Welding wire surfaces and their effect on the MSG and TIG process

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Hardly visible to the naked eye and therefore often underestimated: The surface condition of welding wires has a strong influence on the feeding properties, current contact, arc stability and welding result.

Using measurement data and high-resolution images, an attempt is made to find answers to the following questions: Are matte or shiny surfaces better for GMA welding?
How do you differentiate between "clean" and "dirty" wires during incoming inspection?
What are the effects of a contaminated wire surface during TIG and MAG welding?

Content:

1 Welding wires requirements

The continuous development of welding wires is an essential contribution to reducing product and welding costs. The properties of welding wires have a direct influence on the welding process and the welding result. Depending on the application, the respective requirements can be weighted differently:

- Favorable price with short delivery times
- Insensitivity to corrosion during storage and thus high durability and availability
- Good feeding properties in the wire feeding system
- Good flow and wetting behavior during welding
- Active contribution to the prevention of weld defects such as pores and binding defects
- High toughness with high weld metal strength to minimize weld cross-sections

Relatively independent of these technical properties, customers increasingly demand a "nice shiny" and clean welding wire as the first quality criterion. The visual appearance of the wire is increasingly being accorded such high importance that even the smallest surface defects visible on the surface lead to complaints without any testing of the welding behavior having been carried out at all.
The difficulty in optimizing the above points is the mutual influence between welding wire and welding process parameters. If there is a change of wire manufacturer with the same wire rod analysis for guide values as before and a procedure qualification test is carried out according to ISO 15614 with the same welding parameters, the influence of the wire surface on the welding process and the weld metal becomes more clearly visible.

2 Production residues on wire surfaces and their effect on the welding process

Basically, the surfaces of welding wires are technical surfaces that, upon close inspection, exhibit a variety of surface defects. As a starting material for the production of solid welding wire electrodes, hot-rolled wire is usually used in diameter 5.5 mm. The surface of this pre-material is always covered with a layer of scale, which must be removed before welding wire production. This is typically done by pickling and/or grinding the wire surface. Descaling roughens the wire surface. The increased roughness is necessary for the drawing process to ensure adequate lubrication of the wires in the drawing tool.

For degrees of deformation up to about 20% reduction in cross-section, the roughness of the wire rod is essentially preserved. For larger cross-section reductions, which are common for MSG welding wires, the drawing conditions dominate the roughness of the drawn wire.

The wires are drawn with final speeds between 10 and 40 m/s (i.e. 36-144 km/h). There are currently no sensors available on the market that could reliably detect even macroscopically large defects (for example, missing copper plating over several meters) in production. Thus, macroscopically visible surface defects are also to be accepted as concomitants of wire production, as long as they do not negatively influence the feedability- and contact behavior of the wire electrodes.
The residual roughness present on the end products, the drawing agent residues embedded in them and any non-metallic particles pressed into the surface are therefore not only unavoidable as production residues, but are also partly necessary for wire production. A reduction of residues unfavorable for welding can be achieved by process control during wire drawing as well as by a more or less large effort of post-weld cleaning operations.

Not all manufacturing residues need to be designated as undesirable. Residual lubricants on the surface may well improve wire feeding as a sliding and contact aid. Furthermore, for some materials it is unavoidable to provide the wire surface with a basic adjusted corrosion protection layer.
Contrary to what is often still believed, copper plating does not provide corrosion protection for the wire electrodes. The copper plating has the main task of enabling good contacting in the contact tube and at the same time serves as a metallic lubricant in the last pass of the wire production and in the contact tube.

Looking at wire surface with a microscope, one can see scoring from the drawing die, scratches from any contact with guide, deflection, and straightening rollers, and remnants of pickling or grinding roughness. In each of these recesses, drawing agent residues will accumulate during the drawing process and, in the case of incomplete cleaning by pickling and/or grinding, residues from the scale of the wire rod.

Causes of scale residues may be wire rod defects [1], such as scratches, or inadequate cleaning during wire drawing in the wire drawing mill. Since wire rod scale is hard and brittle and does not have the necessary elongation at break for the multi-stage solid forming of the wire, it is torn open during the manufacturing process and finely distributed into the surface in fragments. The oxide particles hang on the wire surface without a firm bond and can detach during subsequent wire transport in the conveyor hose of the welding system.
This can result in a nest-like accumulation. Once embedded in the wire core, they can scrape off further particles from the wire surface up to a nest formation. If a nest detaches from the conveying hose as a whole shortly before a blockage occurs, a localized, clearly visible entry into the melt can lead to subsequent pore, binding defect and slag formation.
Wire rod scale residues is also undesirable from the point of view of the wire rod manufacturer, because the hard particles increase the wear of the drawing dies. During the multi-stage forming process, deposits of drawing agent residues are formed under the oxide particles embedded on the wire surface, which can no longer be removed or can only be removed at great expense by the final wire cleaning system.

3 Effects on the TIG process

The TIG process shows the effects of a contaminated wire surface most clearly, since it is metallurgically "inert" and does not provide for slag formation with subsequent removal. It does not matter whether the contamination originates from a workpiece surface that has not been completely ground to a bright metallic finish or from an oxide-contaminated wire surface.

The following findings were observed during welding and subsequent destructive testing:

- Poor flow properties and wetting with the risk of bonding defects on the weld flank > steep welding beads instead of flat transitions to the base metal as desired.
- Larger visible pores on the bead surface or hidden below the surface as micropores, which can only be opened and thus made visible by grinding off half the layer thickness
- Unsteady bath movement during welding > visible oxide deposits form in the molten metal, which are successively precipitated, either as isolated slags on the bead surface or also as smaller oxide particles on the bead edge
- Accumulations at the end crater: The slags are concentrated with the melt front during welding in the end crater and are visible as a clear accumulation in the form of an "oxide cap" at the shutdown point
- Enclosures of non-metallic inclusions (metallographic evaluation)
- Increased strength with very low toughness > oxygen in the steel makes it hard and brittle.

4 Effects on the MAG process

The oxide particles embedded in the wire surface primarily have a negative effect on the current contact and make wire feeding more difficult by increasing the number of friction points of the wire in the conveying hose (see Figs. 1 and 2). Extensive comparative measurements of different welding wires prove that the current transfer in the contact tip is mainly responsible for the conveying problems. Since the particles partially protrude from the surface, they additionally increase the coefficient of friction and lead to a significant increase in the total conveying resistance or the required conveying force.

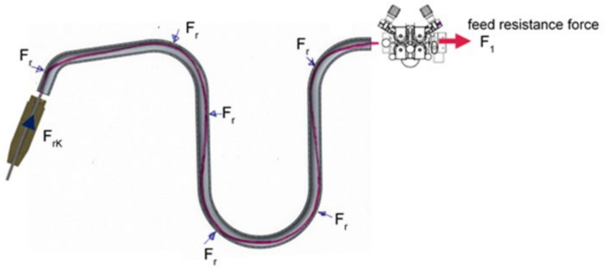

Fig. 1: Wire feeding with normal friction contact

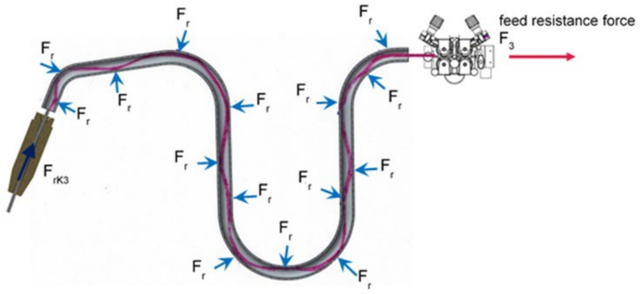

Fig. 2: Wire feeding with increased friction contact

Depending on the wire feed unit and the wire feed length, disturbing wire speed fluctuations with slip-stick effects cause problems for the process. The result is sometimes strong fluctuations in the free wire length (stick-out) and thus irregularities in the weld penetration depth. In multilayer welding, zonal crack-sensitive coarse grain zones can occur due to a reduced weld penetration depth with reduced intermediate layers tempering.
In the case of current-controlled burner spacing control, unstable control behavior sometimes occurs with strongly fluctuating burner spacing and undesirable spatter formation, which increases the wear of the current contact nozzle.

The directly remaining input of oxide particles and the associated additional oxygen, which were observed to be disadvantageous in TIG welding, could not be observed in MAG welding, since slag is generally formed anyway via the active gas component in the shielding gas, which is subsequently removed.

5 Test methods for evaluating wire surfaces

Unfortunately, there is currently no testing standard or equivalent standard specification for wire surfaces that a user could refer to when ordering wires. While wire rods are completely visually accessible, the user can only inspect the upper layer of wire coils.
In any case, these are random tests, which do not always reliably capture the effects of variations or instabilities in the wire manufacturing process. Special importance is therefore attached to inspections during production.

The following tests can be performed during or after production:

a) Microscopic examination of the wire surface with focus stacking
b) Scanning electron microscopy at low magnification
c) Chemical analysis
d) Wipe test / “Tissuetest”
e) Welding test
f) Welding Wire Test Equipment “WWTE” & WWTE TV” (details upon request)

Excursus: Benchtop unit "WWTE TV" from GEO for testing MIG/MAG welding wires

The device, specially developed for testing MIG/MAG welding wires, is used to measure the feeding resistance and the voltage drop in the contact tip in the run without arc under the conditions adapted to the welding process. In numerous tests with different welding wires (steel, Ni alloys, aluminum), which were carried out by GEO itself as well as by the customers using the device, a very good correlation of the measurement results with the welding results could be proven (see also later in chapter 7).

6 Cleaning methods during wire production

As already described in the introduction, the wire rod must first be freed from scale in wire rod production. Depending on the descaling technology used in wire production, the wire is already ordered from the steel manufacturer as suitable "for mechanical descaling" (bend descaling/grinding) or "for chemical descaling" (pickling). For mechanical descaling, the wires are rolled at higher final rolling temperatures to produce the thickest possible scale layer formation. In contrast, wires rolled for chemical descaling have a very thin scale layer, which is pickled off by immersing the entire wire rod coil in hydrochloric acid.

The following procedures are established:

- Scale breaking: Bending the wire alternately usually in four or more planes. This stretches the outside during bending. Since the scale layer has virtually no plastic deformability, it partially breaks and falls off. In the process, the inside is compressed and the scale is also broken, but pressed into the metal. When the bending direction is changed, the scale residues remaining on the previously stretched side are correspondingly pressed into the metal by the upsetting. In the end, you get a wire that is visually free of scale, but with many oxide particles, some of which are deeply embedded in the metal. These particles cannot be captured by subsequent brushing and do not disappear in the drawing process, but are distributed in a refined manner far into the wire surface.

- Grinding: The wire surface is ground with abrasive paper across the wire axis at a removal rate of up to 0.1 mm. This removes the scale residues somewhat better than with scale breaking, but again not completely. In addition, the scale particles remain in the sandpaper and are partially crushed into the softened surface. The state of the art today are 2-stage sanding systems in which coarse and fine sandpapers can be combined one after the other. The structure of the wire surface after grinding is not suitable for feeding sufficient quantities of drawing soap into the die. Therefore, a coating with a salt lubricant carrier must be applied before the first draw.

- Pickling: is currently the most thorough method of removing oxide residues. In the pickling line, the entire wire rod coil is pickled by immersion in hydrochloric acid. The roughness of the wire achieved in this process is essentially the result of the hydrochloric acid attacking the wire surface. The metallic bright and roughened surface is naturally highly active in air and must be protected against corrosion by suitable passivation measures and correspondingly good storage conditions. Pickled wires generally have very good drawing properties due to their surface structure. Residues of passivating agents and any rust film formed during storage can be removed very easily by the grinding equipment described above.

In the following drawing operations (for a 1.2 mm inert gas wire typically 14 draws), it is important from the wire drawing point of view to ensure that the lubricating film between the drawing die and the wire does not break at any point. As soon as the tool and wire have metallic contact, drawing grooves are formed. In the case of two-dimensional and prolonged contact, friction welding occurs, which leads to the destruction of the tool and thus also of the wire.

If the aim is to achieve the thickest and most stable lubricant film possible on the wire surface during production, this lubricant film must be removed as thoroughly as possible for copper plating and for the end product.

Copper plating of the wire is done in a sulfuric acid solution. In this process, the copper plating system inherently takes over the essential part of the wire cleaning. Additional cleaning stages can be realized by reducing the lubricant deposits in the last draws before copper plating, additional brushing, special cleaning agents instead of drawing soaps, or an additional pickling stage placed before copper plating.

After copper plating, the final draw is performed as a single drawing operation with relatively small cross-sectional reduction. This so-called polishing pass is not carried out with a dry lubricant, but with a basic drawing emulsion as lubricant. The copper crystals separated on the wire surface are leveled in a so-called polishing pass, so that the macroscopic appearance of the wire appears shiny and uniformly copper-plated (see Fig. 6).

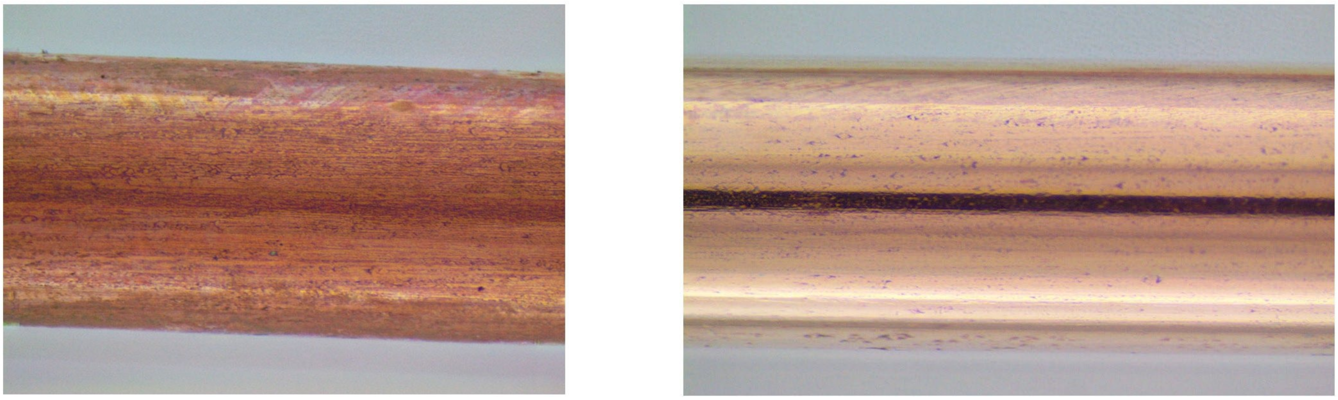

Fig. 6. Wire surface before (left) and after polishing pass (right)

7 Current contacting of smooth and rough or matte wires in comparison

Many of the investigations carried out with the WWTE and WWTE TV test systems (see Figs. 7 and 8) have shown that the causes of the wire feeding problems in the MIG/MAG welding process lie in the contact tube during current transfer (see also "Surface treatment of ER70S-6 welding wires" [2]). Here, in addition to the cleanliness of the wire surface, its texture also plays a very important role.

The surface finish of welding wire can be divided into shiny (bright drawn) and matte (matt drawn) surfaces according to the visual appearance of the surface. The so-called matte drawn surfaces are more likely to be found in stainless steel or Ni alloys. Most of the remaining wires have bare drawn surfaces.
Based on numerous responses from users, it became clear that glossy surfaces are a key selling feature. In addition, many wire users or welders believe that a "sparkling" wire is better to weld. In some cases, this also represents one of the reasons for copper plating. The view that a stable, smooth wire run can be expected with an optically shiny wire surface could not be confirmed by investigations carried out by GEO for various welding wire manufacturers to clarify complaints about wire feeding problems despite a "shiny" surface.
Therefore, further comparative investigations were carried out with a focus on surface texture. The mean and standard deviation of the voltage drop in the contact tip of identical wires with shiny and matte surfaces were compared.

Fig. 7. Welding wire test system WWTE by GEO

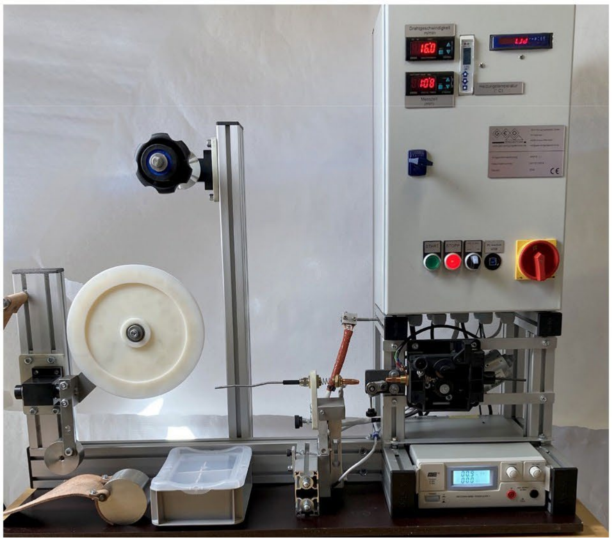

Fig. 8. Welding wire test system WWTE-TV

The measurement results shown in figures 9 to 14 indicate cross-material **significantly better current transmission with rough wire surfaces.** This is consistent with statements from other studies [3,4].

Physically, this phenomenon can be explained as follows: Every system tries to minimize its energy. The wire is not positively driven in the contact tube and therefore chooses the lightest path with the minimum possible contact force when passing through the contact tube. An ideally round wire without defects would ideally only form an infinitely small point contact. A real (shiny) wire surface with very low roughness, however, is not ideally round and not ideally straight in the longitudinal direction. This does not necessarily increase the point of contact, but will vary the contact position.
In case of really rough or matt wire surface, the probability of metallic contact with the wall of the contact tube is increased many times due to the many roughness peaks. In exaggerated terms, one could think of a wire surface as a brush whose bristles also allow multiple point contacts on a larger surface because of its soft and smooth ease of deformation. The carbon brushes used in motor and generator construction show a similar behavior.
In the case of rough surfaces, the very small distances between the wire surface and the contact tube wall also increase the probability of a current transfer due to peak discharge, even with a relatively small potential difference of U = 20-30 V.
The wire surface roughness has another advantage, especially when lubricants are used (essential for some materials): when the surface is wetted, any excess ends up in the "depths" of the rough surface structure. The surface tips responsible for electrical contact, on the other hand, are only wetted with the minimum possible amount of lubricant. This minimizes the electro-insulating effect, but the sliding properties are still ensured and there are significantly fewer deposits in the feed hose as well as in the contact tube.
It is important that the lubricant retains its sliding properties even at the high temperatures (approx. 300 °C) of the contact tip during the welding process. Here, GEO's WWF-U300 lubricant has already proven excellent in applications with different materials.

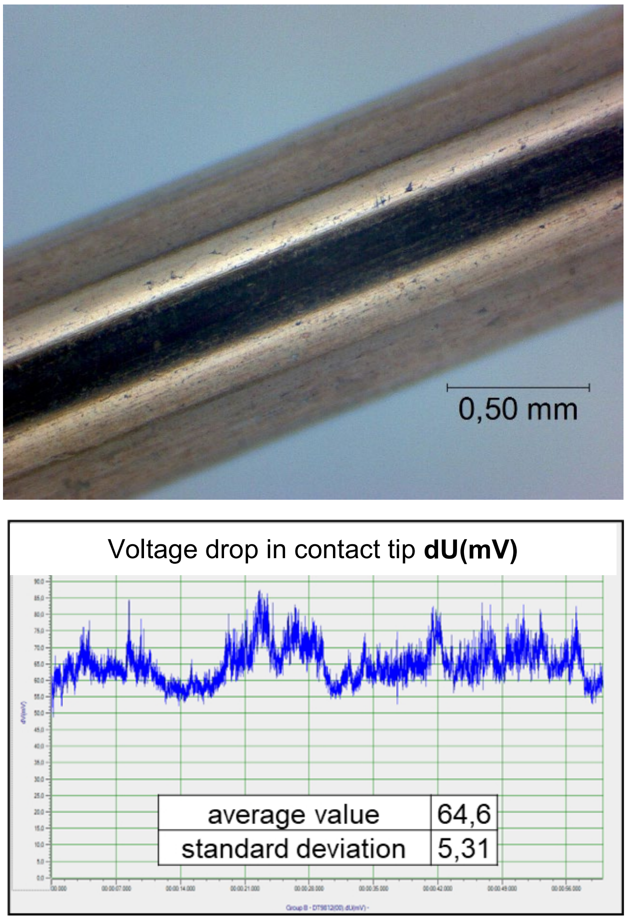

Fig. 9: Copper-plated welding wire SG 2, delivery condition

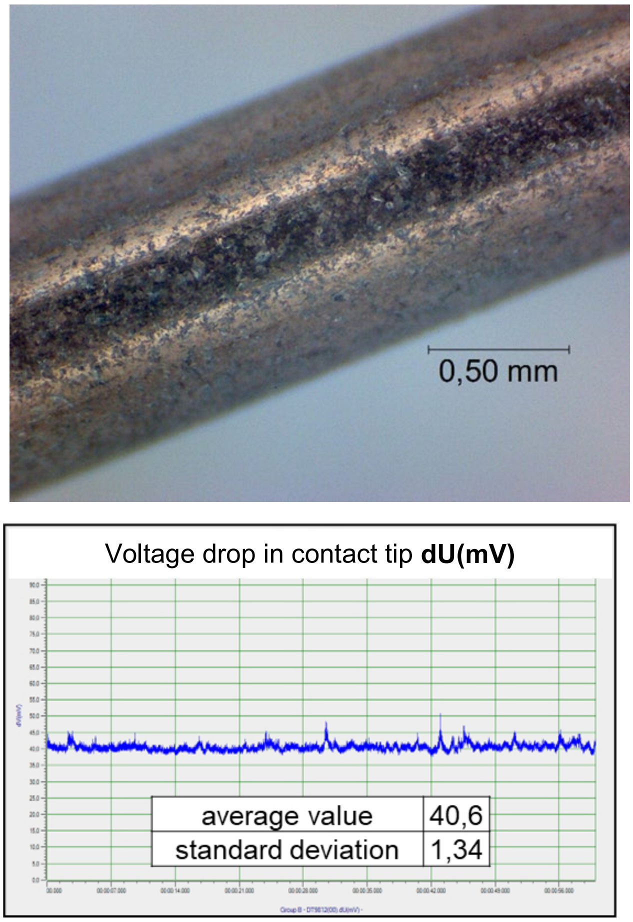

Fig. 10: same copper-plated welding wire SG 2, sandblasted

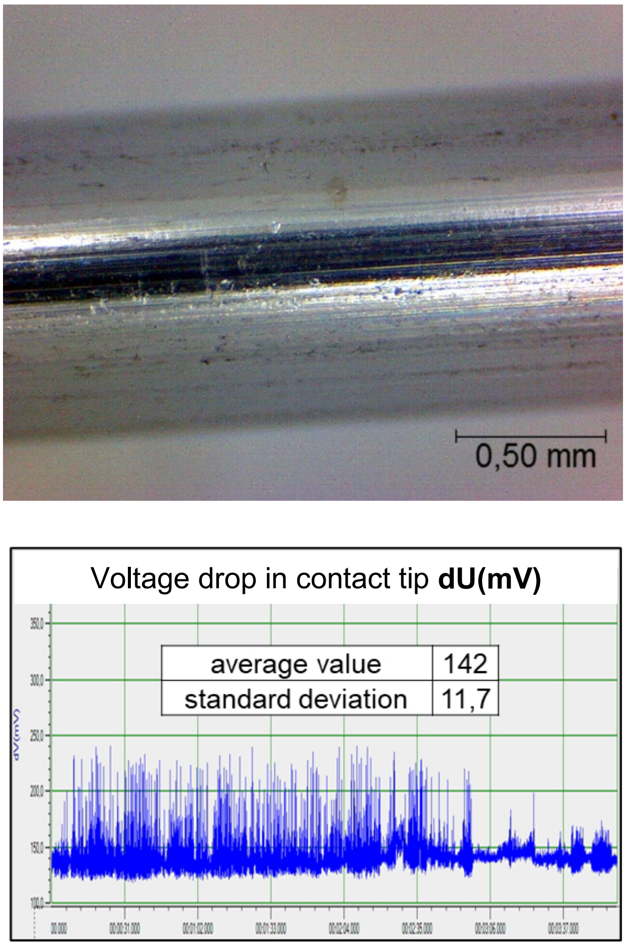

Fig. 11: Nickel-based welding wire W.Nr.2.4856, delivery condition

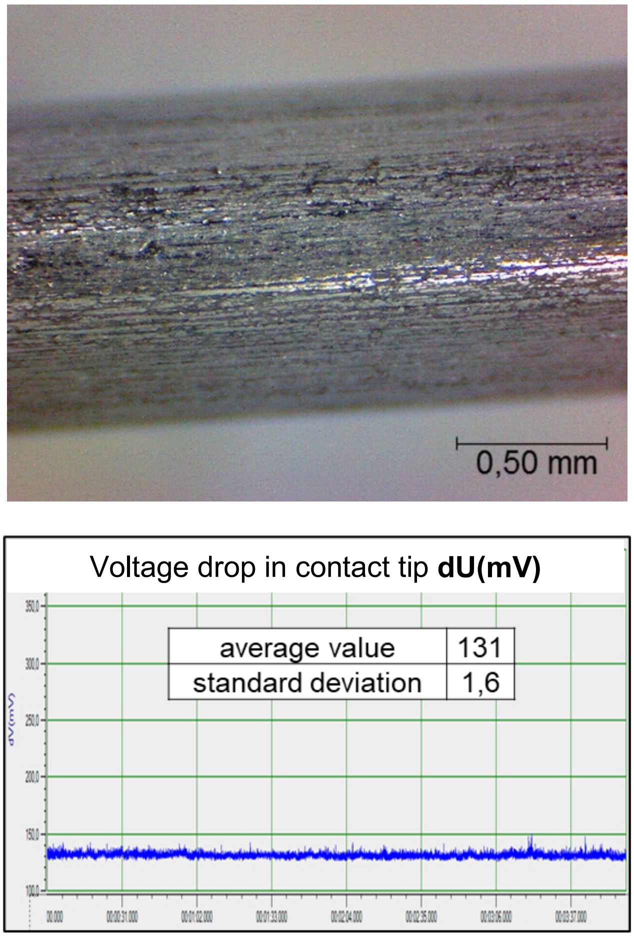

Fig. 12. Same nickel-based welding wire W.Nr.2.4856, sandblasted

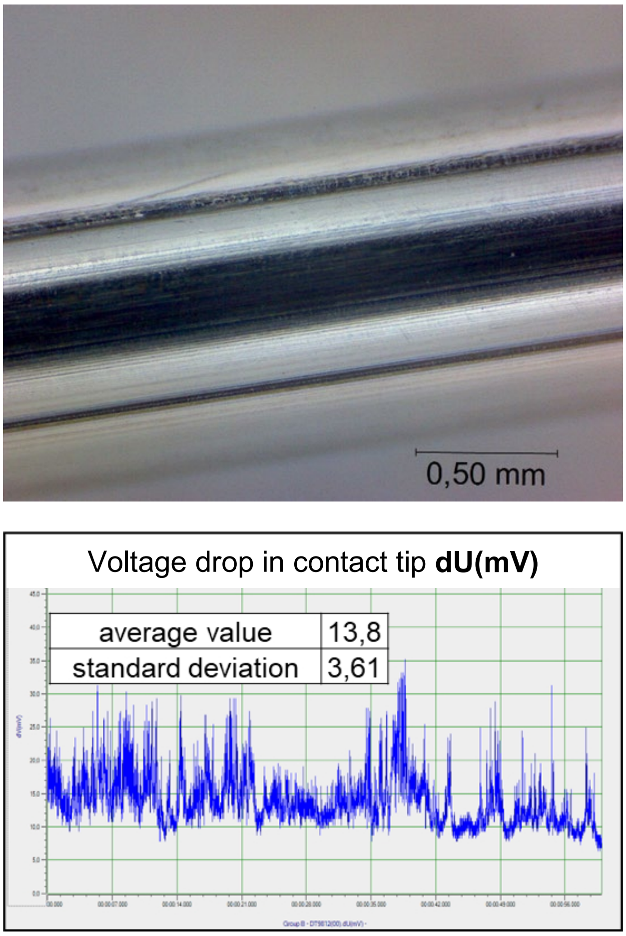

Fig. 13. Al-wire ER 5183, delivery condition

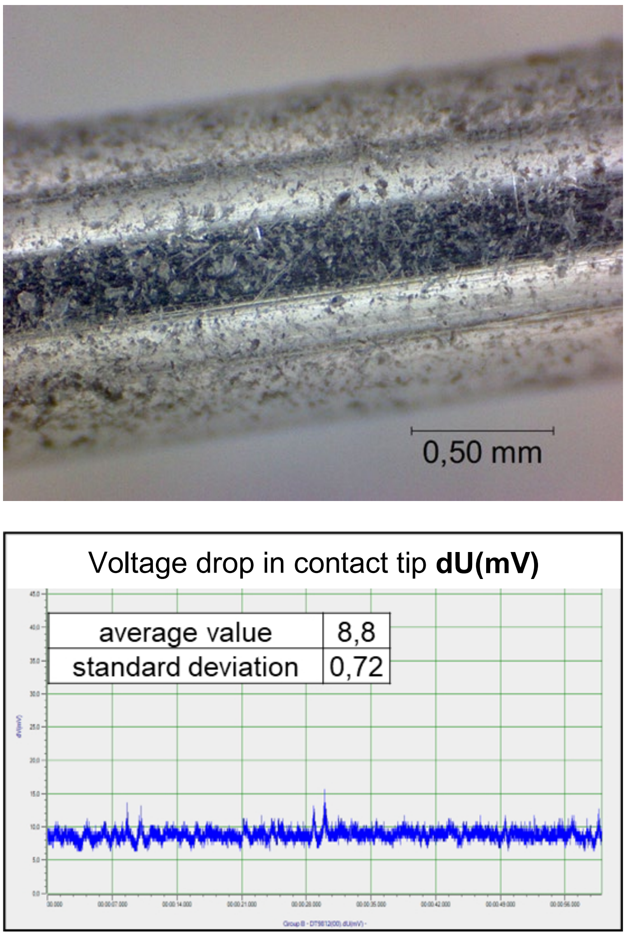

Fig. 14. same Al-wire ER 5183, sandblasted

8 Outlook

Optimized wire surfaces are an important building block in the optimization of welding processes and weld metal. High-quality clean wires widen the process window during welding and simplify the production of defect-free seams with the required mechanical-technological properties. Progressive digitalization using state-of-the-art laboratory diagnostics will continue to be an important lever for continuously improving the performance of welding consumables in the future.

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