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BASELINE ESTIMATION OF ULTRASONIC RESPONSE OF METALLIC STRUCTURES FABRICATED VIA LASER DIRECT ENERGY DEPOSITION (DED)

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ABSTRACT

Laser Directed Energy Deposition (DED) is an additive manufacturing (AM) technique which enables us to fabricate 3D structures by melting material as it is deposited. The mechanical behavior and reliability of components fabricated via laser DED is still not completely understood, which in turn is disadvantageous for its adoption in the industry at a large scale. The goal is to fabricate components with similar properties as those fabricated by traditional manufacturing processes. An evaluation of the mechanical properties of laser DED structures is necessary to determine their adequacy in engineering applications.

The present study compares the ultrasonic response of pure Stainless Steel (SS) 420LC and Inconel 718LC samples fabricated via DED to samples of the same materials fabricated via cold-rolling in order to establish the baseline UT response. This work focuses on the ultrasonic velocities, attenuation and backscatter coefficients as functions of frequency. The velocities were also used to measure any anisotropy in the samples. Ultrasonic C-Scans are presented to quantify any defects found during fabrication. These will be compared against destructive measurements.

Keywords: Laser directed energy deposition, stainless steel, Inconel, ultrasonic velocity, attenuation, backscatter, anisotropy

1. INTRODUCTION

Additive Manufacturing (AM), of metal powders is a well-known technology that enables the fabrication, directly from a CAD model, of 3D objects with intricate and complex geometries by joining materials in successive cross-sectional layers. This is achieved with such precision and control that cannot be compared to subtractive manufacturing techniques [1-5]. AM, being a versatile, flexible and highly customizable technology, can suite most sectors of industrial production such as aerospace, automotive or medical [3].

Laser Directed Energy Deposition (DED) is an AM technique predominantly used for metal powders, where material powder is melted as it is being deposited, by the use of focused thermal energy (laser) [1,2]. With laser DED, 99.9% of the theoretical density of the material can be achieved. It is applicable to the repair of parts or the addition of coatings to existing surfaces [4]. A variety of metals have been investigated for laser DED, including stainless steel, Inconel, titanium alloys, and more [6]. Also, laser DED is especially useful for the production of functionally graded components.

While the critical challenge remains in translating the superiority of this technology into fabricating components that are functional as those obtained from traditional manufacturing processes, there is a need for extending the current understanding of what can be achieved from laser DED, along with the inspectibility of structures fabricated using laser DED. With this as the objective, the present study aims to establish a baseline by investigating the ultrasonic response of stainless steel 420LC and Inconel 718LC samples obtained via laser DED and cold-rolling. The microstructural properties were also investigated by comparing the attenuation coefficient and backscatter coefficient of these samples.

2. MATERIALS AND METHODS

Four samples were used for this study, two stainless steel (SS) 420LC and Inconel 718LC samples were fabricated via laser DED and the other two were cold-rolled obtained from a commercial supplier. The dimensions of the DED samples were 25.4 mm (L) X 25.4 mm (W) X 19.05 mm (H) (1 in X 1 in X 0.75 in), where L, W and H were defined as the first, second and third directions for wave propagation, respectively. The SS cold-rolled sample was a cube of side length 25.4 mm (1 in) and also three directions were chosen. The Inconel cold-rolled sample had

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dimensions of 18.28 mm (L) X 17.48 mm (W) X 26.52 mm (H) (~0.72x0.7x1 in^3), and again, L, W and H were respectively selected as the first, second and third directions for wave propagation.

The setup of the experiment consisted of a pulser/receiver, an oscilloscope, a 5 MHz longitudinal wave, a 2.25 MHz shear wave and a 5 MHz delay line ultrasonic contact transducers.

Using the pulse-echo method, the longitudinal velocity was measured 5 times per direction in each of the samples. The shear velocity of the samples (except the Inconel DED sample) was measured 4 times in each direction (2 measurements per polarization orientation of the transducer). The through-transmission method was used to measure the shear velocity of the Inconel DED sample, also 4 times per direction (2 per polarization orientation).

For the attenuation and backscatter coefficients measurement, the pulse-echo method with the delay line transducer were used. Attenuation was calculated using three echo technique, and backscatter coefficient was calculated using the RMS noise between front wall and 1st backwall.

3. RESULTS AND DISCUSSION

As it can be seen in Table 1, the results of the longitudinal velocities of the SS samples show a considerable difference between the two methods of fabrication. For example, in the direction 3 of the SS sample, the longitudinal velocity of the cold-rolled sample is 420 m/s larger than the value of the laser DED sample. Also, and as expected, there is a marked distinction in the velocity of the rolling direction (5979.11 ± 2.22 m/s) in relation to the other directions (~ 6128 m/s) in the SS cold-rolled sample. Figure 1 shows a comparison of the longitudinal velocities of the SS samples, for both laser DED and cold-rolling fabrication, over the three directions of propagation.

TABLE 1. LONGITUDINAL VELOCITIES (m/s) OF THE LASER DED AND COLD-ROLLED SAMPLES OVER THREE DIRECTIONS OF WAVE PROPAGATION

Material	Wave propagation	Fabrication method	
		Laser DED	Cold-rolled
SS 420	Direction 1	5708.97 ± 4.37	5979.11 ± 2.22
	Direction 2	5700.59 ± 4.00	6127.47 ± 2.00
	Direction 3	5708.60 ± 2.15	6129.32 ± 1.53
Inconel 718	Direction 1	5754.55 ± 3.48	5761.26 ± 3.64
	Direction 2	5682.63 ± 4.73	5775.68 ± 2.36
	Direction 3	5599.49 ± 2.81	5760.21 ± 1.53

Some consistency in the longitudinal velocities over the three directions of the SS laser DED sample can be observed, where the variation between the larger (5708.97 ± 4.37 m/s) and smaller (5700.59 ± 4.00 m/s) value is 0.15%. However, this is not the case for the Inconel laser DED sample, which shows a variation of 2.69% between the larger (5754.55 ± 3.48 m/s) and smaller (5599.49 ± 2.81 m/s) value of longitudinal velocity. Also for the longitudinal velocities of the Inconel samples, the results do not show a consistent difference between the two fabrication methods, apart from the slightly larger values of the cold-rolled samples.

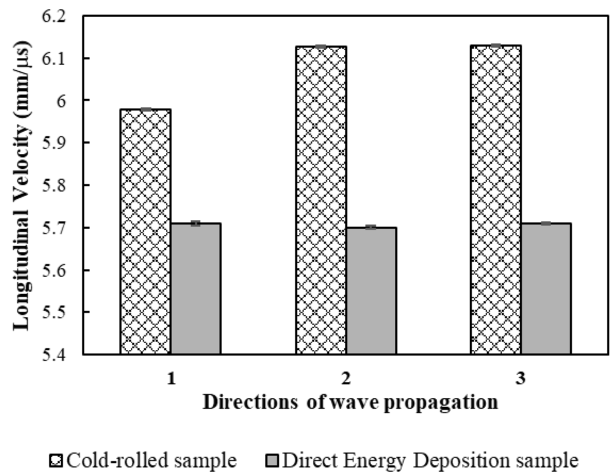

FIGURE 1: LONGITUDINAL VELOCITY OF THE STAINLESS STEEL SAMPLES

TABLE 2. SHEAR VELOCITIES (m/s) OF THE LASER DED AND COLD-ROLLED INCONEL SAMPLES OVER THREE DIRECTIONS OF WAVE PROPAGATION AND SHEAR POLARIZATIONS

Material	Wave propagation and shear polarization	Fabrication method	
		Laser DED	Cold-rolled
Inconel 718LC	D1-2[1]	2876.89 ± 7.75	3030.12 ± 0.69
	D1-3[1]	3380.15 ± 2.90	3038.93 ± 0.06
	D2-1[1]	3410.49 ± 2.92	3032.49 ± 0.53
	D2-3[1]	2839.42 ± 1.09	3038.55 ± 0.66
	D3-1[1]	3585.71 ± 2.73	3034.33 ± 0.17
	D3-2[1]	3578.13 ± 0.54	3037.19 ± 0.70

Note 1: D1-2 means the wave is propagation along direction 1 and the shear polarization is on direction 2.

The shear velocities provide a better understanding of the highly anisotropic nature of the laser DED samples, where the values changed according to the shear polarization, as can be seen in Table 2. It can be observed that the velocity values of the cold-rolled sample along the different directions and shear polarizations is almost constant (~3035 m/s), whereas the values of the laser DED sample show a high variation, with some values being smaller (e.g. 2876.89 ± 7.75 m/s in D1-2) and others being larger (e.g. 3585.71 ± 2.73 m/s in D3-1) than the average shear velocity of the Inconel cold-rolled sample. A comparison between the shear velocity of the Inconel samples over the three directions of propagation and shear polarizations is shown in Fig. 2.

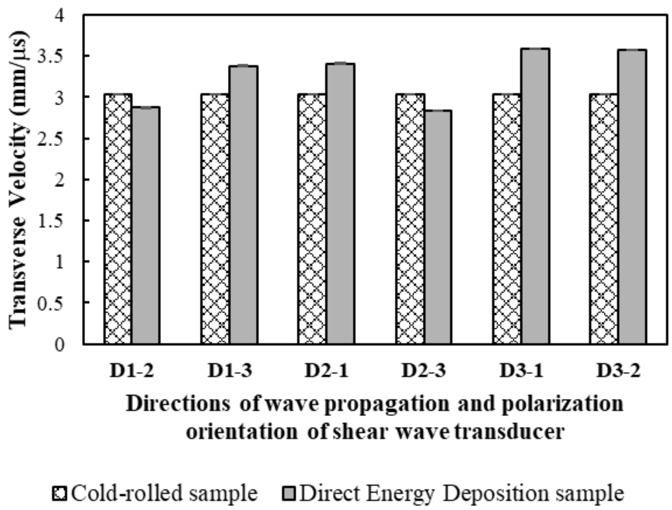

FIGURE 2: TRANSVERSE VELOCITY OF THE INCONEL SAMPLES

4. CONCLUSION

The ultrasonic longitudinal velocity of the laser DED samples was found to be different from cold-rolled samples by 6.97% in the SS samples and 2.79% in the Inconel samples. The shear wave velocity measurements on the SS laser DED sample showed mild anisotropy, and on the Inconel DED sample showed a higher degree of anisotropy. The measurement of complete elastic constants assuming them to be orthotropic will be presented in the final poster. The attenuation and backscatter coefficients as a function of direction will also be presented along with some destructive measurements.

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