WELDING INTERNATIONAL

Translations from the World's Welding Press

1987 Volume 1 Number 10

Welding International contains translations of complete articles selected from leading Soviet, Japanese, Chinese, East European and Italian journals, as listed overleaf. A section at the end of each issue is devoted to translations of contents lists from the latest issues of these journals. Readers are invited to use the form on the last page to recommend articles for full translation in future issues.

Published by The Welding Institute, Abington Hall,
Abington, Cambridge CB1 6AL, UK
in collaboration with
The British Library Document Supply Centre, Boston Spa,
Wetherby, West Yorkshire LS23 7BQ, UK

ISSN 0950-7116

CONTENTS

WELDING INTERNATIONAL

1987 Vol 1 No 10

Editorial
Dr Richard Smith
Peter Adams
John Loader

Translations from Russian
Victor Riecansky

Production
Paul Tomson
Brenda Gutteridge

Subscriptions
Daphne Hannah

Translations
The China Welding Institution
Midland Technical Translations
Japan Services Group Cambridge
T MacDonald

TRANSLATIONS

Load carrying capacity of welded joints in high strength steels in the range of fatigue strength for finite life
V V Yakubovskii, V V Novozhilov, V I Rudyi and V L Laptev AS/87/1/7 Translation **220** 906

Press welding dissimilar non-ferrous metals with heating by an arc moving under the effect of a magnetic field
S I Kuchuk-Yatsenko, V V Yumatov, V Yu Ignatenko and L Yu Sorokina AS/87/1/17 Translation **221** 911

Calculations of the form of the penetration zone in laser welding using a model of two heat sources
N A Klykov, A A Dammer, A V Druzhinin and M M Malysh AS/87/1/20 Translation **222** 914

Thermodynamic analysis of the processes taking place in gaps of multi-layer hermetic packets during roll welding
I A Ryabtsev AS/87/1/28 Translation **223** 917

Mechanical properties of welded joints in components of VVER-1000 reactors
A S Zubchenko, S I Nosov, A A Popov, S A Shpak and A G Mazep AS/87/1/47 Translation **224** 922

Structural adhesives for adhesive bonding
H Ohgi JJ/87/2/31 Translation **129** 927

Surface modification by laser and electron beams
H Maruo and I Miyamoto JJ/87/3/129 Translation **144** 935

Cutting metal underwater — state-of-the-art
R Jastrzebski PS/87/2/15 Translation **150** 941

Submerged-arc welding thick rolled plates with a reduced gap
N P Roshchupkin et al SP/87/1/19 Translation **213** 947

A criterion for evaluating the activity of fused welding fluxes
N N Potapov and S A Kurlanov SP/87/1/24 Translation **214** 951

Examination of the process of welding thin wall shells with initial heating
G P Lezhnin and V E Tul'skikh SP/87/1/32 Translation **215** 955

A method of calculating the production quality of welded structures working under static loading
S V Milanchev SP/87/1/34 Translation **216** 959

Distribution of pressure in the pool crater in welding with a penetrating arc
Yu N Korneev et al SP/87/1/37 Translation **217** 963

Examination of the cold cracking resistance of welded joints in high strength, medium alloy steels by the implant method
A I Savchenko, N V Pavlov, V P Simyakin, S A Zurov, S I Kapuntsov and N N Nikulina SP/87/1/39 Translation **218** 966

Nuclear power in China — the first atomic power station under construction
Yoshio Ando WT/87/1/98 Translation **088** 969

Application of corrosion resistant coatings to gas turbines
H Kanao and T Doi WT/87/4/57 Translation **147** 976

The Monte Carlo method in welding practice
R Schmidt ZM/86/12/1396 Translation **110** 983

Laser hardening of steel and cast iron
P Wiesner and M Eckstein ZM/87/1/65 Translation **125** 986

Soviet welding inventions 990

CONTENTS LISTS

Avtomaticheskaya Svarka 1987 **40** (2) 993
Avtomaticheskaya Svarka 1987 **40** (3) 993
Journal of the Japan Welding Society 1987 **56** (5 and 6) 993
Journal of Light Metal Welding and Construction 1987 **25** (8) 994
Prace Instytutu Spawalnictwa 1986 (1-2) 994
Quarterly Journal of the Japan Welding Society 1987 **5** (3) 994
Svarochnoe Proizvodstvo 1987 **34** (2) 995
Svarochnoe Proizvodstvo 1987 **34** (3) 995
Schweisstechnik (Berlin) 1987 **37** (7) 995
Transactions of the China Welding Institution 1987 **8** (2) 995
Welding Technique 1987 **35** (8) 996
ZIS-Mitteilungen 1987 **29** (5) 996
Zvaranie 1987 **36** (7) 996

Publisher's information
Printed and published by The Welding Institute.
Editorial and circulation offices:
The Welding Institute, Abington Hall, Abington, Cambridge CB1 6AL, UK
T: 0223 891162 Tx: 81183
Tfx: 0223 892588

Przeglad Spawalnictwa 1987 **XXXIX** (2) 15-20

Cutting metal underwater — state-of-the-art

R Jastrzebski

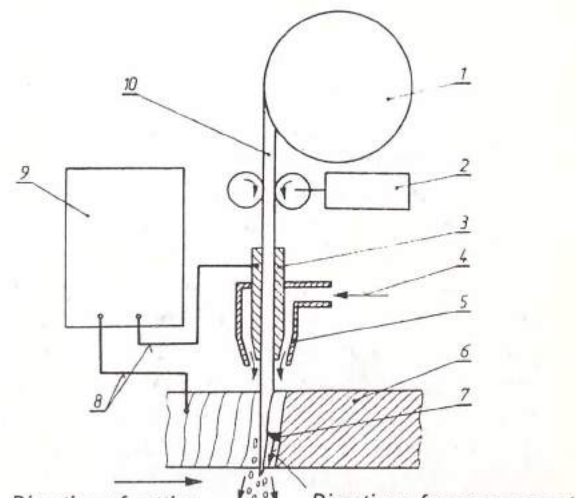
Foundry Repair Company, Works No.3, Cracow

Selected from *Przeglad Spawalnictwa* 1987 **XXXIX** (2): Reference PS/87/2/15: Translation 150

UNDERWATER ARC CUTTING USING A WATER JET

In underwater arc cutting using a consumable electrode and a water jet the electric arc is struck between the cut material and the electrode. The metal is melted and the flow of water emerging at a high pressure from the nozzle hurls droplets of metal heated in the arc to a considerable distance before they manage to solidify. The electrode wire enters the cutting groove, in which the electric arc moves downward (Fig.1). The arc is struck in the upper part of the groove and extinguished in the lower part, the cycle being repeated.[1-4] This cutting mechanism saves a large amount of energy (cutting with a groove not much larger than the electrode diameter of 2.5mm), the consumption being three times lower than in plasma cutting.[5] Thicker sheets can be cut using higher speeds than plasma cutting and cut surfaces can also be achieved without distorting any part of the sheet. It has been demonstrated that the droplets of metal solidify rapidly in the water, but droplets are removed to a considerable distance from the surface of the metal without further heating. Moreover, the molten metal is washed out by a high density medium (water), and not by a low density gas, as when cutting in air.

The phenomena taking place during cutting and cutting parameters are given in published data,[1-6] which also provide a theoretical explanation of the mechanism of cutting and give an example of the construction of the holder and cutting apparatus for this method.[7] The cutting speed using this method is proportional to the current intensity. The current value selected is between 1000-2000A. The open circuit voltage of the welder is about 30V for a depth of 1m and 50V for a depth of 200m. The Table shows the optimum parameters for cutting various materials, while Fig.2 illustrates the cut surface quality of stainless steel. Cutting can be performed with direct or alternating current. A greater depth of cutting improves the quality of the cut surface,



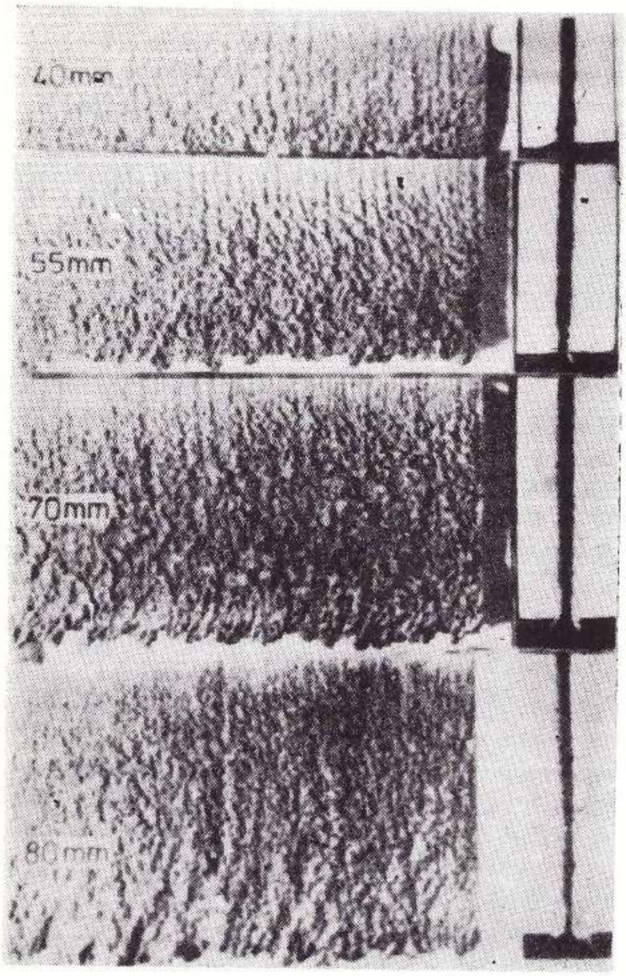
1 *Underwater arc cutting with consumable electrode and water jet:*[7] 1 — *Coil of wire;* 2 — *Wire feeder;* 3 — *Jet nozzle;* 4 — *Water;* 5 — *Water nozzle;* 6 — *Cut material;* 7 — *Electric arc;* 8 — *Electric cables;* 9 — *Welding rectifier;* 10 — *Electrode.*

but the cutting speed does not change.[6] The method is not sensitive to changes in the distance between the nozzle and the cut material and can be used for cutting stainless steel and aluminium.

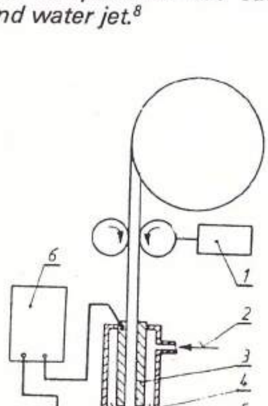
OXYGEN ARC CUTTING UNDERWATER

Figure 3 illustrates semi-automatic oxygen arc cutting. As in the case of arc cutting, the shape of the cutting gap is formed by the water jet. When the conditions have been worked out for stabilising the gas bubble surrounding the metal at a temperature higher than ignition temperature, this method ensures a high cutting speed.[9-10] Figure 4 shows automatic oxy-arc cutting methods using a hollow electrode. As in the case of gravity cutting and also cutting by the contact method, the electrode has a rutile covering and bears against the cut metal (low carbon steel) via a water-repellent substance. An arc heated to the ignition temperature is struck between the metal part of the electrode and the material, and the metal melts in a flow of oxygen emerging from an aperture in the electrode. A novel feature of this method is that the tip of the electrode is automatically guided along the cut metal, a step which increases cutting speed by several times as against conventional methods (Fig.5). In gravity cutting, the electrode is moved in a similar way to gravity welding, with contact between the end of the melting electrode

This article is a reply to the article by W Kalczyński entitled: 'Methods of cutting metal underwater', published in No.2/86 of Przeglad Spawalnictwa. *In this article, the author has attempted to demonstrate that the method of arc cutting can be used underwater and that underwater plasma cutting is not the only method enabling steel to be cut at great depths.*

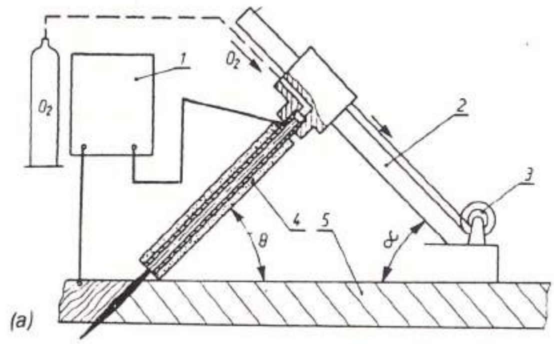


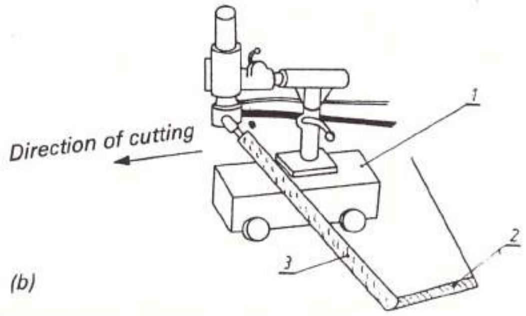
2 *Surface of sample after arc cutting with consumable electrode and water jet.*[8]



3 *Semi-automatic underwater oxy-arc cutting:*[9] *1 — Wire feeder; 2 — Inflow of oxygen; 3 — Jet nozzle; 4 — Nozzles; 5 — Cut material; 6 — Current source.*

(Fig.4a) and the metal. The contact method obviates the disadvantages of cutting thin plates by the gravity method, in which an excessive quantity of heat is generated, greater than is required for maintaining the ignition temperature and for the fusion of the electrode. The use of an additional mechanism for moving the electrode (a carriage or a mobile column in the case of tube cutting)[11,13,14] renders the cutting speed independent of the intensity of current required for melting the electrode.





4 *Underwater oxy-arc cutting with a hollow electrode: a) Gravity cutting,*[11] *1 — Current source; 2 — Guide column; 3 — Pneumatic motor; 4 — Electrode; 5 — Steel sheet; b) Cutting by contact method, 1 — Carriage; 2 — Cutting gap; 3 — Electrode.*

Its high cutting performance and low sensitivity to contamination of the sheet with concrete were the decisive factors in the decision to use the oxy-arc cutting method instead of contact cutting for cutting tubes in the construction of the Sakai Bridge near Osaka.[13,14] The water was pumped out via a casing made up of pipes which were disposed on the periphery of a circle, interconnected by locks and driven into the bottom of the bay. After the brickwork of the bridge pillar had been completed, unwanted pipes were cut off and removed by special equipment for clamping and cutting the tubes underwater and removing the cut-off sections. The operation of cutting off sections of tube 920mm in diameter with a wall thickness of 16mm lasted 2-3min, representing about one tenth of the time taken by the operation using conventional methods. Cutting was possible up to a depth of 150m.[14]

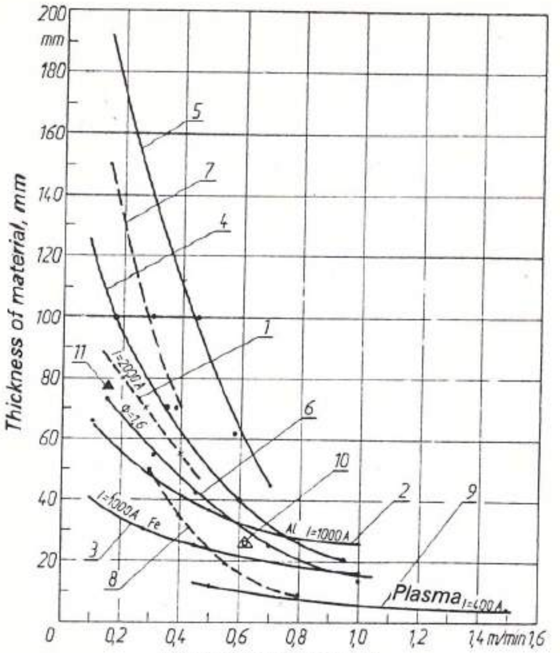
GAS CUTTING WITH A WATER CURTAIN

Figure 6 illustrates underwater gas cutting using a water curtain.[8,15] A water jet in the form of a curtain surrounding the gas cutting torch was used to stabilise the gas bubble in the cutting zone (Fig.7). If cutting is performed without a water curtain the gas bubble grows (as a result of gas feed, waste gases, steam), and after reaching a critical size it is torn off and replaced by a flow of water which cools the metal and reduces the surface of the heated metal (Fig.7*a*). When a water curtain is used, the water 'trims' the gas bubble, so that the gases leave the cutting area in the form of small bubbles, and the gas bubble does not grow to the critical size (Fig.7*b*). In the methods devised prior to World War II[16-18] the area surrounding the nucleus of the gas bubble was stabilised, but this failed to ensure a durable gas

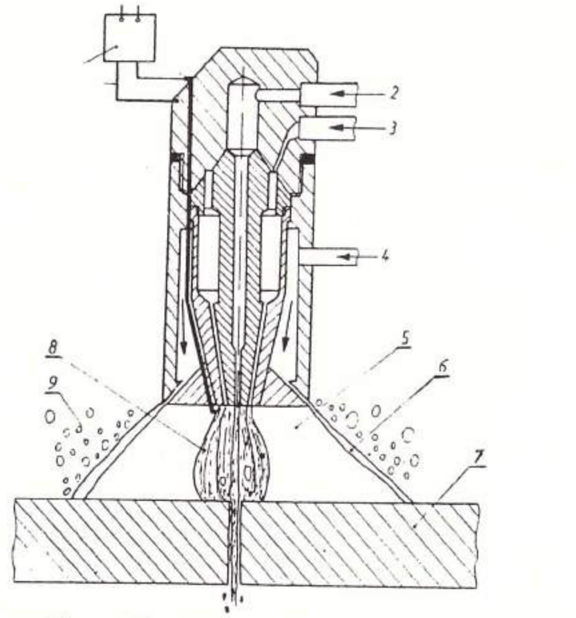
Optimum parameters of underwater cutting by various methods

Cutting method	Cutting thickness, mm	Cutting depth, m	Cutting current, A	Voltage, V	Water pressure, at	Water consumption, litre/min	Cut material	Cutting speed, m/min
Arc with consumable electrode and water jet, Ref.1	9	0.1	1000	25-30	5	6.2	Low carbon steel	1.5
	16	0.1	1000	25-30	5	6.2	Low carbon steel	0.9
	20	0.1	1000	28-33	5	6.2	Low carbon steel	0.6
	30	0.1	1000	30-35	5	6.2	Low carbon steel	0.25
Ref.6	9	0.1	800	38	5	6.2	Low carbon steel	1.2
	9	200	800	48	5	6.2	Low carbon steel	1.2
	16	0.1	1000	40	5	6.2	Low carbon steel	0.755
	16	200	1000	50	5	6.2	Low carbon steel	0.75
	25	0.1	1000	40	5	6.2	Low carbon steel	0.35
	25	200	1000	50	5	6.2	Low carbon steel	0.35
Ref.1	12	0.1	1200	400	5	6.2	Stainless steel	1.4
	20	0.1	1200	40	5	6.2	Stainless steel	0.9
	30	0.1	1200	40	5	6.2	Stainless steel	0.55
	45	0.1	1200	45	5	6.2	Stainless steel	0.35
Ref.5	40	0.2	1700	33	4	23	Stainless steel	0.4
	55	0.2	2000	33	4	23	Stainless steel	0.4
	70	0.2	2000	33	4	23	Stainless steel	0.28
	80	0.2	2000	33	4	23	Stainless steel	0.2
Ref.6	20	0.1	800	40	3.5	4.2	Aluminium	1
	20	200	800	500	3.5	4.2	Aluminium	1
	40	0.1	1000	40	3.5	4.2	Aluminium	0.4
	40	200	1000	500	3.5	4.2	Aluminium	0.4
	60	0.1	1000	40	3.5	4.2	Aluminium	0.15
	60	200	1000	50	3.5	4.2	Aluminium	0.15
Oxy-arc, Gravity Ref.11	12	0.3	300	47-50	—	—	Low carbon steel	0.95
	20	0.3	300	47-50	—	—	Low carbon steel	0.95
	40	0.3	300	47-50	—	—	Low carbon steel	0.95
	70	0.3	300	47-50	—	—	Low carbon steel	0.95
	110	0.3	300	47-50	—	—	Low carbon steel	0.95
Contact Ref.13	16	3	300		—	—	Low carbon steel	1
Gas with water curtain Ref.15	9	0.3	—	—	—	—	Low carbon steel	0.8
	19	0.3	—	—	—	—	Low carbon steel	0.55
	25	0.3	—	—	—	—	Low carbon steel	0.45
	35	0.3	—	—	—	—	Low carbon steel	0.4
	50	0.3	—	—	—	—	Low carbon steel	0.3

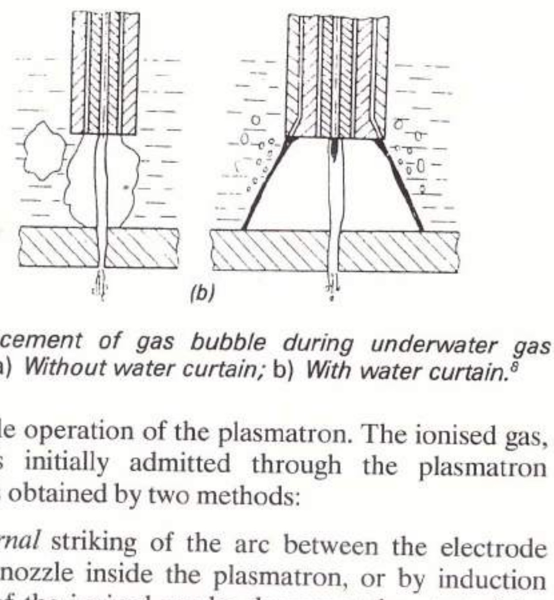
screen for the melting metal. Masanobu Hamasaki[8] stated that the stabilisation of the gas bubble may enhance the cutting speed by several times and produce results which do not differ from those of gas cutting in air. Stabilisation with a water curtain resulted in a faultless connection guaranteeing a bending angle of 180° in the underwater gas cutting of sheets for MIG welding underwater. Figure 8 shows the quality of oxygen gas cutting underwater for different thicknesses of steel sheet. An increase in the diameter of the cutting oxygen aperture to 2.3mm can produce cutting speeds of 0.4 and 0.3 m/min for a sheet thickness of 70 and 100mm respectively. Figure 5 shows the parameters for cutting scrap and the optimum cutting parameters. The speed of cutting sheets 19mm in thickness is 0.85 m/min. Cutting by this method can be performed at considerable depths if ethylene is used as the heating gas.[15]



5 *Dependence of cutting speed on thickness of material for different methods of underwater metal cutting: arc cutting with consumable electrode and water jet;*[8] *curve 1 — optimum cutting speed, current 2000A,*[5] *stainless steel, curve 2 — maximum cutting speed, current 1000A, stainless steel,*[6] *curve 3 — maximum steel cutting speed, current 1000A;*[6] *gravity cutting, curve 4 — optimum steel cutting speed, current 300A;*[11] *gas cutting with water curtain, curve 5 — maximum speed, diameter of cutting oxygen nozzle 2.3mm, curve 6 — maximum parameters, diameter of cutting oxygen nozzle 1.6mm, curve 7 — optimum parameters, diameter of cutting oxygen nozzle 2.3mm, curve 8 — optimum parameters, diameter of cutting oxygen nozzle 1.6mm; plasma cutting, curve 9 — optimum parameters, current 400A, Ar consumption 48.71 litre/min, stainless steel sheet;*[12] *point 10 — optimum cutting parameters of steel sheet 25mm thick, current 600A, gas consumption 226 litre/min;*[12] *point 11 — optimum plasma cutting parameters in air with inflow of water, current 660A, cutting voltage 200V, stainless steel 76mm in thickness.*



6 *Gas cutting with water curtain:*[8,15] 1 — *Ioniser or igniter;* 2 — *Cutting oxygen;* 3 — *Heating gas;* 4 — *Water (0.5MPa);* 5 — *Gas space;* 6 — *Water curtain;* 7 — *Cut material;* 8 — *Heating flame;* 9 — *Water.*



7 *Displacement of gas bubble during underwater gas cutting:* a) *Without water curtain;* b) *With water curtain.*[8]

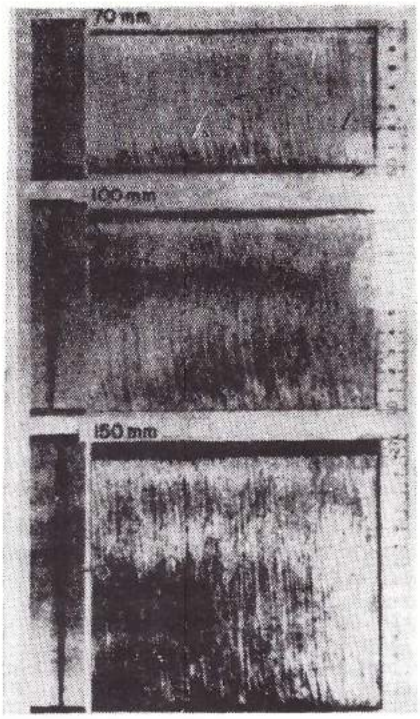
PLASMA CUTTING

Plasma at a significantly higher temperature than the plasma of a free arc is obtained when ionised gas flows at a considerable speed through a narrow nozzle. The electrostatic field set up in this process causes ionised particles to be forced out to the axis of the copper nozzle and less ionised particles in the direction of the nozzle edges. The densification of ionised high energy particles in the axis of the nozzle causes a local increase in the energy per unit volume and a rise in temperature to a value several times higher than the temperature of a free arc. The presence in the layer of the nozzle adjacent to the wall of non-ionised gas particles at a substantially lower temperature cools the nozzle from inside. The nozzle is cooled with water. The plasmatron nozzle is so strongly heated that water cooling might be inadequate but for the cooling from inside as a result of the inflow of the non-ionised gases. For a particular electric current in the plasmatron, therefore, a plasma creating gas flow is selected which is indispensable for cooling the nozzle and stable operation of the plasmatron. The ionised gas, which is initially admitted through the plasmatron nozzle, is obtained by two methods:

— *internal* striking of the arc between the electrode and the nozzle inside the plasmatron, or by induction heating of the ionised gas by the arc at the start of the process, or in an electrostatic field of high frequency between the tungsten electrode and the nozzle;
— from *outside,* by striking the arc between the tungsten electrode and the material situated outside the plasmatron, so that the electric arc passes through the narrow plasmatron nozzle.

These two methods are used simultaneously underwater, the internal method being adopted for striking an external arc.[19]

Plasma cutting is one of the most efficient methods for cutting metal in air. As shown by tests carried out by American research workers,[12,20,21] research performed in Poland and other published data, this method is also efficient underwater, more particularly in comparison with the methods devised prior to World War II.[16-18] Plasma torches are used without appreciable alterations for cutting underwater. The alterations made principally



8 *Surface of sample after underwater cutting by gas method with water curtain.*[5]

relate to the difficulty of striking a plasma arc and as protection against electric shock, having regard to the high feed voltage (above 150V). The other changes have been connected either with the need to avoid existing patent claims or the necessity of adopting different cutting parameters than in air, connected amongst other things with the increase in arc voltage for increasing pressure together with the depth of the water. The patent description in Ref.19 presents no novel features enabling plasma cutting to be performed underwater, but measures connected with rapid cooling and the instability of the gas bubble around the underwater cutting place. Figure 5 shows the relationship between the thickness of the material and the underwater plasma cutting speed for stainless steel, using a current of 400A. It also shows cutting parameters using different current values. The nozzle is cooled with water from the surroundings, whose displacement is much less than in the case of the forced cooling system used in air.[19] On the basis of Fig.5 it can be asserted that use is made of a nozzle for the internal arc which has a significantly larger length than the diameter of the cylindrical part, while during cutting the torch operates with external plasma. Published data from the USSR indicate that stable operation with an external plasma requires a nozzle the length of whose cylindrical part is equal to its diameter. The author's experiences with this kind of torch for underwater cutting indicate that with such parameters (the gas discharges are much too low) not more than a few metres of sheet metal can be cut without interruption. In this respect we must wait for the results of tests in the field of stable cutting parameters. Reference 14 states the cutting speed decreases with an increase in gas consumption. On the other hand, Ref.20 states that steel sheet having a thickness of 25mm can be cut at a speed of 0.625 m/min with a current of 600A, whilst stainless steel sheets of the same thickness can be cut at a speed of 0.75 m/min. The authors of Ref.12 state that the cutting speed of stainless steel of the same thickness is 1.27 m/min with a current of 710A.

COMPARISON OF UNDERWATER METAL CUTTING METHODS

The performance of work underwater is associated with the use of floating equipment (salvage vessels, barges), hoisting gear and crews for servicing the diving equipment on the surface. Divers' working time is limited by the necessary decompression period, which increases together with the cutting depth. Moreover, when working at great depths divers quickly become tired and their movements lack precision; they are liable to electric shock and the work of too large a number of divers is limited by the possible entanglement of lines. The maximum depth of effective diving operations is about 300m. Productive and cheap (oxygen) methods and automation must be used to reduce the costs of underwater work.[13] The possibility of cutting thick sheets of high carbon steels, stainless steel and non-ferrous metals significantly extends the field of application of thermal underwater cutting.[5,12] A decisive factor as regards costs and possible use is the high cutting speed over a wide range of thicknesses and materials. For example, the cutting speed of low carbon steel sheets at a depth of 10m is:

— by the plasma method — 0.75 and 0.625 m/min for thicknesses of 12.5 and 25mm respectively.[19,20]
— by the arc method — 0.75 m/min for a thickness of 16mm;[11]
— by the oxy-arc method taking the place of the contact method — 1 m/min for a thickness of 16mm;[13]
— by the oxygen gas method — 0.85 m/min for a thickness of 19mm.[8]

As these data show, the differences in underwater cutting speeds using the aforementioned methods on low carbon steels having a thickness of 13-19mm do not exceed 30%, the average cutting speed being 0.9 m/min. To facilitate a comparison between the underwater cutting methods, in Fig.5 curves are plotted of the thickness of the material as a function of cutting speed for various materials and different values of cutting current and oxygen consumption in the case of the oxygen methods. The graph shows that for the underwater cutting of low carbon steels the most productive methods over a wide range of thicknesses are the oxy-arc and the oxygen gas cutting methods. Using underwater oxy-arc and oxygen gas cutting it is possible to cut steels of thicknesses 110 and 150mm respectively. Plasma and arc cutting are somewhat less productive. These findings do not correspond with the information given in Ref.16, which states that only the plasma method allows the efficient cutting of steel having a thickness of several tens of millimetres.

The quality of oxygen cutting is so good that a radiographic examination of underwater welds produced following underwater gas cutting without additional mechanical processing showed no faults, the bending angle being 180°.[8] The Table shows the optimum cutting parameters. High carbon steels, stainless steels and non-ferrous metals can be cut by the underwater plasma cutting method and the underwater arc cutting method with consumable electrode and water jet. Reference 5 presents a comparison between these methods. Underwater arc cutting enables stainless steel sheets having a thickness of 75mm to be cut at a speed of 0.25 m/min, using a power of 100kV A (66kW). The plasma cutting of sheets of the same thickness with a current of 900A requires a power of 360kV A (190kW). The width of the arc cutting gap is 3-4mm, the width of plasma cutting being 12-14mm. The quality of the cut surface is similar. These data indicate that plasmatrons absorb three times more energy than installations for underwater cutting with a consumable electrode and water jet. The open circuit voltage of an arc cutting welder is 50V, while the feed voltage of a plasmatron is between 150 and 400V. If the depth is increased from 10 to 30m, the speed of underwater plasma cutting of sheets 12.5mm in thickness diminishes from 0.75 to 0.5 m/min.[19] As shown by Ref.22, the maximum cutting thickness with the plasma method is 100mm at a depth of 1m, while it is already only 40mm at a depth of 20m.

In the case of arc cutting with a consumable electrode and a water jet, the cutting speed is the same at a depth of 200m as in shallow water. Cutting depth has no effect on the results, and cutting surface quality increases with depth.[6] Reference 14 demonstrates that pipes can be successfully cut by the oxy-arc method at a depth of 150m.

CONCLUSIONS

The differences between the most productive methods in the plasma, arc, oxy-arc and oxygen gas underwater cutting of low carbon steels with a thickness of 13-19mm do not exceed 30% and values of 0.7-1 m/min. The oxy-arc and oxygen gas cutting methods are the most productive for the underwater cutting of low carbon steel in the thickness range 16-100mm. Low carbon steel 110mm thick can be cut underwater by the oxygen arc gravity method, whilst steel 150mm thick can be cut underwater by oxygen gas cutting, using a water curtain. Sheet metal cut underwater by the oxygen gas method can be welded underwater, the result being faultless joints of adequate bend strength. For the underwater cutting of stainless steel 80mm in thickness three times more energy is required for plasma cutting than for arc cutting using a consumable electrode and a water jet. In the case of underwater plasma cutting, the thickness of the sheet cut and the cutting speed decrease rapidly with depth, while the results of arc cutting using a consumable electrode and a water jet are independent of depth. Plasmatrons are supplied with a voltage several times greater than the remaining equipment in underwater cutting methods, and this significantly increases the risk of underwater electrocution. In his Paper published in *Przeglad Spawalnictwa* (No.2/1986), Dr W Kalczyński stated incorrectly that arc cutting methods are not used underwater because of the low cutting speed, and that the only method enabling steel several tens of millimetres thickness to be cut underwater was plasma cutting.

References

1 Hamasaki M, Tateiwa F and Watanabe M: 'Underwater cutting using a consumable electrode water jet technique.' *Trans Japan Welding Society* 1975 (3).

2 Hamasaki M: 'Underwater cutting using a consumable electrode water jet technique.' *Welding and Metal Fabrication* 7 1975 (8).

3 Hamasaki M, Tateiwa F and Ogawa Y: 'Underwater cutting using an AC constant voltage welder.' *Metal Construction* 1977 (2).

4 Hamasaki M and Tateiwa F: 'Underwater cutting using a consumable electrode water jet technique — with an AC constant voltage welder.' *Trans Japan Welding Society* 1 1977 (1).

5 Hamasaki M *et al*: 'Underwater cutting of stainless steel plate and pipe for dismantling reactor pressure vessels.' *Metal Construction* 1982 (4-8).

6 Hamasaki M and Tateiwa F: 'Underwater cutting using a consumable electrode water jet technique at great depth.' *Trans Japan Welding Society* 1981 (1).

7 Jastrzebski R: 'Influence of selected technical parameters on the speed of arc cutting of metals underwater using a consumable electrode and a water jet.' Master's thesis. Academy of Mining and Metallurgy, Institute of Basic Mechanical Engineering, March, 1985.

8 Hamasaki M and Murao Y: 'Water curtain torch aids underwater cutting.' *Welding and Metal Fabrication* 1978 **46** February.

9 Lesiński K J *et al*: 'Technology of semi-automatic oxy-arc cutting underwater.' Scientific and technical conference: 'Problems of cutting and welding underwater'. Gdansk 1985.

10 Lesiński K J *et al*: 'Oxygen arc flame cutting underwater.' *Schweisstechnik* 1983 (11).

11 Hamasaki M *et al*: 'Underwater cutting of mild steel using gravity technique.' *Trans Japan Welding Society* 1977 (1).

12 Wodtke C H *et al*: 'Development of underwater plasma arc cutting.' *Welding Journal* 1976 (1).

13 Hamasaki M and Katsumura M: 'Underwater oxy-arc cutting of mild steel using a contact technique.' *Trans Japan Welding Society* 1977 (2).

14 Hamasaki M: 'Automatic underwater oxy-arc cutting of tubes.' Reports of the Government Industrial Research Institute, 1981 (1).

15 Hamasaki M and Murao Y: 'Underwater gas cutting.' *Trans Japan Welding Society* 1978 (2).

16 Kalczyński W: 'Methods of cutting metal underwater.' *Przeglad Spawalnictwa* 1986 (2).

17 Madatov K: 'Underwater cutting and welding.' *Russian Welding Journal* 1960.

18 Cwiek Z: 'Cutting and welding underwater.' PWT, Warsaw, 1953.

19 Kalczyński W and Klimpel A: 'Arc plasma underwater cutting.' Underwater Welding International Conference, Trondheim, 1983.

20 Wodtke C J: 'Constructed arc process cuts metals underwater.' *Metal Progress* 1960 (6).

21 Moss A R and Young W J: 'A deep water simulator for arc plasma investigations.' Welding Institute Conf: 'Underwater welding for offshore installations', 1977.

22 Bach F and Erdman Jestnitzer F: 'Thermal cutting processes in offshore plants.' Intl Conf: 'Joining of metals', Denmark, 1984.