COBEM-2017-0694
EFFECT OF THE WATER IN THE CONTACT TIP IN UNDERWATER FCAW

Marcelo Teodoro Assunção
Alexandre Queiroz Bracarense
Universidade Federal de Minas Gerais – Programa de Pós Graduação em Engenharia Mecânica
Av. Antônio Carlos, 6627 - Pampulha 31270-901 - Belo Horizonte, MG – Brazil
m.teodoro1@hotmail.com
queiroz@demec.ufmg.br

Abstract. Underwater welding is an important process employed to repair offshore and marine structures with advantages of not handling the components off the water. However, the process is performed with lower stability in comparison with welds performed in open air. Under the water, the welding arc is surrounded and compressed by water. When flux cored arc welding - FCAW - is performed in wet condition, water fills the gap between the contact tip and the tubular wire, resulting in a worse current transfer, reducing the process stability. In the present work, with the view to improve the stability of underwater FCAW with self-shielding electrode, a welding torch was developed at LRSS-UFMG. The torch has a sealing system that insulates the contact tip from the water, so that a fraction of the wire length called stick out is kept dry inside the device. A two-level factorial design was used for experimentation and an Analysis of Variance was conducted to validate the results. Current coefficient of variation was used as the index of stability. Welds performed with the torch have shown more stable arc in comparison to beads deposited with no mechanical barrier between water and the contact tip.

Keywords: Welding torch, underwater FCAW, arc stability.

1. INTRODUCTION

The large number of existing offshore structures to support undersea gas and oil exploitation requires underwater welding process to address repair applications. A great majority of offshore structure repairing is carried out at shallow water depths, because of high probability of collision between ships and platforms. Structural components can also show age-related phenomena evidence, such as fatigue and corrosion (Verma and Hairish, 2012). When it is not possible or viable to place the metal structure or components into dry docs, welding operations are performed in water environment.

Underwater wet welding is performed at ambient pressure with no mechanical barrier between water and arc voltaic. Simplicity of the process makes it possible to perform welds even in geometrically complex structures (Labanowski et al, 2008; Nixon and Graham, 1993; Shi et al, 2012). However, in addition to the practical difficulties in performing welds underwater, weld beads are susceptible to high cooling rates caused by the surrounding water, resulting in reduction in tensile strength and ductility (Tsai and Masabuchi, 1973).

Wet welding with coated electrodes (SMAW) is the most used method of joining metal under water, due to cost effectiveness and versatility. Although, the use of tubular electrodes (FCAW) offers higher productivity. Handling shielding gas in offshore application is a matter always addressed. Thus, using a self-shielding tubular wire in underwater application lead to gains of time and reduce costs (Vilarinho and Lucas, 2009).

In underwater FCAW, the welding arc is surrounded by water instead of air. The water environment compresses the arc column on weld pool. The welding arc changes along with the changing bubbles, resulting in fluctuations of current and voltage signals (Jia et al., 2013). The presence of water on the electric parts can also reduce stability of the process. As the wire passes through the contact tip, water fills the gap between these two components and interferes negatively on electric current transfer. Andrade et al (1993) studied the occurrence of micro-fusions between the tubular wire and the contact tip as a cause of the poor stability and suggested addressing this problem by changing the contact tip material and using a high-pressure airflow to expel the water from the nozzle hole.

A tool for underwater welding was patented for Stingelin et al (1979). The device comprises an open-mouthed bell with the electrode inside, a circulating water flow forms a vortex that passes along the bell. The resulting centrifugal forces prevents water from entering inside the torch. Sagara et al (1977) developed a welding torch that prevents the entry

of water by means of a high-speed curtain of water directed obliquely onto the member to be welded, in addiction of gas injected into the volume enclosed.

The objective of this paper is to perform an analysis of arc stability indexes calculated from data registered from electrical signals on welds performed using the torch developed at LRSS-UFMG and on welds performed as in conventional underwater FCAW.

2. EXPERIMENTAL PROCEDURE

2.1 Development of welding torch

In order to reduce the problems related to the presence of water in the gap in between the tubular wire and the contact tip hole in wet welding, a torch for underwater FCAW was developed at Laboratório de Robótica, Soldagem e Simulação - LRSS – UFMG, the torch is shown in Fig.1. The device is equipped with a sealing system that prevents water from entering the contact tip surroundings as the wire passes through. A fraction of the wire in the Contact Tip to Work Distance (CTWD) remains on the water environment while the remaining length of the tubular wire is kept dry inside the torch. It is possible to weld in both configurations using the torch, as in conventional underwater FCAW and keeping the electric parts isolated from water.
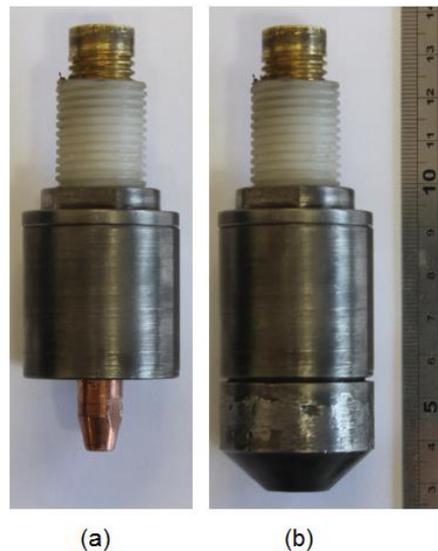

Figure 1: Welding torch for underwater FCAW. (a) With no sealing system assembled and (b) with the sealing system that prevents water from entering the contact tip surroundings.

2.2 Experimental setup

To perform the experiments, welding was carried out in a 0,8 x 0,4 x 0,6m water tank at 0,4m water depth. The welding torch was mounted on a one-axis mechanized horizontal system perpendicular to the working piece. This setting allowed control of torch position, welding speed and CTWD, and resulted in a linear weld bead profile. Bead-on-plate welds were deposited on A36 steel plates with dimensions of 100mm x 220mm x 19mm using a 1,6mm diameter commercial rutile self-shielding tubular wire (ASME SFA 5.20 E71T-11) on electrode negative (CC-). Welding current was measured by a Hall effect sensor. Welding voltage channel was connected to the working piece and the welding torch. Welding voltage, current and wire speed were monitored simultaneously at a frequency of 5 kHz by a data acquisition system. The experimental setup is illustrated in Fig. 2.
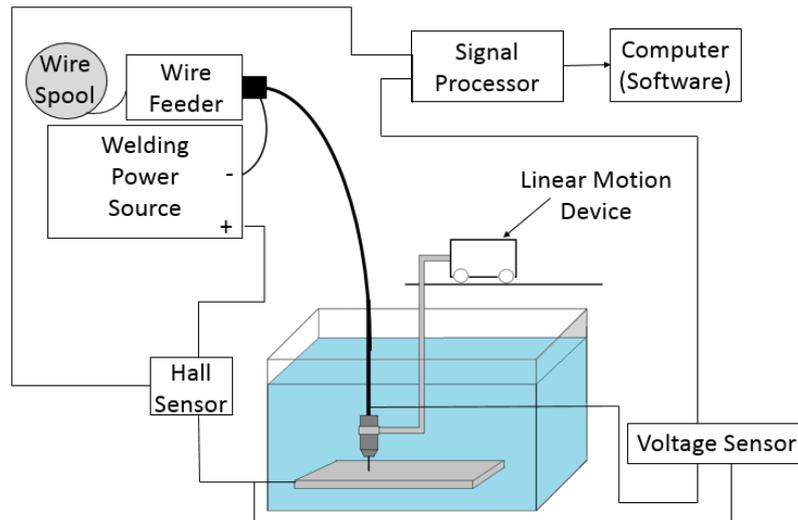
Figure 2: Experimental setup

2.3 Identification of factors and responses

For the purpose of evaluating the effect of welding parameters on arc stability indexes, a two-level factorial design was carried out. In a factorial design, in each complete trial or replication of the experiment, all possible combinations of the levels of the factors are investigated (Montgomery, 2008). The factors studied were "welding condition", CTWD, voltage and wire speed.

The first factor, condition, is qualitative, the two levels are the contact tip wet, as in conventional underwater FCAW, and the contact tip dry (inside the torch). The factors CTWD, voltage and wire speed are quantitative and their respective levels were fixed after literature review and by conducting trial runs. Table 1 presents the input variables with their respective levels and Tab. 2 shows the experimental matrix for the $2^4 = (16)$ factorial design. Welds were deposited randomly according to the levels of parameters in the design matrix. For all runs, welding travel speed was set to 450 mm/min and the torch was positioned perpendicular to the working piece.

Table 1: Test factors for welding experiment

Factor	Name	Units	Low Level (-)	High Level (+)
A	Condition	-	Contact Tip Dry	Contact Tip in Water
B	CTWD	mm	15	20
C	Voltage	V	26	30
D	Wire Speed	m/min	4	5

Table 2: Matrix Experimentation

Run Number	Factor			
	A	B	C	D
1	-	-	-	-
2	-	-	-	+
3	-	-	+	-
4	-	-	+	+
5	-	+	-	-
6	-	+	-	+
7	-	+	+	-
8	-	+	+	+
9	+	-	-	-
10	+	-	-	+
11	+	-	+	-
12	+	-	+	+
13	+	+	-	-
14	+	+	-	+
15	+	+	+	-
16	+	+	+	+

After the welding process, the stability index analyzed as response from the design matrix was the current coefficient of variation, due to the fact that a constant voltage welding source was used. The responses were calculated between the tenth and the twenty-fifth seconds of welding, for all runs. The effect of a factor is defined to be the change in response produced by a change in the level of the factor. It can be calculated by averaging the highs and the lows to determine the difference or contrast. (Montgomery, 2008; Anderson and Whitcomb, 2007). The effect of each factor, as well as interaction effects, were calculated from the factorial design according to Eq. (1).

$$\text{Effect} = \frac{\Sigma Y_+}{n_+} - \frac{\Sigma Y_-}{n_-} \tag{1}$$

Where the 'Y's refer to the responses at high (+) and low (-) levels, and the 'n's refer to the number of data points collected at each level. With the view to validate the results, an Analysis of Variance was performed.

3 RESULTS AND DISCUSSION

3.1 Main effects and interaction effects

The main effects, interaction effects and experimental results are shown in Tab. 3. The Y1 column is the current coefficient of variation.

Table 3: Design matrix and experimental results

Run	Main Effects				Interaction Effects											Y1: C.V. Current
	A	B	C	D	AB	AC	AD	BC	BD	CD	ABC	ABD	ACD	BCD	ABCD	
1	-	-	-	-	+	+	+	+	+	+	+	-	-	-	+	15,764
2	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-	12,111
3	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-	17,867
4	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+	14,098
5	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-	16,801
6	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+	14,049
7	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+	19,775
8	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-	15,042
9	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	14,228
10	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+	12,523
11	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+	23,112
12	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-	18,103
13	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+	37,412
14	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-	27,149
15	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-	33,123
16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	36,168
Effect	9,539	8,964	3,406	-3,605	7,507	1,392	0,122	-1,232	-0,071	0,988	-1,201	-0,055	1,512	1,844	2,310	20,458

In comparison to the overall spread of results shown on the bottom line in Tab. 3, factors A and B, and the interaction AB, have the biggest effects on current coefficient of variation. Figure 3 shows a normal probability plot for the effects. The effects and interactions that fall in line near zero represent a normal scatter, which means that these effects vary only due to normal causes, so they are probably insignificant on current coefficient of variation. The three effects that fall out of the line are most significant on the response, so, the factors condition, CTWD and their interaction are considered to affect current coefficient of variation.
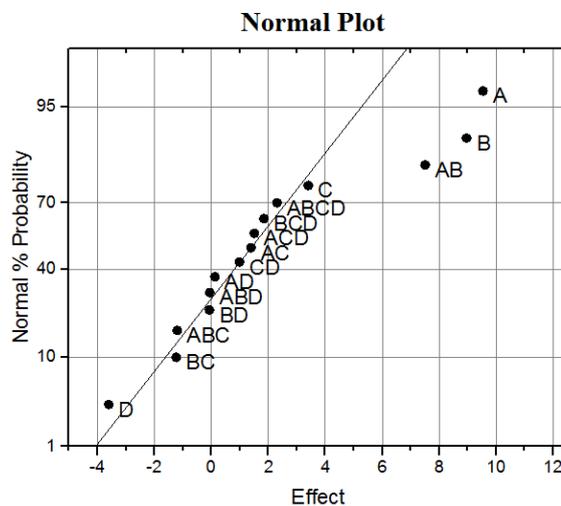

Figure 3: Normal Probability Plot of effects for current coefficient of variation

Figure 4 shows the effects of factors A and B. Both increase the response in 9.539% and 8.964%, respectively, by changing to their higher levels.
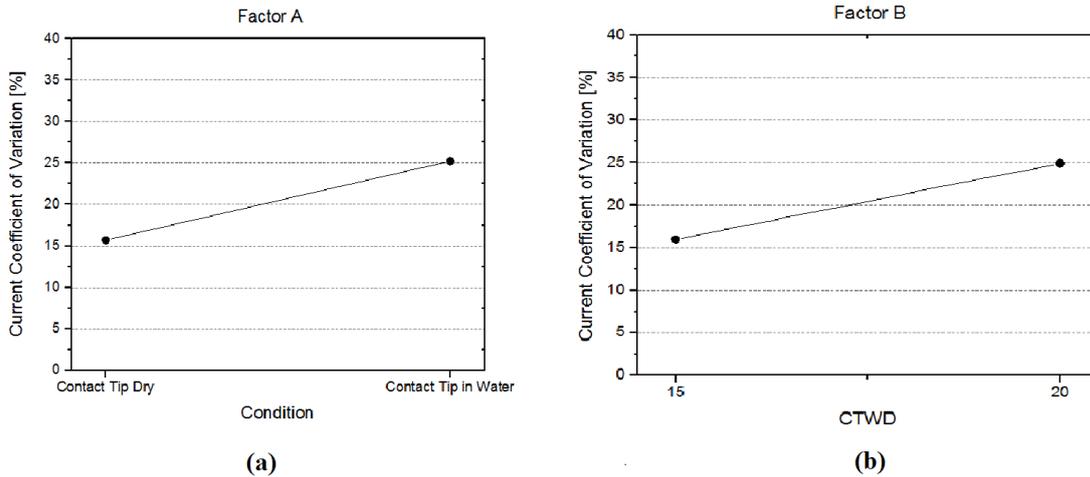
Figure 4: (a) Effect of factor A; (b) Effect of factor B

Considering only the main effects, factors A and B should be set to their lower levels to minimize the response. However, it is necessary to analyze the important interactions. When factors are involved in significant interactions, special attention must be given to analyze them (Montgomery, 2008).

The AB interaction is shown in Fig. 5. It is noted that, when the contact tip is kept dry, a little change occur in the response by increasing the CTWD from 15 to 20mm. However, the welding arc becomes more unstable as the distance from contact tip to working piece increases when the contact tip is in water environment. This can be justified by the fact that an increase in contact tip to plate distance increases the circuit resistance, which reduces welding current. The presence of water in the gap between the contact tip hole and the wire promotes worse electric contact as the electrode passes through. Poor electric contact increases the frequency of micro fusions between wire and contact tip, resulting in larger variations on current signal (Andrade and Dutra, 1993).
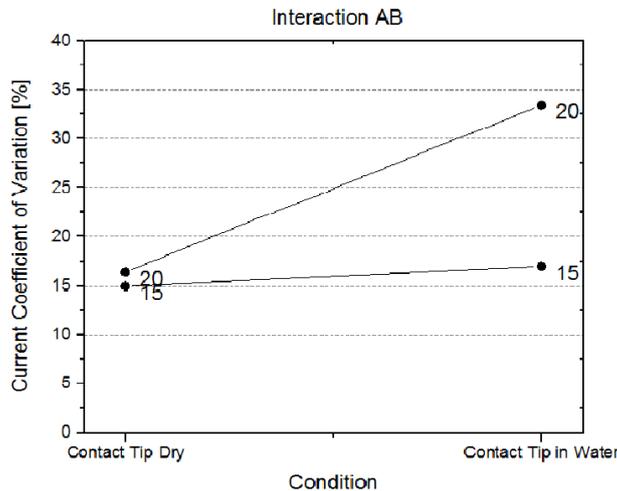

Figure 5: Effect of interaction AB

3.2 Analysis of Variance – ANOVA

The ANOVA for Current Coefficient of Variation Response is shown in Tab. 4. The model is created from the sum of squares of factors that have the largest effects on response. The three largest effects (A, B and AB) are the vital few

that stood out on the normal plot (Fig. 3). The smaller effects, which fell in the near-zero line, were pooled together as an estimate of error called "Residual". The "Fo" for the model and each individual effect were compared to the reference distribution for F with the same degrees of freedom. It was noted that the probability of getting an F as high as the observed, due to chance alone, is less than 0,1%. Therefore, it can be stated with more than 99,9% of confidence that factors A, B and AB are the main effects on Current Coefficient of Variation.

Table 4: Analysis of Variance for Current Coefficient of Variation Response

Analysis of Variance - ANOVA					
Source	Sum of Squares	Degrees of Freedom	Mean Square	Fo	P-value
Model	910.85	3	303.62	21.94	<0.001
A	363.98	1	363.98	26.30	<0.001
B	321.43	1	321.43	23.23	<0.001
AB	225.45	1	225.45	16.29	<0,001
Residual	166.07	12	13.84		
Cor Total	1076.920648	15			

3.3 Diagnosing Residuals

In order to validate statistical assumptions made to this point, a mathematical equation was used to predict the response for the model tested in the ANOVA. The model with coded factors is shown in Eq. (2).

$$\hat{Y}=20.458+4.77*A+4.48*B+3.75*AB \tag{2}$$

Where A, B and AB represents the factor level (+ or -) input values, according to Tab. 2.

The discrepancy between the predicted value and the actual observed value is called the residual error. It is assumed that residuals are normally distributed and independent with constant variance. The normal plot for error is shown in Fig. 6. It can be stated that all residuals are normally distributed, all points on this plot lie reasonably close to a straight line, lending support to the conclusion that factors A, B and AB are the only significant effects and that the underlying assumptions of the analysis are satisfied.
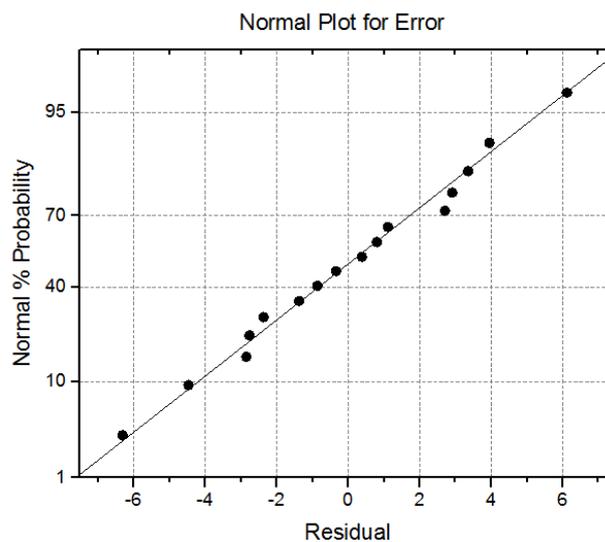

Figure 6: Normal plot of residuals

3.4 Welding current coefficient of variation

The welding current coefficients of variation are plotted in Fig. 7. The graph was plotted according to the welding runs listed in Tab. 2. The runs in which the contact tip were kept dry were plotted against their respective runs with the contact tip in water, keeping the levels for the remaining factors. It is noted that as the factors levels increase, from left to right, the welding arc becomes more unstable when the contact tip is wet. However, when the electric contact is kept dry, the current coefficient of variation shows a much smaller fluctuation. The smaller the sample range is (Coefficient of variation), the smaller the fluctuation is, which means the arc is more stable (Shi et al, 2012). This behavior lends support to the conclusion that the welding stability is improved by keeping the sliding electrical contact isolated from water.
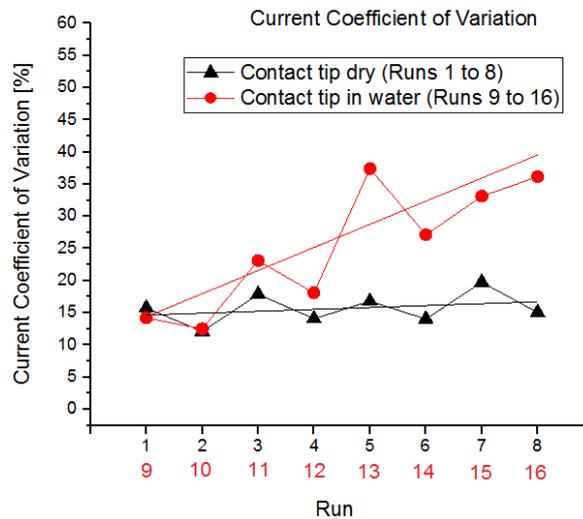

Figure 7: Current coefficient of variation

4. CONCLUSIONS

A torch for underwater FCAW was developed at LRSS-UFMG. The device is equipped with sealing components that prevents the entry of water in the contact tip surroundings as welding is performed. Welds were carried out using the torch and as in conventional underwater FCAW, keeping the electrical parts into the water. A two-level factorial design was conducted with the purpose of evaluating the effect of welding parameters on arc stability indexes. The response selected from the design experiment was the current coefficient of variation.

Among the factors selected for the factorial design, welding Condition, CTWD and their interaction are the most influent on current coefficient of variation. Keeping the contact tip dry inside the torch promotes a more stable arc in comparison with welds carried out with the contact tip in water environment. When the contact tip is kept dry, a little change occur in the response by increasing CTWD, voltage and wire speed to their higher levels. However, the welding arc becomes more unstable as the parameters levels increase when the contact tip is in water environment. The presence of water in the gap between the wire and the contact tip hole promotes a worse current transfer, resulting in more unstable arc.

5. ACKNOWLEDGMENTS

6. REFERENCES

Anderson, M. J., & Whitcomb, P. J. *DOE simplified: practical tools for effective experimentation*. 2nd ed. 2007. CRC Press.

Andrade, L; Dutra, J. *Soldagem Subaquática Molhada com Eletrodo Tubular.* XII Congresso Brasileiro de Engenharia Mecânica, 1993.

Jia, C.; Zhang, T.; Maksimov, S.; Yuan, X.; *Spectroscopic analysis of the arc plasma of underwater wet flux-cored arc welding.* Journal of Materials Processing Technology, March 2013.

Labanowski, J.; Fydrych, D.; Rogalski, G.; *Underwater Welding: A review.* Advances in Materials Science, Vol. 8, No. 3, December 2008.

Montgomery, D.C, *Design and Analysis of Experiments.* 7th ed. 2008. John Willey & Sons.

Nixon, J. H.; Graham, S.R.B.; *Arc Instability in shallow water wet welding.* Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering. American Society of Mechanical Engineers, 1993.

Sagara, H., Nishio, Y., Wada, H., & Hiromoto, Y. (1977). *U.S. Patent No. 4,029,930.* Washington, DC: U.S. Patent and Trademark Office.

Shi, Y., Zheng, Z., & Huang, J. *Study on Arc Stability of Underwater Wet Flux-Cored Arc Welding.* Proceedings of the 10th International Conference on Frontiers of Design and Manufacturing, June 10-12, 2012, Chongqing, China.

Stingelin, V., Budliger, J. P., Katzarkoff, J., Walt, G., & Roggen, R. (1979). *U.S. Patent No. 4,172,974.* Washington, DC: U.S. Patent and Trademark Office.

Tsai, Chon-Liand; Masubuchi, K.; *Interpretive report on underwater welding.* Welding Research Council Bulletin No 224, 1973.

Verma, K.; Hairish K. *Underwater Welding: Recent Trends and Future Scope.* International Journal on Emerging Technologies, September 2012.

Vilarinho, L.O.; Lucas, B. *Initial Trials of Underwater Wet Welding Using Mechanised FCAW Process.* 20th International Congress of Mechanical Engineering, November 15-20, 2009, Gramado, RS, Brazil.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.