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PATENT SPECIFICATION

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(54) ELECTRIC ARC CUTTING AND GOUGING METHOD /

(71) We, AIR PRODUCTS AND CHEMICALS, INC., of P.O. Box 538, Allentown, Pennsylvania 18105, United States of America, a Corporation of the State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention pertains to the field of cutting and gouging metals submerged in a relatively non-volatile liquid. The largest field of use of the present invention is in the electric-arc cutting and gouging of metallic objects submerged under large bodies of water such as rivers, lakes, oceans and the like. Such objects can be sunken vessels, submerged portions of floating vessels such as ships, barges and the like, fixed submerged structures such as bridge pilings, coffer dams, piers, or other submerged structural objects. In recent years, electric-arc cutting is being used extensively for the construction and maintenance of offshore oil and gas drilling platforms.

The conventional electric-arc cutting processes used under water are detailed in U.S. Patents, 2,396,307; 2,417,650; 3,462,463; and 3,751,625. All of these patents disclose in detail underwater cutting torches which employ the well-known oxy-arc process. In the conventional oxy-arc process an electric-arc is struck between a hollow electrode and the workpiece. Simultaneously, oxygen gas is forced down through the center bore of the electrode to provide the chemical reaction in the cutting process. Such processes are limited to through cutting of metals.

In area of underwater construction and salvage, it is sometimes desirable to remove only a portion of the surface of a metallic object in preparation for underwater welding. U.S. Patent 2,706,236 discloses the well-known air-carbon arc cutting and gouging process which for many years has been used on dry land for preparing metal objects for welding. The air-carbon arc cutting and gouging process employs at carbon (graphite) electrode to establish an arc between the electrode and the workpiece to heat and melt the portion of the workpiece under the arc. Simultaneously, a stream of compressed air is forced down along the electrode to forcibly remove the molten metal from the influence of the arc and from the workpiece thus enabling a skilled operator to gouge the metal for subsequent filler metal welding. The air-carbon arc process has also been used for complete cutting of metallic objects as well as for removing portions of metal objects such as studs, bolts, gusset plates, rivets and the like.

With the conventional oxy-arc process it is not possible to provide for gouging of metallic workpieces submerged in an aqueous environment. Also conventional underwater cutting processes require a source of oxygen which is usually conducted to the torch via a hose from an oxygen bottle on the diving support boat commonly referred to as a tender. With the use of oxygen, the safety hazards increase as well as the opportunity for hoses to become fouled, kinked or severed as they extend for long distances from the surface to the point of use underwater.

It has been found that the use of oxygen in electric-arc cutting underwater can be eliminated and a process achieved wherein the electric-arc can be used underwater for both cutting and gouging. Particularly it has been discovered that the underwater cutting and gouging process may be achieved by employing an electrode to strike and maintain an arc between the electrode and the workpiece to heat and melt the workpiece while simultaneously impinging a stream of liquid against the molten metal to remove the molten metal from the influence of the arc and from the workpiece.

Thus according to the present invention there is provided a method of removing metal from an object submerged in a liquid medium comprising the steps of:

establishing an electric arc between an electrode and the object; and directing at least one stream of high pressure liquid so as to pass between the electrode and the object and to impinge upon and carry metal away from the object.

By controlling the current in the arc and movement of the arc, an operator can cut, groove or gouge a workpiece underwater. It will be appreciated that the invention encompasses electric-arc cutting or gouging in any relatively non-volatile liquid medium wherein the medium can be employed to remove the molten metal from the influence of the arc.

The process of the present invention can rely upon the liquid environment (e.g. water) as the means for removing molten metal from the influence of the arc and from the workpiece thus enabling a skilled operator to make a groove or gouge or to completely cut through a metallic object submerged in the environment. If the liquid environment is water or some other relatively non-volatile liquid, a submersible pump can be used to provide the liquid stream thus obviating the need for long support hoses from a remote source of liquid under pressure. Alternatively, liquid can be supplied by a conventional pump maintained on the diving tender.

The invention thus provides a new electric-arc process for cutting or gouging metallic articles submerged in a liquid medium, which is not dependent on oxygen or chemical reaction to carry out the cutting process.

The method of the invention will now be described by way of example with particular reference to the accompanying drawings in which:

Figure 1 is, a front elevational view of an underwater cutting and gouging torch useful in performing the method of the invention.

Figure 2 is a partial sectional right side elevational view of the torch of Figure 1.

Figure 3 is a sectional view taken according to section line 3—3 of Figure 1, with the addition of an electrode, illustrating the method of the invention.

Figure 4 is a front elevational view of a test torch head used to develop the method of the present invention.

Figure 5 is a section taken along lines 5—5 of Figure 4.

Referring to the drawing, there is shown in Figure 1 a prototype torch devised for carrying out the method of the present invention. Other torches have been devised and are described in more detail in our copending U.K. Patent Application No. 7659/77 (Serial No. 1,573,782).

The torch 10 of Figure 1 includes a handle 12 and a head 14. The handle portion 12 was fabricated from a single piece of conductive metal fabricated from a conventional copper alloy used for underwater torches. The handle 12 includes a threaded portion 16 for receiving power cable adapter 18 having a complementary threaded portion. The power cable adapter 18 is in turn connected to a main power cable 20 which in turn is connected to a suitable power supply (not shown) by a power supply lug or connector 22. The entire power cable 20 is covered by an insulating coating 24 as is well-known in the art. An insulating boot 26 covers cable adapter 18 and ensures a fluid tight seal between the cable adapter 18 and torch handle 12. Torch handle 12 has an insulating coating 28 so that the torch can carry a current and be safely gripped by an operator.

As shown in Figure 3, the torch head 14 includes the head block 30 fabricated from a copper-based metal alloy having therein a first counter bored portion 32 the larger diameter portion being threaded to receive hose adapter 34. Hose adapter 34 has a barbed portion for receiving a liquid conduit 36 which extends for a suitable length and terminates with a conventional hose connector 38 with suitable means, e.g. threads, for affixing connector 38 to a liquid pressure source such as a pump. Conduit or hose 36 is fastened to adapters 34 and 38 respectively as by conventional hose clamps 40 and 42.

Disposed within head block 30 is a recess 44 of suitable shape to receive an electrode shown generally as 46. Communicating with the recess 44 is a threaded port 48 which has disposed therein a stem 50 and knob 52. The stem 50 can move into the recess 44 thus exerting a positive gripping force on electrode 46. A small passage 54 communicates with counter bore 32 so that liquid pressure can be employed to eject the stub of the electrode after it is partially consumed.

Adjacent to and having a center line generally parallel to recess 44 is a tapered passage 56. Tapered passage 56 begins at counter bore 32 and ends on the face of head block 30 adjacent to recess 44 as is shown in Figure 1.

Electrode 46 includes a first thin coating of a metal 58 such as copper, the entire surface except the tapered tip 60 of electrode 46 being coated with the copper

layer. Disposed over the copper layer 58 is an insulating layer 62 extending for a substantial length along the portion of the electrode projecting from head block 30.

The preferred electrode for the process is a direct current (DC) electrode which is normally used for the air-carbon arc cutting and gouging process. Such electrodes are available from the Arcair Company, Lancaster, Ohio, National Carbon Division of Union Carbide and Airco-Speer Carbon and Graphite Division of Airco, Inc. The graphite electrode is provided with a thin coating of a conductive metal, e.g. copper, as is well known in the art. For the process of the instant invention, it is necessary to provide an electrically insulating coating on those portions of the electrode except for the tip, that are exposed to the diver and the surrounding environment. After considerable testing, a coating such as disclosed in U.S. Patent 3,835,288, the specification of which is incorporated here by reference, was found to be satisfactory. In particular, an epoxy resin such as sold by Michigan Chrome and Chemical Company under the trade designation MICCRON-TYPE 650 epoxy is ideally suited as a coating.

As with handle 12, head block 30 has an insulating coating 64 to prevent shock should the user touch the head 14 while the torch is being used.

In use, conduit 36 is connected to a source of liquid under pressure. If the diver is working in a large pool of water such as a lake, fitting 38 can be connected to a submersible pump which is maintained near the site of torch operation. Connector 22 of conduit 20, is fastened to a welding power supply as is well known in the art.

A graphite electrode such as commonly employed in the air-carbon arc cutting and gouging process having first been provided with an insulating coating 62 is placed in recess 44.

The diver then strikes an arc between point 60 of electrode 46 and the workpiece (not shown) to initiate heating and melting of the underlying metal. After the arc is struck, liquid is forced through conduit 36 and out through tapered passage 56 and generally in the direction of the arc. As the arc heats the metal, the stream of liquid under pressure forces molten metal away from the arc and off the workpiece thus enabling an operator to either perform a gouging operation on the workpiece or a complete cut through the workpiece.

In addition to the conventional round electrode such as shown in Figure 3, a conventional flat electrode such as disclosed in U.S. Patent 3,566,069, was used for testing the method of the instant invention. The flat electrode was also provided with an insulating coating such as used with the round electrodes. Of course, when using the flat electrodes, the configuration of aperture 44 in torch head 14 had to be modified to accommodate the flat electrodes which have a cross-sectional shape similar to a rectangle with semi-circular ends.

A large number of tests were run in a diving tank containing fresh water wherein workpieces could be supported for trials at a depth of eight feet. Using a torch such as shown in the drawing in combination with various power supplies, diving tank tests were conducted and data recorded. The power supplies included a Model SR600 DC power supply manufactured by the Miller Electric Company of Appleton, Wisconsin, a Model LSR-1400 liquid carbonic DC arc welder manufactured by Liquid Carbonic Division of Chemetron Corporation and a SEAPACK-350 diesel engine DC power source sold by the Arcair Company. In addition, various tests were run using both a surface pump sold as hypro series 5300 piston pump powered by a Dayton Model 4K783-D motor, the combination which is sold by Sand M Pump Company, Houston, Texas and an Aqua-sub model 12D 5A type 70 submersible pump offered for sale by TRW, Inc.

On the basis of the tests accomplished, it was discovered that when the power source setting was maintained between 80 and 100% of the duty cycle and the water pressure was between 80 and 100 psi above the ambient pressure surrounding the submerged article effective cutting and gouging can take place. As with the conventional hand-operated air-carbon arc cutting and gouging process, the operator can influence the quality of the gouge; however, even an inexperienced operator can make gouges or completely cut through a submerged article.

Set forth in Table I below are a series of tests which were run to verify the inventive process.

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TABLE I

Test No.	Metal Plate Material	Process (a)	Electrode Size & Type (b)	Power Source (c)	Arc Parameters		Grams Carbon Used	Inches Carbon Used	Lbs. Metal Removed
					Volts	Amps			
IRD2-1	1/2" Mild Steel	G	5/16" x 9"	Miller	40	450	4.5	1.6	.14
IRD2-2	1/2" Mild Steel	C	5/16" x 9"	Miller	30	600	7.15	2.59	.23
IRD2-3	1" Mild Steel	G	3/8" x 9"	Miller	40	468	8.9	2.32	.52
IRD2-4	1/2" Mild Steel	C	3/8" x 9"	Miller	27	710	13.8	3.47	.41
IRD2-5	3/8" Mild Steel	C	3/8" x 9"	Miller	30	700	6.35	1.65	.22
IRD2-6	1" Mild Steel	G	1/2" x 9"	Miller	35	526	7.0	1.11	.54
IRD2-7	1/2" Mild Steel	C	1/2" x 9"	Miller	30	698	6.9	1.07	.50
IRD2-8	3/8" Mild Steel	C	1/2" x 9"	Miller	28	713	3.75	.58	.16
IRD3-1	1/2" Mild Steel	FG	5/8" flat x 9"	L.C.	30	623	4.9	1.13	.04
IRD3-2	1/2" Mild Steel	S	5/8" flat x 9"	L.C.	55	338	13.9	3.25	.12
IRD3-3	1/2" Mild Steel	FG	5/8" flat x 9"	L.C.	45	450	5.2	1.4	.14
IRD3-4	1/2" Mild Steel	S	5/8" flat x 9"	L.C.	50	375	7.55	1.75	.14
IRD4-1	3/8" Mild Steel	G @ 20psi	5/16" x 9"	L.C.	36	512	2.8	1.0	.01
IRD4-2	3/8" Mild Steel	G @ 40psi	5/16" x 9"	L.C.	34	526	4.5	1.5	.06
IRD4-3	3/8" Mild Steel	G @ 60psi	5/16" x 9"	L.C.	37	488	4.8	1.5	.17
IRD4-4	3/8" Mild Steel	G @ 80psi	5/16" x 9"	L.C.	33	576	3.55	1.25	.15
IRD4-5	3/8" Mild Steel	G @ 95psi	5/16" x 9"	L.C.	35	518	2.8	1.0	.13
IRD4-6	3/8" Mild Steel	G @ 120psi	5/16" x 9"	L.C.	39	475	3.0	1.0	.15
IRD5-1	3/8" Mild Steel	G	5/16" x 9"	L.C.	35	500	2.05	1.0	.054
IRD5-2	3/8" Mild Steel	C	5/16" x 9"	L.C.	32	520	6.35	2.0	.021
IRD5-3	Lap Joint 3/8" Filler Weld	R	5/16" x 9"	L.C.	34	512	1.4	.5	.10
IRD5-4	3/8" Mild Steel	G	5/16" x 9"	L.C.	30	580	2.3	1.125	.14
IRD5-5	3/8" Mild Steel	C	5/16" x 9"	L.C.	31	563	4.55	1.5	.17
IRD5-6	Lap Joint 3/8"	R	5/16" x 9"	L.C.	34	512	1.85	.875	.14

(12)

TABLE I (Continued)

Test No.	Metal Plate Material	Process (a)	Electrode Size & Type (b)	Power Source (c)	Arc Parameters		Grams Carbon Used	Inches Carbon Used	Lbs. Metal Removed
					Volts	Amps			
1RD6-1	3/8" Mild Steel	g @ 7/8"	5/16" x 9"	Miller	55	308	4.11	1.125	.142
1RD6-2	3/8" Mild Steel	g @ 6/8"	5/16" x 9"	Miller	50	338	3.03	1.0	.138
1RD6-3	3/8" Mild Steel	g @ 5/8"	5/16" x 9"	Miller	45	375	3.46	1.125	.174
1RD6-4	3/8" Mild Steel	g @ 4/8"	5/16" x 9"	Miller	48	360	2.69	.969	.155
1RD6-5	3/8" Mild Steel	g @ 3/8"	5/16" x 9"	Miller	—	—	3.21	1.063	.173
1RD6-6	3/8" Mild Steel	g @ 2/8"	5/16" x 9"	Miller	—	—	3.29	1.125	.165
1RD6-7	3/8" Mild Steel	g @ 1/8"	5/16" x 9"	Miller	—	—	3.42	1.063	.148
2RD4-1	Bolt Weld on 1/2" Plate	R	5/16" x 8'6"	Miller	29	473	2.1	.766	.1
2RD4-2	Pipe Weld on 1/2" Plate	R	5/16" x 8'6"	Miller	32	563	5.5	1.848	.2
2RD4-3	T-Joint Weld 3/4" Plate	R	5/16" x 8'6"	Miller	27	538	4.1	1.417	.17
2RD4-4	Simulated Crack 1/2"	G	5/16" x 8'6"	Miller	29	361	1.3	.474	.06
2RD4-5	Circle from 3/8"	C	5/16" x 8'6"	Miller	22	616	10.5	3.643	.27
2RD4-6	Circle from 3/8"	C	5/16" x 8'6"	Miller	38	458	20.9	7.455	.51
2RD4-7	Scarfing 1/2" Plate	S	A5/8" Flat x 8-1/2"	Miller	33	579	57.6	15.548	.52
2RD4-8	T-Joint Weld 3/4" Plate	R	A5/8" Flat x 8-1/2"	Miller	26	639	9.7	2.776	.10
2RD5-1	1/2" Mild Steel	G	5/16" x 8-1/2"	Miller	—	400	4.5	1.5	.2
2RD5-2	1/2" Mild Steel	G	5/16" x 8-1/2"	Miller	—	420	5.2	5.2	.2
2RD5-3	1/2" Mild Steel	G	5/16" x 8-1/2"	Miller	—	560	8.6	2.9	.09
2RD5-4	1/2" Mild Steel	G	5/16" x 8-1/2"	Miller	—	540	7.4	2.5	.09
2RD6-1	1/2" Mild Steel	G	5/16" x 9"	L.C.	—	480	5.9	2.08	.295
2RD6-2	1/2" Mild Steel	G	5/16" x 9"	L.C.	—	440	6.3	2.16	.250
2RD6-3	1/2" Mild Steel	C	5/16" x 9"	L.C.	—	630	14.6	4.98	.310
2RD6-4	1/2" Mild Steel	C	5/16" x 9"	L.C.	—	640	17.0	5.98	.625
2RD7-1	1/2" Mild Steel	G	5/16" x 9"	L.C.	—	600	8.9	2.87	.30
2RD7-2	1/2" Mild Steel	C	5/16" x 9"	L.C.	—	610	9.5	3.39	.30
2RD7-3	1/2" Mild Steel	G	5/16" x 9"	L.C.	—	600	4.7	1.71	.18
2RD7-4	1/2" Mild Steel	C	5/16" x 9"	L.C.	—	620	12.7	4.40	.32

TABLE I (Continued)

Test No.	Metal Plate Material	Process (a)	Electrode Size & Type (b)	Power Source (c)	Arc Parameters		Arc Time (Mins.)	Grams Carbon Used	Inches Carbon Used	Lbs. Metal Removed
					Volts	Amps				
1RD1-1	3/8" Mild Steel	G	5/16" x 9"	Arcair	40	385	.4	3.5	1.0	.17
1RD1-2	3/8" Mild Steel	C	5/16" x 9"	Arcair	25	472	.8	10.4	3.0	.13
1RD1-3	1/2" Mild Steel	C	5/16" x 9"	Arcair	23	486	.9	15.35	4.5	.12
1RD1-4	Lap Weld 3/8" Plate	C	5/16" x 9"	Arcair	28	463	.3	5.65	1.75	.32
1RD1-5	3/8" Mild Steel	C	3/8" x 9"	Arcair	34	418	.3	2.2	.5	.10
1RD1-6	3/8" Mild Steel	C	3/8" x 9"	Arcair	25	450	1.35	9.7	2.38	.17
2RD2-1	Zig-Zag Tacked	G	5/16" x 8-1/2"	L.C.	40	340	.2	2.4	.8	.145
2RD2-2	Mild Steel	G	5/16" x 8-1/2"	L.C.	40	460	.5	6.6	2.2	.25
2RD2-3	Mild Steel	C	5/16" x 8-1/2"	L.C.	30	570	1.05	10.9	3.7	.25
2RD2-4	T-Joint	R	5/16" x 8-1/2"	L.C.	32	510	.87	7.8	2.6	.25
2RD2-5	Zig-Zag Tacked	G	5/16" x 8-1/2"	L.C.	38	400	.18	2.9	1.0	.14
2RD2-6	Mild Steel	G	5/16" x 8-1/2"	L.C.	40	420	.55	6.8	2.3	.25
2RD2-7	Mild Steel	C	5/16" x 8-1/2"	L.C.	30	580	.89	17.5	5.9	.27
2RD2-8	T-Joint	R	5/16" x 8-1/2"	L.C.	32	550	.66	7.2	2.4	.195
2RD2-9	Mild Steel	G	5/16" x 9"	L.C.	46	400	.45	5.7	1.9	.19
2RD2-10	Mild Steel	G	5/16" x 8-1/2"	L.C.	46	410	.65	6.9	2.4	.33
2RD2-11	Mild Steel	G	5/16" x 8"	L.C.	50	400	.57	7.2	2.4	.33
2RD2-12	Mild Steel	G	5/16" x 8"	L.C.	44	410	.61	6.5	2.1	.26
2RD2-13	Mild Steel	G	5/16" x 7-1/2"	L.C.	44	370	.62	7.5	2.6	.395
2RD2-14	Mild Steel	G	5/16" x 7"	L.C.	42	405	—	7.0	2.5	.345
2RD2-15	Mild Steel	G	A5/16" x 8-1/2"	L.C.	40	420	—	5.7	1.9	.175
2RD2-16	Mild Steel	G	A5/16" x 8-1/2"	L.C.	46	440	.63	7.9	2.7	.31
2RD3-1	1/2" Mild Steel	S	A5/8" Flat x 8-1/2"	L.C.	40	400	.4	4.5	1.2	.07
2RD3-2	1/2" Mild Steel	S	A5/8" Flat x 8-1/2"	L.C.	36	475	.7	8.5	2.4	.162
2RD3-3	1/2" Mild Steel	S	A5/8" Flat x 12"	L.C.	35	500	1.1	7.3	2.0	.065
2RD3-4	1/2" Mild Steel	S	A5/8" Flat x 9"	L.C.	35	500	.5	8.2	2.2	.075
2RD3-5	1/2" Mild Steel	S	A5/8" Flat x 8"	L.C.	39	450	.3	—	—	.057
2RD3-6	1/2" Mild Steel	S	A5/8" Flat x 7"	L.C.	40	500	.4	4.2	1.2	—

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TABLE I (Continued)

Test No.	Metal Plate Material	Process (a)	Electrode Size & Type (b)	Power Source (c)	Arc Parameters		Grams Carbon Used	Inches Carbon Used	Lbs. Metal Removed
					Volts	Amps			
2RD3-7	1/2" Mild Steel	G	5/16" x 8-1/2"	L.C.	42	390	6.0	2.2	.342
2RD3-8	1/2" Mild Steel	C	5/16" x 8-1/2"	L.C.	30	590	7.3	2.5	.250
2RD3-9	1/2" Mild Steel	G	5/16" x 8-1/2"	L.C.	45	515	7.3	2.5	.244
2RD3-10	1/2" Mild Steel	C	5/16" x 8-1/2"	L.C.	30	590	13.8	4.7	.148
92RD7-1	T-Joint Weld (1")	R	5/16" x 12"	Miller	45	560	—	4.0	.48 est.
92RD7-2	T-Joint Weld (1")	R	5/16" x 9-1/2"	Miller	51	520	—	2.62	.35 est.
92RD7-3	T-Joint Weld (1")	R	5/16" x 8-1/2"	Miller	51	480	—	—	.16 est.
92RD8-1	T-Joint Weld (1/2")	R	5/16" x 12"	Miller	34	450	—	3.25	.31 est.
92RD8-2	T-Joint Weld (1/2")	R	5/16" x 12"	Miller	40	370	—	2.0	.26 est.
92RD8-3	T-Joint Weld (1/2")	R	5/16" x 9-1/2"	Miller	38	460	—	2.25	.29 est.
92RD8-4	T-Joint Weld (1/2")	R	5/16" x 8-1/2"	Miller	38	400	—	2.06	.36 est.
92RD8-5	T-Joint Weld (1/2")	R	5/16" x 7-1/2"	Miller	45	370	—	2.88	.36 est.
92RD8-6	3/4" Mild Steel	G	5/16" x 12"	Miller	41	340	—	6.81	.91
92RD8-7	1/2" Mild Steel	G	5/16" x 12"	Miller	43	330	—	3.0	.36
92RD8-8	1/2" Mild Steel	G	5/16" x 9-1/2"	Miller	44	310	—	2.75	.36
92RD8-9	1/2" Mild Steel	G	5/16" x 8-1/2"	Miller	45	295	—	2.63	.42
92RD8-10	1/2" Mild Steel	G	5/16" x 7-1/2"	Miller	44	300	—	3.13	.46
92RD8-11	1/2" Mild Steel	C	5/16" x 12"	Miller	32	450	—	2.25	.26
92RD8-12	1/2" Mild Steel	C	A5/16" x 12"	Miller	20	480	—	5.75	.19
92RD8-13	1/2" Mild Steel	C	A1/4" x 12"	Miller	29	380	—	6.75	.20
92RD8-14	1/2" Mild Steel	C	A1/4" AC x 12"	SP-60%	—	480	—	—	—
92RD8-15	1/2" Mild Steel	C	A1/4" AC x 12"	SP-60%	27	433	—	—	—
92RD8-16	1/2" Mild Steel	C	A5/16" AC x 12"	SP-60%	27	500	—	—	—

TABLE I (Continued)

Test No.	Metal Plate Material	Process (a)	Electrode Size & Type (b)	Power Source (c)	Arc Parameters		Arc Time (Mins.)	Grams Carbon Used	Inches Carbon Used	Lbs. Metal Removed
					Volts	Amps				
2RD1-1	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	45	350	—	4.5	1.35	.15
2RD1-2	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	50	425	—	4.9	1.51	.18
2RD1-3	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	45	400	—	5.9	1.82	.17
2RD1-4	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	45	425	—	4.1	1.22	.15
2RD1-5	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	45	400	—	3.0	0.91	.14
2RD1-6	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	45	400	—	3.7	1.13	.14
2RD1-7	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	45	400	—	3.9	1.18	.13
2RD1-8	1/2" Mild Steel	G	A5/16" AC x 8-1/2"	L.C.	45	425	—	3.9	1.19	.16

(a) R = Weld removal, G = gouging, C = cutting, S = scarfing, FG = flat gouging

(b) Electrodes are copper coated D.C. electrodes produced by National Carbon Division of Union Carbide Corporation except where noted.

A = Arcair (All electrodes epoxy coated over copper).

(c) 600 Miller Power Source Settings on 80% of max. range, 400 Liquid Carbon Settings on 100% of max. range.

From the foregoing it is obvious that the method of the instant invention can be used not only for cutting but also for weld removal, gouging, scarfing, or flat gouging operations underwater. Such operations have heretofore been unavailable to the underwater salvage operator. Furthermore, from the evidence present in the foregoing table, it is obvious that various electrode sizes can be used and that there is good utilization of the electrode per amount of metal removed.

As indicated above, those tests run in the shallow tank were run at a depth of about 18", whereas those tests run in the deep tank were run at eight feet thus showing that the inventive process can work at depth. In addition, a prototype torch was sent out to field and was found to work in ambient conditions in the Gulf of Mexico. In the field trials, various thicknesses of steel plate ranging from 3/32 of an inch of thickness to 3/4 of an inch in thickness were cut using a standard power supply with a current of between 500 and 600 amps and a water pressure in the torch of 140 psi. Cutting was as follows:

	Plate Thickness	Inches Per Minute
15	3/32"	50
	3/16"	24
	1/4"	18
	3/4"	1.4

20 In addition, 32" diameter steel pipe having a 3/4" wall thickness was completely

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severed. Another test performed a gouge 1-1/2" wide 3/8" deep in a steel pipeline 12' long. The method of the instant invention was found applicable to cutting brass, aluminum and a proprietary corrosion resistant alloy of the field trial company. Lastly, 1" diameter steel wire rope could be cut completely through in 10 seconds during the test.

During the development of the invention, various configurations for the fluid passage 56 were tried. The one shown in Figure 3 where the longitudinal axis of passage 56 is offset from the longitudinal axis of counter bore 32 was found to be satisfactory.

There is shown in Figure 4 and Figure 5 a preferred nozzle configuration, the figures illustrating a test block used to verify the nozzle configuration. The test block (head) 70 of Figure 4 is fabricated from an alloy similar to the alloy used for the head 14 of the torch of Figures 1-3. Block 70 includes a first recess 72 for receiving the electrode. The outer end of recess 72 contains a tapered opening 74 to facilitate entry and removal of electrodes. Head 70 also includes a threaded passage 76 which receives a threaded stud (not shown) to secure the electrode within the recess 72. Adjacent to the recess 72 is a tapered passage 78 which communicates with a threaded bore 80 to receive the hose (not shown). Passage 78 was found to provide the best gouging characteristics when it was 1-3/8" long, having a large diameter of .1224", a small diameter of .1137" and a maximum radius of 0.020" at the transition 82 between the passage 78 and the bore 80. Of course, the possibility of establishing other passage configurations is wide, and the invention in its broadest sense is not limited to a passage having the foregoing configurations. For example, a nozzle configuration could be provided in which a cone of water surrounding the electrode is directed at the workpiece to remove molten metal.

Set forth in Table II is a comparison summary of results using the orifice of Figures 4 and 5 which is denoted as radius and centered in comparison to the standard orifice (Fig. 3).

TABLE II
SUMMARY OF TABLE I RESULTS

Item	No.	Torch Orifice	Volts	Amps	Arc Time (Mins.)	Grams Carbon Used	Inches of Carbon Used	Lbs. Metal Removed
GROOVING	15	Radius & Centered	40	447	5.75	53.21	18.110	2.42
WELD REMOVAL	5	Standard	30	510	1.75	18.75	6.281	.89
CUTTING	6	Radius & Centered	28	556	4.70	68.95	22.47	1.555

In the foregoing it is apparent that the radius and centered orifices operate similar to the standard orifice with improved fluid flow properties; however, the metal removal characteristics are almost identical.

It should be understood that the method of the invention is not limited in any way by the particular dimensions of the orifice.

Set forth on Table III are a series of comparative tests showing metal removal using a torch and method of the instant invention and a standard underwater electrode (U.S. Patent 3,835,288) in a standard underwater torch (U.S. Patent 3,751,625) employing the well-known oxy-arc underwater cutting method. The patented electrode is a length of hollow steel tubing having the epoxy coating thereon. As set forth in Table III below, tests 1 and 2 were conducted using the standard oxy-arc cutting technique. Tests 3, 4 and 5 were run with the method of the present invention.

TABLE III
METAL REMOVAL TEST DATA

Test	Weight of Elect. (a)	Amp.	Volt	Length or weight of Electrode Used	Lbs. of Metal Removed	Total Arc Time (Mins.)	Lbs. Per Min. Arc Time	Lbs. Per Elect.	Arc. Mins. Per Electrode	Length & Widths of cut Per Electrode
1	125.1g	483	36	10.75"	0.51	0.6	.85	.52	.61	13.05" x 4/8"
2	123.3g	503	33	10.5"	0.51	0.6	.85	.53	.63	10.48" x 3/8"
1 & 2		493	35	21.25"	1.02	1.2	.85	.53	.62	11.78" x 3/8"
3 (b)	approx. 22.0g	556	28	22.47"	1.555	4.7	.331	.415	.80	7.97"1 x 3/8" w/Electrode
4 (c)	approx. 22.0g	510	30	6.281"	0.89	1.75	.509	.850	.60	7.97"1 x 3/8" w/Electrode
5 (d)	approx. 22.0g	447	40	53.21g	2.42	5.75	.421	.802	.52	7.97"1 x 3/8" w/Electrode

Notes:

- (a) All electrodes 5/16" diameter - Test Material 1/2" Thick Mild Steel Plate
 (b) Average of 6 trials using method of invention to cut through plate
 (c) Average of 5 trials using method of invention to remove lap welded plate
 (d) Average of 15 trials using method of invention to groove plate

From the foregoing it can be seen that, notwithstanding its short or usable length (6" as compared to 11" in a conventional oxy-arc electrode) the graphite electrode removes 60 and 51% respectively more metal when removing welds and grooving than did the conventional oxy-arc electrode. When reviewing the table, the oxy-arc process appears to be faster when comparing the pounds per minute of arc time between the two processes. However, when the arc minutes per electrode parameter is considered, the method of the invention in regard to weld removal and grooving is much more efficient.

While the oxy-arc process may have an advantage in cutting operations, the pro-

cess of the instant invention enables the underwater salvage operator to perform weld removal, grooving, and gouging operations heretofore not possible with an oxy-arc torch.

The process of the instant invention is also usable for cleaning surface scale and removing barnacles from submerged objects.

WHAT WE CLAIM IS:—

1. A method of removing metal from an object submerged in a liquid medium comprising the steps of:

establishing an electric arc between an electrode and the object; and

directing at least one stream of high pressure liquid so as to pass between the electrode and the object and to impinge upon and carry metal away from the object.

2. A method of removing metal from an object submerged in a liquid medium comprising the steps of:

establishing an electric arc between an elongated solid electrode and the object thus heating and melting that portion of the object under the arc; and

removing the molten metal from the portion of the object being heated by and beneath the arc by directing at least one stream of high pressure liquid so as to pass between the electrode and the object being heated and to impinge upon and carry molten metal away from the object.

3. A method according to Claim 1 or Claim 2 wherein the arc maintained between the electrode and the object and the point of impingement of the stream of liquid upon the object are continuously moved along the surface of the object to effect continuous metal removal from the object.

4. A method according to any preceding claim wherein the liquid is the medium in which the object is submerged.

5. A method according to Claim 4 wherein the liquid is water.

6. A method according to any preceding claim wherein the electrode is a solid carbonaceous rod covered with a first thin layer of a conductive material and a second layer of an electrically insulating material covering a substantial portion of the first layer and the electrode.

7. A method according to any preceding claim wherein the electrode is held in a suitable gripping device and the stream of liquid is directed at the object from the location at which the electrode is gripped.

8. A method of grooving, gouging or cutting a metal workpiece submerged in water comprising the steps of:

positioning a consumable solid elongated electrode held in a suitable gripping device so that a portion of the electrode projects toward the workpiece;

establishing and maintaining an electric-arc between the projecting end of the electrode and the workpiece to melt that portion of the metal under the arc; and

directing at least one stream of water under pressure to impinge upon and remove the molten metal from the workpiece beneath the arc.

9. A method according to Claim 8 wherein the electrode is a carbonaceous material covered by a thin conductive coating which in turn is covered by an electrically insulating coating, the electrically insulating coating covering the projecting length of the electrode.

10. A method according to Claim 8 or Claim 9 wherein a water stream is directed toward the workpiece from the location at which the electrode is gripped.

11. A method according to Claim 8 or Claim 9 wherein a plurality of streams are directed at the workpiece.

12. A method according to Claim 8 or Claim 10 wherein a cone of water surrounding the electrode is directed at the workpiece to remove the molten metal.

13. A method of removing material from an object according to Claim 1 and substantially as hereinbefore described with particular reference to the accompanying drawings.

MATHYS & SQUIRE,
Chartered Patent Agents,
10 Fleet Street,
London, E.C.4,
Agents for the Applicants.

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The process of the instant invention is also usable for cleaning surface scale and removing barnacles from submerged objects.

WHAT WE CLAIM IS:—

1. A method of removing metal from an object submerged in a liquid medium comprising the steps of:

establishing an electric arc between an electrode and the object; and

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2. A method of removing metal from an object submerged in a liquid medium comprising the steps of:

establishing an electric arc between an elongated solid electrode and the object thus heating and melting that portion of the object under the arc; and

removing the molten metal from the portion of the object being heated by and beneath the arc by directing at least one stream of high pressure liquid so as to pass between the electrode and the object being heated and to impinge upon and carry molten metal away from the object.

3. A method according to Claim 1 or Claim 2 wherein the arc maintained between the electrode and the object and the point of impingement of the stream of liquid upon the object are continuously moved along the surface of the object to effect continuous metal removal from the object.

4. A method according to any preceding claim wherein the liquid is the medium in which the object is submerged.

5. A method according to Claim 4 wherein the liquid is water.

6. A method according to any preceding claim wherein the electrode is a solid carbonaceous rod covered with a first thin layer of a conductive material and a second layer of an electrically insulating material covering a substantial portion of the first layer and the electrode.

7. A method according to any preceding claim wherein the electrode is held in a suitable gripping device and the stream of liquid is directed at the object from the location at which the electrode is gripped.

8. A method of grooving, gouging or cutting a metal workpiece submerged in water comprising the steps of:

positioning a consumable solid elongated electrode held in a suitable gripping device so that a portion of the electrode projects toward the workpiece;

establishing and maintaining an electric-arc between the projecting end of the electrode and the workpiece to melt that portion of the metal under the arc; and

directing at least one stream of water under pressure to impinge upon and remove the molten metal from the workpiece beneath the arc.

9. A method according to Claim 8 wherein the electrode is a carbonaceous material covered by a thin conductive coating which in turn is covered by an electrically insulating coating, the electrically insulating coating covering the projecting length of the electrode.

10. A method according to Claim 8 or Claim 9 wherein a water stream is directed toward the workpiece from the location at which the electrode is gripped.

11. A method according to Claim 8 or Claim 9 wherein a plurality of streams are directed at the workpiece.

12. A method according to Claim 8 or Claim 10 wherein a cone of water surrounding the electrode is directed at the workpiece to remove the molten metal.

13. A method of removing material from an object according to Claim 1 and substantially as hereinbefore described with particular reference to the accompanying drawings.

MATHYS & SQUIRE,
Chartered Patent Agents,
10 Fleet Street,
London, E.C.4,
Agents for the Applicants.