Surface Waviness Of Weld Bead (Layer) Of Gtaw Based Wire Arc Additive Manufacturing Process

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ABSTRAK

Manufaktur aditif menjadi fokus industri dan penelitian karena banyaknya perkembangan baru dalam proses dan sistem. Hal ini semakin diperkuat oleh tren umum menuju efisiensi sumber daya, karena proses manufaktur aditif menawarkan kemungkinan produksi bentuk mendekati bentuk ukuran sesuai kebutuhan. Produk manufaktur aditif bisa mengalami ketidaksempurnaan permukaan yang dinilai dalam penelitian ini adalah profil morfologi atau kelengkungan permukaan (surface waviness) lapisan manik las (bead). Umumnya, kelengkungan permukaan dapat disebut sebagai "punuk (hump)" yang disebabkan dalam proses pengelasan. Untuk mencapai target capaian produk dengan kondisi permukaan yang relatif memiliki surface waviness yang minimal dilakukan eksperimen dan analisis proses manufaktur aditif dengan pengelasan GTAW pada material substrat AA 6061 dengan filler ER 5356. Eksperimen dilakukan dengan terlebih dahulu menentukan parameter proses dan faktor yang berpengaruh terhadap kualitas hasil lapisan manik las atau layer. Layer yang bertumpuk secara berlapis akan diukur geometri lebar dan tinggi nya, dilakukan uji kelengkungan permukaan (surface waviness) dan dianalisis. Laju pengendapan atau deposit filler, travel speed, dan kecepatan umpan filler menentukan tingkat kelengkungan permukaan (surface waviness). Pada penelitian ini kelengkungan permukaan yang tinggi terjadi pada wire feeder speed (WFS) 25 mm/s dengan travel speed (TS) sebesar 80 mm/min.

Kata kunci: Geometri Manik; Kelengkungan Permukaan; WAAM-GTAW

ABSTRACT

Additive manufacturing has become a focus of industry and research due to the many new developments in processes and systems. This is further strengthened by the trend of resource efficiency, as manufacturing processes towards additive manufacturing offer the possibility of producing close to the required size shape. Additive manufactured products can experience surface imperfections assessed in this study, namely the morphology profile or surface curvature (surface waviness) of the weld bead layer. Generally, surface curvature can be referred to as a "hump" caused by the welding process. To achieve the target of achieving products with relatively minimal surface waviness, experiments and analysis of the manufacturing process using GTAW additive welding on AA 6061 substrate material with ER 5356 filler were conducted. The experiments were carried out by first determining the process parameters and factors that affect the quality of the weld bead layer. The layers stacked in layers were measured for their width and height geometry, surface waviness tests were conducted, and analysis was carried out. The deposition rate or filler deposit, travel speed, and filler feed speed determine the level of surface waviness. In this study, high surface curvature occurred at a wire feeder speed (WFS) of 25 mm/s with a travel speed (TS) of 80 mm/min.

Keywords: *Bead Geometry; WAAM-GTAW; Surface Waviness*

INTRODUCTION

Additive manufacturing is currently a focus of industry and research due to the numerous new developments in processes and systems. This is further reinforced by the general trend toward resource efficiency, as additive manufacturing (AM) processes offer the possibility of producing near-network shapes or shapes to specific dimensions. The primary factors influencing the choice of an additive manufacturing process are the achievable complexity and resolution, as well as the filler deposition rate and component size [1]. Specific application requirements must be considered when selecting an additive manufacturing technology. When selecting the best additive manufacturing (AM) technology, it is important to consider elements such as material characteristics, component size, tolerances, and post-processing requirements. WAAM is particularly suitable when speed, scalability, cost-effectiveness, and a wide range of content options are important considerations [2]. Furthermore, additive manufacturing provides more degrees of freedom for product design than conventional manufacturing processes and opens up the possibility of load-optimized designs [1][3].

Unlike other additive manufacturing processes, WAAM is highly sensitive to small variations in key process parameters, including travel speed, wire feeder speed, current, inter-pass temperature, and the condition of the previous layer. Even small changes in any of these factors can significantly impact the surface finish or wall geometry of the subsequent weld [4], which can result in surface degradation. The surface imperfection assessed in this study is the morphological profile or surface waviness of the weld bead. Generally, surface waviness can be referred to as a "hump" caused during the welding process. This is usually caused by fluid flow within the molten weld pool due to variations in the surface tension of the molten metal [5]. Common issues with WAAM surface quality stem from process stability, including factors such as path planning, parameter configuration, molten pool shielding, and the specific chemical properties of the alloy. The main challenges associated with WAAM with aluminum alloy feedstock are the formation of porosity, residual stress, and cracking [6].

Despite these advances, the integration of AM into production lines remains hampered by persistent challenges, particularly the surface quality of as-built components. Compared with conventionally manufactured components, AM surfaces often exhibit roughness, warpage, and geometric deviations due to complex thermofluid phenomena during the deposition process. These irregularities not only degrade the component's mechanical performance by reducing fatigue resistance, wear behavior, and dimensional tolerances, but also require extensive post-processing to meet industry standards [7].

Surface waviness is inherent to this process. However, high surface waviness in WAAM-manufactured components can affect the structural integrity and surface finish of the final component. This leads to increased post-processing requirements, which can compromise the potential benefits of WAAM in terms of lower cost and material savings.

Sequeira Almeida (2012) first focused on the issue of surface waviness. Surface waviness is defined quantitatively as the ratio of peaks to valleys [8]. This waviness arises from the geometry of the weld bead and the overlap between them. This can negatively impact the fusion quality of subsequent layers, resulting in deviations from the desired final product height and ultimately reducing its overall quality. This study aims to investigate the influence of process parameters on the surface curvature of components manufactured using WAAM.

Further reduction, or even elimination of surface curvature to create a smooth surface, is quite difficult; therefore, uncovering the formation of surface curvature and reducing its value is of great significance [8].

RESEARCH METHODS

In this study, the supporting material as a substrate is AA6061 with dimensions of 125 mm x 55 mm x 6 mm, and ER-5356 welding wire (A lMg5 Cr) is used as a substrate and filler metal or feedstock with a diameter of 1.2 mm. High purity argon (99.9%) is used as a shielding gas with a flow rate of 11 L/min. The GTAW-based WAAM process parameters used can be seen in Table 1.

Table 1. WAAM-GTAW Process parameters

Parameter	Value
Type of welding current	AC
Alternating current frequency	50 Hz
Wire feed speed	23, 24, 25 mm/s
TS (Tavel Speed)	80, 85, and 90 mm/min
Argon	99,9 % purity
Shield gas flow rate	11 L/min
Current intensity	120A
Tungsten electrode diameter	2.4 mm

AWS pure tungsten electrode EWP class (green tip) with a diameter of 2.4 mm at the tip is

made into a ball shape with standard AC polarity. The experiment was carried out with a WAAM machine based on TIG (Tungsten Inert Gas) welding, the experiment was carried out with a 3-axis automatic welding machine with a CNC-based control system, the program control system for the movement process uses MACH3 software with motion settings via the x, y and z axes in the CNC machine programming language, namely G-code. In this study, the GTAW welding machine used is a MultiPro TIG 315 JIY welding machine assisted by a 3-axis CNC machine. While the welding wire feed (filler) setting uses a control system with Arduino-Uno with intermittent feeding [9].

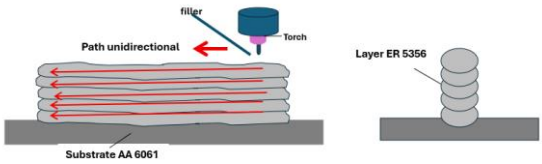


Figure 1. Schematic of the deposition path direction (unidirectional path) of ER 5356 filler

The movement of the CNC router machine is controlled by MACH3 software by entering the G-Code program or creating coding where the numbers correspond to the process parameters to be used such as travel speed, zero coordinates, the expected start and end of each axis. Figure 2. Shows the stages of the additive manufacturing process with the WAAM method based on GTAW.



Figure 2. Stages of the additive manufacturing process using the GTAW-based WAAM method.

Waviness is a critical quality metric that plays a crucial role in determining process and post-process requirements for fabricated components. This gap is significant because waviness is not only a surface feature but also a functional defect that affects fatigue resistance, dimensional accuracy, and interlayer bonding.

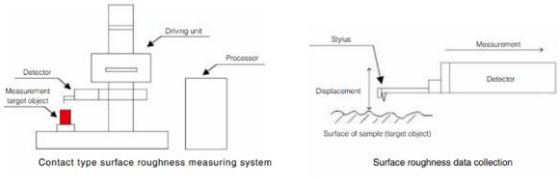


Figure 3. Contact type instrument used to measure surface waviness [10].

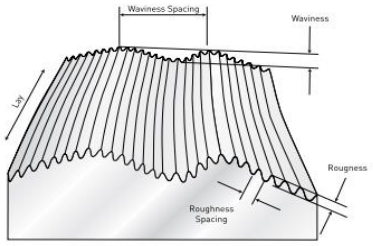


Figure 4. Roughness and waviness, components of Surface Texture [11]

Measurement of surface waviness on the WAAM-GTAW layer (weld bead) using the SURFCOM 2900SD3 measuring tool as shown in Figure 5.



Figure 5. Measuring tool and process for measuring surface waviness of the weld bead layer

RESULTS AND DISCUSSION

The weld bead layers formed in layers or layer by layer from the WAAM-GTAW process will have geometry and dimensions that are influenced by the process parameters. Next, the geometric dimensions of the width and height of the weld bead were measured using a Dino-Lite measuring tool, and the surface waviness was also measured. Measurement data were obtained from 9 (nine) specimens with varying wire feeder speed and travel speed process factors or variables shown in Figure 6.

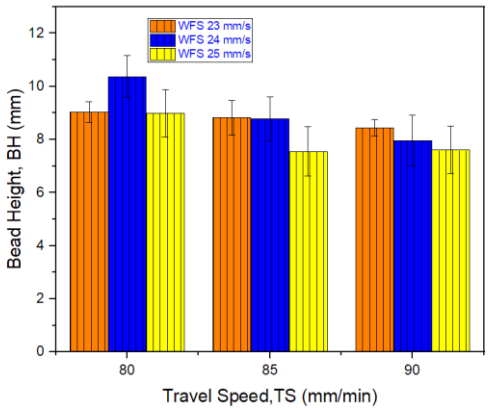


Figure 6. Geometric correlation of weld bead height (BH), travel speed, and wire feeder speed.

Figure 6. The tendency of the weld bead height to decrease with increasing welding wire feed speed and travel speed. The behavior of the bead height tends to increase with increasing welding wire feed speed, which also increases inversely [12]. The layer height (weld bead) and layer uniformity directly affect the curvature of the final surface.

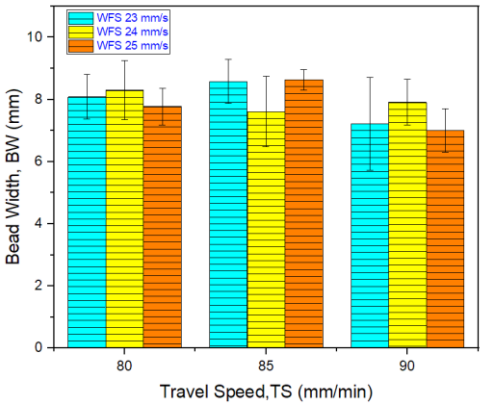


Figure 7. Geometric correlation of weld bead height (BH), travel speed, and wire feeder speed.

With a large wire feeder speed, it forms an optimum layer width (weld bead) at a large travel speed as shown in Figure 7. Measurement of surface curvature is carried out on the area or surface area of the upper plane in the longitudinal direction as shown in Figure 8.

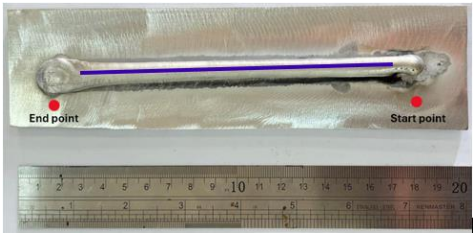


Figure 8. Measurement of surface waviness of the weld bead (layer) along the blue line.

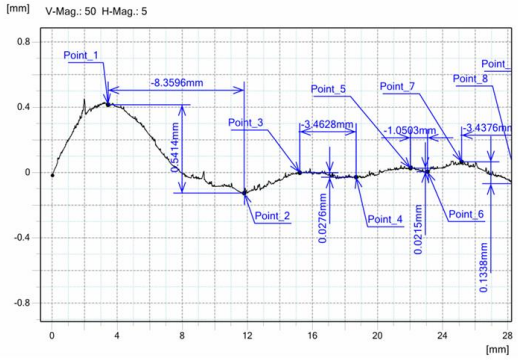


Figure 9. Measurement points of the peak and valley sections of the layer profile (weld bead).

From the surface waviness measurement data, the wire feeder speed shows a clear positive correlation with the curvature.

Table 2. Data from surface waviness measurements of the weld bead layer (layer) of the WAAM-GTAW process

PARAMETER		WAVINESS (mm)						MEAN	ST.DEV
WFS	Travel Spe	1	2	3	4	5	6		
23	80	0,0763	0,31	0,0281	0,3569	0,0807	0,0435	0,1704	0,1512
	85	0,0459	0,0485	0,0015	0,1271	0,157	0,0049	0,0642	0,0642
	90	0,0018	0,1005	0,4619	0,0431	0,0217	0,0939	0,1205	0,1718
24	80	0,0455	0,058	0,033	0,0346	0,1841	0,229	0,0974	0,0862
	85	0,2186	0,0336	0,426	0,1629	0,234	0,345	0,2103	0,1634
	90	0,7988	0,0856	0,1987	0,3276	0,0698	0,0394	0,2533	0,2876
25	80	0,1167	0,1274	0,1598	0,239	0,04	0,9817	0,2774	0,3510
	85	0,5414	0,0276	0,0215	0,1338	0,116	0,236	0,1794	0,1941
	90	0,2065	0,0079	0,1804	0,2697	0,1919	0,1056	0,1603	0,0913

Higher feed rates increase the amount of material supplied per unit time, which can result in local over-accumulation and irregular bead buildup, thus amplifying surface undulations [13].

CONCLUSION

The surface waviness of the weld bead layer from the GTAW-based WAAM process with ER 5356 welding wire originates from the dimensions and geometry of the layer (weld bead) formed. Synchronization of the filler deposition rate, travel speed, and filler feed speed determines the level of surface waviness. In this study, high surface waviness occurred at a wire feeder speed (WFS) of 25 mm/s with a travel speed (TS) of 80 mm/min. The greater the wire feeder speed and the smaller the travel speed, the greater the surface waviness formed. Various parameters significantly affect surface waviness during the WAAM-GTAW process. Specifically, the wire feeder speed has been identified as the most influential factor.

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