Cellulosic-covered Electrode Storage Conditions – Influence on Welding Performance and Weld Properties

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ABSTRACT

Cellulosic-covered electrodes have been used for shielded metal arc welding (SMAW) circumferential welding of line pipe over many decades. They are characterized by electrode coverings containing organic matter. Unlike low hydrogen SMAW electrodes that achieve optimum results at low covering moisture levels, cellulosic-covered electrodes require much higher covering moisture levels for proper operation. For example, pipe welders have been known to deliberately expose electrodes to the weather, or even dip them in water prior to use. Further, Johnson and Bruce [1] recently suggested that high incidents of hydrogen assisted cracking (HAC) might be associated with low moisture levels in the cellulosic-covered electrodes used. This suggests further that storage and handling practices based on conventional wisdom in the field may not be sufficient as the industry transitions to more demanding applications and higher strength materials. Consequently, this work was undertaken to develop more definitive information on the performance of cellulosic-covered electrodes for three purposes:

- determine the influence of various storage and handling practices on electrode covering moisture,
- determine the influence of covering moisture on electrode operability, weld metal chemical composition and weld hardness, and
- develop more definitive guidelines for cellulosic-covered electrode storage and handling practice.

Three different E8010 type electrodes (one E8018-G and two E8018-P1) were subjected to various storage conditions - temperatures from –40°C (-40°F) to 66°C (150°F), and time periods up to 196 hours. As temperature increased there was a tendency for lower electrode covering moisture levels with corresponding increases in weld metal alloy content (particularly Mn, Si, and Ti), increased weld hardness, increased weld strength and higher tendency to HAC. Variations in electrode operation were also noted.

KEYWORDS

SMAW, Cellulosic-covered Electrodes, Covering Moisture, Storage Condition, Weld Strength, Weld Hardness, Chemical Composition, Hydrogen Assisted Cracking

BACKGROUND

A recent paper by M.Q. Johnson and W. A. Bruce [1] dealt with incidents of hydrogen-assisted cracking (HAC) in the welds of line pipe welded with cellulosic-covered electrodes.

A number of topics related to the possible causes for the HAC in the girth welds were discussed. One of these topics was the effect of covering moisture on electrode operation and the resulting weld metal chemical composition and hardness This led to questions about storage conditions and the effect on covering moisture for temperatures between room temperature (24°C (75°F)) and 86°C (186°F) as well as for different lengths of storage time.

Consequently, this work was undertaken to take a closer look at the effects of reduced moisture levels on cellulosic-covered electrode operation and weld performance. Some of these effects are known through practical experience. The changes in operating characteristics are a more globular metal transfer across the arc and a less forceful arc. These changes in welding characteristics were consistent for electrodes that have lower covering moisture content. A possible mechanism explaining the relationship between covering moisture content and arc force could be the very rapid, extreme change in volume as water changes from a liquid to a vapor. This rapid expansion might be causing metal droplets to travel faster creating more arc force. This rapid expansion could also be causing the molten metal to transfer across the arc as soon as it becomes molten which would result in a fine, spray droplet transfer. Conversely, lower moisture levels would have a lesser amount of vapor expanding which would lead to a lower arc force. It would also allow the molten droplets grow to a larger size before transferring across the arc, yielding a more globular droplet transfer.

Field practice supports this idea. It is common practice (although not recommended) for welders to improve the operability of dry electrodes by re-hydrating them in some manner. A few examples of re-hydrating techniques are:

a) leaving containers open to the atmosphere in a humid location,
b) wiping them with a damp rag,
c) dipping the electrodes in water.

The potential problem with re-hydrating dry electrodes in this manner is the lack of control over the amount of re-hydration that actually takes place.

TECHNICAL APPROACH

Three E8010 type electrodes with different designs (identified as Sample A (3/16 in. E8010-G), Sample B (5.0 mm E8010-P1), and Sample C (5.0 mm E8010-P1)) and manufactured by two different electrode manufacturers were utilized in this investigation. The first objective of this investigation was to establish a correlation between covering moisture (as measured by % weight loss @ 149°C (300°F)) and storage condition. To do this, covering moisture levels from electrodes taken from newly opened containers were compared to covering moisture levels from electrodes that have been intentionally stored, unprotected at 49°C (120°F) and 66°C (150°F). A Lindberg/Blue M mechanical oven (model number MO1450C-1) was used for the storage of all electrodes subjected to storage temperatures above room temperature.

The time necessary for the covering weight loss to reach a relatively stable moisture level for electrodes stored at 49°C (120°F) and 66°C (150°F) was established. This was done by plotting covering moisture content vs. the time stored at temperature. When the covering moisture had reached a point where continued storage only produced minimal further weight loss, that time at temperature was selected for the storage of electrodes to be used in comparison weld tests.

Simulated pipe joints (SPJ's) were then welded with as-received electrodes as well as electrodes stored at 49°C (120° F) and 66°C (150° F) for the selected time period and the weld metal properties compared. For correlation purposes the term "as-received" refers to material stored at 24°C (75°F). A second series of tests added a –40°C (-40° F) storage temperature to the other three temperatures. SPJ's were used instead of actual pipe joints for two reasons. First was for the ease of testing. SPJ's are easier to machine, easier to set up, and easier to weld. Second, SPJ's allow testing to be conducted in a single position. Actual pipe welds are always changing position as the welding progresses around the circumference. This is beneficial when weld metal chemical composition, weld metal hardness, and weld metal tensile specimens are all going to be machined out of one weldment.

Weld metal cracking behavior was examined using the Gapped Bead-on-Plate (GBOP) test, which was developed for evaluating the relative sensitivity to hydrogen cracking of weld metal. Graville [2] has detailed the different weldability tests for hydrogen cracking and the GBOP test best suited to this investigation due to the unique applicability to weld metal cracking. Most of the work involved machining the weldment pieces and setting up the welds. The actual welding and evaluation was very quick and easy.

Covering Moisture Determination

Covering moistures were determined by weight loss on heating. Approximately 3 – 8 grams (actual amount to be recorded) of covering from the subject electrode was placed it in a tin with a lid and weighed to obtain the initial total sample-filled tin weight. The weighed sample-filled tin was placed, open but with the lid, into an oven (GCA Precision Scientific, model 26) at 143 – 197°C (290 – 315°F) for 20 – 25 min. The sample-filled tin was then removed and the lid put back in place and left to cool to ambient room temperature. After cooling, the sample-filled tin was weighed again to obtain the final sample-filled tin weight. The initial sample-filled tin weight minus the final sample-filled tin weight divided by the sample weight and multiplied by 100 is the % weight loss.

Drying Curve Determination for Storage at 49°C (120°F) and 66°C (150°F)

Unopened containers of the three different cellulosic-covered electrodes were opened and sample electrodes were tested for covering moisture content. Electrodes were then removed from each of these containers, put on a rack in the oven, and held at 49°C (120°F) for 7 days (168 hrs.). Samples were removed and tested for covering moisture after 1, 2, 3, 4, 8, 12, 16, 24, 48, 72, 96, and 168 hrs. in the oven.

This test was repeated with another unopened container with the oven set at 66°C (150°F).

These test results were plotted as covering moisture content vs. time at temperature. The resulting graphs allowed selection of a time at temperature where the rate of change in covering moisture level vs. time was minimal.

These tests showed that the covering moisture content (weight loss) starts to level off to a low level after 48 hours at 49°C (120°F) and to a different low level after 24 hours at 66°C (150°F) for all three electrodes. In both cases, actual equilibrium moisture levels are not reached until about 110 – 150 hrs.

Welding, Test 1

For the first test (T1), each type of electrode was welded on simulated pipe joints (SPJ's) made from 17 mm (0.685 in.) wall X70 pipe steel and having the joint configuration shown in Figure 1. Testing was conducted with electrodes in the as-received, stored at 49°C (120°F) for 48 hrs., and stored at 66°C (150°F) for 24 hrs. conditions. These welds were analyzed for weld deposit chemical composition and hardness. Any differences in welding operability were noted.

Welding, Test 2

The first test was repeated to verify the initial test results and to check possible variation from one batch of electrode (same design) to another batch. This second test (T2) was welded using different batches of electrode for all three electrode types. The second test added electrode storage at –40°C (–40°F) for 48 hrs. to the initial storage conditions and all weld metal tensile tests to the weld analyses. Storage at -40°C (–40°F) was accomplished by putting the electrodes in a dry ice container where the air temperature averaged –40°C (–40°F). The electrodes stored at temperatures higher than room temperature cooled to room temperature within a few minutes. By the time the electrodes were transported from the oven to the welding station, they were already almost at room temperature. The electrodes that were stored at –40°C (-40° F) were stored in a sealed can. The can was not opened for welding until the can had reached room temperature.

Welding Procedure and Joint Configuration

Welding was conducted in the vertical position with a downward progression, welded at 170 – 180 amps DCEP using a 400 amp transformer welder, simulating welding a pipe in the 3 o'clock position. All welding was performed in the same welding station, by the same operator.

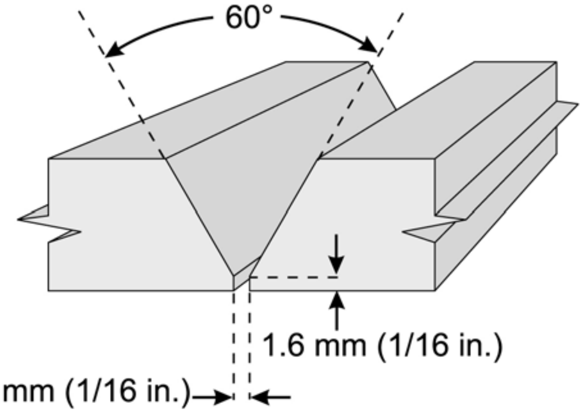

Figure 1: Drawing of the Simulated Pipe Joint (SPJ) Used in this Investigation

Gapped-Bead-On-Plate (GBOP) Tests

To exaggerate the cracking tendency due to HAC, a series of GBOP welds were made. This increased cracking tendency is accomplished by welding across an air gap, which acts as a fracture initiation site. This test permits comparisons of resistance to HAC tendencies, but only shows relative differences in cracking tendency. A variable used in this testing was the preheat temperature (the higher the preheat temperature, the lower the cracking tendency for a given electrode). The preheat used for this testing was 163°C (325°F).

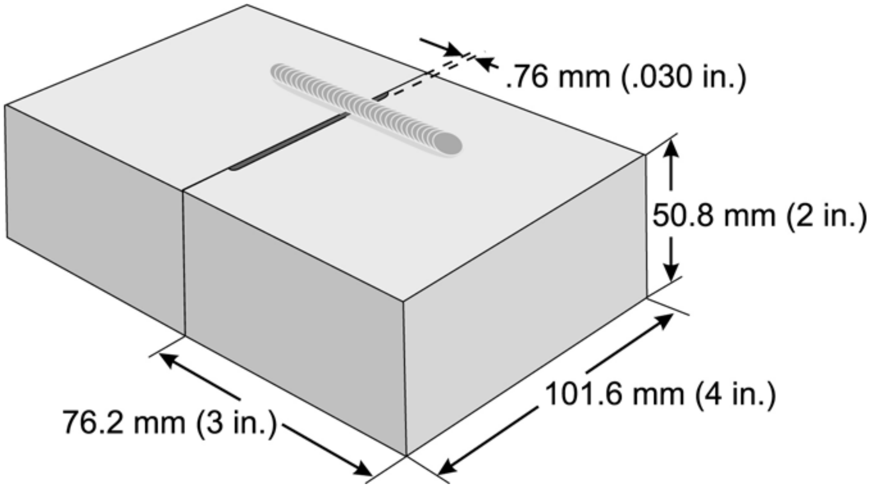

Figure 2: Drawing of the Gapped Bead-on-Plate (GBOP) Weld Joint

Fixturing

Two steel blocks (50.8 mm X 76.2 mm X 101.6 mm (2 in.X3 in.X4 in.)) were held fully restrained in a fixture with the 101.6 mm (4 in.) edges butted together. One of the blocks had a 0.76 mm (0.030 in.) groove machined vertically in the middle of the butted 101.6 mm (4 in.) face. This formed the air gap that was welded across. The blocks and the fixture were preheated to above 163°C (325°F) and allowed to cool to 163°C (325°F) before welding. The blocks remained fully restrained for 24 hrs. after welding.

Welding

Three welds were made (one weld on each set of two blocks) with each electrode type in the as-received condition and after storing for 24 hrs. at 66°C (150°F). The welds were made in the flat position at 160 amps DC+. Welding was initiated on the un-grooved block, progressed across the groove (air gap), and finished on the grooved block.

Analysis

After 24 hrs the test blocks at room temperature were released from the fixtures and the welds broken. The percent cracking was averaged for the three welds at each data point.

RESULTS and DISCUSSIONS

Drying Curves

The drying curves were used to establish relatively stable test conditions for assessment of welding characteristics and weld metal properties, Figures 3-6. They also illustrate that electrode covering moisture levels are significantly reduced with storage at temperature.

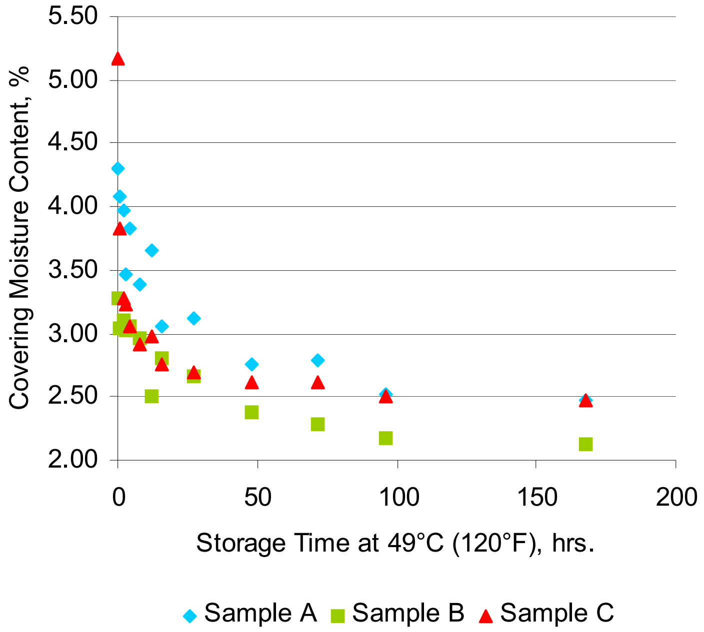

Figure 3: Covering Moisture Content vs. Time Stored at 49°C (120°F)

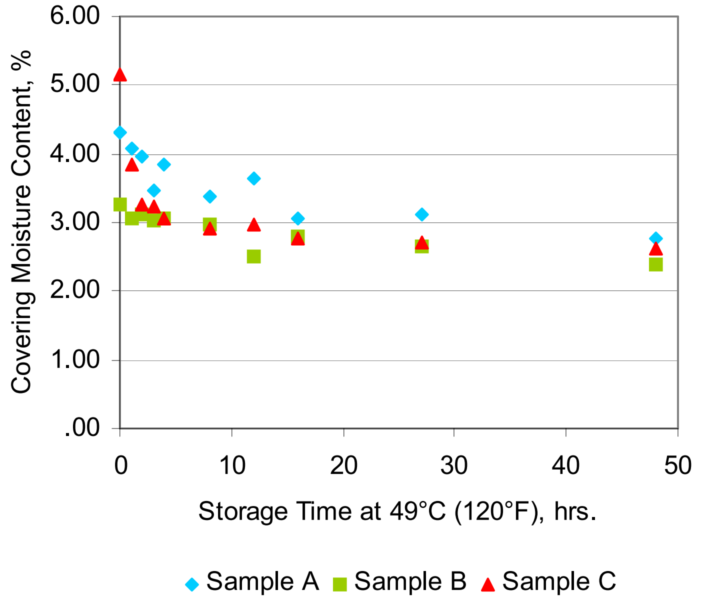

Figure 4: First 48 hrs of Figure 3 Expanded

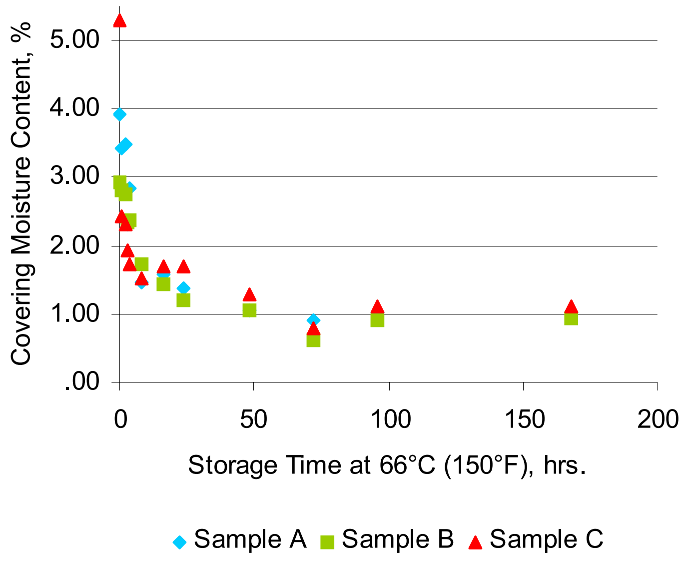

Figure 5: Covering Moisture vs. Time Stored at 66°C (150°F)

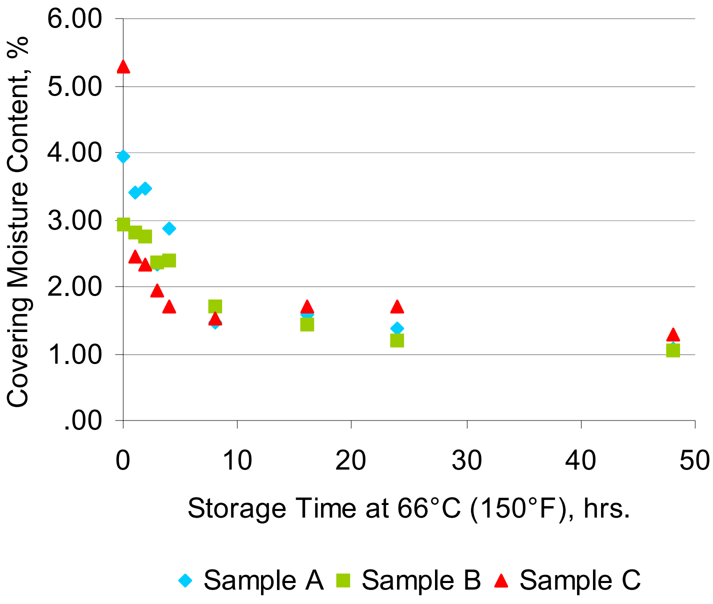

Figure 6: First 48 hrs of Figure 5 Expanded

Note that even though all of the electrodes start at different covering moisture levels, all three electrode types have similar drying curves at 49°C (120°F), and almost identical drying curves at 66°C (150°F) after the first couple of hours.

Actual moisture equilibrium appears to occur between 100 and 150 hours at temperature. This was too long of a lead-time to schedule the welding with the stored electrodes. After 48 hrs. at 49°C (120° F) and 24 hrs at 66°C (150°F) the change in covering moisture content is considered sufficiently stable. Scheduling welding 24 and 48 hrs. in advance was much more manageable, which is the reason that these times were selected for preparing the stored electrodes for the welding comparison tests.

SPJ Test Results

	Covering Moisture Content, %					
	Sample A		Sample B		Sample C	
Storage Condition	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Stored 48 hrs. @ -40° C (-40°F)	---	3.77	---	3.18	---	6.12
As-received (24° C (75° F))	4.32	3.66	3.38	3.29	5.42	6.14
Stored 48 hrs. @ 49° C (120°F)	2.79	2.29	2.28	2.08	2.62	2.19
Stored 24 hrs. @ 66° C (150°F)	1.25	1.44	1.11	1.22	1.35	1.39

Table 1: Covering Moistures for the Electrode Used for the SPJ Welding Tests

Comparison of the differences among the three samples is a comparison of the differences among designs. Comparison of the differences between the two tests within a sample is a comparison of the differences from batch to batch within the same design. Different batches of the same electrode designs have different as-received covering moisture contents showing that there are natural variations occurring regardless of the design.

The different designs had different starting covering moisture content but ended up with similar covering moisture content (within 15%) after storage at 66°C (150°F). There was a lot more variation in covering moisture content design to design and batch to batch within a given design after the storage at 49°C (120°F). This greater variation at 49°C (120°F) may mean that the storage time at this temperature should be increased to limit the variation in future testing.

Electrode Operability

The welder observed a change in operating characteristics for all three electrodes when they were stored for 24 hours at 66°C (150°F) compared to the as-received electrodes. The arcs were softer and the metal transfer was more globular with electrodes stored at 66°C (150°F). Sample B also exhibited some longitudinal covering cracking when stored at 66°C (150°F). This was most likely due to the continued cross-linking of the silicate binder used for stick electrodes. As the cross-links form the covering contracts, putting it in tension. If a given design does not have enough silicate binder to form strong cross-links uniformly around the electrode, this increase in tension can cause a rift along a weak region forming the covering crack. All three electrodes showed an increase in tendency for porosity when stored at 66°C (150°F), although Sample B was the most affected. This increase in porosity is consistent with what is expected for dry electrodes. This could be due to lower levels of water vapor being created while welding that helps to form a protective positive pressure barrier against the atmosphere.

The welder reported only slight changes in the operating characteristics for the electrodes stored for 48 hrs. at 49°C (120°F) compared to the as-received electrodes. The arcs were softer and the metal transfer was more globular with electrodes stored at 49°C (120°F), but not to the degree observed for the electrodes stored at 66°C (150°F). This altered operation varied from electrode to electrode, with some having operability comparable to the as-received electrodes.

No change in welding operating characteristics were observed for the electrodes stored at –40°C (-40°F).

SPJ Weld Metal Properties

Weld metal mechanical performance corresponding with the reduction in electrode covering moisture levels is summarized in Figures 7-10.

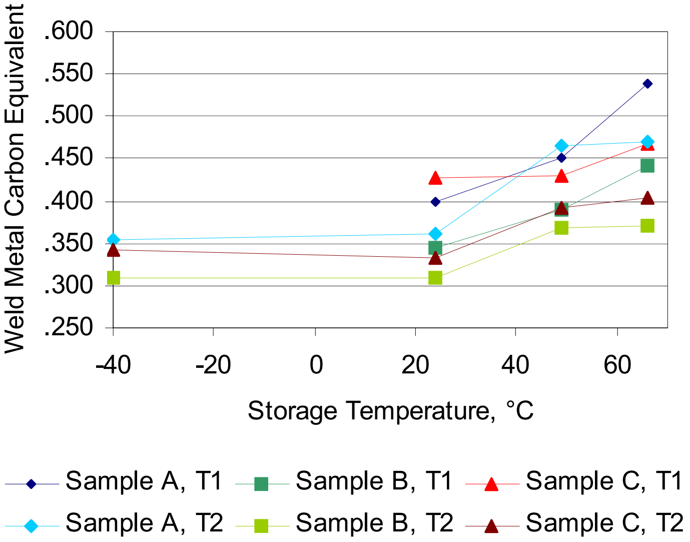

Figure 7: Weld Metal Carbon Equivalent (Ceq) vs. Electrode Storage Temperature
Ceq = C + (Mn + Si)/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15

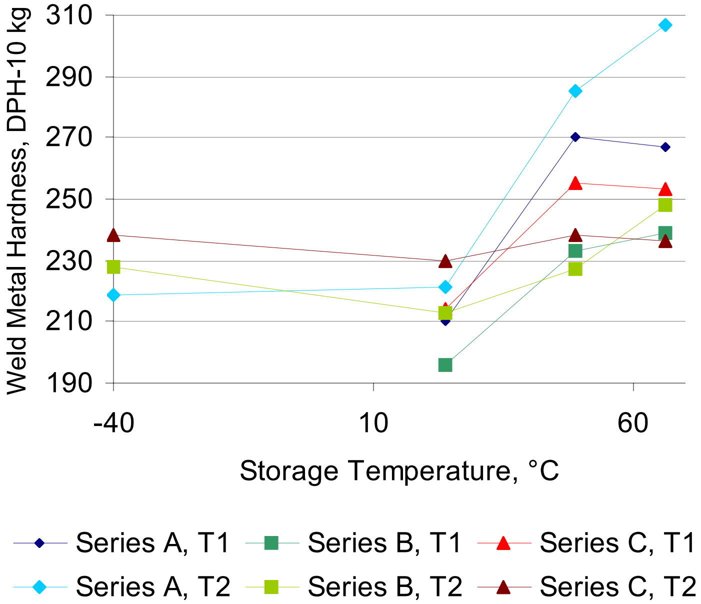

Figure 8: Weld Metal Hardness vs. Electrode Storage Temperature

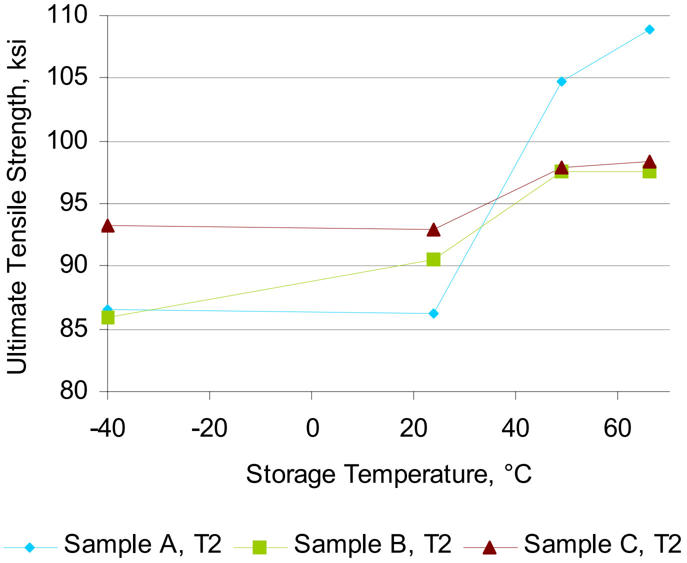

Figure 9: Weld Metal Tensile Strength vs. Electrode Storage Temperature

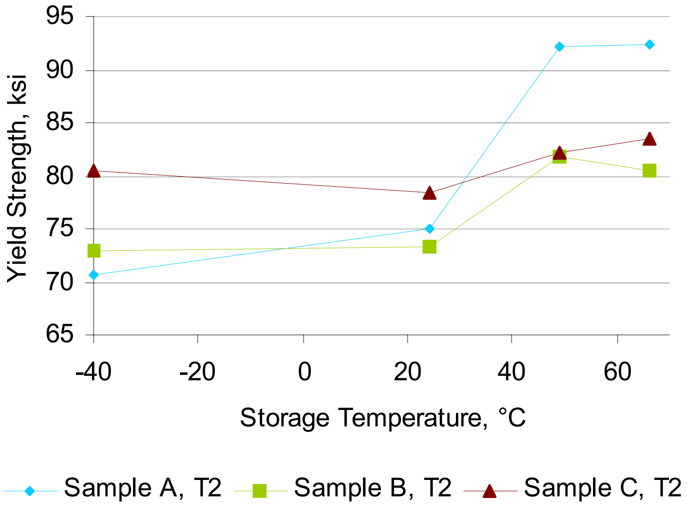

Figure 10: Weld Metal Yield Strength vs. Electrode Storage Test

Note that, though the covering drying curves were similar for all three electrode types, the SPJ weld test results differ among electrode designs. There was an increase in weld metal Ceq, hardness, and tensile test results with electrodes stored at 49°C (120°F) and 66°C (150°F) compared to those stored at room temperature or –40°C (-40°F). The magnitudes of these increases varied from design to design as well as from batch to batch within a given design. Sample A showed the largest increases in weld metal Ceq, hardness, and tensile properties.

Gap Bead On Plate HAC Results

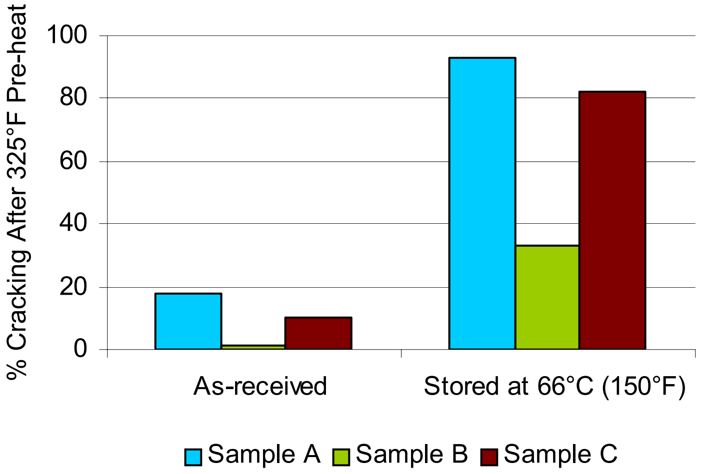

Figure 11: Gap Bead On Plate Test, HAC Results

On the GBOP test both Sample A and Sample C showed a substantial increase in HAC comparing the electrodes stored at 150°F to those in the "as-received" condition. The increase in HAC for Sample B was much less than for the other two samples. This again shows that design can limit the affects of electrode storage at higher temperatures.

Discussion

The increased susceptibility to weld metal HAC illustrated by the GBOP test results is consistent with changes observed in carbon equivalent, hardness, and strength. This can be explained by the differences in the metal droplet size transfer across the arc. Alloy contained in these droplets is subjected to oxidation as the droplet passes across the arc. This oxidation occurs on the surface of the droplets. As the droplet size increases, the ratio of the surface area (S.A.) of the droplet to the volume (V) of the droplet decreases.

S.A. of a sphere = $4\pi r^2$ V of a sphere = $\frac{4}{3}\pi r^3$ $\frac{S.A.}{V} = \frac{3}{r}$

The S.A. to V ratio for a unit volume of weld metal is inversely proportional to the radius of the droplet, so the ratio decreases at the same rate as the droplet radius increases. A lower S.A. to V ratio decreases the amount of alloy in the droplet that is in the position for oxidation (i.e. on the surface of the droplet), increasing the alloy content of the weld metal (most notably Mn, Si, Ti, and C). Even when the increase in droplet size is not noticeable to the eye, the alloy in the deposit will still increase, sometimes more dramatically than expected.

The increase in deposit alloy due to the decrease in covering moisture may also be explained by a shift in the water-gas reaction in the welding-arc atmosphere. The water-gas reaction is stated:

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

If the moisture (H_2O) available is reduced, the water-gas reaction is driven to the left. This yields a higher concentration of CO in the arc atmosphere which makes it a more reducing, less oxidizing atmosphere. Less alloy would then be oxidized during the metal transfer across the arc, yielding more alloy in the deposit. The reducing affect of the shift in the water-gas reaction may be in part negated by the fact that less moisture changing from liquid to vapor during welding also reduces the amount of arc protection from atmospheric oxygen supplied by the water vapor formation.

The loss of arc force due to covering moisture loss causes another problem. Welders will often increase the amperage to regain the lost arc force. This higher amperage makes the weld puddle more fluid, adversely affecting the stackability of a given electrode by causing the welder to weld with a faster travel speed in order to control the weld puddle. Loss of stackability will increase the number of passes required to fill the pipe joint (smaller weld size), which leads to a loss of productivity. Smaller passes result in a higher cooling rate that can lead to higher weld hardness. Increased puddle fluidity can also increase the amount of internal porosity, often not noticed until NDT testing of the weld conducted at a later time. This leads to costly repairs.

CONCLUSIONS

1. Storage of cellulosic-covered electrodes at elevated temperatures result in the following:
    a) Loss of covering moisture even after only a few hours.
    b) Increased weld metal carbon equivalent, hardness, tensile strength, yield strength, and HAC.
    c) Lower arc force and more globular metal transfer across the arc.
    d) Increased weld porosity.
    e) Possible covering cracking.
2. The most probable explanation for this is the decrease in the volume of gas vapor formed during welding when the moisture level of the covering of a cellulosic-covered electrode is reduced. Since water volume increases approximately 1600 times transforming from liquid to a vapor, there is a very high positive pressure at the arc. This high pressure causes the high arc force which it turn yields a finer spray transfer. The finer spray transfer allows more alloy to be oxidized during transfer across the arc, leading to lowered alloy in the deposit. The carbon equivalent, weld hardness, tensile strength, yield strength, and HAC are all at lower, more manageable levels with the lower deposit alloy level.

RECOMMENDATIONS

1. Explore whether covering moisture loss occurs in unopened cans when stored at higher than room temperature conditions or whether it is just an “open product” phenomenon.
2. Explore an increased number of storage temperatures between room temperature and 49°C 120°F to determine at what storage temperature there are no adverse effects on welding operability and mechanical properties.
3. Explore design changes that will retain covering moisture levels more effectively, even when exposed to higher than room temperature conditions.
4. Explore whether electrodes can be designed and manufactured at the “equilibrium” moisture level, so that they are not subject to the variation.

REFERENCES

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