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Improving Surface Smoothness of Aluminium Alloys Multi-Bead Weld for Welding Rapid Forming Application

Abdullah Wagiman[1,a], Md Saidin Wahab[1,b], Mohd Amri Lajis[1,c] and Azuddin Mamat[2,d]

[1]Advanced Manufacturing and Material Centre (AMMC), Universiti Tun Hussein Onn Malaysia, Johor, Malaysia

[2]Faculty of Engineering, Universiti Malaya, Malaysia

[a]abdulla@uthm.edu.my, [b]saidin@uthm.edu.my, [c]amri@uthm.edu.my, [d]azuddin@um.edu.my

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Abstract. Understanding the interference of multi-bead parameters on surface smoothness is essential for accuracy of the formed parts made by welding rapid forming. This paper presents an investigation on surface smoothness of multi-bead aluminium alloys. Deposition path planning and overlap ratio is manipulated in order to improve surface smoothness. Observation on bead cross section indicates that deposition path planning has remarkable effect on the surface smoothness. Multi-bead that developed using continuous path planning produced surface smoothness of 0.46 mm – 1.34 mm and most bead present wavy type surfaces. The surface smoothness is improved by increasing the overlap ratio. Meanwhile, skip path planning produced good surface smoothness of 0.11 mm – 0.28 mm. An improved surface smoothness featuring flat surface type is obtained with this path planning.

Introduction

In recent years, many researchers produce a functional component of metallic part using welding rapid forming. This is due to various reasons such as higher deposition rate, lower cost and simple equipment. Many types of arc welding have been investigated such as gas tungsten arc welding (GTAW) [1], gas metal arc welding (GMAW) [2] and submerged arc welding (SAW) [3]. The process is able to rapidly forming functional part, but the drawback is that the process involves excessive spatter and distortion. Another researcher reports the usage of laser [4] and electron beam [5] in welding rapid forming of the functional part. The process is capable to produce part without spatter and distortion due to process stability and focused heating of high heat density beam. However, both processes incur high initial cost if compared with arc welding.

Currently, welding machine has a controllable feature of droplet size, which is necessary for the product accuracy. This includes a new modified Gas Metal Arc Welding (GMAW), identified as Cold Metal Transfer - Gas Metal Arc Welding (CMT - GMAW) which offers low initial cost, controllable spatter and low heat input. The system integrates the wire motions with the metal transfer condition via a digital process control. This integration enables the system detecting the short circuit. Every time the short circuit occurs, the system will mechanically control the wire retraction to help detach the molten droplet. These features provide arc stability during metal deposition and eliminate spatter during welding which is suitable for application of welding rapid forming.

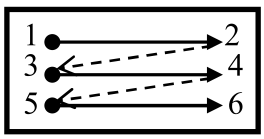
During the rapid forming process, the surface smoothness of multi pass bead has great influence on the dimensional accuracy of the produced parts. For example, the surface smoothness of the preceding layer of the multi pass bead that featuring wave surface will affect the dimensional accuracy of subsequent layer and onward. Further discussion on the effect of surface smoothness on dimensional accuracy can be found in [2]. In order to eliminate the effect of surface smoothness, Song [6], [7] introduced additive and subtractive technique. The technique, alternating the welding and milling process has improved the dimensional accuracy. However, it will affect the processing time of welding rapid forming. Also, the production cost increase due to short service tool life as the milling process is entirely carried out at high temperature. Meanwhile, Zhu [8] propose orthogonal and stack path planning with appropriate overlap ratio. Although the surface smoothness is improved, the part produce by both methods still needs finishing process to remove the undesirable wave surface.

Using fine metal droplet size is another method to produce a good surface finish as introduced by Cao [9]. However, this method leads to time consuming, especially when producing larger parts. Another method to obtain high dimensional accuracy of the part produce by welding rapid forming is by producing flat surface multi pass bead. Therefore, this research work aim to produce multi-bead featuring flat surface profiles by manipulating overlap ratio and deposition path planning. The flat surface profile is determined from the surface smoothness and multi pass bead cross section.

Experimental Equipment and Procedure

In this work, the multi-bead is developed using CMT-GMAW welding source with an expert system made by EWM GmbH. 1 mm in diameter AlSi5 is used as filler wire. While, argon gas at a flow rate of 15 L/min is used as the shielding gas. The weld torch is fixed to the 3 axis NC table to provide a constant welding speed and arc length during the deposition process. The welding torch angle was set at 60^0 from horizontal. Al 6061-T6 is used as a substrate. Prior to the experiment, the surface of the samples is wire brushed and cleaned with ethanol to eliminate aluminium oxide on the surface. The weld bead is produced using constant heat input. Welding speed, current and voltage are fixed at 50 mm/s, 30A and 10 Volt respectively. This parameter is selected based on previous work [10]. The multi pass weld bead is developed using different deposition path planning and overlapping percentage. In this work, overlapping percentage is defined as the ratio of bead width subtracted from bead offset to bead width. Table 1 shows the selected overlapping percentage and deposition path planning investigated in this work.

Table 1: Welding parameters

<table>
<tr><th>Specimen number</th><th>Overlapping percentage (%)</th><th>Deposition path planning</th><th>Schematic diagram of the deposition path planning</th></tr>
<tr><td>1</td><td>50</td><td rowspan="6">Continuous</td><td rowspan="6">
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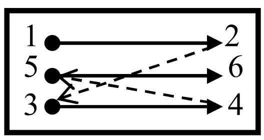
<tr><td>5</td><td>70</td></tr>
<tr><td>6</td><td>75</td></tr>
<tr><td>7</td><td>50</td><td rowspan="6">Skip</td><td rowspan="6">
</td></tr>
<tr><td>8</td><td>55</td></tr>
<tr><td>9</td><td>60</td></tr>
<tr><td>10</td><td>65</td></tr>
<tr><td>11</td><td>70</td></tr>
<tr><td>12</td><td>75</td></tr>
</table>

A multi-bead of three overlap beads developed on the substrate were first inspected by liquid dye penetrant to obtain non-crack bead. The multi-bead were cut in cross-section into a small specimen using a diamond cutoff wheel. The specimen, then mounted in epoxy for bead geometry profile measurement. The surface smoothness of multi-bead is measured using a profile projector. In this work, the surface smoothness (t) is defined as a distance between highest points of weld bead (wave crest) to the lowest point of the bead (wave trough) as depicted in Fig. 1.

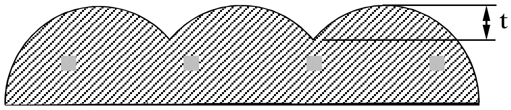


Fig. 1: Schematic diagram of surface smoothness value

Result and Discussion

The welding parameter selected in this work produced single pass weld bead reinforcement and width of 1.73 mm and 5.5 mm respectively as shown in Fig. 1. The single bead has a ratio of width to weld bead reinforcement of 3.2 and longitudinal surface roughness value of 50µm. Also, bead presents half-ellipse shape, flat surface on the top of the bead and free spatter defect.

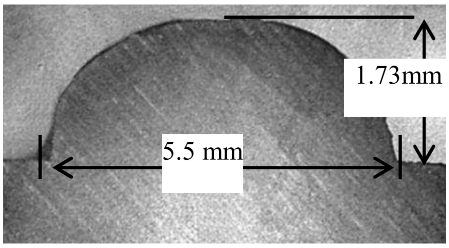
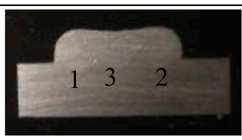
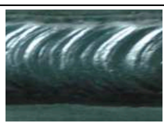


Fig. 2: Cross section of single weld bead

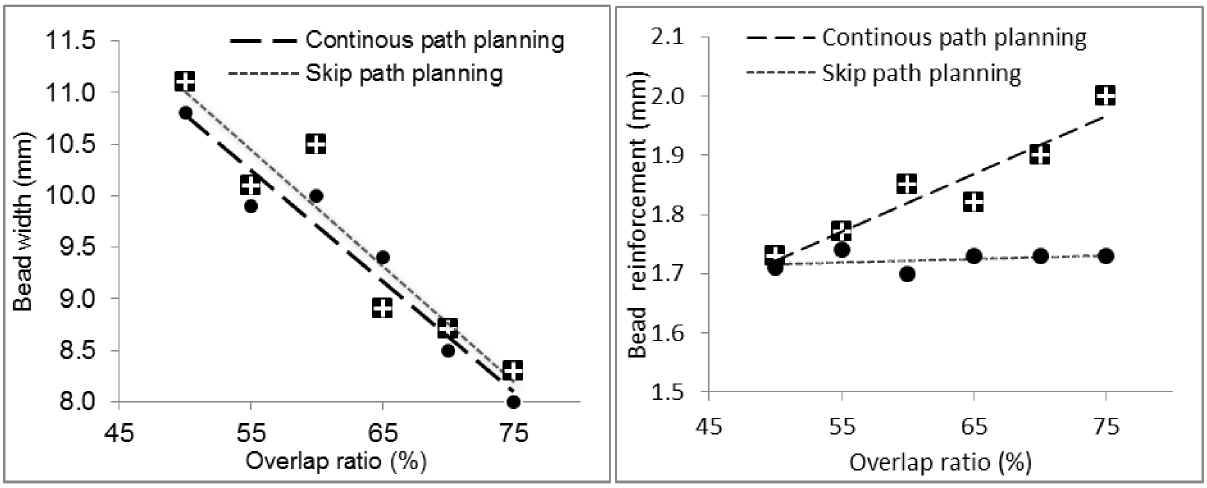
The multi-bead is developed using the process parameter which corresponds to the single pass weld bead reinforcement of 1.73 mm. Table 2 shows a selected cross section of the multi pass bead obtained from different deposition path planning and overlap ratio. In general, four types of surface profile can be observed which are wavy, convex and wavy, concave and flat.

Table 2: Cross section of the multi pass bead

No.	Top	Cross section	Type of surface	Surface smoothness value, t (mm)
1			Wavy	1.34
6			Convex and wavy	0.46
7			Concave	0.28
12			Flat	0.11

A multi-bead that developed using continuous path planning has obvious surface smoothness value if compared to skips path planning. A multi-bead that produced by 50% and 70% overlap ratio in continuous path planning has surface smoothness value of 1.34 mm and 0.46 mm respectively. According to Surayakumar [11], the metal droplets of subsequent bead are flowing and fills automatically the bead valley during the overlapping of adjacent beads. In continuous path planning, a cross section of deposited metal can be divided into two sides which are redeposited side and advancing side. Excessive metal deposition always happens in redeposited side, while shortage metal deposition on advancing side. This different establish a wavy surface profile. The wavy surface is more pronounce on the multi pass bead that treated with smaller overlap ratio due to larger unsymmetrical differences. Multi-bead that observed obvious wavy surface has larger surface smoothness value, thus deteriorated the accuracy of the product. The surface smoothness can be improved by using higher overlap ratio. However, in this case, increasing the overlap ratio to 75 % resulted in convex with wavy surface profile due to excessive metal deposition.

Using skip path planning and overlap ratio of 50% produced multi pass bead with concave surface profile due to insufficient metal deposition to fill the gap between the first pass and second pass. The flat surface profile is obtained when the overlap ratio is 75%. Increasing the overlap ratio to 75% provide enough metal deposition for filling the gap between the valley of the first pass and second pass. This flat surface has surface smoothness value of 0.11 mm which provides a better surface finish and accuracy. Flat surface is obtained in skip path planning due to metal redeposited is taking place in symmetrical.



(a) (b)

Fig.2: Effect of overlap ratio on (a) bead width (b) bead reinforcement

Fig. 2 shows the effect of the overlap ratio on multi-bead width and reinforcement. For both path planning, the overlap ratio is remarkable affected the multi-bead width. A reduction in the overlap ratio will decrease the surface area of the deposited metal, thus reducing the weld bead width (Fig. 2(a)). [2], [8] and [11] also report the same pattern. Contrarily, continuous path planning and skip has affected differently on the bead reinforcement. The reinforcement of multi-bead developed in the continuous path planning resulted in gradual increase when the overlap ratio is increased. In this plan, the metal is deposited on unsymmetrical volume. The area consists of redeposited side and advancing side. Excessive metal deposition occurs on the redoposited side while moderate on advancing side. The excess volume tends to flow upward and thus form the convex bead shape.

Multi-bead developed in skip path planning resulted in constant bead reinforcement, although the overlap ratio increased as shown in Fig 2 (b). The reason is that the skip path planning provides symmetrical volume due to both sides is redeposited side. This symmetrical volume helps to eliminate excessive metal deposition on the redeposited side which in turn producing good surface smoothness. Therefore, it can be expected that multi pass bead developed using skip path planning will result in concave, convex or flat surface without featuring wavy surface profiles. The formation of this surface profile improved the surface smoothness, thus provide better surface finish and product accuracy.

Conclusion

The research result indicated that deposition path planning has remarkable effect on the type of surface. This effect is due to symmetrical and unsymmetrical volume of the deposited metal. Two path planning that investigated in this research work produced different types of surface. Multipass bead developed in continuous path planning results poorer surface smoothness. Although, increasing the overlap ratio improve the surface smoothness, but most of the bead still featuring wavy surface type. A flat surface type of multi-bead is obtained when the metal droplet is deposited using skip path planning. However, this planning mode resulted concave surface if treated at a higher overlap ratio due to shortage of deposited metal. Also, lowering the overlap ratio could result convex surface type due to excessive deposited metal. The result indicates multi bead featuring flat surface type have better surface smoothness then others surface type

References

[1] H. Wang, W. Jiang, J. Ouyang, and R. Kovacevic, Rapid prototyping of 4043 Al-alloy parts by VP-GTAW, J. Mater. Process. Technol., 148 (2004) 93–102.

[2] Y. Cao, S. Zhu, X. Liang, and W. Wang, Overlapping model of beads and curve fitting of bead section for rapid manufacturing by robotic MAG welding process, Robot. Comput. Integr. Manuf., 27 (2011) 641–645.

[3] K. Kassmaul, F.W. Schoch, H. Lucknow, High quality large components '"shape welded"' by a SAW process, Weld. J., 62 (1983).

[4] J.-H. Lee, J.-H. Jang, B.-D. Joo, H.-S. Yim, and Y.-H. Moon, Application of direct laser metal tooling for AISI H13 tool steel, Trans. Nonferrous Met. Soc. China, 19 (2009) 284–287.

[5] P. Wanjara, M. Brochu, and M. Jahazi, Electron beam freeforming of stainless steel using solid wire feed, Mater. Des., 28 (2007) 2278–2286.

[6] Y. Song, S. Park, D. Choi, and H. Jee, 3D welding and milling : Part I – a direct approach for freeform fabrication of metallic prototypes, 45 (2005) 1057–1062.

[7] Y. Song, S. Park, and S. Chae, 3D welding and milling : part II — optimization of the 3D welding process using an experimental design approach, 45 (2005) 1063–1069.

[8] S. Zhu, C. Li, C. Shen, and Y. Liang, Surface smoothness of welding rapid forming parts, ICRM2010-Green Manuf., (2010).

[9] W. Cao and Y. Miyamoto, Freeform fabrication of aluminum parts by direct deposition of molten aluminum, J. Mater. Process. Technol., 173 (2006) 209–212.

[10] A. Wagiman, M. S. Bin Wahab, Z. Mohid, and A. Mamat, Effect of GMAW-CMT Heat Input on Weld Bead Profile Geometry for Freeform Fabrication of Aluminium Parts, Appl. Mech. Mater., 465–466 (2013) 1370–1374.

[11] S. Suryakumar, K. P. Karunakaran, A. Bernard, U. Chandrasekhar, and N. Raghavender, Weld bead modeling and process optimization in Hybrid Layered Manufacturing, *Comput. Des.*, 43 (2011) 331–344