The Mechanism of Porosity Formation in Underwater Wet Welds

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Introduction:

Despite the extensive research work conducted in the past years, several problems are still present in underwater wet welding (UWW), among them is porosity, loss of alloying elements, and hydrogen cracking. Depending on the welding conditions, one or more of these problems may be present to result in reduced mechanical properties of the wet welds.

It is well established that as water depth increases porosity increases, however the mechanism of porosity formation is not well understood. This work presents recent research results regarding the mechanism of porosity formation in UWW using the SMAW process with flux-covered electrodes.

Technical Approach:

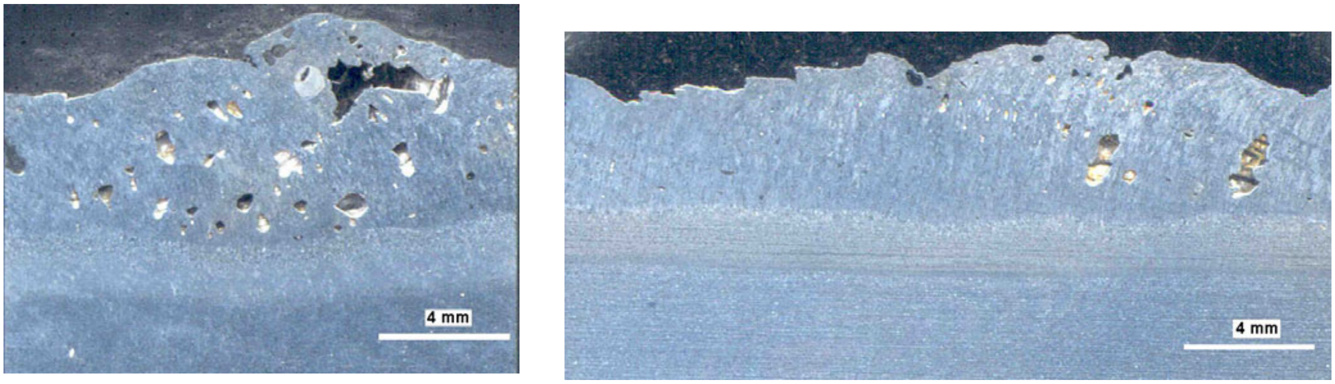
Bead-on-plate (BOP) wet welds have been deposited in fresh water, inside a pressurized chamber with a gravity welding system, at a pressure equivalent to 50 and 75 m water depth. During welding, the arc voltage was recorded for further analysis of the operative metal transfer modes with the selected welding conditions. Constant and pulsed welding current were used to deposit BOP wet welds, which were sectioned subsequently for porosity measurements.

Commercial electrodes and bare steel core rods were melted using the gas tungsten arc welding (GTAW) process. The droplets detached from the electrode or steel rod were collected for analysis. In addition, droplets attached to the electrode tip and steel rod tip were sectioned for macro- and micro-scopic analyses.

Results and Discussion:

From the arc voltage signals and porosity measurement it was determined that short-circuiting transfer produced more porosity in the weld metal than globular metal transfer mode for the same electrode type, size, and water depth. As such, to reduce weld metal porosity, smaller droplets are needed.

Figure 1a presents a longitudinal section macrograph from the wet weld deposited with constant current to illustrate the size and uniform distribution of the pores. Figure 1b shows a longitudinal section macrograph of the wet weld deposited with pulsed current. It is clear that pulsed current significantly reduced weld metal porosity, from 10.3 to 3.2 pct. However, the pulsing current parameters must be further optimized to reduce the porosity shown on the right-hand side of Figure 1b.



(a) 10.3 pct. porosity.

(b) 3.2 pct. Porosity.

Figure 1. Wet weld longitudinal sections deposited with (a) constant current and (b) pulsed current.

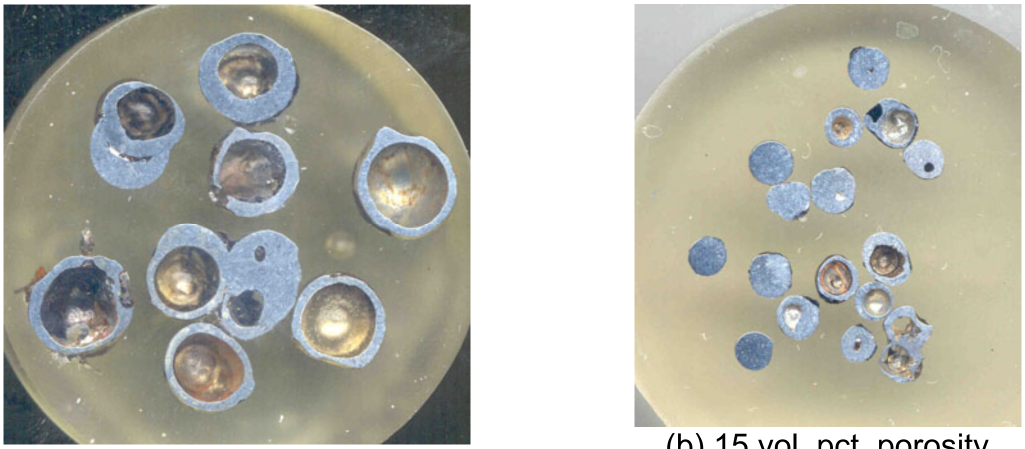
During welding, the liquid metal from the electrode is covered with molten slag to form droplets. The droplet sizes, among other factors, depend on the arc length, which in turn depends on the depth of the weld pool plus the depth of the flux cone formed at the electrode tip. Longer arcs could allow the formation of large droplets at low current values that would short-circuit with the weld pool.

As a droplet forms at the tip of the electrode, hydrogen, the main gas ingredient found in droplets, according to the literature, could diffuse into the droplet and form internal porosity. Therefore, gas is transported in the liquid metal droplets and incorporated to the weld metal, part of this gas escapes from the weld and the other part is trapped forming the weld metal porosity typically observed in wet welds.

Droplets collected from AWS E7018 electrodes melted in dry conditions using the GTAW process are shown in Figure 2. It is clearly demonstrated that the droplet size reduces with increasing current, in agreement with the literature.

Figure 2. Droplets collected from E7018 electrodes melted with GTAW process using three welding current values (90, 120 and 140 A).

The droplets collected during welding at 90 and 140 A were cold mounted on epoxy for cross-sectioning, Figure 3. Porosity is 41 vol. pct. for the large droplets and 15 vol. pct. for the small droplets. This probes that more gas is transported by large droplets than by small droplets.



(a) 41 vol. pct. porosity

(b) 15 vol. pct. porosity

Figure 3. Cross-section macrographs of the droplets collected during dry welding at (a) 90 A and (b) 140 A.

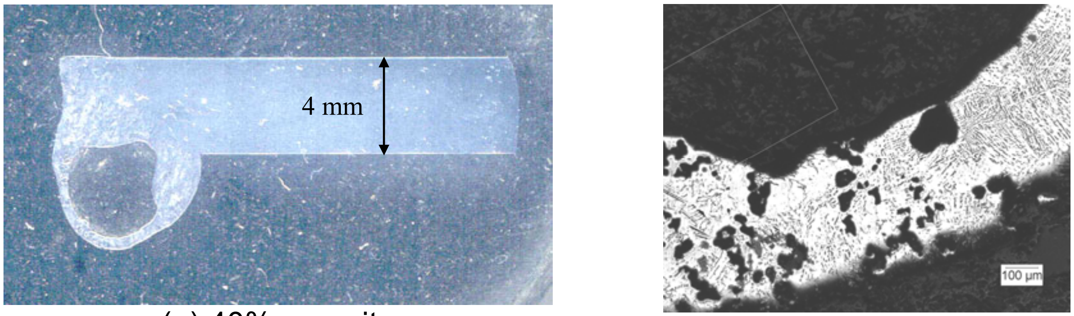
Figure 4a shows a slag-covered droplet attached to the electrode tip, in which a hole in the slag at the bottom of the droplet is visible. This hole, likely caused by hydrogen gas during droplet formation, could provide entry point for gas diffusion. Figure 4b presents the cross-section of the attached droplet showing internal porosity.

(a)

(b) 3.7 % porosity

Figure 4. (a) Macrograph of the droplet attached to the electrode tip and (b) cross-section macrograph of the droplet.

Larger amount of porosity is observed in droplets formed at the tip of bare steel rods due to the lack of shielding gas and slag protection, Figure 5a. The bottom side of the droplet is shown in Figure 5b, one can see a porous wall through which gases could diffuse in.



(a) 40% porosity

(b)

Figure 5. (a) Macrograph of a droplet attached to the bare steel rod and (b) micrograph taken at the bottom side of the droplet.

Conclusions

Based on the observations of this experimental research work, the following conclusions can be reached.

1. As the electrode melts in the welding arc, gas diffuses into the liquid metal of the forming droplet.
2. The gas inside the droplets is transported into the weld pool where it is partially trapped in the wet weld metal to form porosity.
3. As the droplet size increases, the amount of porosity also increases.
4. Increasing welding current reduces the droplet sizes.
5. Pulsed current or flux coating formulation manipulation is an option to reduce the droplet sizes and therefore wet weld metal porosity.