Follow the track

The effects of silicon dioxide on GTA welding
Silicon dioxide, in other words sand, turns out to be a highly useful helper for arc welding processes. It can be used as a tracer for a welding robot to follow the weld line and it can also make welding go faster and «deeper». At the Materials Science department of the Delft University of Technology, chemical engineer Wilma Middel looked into the matter and created the basis for a new type of seam tracking sensor.

In this day and age of cyber technology, it tends to slip our mind that not all the bits and bytes in the world will be able to fit a nut onto a bolt. Life in a virtual world has its benefits, but people aren’t designed for virtual living.

We need tangible objects (or at least we think we do), and these have to be manufactured. Bits and bytes can help but in the end the dirty work has to be done using techniques that have been in use for decades, sometimes even centuries. Welding is one of these techniques.

What would a Sunday drive in the country be like if we didn’t have welding to build cars? Welding is a fairly old technique, but in the past two decades it has been receiving increasing support from the bits and bytes. You’ll be hard put to it to find a modern car that wasn’t built by a welding robot (mostly of the spot-welding kind), unless it were a Rolls Royce. Robot welding depends on seam tracking systems. These are often camera-based, but cameras have their drawbacks, if only because they have to operate in what is hardly a camera-friendly environment, with all the glare and interfering fumes.

Scent
Wilma Middel was asked to tackle the problem of designing a different type of seam tracking system. To Middel, who obtained her degree in chemistry at Utrecht University, welding was still an unexplored region (‘I thought arc welding had to do with welding in curves’). The idea was to apply a certain material onto, or preferably alongside the prospective weld track in order to give the welding robot a «scent» that it could follow.

Middel: ‘Certain materials affect the arc voltage. Silicon dioxide, for example, increases the voltage from, say, 11 volts to 13 volts. This is a property that can be used to guide the welding robot, for instance by applying a strip of silicon dioxide on either side of the welding joint. As the welding torch oscillates to and fro, each time it encounters the sand track, a simple feedback control system can ensure it remains between the tracks. I have experimented with various types of material, and silicon dioxide worked particularly well.’

There still remained one small problem to solve: how do you prevent the sand from being blown away when the welding arc blazes closer? As it turned out, all it took was the application of an emulsion of sand in acetone.

Flux
Research completed, patent applied for, end of story?
Well, not quite. First of all, working for a scientific institute means that the least you can do is to look for a scientific explanation of the phenomenon. The patent business is a bit more complicated. Patents are not an end in themselves for scientific institutions, but in recent years even technical universities have been filing increasing numbers of patent applications. The principle of the new type of sensor seemed to be just the right material for a patent. Sadly, funds were lacking, so commerce was given a miss and it was back to science.

The increase in the welding arc voltage caused by the presence of silicon dioxide (for example) has other effects than just creating a seam tracking ability. Various welding institutes and businesses are engaged in research on what is known as flux welding. This is a type of arc welding, in which the weld pool is narrower and deeper. That not only improves the quality of the welding joint, it also speeds up the welding process. As far back as the nineteen sixties, the Russians had discovered that the weld pool will become narrower and deeper by the application of certain additives to the welding joint. As was only to be expected during the Cold War, the discovery was kept under wraps. The flux improver was said to be a complex mixture of a number of materials. A number of welding institutes, including some of renown, looked into the matter, and in the end, sand proved to be the best solution.

Middel: ‘By improving the penetration, the welding process can be speeded up, or kept at the same speed, but using a lower current. For example: you might process 3 mm steel using a welding current of 80 amps instead of 110 amps.’

In addition, the flux welding process ensures that the section of material thermally affected by the welding process does not vary as much in width from top to bottom. Normal arc welding produces a bowl-shaped welding zone section, with the result that after welding, the work piece will tend to warp.

‘The penetration improvement was a known effect, but the mechanism that caused it was unknown. My assignment was to find out what it is. Apart from its scientific importance, research like this has a practical application, too. If you know which factors affect the process, you also know where to look to improve it.’

So Middel investigated the effects of the presence of an additive on the welding arc and on the welding area. She confined her research mostly to gta (Gas Tungsten Arc) welding.

**Arc Trailing**

Middel had four possible explanations for the effects additives exert on the welding arc (voltage). The first idea was that the chemical reactions of the additives (association/disassociation) change the way heat is being conducted inside the arc, increasing the arc voltage. The second idea is that additives cause arc trailing: the arc remains behind with respect to the welding arc. As a result, the effective arc length increases and hence the voltage increases as well.

The third idea was that argon, which is used as an inert shielding gas in arc welding, has a high ionisation potential, i.e. it takes a high voltage to induce it to

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**Surface tension in relation to the temperature of iron.**

Remarkably, the curve for pure iron (A) slopes downward. In the welding zone, this results in an outward directed Marangoni flow. A small quantity of sulphur (B) or oxygen (C) in the liquid iron will result in a rising curve, i.e. an inward directed flow.
release electrons. The addition of materials with a lower ionisation potential could result in a lower arc voltage, but since the ionised molecules of the additive were now replacing the iron ions that formerly were supplied by the steel being welded, this did not appear to be a tenable proposition. The fourth idea to explain the effect of the additive may not have been entirely new, but Middel was one of the first to perform calculations on it. The additive (in this case silicon dioxide) decomposes. An welding arc contains a lot of free electrons. The decomposed additive attracts electrons (forming negative ions), causing the arc weld to contract, and the arc voltage to increase.

Idea number three, the forming of positive ions, turns out to be a dud. Ideas one and two however, the change in conductivity inside the arc, and the elongation of the arc, proved to account for some 10 to 15% of the observed phenomenon (the increased arc voltage). Middel’s calculations showed that the most important contribution by far is caused by explanation number four, the removal of electrons from the welding arc by the decomposition products of the additives, resulting in an decreased conductivity, and consequently, an increased arc voltage.

**Depth to width ratio**

Middel also investigated the weld pool. Why does the silicon dioxide affect the depth to width ratio of the weld pool?

‘The silicon dioxide on top of the weld pool melts, and forms a protective barrier,’ Middel explains. ‘As a result, the contact area between the arc and the weld pool decreases, causing the current to be intensified, which in turn increases the depth to width ratio of the weld pool.’

It appears that an inward directed flow is created inside the liquid weld metal. This could be the result of differences in surface tension (the so-called Marangoni flow) and Lorentz forces (forces that act on a charged particle moving in a magnetic field). The flow caused by the Lorentz force proved to be particularly important. Middel: ‘This is more than just theory, for knowing this we can start looking for materials that will contract the arc even more to increase the Lorentz current.’

Another result is that the effect of silicon dioxide on the arc decreases as the current in the arc increases. ‘The difference is not so large in the arc voltage as in the depth of the welding zone. This means that rather than any changes in arc voltage, it is the Lorentz force that accounts for the increased weld pool. As a consequence, welding with additives is still favourable at higher welding currents.’

Apart from silicon dioxide, Middel has tested several other additives to study their effect on flux welding, including iron and magnesium oxide, sodium, potassium, and calcium chloride, and a number of carbonates. The selection forms the fruit of her scientific endeavours.

‘They all are oxides that can produce negative ions, or materials with a low ionisation potential, such as sodium or potassium compounds, but silicon dioxide

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**Schematic diagram of the test setup.**

**Graphical interface of the control software for the test setup.**

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In addition to feeding control commands to the welding system, it measures the arc voltage in real time with an accuracy of millivolts. The readings may be used to track the welding joint using the newly developed seam tracking system.
proved to have the best effect’, Middel says. ‘Some other materials have a similar effect – and of these, iron oxide, i.e. rust is the most interesting – but the effect was not as pronounced.’

**Industry**

It’s all very interesting, but what is going to happen with the results of the research, supervised by Professor Gert den Ouden?

Middel: ‘Of course, you keep hoping that this will not be the last to be heard of it, and that other people will continue the Research. A patent would have been nice.’

‘Couldn’t industry take it on? ‘There are still a few things that need to be sorted out in the sensor system. For one thing, I only welded relatively simple patterns, none of them circular. I have written a computer program to handle the feedback to the welding robot control, but we still have to find out whether it will continue to work as a seam tracking system, whatever the circumstances.’

After decades of halting progress, flux welding appears to be on the way up. The Russians started the ball rolling, the Welding Institute at Cambridge spent years on the process, but in the end it was the Edison Welding Institute at Columbus (Ohio, usa) that managed to make the technique commercially viable. Now, the Dutch tno research institute has also taken up flux welding, for although the process is being researched all over the world, there are still a few experiments that remain to be done. For instance, sometimes welds obtained with additives have an irregular appearance, so they have to be worked on when the welding is over. This is caused by pollutants entering the welding zone during the welding process. Perhaps additives other than silicon dioxide can prevent this. Middel’s research results can also come in useful for welding methods other than tig welding, and for plasma cutting.

‘You can apply the results in various ways,’ she explains. ‘For example, a useful side effect when welding pipes together is that the seam tracking system can automatically shut down the welding system once the joint is completed, since the silicon dioxide will have disappeared from the bit it passed over previously. You can also use an additive to mark off a piece of metal that you want to cover with a metal coating, to improve the quality of full-depth welds, etc. The main attraction of my sensor system is that it is very simple and that it is not affected by welding fumes, glare, and other sources of interference that affect cameras.’

Even so, Middel thinks that the flux applications will be quicker off the mark than her sensor system, since that still needs to be worked on. In the meantime, Middel has started to explore new avenues, in the world of bearings.

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The effect of silicon dioxide on the arc voltage relative to the following parameters: arc length, welding current and travel speed.

As the arc length increases, the effect of the silicon dioxide on the welding arc increases.

As the current increases, the effect of the silicon dioxide decreases.

Remarkably, the effect of silicon dioxide on the arc voltage increases as the travel speed of the arc increases. This is caused mainly by the dragging effect on the arc. As the travel speed increases, the dragging effect becomes more marked.
Views of the welding arc, parallel to the direction of travel. Photograph A was taken without SiO2. Photograph B clearly shows that the welding arc contracts in the presence of SiO2. The contraction results in an increased arc voltage.

Views perpendicular to the direction of travel. No SiO2 was used for photograph A. As a result of the SiO2 in photograph B the arc starts to drag. The effect of this is that the effective arc length increases, and consequently, the arc voltage increases.

Depth-to-width ratio of weld pools with various additives. All additives result in improved weld pool penetration.

Schematic diagram of the various sub zones within the microstructure of mild steel Fe360 relative to the peak temperature in the weld metal and the heat-affected zone.
(A) Welding zone with SiO2, (B) Welding zone without additives. The weld in A is deeper and narrower, whereas the heat-affected zone is wider.

Stainless steel welds without (A) and with SiO2 (B) at a current of 250 amps.

Fully penetrated welds in stainless steel without SiO2 (A) at a current of 110 amps and with SiO2 (B) at a current of 80 amps. This shows that the addition of SiO2 reduces the energy requirement for an identical result. In addition, the weld is more symmetrical, which reduces warping during cooling.
Views of experiments with the new seam tracking system. The results confirm that the sensor works, although it still needs some work done on it before the sensor becomes commercially viable.

There are three basic ways in which SiO2 can be used for tracking a welding joint. Using the first option, the arc oscillates between two lines of SiO2. In this case, the arc voltage increases when the arc reaches the additive. The increase is used as a trigger to reverse the transverse motion of the arc. The second option also uses the increase in arc voltage. In this case the computer ensures that the arc returns to the additive line at regular intervals. The third option, in which welding takes place through the additive, makes use of the voltage reduction at the moment the arc leaves the additive.