Experimental report

07/02/2022

Proposal: **1-02-321** **Council:** 10/2020

Title: Residual stress state of additive manufactured 316L Stainless Steel parts : Round 2.

Research area: Engineering

This proposal is a continuation of 1-02-283

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Samples: stainless steel sample

Instrument	Requested days	Allocated days	From	To
SALSA	2	2	12/03/2021	15/03/2021

Abstract:

The studied 316L SS specimens were obtained with successive deposition of molten metallic wire using electrical arc generated with a welding process : Gas Metal Arc Welding (GMAW). This welding process is studied for its capability to build large additive manufactured (AM) parts. However, this process produces large grain size, important geometrical deformations and tensile residual stress in the AM parts. The lowering of geometrical deformations and tensile residual stress in the AM part can be done through an adequate settings of welding parameters and deposition path strategy. This research project is part of Camille CAMBON PhD (Oct. 2017 – Aug. 2021). Camille is carrying out both experimental and numerical works on how the process parameters (welding parameters, deposition path, …) affect the geometrical deformations and the induced residual stresses. Few AM specimen have been analyzed with Neutron Diffraction at SALSA diffractometer in end of August 2020. Half of the specimens have been analyzed. Furthermore, 80% of the measurements performed in remelted zone were not relevant, likely due to our choice of volume gage or wavelength.We are applying to analyze the last specimens.

REPORT EXPERIMENT 1-02-321 (experiment 85620)
Residual stress state of additive manufactured 316L Stainless Steel parts : Round 2.

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1 Summary of the experimental proposal

This proposal is a complementary investigation to the one carried out in September 2020 [1]. Because of the restrictions due to the Covid-19 pandemia, some of the measurements have not been done.

In these experiments, a relation between the deposition parameters (based on welding energy) and the generated residual stresses is investigated. Secondly, the effect of layer addition on the previous one is also studied in order to observe the residual stress changes after a layer addition.

The specimens still consist of a base plate (SS 304L) with layers deposited on its thickness. The layers are made from melted SS316L wire. The base plate (or parent) size is 150 x 53 x 6 mm as shown in figure 1.

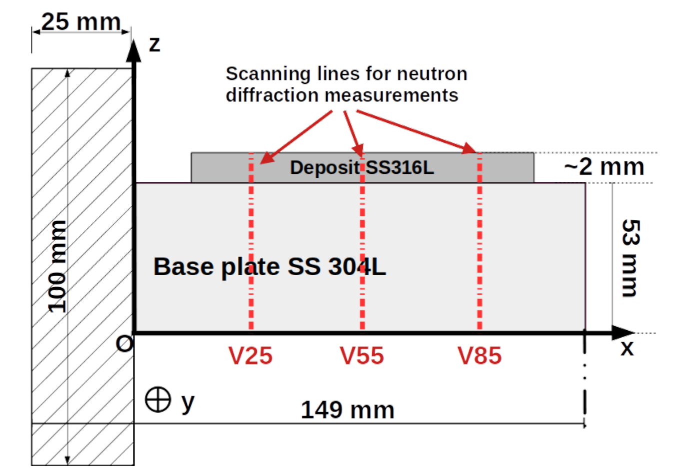

Figure 1: basic sketch of specimen with one deposit (on the slice of the SS304L substrate). Three lines were used for neutron strain scanning (red dashed lines).

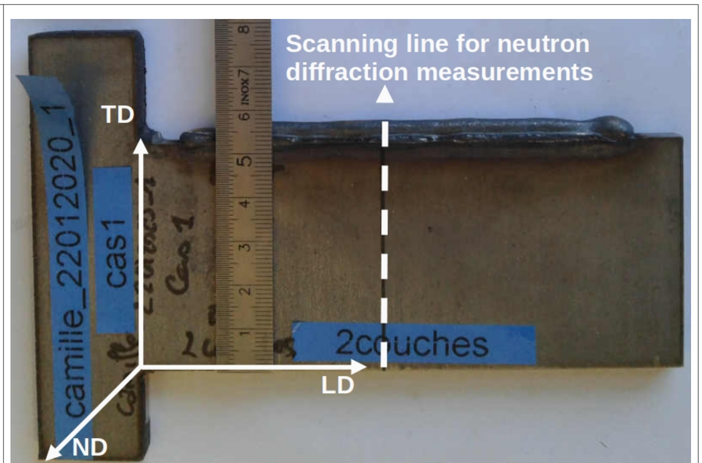

Figure 2: photography of the specimen with 2 layers. The three main directions (LD, TD and ND) are defined as shown in the photography.

In these experiments, the gauge volume settings was set to 2 x 2 x 2 mm^3 with x axis is along σ_{long} , y axis is along σ_{norm} and z axis is along σ_{trans} as shown in figure 2 in order to improve the signal in the melted zones. The wavelength was also set to 1,65 A with a diffracted angle of 2Θ = 98,502°. The considered crystallographic plane was the Fe-311 as in [1].

4 specimens are investigated : two specimens have 5 deposits but they were elaborated with different deposition parameters (energies) in order to observe any changes in the residuals stresses. 2 other specimens have 2 and 3 deposits : the aim is to observe the effect of additional deposit on the stress components. No “comb-like” specimens were used in this work because

2 Effect of layer addition on residual stresses

Four specimens have been used: one layer, two layers, three layers and five layers. All the specimens have been build under the same process parameters (or welding energies). The measurements have been performed once the specimens have reached the room temperature. The reference diffracted $2\theta_0$ angle was calculated assuming the plane stress assumption, thus $\sigma_{norm}=0$ [2, 3]. This assumption was validated according the first neutron diffraction experiments carried out previously [3] on similar specimens (on the 1 layer and 5 layers specimens).

The longitudinal stress distributions, along line V55 of figure 1, are reported in figure 3. The overall trend of the stress distribution is similar in the bottom half of the specimen. The main differences are noticed in the half top part of the specimen. The maximum values of the longitudinal stress have changed after each new layer. The maximum have been reached after the 1st layer. The lowest one after the 2nd layer then this value seems to stabilize after 3 layers. The position of this peak value shifted upward as the number of layer was added. One part of the results presented in figure 3 will be presented at the ICRS11 in March 2022 [4].

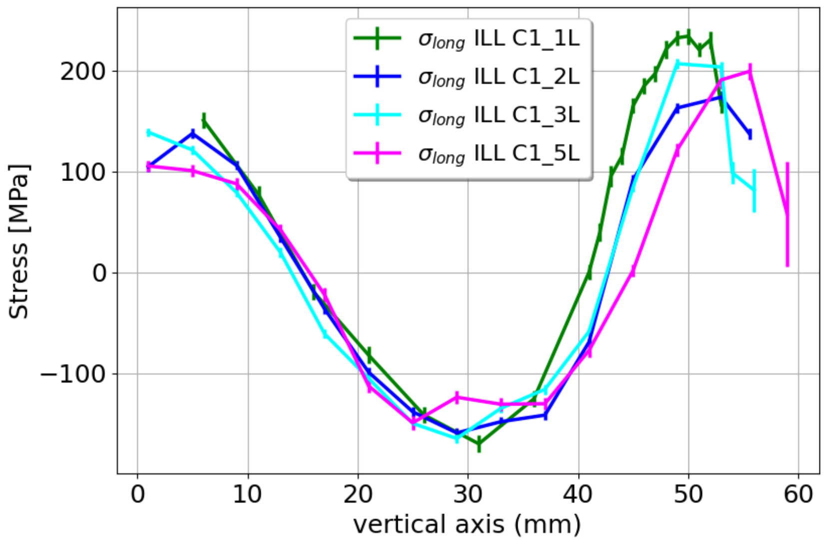

Figure 3: effect of layer addition on the residual stresses along line V55, see figure 1. ILL means Institute Laue Langevin where the measurements have been done, C1 means 1st set of process parameters, 1L is for 1 layer, 2L for 2 layers and so on.

3 Effect of process parameters on the residual stresses for 5 layers specimens

The effect of process parameters, namely welding voltage and current and also deposition speed have been investigated on the resulting residual stress field. The process parameters are shown in table 1. Three cases have been studied as these settings allowed building "wall" structure (the resulting melting and wetting avoided any collapse of the wall during the deposition procedure). The 1st layer has been deposited under the same conditions for the three cases as the parent material was cold. From the 2nd layer up to the 5th one, the process parameters were modified as stated in table 1.

Parameters	**Set** 1 **layer** 1	**Set** 1 **layer** *n*	**Set** 2 **layer** 1	**Set** 2 **layer** *n*	**Set** 3 **layer** 1	**Set** 3 **layer** *n*
U (V)	13.5	13	14.5	13.6	14.5	13.6
I (A)	119	99	144	122	144	122
S_w (m/s)	0.007	0.007	0.007	0.007	0.0086	0.0086
E (J/mm)	183.6	147.1	238.7	189.7	194.2	154.3
S_f (m/min)	3.2	2.5	4.2	3.3	4.2	3.3

Table 1: process parameters used for the deposition of the layers. The 1st layer was deposited with the same process parameters for the 3 different cases. This was necessary in order to get a good melting and wetting on the cold parent. The process parameters were varied from the 2nd layer up to the 5th one.

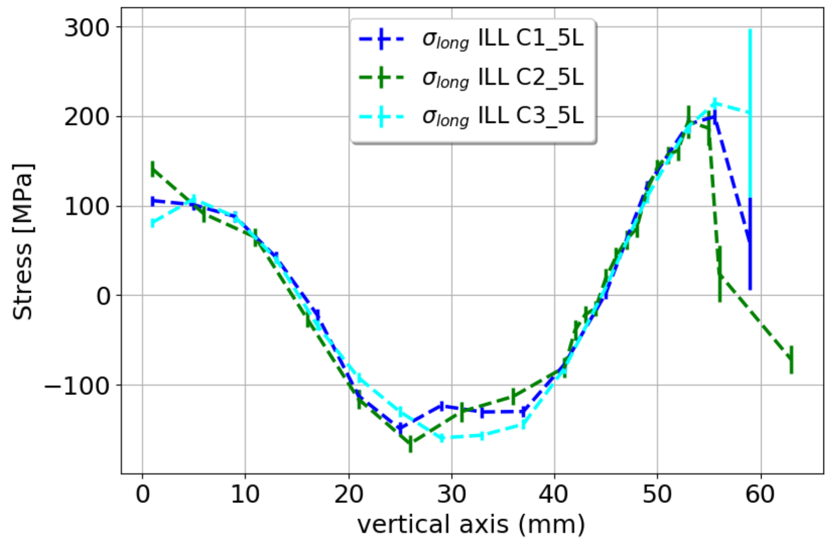

Figure 4: effect of process parameters (welding energies) on the longitudinal stress profile after 5 layers.

The measured longitudinal stress profiles (along V55) do not exhibit any significant changes along the V55 line. The main differences are observed in the melted zone, for z > 55 mm (the melted zone is located between 53 and 63 mm for 5 layers specimens), where the neutron diffraction was quite difficult to analyze because of the textured micro-structure. The error bars are the greatest in this zone as it can be seen on figure 4. The specimen C2 had one measured stress value in the 5th layer (z~62 mm) with a good accuracy. The large grains (millimeter long) present in the melted zone prevent any good diffraction signal. The largest volume gauge used in these experiments did not improve the measurements of the strain/stress values.

4 Conclusions on this experimental campaign

First of all, we warmly thank the staff of the ILL, especially Sandra CABEZA and Thilo PIRLING, for their support and help. We don't repeat it enough!!!

Secondly, the results of this campaign can be summarized as follow:

1. the effect of layer addition is visible on the residual stress profiles. After the addition of 3 layers, it seems that the maximum longitudinal value did not change but the position of the peak moved up.
2. unfortunately, the new size of the volume gauge did not improve the diffracted signal.
3. the effect of process parameters (welding energies) is not observed on specimens with 5 layers.

References

[1] Rouquette, S.; Bendaoud, I.; Cabeza, S.; Cambon, C.; Deschaux-Beaume, F.; Hacquard, C.; Pirling, T.; Soulié, F. Strain/stress measurement of 316L Stainless Steel additively manufactured walls with Gas Metal Arc Welding process. Technical report, Institut Laue-Langevin (ILL), 2020. doi:10.5291/ILL-DATA.1-02-283.
[2] M.T. Hutchings, P.J. Withers, T.M. Holden, T. Lorentzen. Introduction to the characterization of residual stress by neutron diffraction, Taylor & Francis (2004).
[3] Rouquette, S., Cambon, C., Bendaoud, I., Cabeza, S., Soulié, F. Validation of plane stress assumption on SS316L specimen with one layer, 10th International Conference on Mechanical Stress Evaluation by Neutron and Synchrotron Radiation, Prague, November 25-27 (2021).
[4] Rouquette S., Cambon C., Bendaoud I., Soulié F. Residual stresses in SS316L specimens after deposition of melted filler wire, 11th International Conference on Residual Stresses, Nancy, March 27th - 30th (2022).