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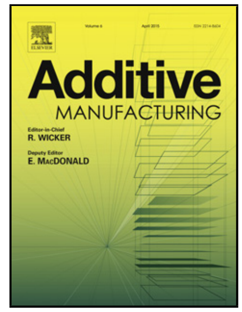

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Thermo-Mechanical Finite Element Analysis of Ultrasonic Powder Consolidation Process

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Abstract
Ultrasonic welding is a solid-state joining process which uses ultrasonic vibration to join materials at relatively low temperatures. Ultrasonic powder consolidation is a derivative of the ultrasonic additive process which consolidates powder material into a dense solid block without melting. During ultrasonic powder consolidation process, metal powder under a compressive load is subjected to transverse ultrasonic vibrations resulting in a fully-dense consolidated product. While ultrasonic powder consolidation process is employed in a wide variety of manufacturing processes, bonding mechanism of powder particles during the consolidation process is not clearly understood. This study uses a coupled thermo-mechanical finite element analysis technique to understand the underlying bonding mechanism involved in ultrasonic powder consolidation process. The study also investigates the effect of critical process parameters including vibrational amplitude and base temperature on the stress, strain, and particle temperature distribution during this process. Based on the results of the simulation, a possible theory on the bonding mechanism involved in ultrasonic powder consolidation process is proposed. The outcomes of this study can be used to further the industrial applications of ultrasonic powder consolidation process as well as other ultrasonic welding based processes.

Keywords: Ultrasonic Consolidation; Finite Element Method; Ultrasonic Vibration; Additive Manufacturing

1. Introduction

Conventional metal powder consolidation processes require high temperatures as well as high stress to achieve full densification and produce the consolidated product [1]. During conventional consolidation, the powder materials are subject to high pressures and temperatures resulting in its melting and solidification [2]. Materials which are exposed to these high temperatures will affect their microstructures and result in the formation of intermetallic phases [3]. Extreme hardness and brittleness characterize these intermetallic phases. The existence of such phases inside a joint restricts its usability [4]. Additionally, the exposure to high temperature demands the use of an appropriate medium such as an inert gas [5]. These limitations make conventional powder consolidation processes not suitable for several engineering applications including aerospace, biomedical and electronic industry.

Ultrasonic Welding (USW) is a solid-state joining process which has the capability of joining both similar and dissimilar materials at relatively low temperatures [6]. This process utilizes ultrasonic energy to manufacture solid structures of various materials including metal foils. Ultrasonic vibrations of 20 kHz frequency or higher are applied laterally to the weld interface through a sonotrode tool along with normal static pressure. This technique is the basis of Ultrasonic Additive Manufacturing (UAM) process which bonds thin metal foils using ultrasonic energy followed by additional subtractive processing [7]. However, fabricating complex three-dimensional (3D) structures using foils through UAM process is time-consuming and often infeasible.