RAPID PROTOTYPING PROCESS USING METAL DIRECTLY

Dr. A. F. Ribeiro, Lic.Informática, MSc, PhD.
Departamento de Electrónica Industrial, Univ. do Minho, 4800 Guimarães, Portugal.
e-mail: fernando@dei.uminho.pt

Prof. John Norrish, MSc.
Faculty of Engineering, University of Wollongong, Wollongong, Australia.
e-mail: John_Norrish@uow.edu.au

Abstract

Rapid Prototyping emerged in the USA in the late 80's and it made the whole industry rethink their way of making prototypes. Several new different process have emerged since then and these vary in materials, times, prices, finishing quality, etc. However, not many have achieved acceptable results with using 100% pure metal. Some heavy industry want prototypes made with metal in order to assess not only the shape of the prototype but also its hardness conditions and functionality of the component in real situations. This technique is still under development at several different places and although some research have been done recently the results are not yet as desired.

In the last couple of years a Rapid Prototyping process involving direct deposition of metal had been under development (as a PhD research) at Cranfield University. The process entails the use of a Gas Metal Arc fusion welding robot which deposits successive layers of metal in such way that it forms a 3D solid component.

A solid model is first drawn using a CAD system, then data indicating the kind of layers and dimension is incorporated and the solid is automatically sliced. This slicing routine also generates reports on the welding time and conditions for the production of the component and automatically generates the robot program.

Depending on the complexity of the component, the time from drawing the component to being ready to press the robot start button to make the component can take less than a couple of hours.

Several test components were produced with good characteristics and perfectly acceptable surface finishing. This paper describes the process and shows some samples.

1. Introduction

The current process was first briefly described by Ribeiro in [1] and as the work is now finished it is here described in more detail.

Rapid Prototyping is a technique to produce prototypes in a short period of time to make companies more competitive. The advantages are tremendous and some of them are: reducing the prototyping time production; the techniques are 'automatic' which means there is less need to have a skilled operative; these processes are less wasteful since they normally operate as an additive process instead of subtractive process; using a CAD program, it is very easy to implement changes in the component and being only necessary to "re-print" it; in most of these processes it is possible to make more than one prototype in one operation; it is possible to leave the automated machining centre machine working with little supervision around the clock.

But traditional RP processes also has some disadvantages like: the size of the prototype is limited by the size of the machine; the machines normally used are very costly; it is not always possible to make the prototype in the required material for final component (most of these techniques use wax, photopolymers, thermoplastics and ceramics or even paper for the initial model). Sometimes, it is very important not only to observe the prototype but also to test it and sometimes to use it. Since typical rapid prototyping samples have limited mechanical, thermal and chemical properties of the materials that can be manufactured these cannot be tested or even used. Techniques which prototype components in 100% metal are not common although some attempts have been made.

To overcome this problem a technique for rapid prototyping components using Robotic Arc Welding has been investigated in the present work.

In this process the component is formed by melting and depositing the metal using the GMA welding process. A CAD drawing system is used to create the initial solid shape and a welding robot is used to manipulate the welding torch.

2. Background

There have been a few attempts at rapid prototyping using welding techniques, but most of these used Numerically Controlled (NC) machines or special purpose automatic machines instead of robots. Where robots have been used these have been programmed manually.

In these the robot was programmed to do only one shape and it was not possible to modify the shape without re-programming again the robot (manually). The robot program was not linked to any CAD package unlike all the other rapid prototyping methods. In none of these cases was the component designed in a CAD package which means that no changes, previews or analysis of the components were possible.

In fact most of the tries that have been made were with very simple geometric shapes such as cylindrical shapes. In some cases they simply involved depositing metal on turn tables with the welding gun stationary. In these attempts the metal deposition rates were very high and the component's final quality was not very recommendable.

3. Working Principle of this Process

The component is first drawn in a CAD system as a 3 dimensions solid model. Then, this has to be sliced like any other RP process although this slicing is slightly different. Instead of calculating the borders of the intersection between a plane and the solid, the centre line is what's required. The centre line represents the path that the robot has to follow in order to deposit the weld bead at the right places to build up the component. The welding parameters are automatically generated by the program (according to the metal to be used) in order to achieve the required bead geometry and stable operating parameters. These parameters were derived from welding studies carried out by Norrish [2] and parametric equations generated by Ogunbiyi and Norrish [3]. Besides the welding parameters, the slicing software automatically generates reports containing time taken for making the component, quantity of material needed, final approximate weight, etc. After the 3D model has been sliced with the routines developed by the author, a program reads the resulting lines/polylines and automatically generates the robot program for making the component and this can be simulated with the use of a robot simulation program to check for collisions or other problems such as access. The robot program may be modified if necessary.

The last step to be carried out is to compile the robot program and to upload it to the robot. The robot is now ready to start welding or in other words to start building up the component as far as the welding system is operational.

4. Apparatus

A graphical description of the rapid prototyping hardware used is shown in Figure 1. The dotted arrows represent ideal situations and not the real work cell.

A computer is connected to the robot controller via a serial cable RS-232-C and also to a printer. The power source and welding consumables are connected to the welding torch which is mounted on the robot arm. The robot builds the component on a table. This table should ideally be controlled by the robot (dotted arrow).

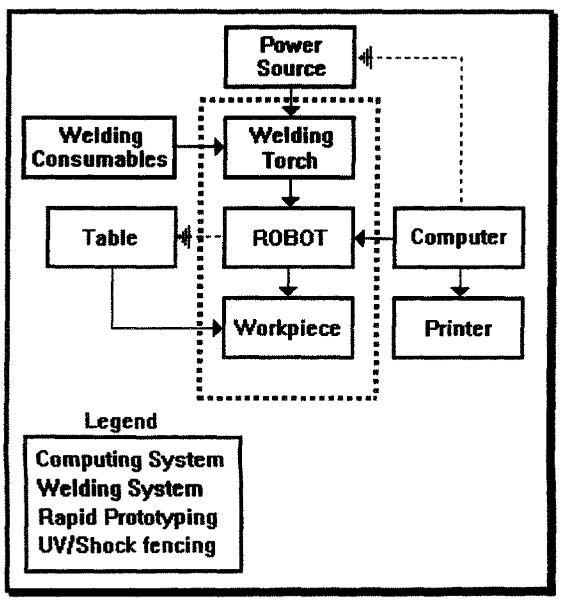

Figure 1 - Rapid Prototyping work cell Hardware

The individual components of the system used here were:

- An ASEA IRb 2000 robot from ABB. This is not a specifically welding robot but a 6 degrees of freedom robot with an S3 controller.
- The Table used for the second case study was a stand alone turn table but for the rest of the samples no turn table was used.
- For most of the components built, the Power Source used was a Migatronic BDH 320 although some tests were later on carried out with a Migatronic BDH 550. The Welding Torch was a BINZEL PUSHPULL torch.
- The computer used for the CAD, off-line programming and downloading, was a PC with an Intel 80486 microprocessor running at 66 MHz with 16 Mbytes of RAM memory. The hard-disk capacity was 250 Mbytes.
- The whole work cell had a fence all around it with glasses containing an Ultra Violet (UV) filter to protect the eyes of the operators in the environment. The robot and table alone had another fence with another UV filter. This second fence was also to protect the physical movements of the robot (shock) and also to protect the eyes from the rays. Should the fence be opened, a circuit would go off and the robot/power source would stop working immediately.
- The consumables were all the necessary ones to a Gas Metal Arc Welding process like the wire, gas and contact tips.

The software used was AutoCAD release 12 for DOS as the CAD system, the Slicing Routine was created by the author of this paper and the Off-Line program to compile and download the robot program was SPORT 1.0.

The use of this particular Hardware/Software is not mandatory. Any suitable Personal Computer could be used. A possible limitation is the **Slicing** program which was developed to work with AutoCAD release 12, but this could be translated to any other language and CAD system. The robot used is not a limitation. In fact this robot was not even fitted with the normal welding robot options. Any other robot could be used if the robot program was generated in the desired language.

5. Test Samples

Three components were choosen to be shown and described in this section although several other were built up.

5.1 Chimney

The first one consists of a 'chimney' shape. The idea was to continue the cylinder in its top part but due to lack of material (and due to its price) it had to be interrupted.

It took about half an hour to draw it in a CAD system and about another half an hour to slice, generate the reports and generate the robot program. This was done in three separate robot programs although it could be done all in one.

It is about 250 mm height and weighs 4,240 Kg (without the base plate) and it lost around about 3 millimeters in height. The width was planned to be 5.6 mm and in the end it was measured and it varyed +/- 0.3 mm. At the location where the robot moves up (from layer to lay) was slightly heigher (about 1 mm) than the rest of the component. After observing this problem, the other components were made using a spiral technique to avoid brupt movements upwards. The welding parameters are of extremely importance for the final dimensions, final surface finishing and final quality and these can make the whole difference between a good component and a bad component.The component here described can be seen in Figure 2.

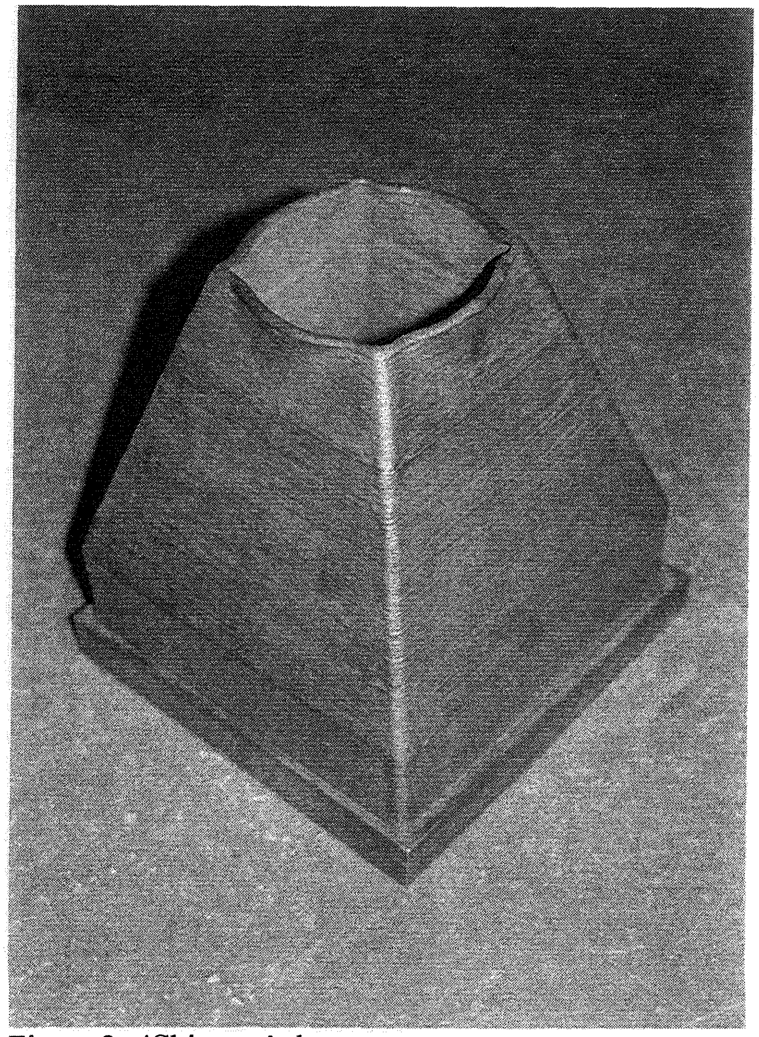

Figure 2 - 'Chimney' shape

5.2 'Bow Tie'

This component consists of a 'bow tie' shape and was intended to study increase of radius and consequent loss of height.

It took about half an hour to draw it in a CAD system and about another half an hour to slice, generate the reports and generate the robot program.

It is about 200 mm height and weighs around about 3 Kg (without the base plate). The width was planned to be 5 mm and in the end it was measured and it varyed +/- 0.2 mm. This component was done with four 'up movements' by the robot which means that instead of moving the whole bead height all in one go it did it in four separate places reducing though the height in that location. Like in the previous component the welding parameters are of extremely importance for the final dimensions, final surface finishing and final quality and these can make the whole difference between a good component and a bad component. This component achieved a good surface finishing, very near geometrical expectations (less than 1 mm in height lost).

The component here described can be seen in Figure 3.

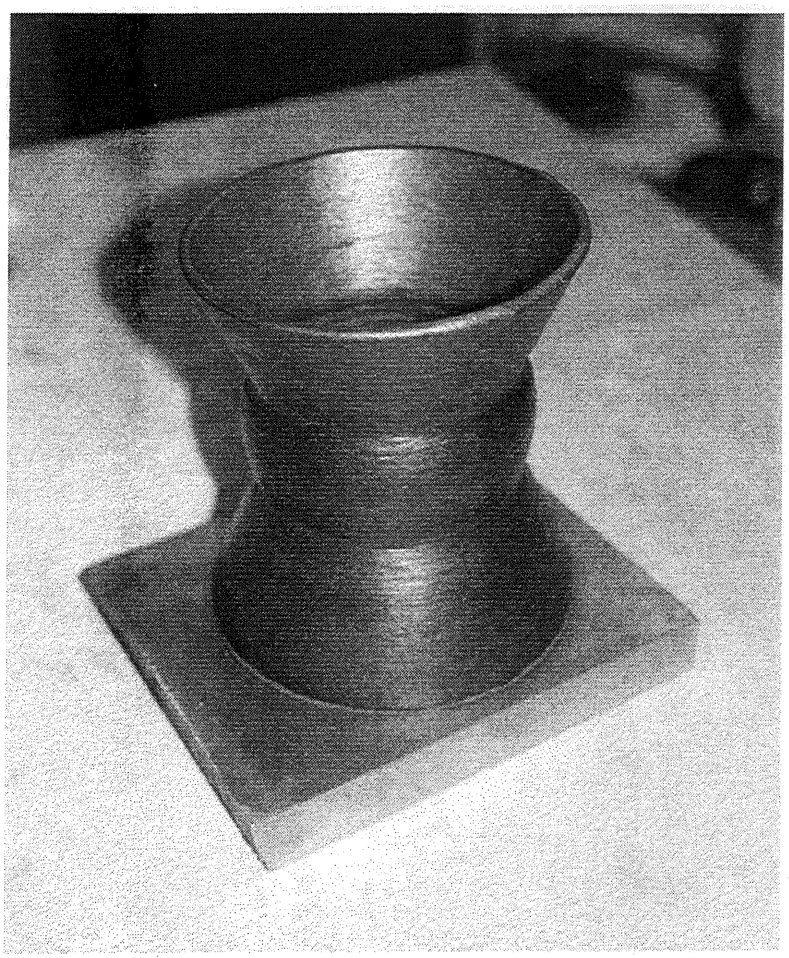

Figure 3 - 'Bow Tie' shape

5.3 Pint Glass

This component consists of a 'pint glass'. It took just under half an hour to draw it in a CAD system and about fifteen minutes to slice, generate the reports and generate the robot program.

It is about 180 mm height and weighs around about 3 Kg (without the base plate). The width was planned to be 6 mm and in the end it was measured and it varyed +/- 0.2 mm. This component was done with a spiral technique which means that instead of moving the whole bead height all in one go it was moving up as it goes along the circle reducing though the height in a particular location. Like for every component the welding parameters are of extremely importance for the final dimensions, final surface finishing and final quality. This component achieved a good surface finishing, very near geometrical expectations (less than 0.5 mm in height lost).

The component here described can be seen in Figure 4.

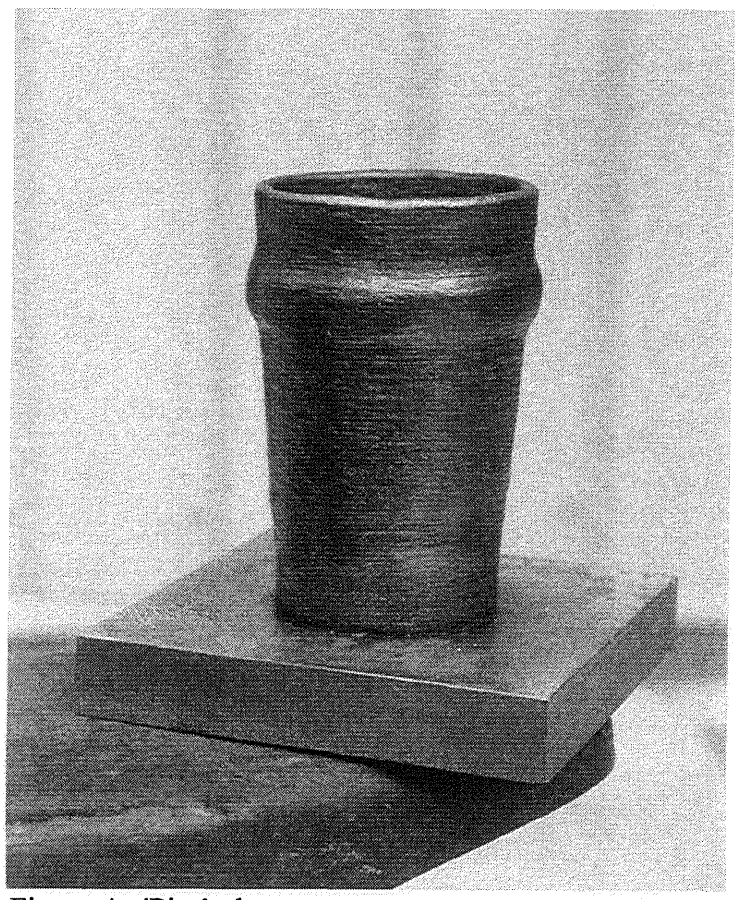

Figure 4 - 'Pint' glass

6. Conclusions

The reason for making a prototype, should not only be to visualise but also useable to test and assess it in its final function. Therefore, it is important to make the prototype with the same material used in the real and final component. This process allows components to be made with metal successfully.

This technique can be used to make not only the prototype but also the final component with the desired metal for 'one-off' production. Therefore, this represents also a new production technique more suitable for low volume production.

Another advantage with this new technique is that different metals can be used during the build up of the component to achieve different structural characteristics in different parts of the same component. This would not be possible with casting. The welding can be stopped at any time, the filler material changed, and the welding started again as far as the metals are compatible. The time to change the wire and the welding parameters is not very long.

In this process the slices are automatically created, the ARLA robot program generated completely automatically and it was not essential to use a robot simulation package to test it, although simulation can be used to save on line time. This means that this process is very automatic with almost none intervention from the user (except for drawing the component in a CAD system).

Several components were made with perfectly acceptable quality in surface finishing, mechanical characteristics and dimensions. The welding parameters are of extremely importance in this proces. The represent the difference between a good component and a bad component.

7. Acknowledgements

Mr. Ribeiro would like to thank John Norrish for his support in this project and his expertise in the welding field and also Dr. McMaster for his academic help in the work. My very special thanks go to John Savill for his strong support in welding all of the components and for solving in an efficient way the practical problems which arose as well as encouraging me to new ideas. A special thank you for my wife is also deserved for her understanding during the difficult periods of this project. My new employer (Universidade do Minho) and my Portuguese sponsor (JNICT) also deserve a big thank you.

---

[1] RIBEIRO, A. F. M., NORRISH, J. AND MCMASTER R., "*Practical case of Rapid Prototyping using Gas Metal Arc Welding*", 5th International Conference on Computer Technology in Welding, Paris, France, 15-16 June 1994.

[2] Norrish, J., "*Advanced Welding Processes*", Institute of Physics Publishing, 1992.

[3] NORRISH, J., Ogunbiyi B., "*An Adaptive Quality Control concept for robotic GMA Welding*", 5th International Conference on Computer Technology in Welding, Paris, France, 15-16 June 1994.