Advanced Microstructure Control in Metal 3D Printing Using a Femtosecond Laser

Project Objective

The objective of this project is to investigate whether ultrafast laser pulses can enable greater precision in metal 3D printing and allow for the printing of alloys, such as metallic glasses, that current 3D printers are unable to handle, by limiting the so-called "heat-affected zone".

Research Description

As part of the project, the plan is to retrofit a metal 3D printer with a femtosecond laser source and then carefully calibrate the device. Once the modified printer is working, test parts will be printed using traditional alloys. This will allow researchers to investigate whether the ultrafast laser actually minimizes the heat-affected zone while ensuring the stability of the molten metal pool. The microstructure of the samples will also be examined and their hardness will be tested to determine whether the internal grains of the metal are significantly finer compared to conventionally printed parts. The most challenging stage will be the attempt to 3D print a bulk metallic glass object. Bulk metallic glass (BMG) is an alloy that can solidify into an amorphous, glass-like form if cooled extremely rapidly. These materials are very strong, but producing large, crack-free iron-based metallic glass parts is difficult – if the cooling is even slightly too slow, the metal crystallizes and loses its unique properties. Conventional 3D printing struggles with such materials; printed parts often turn out partially crystallized or cracked due to the high temperature of the process. The femtosecond laser offers a new opportunity to avoid this problem. By delivering energy in ultrashort bursts, each layer solidifies before heat has a chance to accumulate, ensuring that the entire printed part remains amorphous. An attempt will be made to print small samples of such metallic glass using the ultrafast laser, ensuring that they remain fully amorphous throughout the process.

Reasons for Pursuing This Research

Metal 3D printing is changing the way we manufacture complex parts. However, current metal 3D printers typically use continuous or long-pulsed lasers to melt metal powder, which introduces a significant amount of heat into each layer. This excess heat spreads out, creating a large "heat-affected zone" around the laser's path, leading to non-uniformity in the structure. As a result, current laser-based 3D printing methods often produce parts that are not as uniform or reliable as desired. There is a need for techniques that can produce metal parts with a more consistent internal structure, free of defects caused by the extensive heat-affected zone. A femtosecond is an incredibly short period of time – a quadrillionth of a second (10^-15 s). In femtosecond lasers, each pulse delivers intense heat to a very small area, melting the metal powder. However, since the pulse lasts only a few femtoseconds, the material has almost no time to transfer heat to the surrounding area and starts cooling immediately after the pulse ends. The heat doesn't have a chance to spread to the rest of the material. By limiting the energy input, the ultrafast laser minimizes the "heat-affected zone" around each melt point. If everything works as intended, it will help avoid many of the problems caused by continuous lasers. Femtosecond pulses may enable the creation of metal parts with a finer and more uniform microstructure than is possible with current methods.

Expected Outcomes

By the end of the project, it is expected that several significant advancements in metal 3D printing technology will be demonstrated. The produced parts are expected to be almost free of the heat-affected zone – which means significantly fewer micro-cracks and internal stresses – and the process will allow for much finer details, creating very small components with reduced distortions. Additionally, it is anticipated that new materials, such as metallic glass, can be printed without crystallization. The potential benefits of this research for industry and society are enormous. If successful, the ultrafast laser will enable the production of better and more reliable metal products in 3D printing. For instance, medical device manufacturers could create wear-resistant, custom implants made from amorphous metal, which would last much longer. On the manufacturing side, reducing defects and distortions would lead to less waste and lower costs. Ultimately, this groundbreaking research could pave the way for a new generation of 3D printers that produce metal components far more efficiently.