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EFFECTS OF DISTORTION ON WIRE AND ARC ADDITIVE MANUFACTURING STRAIGHT WALLS

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ABSTRACT

Wire and Arc Additive Manufacturing (WAAM) is a developing rapid prototyping and manufacturing technology which allows the production of large custom made metal parts with high deposition rates, a major concern of the aircraft industry. Despite this, there is few researches on the design method and application of WAAM technology in the aircraft industry. The overall aim of this paper is to study the machinability of the part manufactured through is process especially when a base plate is require. The results showed that removing the best plate prior or after machining can have a significant effect on the overall effective wall width of the samples.

Contribution/Originality: This study is one of very few studies which have investigated the machinability of Wire and Arc Additive Manufactured thin walls using mild steel. The study shows the effects of machining of WAAM thin walls in relation to the base plate in order to produce useable WAAM parts.

1. INTRODUCTION

Additive Manufacturing (AM) is an innovative manufacturing process generated as a consequence of developments in diverse technology sectors, especially the advantages in computer technology [1].

Wire and Arc Additive Manufacturing (WAAM) is a technology combining the arc welding techniques with wire feeding. WAAM process has been successfully applied to aero engine components [2]. With the growing demand from the aircraft industry, the application of AM has transferred from engine to airframes. Laser and powder additive manufacturing technology is constrained by its speed and size [3]. However, WAAM is an ideal process which aims to produce large aerospace components.

Research presents that WAAM can reduce the cost by 62.5% and the wastage material by 90% for complex Ti-6Al-4V parts compared with the conventional process [4]. It also shows that WAAM combined with conventional manufacturing process can decrease cost and lead time significantly [5].

Distortion of materials is one of the foremost issues associated with the welding process. Contraction during the cooling of materials after deposition causes a tensile residual stress, predominantly in the longitudinal direction [6]. Any welding process induces changes in the base material and generates unwanted stress and deformation due to heat input. These stresses remain in the material after welding deposition and result in an unwanted distortion [7]. To counterbalance some of these stresses triggered by the welding process, the structure deforms, creating distortion. Loss of dimensional control with structural integrity and an upsurge of fabrication costs owing to poor fit-up between manufacture parts are both consequences of distortion [8]. This has a huge effect when machining a deformed WAAM thin wall, especially when dealing in microns as against the welding world, which is usually in 0.1mm scale. Although thick-deposited walls also deform, it is much more crucial with thin WAAM walls because less materials could be machined away from it.

The study is aimed at reviewing the effects of distortion in machining of WAAM wall structures. Building WAAM parts requires a supporting structure; i.e. base plate, which might be removed after depositing the necessary part. This study intends to analyse the effect of removing this base plate in the form of distortion on the WAAM wall build-up. The result is intended to give an idea of distortion in the sample, which, if not accounted for, might affect the effective wall width of the sample. It also gives the best method to cut off the base plate before or after machining to be able to get a reasonable and accurate result in the subsequent wall width.

In the actual sense, effective wall width is the material that will be left after machining both surfaces of the deposited walls. It is the final product after machining and understanding the capabilities and limitations of distortion is critical to the control of deposition of materials during welding. Hence, knowledge of weld deposition distortion is critical in order to improve the wasted quality of additive layer manufactured structures.

2. MATERIAL AND METHODOLOGY

In conducting this experiment, the pre-set conditions used in conducting the experiment are shown in Table 1.
In order to obtain an insight into the effects of distortion, two sets of WAAM square samples (see Figure 1) were deposited using the integrated SAM Edgetek machine using the conditions in Table 1.

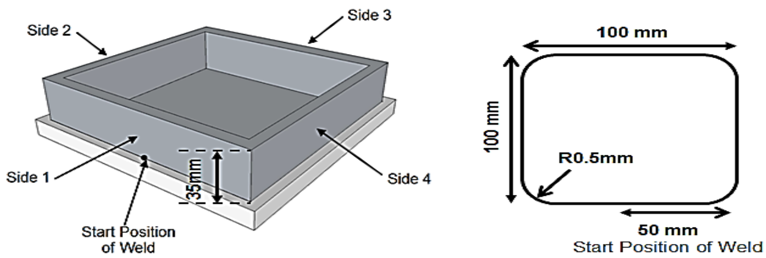

Figure-1. The Nominal WAAM CAD model and centreline tool path for the square sample

The welding parameters used in the deposition are shown below in Tables 2 and 3. In the two sets of deposited samples, the WFS was kept constant at 1.2 m/min but the TS was varied. TS was set for 0.2 m/min for the first trial and 0.4 m/min for the second trial.The variation in the TS was applied in order to manufacture samples with different widths.

A systematic experimental approach was used and this involved two stages. Stage 1 involved deposition of the sample on a base plate (120mm x 120mm x 10mm), measuring the wall perpendicularity on the CMM machine. The base plate was subsequently removed using band saw leaving the manufactured part without the base plate and the wall perpendicularity was measured again in order to analyse the effects of removing the base plate on the wall structure

Stage 2 of the experiment also involved the deposition of the square sample on the base plate, measured the perpendicularity of the deposited WAAM wall and subsequently machined the wall surfaces and measured the perpendicularity of the machined wall again. Thereafter, removing the base plate and re-measuring again using the same process as in stage 1. The measurement of the cut samples were carried out immediately after removing the base plate and repeated again after 10 days. This was carried out in order to verify whether there were still stresses in the material, which might be further relieved after removing the base plate.

Table-1. Pre-experiment conditions

Power source	Shielding gas	Flow rate ($l\,min^{-1}$)	Program mode	CTWD (mm)	WD (mm)	Effic (η)
Lincoln power wave 455/STT	Ar/CO_2 (20%)	16	Mode 40	13	1.2	0.8

Table-1. Summary WAAM deposition parameters utilised in the trial using TS of 0.2m/min

Trial no	TS (m/min)	WFS (m/min)	H (mm)	W (mm)	EWW (mm)	V (volt)	I (A)	HI (J/mm)
GEB2	0.2	1.2	34.89	4.94	3.58	18.87	73.01	330.60
GEB4	0.2	1.2	34.22	5.01	3.77	19.56	77.25	362.64
GEB5	0.2	1.2	34.72	4.96	3.56	20.01	78.02	374.68

Table-3. Summary WAAM deposition parameters utilised in the trial using TS of 0.3m/min.

Trial no	TS (m/min)	WFS (m/min)	H (mm)	W (mm)	EWW	V (volt)	I (A)	HI (J/mm)
GE3	0.4	1.2	32.51	4.15	2.67	18.23	73.52	160.83
GE9	0.4	1.2	33.21	4.14	2.57	19.22	75.94	175.15
GE10	0.4	1.2	32.28	4.15	2.32	19.56	74.25	174.28

The measurements were taken on the Coordinate Measurement Machine (CMM) as shown in Figure 2. The CMM measures the perpendicularity of the wall by using its probe to take thirty six points on each of the four walls on the outside and inside of the structure (see Figure 2 for illustrations of sides 1, 2, 3 and 4) of the sample and calculate the perpendicularity.

After the deposition of the WAAM sample, the width and the height were measured with the aid of both the CMM machine and a digital venire calliper and the results compared. The experiments were repeated five times to improve the overall accuracy of the result.

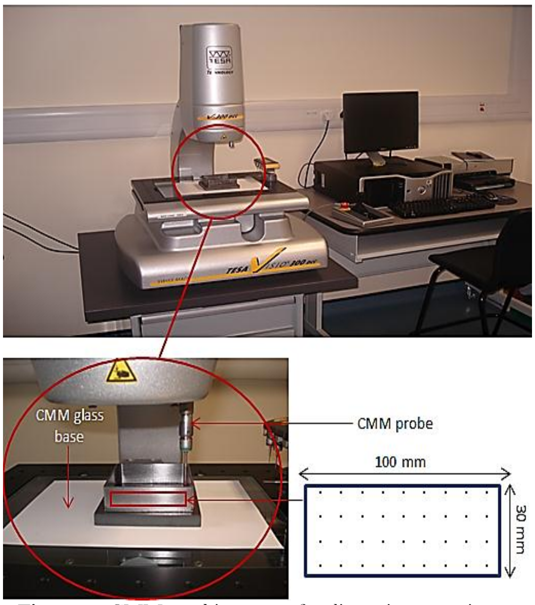

Figure-1. CMM machine setup for distortion experiment

Figure-3. Deposited sample with the base plate without machining

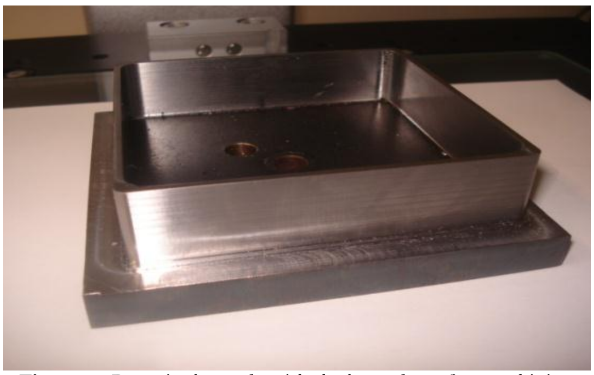

Figure-4. Deposited sample with the base plate after machining

Figure-5. Deposited machined sample without the base plate

3. RESULTS

Figure 6 shows the result of the trials when the sample was not machined nor was its base plate removed. This is the deposited sample on the base plate (see Figure 3) and this is the level of perpendicularity of the deposited wall prior to removing the base plate and prior to machining. It can be seen from Figure 6 that the deposited walls were not actually perpendicular to the base plate, but the graph shows the actual perpendicularity of each of the four walls deposited which can be compared to when the base plate is removed or the surface of the wall machined.

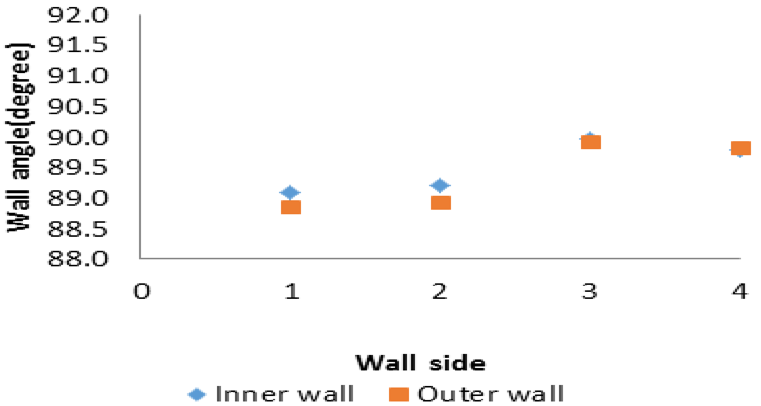

Figure-6. Position of the walls of the deposited sample with the base plate (without machining the surface of the sample).

The position of the same sample just after removing the base plate is shown in Figure 7. It is, however, noticable that there were changes in the position of the perpendicularity of the sample when compared to the condition shown in Figure 6 . These changes were noticed, but in the welding point of view, looked so insignificant. However, when considering the machinability of the sample coupled with the consideration of the effective wall, it is important to take this into consideration when building WAAM parts that require machining.

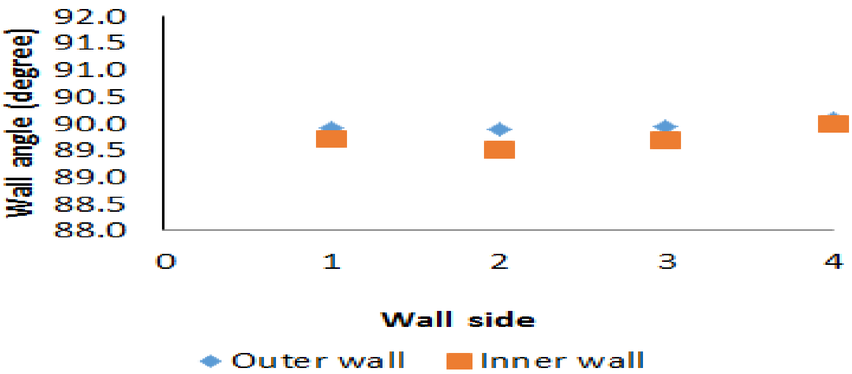

Figure-7. Position of the walls of the deposited sample after removing the base plate (without machining the surface of the sample)

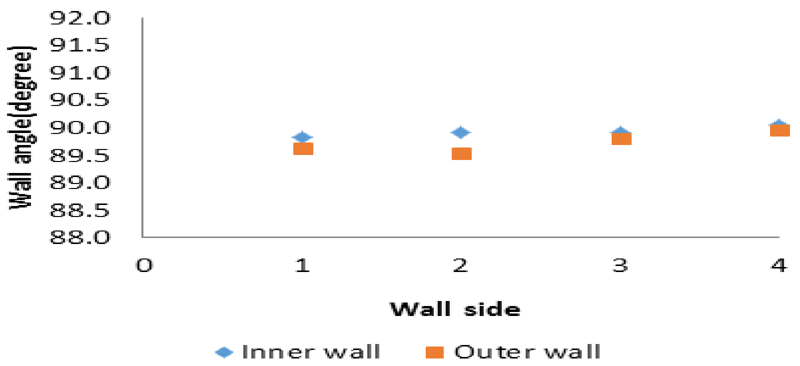

Figure-8. Position of the walls of the deposited sample after removing the base plate and left for 10 days (without machining the surface of the sample).

Figure 8 describes the position of the deposited sample when it is left for 10 days after removing the base plate. The sample did not show any significant changes from what was observed in Figure 6. Small changes were, however, noticed in wall side 3 of the sample.

Figure 9. Figure 10 and Figure 11 highlight the position of the sample when the surfaces of the sample were machined. Figure 7-29 shows the position of the sample with the base plate after machining.

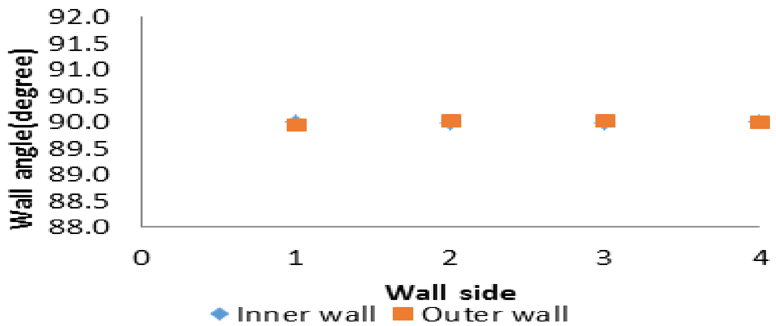

Figure-9. Position of the walls of the deposited sample before removing the base plate after machining the surface of the sample.

It can be seen from the graph that the walls of the deposited samples were straight due to the machining of both the inner and the outer surfaces. The base plate of this sample has, however, not been removed.

Moreover, the sample was left for a further 10 days and re-measured again and the result is shown in Figure 10. The result shows no indication of further movement or distortion of the wall after 10 days.

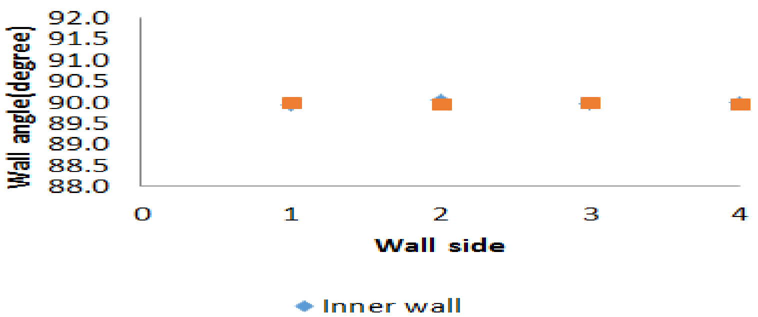

Figure-10. Position of the walls of the deposited sample before removing the base plate and re-measuring 10 days after machining the surface of the sample

There were no major differences in the position of the wall as shown earlier in Figure 9.

Figure 11 shows the position of the walls of the deposited sample after removing the base plate, after machining the surfaces. The result shows a significant change in the position of the walls. This is an indication of some stresses being relieved in the material after removing the base plate. The same sample was left for 10 days and the sample re-measured; Figure 12 shows the result, which indicates that there were no significant changes in the position of the samples.

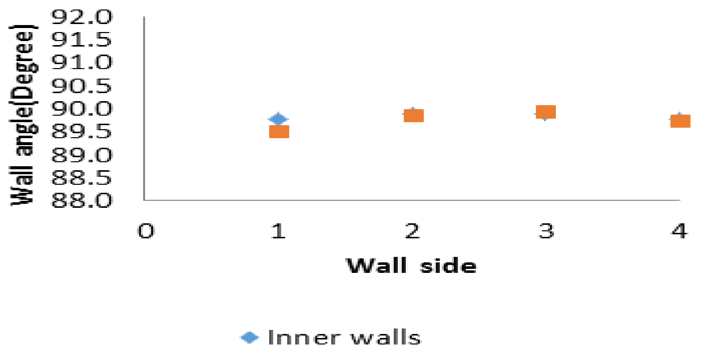

Figure-11. Position of the walls of the deposited sample after removing the base plate after machining the surface of the sample.

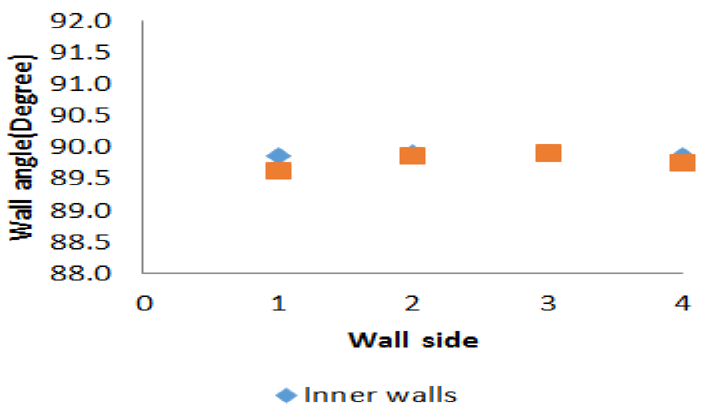

Figure-12. Position of the walls of the deposited sample after removing the base plate and re-measured 10 day after machining the surface of the sample

4. DISCUSSION

A key element to a fully successful application of WAAM is the ability to understand the impact of machining and the usage of a base plate as a support during the manufacture of a WAAM part. This section of the thesis focuses on the effects of removing the base plate on the deposited WAAM samples. This was carried out with the aim of identifying the best way to remove the base plate in order to counter the problem created by stresses induced and other dimensional inaccuracy during the process of base plate removal or machining.

The result of this study shows that the stresses on the deposited walls were relieved during the process of removing the base plate, which led to the wall being moved away from its original position. However, there was no further distortion of the wall when left for 10 days after removing the base plate.

The distortion in the wall can be attributed to some of the stresses being relieved, which is due to the non-uniform shrinkage over structural thickness that produced the angular distortion due to the welding temperature distribution, as the built in stress could not be relieved. The process of cutting the base plates could also have contributed to the redistribution of the stresses in the wall. Leggatt [9] noted that the residual stresses may have been affected by operations other than welding occurring during material manufacture, or service life. There may be no record of some of these operations, even for components with demanding quality control requirements.

The final shape of the wall accounts for useful parts; the aim of any good production process is to reduce the material wastage and improve the buy to fly ratio. The shape of the deposited thin wall affects the effective wall width and, if not properly controlled, could cause huge material wastage. Conclusively, from the result obtained in the above experimental results, it can be seen that removing the base plate shows a significant effect on the wall position and the geometrical accuracy, and once the base plate is removed, the structure remains stable. However, machining deposited structures shows no significant distortion after 10 days due to the residual stress effect and removing the base plate of the machined structure shows a significant effect on the structure.

5. CONCLUSION

- In WAAM process, removing the base plate can have a significant effect on the stresses induced into the deposited wall and this also alters the physical geometries of the wall structure, and the effects on the machining of thin walls can be desirable. It was discovered that it is always better to remove the base plate prior to machining in order to have a less desirable effect on wall straightness.
- Deposition parameters is the key to the control of the effective wall width in machining of WAAM walls in order to achieve the required EWW, as any significant deviation from the shape and profile of the deposited wall will result in an increase in the material removal and wastage, and thereby contributing unnecessary costs.
- It was discovered that the deposited WAAM wall can be in four different shapes apart from being straight and each of these shapes has a significant effect on the machinability of WAAM wall

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REFERENCES

[1] I. Gibson, D. W. Rosen, and B. Stucker, *Additive manufacturing technologies: Rapid ptototyping tp direct digital manufacturing*. New York Heidelberg Dordrecht London: Springer, 2010.

[2] S. Lott, "Additive layer manufacture expands options for airframes." Retrieved from http://www.aero-mag.com/features/41/200910/59/ [Accessed 20th Aoril, 2012], 2009.

[3] G. Byrne and E. Scholta, "Environmentally clean machining processes — a strategic approach," *CIRP Annals - Manufacturing Technology*, vol. 42, pp. 471 - 474, 1993. *View at Google Scholar* | *View at Publisher*

[4] J. Choi and Y. Chang, "Characteristics of laser aided direct metal/material deposition process for tool steel," *International Journal of Machine Tools and Manufacture*, vol. 45, pp. 597 – 607, 2005. *View at Google Scholar* | *View at Publisher*

[5] K. B. Shettigar, "Feature based model for RUAM cost modelling and comparative cost analysis," M.Sc. Thesis in School of Applied Sciences (SAS), Cranfield University, Cranfield, 2010.

[6] P. Colegrove, C. Ikeagu, A. Thistlethwaite, S. Williams, T. Nagy, W. Suder, A. Steuwer, and T. Pirling, "Welding process impact on residual stress and distortion," *Science and Technology of Welding and Joining*, vol. 14, pp. 717 – 725, 2009. *View at Google Scholar*

[7] K. Farad and H. Mehdi, "A new approach for predicting and optimising weld bead geometries in GWAN," *International Journal of Aerospace and Mechanical Engineering*, vol. 5, pp. 56 - 62, 2011.

[8] E. C. Santos, M. Shiomi, K. Osakada, and T. Laoui, "Rapid manufacturing of metal components by laser forming," *International Journal of Machine Tools and Manufacture*, vol. 46, pp. 1459 - 1468, 2006. *View at Google Scholar*

[9] R. H. Leggatt, "Residual stresses in welded structures," *International Journal of Pressure Vessels and Piping*, vol. 85, pp. 144 – 151, 2008. *View at Google Scholar*