



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0939

LASER SCANNING METHOD FOR DETERMINATION OF GEOMETRIC QUALITY PARAMETERS OF PREFORMS PRODUCED BY WIRE + ARC ADDITIVE MANUFACTURING

Igor Oliveira Felice
Danielle Monteiro Souza
Leandro João da Silva
Douglas Bezerra de Araújo
Ruham Pablo Reis

Universidade Federal de Uberlândia – Avenida João Naves de Ávila, 2121, Uberlândia / MG - Brazil
igor.ofelice@gmail.com
sdaniellemonteiro@gmail.com
leandro.tools@gmail.com
dbaraújo@ufu.br
ruhamreis@ufu.br

Abstract. *In wire + arc additive manufacturing (WAAM), the construction of preforms closer to the final geometry, that is, with a lower buy-to-apply ratio, reflects less post-processing and higher productivity. This factor becomes even more important for materials of high cost and tough machinability. In addition, rework and/or spoilage due to geometric deviation during deposition represent significant losses. Therefore, non-invasive monitoring approaches are of great interest. In this sense, the present work aims to evaluate and validate a software developed with Matlab® for non-invasive geometric verification based on image analysis, making use of a reference part. The projection of a laser line on the lateral surface of the structure at three levels of inclination was filmed while the wall at constant speed. Through the software, the surface can be virtually rebuilt. The geometric outcomes were compared to the known dimensions of the reference part. The results obtained demonstrate that such method was able to verify surface form and waviness deviations, but presented some errors which can be minimized with parameter optimization. Thus, the methodology has its potential, but needs further developments to improve the results.*

Keywords: WAAM, additive manufacturing, CMT, non-invasive evaluation, geometry quality, image analysis

1. INTRODUCTION

Additive manufacturing (AM) has been presented as an alternative and complementary technique for current conventional and subtractive methods of manufacturing (Townsend et al., 2016). Specially arc wire + additive manufacturing (WAAM) has presented many advantages over traditional manufacturing processes, especially in terms of increasing economic gains and minimizing environmental impacts (Sequeira Almeida & Williams, 2010), directly affecting the sustainability of the process. The high deposition rate, lower equipment costs and the possibility of manufacturing large parts make the technique efficient in terms of productivity. In addition, low residue issues and the construction of near net shape parts contribute in terms of ecological aspects. The versatility of the process over high performance metals (titanium, 6Al4V, 17-4 PH stainless steel, cobalt chrome and Inconel 625,) becomes one of the main reasons for the adoption of AM by different industrial sectors.

However, one of the main obstacles presented by this technique is related to the high level of energy input generated during material deposition. The high heating rate of the layers can reduce productivity, cause geometric deviations in a superficial and volumetric form and negatively alter the mechanical and physical properties of the preforms, even intensifying the effects of residual stresses (Souza, 2017). Manvatkar et al. (2014), for instance, verified a considerable increase of the melting pool dimensions, a superior temperature presented in the previous layer, an attenuation of the cooling rate and hardness with the increase of deposited layers. Another important issue when it comes to quality control in additively manufactured parts is related to geometric deviations.

Topography is the term typically used to describe the entire geometric information associated with a surface shape and its features (Townsend et al., 2016) and it is strongly modified in additively manufactured parts by the thermal effects. Also, the surface regularity becomes a topographic feature of great interest in AM as the staircase effect (Figure 1) caused by layer by layer deposition cannot be eliminated and is intrinsic to the process. However, it is believed that with proper thermal management, better surface quality can be achieved by mitigating this aforementioned effect.

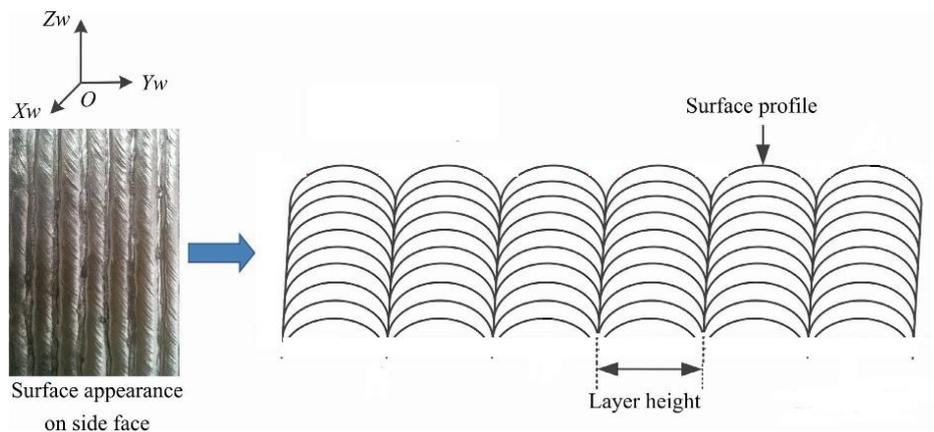


Figure 1 – Side surface and staircase effect in AM (Xiong et al. 2018).

In this sense, to minimize the thermal effects of the process and eliminate the necessity to stop deposition for layer cooling (natural cooling), various thermal management methods have been developed. The so-called Near-Immersion Active Cooling (NIAC) is one of such techniques and it is based on the continuous and controlled quasi-immersion of the preform into a liquid cooling fluid (typically water) during its construction (da Silva, et al., 2018). The cooling rate of the non-immersed part of the preform is controlled by the water level, which demand is dependent on the energy input by the heat source. This distance between the top of the preform and the water lamina has the excessive vaporization as the minimum limit, which can disturb the electric arc and/or contaminate it (da Silva, et al., 2018). A schematic representation of this technique is presented in Figure 2.

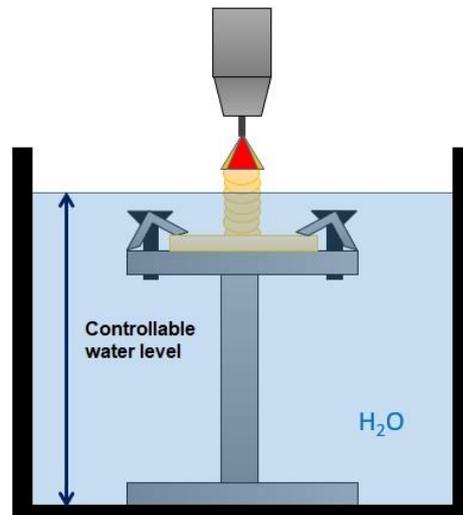


Figure 2 – Schematic representation of the experimental approach of the NIAC technique (da Silva, et al., 2018).

In this way, it is possible to reduce the heat accumulation and to adapt the geometric quality and mechanical properties of the part manufactured according to its design, as well as to increase the productivity of the process. Recently, da Silva et al. (2018) verified a considerable increase in height and width reduction in walls produced by WAAM using the NIAC technique compared with natural and passive cooling approaches as shown in the graph of the Figure 3. It was possible to improve the structures in geometrical aspects, especially concerning surface waviness. The same work verified that the thermal management does not induce increment of porosity and favors the balance of mechanical properties of the preforms.

Among the possible methods of geometric quality and mechanical properties verification, the usage of image analysis techniques has expanded in recent years due to the low cost of development and the flexibility to be applied on specimens of the most varied features. Ortega et al. (2018) used a Breuckmann 3D commercial scanner to analyze geometric parameters of layers deposited by WAAM. Using the Gomatic analysis software they calculated the total volume of the deposit while a Python routine extracted the values of height, width and contact angle of the layers. Xiong et al. (2018) developed their own software, based on laser scanning and subsequent processing of the obtained

surface data to evaluate geometric parameters of preforms also manufactured by WAAM. Figure 4 (a) and (b) show the validation steps of the software developed by them and Figure 4 (c) show the volume reconstructed by the commercial software. However, in these cases the preform area analyzed was quite limited and thus might not represent the hole preform geometric quality.

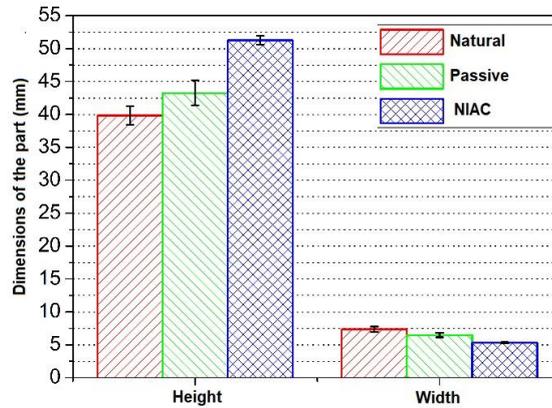


Figure 3 – Effect of thermal management techniques on preform height and width. (da Silva, et al., 2018)

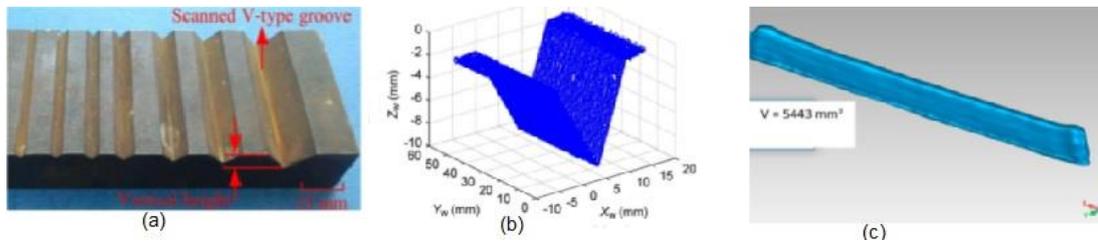


Figure 4 – (a) and (b) Steps of software validation (Xiong et al. 2018). (c) Preform volume reconstruction (Ortega et al. 2018).

Therefore, the development of image analysis techniques applied to WAAM is relevant because of the following aspects: low cost (compared to other commercial scanning methods); the possibility of a macro-geometric surface analysis; the elimination of contact evaluation methods which can damage the structure; and even dispense the necessity of cross-sectional cutting for measurements as it is still very often and traditionally carried out, which hinders the representativeness of the entire part produced.

Thus, this work aims to present the preliminary validation of a software that will be used in the evaluation of the geometric quality of preforms made by WAAM with the application of the NIAC technique for thermal management.

2. METHODOLOGY

2.1 Construction of the reference part

For the validation of the geometric quality analysis software, a reference part, shown in Fig. 5 (a), was constructed of aluminum alloy and used to compare its geometric measurements with the values obtained by the software. It was decided to manufacture a structure with six levels of height (or five height differences), reproducing in dimension the lateral waviness gradations of preforms manufactured by additive manufacture, as seen in Fig. 5 (b). Five points were defined along the longitude of the part to perform the measurements. Initially, a part with flat surfaces and constant height differences with their values presented in Table 1 was expected.

Height difference	Expected measurement
h1	2 mm
h2	1 mm
h3	0.5 mm
h4	0.25 mm
h5	0.125 mm

Table 1 – Expected measurements of height difference for the reference part.

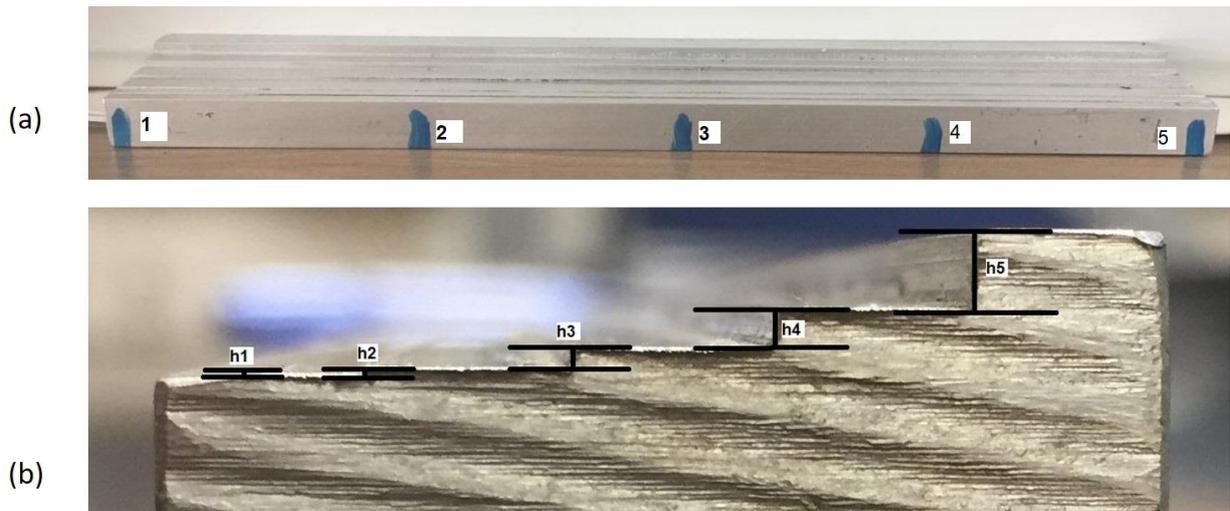


Figure 5 - Reference part used for software validation. (a) Overview (b) Detailed view of steps.

2.2 Scanning and Surface Reconstruction

A commercial line laser was projected on the lateral surface of the reference part and it was filmed while it was moving at constant speed. To acquire the film, a Canon PowerShot SX50 HS camera, configured according to the data in Figure 6, was used and the scanning and recording step occurred in a dark room to mitigate possible interference from other light sources. A CNC table was used for the movement of the reference part, thus guaranteeing a constant speed of 600 mm/s. The variation of the laser incidence was evaluated in three levels of angulation (40°, 50° and 60°), with two repetitions at each scan. Figure 6 shows the layout of the equipment used.

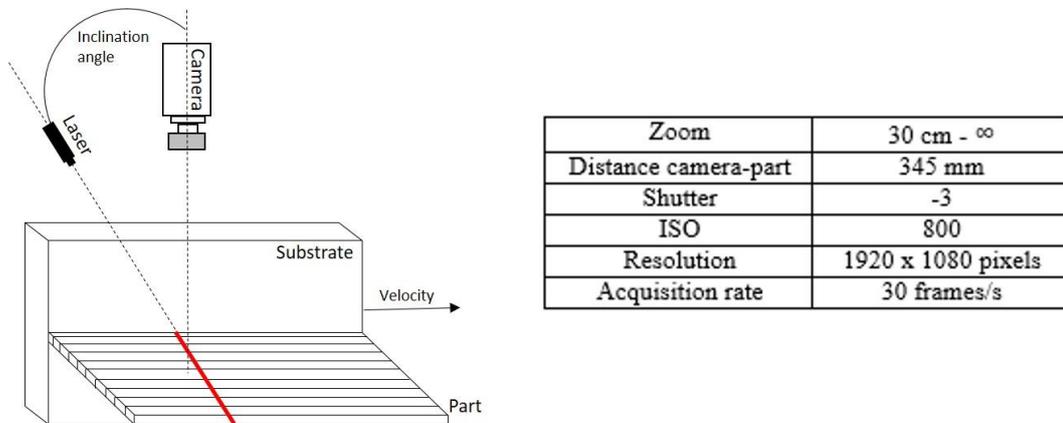


Figure 6 - Layout of equipment used in the scanning and data of camera settings.

The software algorithm for virtual surface reconstruction was implemented in Matlab®, which processed the files generated in .MOV format. In a three-dimensional system, the coordinates of each surface point were obtained and used for both computational reference part reproduction and subsequent calculations steps (Figure 7).

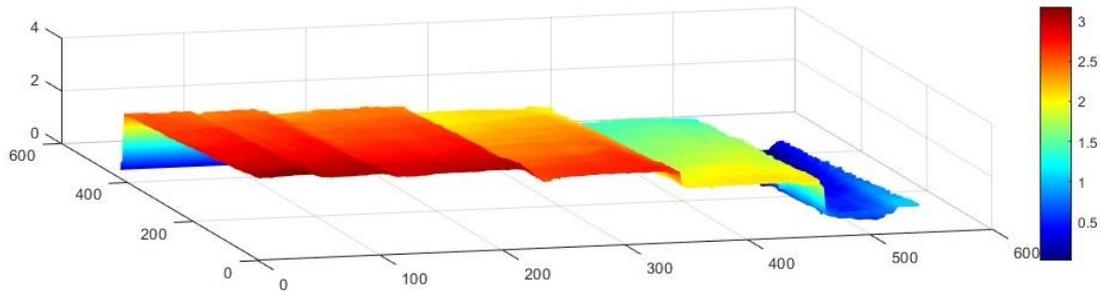


Figure 7 - Virtual reconstruction of the scanned reference part.

2.3 Surface geometric parameters

The parameters used for comparison and validation of the software are surface inclination (or flatness) and average height differences between surfaces. For this, the reference part was divided into 5 equally spaced positions, according to Figure 5 (a), where these parameters were calculated after measurements obtained by the conventional method (with contact) and compared with values from the software analysis technique.

The conventional method was performed at 25°C using a Mitutoyo HDS-H12 "C digital height gauge with nominal range of 300 mm and resolution 0.01 mm. The height of each surface was measured three times at each of the five positions along the length and the mean values were obtained. The height difference between surfaces was calculated for each position and also averaged over each entire surface of the part. To evaluate the inclination, the difference between the heights in the initial (Point 1) and final (Point 5) region of the reference part surface was considered.

For the software analysis, surface points from the virtual reconstruction were used and the laser light reflection interference at the beginning of the scan was eliminated. In a specific calculation-oriented part of the algorithm, each of the six surfaces of the reference part was divided into 5 equally spaced positions, as in the conventional method. A range of 30 frames in each position was used to provide greater representativeness for the 5 analysis regions and the average height of these frames was obtained. The difference in these height averages was used for comparison with the conventional method. The inclination was verified by comparing the heights of the two extreme positions.

3. RESULTS AND DISCUSSION

After the scanning and virtual reconstruction of the side of the parts, illustrated by Figure 7, the geometric data of the surface were obtained. The comparison of percentage errors of the height differences between all surface levels are shown in Figures 8, 9, 10, 11 and 12. They were calculated from the values obtained by the scanner in comparison with the measurements made by the height gauge. It was noted that for the minimum height differences (between surfaces 2 and 1), where a superior sensitivity of the scanner is required, an extremely high relative error was observed, compromising the accuracy of the measurement system for this low operating range. As the height differences were larger, the errors decreased dramatically but still showed to be far from an acceptable operating range for software validation. Thus, it was possible to verify that the method can be well used but lacks advances to determine the proper resolution to the scanning system in conjunction with the software.

It was also observed that the increase of the laser angle is directly related to the reduction of the relative error with the use of the scanner, and the angle of 60° presents a lower percentage of error. This fact is explained by the increase of the inclination causing an increment of the area projected by the laser on the reference part surface, which was more sensitive to the camera used and consequently to the software used in the image analysis.

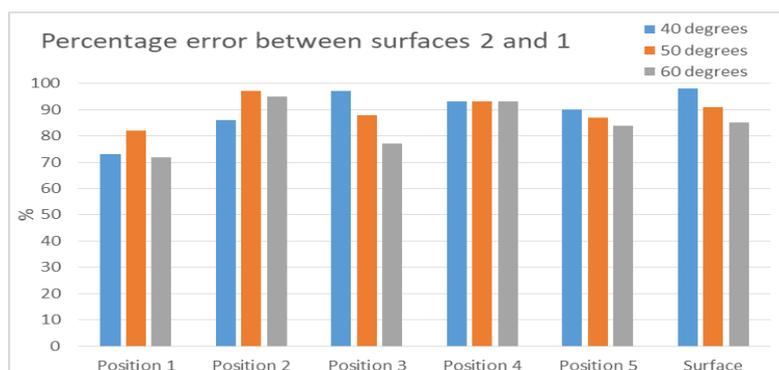


Figure 8 – Percentage error in the difference of heights between surfaces 2 and 1 of the reference part.

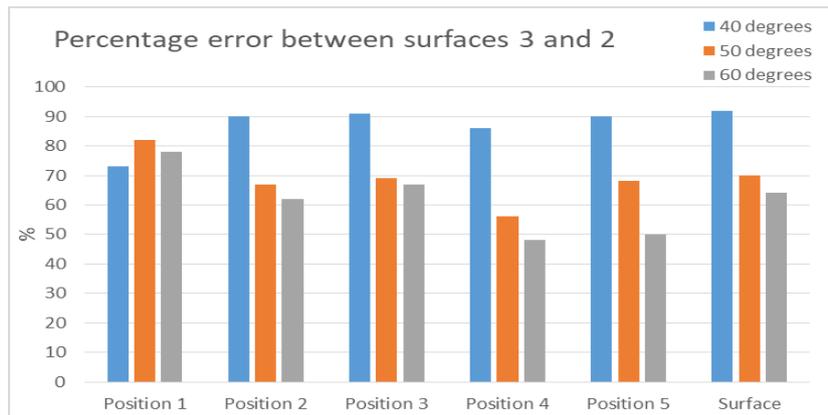


Figure 9 – Percentage error in the difference of heights between surfaces 3 and 2 of the reference part.

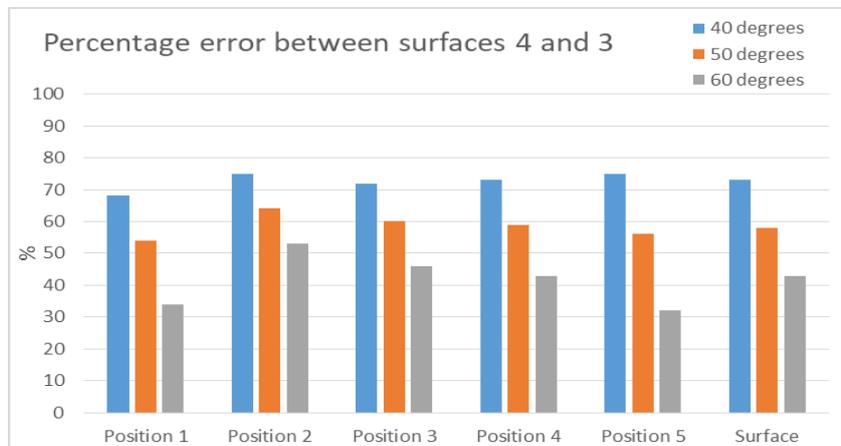


Figure 10 – Percentage error in the difference of heights between surfaces 4 and 3 of the reference part.

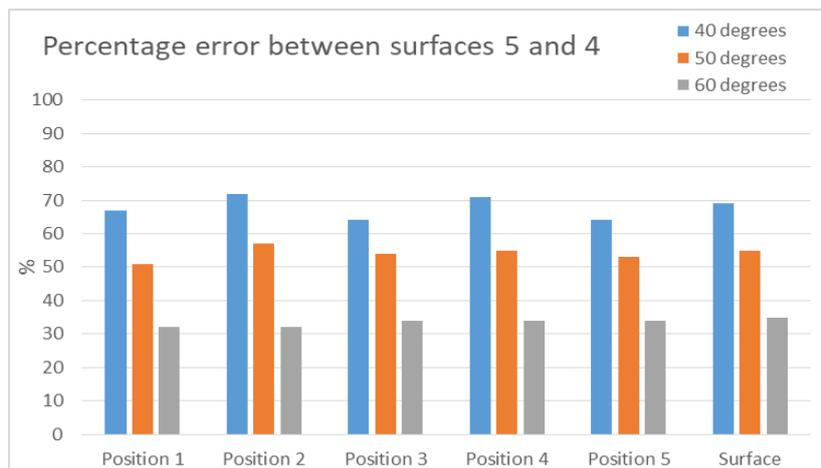


Figure 11 – Percentage error in the difference of heights between surfaces 5 and 4 of the reference part.

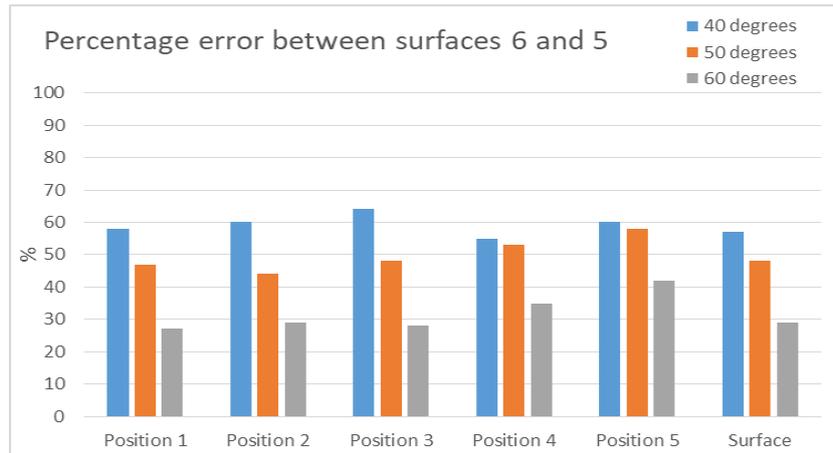


Figure 12 - Percentage error in the difference of heights between surfaces 6 and 5 of the reference part.

The inclination of each surface was also verified for the three angulations of the laser and compared to the reference condition, measured with the height gauge. The results are presented in Figure 13. Taking into account the measurements of the height gauge, it was verified that the piece had very small deviations and could be considered flat for all the 6 surfaces according to the resolution expected. However, a considerable inclination was noticed for the software analysis. Such divergence was systematic and constant for each laser angulation and can be attributed to the alignment and positioning error of the reference part on the table, and noted by the scanner sensitivity. That was an important result as the perception of the method to form deviations was considerable. At 50 and 60 degrees, surface 6 showed considerable laser reflection and therefore its inclination values were unstable.

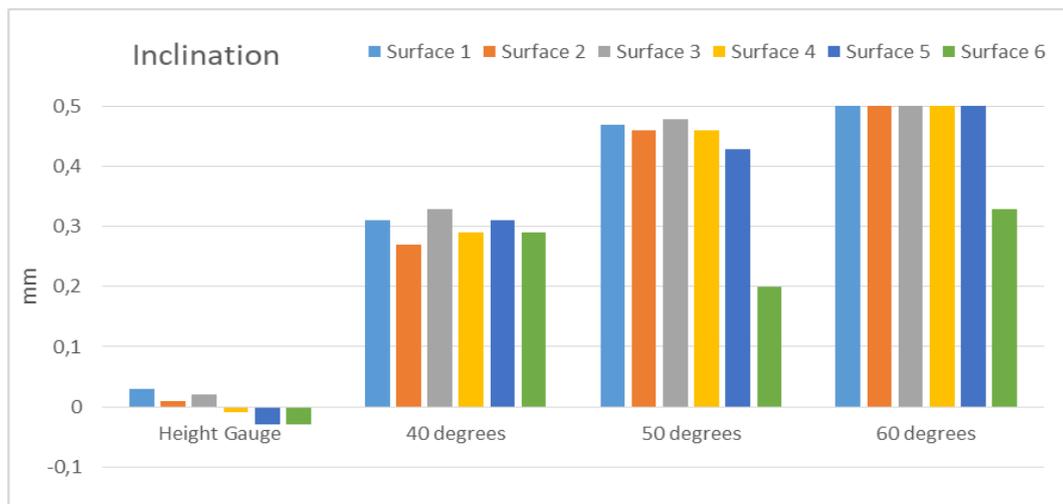


Figure 13 – Surface inclination, in millimeters, of the reference part for each scanning condition.

In an attempt to mitigate errors, a laser with manual focus adjustment was used to replace the conventional equipment of previous tests. In the first scans, an exaggerated brightness on the metallic surface was observed due to the high power of the apparatus, which led to a virtual reconstruction of the surface in poor quality (Figure 14). Thus, an Instrutherm DC power supply model FA-3005 was used to make the voltage and current adjustments to suit the laser power.

New scans were performed to test the modified set, involving the laser module with manual focus adjustment and the electronic power supply. Through virtual surface reconstruction, it was possible to observe a higher quality in the structure geometry (Figure 15). The effect of excessive brightness was reduced (Figure 16) and preliminary analysis indicated 18% percentage errors for height difference between surfaces 5 and 4 and angle inclination of 35°, which is a considerable advance. Thus, it was verified the need to vary other parameters to optimize the software under development in order to validate it for analysis of other geometries.

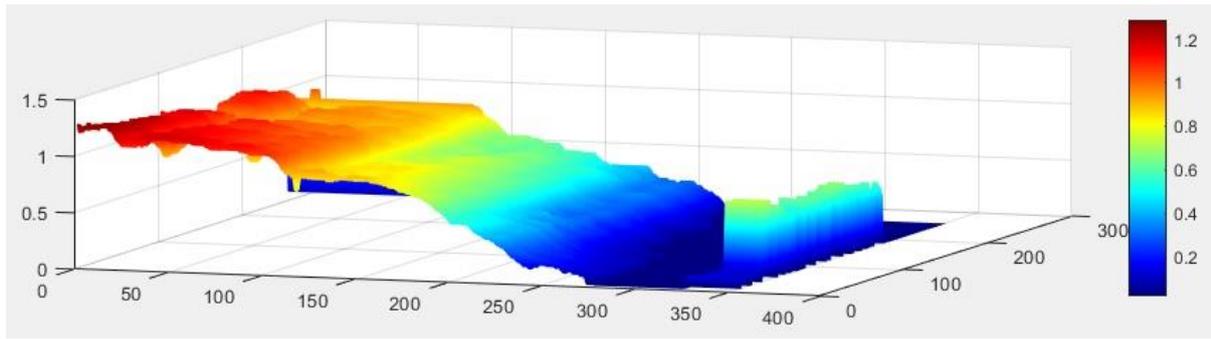


Figure 14 – Influence of high laser brightness on surface reconstruction of the part.

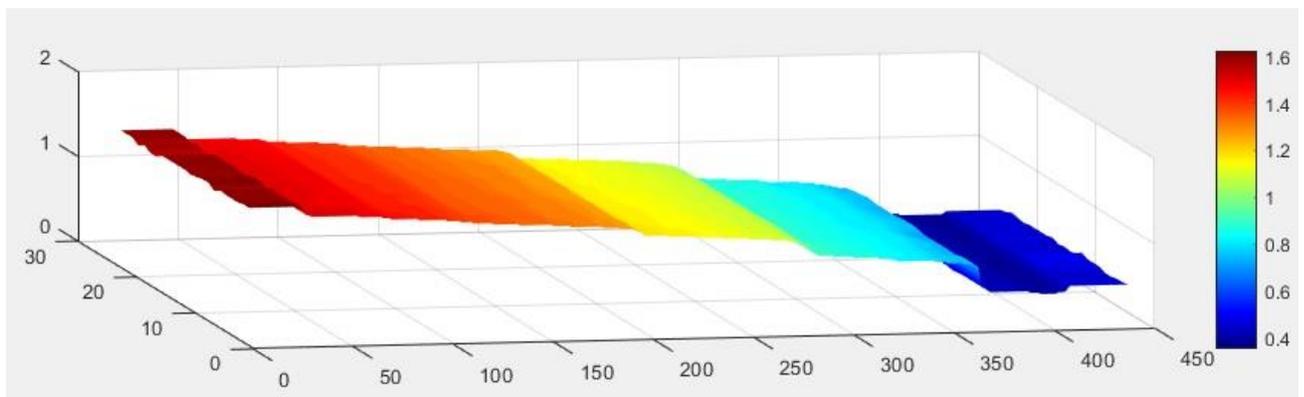


Figure 15 – Virtual surface after the use of new equipment..



Figure 16 - Elimination of excessive brightness after using new equipment.

4. CONCLUSIONS

The use of image analysis software for geometric quality evaluation can be a relevant tool in the manufacture of WAAM parts since important parameters can be observed during the scanning process. So far, it was possible to conclude that the highest (60°) inclination angle of the laser presented the least percentage error in the first set. The attempt to reduce errors with new, better quality equipment had a positive effect as errors dropped considerably. It was also possible to detect alignment deviations related to the positioning of the reference part. It is possible to conclude that such capacity of the developed technique can be exploited to measure volumetric geometric deviations.

Other parameters such as scan speed, quality and laser focus and camera-to-part distance will be explored in order to verify their influence in the scan quality with the recurring target of minimizing errors and then obtain a validation of the software for the proposed application.

5. ACKNOWLEDGEMENTS

The authors acknowledge the Center for Research and Development of Welding Processes (Laprosolda) at Federal University of Uberlândia for the laboratorial infrastructure. This study was supported by the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES), through Finance Code 001 and by the Brazilian National Council for Scientific and Technological Development (CNPq), through grant 315092/2018-1.

6. REFERENCES

- da Silva, L. J., Souza, D. M., Araújo, D. B., Saad, N. d., Reis, R. P., & Scotti, A. (2018). Gerenciamento Térmico via Resfriamento Ativo por Quase-imersão Aplicado à Manufatura Aditiva por Fusão-Deposição a Arco. *Anais XLIV Congresso Nacional de Soldagem*.
- Manvatkar, V., De, A., & Debroy, T. (2014). Heat transfer and material flow during laser assisted multilayer additive manufacturing. *Journal of Applied Physics*, pp. 1-8.
- Ortega, A. G., Galvan, L. C., Deschaux-Beaume, F., Mezrag, B., & Rouquette, S. (2018). Effect of process parameters on the quality of aluminium alloy Al5Si deposits in wire and arc additive manufacturing using a cold metal transfer process. *Science and Technology of Welding and Joining*, pp. 316-332.
- Sequeira Almeida, P. M., & Williams, S. (2010, January). Innovative process model of Ti-6Al-4V additive layer manufacturing using cold metal transfer (CMT). *21st Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference*, pp. 25-36.
- Souza, D. M. (2017). *Estudo de diferentes estratégias de resfriamento de paredes de alumínio fabricadas por manufatura aditiva a arco elétrico*. Uberlândia: UFU.
- Townsend, A., Senin, N., Blunt, L., Leach, R. K., Taylor, J. S. (2016). Surface texture metrology for metal additive manufacturing: a review. *Precision Engineering* 46, pp. 34-47.
- Xiong, J., Li, Y., Li, R., & Ziqiu, Y. (2018). Influences of process parameters on surface roughness of multi-layer singlepass thin-walled parts in GMAW-based additive manufacturing. *Journal of Materials Processing Tech.*, pp. 128-136.

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