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Laser engineered net shaping process for SAE 4140 low alloy steel

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ABSTRACT

This paper presents the investigation of the macrostructure, microstructure, and solidification structure of two ferrous based materials produced by the LENS™ process. The material deposited and examined in this work was a SAE 4140 low alloy steel. The focus of this work is to (1) identify the solidification structure and measure the Dendritic Arm Spacing (DAS) to determine growth/cooling rates at the solid/liquid interface, (2) identify and quantify discontinuities in the build structure, and (3) examine the affect of solidification and thermal history on the sample microstructure to further the understanding of the LENS™ process.

1. Introduction

The development of direct metal fabrication for prototype and high performance parts has been initially driven by the need to reduce the time to market for new products [1–3]. Direct metal fabrication techniques have been developed over time based on rapid prototyping evolution. There are many different forms of rapid prototyping, but they can be broken down into two main categories. The first category, rapid tooling, are methods that rely on an enhanced casting process, which is expedited by means of creating tooling in an efficient process. Examples of such rapid tooling (RT) techniques would include stereo lithography, plastic pattern, and ice patterns. Tooling is first created to make the mold followed by casting the part. These processes reduce the manufacturing time of the tooling. The second category, rapid manufacture (RM), produces the final part directly using a direct metal deposition (DMD) technique. Several of the techniques used for this are jet solidification, 3-D welding, shape deposition manufacturing (SDM), election beam manufacturing (EBM), and laser based manufacturing techniques (LBMT).

Within the laser-based manufacturing techniques several of the available methods are selective laser sintering (SLS), direct metal laser sintering (DMLS), and laser engineered net shaping (LENS™). Of these laser based techniques, the LENS™ technique has been chosen [4] to be evaluated.

The LENS™ system has been in development for more than 15 years. LENS™ was developed by Sandia National Laboratories under a Cooperative Research and Development Agreement (CRADA) with United Technologies Pratt and Whitney (UTPW) [1]. The LENS™ system was commercialized by Optomec Design Corporation.

The LENS™ system typically consists of a high-power Nd; YAG (750–1000 W) laser, which is focused on a metal substrate to create a molten pool. Once the molten pool is created, powdered metal is subsequently added to the pool to create more volume, thereby building up the material locally. The powder is directed into the pool by means of inert gas (-usually argon). The process also takes place in an atmospherically controlled environment typically of argon with oxygen levels less than 10 ppm to avoid oxidation of the melt [5].

The substrate on which the part is to be built is positioned on a *X–Y* table which is computer controlled to create the master pattern required to build the structure. The build height of the structure is controlled by movement in the *Z* direction of the laser and powder delivery system. The build is created by subsequently depositing one layer on top of one another until the assembly is completed. A schematic of the LENS™ process is shown in Fig. 1. The movement of both the *X–Y* table and laser/powder delivery system are computer controlled. The input to create the structure is originally derived from a CAD (Computer Aided Drawing) file. The CAD file is sliced into the various layers needed to build the structure. The information is then provided by the CAD file to the LENS™ system to replicate the structure or part.

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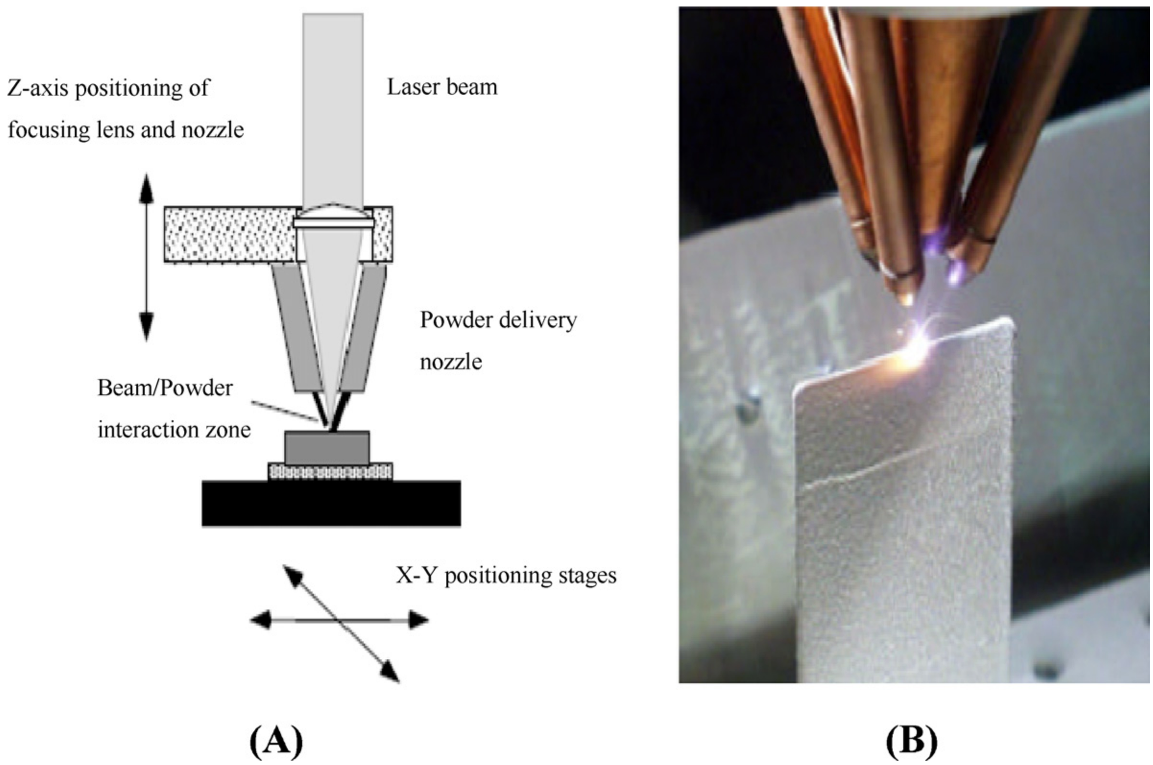

Fig. 1. LENS schematics (A) Schematic representation of the LENS^{TM} process (B) Single line, single wall specimen produced by LENS^{TM} (1).

1.1. TACOM 4140 Sample

The sample provided by Alion Science & Technology for initial evaluation was to be used to develop metallographic techniques in order to determine solidification and metallurgical characteristics. The sample was built in the shape of a solid cylinder approximately 25.4 mm in diameter and 78.5 mm high. Atomized powder of SAE 4140 low alloy steel chemical composition was used in the LENS^{TM} production of these test samples (see Fig. 2). The substrate, which the 4140 powder was deposited on, was 316 L Stainless Steel. No other information or specifications with regard to the sample was provided.

2. Processing methods and experimental design

The TACOM samples were produced on an Optomec LENS^{TM} Model 750, using a retrofit 4-diode bank laser, made by Fraunhofer [6]. The Cover and Assist gas used was nitrogen. Nitrogen versus argon was used in the initial builds to facilitate the feasible deployment of the LENS^{TM} system. Nitrogen gas can be produced on site from air versus argon, which would have to be transported to the build site. Additional information based on typical build conditions were: Laser amps: 35–45, Hatch Shrink 0.015 in., Hatch size 0.015 in., layer thickness 0.01 in., Laser feed rate 40 in./min, and powder feed rate of 20 rpm. No specific processing information on the sample analyzed was provided.

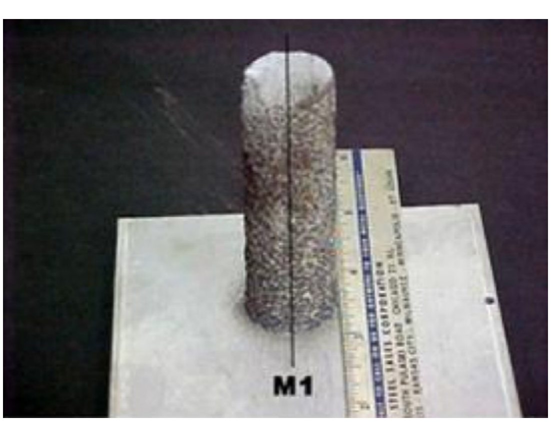

Fig. 2. The 4140 sample as received. The sample is marked M1 with the location of the longitudinal section for metallographic examination.

3. Metallographic sample preparation and examination

The 4140 sample produced by Alion Science & Technology was sectioned longitudinally into two pieces. Sample sectioning was done using both an Electrical Discharge Machining (EDM) machine utilizing a brass .010″ diameter wire. Multiple passes (3) were taken during the cutting operations to minimize any skin effect due to the EDM process. In addition a standard water-soluble oil cut off wheel was also used in the initial cutting operation to get sections for polishing. One piece was subsequently section further into three samples for mounting to examine the entire center longitudinal axis. The sections are numbered Sample 1, which is closest to the substrate, Sample 2 is the center section, and Sample 3 is the top section, as shown in Fig. 3. A transverse section was extracted from the remaining piece. A schematic of the samples illustrates the orientation of the sample with respect to the *X*, *Y*, and *Z*-axis shown in Fig. 4.

The grinding, polishing, and etching procedures used are given in Table 1.

A Nikon Eclipse TS 100, Nikon Epiphot 300, and Leco 300 metallograph were used to photograph the microstructures and do quantitative metallurgical investigations. Both the Clemex Image Analysis and Pax-it software package were used to evaluate such items as percent porosity, layer and hatch spacing, and particles size.