Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 7 (2017) 59 – 65

Procedia MANUFACTURING

International Conference on Sustainable Materials Processing and Manufacturing, SMPM 2017, 23-25 January 2017, Kruger National Park

Fundamentals of Mechanical Design and Analysis for AM Fabricated Parts

Alexander V. Manzhirov*

Institute for Problems in Mechanics of the Russian Academy of Sciences,Vernadsky Ave 101 Bldg 1, Moscow, 119526, Russia
National Research Nuclear University MEPhI, Kashirskoye shosse 31, Moscow, 115409, Russia
Bauman Moscow State Technical University, 2nd Baumanskaya Str 5/1, Moscow, 105005, Russia
Moscow Technological University, Vernadsky Ave 78, Moscow, 119454, Russia

Abstract

Additive Manufacturing (AM) technologies are an exciting area of the modern industrial revolution and have applications in instrumentation, engineering, medicine, electronics, aerospace industry, and other fields. They include stereolithography, electrolytic deposition, thermal and laser-based 3D printing, 3D-IC fabrication technologies, etc. and are booming nowadays owing to their ability to fabricate products with unique characteristics that cannot be made with traditional fabrication techniques. AM enables cost-effective production of customized geometry and parts by direct fabrication from 3D data and mathematical models. However, to further the progress in the emerging area and empower scientists, engineers, and designers to fully implement the novel processes' capabilities, there is a need for a systematic study of mechanical design and analysis for AM technologies. Despite much progress in the area of AM technologies, problems of mechanical design and analysis for AM fabricated parts yet remain to be solved. So far, three main problems can be isolated: (i) the onset of residual stresses, which inevitably occur in the manufacturing process and can lead to failure of the parts, (ii) the distortion of the final shape of AM fabricated parts, and (iii) the development of technical and technological solutions aimed at improving existing AM technologies and creating new ones. This paper deals with an approach to modeling surface growth processes in solids.

Peer-review under responsibility of the organizing committee of SMPM 2017

Keywords: additive manufacturing technologies; growing solid; viscoelastic material; shape; strength

* Corresponding author. Tel.: +7-495-434-4138; fax: +7-499-739-9531.
E-mail address: manzh@inbox.ru

Peer-review under responsibility of the organizing committee of SMPM 2017
doi:10.1016/j.promfg.2016.12.017

1. Specific Features of Additive Manufacturing

Deformation processes in a solid whose composition, mass, or volume varies in a piecewise continuous manner due to the influx of new material is of great interest for engineers, researchers and technologists in numerous areas. The solid mechanics problems arising in the field of modeling of such processes are completely new and form a separate field of research known as Mechanics of Growing Solids. Its importance is determined by the fact that almost all solid objects in nature and technology (buildings, structures, structural components, machine parts, trees, bones, soft tissues, etc.) appear under some growth process. The process of growth of a solid is studied in the fundamental scientific area called Mechanics of Growing Solids. This area deals with all sorts of solid materials including elastic, viscoelastic, plastic, composite and graded materials (see, e.g., [1–7]).

Additive manufacturing technologies are a particular case of growth processes. Mathematical modeling of additive manufacturing technologies is aimed at improving the performance of device, machine, and mechanism parts. The fundamentally new mathematical models considered in the paper describe the evolution of the end product stress-strain state in additive manufacturing and are of general interest for modern technologies in engineering, medicine, electronics industry, aerospace industry, and other fields (see, e.g., [8–22]).

A continuously growing solid is a solid whose composition, mass or volume varies because of a continuous addition of material to its surface. The process of adding new material to the solid is called growth as well as in particular cases accretion, erection, building-up, healing, etc. For continuous growth, the following basic stages of its deformation are strictly followed: before, during, and after the growth process. Each of these stages is characterized by instants when it starts and ends. The first is characterized by the instant of application of a load to the solid and the instant when growth starts. The second by the instant when growth starts and the instant when it ends. Conversely, the third is characterized by the instant when growth ends and the instant when it starts. The solid on whose surface new material is deposited starting from the instant when accretion starts is called the basic or original solid. Note that growth can also occur without the basic solid, starting from an infinitesimal material element. The part of the surface where infinitesimal pieces of the material are deposited at the actual instant is called the growth surface. The growth surface may be disconnected, in general. In particular, it can be the whole surface of the solid. Finally, the part of the surface of the original or the growing solid that coincides with the growth surface at the instant when growth starts will be called the base surface. The base surface is clearly the part of the surface of the solid on which material is to be deposited during the next stage of continuous growth. At different stages, it coincides, as a rule, with the surface between the basic solid and the additional solid as well as with the surfaces between the sub-solids (see, e.g., [1–3]).

Let the basic solid, which is made from a viscoelastic ageing material (see, e.g., [1–3]), occupies a domain Ω_0 with the surface S_0 and is free of stresses up to the instant τ_0 of application of the load. From τ_0 up to the instant τ_1 when growth starts the classical boundary conditions are given on S_0, the specific form of which is stated below. At τ_1 the continuous growth of a solid begins due to the addition of material particles to the growth surface $S^*(t)$. As it grows, the solid occupies a domain $\Omega(t)$ with surface $S(t)$. It is obvious that $S^*(t) \subseteq S(t)$. The instant when a particle characterized by a position vector x is deposited on the solid will be denoted by $\tau^*(\mathbf{x})$ and called the instant of deposition of the particle on the growing solid. The configuration of the accreted solid is completely defined by the function $\tau^*(\mathbf{x})$ depending on the spatial coordinates. Boundedness and piecewise-continuity are the general conditions usually imposed on $\tau^*(\mathbf{x})$.

Denote by $\tau_1^*(\mathbf{x})$ the instant when an element of the growing solid is formed and by $\tau_0(\mathbf{x})$ the instant when a load is applied to it. Naturally, $\tau_1^*(\mathbf{x}) \le \tau_0(\mathbf{x}) = \tau_0$ for the elements of the basic solid ($\mathbf{x} \in \Omega_0$).

To simplify the problem, the isotermic and inertialess case of small deformations are considered.

The vector equilibrium equation is obviously satisfied in the domain occupied by the growing solid at each instant of time. For quasistatic processes, it has the form

$$\mathbf{x} \in \Omega(t) : \nabla \cdot \mathbf{T} = \mathbf{O},$$