SURFACE TREATMENT OF WELDING WIRES (ER70SS) AND ITS EFFECT ON THE WELDING CHARACTERISTICS

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Type ER70SS welding wire is offered with and without a copper coating. The welding characteristics of this often used welding wire, especially the process instabilities and the causes thereof when MSG welding, have been thoroughly investigated and the complexity of the topic has been explained in numerous publications [1-5]. In practice, the conveying properties of the wire electrode are repeatedly blamed for the process instabilities.

Steps taken by manufacturers to improve the surface finish and thus improve the welding energy flow to the contact tip in the case of poor welding wire flow, often had little to no effect [5,6]. In order to reduce friction, many welding wire manufacturers revert to coating the wire surface. What effect the wire coating has on the welding characteristic has been the subject of many a manufacturers internal study. Just how the coating alone effects the welding process is difficult to assess with any certainty.

20 – 60 mg/m^2 of coating material is often applied to the welding wire surface on which – depending on how the wire has been processed- 10 – 100 mg/m^2 of residual drawing lubricant is present. It can be assumed that the residual drawing lubricant influence decisively a continuous, uniform supply of the welding wire to the melt zone thus having a major effect on the weld.

In order to present the effects of deep cleaning a wire using a wet/chemical system that cleans the very pores of the wire surface, GEO undertook cleaning and coating tests. Coated and uncoated wire from several manufacturers was used.

The characteristics were then compared and documented following tests on a GEO designed weld testing unit Type (WWTE). The results are presented below:

Comments on the measurements made on the GEO Weld Testing Unit Type WWTE:

Comparison parameters of the welding characteristics of the wires were made simultaneous. When welding and not welding and presented one above the other on the timeline:

- Feed resistance/friction F (in Newton);
- Welding current I (in Amper);
- Welding voltage U (in Volt);
- Wire line speed S2 (in meter/minute) immediately after the feed rollers. The amount of standard deviation σ_{S2} of this wire speed is an indication of the amount of slip on the feeding rollers;
- Wire speed S3 (in meters/minute) measured directly in front of the welding gun. The amount of standard deviation σ_{S3} of this wire speed is an indication of contact problems or wire slippage at the contact tip.

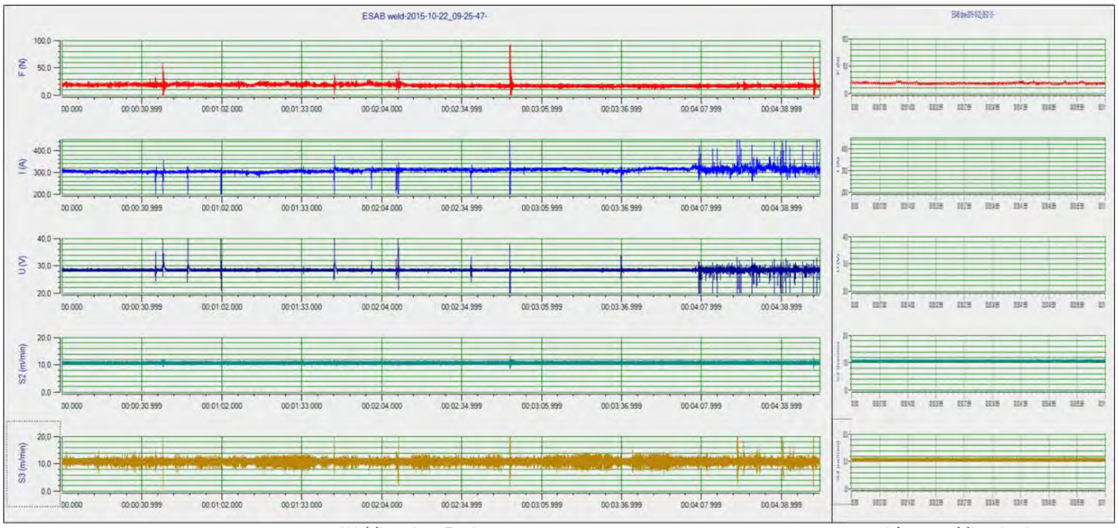
The values were then compared and statically evaluated.

By comparing the measurements taken during welding and not welding it is possible to determine the origin of any process instability.

Item 1 shows the protocol of the measured values made on a GEO welding station using a normal welding wire type (ARISTOROD 12.50).

Welding protocol:	ESAB WP015
Data files:	ESAB ohne-2015-10-22_09-21-31-
	ESAB weld-2015-10-22_09-25-47-

Manufacturer:	ESAB	Shielding gas:	Ar+18%CO2
Wire type:	Aristorod 12.50	Liner type:	steel
Diameter:	1,2 mm	Wire speed (m/min):	10
Surface processing:	ESAB (~ 60 мг/м^2)	Welding speed (cm/min):	40



	Welding time 5 minutes					without welding 1 minute		
Measured parameters/ Messwerte	F (N)	I (A)	U (V)	S2 (m/min)	S3 (m/min)	F (N)	S2 (m/min)	S3 (m/min)
Mean/ Mittelwert	18,3	309	28,5	10,8	10,8	19	10,7	10,8
Delta /maximale Spreizung	96	471	81	4,7	36	12	1,56	2,6
Standard deviation/ standard Abweichung	2,7	14	1,6	0,22	0,94	1,5	0,18	0,33

Item 1: Welding protocol example..

Left – plotted measurement curve during welding (5 minutes);

Right – without welding (1 minute)

For clarity only the following curves are used:

- F (N) – feed resistance
- S2 (m/min) – Wire speed immediately after the feed rollers
- S3 (m/min) – Wire speed S3 immediately in front of the welding gun

Bare Wire (no copper coating)

Bare welding wire is often cleaned after the wire drawing process in order to reduce residual drawing lubricants and metal particles. Brushing or textile [7] are often used.
However, these cleaning methods only remove the contamination from the visible surface of the wire. Deeper contamination remains. Even the steps taken by the wire producer to spray the final drawing die is of no use. The contamination from drawing soaps (Ca or NA soaps) remains in the micro cracks and pores of the wire surface. The samples examined show that normally the surface of the copper coated wire is far better than the non-coated wire (See photos 2 and 3)

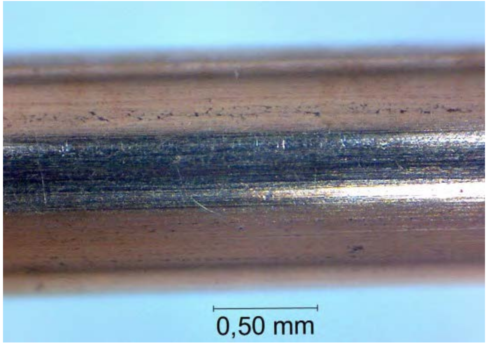


Photo 2: Surface of copper coated wire

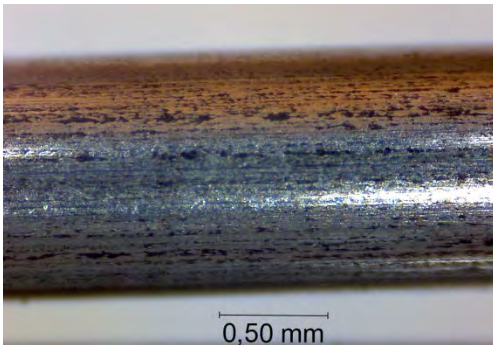


Photo 3: Surface of non-copper coated (bare) wire

Without welding the measured feed friction and wire feed value (S 2 and S 3) show similar values. However, when welding, albeit near equal feed resistance, the variation in wire speed S 3 at the welding gun is much less with bare wires than with copper coated wires. (Photos 4 and 5)

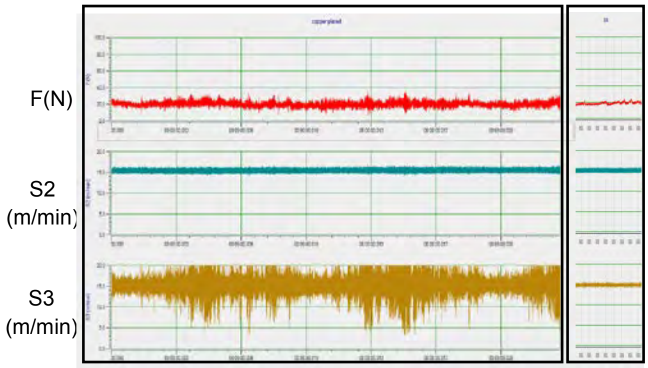


Photo 4: Measure curves of a copper coated wire when welding with 350A, σ_{S3}= *2,22 m/min* and when not welding, σ_{S3}= *0,22 m/min*

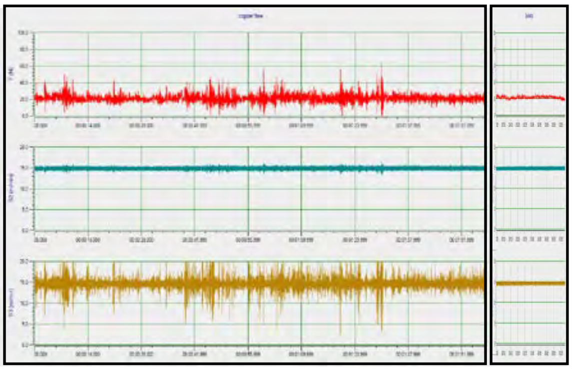


Photo 5: Measure curves of a bare wire when welding with 350A, σ_{S3}= *1,20 m/min* and when not welding, σ_{S3}= *0,25 m/min*

These variations only occur in the welding gun when welding and can be attributed to the current passage at the contact point. From a practical point of view the welder experiences a vibration and attributes this to poor feeding of the wire.

This phenomenon is initially difficult to understand because the specific coefficient of friction of copper is less than that of steel (by a factor of > 10) and the surface of copper wires has a better finish (see Photos 2 and 3). Further observation shows residual lubrication on the wire surface has a considerable influence on the material characteristics and on the contact tip.

Photos (6 – 9) show the ends of various bare wires (no copper coating ER70S6, High alloy, FCW) taken from the contact point. All wires ends show clearly micro welding seams.

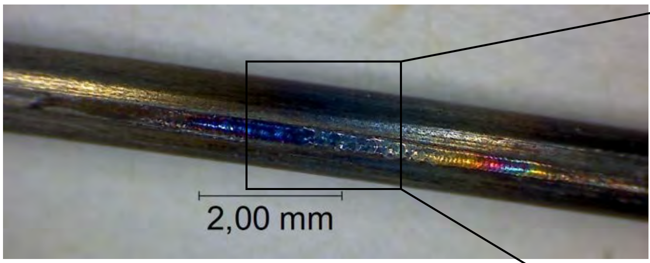


Photo 6: The micro welding seam at the contact area from the contact point (Photo 10). Solid welding wire ER70S6, Quantity of contamination:
Total about 900 mg/m^2
Quantity of CH about 150 mg/m^2

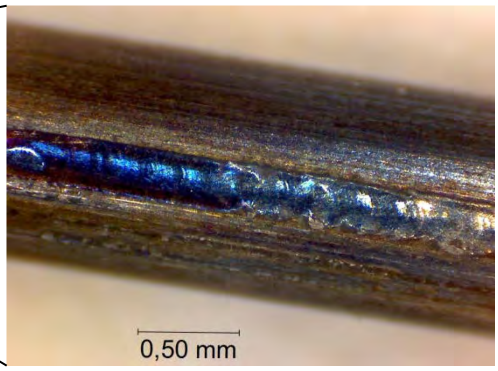


Photo 6.1: Enlargement of photo 6

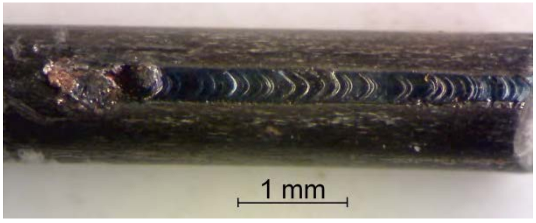


Photo 7: The micro welding seam at the contact point of FCW diameter 1,4 mm, drawn with Ca- and Na Soap, Remaining SH qty about 300 mg/m^2

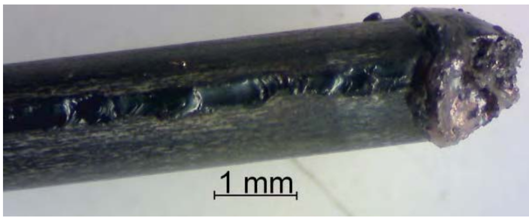


Photo 8: Micro welding seam at the end of a FCW diameter 1,6 mm. Residual drawing lubrication: Graphite

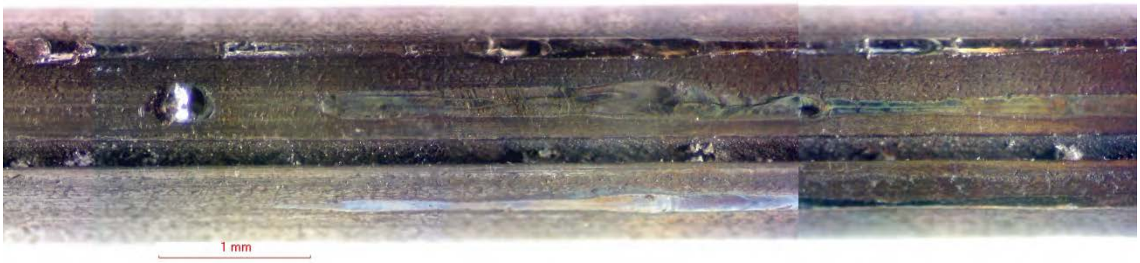


Photo 9: Several micro welding seams on a FCW dimeter 1.4 mm. The wire was cleaned and then coated with graphite.

In other studies [5] the creation of micro welding seams is attributable to the wear of the contact tip.
The wear at the contact point was generated by “topographical irregularities of the wire surface as well as layers of residual contamination and coating materials with poor electrical qualities which in turn increase the resistance between wire surface and the contact point” [5].
However, the micro weld seams shown in photos 5 – 9 were created when welding with new contact points. There was no wear at the contact points (Photo 10) after about 20 minutes of welding. It was more like a deposit (Photo 11 and 12).

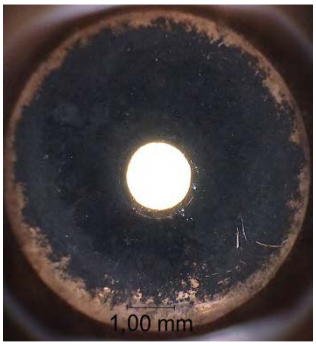


Photo10: Contact tip after a 5 minute welding test with wire as shown in photo 5

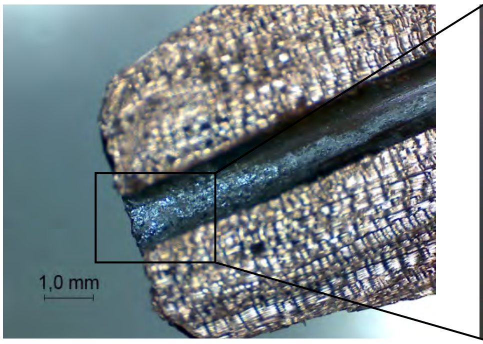


Photo 11: Bisected contact point after a 20 minute welding test with wire as shown in photo 7

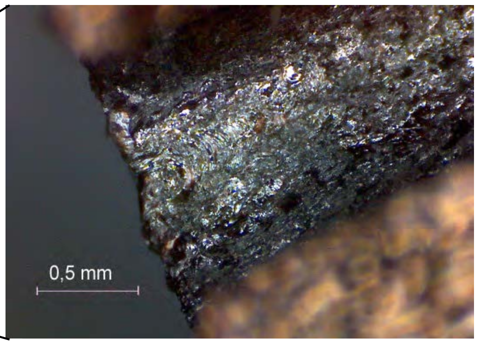
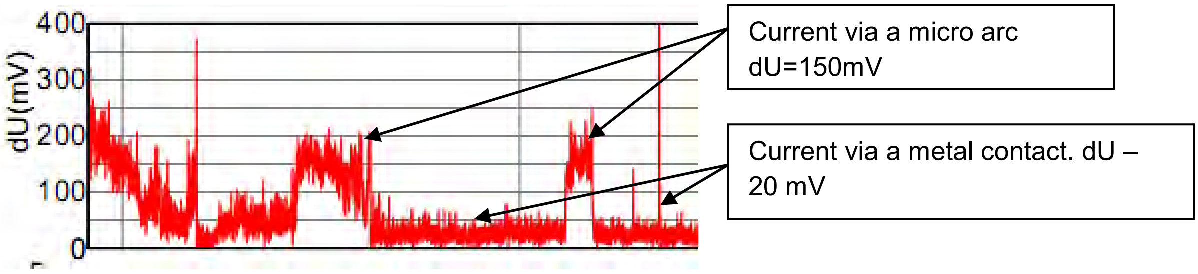


Photo 12: Enlargement of photo 11

We feel the creation of micro welding seams does not originate from wear at the contact point but may come from the previously mentioned "topographical irregularities of the wire surface". Also from layers of residual contamination and coating material with poor electrical qualities [5].

The photos 6 – 9 shows that it appears residual drawing and coating materials lead to current flow on the inside of the contact tip is mainly transferred via a permanent micro arc and not via a metal contact. This permanent micro arc leads to the creation of micro welding seams. Recognizably current passage through a micro arc results in an increased voltage drop and heating of the contact point.
Depending on the wire surface and the amount of coating material, the current can jump back and forth between the metal contact and the arc during the welding process. This is shown in the in the voltage drop graph (Item 13)



Item 13 Voltage drop in a contact point during a welding process

In order to document the effect of residual drawing and coating materials on the formation of micro weld seams, the uncoated welding wire was first cleaned using an ultrasonic cleaning system which removes all contamination from all possible micro cracks and pores in the wire surface (Surface shown on Photo 3, 3 and 6.1). Following the ultrasonic cleaning the wire was tested by holding it against a white filter paper moistened with white spirit. It left no trace of dirt and on heating the wire to >700 degrees C no smoke was detectable. Evidence of a wire free of all surface contamination. Welding tests with this clean wire produced zero micro weld seams. Slight erosion at the contact point was observed in a few cases (Photos 14 and 14.1). On some of the wire examined the contact point was no longer detectable.

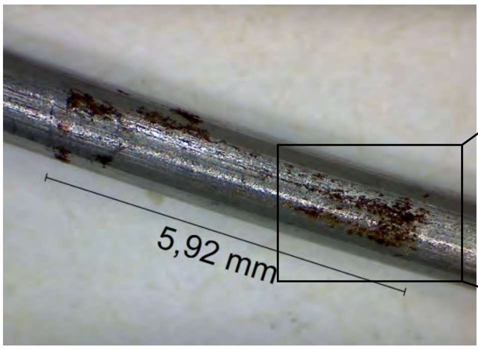


Photo 14: Typical appearance of a contact point after current transfer via a metal contact. (from the middle of the contact point)

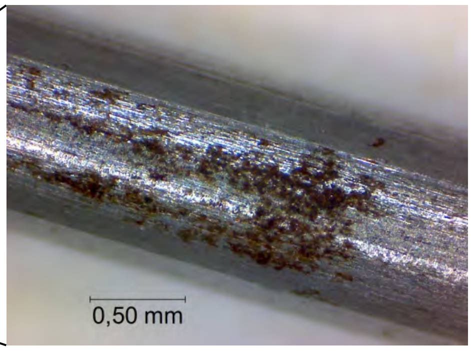
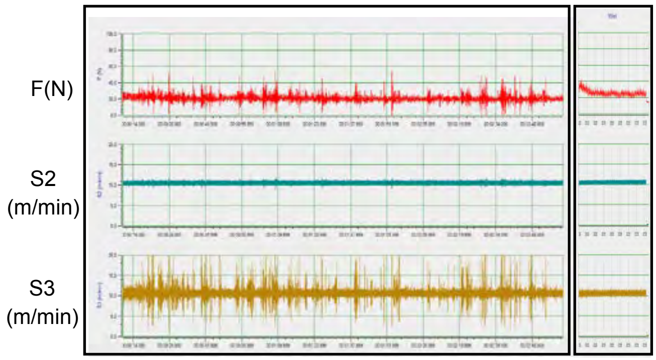


Photo 14.1: Enlargement from photo 14

With a very clean wire surface the current flow is transferred 100% via a metal contact. Cleaning the micro surface cracks and pores of the wire surface results in a measurable improvement in contact characteristics. It is noticeable that albeit a significant increase in the feed resistance (from 22 N to 39 N) there is a definite reduction in wire speed variation. (Item 15 and 16)



Item 15: Measurement curves taken during welding tests on bare wire ER70S6, Ø1,2 mm (Contact point as shown in items 6 and 6.1).

Welding with welding current 300A

Average feed resistance value ***F** =22 N*

Wire feed speed 10,5 m/min

Standard deviations:

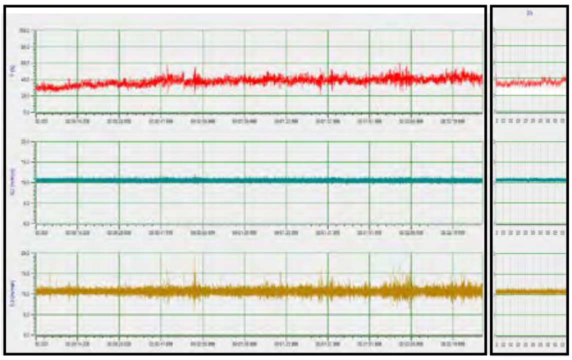
σ_{S2}= 0,24 m/min (behind feed rollers)

σ_{S3}= 1,57 m/min (at the welding gun)

Without welding:

σ_{S2}= 0,21 m/min (behind feed rollers)

σ_{S3}= 0,36 m/min (at the welding gun)



Item 16: Measurement curves from tests using the same bare welding wire ER70S6, Ø1,2 mm following ultrasonic cleaning of the wire (Contact point as shown on Item 14 and 14.1)

Welding with welding current 300A

Average feed resistance value ***F** =39 N*

Wire feed speed 10,5 m/min

Standard deviations:

σ_{S2}= 0,21 m/min (behind feed rollers)

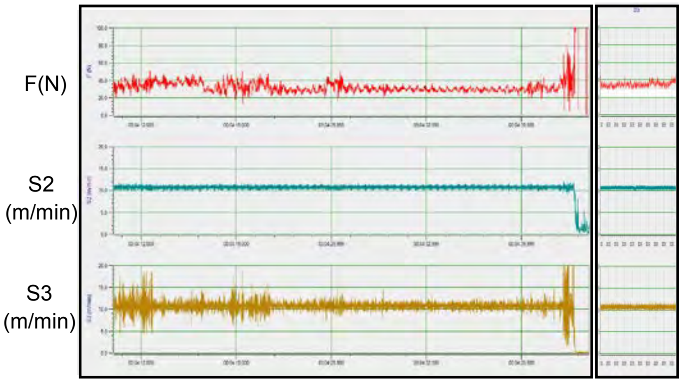
σ_{S3}= 0,8 m/min (at the welding gun)

Without welding:

σ_{S2}= 0,19 m/min (behind feed rollers)

σ_{S3}= 0,32 m/min (at the welding gun)

During further welding tests with clean welding wire (ultrasonic) sporadic high vibrations were observed sometimes combined with “welding up” of the wire at the contact tip (Item 17).



Item17: Measurement curves from the same wire as in Item 16 taken from a later welding period. The wire is “welded up” in the contact tip causing the welding process to stop. The Items 19 and 21 show the contact point of the wire in question.

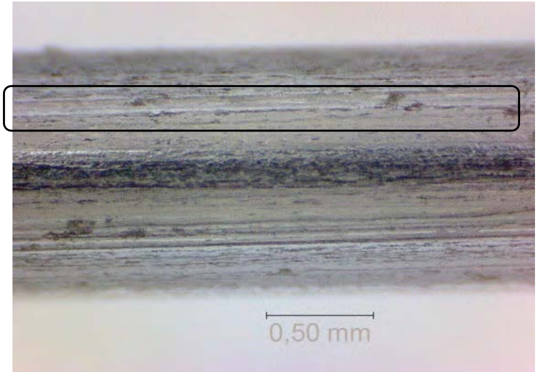


Photo 18: heavy surface damage (welding test on Item 17). It is a scored groove about 10 µm wide and 2 µm deep with raised edges for a length of about 80 cm.

It was verified that these vibrations were caused by these damaged surface areas (Item 18). These heavily damaged areas lead to a reduction in the wires contact surface at the contact tip resulting in:

- Current reduction;
- Dipping of the wire into the molten pool creating splash and jumps in the measurement curves; Increase in voltage and formation of an arc and melting of metal at the contact area on the inside of the contact point (Item 19 – 21).

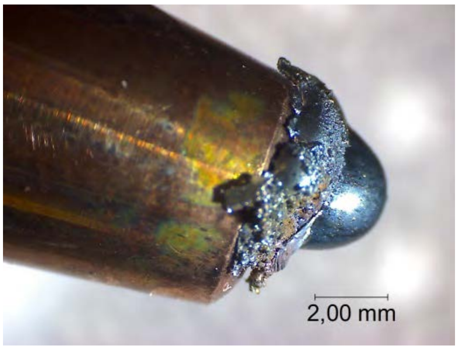


Photo 19: Contact tip with the inner “welded up” and outer burnt wire. Same wire as shown on item 18.

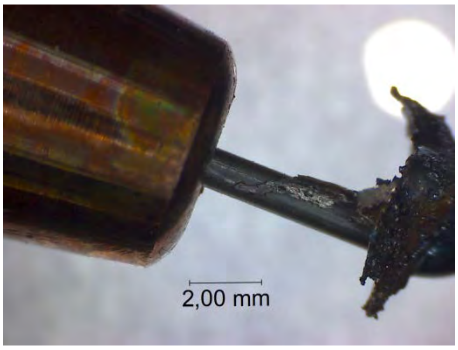


Photo 20: same contact tip showing the wire pushed from behind out of the contact tip.

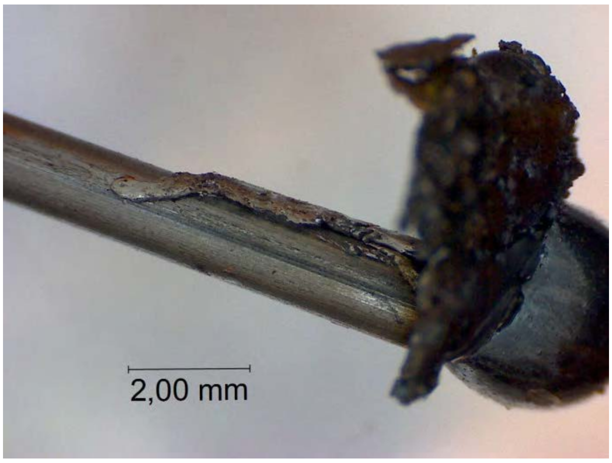
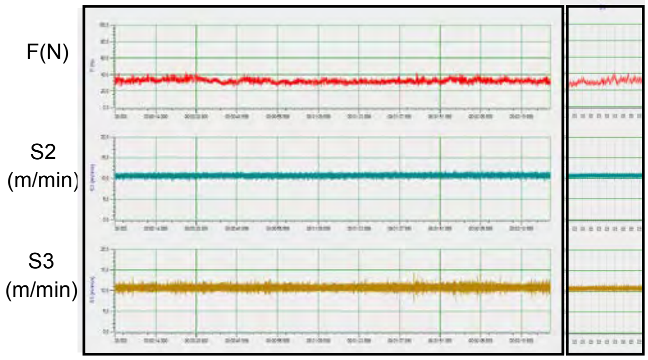


Photo 21: In this enlargement the score grooves, where the arc originated, can clearly be seen. Furthermore it can be seen that the wire was not welded to the contact tip. The major part of the cooled metal blocked the wire in the bore of the contact tip.

By applying a small quantity (< 15 mg/m^2) of a special lubrication, the vibrations and the feed friction could be considerably reduced. (Item 22). The lubrication used WWF-U300 assures a constant sliding effect even at high temperatures and prevent sticking of the wire. During lengthy welding tests sporadic deviations in the measurement curves were seen, however sticking of the wire in the contact tip was totally eliminated.



Item 22: Measurement curves from welding tests with bare wire, ultrasonically cleaned and then coated with WWU-U300 (< 10 mg/m^2).

Average feed resistance ***F** = 32 N*

Feed rate 10,5 m/min

Standard deviations:

σ_{S2}= 0,25 m/min (behind feed rollers)

σ_{S3}= 0,52 m/min (at welding gun)

Without welding:

σ_{S2}= 0,22 m/min (behind feed rollers)

σ_{S3}= 0,34 m/min (at welding gun)

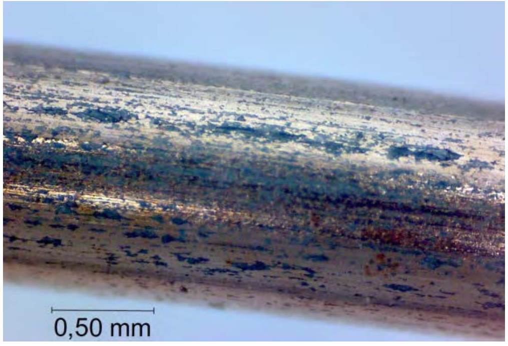
The contact area at the contact tip was not visible.

Copper coated wire

The series of tests with contaminated, copper coated wire showed, as detailed above, that when welding, the vibrations alternatively the standard deviations in the wire speed σ_{S3} also at very low feed resistance values, were always higher than when welding with bare wire (Item 2 and 3).

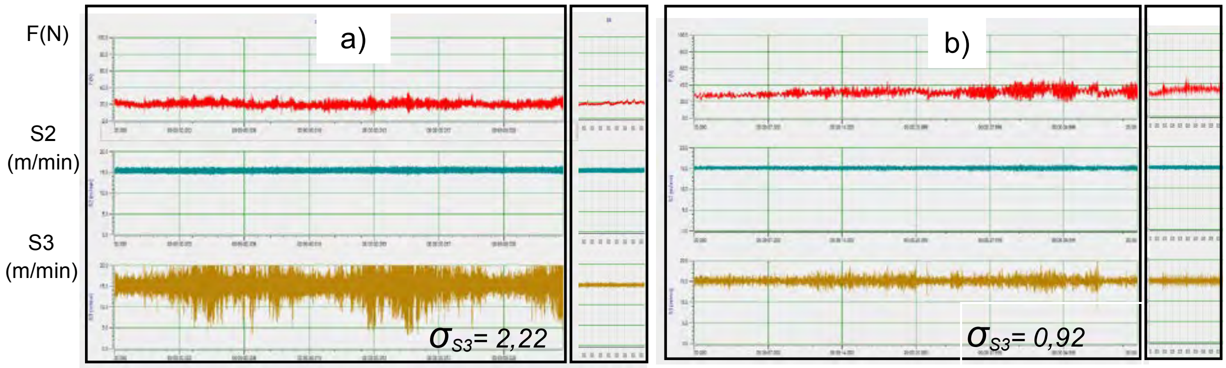
By applying a small quantity of WWF-U300 lubrication (< 10 mg/m^2) it was possible to prevent a “welding up” of the contact tip, but reduction in vibration was minimal.

Considering the conductivity of the copper, which is more than 10 times better than steel, and thus accompanied by a much lower voltage drop in the contact tip (as proven in other studies (10)), this phenomenon is, as mentioned previously, at first glance incomprehensible, especially considering that the copper coated wire surface, under the microscope, showed fewer defects (see photos 2 and 3). Attempting to explain the circumstances, the copper coated wire, like the bare wire, was also ultrasonically cleaned. Item 23 shows clearly how the ultrasonic cleaning exposes many hidden defects in the wire surface.



Item 23: Surface of the same copper coated wire as shown in Item 2 after ultrasonic cleaning which removes contamination from micro cracks and pores.

Following welding tests have proven that after ultrasonic cleaning a significant reduction in vibrations / standard deviation values of the wire speed σS3 was achieved in spite of an apparent lower quality surface finish and a higher feed resistance. (Bild 24).



Item 24: Comparison of measurement curves of the copper coated wire

a) Condition as per Item 2
b) Following an ultrasonic cleaning. Condition as Item 23

Furthermore the test results give reason to assume that the copper coating does not form an even metallic contact with the wire surface. Possibly the process at the contact area occurs in such a manner that the copper coating melts first at the contact tip and sticks to the wall of the bore in the contact point (copper to copper). Owing to the relative speed of the wire the melted copper does not adhere to the hot zone where the current transfer takes place but in a cold zone in the direction of the wire feed. A metal deposit is formed that briefly increases the friction, noticeable when measuring the wire feed rate and noticeable by the welder in the form of vibrations. The situation is shown in Items 25 and 26.

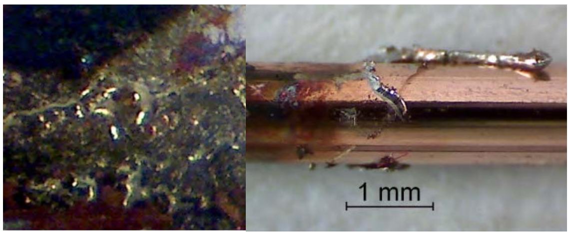
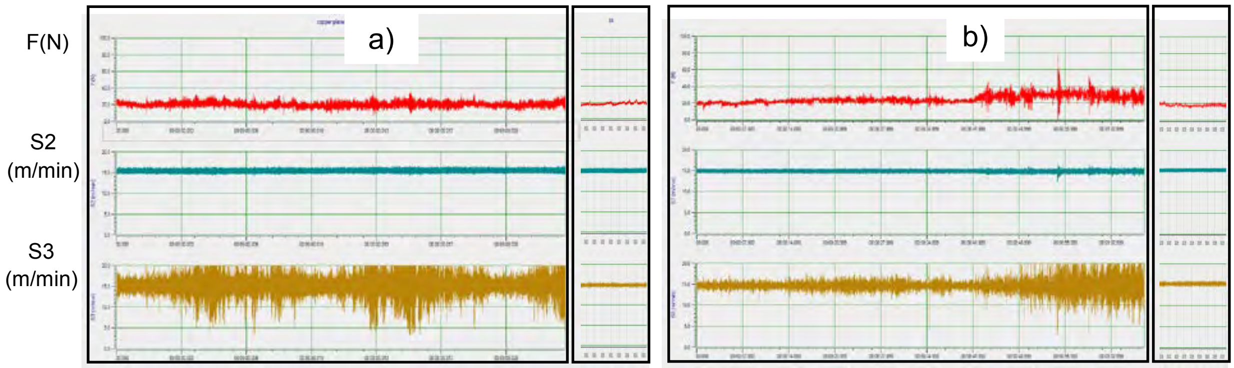


Photo 25: molten copper on the wire surface from the contact tip

Photo 26: Copper deposits in the contact tip (located about 3 mm deep)

The vibrations can be reduced, for example, by the application of a high quantity of graphite or similar conductive lubricant (Item 27). For the test in question this was achieved by completely filling the spiral feed tube with graphite. The resulting effect only functioned while there was sufficient graphite in the spiral feed tube. As the quantity of the graphite in the spiral feed tube reduced, the vibrations increased.



Item 27: Comparison of the measurement curves of copper coated wire:

a) Feed in a standard steel spiral feed tube
b) Feed in the same steel spiral feed tube filled with graphite. It can be clearly seen that after about one minute of welding, as the graphite quantity is reduce the vibrations increase.

After a further approximately 3 minutes operation and a further reduction of graphite, residual graphite can be seen on the wire resulting from the welding test (Photo 28).

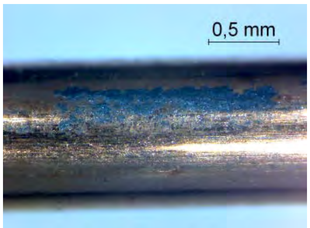


Photo 28: an approximate 15 to 20 µm thick graphite layer on the wire surface. Wire taken out of the graphite filled spiral feed tube after the welding test Item 27 b).

Resumee

Non-copper coated wires with a surface showing residual wire drawing lubricants can result in a good weld with minimal spray and vibrations if the residue is evenly distributed and at the same time reduced. The same results are possible by using a suitable wire coating lubricant. This does however result in a higher voltage and temperature drop at the contact tip and high hydrogen content in the weld.

Ultrasonic cleaning of non-copper coated wire not only leads to a drastic reduction of hydrogen it also ensures:

- a positive metallic contact at the contact tip;
- a reduction in voltage drop and heat developed in the contact point;
- a reduction in vibrations and better weld characteristics

The negative effects of rough wire surface defects can be significantly reduced by the application of a suitable lubricant. For wires without surface defects a rust prevention coating is advisable.

From tests using copper coated wires it can be seen that there are three possible ways to reduce, or even avoid vibrations:

1. Ensure an in depth cleaning (ultrasonic) of the wire prior to copper coating thus achieving a clean metallic contact surface or a thorough chemical contact of the copper coating.

2. Welding up of the contact point can be prevented by the use of a lubricant (for example WWF-U300 with increased anti-adhesion characteristics), that does not lose its lubricating qualities at high temperature and at the same time prevents adhesion. The vibration cannot be totally eliminated but they can be considerable reduced.

3. The application of a conductive coating increases the area of the contact point. For a relevant increase of the contact area an unrealistic amount of coating would be necessary. *****

Tests have shown that an in depth cleaning (ultrasonic) of the wire surface is recommended.

The tests were undertaken at the company GEO-Reinigungstechnik GmbH under the direction of Mr. Richard Fichtner.

[*] *Note:*
As the distance from the wire surface to the surface of the contact tube at the contact point increases by the square, a doubling of the contact area would necessitate a 4 fold increase in the coating material volume. Owing to the fact that the conductivity of the coating material is usually potentially less than that of metal, it would require a large quantity to obtain a relevant increase at the contact point. For example: To improve the contact point by a factor of 2, using graphite with a specific resistance of 8 Ohms mm2/m (with copper 0.0017 Ohm mm2/m) it would be necessary to increase the contact surface 470 times. 470 squared increase of the coated material volume which is no longer realistic.

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