stress to deformation and, potentially, exactly what characterization of deformation to anticipate. Finally, and most importantly, we intend to allow for specialization in our framework between different input polymers, providing for simple, case-specific, modeling and optimization.

Currently, we have finished the simpler elements of the particle-particle interactions and the temperature modelling; however, our interparticle interactions have not been made dependent on temperature, nor have we constructed the more comprehensive continuum mechanics model for characterization of finished AM product strength. We intend to obtain results pertaining to optimal print bed temperature for various filaments/parameters, warping and bonding strength characterizations for standard shapes, and potential solutions to better support ideal bonding temperatures and conditions; however, the main product is a 3d model of the finished product which can be further analyzed in myriad ways.

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