Transient nucleation effects in additive manufacturing of metallic glasses

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ABSTRACT

Bulk metallic glasses (BMGs) is a promising novel class of materials with remarkable mechanical and magnetic properties in comparison to conventional metallic materials. Synthesizing BMGs requires high cooling rates in order to avoid the nucleation of crystalline phases and instead obtain an amorphous atomic structure. The layer by layer approach utilized in additive manufacturing (AM) enables the possibility to maintain high cooling rates during processing and serves as a promising alternative to casting with the capability to produce BMG components without geometric limitations. Understanding and being able to predict the process of nucleation and growth during AM processing of bulk metallic glasses is therefore of fundamental importance.

Classical nucleation and growth theory (CNGT) has been shown to be a succesful theory to model the process of nucleation and growth in several different materials and processes [2]. The theory provides a compelling framework which can be used to predict the nucleation and growth rate of nuclei, the time evolution of the nuclei size distribution and nuclei and matrix composition. However, in CNGT it is frequently assumed that nucleation occurs under steady-state conditions, implying that the nucleation rate is constant in time. This is a fair assumption in most applications, but has also been shown to be incorrect when nucleation proceeds under rapid cooling or heating of the material [1], such as in AM processing of metallic materials.

In the present work we model the process of nucleation and growth using a modified CNGT model, which takes into account the transient behaviour of the nucleation rate. The model is parametrized using thermodynamic and kinetic data of a zirconium based bulk metallic glass and utilizes temperature history from thermal field modelling of the selective laser melting process of the same material. The results are analysed and compared with a steady-state CNGT model as reference and the consequences of the steady-state assumption are discussed.

Acknowledgements

The SSF-project Additive Manufacturing - Development of Process and Material [grant number GMT14-0048], is gratefully acknowledged.

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