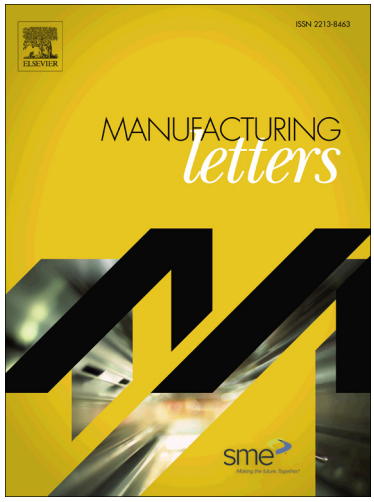

Letters

Metamorphic Manufacturing: The Third Wave in Digital Manufacturing

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Metamorphic Manufacturing: The Third Wave in Digital Manufacturing

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1. Introduction

Agile and reconfigurable manufacturing has been dominated by two waves of innovation. The first was numerically controlled subtractive manufacturing, commonly known as CNC machining, and began real development and limited use in the 1950's and became commonplace in the 1980's. The second wave which is underway now is numerically controlled additive manufacturing, often called 3-D printing. There is rightly much excitement about these technologies as they have revolutionized how we make things, however, they both have shortcomings.

Machining is a time-consuming process and only a fraction of the original material is used in the part (a large fraction being turned to machining chips). In addition, there is limited opportunity to locally improve or modify material microstructure or properties locally.

Additive manufacturing is in its early stages of development and commercialization. This technology offers substantial opportunities compared to conventional powder metallurgy processing. In particular, additive manufacturing offers unprecedented opportunity for topology optimization. However, this process produces significant waste in the form unused powders that are often not reusable for high quality parts; secondary operations, such as hot isostatic pressing, are often needed for high performance and the costs of raw materials and equipment usage can be high.

With this short note, we hope to introduce the concept of metamorphic manufacturing, and argue it should be developed to take its place alongside subtractive and additive manufacturing as a technology for the digitally-controlled creation of high-performance structural metallic components.

2. Metamorphic Manufacturing

Imagine if a machine can act like a blacksmith, squeezing and bending metal into shape, and doing this at temperatures and with deformation conditions that actually improve the materials properties by homogenizing the structure and refining grains. This focus on properties has been emphasized of late [1]. We refer to this process of digitally-controlled incremental forming as metamorphic manufacturing. We choose the term metamorphic because both material shape as well as structure are transformed in a digitally-prescribed manner during the process. In some sense, all metal forming operations are 'metamorphic', but we are limiting our definition of metamorphic manufacturing to those processes that use incremental, Computer Numerically Controlled deformation, and may include closed loop feedback to optimize shape or minimize defects. Figure 1 shows this current and future state.