Investigation of fundamental ultrasonic propagation characteristics in NDT of Electron Beam Melted additive manufactured samples

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Abstract
New approaches for efficient NDT inspection of modern additively manufactured metallic components are required urgently to qualify and validate the next generation of metallic parts across a range of industries. Ultrasonic testing is a fundamental component of NDT for such additive manufacturing processes. This work studies the ultrasonic propagation characteristics of EBM manufactured sample coupons in Alloy 718 material. Fundamental longitudinal and shear wave velocity measurements are experimentally measured in 3 orthogonal build directions of the sample coupons. Results show a dependency of the ultrasonic velocities and the build direction. The measured velocities are further verified in a phased array measurement showing successful results that highlights the potential of continued studies with synthetic apertures techniques.

Introduction

Based on mechanical wave propagation, ultrasonics represent a central group of NDT techniques with a wide range of applications, among them monitoring and inspection AM-components [1]. For reliable usage of ultrasonic phased array systems and synthetic aperture techniques, an important requirement is understanding of the acoustic propagation characteristics of the material and object under investigation. Motivated by the need for inspection of components created with new emerging combinations of processes and materials, this work investigates the fundamental ultrasonic propagation characteristics of square test sample coupons in Alloy 718 material built with electron beam melting (EBM) technique [2] in three orthogonal directions. Results describing the ultrasonic propagation characteristics are then extended into a subsequent measurement using phased array and synthetic aperture processing.

Electron beam manufacturing and sample coupons

The test sample coupons used in this study have the dimensions 50x50x5 mm^3 and are built in Alloy 718 material using the EBM technique [2] with an Arcam A2X machine configured with standard build parameters. A sketch showing an overview of the EBM technique is shown in Figure 1. With the EBM technique, which is a powder-bed fusion technique, the components are created by selective melting through scanning of the powder particles using an electron beam. By adding more powder and repeating the

selective melting layer-by-layer, the components take form. As a result, inherent to the process itself, the layers of the samples will be subjected to different cooling rates and heat exchange. In turn, this typically give rise to a columnar grain structure and thus anisotropic mechanical properties [3]. Naturally, the anisotropic behaviour is of importance when performing ultrasonic measurements. For this reason, test samples are created according to three orthogonal build orientations, see Figure 1. The three different sample types are denoted XY, XZ and YZ according to their orientations related to an X-Y-Z coordinate system, see Figure 1. Note that the base plate of the build is coincident with the X-Y plane of the coordinate system. Accordingly, the build direction for all specimens follow the Z-axis.

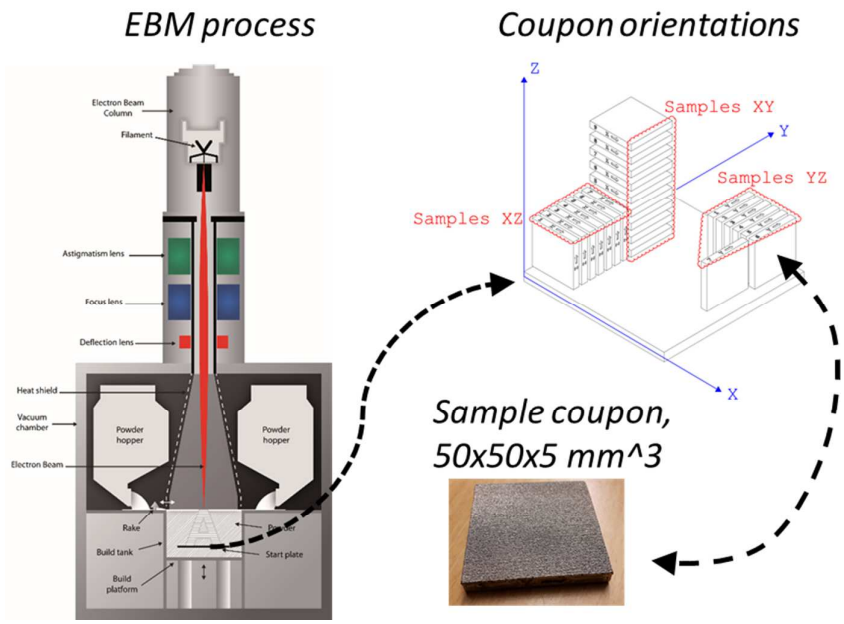

Figure 1. Overview of EBM process (left) and orientations of test sample coupons (top right), and photograph of one test sample (bottom right).

Measurements and results

The longitudinal and transversal wave velocities are measured for 4 pieces of the samples of type XY and for 5 pieces of samples of type XZ and YZ; the measurement comprises 14 samples in total. The velocities are measured at the three different frequencies of 1 MHz, 2.25 MHz and 5 MHz using a set-up consisting of two transducers placed in an immersion water tank with the test sample coupon in between the transducers. The longitudinal wave velocity is measured using a time-of-flight procedure, and the transversal wave velocity is calculated from the critical angle, which is measured through rotation of the test sample between the transducer pair.

First, the samples were measured in as-built conditions and due to uneven surfaces, see Fig 1, no reliable and consistent results could be acquired; typically underestimated longitudinal wave velocities and scattered results were observed. After machining (grinding) of the top and bottom surface for all samples, new measurements were performed which provided more reliable results presented here in Fig. 2. Results in Fig. 2 show that the samples of type XY, which are orientated parallel to the base plate, are associated with a generally lower velocity for both the longitudinal wave and transversal

wave compared with the samples of type XZ and YZ. This result is in agreement with the literature that establishes that a lower Young's modulus is expected parallel to the build direction (Z axis) [3]. Regarding the potential difference between samples of type XZ and YZ, no significant differences can be deduced from the results at this stage. Some intra-set variations and spread within each group of samples (XY, XZ and YZ) are also observed. Although not investigated in this study, but through the experience gained in related studies at University West, this result is reasonable to be expected since the orientation and location of the samples in the build chamber are associated with varying thermal histories and thereby varying microstructure.

As a continuation of the ultrasonic propagation velocities measurements, the samples were inspected with both a contact and immersion based phased array set-up employing a full matrix capture (FMC) for both cases. Data were processed using a refraction compensation based total focusing method (TFM) [4] with one example result presented in Fig. 2. As anticipated, no apparent defects are identified. In Figure 2, the initial surface of the sample is shown with red colour and the back wall of the sample is constructed in a correct position. The second and third back wall echoes are also viewable in the image. These results suggests that the used technique is a suitable candidate for further studies with samples containing defects as well as of more complex geometry. Furthermore, results from the phased array inspection also confirm the previously measured ultrasonic velocities of the samples through the successful construction of the back walls.

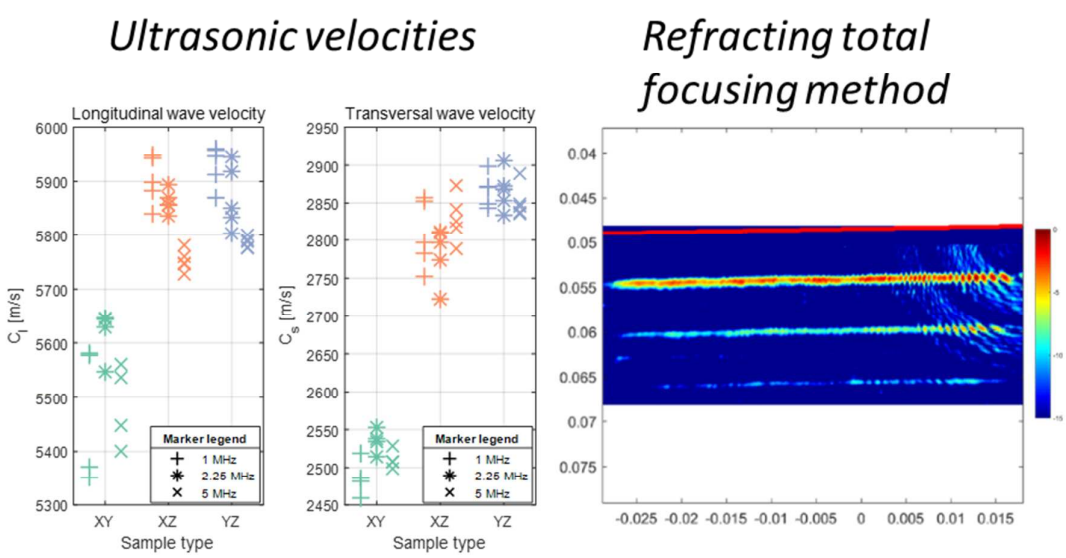

Figure 2. Measured ultrasonic velocities(left) and reflection image from a refracting total focusing method (right). The red solid line in the reflection image corresponds to the surface of the sample.

Conclusions

The measurements initially faced difficulties due to the rough as-built surfaces of the samples. After machining of the surfaces, ultrasonic propagation velocities were successfully measured with varying velocities observed as function of the sample orientation related to the build direction. A phased array investigation was conducted with successful results highlighting the potential for further studies using the adopted

phased array technique in non-destructive evaluation of Alloy 718 components built with EBM process.

References

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