Characterization of the plasma shape of the TIG welding ARC

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ABSTRACT

Tungsten electrodes were prepared to analyse the plasma geometry at TIG welding. The investigated electrodes were LaO_2, ThO_2 alloyed. Tip flatted electrodes were grinded as well. The shape of plasma were analysed for 36 different electrodes. Analysing of digital pictures, the plasma geometry were measured. Whole and brightest plasma area was checked as well. Measured values were represented as a function of taper angles. Main conclusion is that the maximum of the diagrams, which characterise the effect of taper angle for sharpened electrodes, were at taper angle of 20-30°. The properties of the red and the black electrodes are running collaterally. Despite of them the characteristics of the gold electrode shift to higher taper angles causing by the high LaO_2 content of the electrode. There was no clear correlation between the electrode taper angle and the shape characteristics of plasma for the electrodes, which were prepared with a flat tip.

Keywords: tungsten electrode, plasma shape, TIG welding

INTRODUCTION

TIG welding has a free-burning arc that can be unstable and tends to wander in the low current range. Increasing of current, the arc diameter increases: this leads to a lack of concentrated power in the work-piece, which results bigger seam and larger heat-affected zone. The plasma temperature is 8000-18000 K in case of TIG-welding. The aim of this work was to analyse of the plasma of TIG welding and elaboration of a new method for them. In the experiences the electrode material and its taper angle were changed. Tungsten electrode material, diameter, grind angle, and tip diameter (flat) vary according to each welding application.

At TIG welding the taper angles of the electrode considerably influence the shape of the plasma, the welding energy and in consequence of that the penetration of the joint. Also there is a considerable difference between the arc ignition capability of W-electrode and wear of electrode, both of them effect on maintenance needs.

Among welders it is widespread the erroneous that the achievement of narrow and deep weld bead can be done with electrode sharpened to small angle. This view also stresses the easy arc ignition and the arc stability, but ignore the intensive wear. The effect of the electrode tip can be summarized by the followings.

When the taper angle of electrode is sharper, the welding process is characterised by easy arc ignition, handle less amperage, wider arc, good arc stability, smaller weld penetration, shorter electrode lifetime. In contrast with it, when the electrode is blunter, generally harder to start the arc, handle more amperage, narrower arc, potential for more arc wandering, deeper weld penetration and longer electrode lifetime.

It is also an important characteristic of electrode tip geometry the electrode tip diameter that forms by grinding back of a sharpened electrode. In most cases it is best for a welder to leave a flat spot or tip diameter at the end of electrode. This reduces erosion at the thin part of a point and reduces the concern that the tip may fall into the weld. Larger tip diameters offer the following trade-offs: easier arc starting, potential for more arc wander, less weld penetration, shorter lifetime, but the smaller tip diameters offer harder arc ignition, good arc stability, deeper weld penetration and longer electrode lifetime.

Producing of tungsten electrodes happens by powder metallurgy and it is no problem the adding of REM-oxides. Alloying is need for two reasons: rare-earth metal oxides increase the current and heat resistance of the electrode and oxides reduce the excitation energy necessary for electron emission. Hereby also the arc ignition also the arc stability considerably improves.

In the tungsten matrix the oxides are usually in fine distribution, but the so-called composite electrodes are composed of clean tungsten core and surrounding that oxide coating. The electrode with such a character suits the quality of both the clean tungsten electrode and tungsten electrode containing oxides, but the disadvantage of it that it can't be produce conic form.

The W-content of unalloyed tungsten electrode (WP according to ISO6848 and EN26848 standards) is at least 99,7 %. It doesn't bear high current density and it less bear the pollutions. Thanks to the low burning temperature (~ 3400 °C) it can be used first of all at welding of Al, Mg and their alloys.

The zirconia alloyed electrodes (WZ3 and WZ8) mainly in use at welding with alternative current, although it can be used for welding with direct current. At welding of light metals it is more wear resistant than the unalloyed type. Its arc ignition characteristics are very good. It can be used in nuclear field too. Its burring temperature is ~ 3800 °C.

Thorium-oxide (WT10…40) containing electrodes have much larger electron emission and higher current density than the unalloyed type. By increasing of thorium-oxide content these favourable features become stronger.

It obtains the same current density at much lower temperature than the unalloyed electrode. Its current capacity is bigger with 20 percent and considerably has more wear resistant than the clean tungsten electrode has them. Its burning temperature is ~ 4000 °C. Primary it is used for direct current welding of low and high alloyed steels, copper, brass, titanium and other metals. It has a poor radioactivity, which considerably influence on excitation of the particles of electrode and so on decrease of required energy for excitation of electrons.

During the welding the welder exposed to very little radiation, but if the radioactive powder produced by the grinding directly touches the human body, because of the permanent radiation it has harmful effect. It is forbidden the using for welding of nuclear installations because of the radioactive radiation, as the particles of electrode can cause metallic inclusions in the weld, and disturb the radiation measuring system.

The electrodes alloyed with cerium-oxide (WC20) are used at welding with low current.

The electrodes alloyed with lanthanum-oxide (WL10…20) – similar to electrodes alloyed with thorium-oxide – have excellent welding features, and they also can be used for welding with alternative current. Its lifetime is very long; it is not radioactive and has not harmful effects for health. As for the case of short welding this alloying has the longest lifetime. Its burring temperature is ~ 4200 °C.

EXPERIMENTS

We used three kinds of electrode for the experiments: WL15 (gold), WL10 (black) and WT20 (red). It was grinded altogether 12 pieces from all three of electrode. The chosen taper angles were 10° 20° 30° 45° 60° 90°. From each of these taper angles we made 2-2 pieces by one electrode. One was left as pointed sharp tip form, but the end of the other made for blunting back. The measure of the blunting was 30 % of cone height. In Fig. 1 can be seen the examined electrodes.

We made the grinding and the blunting of the end of the electrode by JA JW-2T type electrode grinder. The shape of the plasma we recorded by digital camera during every welding. Some of these are shown in Fig. 2. Pictures show clearly that from the side of brightness it can be definitely separate so-called "inner plasma", inside the "complete plasma". It is obvious that the explanation of this colour interval separation is the characteristic distribution of plasma temperature. The permanent experimental parameters applied at welding and at plasma photography are the followings:

Welding current: I = 40 ampere
Diameter of tungsten electrodes 1,6 mm
Sticking out of electrode: 6 mm
Arc gap (electrode/material distance): 3 mm
TIG torch positioning: vertical
Welding time: 5 s
Base material: AISI 304L stainless steel
Base material temperature: 20°C

Shielding gas: argon
Shielding gas flow: 8 litre/min
Ceramic gas nozzle: "No.5" (47×8,0 mm)
Welding machine: ESAB Aristotig 350
Distance of camera from electrode
Type of camera: Olympus Camedia 5000
Diaphragm and time: 5,6 and 1/1000 s
Filter glass: Type 6

The choice of suitable filter glass and photography parameters we had to work out experimentally. The optimal conditions were protected with No.6 filter glass. If the glass is too weak it isn't good, because the plasma is almost completely white, so it can't be broken down into different phases. Too strong glass isn't suitable also, as almost nothing can be seen from the wanted examination part. As for the setting of the camera the most suitable was the 5.6 diaphragm ad 1/1000 sec exposition time.

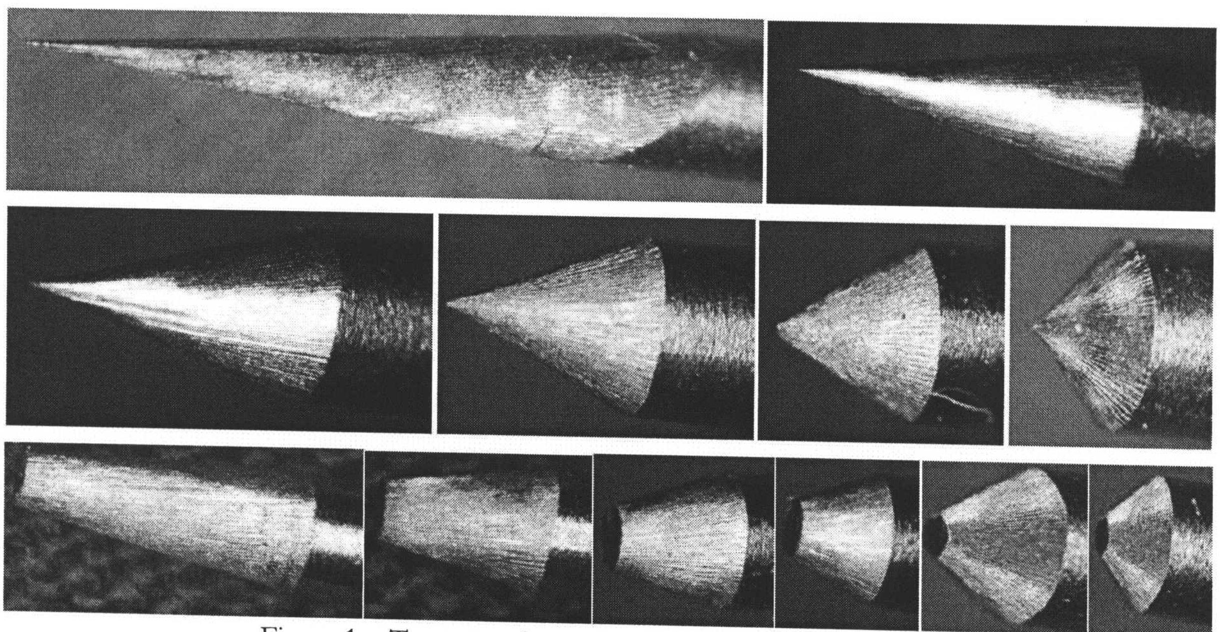

Figure 1 – Tungsten electrodes before welding experiments

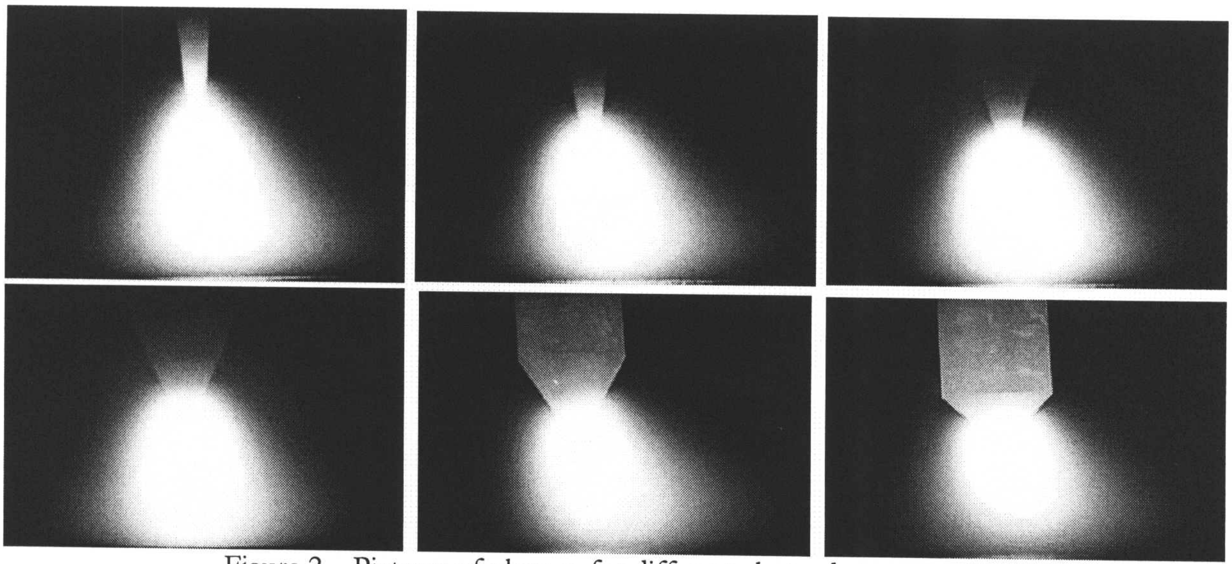

Figure 2 – Pictures of plasmas for different electrode taper angles.
The inner area of the plasma have white colour

ANALYSIS OF PLASMA ON PICTURES

In the pictures made during the welding experiments parameters examined from the view of analysis – can be seen in Fig. 3 – were the followings:

Width the plasma; B, b
Height of the plasma; H, h
Height of the plasma at maximal width; L, l
Half-height width of the plasma; W, w
Area of the plasma on picture; A_T, a_T
Area of lower part of plasma; S_T, s_T

Penetration of weld
Maximal width of weld
Area of weld bead from above
Maximal cross section area of weld

We divided the plasma into two main parts: total and inner plasma (capital letters relate to total plasma, small letters relate to inner plasma, analysis of digital pictures on the basis of this will be detailed in what follows).

We made three photos from each examined parameters of the plasma at all the welding. Beyond examination of plasma we examined by itself the welds. Arc-spot welds were welded during the same time – 5 second – onto austenitic stainless steel plates. In connection with the welds were made metallographic specimens for optical microscopic examinations, but they are not detailed in this paper.

The essence of examination method of TIG welding plasma is the following: for process of the photos were used programs Corel Photo Paint and Corel Draw. In Corel Photo Paint With Magic Wand Mask Tool was determined a tolerance limit – 50 was found as optimum – which covers the significant part of plasma. Of course to cover the whole plasma shape would be impossible task for any program, so the tolerance limit was chosen that plasma doesn't contain parts unimportant for us. Examination only with this tolerance limit wouldn't be enough for qualification of plasma, that is why was chosen another tolerance limit – it was 10 – which designates the most intensive part of welding arc plasma. Plasma energy is the highest in this domain. In Fig. 3 the two domains can be separated well: total is the domain with tolerance limit 50, and dark inner part is the domain with tolerance limit 10.

Photos treated by Corel PhotoPaint were converted into Corel Draw. Examining each plasma shape was measured – at both tolerance limits – including plasma sizes: width, height, area, height at the longest width and half-height width. As at every welding were taken three photos it was possible to read three values in connection with every parameter, and later to take average of them. On the basis of average values was drawn a diagram.
To determine the area was chosen the "Measure" software. Also was taken the average of these data and made a diagram. The Measure software is excellent for suitable illustration the parameters, but first of all it was used only for determination of the plasma area.

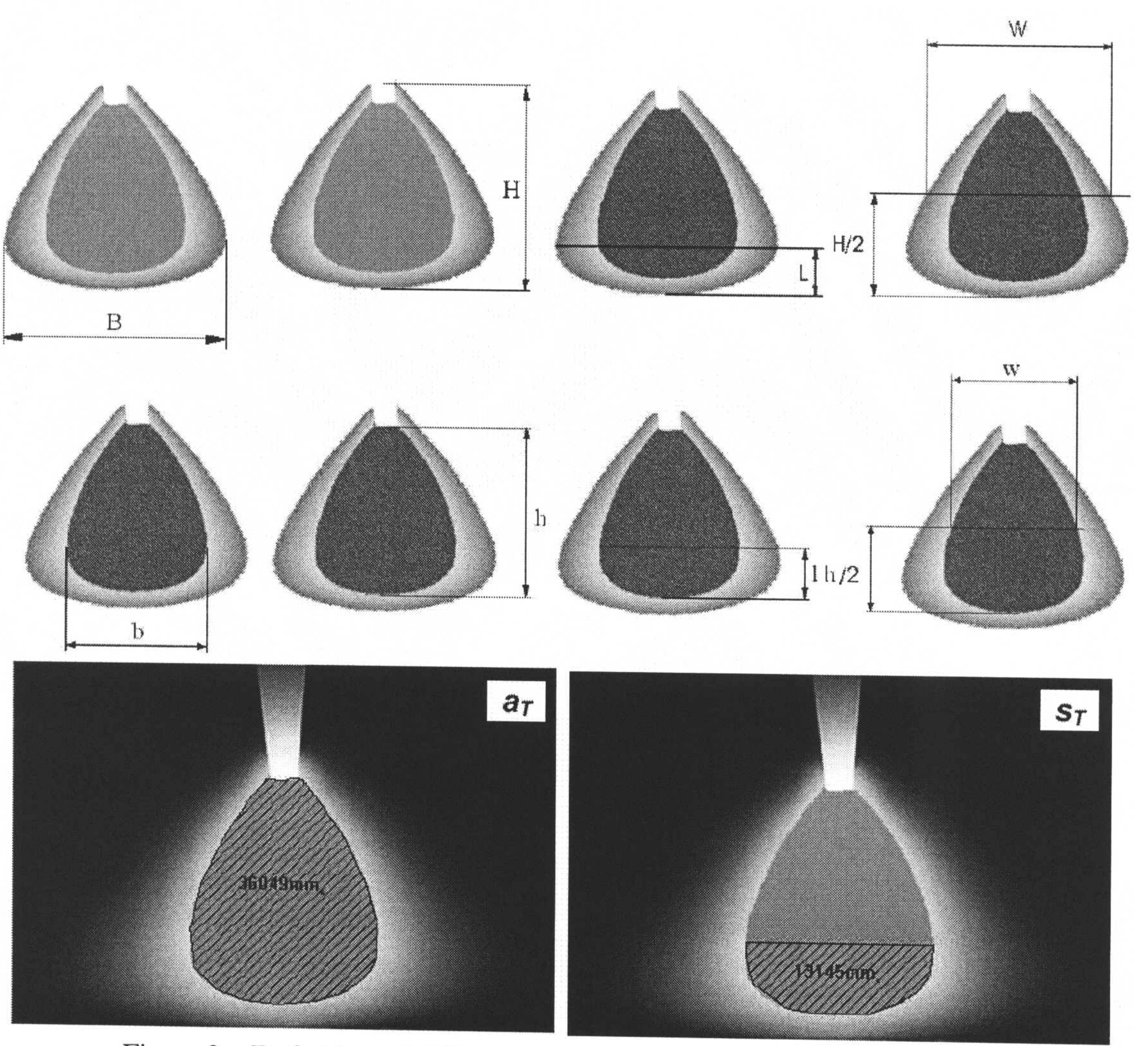

Figure 3 – Definition of different shape characteristics of the plasma shape

RESULTS AND DISCUSSION

In pictures about plasmas of sharp electrodes to 50- tolerance limit was given width B of plasma and to 10- tolerance limit width b (Fig. 4 and Fig. 5). "Rdu"dimension given for characteristics of plasma in Figures is a relative digital unit used for image analysis.
Curves of black and red electrodes are also parallel; curve of the red electrode is the upper. Plasma width of the gold electrode becomes narrower with the increasing of taper angle. At smaller electrode

taper angle still isn't a difference only above 30°. Curves have their own upper limits. The maximum is at 20°, except for the black electrode.

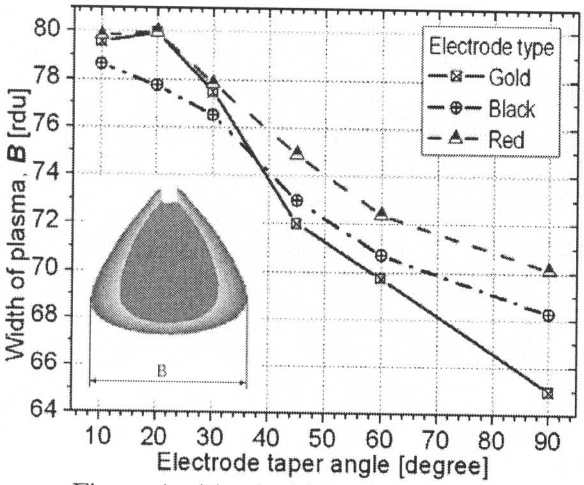

Figure 4 – Total width of the plasma in function of taper angle

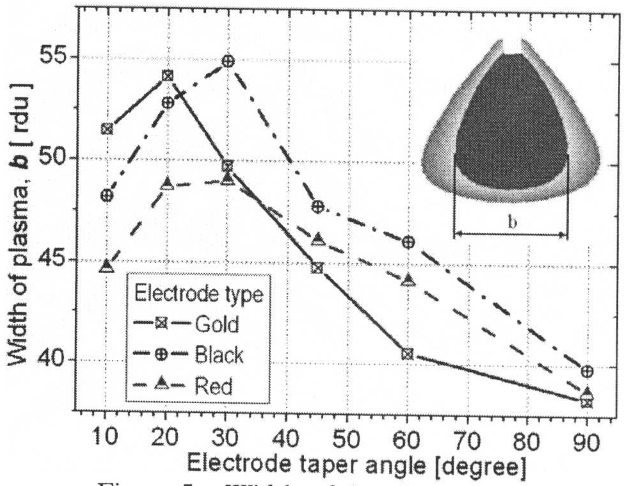

Figure 5 – Width of the plasma core in function of taper angle

At first sight measure series in Fig 5 shows similar results to results measured at 50-tolerance limit. But the difference is the fact that curve of black and red electrodes are changed. Their maximum is also at 30°. The curve of gold WL15 electrode similar to foregoing is moved to the left towards the smaller taper angles and maximum of it is 20°. This shift can be seen at other plasma shape characteristics too.
Curves in Fig. 6 showing H-height of plasma have hyperbola characters. There also above can be seen curve of red electrode type WT20, and again can be found that curves of red an black electrodes are similar to each other. In the case of gold electrode WL15 plasma height shows difference similar to plasma width comparing with other two electrodes. Like in Fig. 7 changes the h height of plasma core with taper angle. It can be seen well that in contrast with H height the height of plasma core decreases linearly at all the three electrode type while the total plasma height increases considerably at the smallest taper angle.
Upper drawn trends are also concern the half-height width W (see Fig. 8): above there is the curve of red electrode and under WL10 (black). But at half-height width of plasma core the curves of two electrodes change their places. Maximum of the curves is at 30°. Gold electrode WL15 also has a difference from the others and the difference in this plasma shape is much stronger.

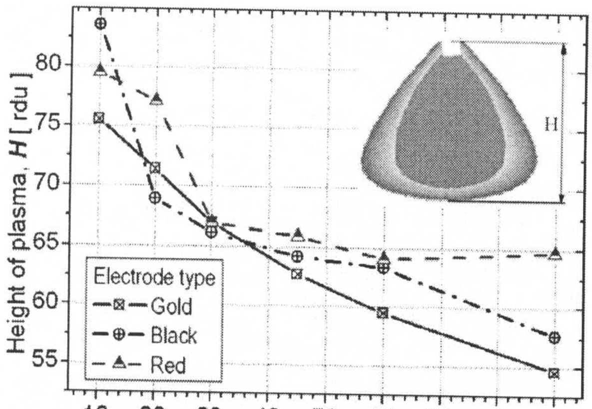

Figure 6 – Height of the plasma in function of taper angle

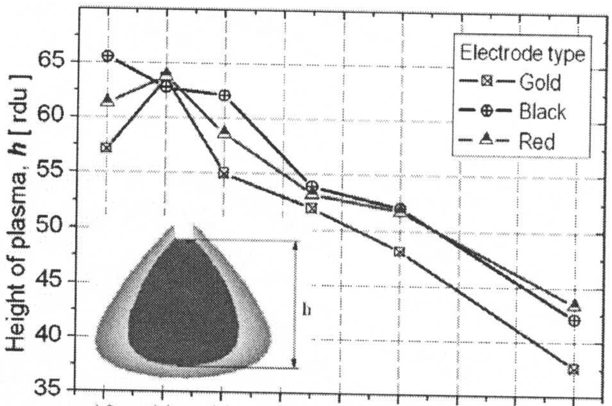

Figure 7 – Height of the plasma core in function of taper angle

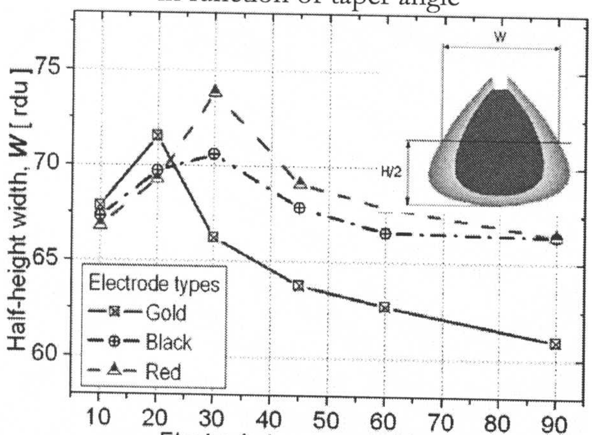

Figure 8 – Half-height width of the plasma in function of taper angle

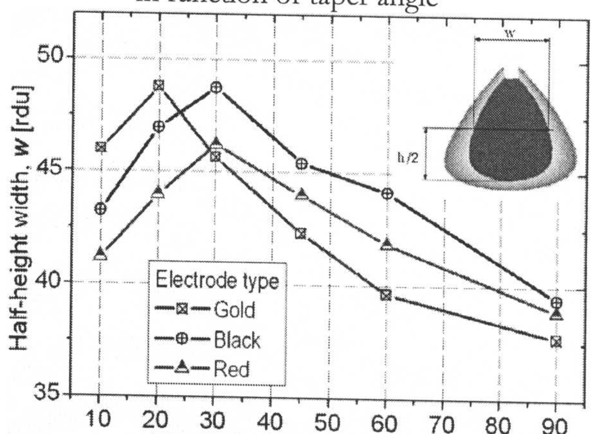

Figure 9 – Half-height width of the plasma core in function of taper angle

Character of the curves in Fig. 10 showing the plasma area are best of all similar to curves in Fig. 5. Looking at this plasma shape feature it can be say that the difference between the electrodes here can be seen considerably better.

On the basis of the examined parameters at blunt electrodes can't be drawn general conclusions. The big dispersion probably can be explained with that the electrodes with such a low diameter (1,6 mm) are very sensitive to a little difference of the blunting too. In spite of the exact grinding the surface quality isn't suitable, if the shapes remain burred. The remained little bur can cause significant troubles in the plasma. In spite of this in Fig. 11 also can be seen the likeness between black and red electrodes and the sliding of gold electrode to the left.

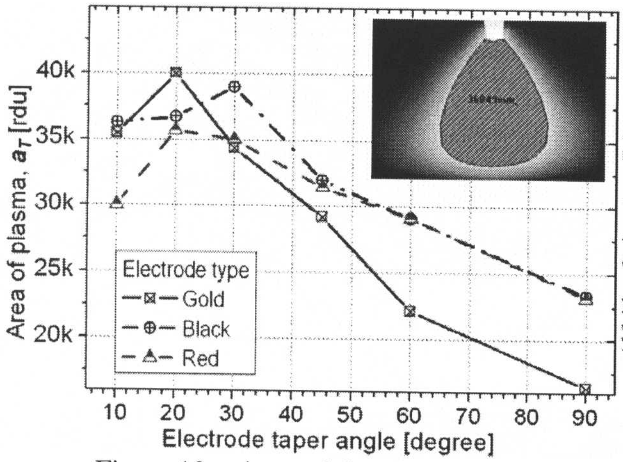

Figure 10 – Area of the plasma core
in function of taper angle

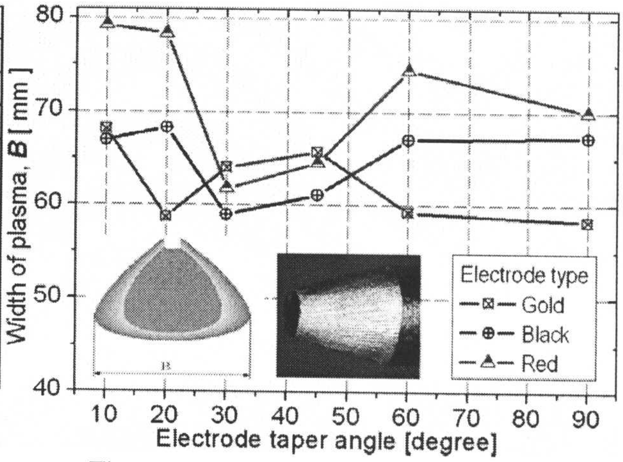

Figure 11 – Total width of the plasma
in function of taper angle for blunted electrodes

We also examined the height measured at widest plasma width, but didn't receive demonstrable tendency, as in best of the cases the plasma shape isn't symmetrical. It happens that during the arc welding it pulls a little to the right or to the left. It is because of that – in many of the literature say exactly the opposite of it – with increase of taper angle grows the possibility of arc wandering. In these cases it is not easy to determine the two widest point of the plasma and this fact considerably increase the interval of measured data. Arc wandering makes more difficult to determine characteristic features of some plasma shapes, effect of which to the plasma shape is shown in Fig.12. Arc wondering becomes considerably stronger because of the wear (Fig. 13).

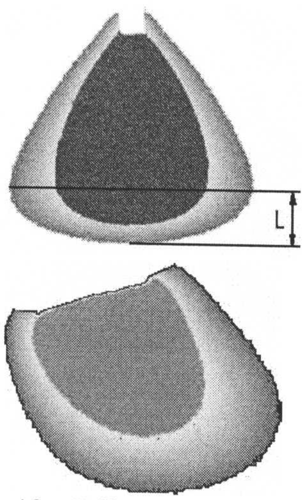

Figure 12 – Effect of arc wandering
on the plasma shape

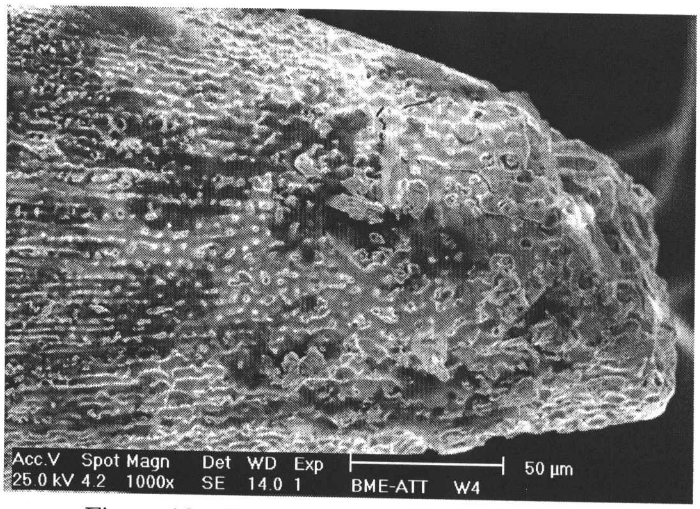

Figure 13 – Wear of an blunted electrode tip

CONCLUSIONS

Diagrams in connection with plasma shape features are similar to each other. Maximum of the curves can be found not at 10° as it can be thought, but usually between 20° and 30°. Lines showing the features of WT20 red and WL10 black electrodes are almost parallel. Comparing the curves of two tolerance limit it can be say that while at tolerance limit 50 there is the red electrode is the upper, at tolerance limit 10 the curve of the black electrode is in the top. On the basis of this we can draw the

conclusion that the plasma of red electrode is bigger than the plasma of black electrode, but as for the most intensive part of the plasma – where plasma energy is the highest – plasma of black electrode is more ideal. That is why this electrode offers deeper penetration parameters. Curve of gold electrode WL15 is riser and shifted towards the smaller taper angle in comparison with the others.
Examining the alloying material of electrodes – gold and black electrodes contain lanthanum-oxide, the red electrode contains thorium-oxide – it could be expected that curves of gold and red electrodes would be similar to each other and the red would differ. Measuring didn't support this hypothesis. Possible reason of it can be the different alloying oxide content. Lanthanum-oxide content of black electrode (WL10) is 0,9-1,2 % and of gold (WL15) is 1,3-1,7 %, so the increase of lanthanum content of the electrode shift the plasma shape features towards the smaller angles. In domain under 20° of sharp electrodes the curve of gold electrode is always above the curve of red and black electrodes. The lifetime of the electrodes is usually short at small taper angles, as the end of it wears quickly, but it isn't true in connection with the tungsten electrodes alloyed with lanthanum-oxide, as they have long lifetime.
Regarding to blunted electrodes we couldn't draw general conclusions. Better results could be received if the grinding of the electrodes happened on such a machine, which had had suitable measuring system and mechanical work-piece turning. The manual work-piece turning isn't enough for this electrode working. Electrode tips with suitable quality can be achieved with polishing.

ACKNOWLEDGMENTS

The Hungariyn Scientific Research Fund supported this research: OTKA T43571.

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