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The influence of the cutting tool geometry on the surface quality of the parts manufactured by WAAM - Wire Arc Additive Manufacturing

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Abstract: Thin-walled components have extensive usage in the aviation, aerospace, automotive, and energy sectors. Wire Arc Additive Manufacturing (WAAM) additive technology is a technology that is used to produce thin-walled components by adding layers by layers. MIG/MAG welding technology is used in WAAM. The milling of thin-walled components often results in chatter, which causes waves on the milled surfaces. The variable helix angle reduces chatter during milling. The study found that a constant helix angle of 30°-30°-30° caused the active part of the wall to deflect towards the cutting tool, resulting in the least desirable outcomes. In contrast, cutting tools with 30°-30°-25° and 30°-30°-35° helix angles produced comparable results with minor surface waves.

1 Introduction

The main reason for studying the influence of the geometry of cutting tools on the surface quality of parts manufactured by WAAM additive technology is the milling of the surfaces made by wire arc additive manufacturing. WAAM is an alternative additive technology that combines an electric arc as a heat source and a welding wire filler material for individual welding layers to achieve the closest form of the component products [1]. For the parts layering used, MIG/MAG welding technology is combined with industrial robots or portal devices. This additive technology belongs to the ISO/ASTM standard 52 900. This process is a member of the Direct Energy Deposition (DED) category of additive manufacturing techniques. WAAM involves depositing layers of metal to create a 3D shape. Thin-walled parts are manufactured by WAAM technology [2]. Thin-walled parts are widely used in the aviation, aerospace, automotive, and energy industries. Due to its form and low rigidity, thin-walled parts can easily deform during milling [3]. Thin-walled part machining follows the WAAM technology. Milling is used to produce precise thin-walled parts. Chatter or vibration is significant during the milling of thin-walled parts. When milling tools are used for thin-walled milling, they cause conversation that creates waves on the machined surface of the part. There are several methods to remove the chatter during thin-walled milling or remove waves on the milled surfaces. The first method uses a stable lobe diagram to predict the regenerative chatter of milling [4-7]. The second method is the appropriate machining strategy (material removal method) for thin walls. Effective machining strategies significantly impact the surface quality of thin-wall parts [8,9]. The third method uses an end mill with a variable pitch [5,10-12] and a variable helix angle. The fourth method is to use sandwich elements [13,14] or to support workpieces or cutting tools support [15]. This study analysed the impact of the angle of the end mill helix on the surface quality of thin-walled AW 5083 aluminium alloy parts manufactured through WAAM technology after milling.

2 Materials and methods

2.1 Wire Arc Additive Manufacturing

Wire Arc Additive Manufacturing (WAAM) additive technology is used to manufacture thin-walled parts. The welding layers were located on the base substrate pad. The dimension of the substrate pad was 100 x 200 x 20 mm. Table 1 shows the chemical composition of the aluminium alloy 5083 for the substrate pad. Fabricate responses are shown in Table 2.

Table 1 Chemical composition of aluminium alloy 5083 [16]

Element	%
Si	0.4
Fe	0.4
Cu	0.1
Mn	0.4-1.0
Mg	4.0-4.9
Zn	0.25
Ti	0.15
Cr	0.05-0.25
Al	Balance

Table 2 Fabrication response for aluminium alloy 5083 [16]

Cold forming	Average
Machinability	Poor
Weldability – Gas	Average
Weldability – Arc	Excellent
Brazability	Poor
Solderability	Poor

Table 3 Chemical composition of wire electrode for aluminium alloy [17]

Element	%
Si	< 0.25
Fe	< 0.40
Cu	< 0.05
Mn	0.70 – 1.10
Mg	4.5 – 5.2
Cr	0.05 – 0.25
Zn	< 0.25
Be	< 0.0003
Ti	< 0.15
Zr	0.10 – 0.20
Others total	< 0.15

The wire was an aluminium alloy AW 5087. The diameter of the wire was 1.2 mm. The wire material was a special alloy AlMg4,5MnZr used to weld the aluminium alloy and the magnesium alloy. The thin-walled part was welded layer by layer using the Fronius TPS600i. The welding parameters are shown in Table 4. The MIG welding process was used to produce thin-walled parts. Three thin-walled parts were made on the substrate pad. Figure 1 shows three thin-walled parts and a sample that was used as a blank material for experimental milling. The preheating temperature of the substrate pad was 330°C, measured by a thermocouple.

Table 4 Experimental parameters of WAAM

Parameters	Value
Welding Current [A]	82
Welding Voltage [V]	20.9
A feed of wire [m/min]	5
Inert welding gas	Ar 4.6
Gas flow [l/min]	15-20
The preheating temperature of the substrate pad	300 °C

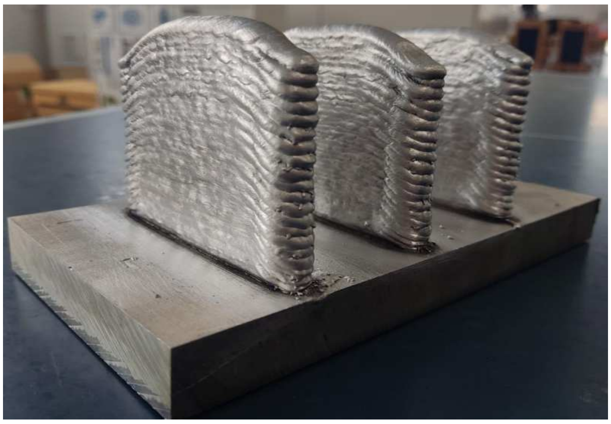

Figure 1 The sample manufactured by the WAAM technology

2.2 Design and manufacturing of cutting tools

The geometry of the milling tools significantly impacts the surface quality of thin-walled parts during milling. One of the investigated geometry parameters was the helix angle. A three-flute milling tool had a different helix angle in the third flute. The tooth pitch was 120°-120°-120°. NuMROTOPlus CAD / CAM software was used to design the milling tool with different helix angles. The helix angle was 30° - 30° - 30°, 30° - 30° - 25°, 30° - 30° - 35°. Figure 5 shows a 3D model of end mills. Table 5 shows the parameters that were used for designing milling tools. The three milling tools were manufactured by the Reinecker WZS 60. Sintered carbide CTS24Z from Ceratizit Group was used to produce end mills. The milling tools were made of cemented carbide.

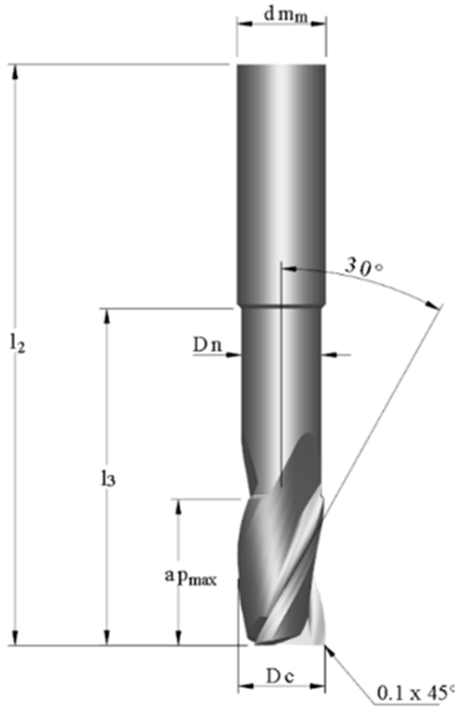

Figure 2 3D CAD model of the designed end mill

Table 5 Geometry parameters for the design of end mills

Parameter of end mill	Value
Diameter – dmm [mm]	10h6
Diameter – Dc [mm]	10
Diameter- Dn [mm]	9
Length – l2 [mm]	72
Length - l3 [mm]	25
Max. depth of cut - ap_{max} [mm]	20
Pitch and division angle [°]	120 – 120 – 120
Teeth number - z	3
Helix angle [°]	30 – 30 – 30
	30 – 30 – 25
	30 – 30 – 35
Rake angle [°]	10
Relief angle [°]	10

2.3 Milling of the thin-walled part

The milling process was performed by the DMG HSC 105 linear. Table 6 shows the experimental parameters for the milling process. Two different depths of cut were used. The axial depth cut for roughing was 10 mm, and the axial depth cut for finishing was 5 mm. The final thickness of the thin wall was 2 mm after milling. The RDOC milling strategy was used [18]. The RDOC strategy will cause the cutting forces during milling to be smaller, and thus have less influence on the thin wall of the thin-walled part being milled. The milling strategies that have been considered to reduce vibrations:

- the use of the down-milling process, which exerts less pressure on the machined wall,
- use of higher cutting speeds and, at the same time, lower radial depths of cut,
- maintaining the 8:1 rule, which defines that the maximum axial depth of the cut should not exceed eight times the thickness.

The tool path milling strategy was generated via the PowerMill CAM software.

Table 6 Experimental parameters of milling

Parameters	Value
Cutting Speed [m.min-1]	1200
Spindle Speed [min-1]	31831
Feed [mm]	0,12
Roughing depth of cutting [mm]	10
Finishing depth of cutting [mm]	5
With of cut [mm]	3,2; 2,5; 1,5

The milling process was carried out without a cooling medium. On some levels of cutting (depth of cutting), the milling of a thin wall was accompanied by an unpleasant sound caused by the wall's insufficient rigidity during the cutting process. Three thin walls were milled from both sides. Figure 3 shows the milled surface of the thin-walled part by the end mill with helix angle 30°-30°-25°.

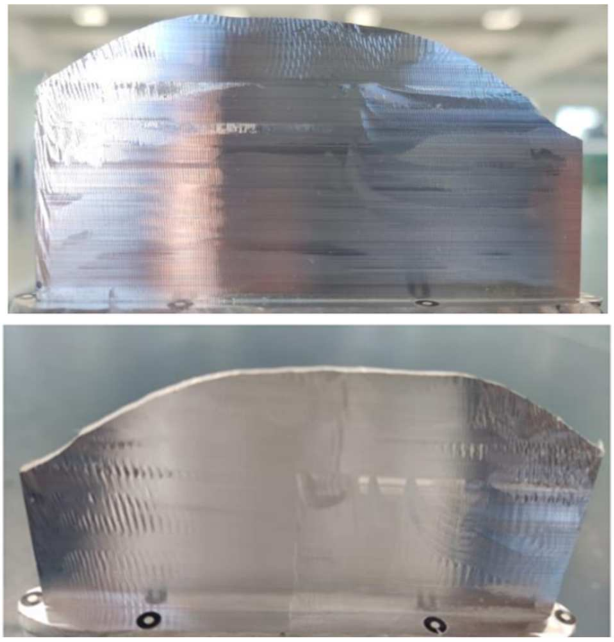

Figure 3 Thin-walled part after milling by end mill with helix angle 25°

Figure 4 shows the milled surface of the thin-walled part by end mill with helix angle 30°-30°-30°. Figure 5 shows the milled surface of the thin-walled part by end mill with helix angle 30°-30°-35°.

Figure 4 Thin-walled part after milling by end mill with helix angle 30°

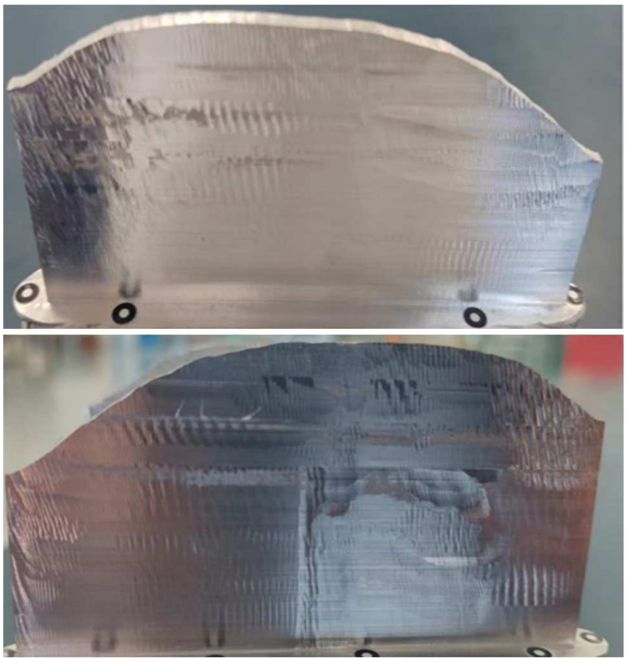

Figure 5 Thin-walled part after milling by end mill with helix angle 35°

2.4 Measurement of the quality of thin-walled parts

Quality measurement was carried out with the GOM ATOS II Triple Scan. The MV 320 measuring volume was used to scan the aluminium parts (Figure 6). The chalk spray was applied to avoid the shiny surface.

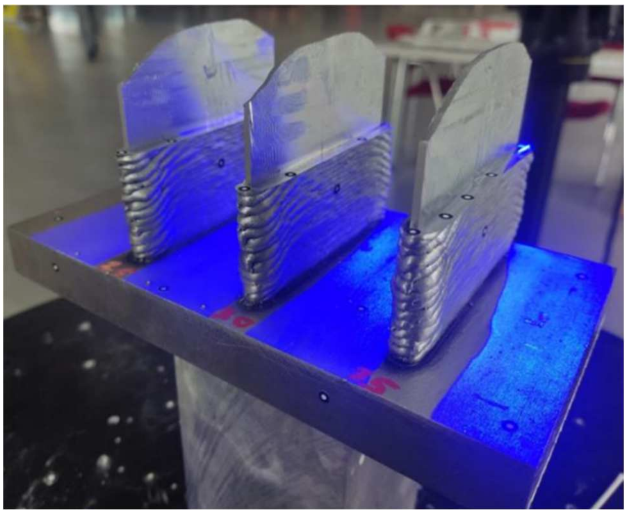

Figure 6 Optical 3D scanning of a thin-walled part after milling

3 Results and discussion

The quality evaluation of milled surfaces of thin-walled parts was realised by the CAQ software GOM Inspect 2001. Colour deviation maps are suitable for quality evaluation because we get a view of deviation information for all surfaces. The tolerance of the colour deviation maps was from +0,5 to -0,5 mm. Figure 7 shows the colour deviation maps of a thin-walled part that was milled by the end mill with a helix angle of 30°-30°-25°. The milled surface was without visible waves, as shown in Figure 3.

This helix angle combination reduces thin-walled parts vibration compared to other cases presented in this paper. The tool with a helix angle of 30°-30°-25° and 30°-30°-35° produces surfaces where a colour map of deviations includes a red and a strong blue colour. However, the waves on the surface are milder than those produced by the 30° cutting tool 30°-30°-30°. Figure 8 shows the colour deviation maps of a thin-walled part that was milled by the end mill with a helix angle of 30°-30°-30°. Figure 9 shows the colour deviation maps of a thin-walled part that was milled by the end mill with a helix angle of 30°-30°-35°.

By comparing the colour maps of the deviations, it was found that the use of a tool with an unconventional geometry positively affected the dimensional accuracy of the manufactured part.

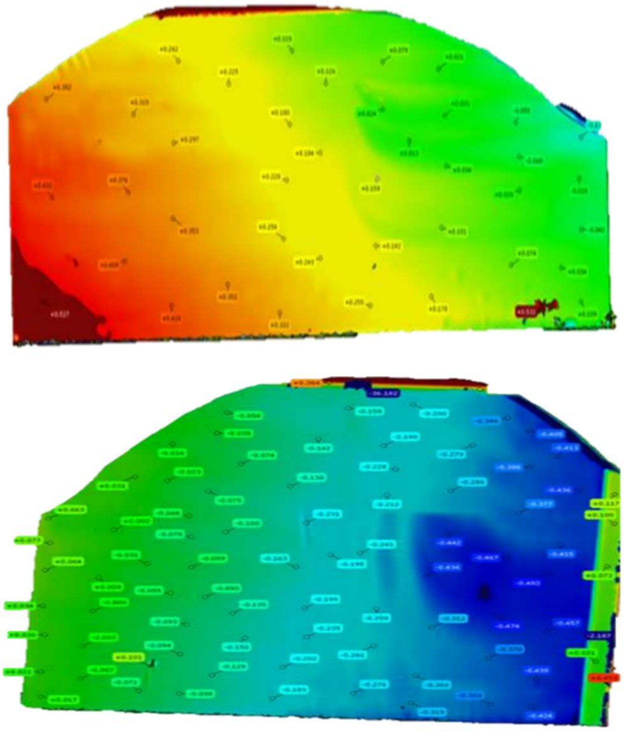

Figure 7 Colour deviation maps of thin-walled parts after milling – helix angle 30°-30°-25°

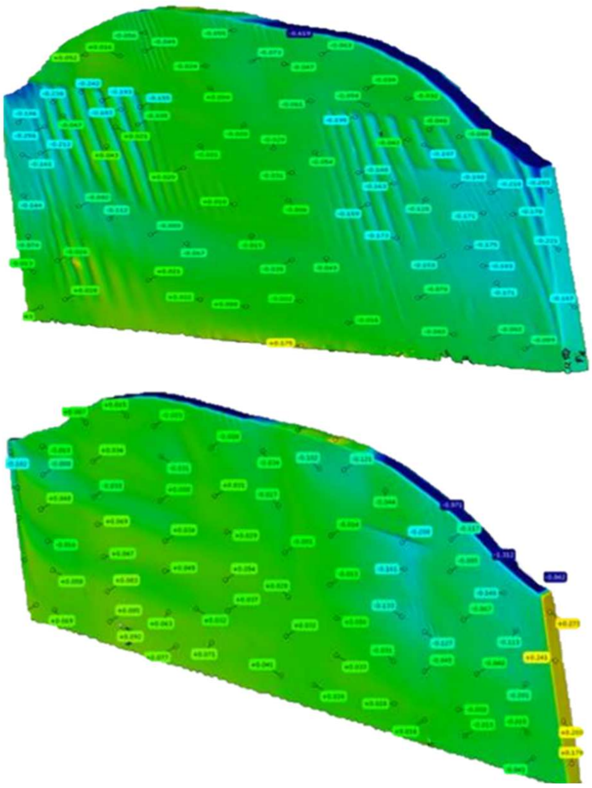

Figure 8 Colour deviation maps of thin-walled parts after milling – helix angle 30°-30°-30°

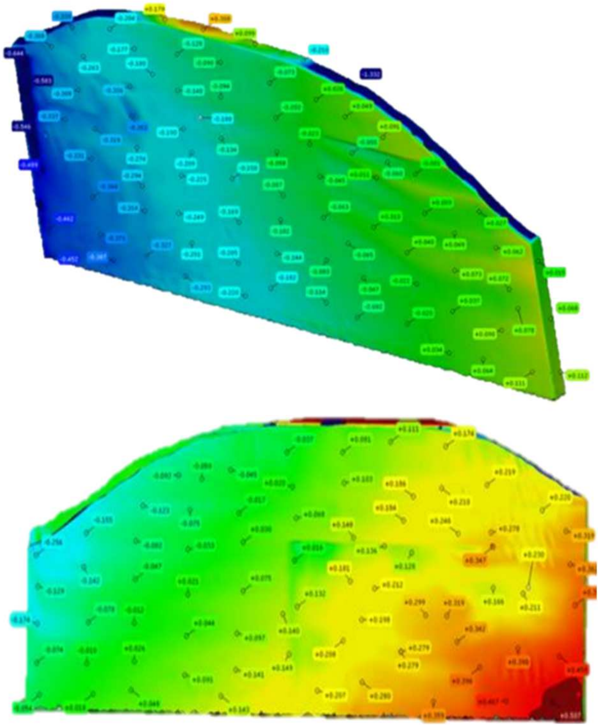

Figure 9 Colour deviation maps of thin-walled parts after milling – helix angle 30°-30°-35°

4 Conclusion

The study's outcome involves the assessment of colour deviation maps, revealing that employing a varying helix angle on the third tooth of the cutter yields favourable outcomes when machining thin-walled components. However, the wall's insufficient rigidity, coupled with frequent natural vibrations, leads to wavering and eventual bending due to its lack of strength. The observations above highlight that the least desirable results were obtained using the approach featuring a constant helix angle of 30°, causing the wall to deflect towards its active part of the cutting tool. In contrast, cutting tools with 25 ° and 35 ° helix angles yielded comparable results.

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Review process

Single-blind peer review process.