Working paper
2005:02

*Henrik Nilsson*

# METAL DEPOSITION EXPERIMENTS

## Electrode angle and weld speed

UNIVERSITY
TROLLHÄTTAN • UDDEVALLA

*Department of Technology, Mathematics & Computer Science*

# Metal Deposition Experiments
# Electrode angle and weld speed
**Henrik Nilsson**

## Summary

The work done in this report is made within the metal deposition research project in the MIA-group (Mechatronics in Industrial Applications) at the University of Trollhättan/Uddevalla (HTU). Metal deposition is a method of building metal work pieces using weld material. The aim of the MIA-groups research is to develop a control system for automated robotised metal deposition.

The research conducted is a continuation of the thesis "*Development of Sensor System for Automated metal deposition*" by Mr Jan-Erik. Henriksson, Ms Jessica Jansson and Mr Simon Cronholm. The aim of the work conducted in this report is to determine what effects changes of the weld speed and electrode angle do to the geometry of the weld seam. During the initial experiments it was noticed that differences in the weld process occurred due to the final rolling method of the plate used. To achieve similar results as in earlier experiments cold rolled plates had to be used.

The electrode angle affects the weld such that the narrowest weld is performed with the electrode perpendicular to the plate. As the electrode is tilted the width of the weld is increased.

The effect of increased weld speed is less oxides on the weld seam, more stable welding process and less deformation of the plate caused by shorter exposure of heat.

While conducting the experiments more experience of improvements in equipment and important parameters for the metal deposition process.

# Contents



## Appendices

# 1 Introduction

One of the research groups active at the University of Trollhättan/Uddevalla (HTU), Sweden, is the MIA-group (Mechatronics in Industrial Applications). It aims to research controlling and supervision of industrial processes. The group was founded during the winter of 2003/2004 as a parallel and co-operating research group to the successful research group VIP (Verkstadsindustriprocesser), also at HTU.

At this point a couple of different projects have been undertaken by the research group among them the development of a sensor and control system for robotised metal deposition. Within this project many smaller areas are researched as starting points of the project, among them experiments with different welding parameters to evaluate how the weld seam geometry changes with different parameter values.

## *1.1 Background*

Metal deposition is a method where a metal feature is built by adding welding material to create the wanted shape. The material is melted using a heat source, e.g. a tungsten electrode (TIG welding equipment) or laser and when the weld material solified it builds up the feature. The idea of the method is building up layers to create the wanted products or add metal features, like flanges, bosses and pads, to existing products.

Some areas of interest for metal deposition are building prototypes, adding features to parts and repairing damaged parts. The advantage of using metal deposition for building prototypes compared to the already available rapid prototyping (RP) and free form fabrication (FFF) methods is that the created part is in metal and therefore has the material properties of the finished part. This makes the method suitable for one of a kind production or small series. The ability to add features to a part gives possibilities to improve and import changes to old parts and also the possibility to use a simple and low cost base feature and adding advanced features by using metal deposition to generate a complex part.

The possibility to repair damage parts instead of discarding them can make a huge saving if the part is expensive, e.g. cast of titanium or stainless steel or tools. It also reduces the waste of material.

Initial work in metal deposition has been conducted at HTU and can be found in the thesis [1].

## *1.2 Previous work*

In the thesis [1] experiments by varying the wire feed and weld current for TIG welding were conducted. The results showed that wire feed only affects the build height while weld current mostly affects the seam width but also, in a very small amount, affects the build height.

Some of the parameters used were:

Weld voltage (AVC controlled): 11.3V

Electrode angle: 70°

Electrode overhang from electrode gas cover: 5 mm

Weld speed: 3 mm/s

Weld wire: 316LSi 1 mm

For the initial four welds, called support welds, the following values were used:

Weld current: 135 A

Wire feed first seam on every layer: 1.1 mm/s

Wire feed other layers: 0.9 mm/s

For the parameters predetermined values for low, mid and high were used according to Table 1.

| Parameter | Low | Mid | High |
|---|---|---|---|
| Weld current (A) | 120 | 140 | 160 |
| Wire feed (m/min) | 0.7 | 0.9 | 1.1 |

**Table 1** – Predetermined values for low, mid and high for the parameters.

The tests were made from five welds, the three first ones side by side on the base plate and the last two on top of the first ones. Geometric measurements were conducted on the second weld seam in the second layer. This weld seam is representative for most weld seams since when a larger feature is to be built then a majority of the weld seams will be built on a previous layer of welds and next to another weld seam.

## 1.3 Aim and objectives

The main aim was to determine how changes in the electrode angle and weld speed changes the geometry of the weld seam.

The objective of the work was to conduct experiments to obtain dependence on the geometry of:

- Electrode angle
- Weld speed

## 1.4 Restrictions

The experiments have only had the two parameters electrode angle and weld speed as variables and only one of them at a time. The only parameters that have been measured are height and width of the second weld on the second layer. The geometry will only be measured using a microscope equiped with a camera that is connected to a PC.

## 1.5 Methodology

The experiments were conducted in the following way:

First the previous experiments in [1] were repeated using the same apparatus and mid parameter values to verify that the new experiments achieves similar results compared with the initial work for metal deposition at HTU.

When similar results have been accomplished the work with finding the weld seam's dependence of weld angle and weld speed. The experiments were conducted by using the same parameters and layout of the welds as in [1] for the initial four weld seams.

The purpose of slowly increasing or decreasing the values of the parameters was to find the limit where the welding process fails.

The surface to perform the weld on was a 150 mm long plate with the thickness 5 mm, made of 316L material. The plate was washed with Acetone to remove inpurities on the plate surface. Then the plate was grinded, using a pneumatic rotational grinder, to remove oxides in the surface. Before welding the surface was again washed with Acetone to remove inputities caused by the grinding or from handling the plate.

The plate was clamped into a heavy clamping fixture, see Figure 1. The purpose of the fixture is to hold the plate in the right place when welding, to prevent the plate of deforming when welded upon and to conduct heat away from plate while welding.

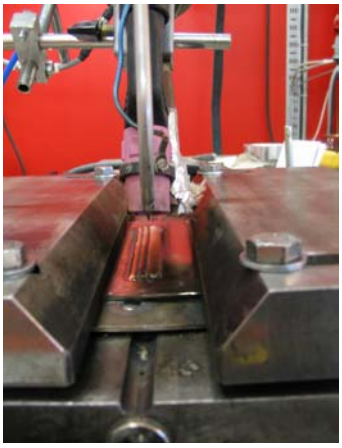

**Figure 1** – The clamp holding a weld plate.

Two different robot programs where used for welding, one that allow the user to enter the angle for the second weld in the second layer and one that allows the user to enter the weld speed for the second weld on the second layer.

When the welding is completed the plate is cut into three pieces using an abrasive cutter see Figure 2.

**Figure 2** – Shows one of the weld plates cut into three pieces for measurements.

Where to place the cuts were determined by examining the welds on the plate, espacally the last weld seam, looking for two parts where the weld results looked stabile for a couple of centimetres, this the place for the cuts. The middle piece of the plate was grinded and polished on both cut sides using a grinding to increase the visibility of the weld seams.

After the grinding the cuts of the plate they were etched, using oxalic to make the welds visible. The plates were put into the microscope and the camera attached to the microscope imported the picture to a PC. A program on the PC was used to determine the height and width of the second weld seam on the second layer as seen in Figure 3 for details.

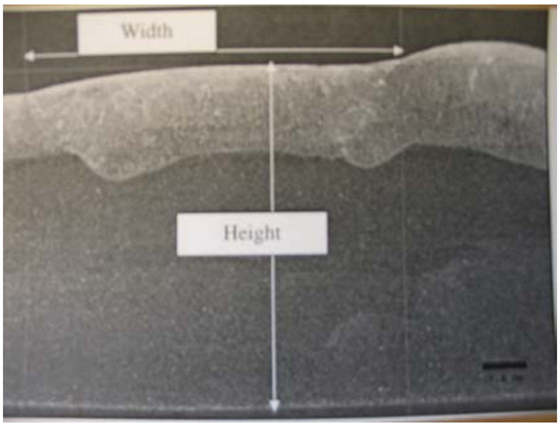


**Figure 3** – Height and width definitions.

In Figure 3 it can be seen that the width of the weld was measured at the widest points of the fifth weld. The height was measured by measuring the distance between the bottom of the plate to the highest point of the fifth weld and then subtracting the length measured from the bottom of the plate to the second weld.

The cuts used for measuring were labelled where U (for up) is closest to the start of the weld seams and D (for down) is closest to the end point of the weld seams.

# 2 Experiments

The experiments were conducted in five steps:

- repeating previous experiments
- increment of electrode angle
- decrement of electrode angle
- increment of weld speed and
- decrement of weld speed

The purpose of the first step was to make sure that the settings of the equipment showed a similar weld result as the setup in [1]. The purpose of the other experiments was to determine how changing one of the weld parameters would affect the geometry of the fifth weld.

## *2.1 Repeating previous experiments*

To make sure that the setup of the welding equipment was similar to the one used in [1] a couple of tests where the parameters were set to standard values.

The verification showed results that were very different from [1]. The welds didn't seam to attach themselves onto the plate and flow out which resulted in a higher and narrower geometry of the weld seam. When several weld seams were laid next to each other a solid layer was not achieved, instead the welds had a couple of millimetres between them. To generate a solid layer of weld material the wire feed had to be increased to values close to 2 m/min. A comparison of the backsides of the plate from the test and one of the test plates from [1] showed that the new plate had a rougher surface. New tests were performed where both the rough surface plates and the smooth plates were welded with the same parameters. The test again showed that the results from welding on the rough surface plates differed a lot from the results form [1] while the smoother plates showed similar results to [1], see appendix A.

Both of the plates were made of the material 316L but with the difference that the new plate had a rougher surface. The reason for different surface finishes can be explained by the fact that the rough surface plate was hot rolled while the smoother plate had been cold rolled.

In further efforts to determine why a plate in the same material generated different results, welding expert Mr Stanislaw Zbieg at Allkommers AB was contacted. Mr Zbiegs explanation for the differences experienced in the experiments was that the rolling determines the amount of sulphur on the surface of the plate. Usually sulphur is thought of as an impurity in steel but can give the alloy some useful features. In this case the cold rolled plate contains up to 0.005% sulphur and the hot rolled 0.001%.

These small quantities of sulphur increase the adhesion and make the weld seam flow out over the plate instead of lump together.

Because of the difference in performance of hot and cold rolled plates cold rolled plates had to be ordered to allow the experiments to be a continuation of the thesis.

A couple of the hot rolled plates were sent to Mr Per Thorin at Volvo Aero Corporation to be cleaned and blasted to see if it is only the layer closest to the surface that makes the welding process fail. A test on the prepared plates showed that the welding process worked as on the cold rolled plates and similar results were generated, see appendix B for pictures.

It was decided that the experiments should be conducted with cold rolled 316L plates as in [1].

## 2.2 Increment of electrode angle

The first parameter to be changed was the electrode angle. The weld speed was kept constant at 3 mm/s. The tool angle was increased in steps of 10°, from 80° to 110°. The reason for not performing experiments with higher tool angles than 110°, even though the process still worked, was that the nozzle would hit the previous weld and interfere with the welding process, see Figure 4. Another thing that occurred was that as the angle increased the gas cover behind the electrode and electrode cover were also angled and did not protect the new weld, causing more oxides to be created on the new weld seam.

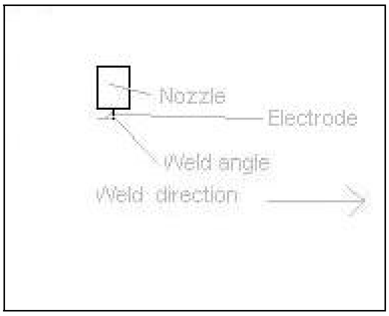


**Figure 4** – Shows the weld head with electrode, nozzle, weld angle and weld direction.

The result of increasing the electrode angle can be seen in Table 1 and Diagram 4.

| Angle | Width (mm) | Height (mm) |
|---|---|---|
| 80° up | 8.66 | 8.11 |
| 80° down | 8.96 | 8.19 |
| 90° up | 8.52 | 8.15 |
| 90° down | 8.58 | 8.19 |
| 100° up | 8.96 | 8.09 |

| | | |
|---|---|---|
| 100° down | 8.90 | 8.03 |
| 110° up | 9.35 | 8.11 |
| 110° down | 9.49 | 8.07 |

**Table 1** – Shows the measured height and width of each of the experiments. Up indicates measurement closer to the start of the welds and down indicates measurement closest to the end point of the welds.

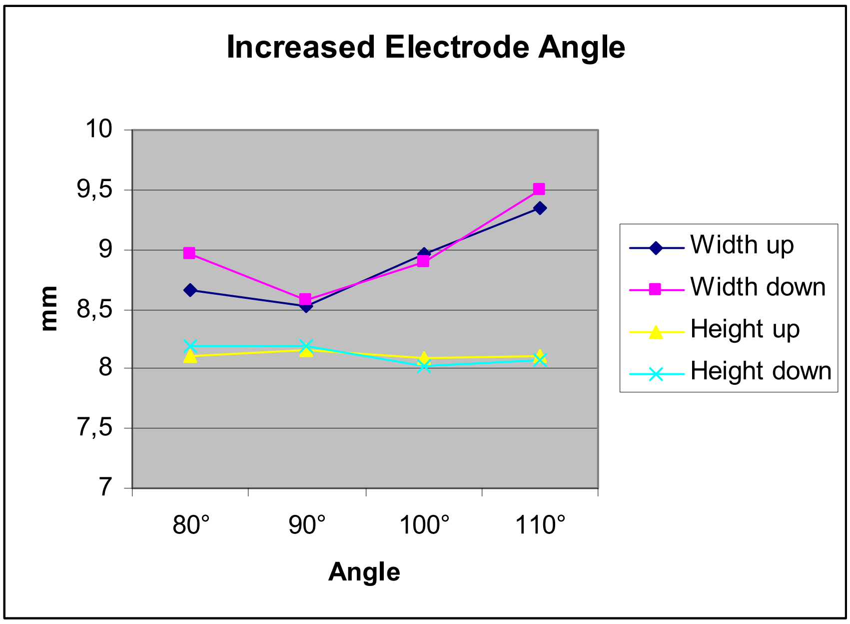


**Diagram 1** – Shows graphs the values presented in Table 1.

In Diagram 1 it can be seen that increasing the angle of the electrode mostly changes the width of the weld seam. The narrowest seam is created with the electrode perpendicular to the plate and tilting the electrode either way will cause an increase in weld width.

In the measurements it can be seen that the maximum height of the weld seam shows very small changes when increasing the weld angle.

## *2.3 Decreasing electrode angle*

The second experiment performed was to decrease the electrode angle, using the previous stated variables as presented in chapter 1.2 and the weld speed at 3 mm/s. The angle was lowered by 10° to 60°. The angle made the extra gas cover to hit the plate and previous seams thereby interfering with the welding process. To avoid this, the extra gas cover was removed, causing the seams to be more affected by oxides. When the test was performed the electrode gas cover collided with the previous weld seam and thereby interfering with the welding process. The result of this experiment is that the electrode angle has to be larger than 60° to avoid collision between the previous weld seam layer and the electrode gas cover at an overhang of 5 mm for the electrode. One way of solving this is to increase the overhang of the electrode but this change is not within the scoop of this report.

## 2.4 Increasing weld speed

For this experiment all parameters were kept as stated in chapter 1.2 except the welding speed. The welding speed was increased in steps of 1 mm/s until that point when the build height seemed to be very small. The results of the experiments can be seen in Table 2 and Diagram 2.

| Weld speed | Width (mm) | Height (mm) |
|---|---|---|
| 4 mm/s up | 6.96 | 8.01 |
| 4 mm/s down | 7.50 | 8.03 |
| 5 mm/s up | 6.04 | 7.95 |
| 5 mm/s down | 6.90 | 8.01 |
| 6 mm/s up | 6.08 | 7.77 |
| 6 mm/s down | 6.13 | 7.83 |
| 7 mm/s up | 5.80 | 7.73 |
| 7 mm/s down | 6.08 | 7.81 |

**Table 2 –** Shows the built height and width of the weld seam when the weld speed is increased.

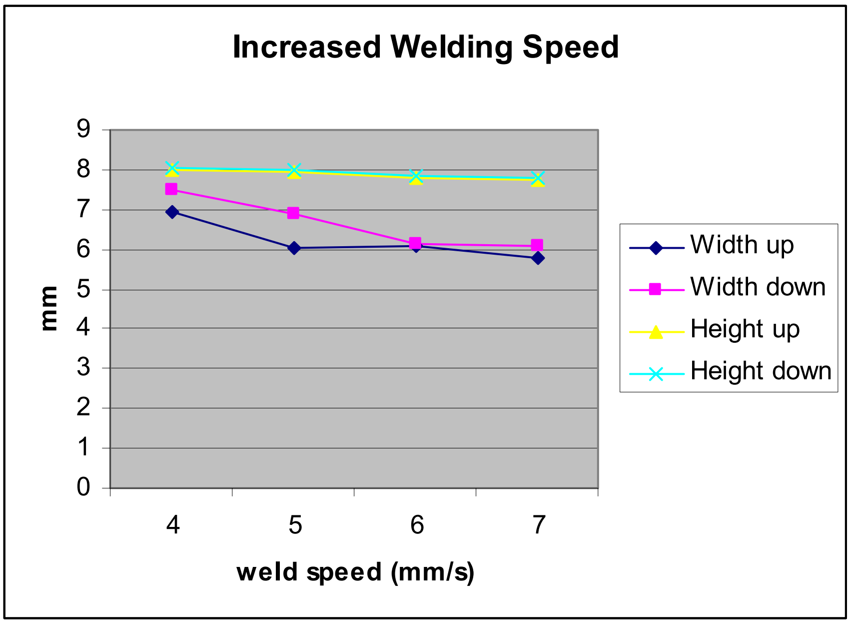


**Diagram 2** – Graphs of height and width from the experiments with increased welding speed.

In Diagram 2 it can be seen that the height is decreased slightly when the speed is increased. One thing to notice is that because the speed is increased and all other parameters kept the same the amount of weld material on each length unit is reduced and also the amount of heat. Because of the overlap between the weld seams and the first seam on the second layer is built with the standard parameters from chapter 1.2 the edge of the fifth weld seam will be mixed with the fourth and will be higher than the other edge. The height of the weld seam is measured on the highest point of the weld and not in the centre of the weld. This may cause another result than if the weld next to the measured weld would have had similar geometry as the measured weld.

During the experiments it was noted that an increase of weld speed to 4 or 5 mm/s caused the weld process to be less stabile than for the standard 3 mm/s weld speed. A result is that the width of the weld seams varies through out the seam.

Experiments with higher weld speeds (6 and 7 mm/s) showed that the weld process stabilises and generates a weld seam with similar width for the entire seam.

## 2.5 Decreasing welding speed

For this experiment the parameters were as stated in chapter 1.2but the welding speed is decreased in steps of 1 mm/s starting on 2 mm/s.

The results can be seen in Table 3 and Diagram 6.

| Weld speed | Width | Height |
|---|---|---|
| 2 mm/s up | 10.40 | 8.44 |
| 2 mm/s down | 10.40 | 8.40 |
| 1 mm/s up | 10.60 | 9.19 |
| 1 mm/s down | 10.95 | 9.15 |

**Table 3** – Shows the results from the experiments when the weld speed is decreased.

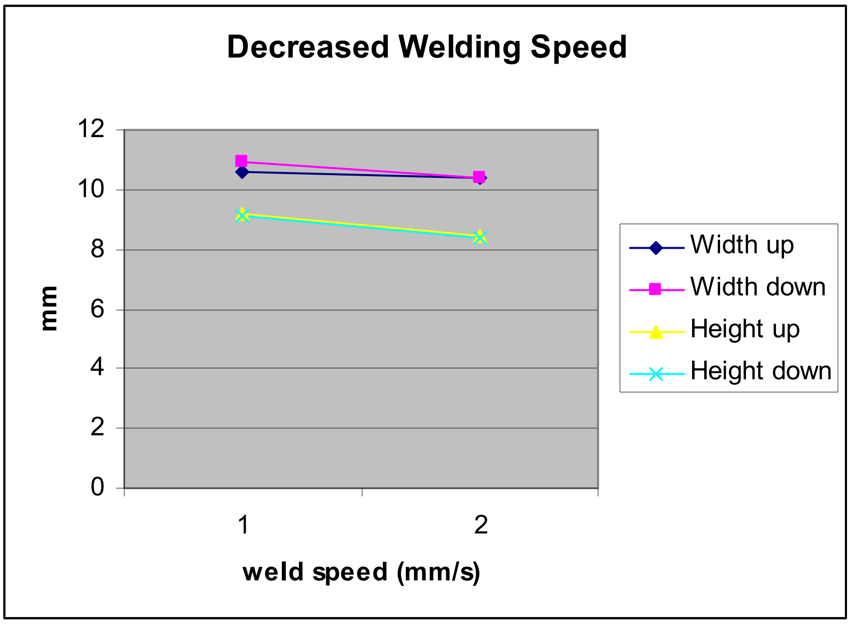


**Diagram 3** – Shows the graphs of the results when the welding speed is decreased.

In Diagram 3 it can be seen that the width only shows a small increase when the speed is decreased while the built height shows a significant increase. Also important is that the measurements show that the measured values are close to each other making the process stabile. One thing that could be observed by looking at the weld seam was the amount of oxides increased significantly as the weld speed decresed.

# 3 Result

From the initial tests used to verify the setup of the welding equipment is similar to the setup when the previous experiments were conducted, it was discovered that when using a hot rolled plate the welding process was very different compared to using a cold rolled plate and also the result of the welding. The difference was that the weld seams did not get the same geometry as in [1], instead the seams became higher and narrower and the result was gaps between the seams instead of a solid layer. To get the same performance from a hot rolled plate as from a cold rolled plate the hot rolled plate must be thoroughly cleaned from inpurities and blasted.

From the measurements conducted on the test plates it can be seen that the width of the weld increases as the electrode angle moves further from 90°. The height only shows a small decrease.

In the tests where the speeds were increased the results from 4 and 5 mm/s showed that the weld process became unstable causing variations in width for the weld. When the speed was increased even more the weld process again became stable with the measurements of the width close to each other. The increased speed also performed a very nice weld with very little oxidation and no binding error visible. The increased speed also has the advantage that the plate is exposed to the welding energy only for a short while, reducing deformation of the plate.

From the tests conducted of altering the angle of the electrode it was noticed that if the angle becomes 60° the electrode gas cover will collide with the previous weld seam layer. The angle should be somewhere between 70° and 110° to avoid collisions.

Tests where the speeds were decreased showed that it is mostly the height of the weld that is affected. Also the amount of oxidations on the weld increased and the deformation of the plate.

# 4 Problems

During the experiments a couple of collisions occurred, most of them when trying to find the electrode angles possible to use. In one of the collisions the wire feed pipe were damaged and had to be exchanged, so instead of using the original bent wire feed pipe bent to be able to be fitted with a sensor as close to the electrode as possible a straight wire feed pipe was used, se Figure 4 for details.

**Figure 4** – Shows the new wire feed pipe (left) and the old wire feed pipe

The new pipe did not cause as much deformation of the weld wire as the bent one. The result of this change was that the weld wire did not oscillate from left to right during welding. The weld wire was now fed into the same place relative to the electrode during the welding causing the weld to be built straight instead of oscillating as before.

When the speed were increased the amount of weld material and energy per length unit decreased. This may cause the measured weld not to integrate with the weld seam next to it as if more energy was used and instead be welded on top of the weld next to it. The measurement is made on the highest point of the fifth weld and because of the extra support of the fourth weld it can be close to the edge of the fifth weld and not close to the middle of the weld.

In all the tests performed the first 1 to 1½ centimetres of the weld was needed for the process to stabilise.

# 5 Conclusions

To be able to use the results from these experiments the weld material should be cold rolled 316L.
By changing the electrode angle the weld width can be affected. When the electrode is perpendicular to the plate the build width becomes the narrowest, by tilting the electrode either way the width is increased.
The maximum tilting angle for the setup used in the experiments is somewhere between 20° and 30° from perpendicular. Using a larger angle will cause collision between the previous layers of weld seams on the plate and the electrode gas cover or the wire feed pipe.
Decreasing the weld speed causes a significant increase in build height but also increases oxides on the weld seam and deformation on the plate.
Increasing the weld speed shows a larger decrease in weld seam width than the build height but also very little oxides is visible on the weld seam. Also the stabile weld process at weld speeds of 6 or 7 mm/s creates more even edges of the welds.

# 6 Recommendations for further work

The experiments with increased speed showed some interesting results. The short exposure of energy reduces the deformation of the plate; the visible small amounts of oxides on the weld seam and the stable welding process are advantages that will be useful in metal deposition. When increasing the speed a rather small decrease in weld height is observed. The reason for this is that the weld is built with overlap to the previous weld. To generate valid values of the build height the weld seam will have to be built next to a weld seam with similar height.

For metal deposition four parameters, weld current, wire feed, weld speed and electrode angle, influence the weld seam. From the knowledge gained for metal deposition in the performed experiments it should be possible to build a work piece or advanced feature to make use of the gained experiments and to find new areas in the process to learn and refine.

From prior experiments at HTU, problems have been encountered when the number of layers gets close to ten. The reason is that the gravity affects the weld pool and makes it flow from on top of the layer to the side of the welds onto the plate. Though not handled in these experiments it is essential to find the solution to this problem if work pieces and features with heights over 1 cm are to be built in the future.

# References

J-E. Henriksson, J. Jansson, S. Cronholm. *Development of Sensor System for Automated metal deposition*. Högskolan Trollhättan Uddevalla. 2004:RT03.

# A First Appendix

## Verification plates

Parameters used are found in chapter 1.2.

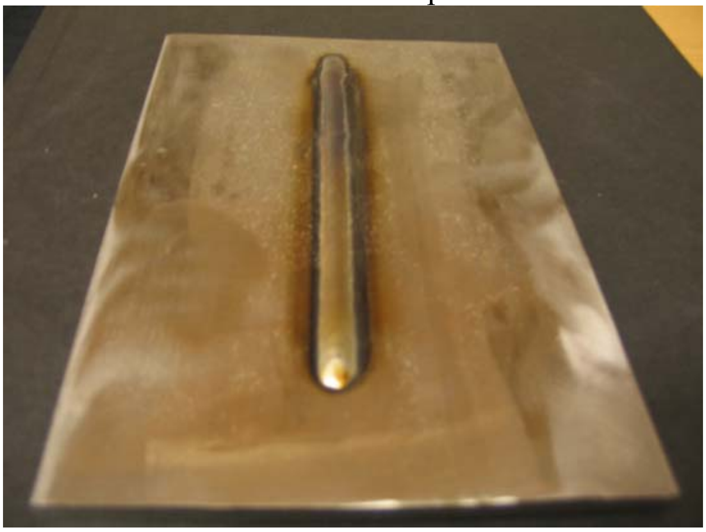

**Figure A-1** – Shows one weld on hot rolled plate. The weld is narrower and higher compared to Figure A-2.

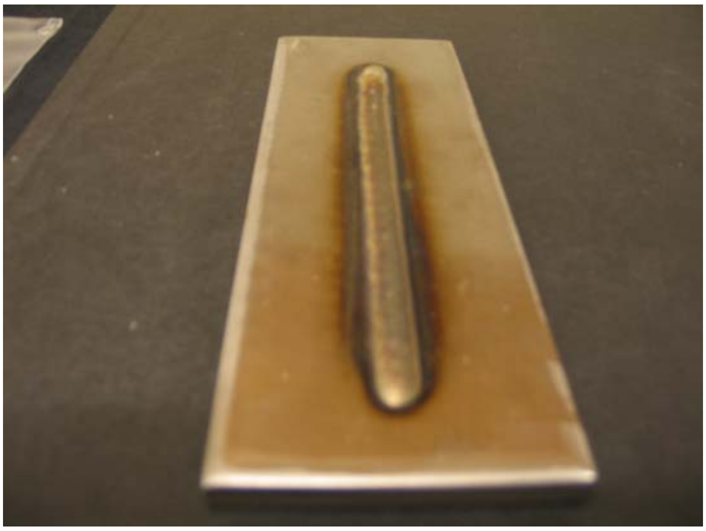

**Figure A-2** – Shows one weld on cold rolled plate. The weld is wider and lower than Figure A-1.

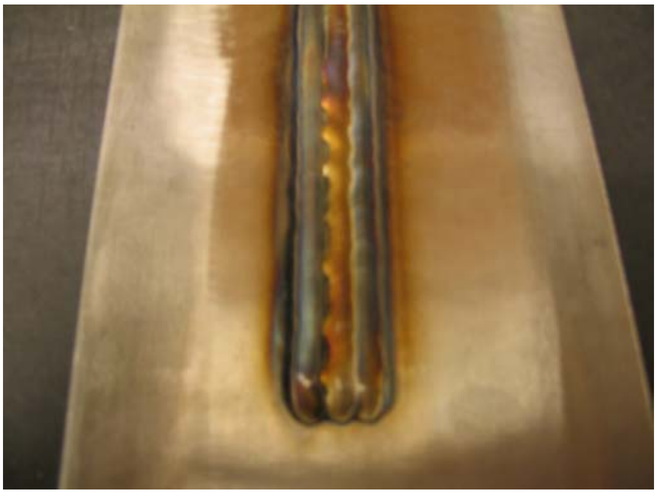

**Figure A-3** – Shows five welds on hot rolled plate. On the picture it can be seen that the welds are not attached to each other. Instead, for most of the welds, the weld seams are distanced from each other.

**Figure A-4** – Shows five welds on cold rolled plate. The welds are attached to each other, making a solid layer of the welds.

# B Cleaned and blasted hot rolled plates

Parameters used are found in chapter 1.2

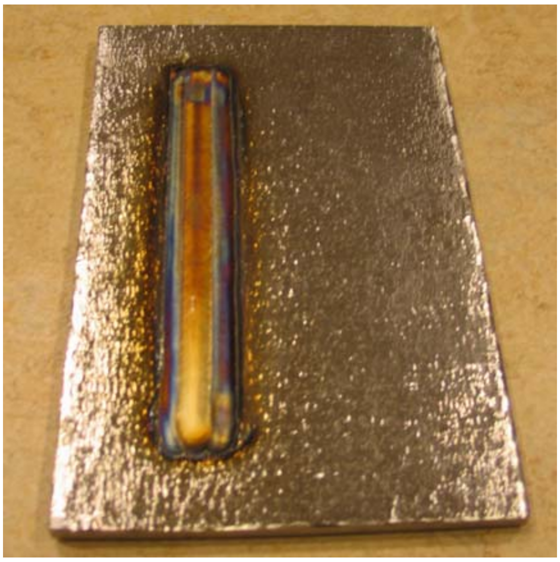

**Diagram B-1** – Shows the cleaned and blasted hot rolled plate with five weld seams.

**Diagram B-1** – Shows the cleaned and blasted hot rolled plate with five weld seams.

# Working Papers from the University of Trollhättan/Uddevalla

1999

Perneman, Jan-Erik, Vilken kunskap lyfter? Om Kunskapslyftet i norra Bohuslän och Fyrstad - erfarenheter från första året och några frågor för framtiden. 99:1

2001

Liss, Ann, Utvärdering av kompetensutvecklingsprogrammet Autism 2000. 01:01

Fredriksdotter Larsson, Ewa, Hur ofta fattar du beslut? - om målbilder och beslut hos företagare och chefer. 01:02

Rydstedt, Leif, Odhner, Miguel, Pettersson, Kristina, På väg till nollvisionen: Nationellt projekt i Trollhättan. En arbets- och organisationspsykologisk utvärdering. 01:03

2002

Kjellén, Bengt, Fear in the Workplace - Meanings, Manifestations and Management. 2002:01

2003

Perneman, Jan-Erik, Johansson, Elisabeth, Arbetsintegrerat lärande (AIL) - om integrationens olika former ur ett kunskapsperspektiv. 2003:01

2004

Fredrikson, Magnus, Dalsland i nyheterna. En innehållsanalys av Göteborgs-Postens bevakning av Dalsland 1997-2003. 2004:01

Karlholm, Gudrun (red), Lärande för pedagogisk utveckling vid HTU. Några exempel på utvecklingsarbeten i lärarens egen undervisning. 2004:02

Kauffeldt, Anders, Welander, Eva, Att handleda handledare - ett led i arbetsintegrerat lärande. 2004:03

Krohn, Karin, Claesson, Silwa, Blivande språklärares syn på sin utbildning. 2004:04

Lievain, Guillaume, Rupil, Damien, Study of different sensor systems and investigation about PosEye for positioning. 2004:05

2005

Persson, Tore, Ottermark, Kenth, En kritisk analys av företagsnätverk. 2005:01

Nilsson, Henrik, Metal Deposition Experiments: Electrode angle and weld speed. 2005:02

UNIVERSITY
TROLLHÄTTAN • UDDEVALLA

ISSN 1653-2384

*All working papers are obtainable through the University of Trollhättan/Uddevalla, Box 936 SE 461 29 Trollhättan Sweden, phone +46 520 - 47 50 00, fax +46 520 - 47 51 99, www.htu.se*