

# AWS Task Group Findings on Moisture Testing of Welding Consumables: Progress Report

*Reproducibility of results with the present thermogravimetric test method proves difficult*

BY M. A. QUINTANA

**ABSTRACT.** This paper summarizes the work of two American Welding Society (AWS) A5A Subcommittee Task Groups assigned to improve the reliability and accuracy of the standard moisture test. After several round-robin test efforts involving different electrode coverings, mineral reference standards, and finally pure water samples, sources of error in the test specification were identified. It was finally concluded that the existing thermogravimetric test method could not be refined sufficiently to achieve the accuracy and reproducibility needed for reliable testing of low-hydrogen electrode coverings and fluxes. Subsequent task group efforts emphasize alternate methods based on Karl-Fisher titration and infrared detection as a basis for a comprehensive AWS test standard.

## Introduction

Hydrogen present as an interstitial impurity has been known for many years to be a factor in delayed cracking of welds (Ref. 1). One of the sources of hydrogen is moisture in the welding consumables and the environment. Hirai, *et al.* (Ref. 2), related the various sources of moisture for the shielded metal arc welding process to the hydrogen content of the weld deposit.

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Moisture in the electrode covering is present as chemically combined water and as absorbed water. The chemically combined water is the as-baked moisture, the content of which is reduced by high-temperature baking during the electrode manufacturing process. The absorbed moisture is the water absorbed by the electrode covering between the time of manufacture and the time of welding. The as-baked moisture is generally considered to be a more significant contributor to weld hydrogen than absorbed moisture. However, both forms of electrode covering moisture are of concern. If the steels being welded are known to be susceptible to hydrogen assisted delayed cracking, then it is beneficial to use electrodes which have low as-baked moisture levels and whose coverings are resistant to moisture absorption. In order to provide criteria for classification of covered electrodes according to moisture resistance as well as as-baked moisture, the AWS A5A subcommittee

assigned a task group chaired by M. Parekh to develop suitable methods. Electrodes were exposed to moisture by various methods and the coverings analyzed for water content in both the as-baked and exposed conditions. The analytical technique employed was the AWS standard moisture test outlined in A5.5 (Ref. 3). It is essentially the same as the test required by U.S. military specifications (Refs. 4, 5). This thermogravimetric method, after Gayley and Wooding (Ref. 6), has seen little refinement since its introduction to the welding industry in 1950. The task group was unable to make any recommendations regarding electrode exposure and absorbed moisture because of inconsistent results. Previous task groups had reported similar inconsistencies (Refs. 7, 8). It was concluded that much of the problem was with the moisture analysis. Unless the moisture test could be modified to improve reproducibility, it would not be possible to assess moisture resistance. It was at this point that the task group began its assessment of the moisture test itself. Based on this work, a later task group, chaired by M. Quintana, began to refine the techniques and write a test standard for moisture analysis of electrode coverings and granular fluxes.

## Experimental Approach

The basic test method (Refs. 3-5), illustrated schematically in Fig. 1, involves combustion of the electrode covering or flux sample at 982°C (1800°F) in an oxy-

### KEY WORDS

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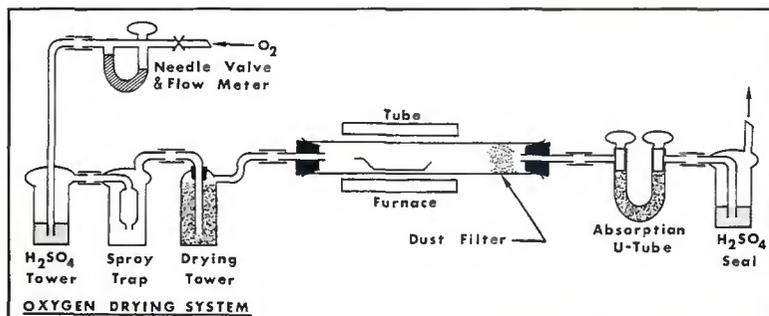


Fig. 1 — Schematic: standard moisture test apparatus.

gen carrier gas for 30 min. A nominal 4-g sample is loaded into the hot zone of the tube furnace in a previously fired and dried combustion boat, either nickel or ceramic. Combustion in oxygen ensures that any hydrogen present forms water in the carrier gas. Thus, the analysis is for total hydrogen measured as water rather than simply an analysis for water. After passing through a glass wool dust filter, water in the carrier gas collects in the absorption U-tube, a Pyrex glass tube packed with desiccant. Prior to analysis of samples, a blank determination is required. This is accomplished by conducting a 30-min water determination for the system containing an empty combustion boat. The water content of the sample is determined as the weight gain of the absorption U-tube (A), minus the blank value (B), normalized against the initial weight of the sample (W).

$$\% \text{ Water} = 100(A - B)/W$$

Since general requirements are set

forth in a schematic format, many equipment and procedural details are left open to individual interpretation. Consequently, there is considerable variation in the way individual laboratories conduct moisture tests. Task group members had become increasingly concerned that some of these variations were the cause of the poor reproducibility characteristic of test results at low water contents. This poor reproducibility was not always due to differences between laboratories. Often, results from an individual laboratory were highly variable. Better definition of test parameters could conceivably reduce the high scatter in moisture test values both within individual laboratories and between laboratories.

Consequently, some additional precautions were taken to promote greater consistency of test results. Use of a high-purity carrier gas instead of a welding grade was encouraged. The use of nickel instead of ceramic for combustion boats was recommended in an effort to reduce blank values. Tubing runs between sys-

tem components were minimized. Replicate analyses became routine practice. Breech fittings, some with push rods, were substituted for the rubber stoppers at combustion tube inlets. A breech fitting allows introduction of the combustion boat in a minimum length of time without completely interrupting the flow of oxygen. It was under these conditions that the task groups conducted their work, each participating laboratory implementing as many additional precautions as resources permitted.

#### Round-Robin Testing of Electrode Coverings

In an effort to minimize variation in the samples tested, it was decided to concentrate on analysis of as-baked moisture. The amount of as-baked moisture for a given electrode would be far less variable than exposed moisture and would allow a better assessment of the variability arising from the test method. Seven electrode types were distributed to the participating laboratories in the task group in sealed containers by the various manufacturers. Four were produced with low-hydrogen/moisture-resistant coverings, while three were produced with high-moisture coverings. The objective was to determine the degree of reproducibility at various levels of electrode covering moisture. Each of five laboratories conducted analyses for each of the electrodes provided. The results are summarized in Table 1.

The results show large inter-laboratory scatter. One way of assessing scatter is to compare the

Table 1—Round Robin on Electrode Coverings (Electrode covering water contents expressed in % by weight)

Electrode	%Water by Laboratory					Mean	SDEV	%VAR		
	Lab A	Lab B	Lab C	Lab D	Lab E					
Low Moisture Electrodes	LM1	0.025	0.070	0.090	0.070	0.065	0.060	0.057	0.025	87
		0.013	0.050	0.100	0.070	0.030	0.030			
		0.019	0.070	0.070	0.070	0.070	0.070			
	LM2	0.028	0.060	0.040	0.060	0.062	0.050	0.050	0.013	51
		0.038	0.060	0.060	0.060	0.040	0.040			
		0.033	0.070	0.050	0.060	0.030	0.030			
	LM3	0.040	0.080	0.090	0.070	0.087	0.070	0.078	0.032	82
		0.053	0.100	0.070	0.070	0.050	0.050			
		0.047	0.090	0.070	0.080	0.180	0.180			
	LM4	0.025	0.100	0.120	0.110	0.104	0.070	0.096	0.029	60
		0.070	0.100	0.120	0.110	0.100	0.100			
		0.048	0.100	0.110	0.120	0.130	0.130			
Non- Moisture Resistant Electrodes	HM1	0.098	0.110	0.140	0.110	0.084	0.060	0.095	0.024	50
		0.073	0.090	0.130	0.100	0.070	0.070			
		0.086	0.060	0.120	0.120	0.090	0.090			
	HM2	0.480	0.430	0.420	0.340	0.411	0.320	0.405	0.047	23
		0.370	0.440	0.420	0.360	0.330	0.330			
		0.425	0.460	0.420	0.440	0.420	0.420			
	HM3	0.240	0.240	0.260	0.240	0.215	0.180	0.229	0.028	24
		0.200	0.220	0.260	0.250	0.190	0.190			
		0.220	0.220	0.230	0.280	0.220	0.220			

**Table 2—Sampling Plan for Standard Reference Materials**

Material	Sample Weight (g)	Expected Water (mg)	Equiv. Water in Nominal 4g Sample (%)
SARM-2	2.300	5	0.13
SARM-2	4.500	10	0.25
SARM-2	10.000	22	0.55
SARM-6	10.000	30	0.75

standard deviation with the average of all results. In a normal distribution, 95% of the results will be within two standard deviations of the average. The percent variability can be expressed as 100 times two standard deviations divided by the average. Consequently, reproducibility is the best when the percent variability is the lowest.

For the low-moisture coverings, variability is as high as 87%. For the high-moisture coverings, the variability is somewhat lower; on the order of 24%. The magnitude of the variability is approximately the same for both electrode covering types. It simply does not have as great a percent impact when the average water contents are higher. It was not possible to consistently correlate the results with systematic variations in testing. Yet, it seemed unlikely that the high scatter in test results was due to actual variability in the electrode coverings, since some laboratories could achieve reasonably reproducible results over several replicate analyses.

It is important to note that such an analysis of variability relates only to the precision or reproducibility of the technique. With such poor reproducibility, it was difficult to establish much confidence in the standard test method. Without a suitable reference standard, it was not possible to determine which laboratories were obtaining the "correct" results. Further, without a reference standard, the analytical accuracy of the test

method could not be determined.

**Standard Reference Materials**

In 1988, the task group began a search for a mineral standard with known moisture content on the same order as the electrode coverings under investigation. Ideally, standards at the 0.05, 0.10, 0.20 and 0.30% by-weight levels were sought to serve as benchmarks for accuracy determination. These levels roughly correspond to moisture levels expected of various electrode covering types and granular fluxes. At that time, the National Bureau of Standards (now the National Institute of Standards and Technology) had no such materials. However, geochemical reference materials were found with "certified" high-temperature water contents. These were South African reference materials, thus the designation "SARM." SARM-2, syenite with 0.22% water by weight, was the lowest water content standard. SARM-6, dunite with 0.30% water by weight, was the only other available standard close to the target water contents needed. All others had "certified" levels much too high to be of use to the task group. Quantities of each were obtained and distributed for round robin testing.

The procedure for use was to condition the standards first by heating to 105°C (221°F) for 4 h before extracting samples for analysis. Short term storage in a desiccator after conditioning avoided any variation due to absorbed water on the test results. The previous round-robin results indicated the quantity of water collected may affect the percentage of variability. Interlaboratory scatter was significantly higher for the electrode covering samples with the lowest water contents. Since the water contents in the two standards did not match the target levels desired, sample weights were adjusted in order to achieve specific quantities of water that would better correspond with the mois-

ture contents in electrode coverings of interest. Table 2 summarizes this sampling plan.

Three replicate analyses of each standard at each weight level were conducted by each of five participating laboratories. The results are summarized in Table 3. As a group, the measured moisture contents for SARM-2 are in closer agreement with the "certified" values than the measured moisture contents for SARM-6. As with the previous round-robin using electrode coverings, the percent variability was much higher when the total quantity of water being measured in mg is small. The 30% variability for the 2.3 g SARM-2 is nearly twice that achieved for the others at 14 to 20%. Although there is some scatter in the variability with sample size, the greatest variability occurs for the smallest sample. Therefore, it was suggested that a partial solution to the scatter in analyses of low-hydrogen/moisture-resistant electrode coverings may be to increase the sample size. The standard test requires a 4-g sample. When the moisture content is anticipated to be 0.10%, an increase in sample size to 10 g would increase the quantity of measured moisture from ≈4 to ≈8 mg. Based on the SARM analyses, variability could be reduced by half. It was concluded that this approach may effect an interim improvement, but it did not address the potential causes of the high scatter or provide a long-term solution.

In addition, not all task group members were satisfied with 14 to 20% interlaboratory variability when analyzing what were supposed to be "certified" reference standards. In examining the individual laboratory results, it became apparent that there was significant variability in results within laboratories also. If the reference materials were truly homogeneous, this indicates that some laboratories were having great difficulty achieving results that could be considered statistically significant. Although

**Table 3—SARM Data Summary (Water contents expressed in % by weight)**

Sample Ident.	Certified Water Level	% Water by Laboratory					Mean	SDEV	% VAR
		LAB A	LAB B	LAB C	LAB D	LAB E			
SARM-2, 2.3 g	0.22	0.252	0.239	0.222	0.274	0.195	0.234	0.035	30
		0.317	0.226	0.235	0.258	0.228			
		0.157	0.230	0.217	0.241	0.228			
SARM-2, 4.5 g	0.22	0.264	0.233	0.238	0.266	0.229	0.243	0.016	14
		0.278	0.231	0.235	0.251	0.220			
		0.247	0.224	0.249	0.246	0.235			
SARM-2, 10 g	0.22	0.284	0.225	0.258	0.250	0.216	0.245	0.024	20
		0.268	0.220	0.259	0.249	0.224			
		0.290	0.220	0.251	0.244	0.220			
SARM-6, 10 g	0.30	0.328	0.323	0.345	0.348	0.290	0.339	0.028	17
		0.412	0.327	0.354	0.345	0.307			
		0.365	0.334	0.351	0.344	0.311			

**Table 4—SARM Certification Statistics: Partial List (Ref. 9)**

Sample Ident.	No. of Analyses	Mean	SDEV	%VAR
SARM-6 (DUNITE)	10	0.39	0.17	87

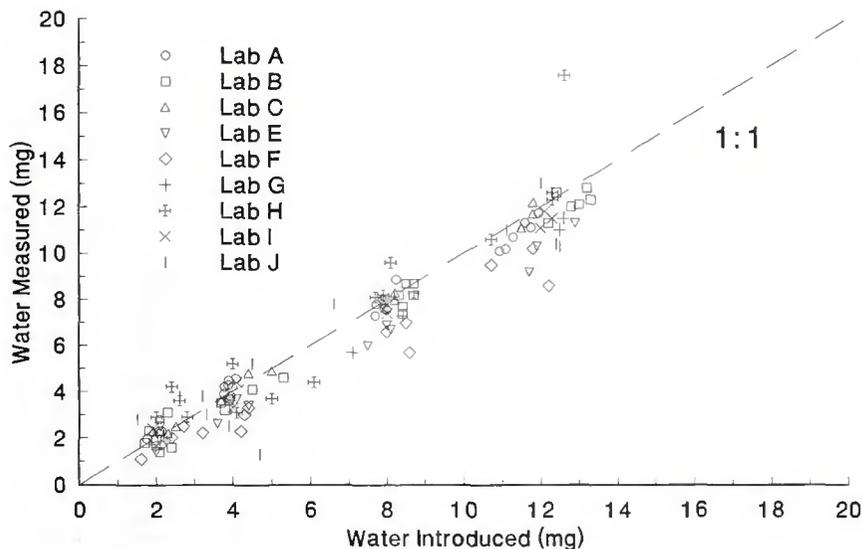


Fig. 2 — Pure water standards (water measured vs. water introduced in capillaries).

the reproducibility using the SARM's was better than the reproducibility experienced with the electrode coverings, the scatter was still unacceptably high especially at the low water levels. The fact that no individual laboratory consistently obtained the certified results made it impossible to assess the potential causes of the high variability or offer a solution.

These concerns lead to questions about the reliability of the reference standards themselves. After some extensive research, the task group was finally able to obtain copies of the certificates of analysis and some background information concerning the method of certification (Ref. 9). The SARM standards were prepared from naturally occurring mineral deposits. Approximately 455 kg of rock for each was collected with sizes ranging from  $0.354 \times 10^4$  to  $7.08 \times 10^4 \text{ cm}^3$ . The material was then crushed to a nominal size of 75  $\mu\text{m}$ . After conducting the low-temperature drying process previously described, many laboratories participated in a round-robin test effort to determine the certified water content for each standard reference material. Although it was difficult to determine the specific analytical techniques employed, most of these laboratories used some type of thermogravimetric analysis. A partial summary of these analyses is presented in Table 4. Note that these are not AWS task group data, but rather the results of a separate round-robin test effort used to determine certified values for the reference standards (Ref. 9). The certified values were determined from a more extensive testing effort. However, these data provide an indication of the uncertainty associated with the certified moisture levels. The standard deviations are approximately half the means for

each sample group. In fact, the variability of data used to determine the certified levels is far higher than the variability experienced by the task group for the same materials.

It was concluded, based on these data, that the "certified" moisture levels for the standard reference materials could not be used reliably by the task group to assess the sources of unacceptably high interlaboratory scatter in moisture testing of electrode coverings. Another method had to be found where a known quantity of water could be introduced and analyzed, thereby providing a means of standardization for the test.

#### Pure Water Standards

After the failed attempt to standardize using mineral reference materials, the task group began searching for alternatives. It was suggested that pure water be introduced to the system in known quantities. Since the principal of detection in the moisture test system is simply the weight gain of the absorption U-tube, it does not matter in what form the water enters the system as long as it enters through the hot zone of the tube furnace and is vaporized in the oxygen carrier gas. It was suggested that distilled water could be introduced either by injection through a septum port in the rubber stopper at the front end of the furnace or by placing a capillary tube containing distilled water in a conditioned combustion boat and conducting an analysis according to the normal procedure. After several trials, the group decided on the capillary tube method for several reasons:

1) The effectiveness of syringe injection is highly dependent upon operator technique. Laboratories not familiar with

the use of syringes would have significant difficulty ensuring that the water actually reached the hot zone of the furnace with this method.

2) Water introduced via capillary tube would be suitably contained ensuring delivery of the entire quantity of water to the hot zone of the furnace.

3) Although the technique is more time consuming than direct injection, the capillary tube method is conceivably more reliable because the amount of water can be verified by weight gain, thus eliminating errors introduced by variable injection technique.

Fused quartz capillary tubes having a 1-mm inside diameter and 25-mm length were selected for the task group's next round-robin test effort. The softening point of the fused quartz is sufficiently high to avoid collapse of the tubes during testing. Capillary tubes containing target levels at 2, 4, 8 and 12 mg distilled water were analyzed in triplicate. These levels correspond to the amount of water to be expected from a 4-g electrode covering or granular flux samples at 0.05, 0.10, 0.20 and 0.30% water, respectively. The actual amount of water introduced for each analysis was verified by weight gain of the capillary tubes. To minimize the risk of saturating the systems with water, the lowest targets were analyzed first and the highest targets last. Each laboratory used a single moisture analysis system for all tests. In addition to analytical results, participating laboratories provided detailed information about their respective moisture analysis systems (e.g., type and length of tubing, type of connections, carrier gas purity, etc.).

Nine laboratories participated in this test effort. The results are summarized in Table 5 and presented graphically in Fig. 2. The amount of water measured as a weight gain in the absorption U-tubes was compared to the amount of water introduced in the capillary tubes and expressed as percent recovery. Although, the general trend exhibited in Fig. 2 approaches a 1:1 correlation, the scatter was very discouraging. Considering all of the results together, percent recovery on average was 97%. However, the variability was excessive with a low of 28% recovery and a high of 187% recovery. As expected from the previous test efforts, the percent error resulting from this excessive scatter was highest for the lowest water levels. A few laboratories actually achieved a nearly consistent 100% recovery, although the scatter was still higher than desired at the low water levels. A review of the information provided about each laboratory's test equipment revealed no differences that could be associated with either poor recoveries or good recoveries.

However, one procedural variable was noted.

The standard method (Refs. 3-5) requires a 20 min. "cool down" period to allow the U-tube to reach ambient temperature before weight determination. Placing a hot item on a balance can cause convection currents which effectively lift the pan and reduce the measurement. Although the U-tube is not actually hot in many cases, the current procedure requires that it be desiccated for 20 min prior to final weight measurement. Laboratories which achieved percent recoveries closest to 100% had eliminated the 20 min cool down having determined final weight within minutes of removing the absorption U-tube from the system. Although this procedural variable might help to explain a systematic error in measurement, it did not resolve the issue of excessive scatter and poor reproducibility. The results indicated that the moisture test systems in all but a few of the participating laboratories were not performing consistently.

The significance of the system blank value was considered, particularly with regard to analysis of small amounts of water. Table 5 indicates that the blank value is often of the same order of magnitude as the water collected at low moisture levels, thus reducing the accu-

racy of the measurement. Further, the blank value which is subtracted from all moisture determinations conducted in a day is the result of a single blank determination at the beginning of the work shift. If the moisture test systems do not perform consistently, then it is possible that the actual system blank varies from this single determination. Such undetected variation in system blank value can introduce a significant random error in testing.

The task group carefully reviewed all of the equipment and procedural details provided by each laboratory and identified several areas possibly contributing to inconsistent performance and blank variability.

1) Tubing — The type may not be as important as the length. Condensation between the end of the combustion tube in the tube furnace and the absorption U-tube is a concern. The tubing run between these components should be minimized to ensure that as much water vapor reaches the U-tube as possible.

2) Connections — The slip connections commonly used are a major source of leaks. Their integrity can be improved by using spring type hose clamps. Lubricant should be avoided because it is a potential source of system contamination.

3) Glass wool dust filter — The quantity of glass wool is important because of the possibility of over packing and restricting carrier gas flow through the system. Location is important to preclude condensation. The plug of glass wool must be located in the combustion tube such that it is warm enough to prevent condensation but not so hot that it flakes and splinters, creating carryover dust of its own. If the combustion tube extension beyond the furnace is significant, heat tape should be used at the effluent end to prevent condensation.

4) Breech fitting — Use of a breech fitting at the entrance to the combustion tube maintains a flow of oxygen and precludes atmospheric contamination of the system during sample loading.

5) Time lapse between completion of 30 min test and weighing the U-tube — The tube should be positioned in the system such that its temperature is as close to ambient as possible at all times. This way the tube never heats up, and the time lapse can be kept to a minimum. It was agreed that, prior to starting the next series of tests, all participants would make every effort to minimize these potential sources of error by minimizing tubing runs as much as possible, tightening connections, and wrapping any significant combustion tube extensions with heat tape.

Table 5—Standardization Using Water Filled Capillary Tubes

Target Water (mg)	Lab A Water			Lab B Water			Lab C Water			Lab E Water			Lab F Water			Lab G Water			Lab H Water			LAB I Water			Lab J Water					
	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)	In (mg)	Out (mg)	Rec (%)			
2	2.14	1.7	79	2.3	3.1	135	1.9	2.3	121	2.0	1.4	70	3.2	2.2	69				2.4	4.2	175	2.3	2.0	87	3.2	3.8	119			
	2.08	2.8	135	1.8	2.3	128	2.3	2.2	96	2.1	2.5	119	2.7	2.5	93				2.6	3.6	138	1.9	2.4	126	2.6	3.8	146			
	2.07	2.3	111	2.0	1.9	95	2.5	2.5	100	2.1	1.9	90	2.4	2.0	83				2.8	2.9	104	2.0	1.7	85	1.5	2.8	187			
	2.07	2.2	106	2.1	1.4	67							1.6	1.1	69				2.0	2.9	145									
	2.13	2.3	108	1.7	1.8	106																								
	1.75	1.97	113	2.4	1.6	67																								
	1.99	1.67	84																											
4	3.78	3.9	104	3.7	3.5	95	4.4	4.8	109	4.4	3.4	77	4.2	2.3	55				5.0	3.7	74	4.0	3.3	83	4.7	1.3	28			
	3.79	4.2	111	3.8	3.2	84	3.7	3.6	97	4.1	3.7	90	4.4	3.3	75				4.1	3.1	76	3.9	3.6	92	3.9	2.5	64			
	3.95	3.8	96	4.5	4.1	91	5.0	4.9	98	3.6	2.6	72	4.3	3.0	70				6.1	4.4	72	4.1	4.4	107	3.3	3.0	91			
	3.98	4.2	106	3.9	3.6	92													4.0	5.2	130				4.5	5.2	116			
	3.89	4.27	110	5.3	4.6	87																								
	3.90	4.47	115	3.9	3.6	92																								
	3.94	3.67	93																											
4.09	4.57	112																												
8	7.72	7.8	101	8.4	7.7	92	8.2	8.3	101	7.5	6.0	80	8.6	5.7	66	8.4	7.3	87	7.9	8.2	104	7.9	7.6	96	6.6	7.8	118			
	7.93	7.6	96	8.7	8.2	94	8.2	8.0	98	8.1	6.7	82	8.5	7.0	82	7.1	5.7	80	7.7	8.1	105	8.0	7.8	98						
	7.89	8.0	101	8.7	8.7	100	8.2	8.0	98	8.0	6.9	86	8.0	6.6	83				8.1	9.6	119	8.0	7.4	93						
	7.69	7.3	95	8.3	8.2	99													8.7	8.3	95									
	7.99	7.57	95	8.4	7.4	88																								
	8.24	8.87	108	8.5	8.7	102																								
12	11.08	10.2	92	13.0	12.1	93	11.5	11.1	97	11.9	10.3	87	12.2	8.6	70	12.6	11.5	91	12.3	12.3	100	12.3	11.5	94	11.1	11.0	99			
	10.92	10.1	92	12.8	12.0	94	11.8	11.7	99	11.7	9.2	79	10.7	9.5	89	12.5	11.0	88	12.6	17.6	140	12.1	11.8	98	12.0	13.0	108			
	11.28	10.7	95	12.4	12.6	102	11.8	12.2	103	12.9	11.3	88	11.8	10.2	86				10.7	10.6	99	12.0	11.1	93	12.5	10.3	82			
	11.75	11.12	95	13.3	12.3	92													12.3	12.6	102				12.4	10.4	84			
	11.95	11.72	98	12.2	11.3	93																								
	11.6	11.32	98	13.2	12.8	97																								
Avg. Blank Value (mg)	0.70			1.63			0.65			1.35			2.34			1.65			1.93			1.03			2.2					



cal chemistry do not utilize Pyrex glass because of the influence of uncontrolled environmental factors such as relative humidity. Given the level of precision needed at low moisture levels, continued use of Pyrex absorption U-tubes was not likely to be successful regardless of any other improvements made in the analytical apparatus or procedure. Consequently, the variability demonstrated in the test results is inherent to the standard test method (Refs. 3-5).

## Summary and Conclusions

In an effort to provide a reliable test procedure for classification of electrode coverings and granular fluxes according to their as-baked and absorbed water contents, two AWS A5A task groups have investigated the suitability of the standard test method and possible improvements within the scope of the existing analytical method. Round-robin test efforts using as-baked electrode coverings of various types indicated inter-laboratory variability as high as 87% for low-hydrogen/moisture-resistant types. When evaluating consumables for conformance to a classification or specification requirements, scatter of this magnitude is unacceptable. Subsequent round-robin tests using mineral reference standards produced similar poor results. The "certified" water contents of these reference standards were determined by similar gravimetric techniques and were plagued by the same uncertainties and variability that the task group was working to resolve. An alternative method of standardization using controlled quantities of distilled water was adapted for use whereby water was introduced to the hot zone of the tube furnace in a fused quartz capillary tube. With each iteration, the task group made

improvements in procedure and equipment. Although, variability was reduced, acceptable levels were never achieved.

The current expectations for moisture levels in welding consumables have exceeded the capabilities of the existing test method. At the time the thermogravimetric method of moisture analysis was developed, electrode coverings typically contained >0.5% water compared to the <0.10% currently expected from low-hydrogen/moisture-resistant electrode coverings and <0.05% currently expected from some granular fluxes. The scatter inherent in the test method may have been tolerable at the 0.5% level, but is no longer acceptable. It was, therefore, the conclusion of the task group that the standard thermogravimetric method of moisture analysis is unsuitable as a basis for testing and classification of many contemporary electrode coverings and granular fluxes.

The task group is currently investigating alternatives based on Karl-Fisher titration and infrared detection as a basis for a new AWS standard for moisture testing. During each phase of this work, a few task group members conducted parallel testing using titration and infrared detection. The preliminary results indicate much greater precision and accuracy than experienced using the thermogravimetric method.

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