

A Novel Welding-Based Solid Freeform Fabrication Technology for Aluminum Alloy

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Today, several new technologies address the rapid creation of models, prototypes, patterns, and limited-run manufacturing. These technologies are capable of producing complex freeform solid objects directly from a computer model of an object without part-specific tooling or knowledge. They are additive processes and have been termed rapid prototyping (RP), desktop manufacturing, and solid freeform fabrication [1]. RP is a promising manufacturing technology that significantly reduces lead times of products from concept to production. One challenge for RP is to develop the capability to directly create functional metallic parts that are dense, metallurgically bonded, geometrically accurate, and have a good surface appearance. A welding-based RP is one of the techniques that offer a promising approach to satisfy the requirements of this challenge. The use of arc welding to create freestanding shapes was established in Germany in the 1960's [2]. Companies such as Krupp, Thyssen, and Sulzer developed welding techniques for the fabrication of large components of simple geometry such as pressure vessels that can weigh up to 500 tons [3]. Other work in this area was undertaken by Babcock and Wilcox [4] who worked mainly on large components produced in an austenitic material. Research work on the welding based RP continues at the University of Nottingham, UK [5], the University of Minho, Portugal, the University of Wollongong, Australia [6-7], University of Kentucky, USA [8], and Southern Methodist University, USA [9-10]. It is important to notice that all of the above research work focuses on the rapid prototyping of parts made of steel. However, aluminum alloys also have a widespread history of applications in the industry. So, the development of a rapid prototyping technique for building functional parts from aluminum alloys is needed.

The developed experimental rapid prototyping system is as follows: There are two vertical axes, the Z-axis and Z'-axis. The Z'-axis is fixed to the Z-axis, and the welding torch is attached to the Z' axis. The Z-axis moves up continuously at a constant speed during the deposition process. This continuous movement produces a smoother surface than could otherwise be achieved. The moving speed of the Z-axis depends on the substrate rotating speed and the deposition layer height. The movement of the Z'-axis is controlled to provide a constant arc length during the deposition process according to the acquired arc length signal. The arc length is monitored in real time by a machine-vision system consisting of a CCD camera, an arc-light filter, and an image processing system. The CCD camera is attached to the torch with a small bracket. The 3-D part is built on a substrate that is fixed on a rotating axis, the R-axis. The R-axis is attached to the Y-axis in the horizontal position. By controlling the movement of the Y-axis in the depositing process, a variable diameter part can be obtained. If the diameter of the part is changed, the rotating speed of the substrate will also be changed to keep the linear speed of the part constant.

The shape and dimensions of the weld bead are very important in the use of the rapid prototyping system based on deposition by a welding technique, because these factors determine the limits of the wall thickness that can be built and influence the quality of the surface finish. Numerous experiments are undertaken to build single-weld

beads for a range of welding conditions. The experiment results show that the heat input is directly proportional to the product of welding current and the welding arc voltage and inversely proportional to the welding speed. Therefore, the relationship between the bead width and the heat input is directly proportional. The bead height is inversely proportional to the heat input while the bead height is directly proportional to the wire feeding speed. The bead width is inversely proportional to the wire feeding speed but the experimental result shows that the wire feeding speed has a very small effect on the bead width. The wire feeding speed can change the bead width by affecting the heat input. Melting the filler metal consumes the welding arc energy, the higher the wire feeding speed, the lower the heat input. However, the consumed energy is a very small fraction of the welding arc energy and can be neglected. Variations in the rate of filler metal applied to the weld result in different arc lengths (and hence different arc voltages). This in turn directly affects the heat input. But if arc length control is applied this effect can also be neglected. Therefore, the bead width only depends on the heat input. Through experiments with different heat inputs and wire feeding speeds the relationship between the bead width and the heat input can be obtained. If the bead width is determined the heat input is also fixed. In this case the bead height only depends on the wire feeding speed.

There are three important issues that have to be addressed in the design of the deposition process based on variable polarity gas tungsten arc welding: the preheating of the substrate, the arc-length monitoring and controlling, and the heat-input controlling. This process allows the cylindrical components to be directly and successfully built of an aluminum alloy. Several parts were made with perfectly acceptable surface quality, mechanical properties, and accurate dimensions. The surface roughness of the deposited parts is found to be on the order of 2 μm by controlling the heat input. The deposited samples possess a maximum hardness at the top layer, and exhibit a slight decrease in hardness going towards the middle and bottom of the deposited layers due to the heat effects of the material that occurs during the deposition. The deposited layers exhibit equiaxed dendrites at the top layer, fine equiaxed grains at the middle and bottom of a deposited wall together with some precipitates distributed at the grain boundary regions, and coarse columnar grains at the bonding zone. The residual microstructure such as grain size and distribution of precipitates is highly dependent on the related locations in the deposited samples.

References

1. J. J. Beaman, J. W. Barlow, D. L. Bourell, R. H. Crawford, H. L. Marcus and K. P. McAlea, 1997, "Solid Freeform Fabrication: A New Direction in Manufacturing", Kluwer Academic Publishers, Dordrecht/Boston/London.
2. Kassmaul, K., Schoch, F. W. and Lucknow, H., "High Quality Large Components "Shape Welded" by a SAW Process", September 1983, Welding Journal
3. Piehl, K-H., "Formgebendes Schweißen von Schwecomponenten", January 1989, Company report: Thyssen Aktiengesellschaft, Duisburg.
4. Doyle, T. E. (Babcock & Wilcox), "Shape Melting Technology", October 1991, The Third International Conference on Desktop Manufacturing: Making Rapid Prototyping Pay Back, The Management Round Table.

5. P. M. Dickens, R. Cobb, I. Gibson, and M. S. Pridham, "Rapid Prototyping Using 3D Welding", Journal of Design and Manufacturing, No.3, 1993.
6. Antonio Fernando Ribeiro and Prof. John Norrish, " Metal Based Rapid Prototyping for More Complex Shapes", 6th Biennial International Conference on "Computer Technology in Welding", TWI, Abington Publishing, 9-12 June 1996, Lanaken, Belgium
7. Antonio Fernando Ribeiro and Prof. John Norrish, " Rapid Prototyping Process Using Metal Directly", Proc. of the 7th Annual Solid Freeform Fabrication Symposium, Aug. 12-14, 1996, Austin, TX
8. Y. M. Zhang, P. Li, Y. Chen, and A. T. Male, "Automated system for welding-based rapid prototyping", Mechatronics, 12, 2002, pp.37-53.
9. Wang, H. and Kovacevic, R., "Rapid Prototyping Based on Variable Polarity Gas Tungsten Arc Welding for Aluminum Alloys", the Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture, Vol. 215, November, 2001, pp. 1519-1527
10. Jandric, Z., J. H., Ouyang and R. Kovacevic, "Effect of Volume of Heat Sink on Process and Physical Properties of Parts Built by Welding Based SFF", 13th Annual Solid Freeform Fabrication Symposium, August, 5-7, 2002, Austin.