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Second Preliminary Report to National Capital Planning Commission on Metallurgical Analysis of Corrosion Studies of Select Proposed Wire Materials for the Eisenhower Memorial Tapestries

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I. Introduction and Background

The NCPC requested assistance from the Materials Science and Engineering Division of NIST in evaluating the wire and braided materials to be used in the fabrication of the Eisenhower Memorial. The relevant properties of interest include but are not limited to corrosion resistance, weld performance and mechanical endurance. This information is to be used by the NCPC to determine whether the proposed Dwight D. Eisenhower Memorial project, as currently designed, meets the durability criteria contained in the Commemorative Works Act (40 U.S.C. 8905)(b)(3))). The work thus far has focused on the selection of the tapestry base materials in the un-welded and welded state, and their performance under environmental testing.

II. Previous report

In the first preliminary report (dated 2-13-13), results were presented showing the response of several stainless steel materials to the ASTM B117 1000-hour salt spray corrosion test, modified with the injection of hydrogen sulfide and carbon soot to attempt to more closely recreate a severe version of the environment that the materials may be exposed to while in service. To summarize the previous results, we observed pitting corrosion within the heat-affected zones adjacent to the wire welds in all three grades of stainless steel (304, 316L and 317L). Pitting occurs in welded stainless steel when the heating near the weld causes the chromium in the metal to react with carbon and form chromium carbides on the boundaries between grains. With the chromium tied up in carbides, it is no longer available to form chromium oxide, which is the naturally occurring protective coating that makes stainless steel stainless. The protection is lost where these boundaries intersect the surface, and the environment selectively attacks these chemically weak areas, causing the formation of corrosion pits. These pits are undesirable because they weaken the wire by reducing its load-bearing cross sectional area and provide locations where fatigue cracks can nucleate.

It was seen that the 304 wires showed the most severe pitting of the three samples, 316L somewhat less and 317L considerably less than either. The pits observed in the 316L sample were roughly hemispherical with a maximum radius of approximately 40 micrometers, while those in the 317L sample were on the order of 5-10 micrometers. This would mean that the pits in the 316L were roughly 5 percent of the diameter of the wire and those in 317 approximately 1 percent. The pitting was seen at a distance from the weld that is consistent with that expected for sensitization in a heat affected zone, and the weld penetration (the amount that the two wires penetrated each other to form the weld) is estimated to be 5% based on an analysis of figure 3 of the report HDR # 194221-RevC, dated 01/16/2013, which is stated to be a polished cross-section of a typical weld.

These results were presented with the caveat that a determination as to the suitability of the materials studied was not made due to the fact that the analyzed samples were not reflective of the materials preferred by the design team.

III. Recent Submission

The most recent set of samples were provided to NIST for similar analyses. 21 specimens of welded wire were provided - 7 each made from 316L, 317L and 321 solid stainless steel wire. It is stated that one each were kept as-fabricated, two were etched to check for sensitization per ASTM 262 with the modifications to the test previously outlined (addition of hydrogen sulfide and carbon to replicate exhaust and soot, respectively). NIST chose samples #6 (316L with salt fog exposure and descaling) and # 13 (317L stainless steel with the same test regimen) for analysis in the scanning electron microscope. These two specimens were trimmed to size and examined in the SEM for weld penetration and morphology and for any pitting that may have occurred in a sensitization zone adjacent to the weld.

The degree of corrosive attack of the base metal (more than 5 millimeters from the weld) appeared identical to the samples previously examined - negligible corrosive attack was observed. In the region near the weld where sensitization would be expected, both the 316L and 317L samples exhibited less pitting than the samples previously examined. These will be examined in more detail with references to the appropriate image figures.

Sample #6: 316L welded wire sample with salt fog exposure

Figures 1 through 3 show the region near the weld where sensitization, if it exists, would be expected to be located. As seen in figures 1 and 2, the density of pits is very low, and figure 3 shows that the average size of the pits is in the range of 2-10 microns, with the morphology being spherical. By way of comparison to the previously examined samples, the pits are significantly smaller and fewer in number in the present samples. These pits do not extend beyond 1% of the wire diameter, if that.

Sample #13: 317L welded wire sample with salt fog exposure

Figures 4 through 6 show the region near the weld where sensitization, if it exists, would be expected to be located. Figure 5 shows that the pits are fairly uniformly distributed in the sensitization zone, and figure 6 shows that they are very small - generally less than a micron in diameter and depth.

IV. Comparisons Between The Submissions

The corrosion performance in the modified salt spray test of the samples in the most recent submission is significantly better than the samples in the previous submission. The extent of pitting is much less in the recently submitted samples, both in number and in size.

One factor that was apparent upon examination of the most recently submitted materials that may account for these differences was the morphology and degree of penetration of the weld. Figure 7 shows the welds from a 316L wire from the previous submission and the current submission. It is seen that the degree of penetration of the weld in the previous submission is higher, evidenced both by the geometry and the presence of melted exudate at the junction. This would imply either a higher welding current or longer welding time or both - in any case a higher welding power. In correspondence between NCPC staff and the fabricator, they indicated that a direct comparison of the welding power between the two sets of samples was not possible as two different welders were used and the process variable data available is not directly comparable. A difference in welding power would lead to higher heating in the region next to the weld and thus a higher chance of and degree of sensitization of the microstructure, leading to more pitting.

The obvious question that might be asked is whether these samples can be deemed to have "passed" the salt spray test. Unfortunately, the ASTM B117 standard does not give a definition of "passing" the test. Determination of whether the material has passed is dependent on the application of the material. For example, in the automotive industry materials are deemed to have passed the salt spray test if there is no visible corrosion. Also, ASTM B117 is written to examine the effects of salt spray on the performance of coatings like paint, not necessarily the performance of the underlying base material.

In the case of the welds for the tapestry for the Eisenhower Memorial, we believe that the extent of pitting is important as it pertains to mechanical performance. The pitted sensitized areas are not going to be of sufficient area to significantly degrade the appearance of the tapestry, but having a pit on the surface that is 10% of the diameter of the wire (seen in places in the previous submission) could very well provide an easy nucleation spot for a fatigue crack to develop under the varying loads due to wind. Over time, these cracks would grow and could lead to individual wire failures.

The salt fog test performed is severe, and is likely much more intense than what the tapestry will see in service. Its purpose is to act as a screening tool for materials selection in this engineering design. The base metal 316L and 317L wires have shown to be adequately resistive of corrosive attack and should perform well in the long term. Of course, the weak link in the structure is the welds, not the base metal, and pitting due to welding induced sensitization has been seen. The pitting seen in the second submission is significantly less than the first submission, and given the need to weld wires to form the tapestry, the density and size of the pits in the second submission samples are close to as small as can be expected with stainless steel in salt fog. While the size of the largest pits seen in the first submission causes concern for mechanical performance, the pits seen in the second submission are not likely to degrade the performance of the tapestry, and in any case are quite unlikely to form in the actual environment of the location of the memorial. If there indeed was a difference in the welding conditions between the two submissions, it is apparent that welding conditions affect corrosion performance.

V. Conclusions

The samples presented to NIST for analysis fairly clearly show the superiority of 317L stainless steel over 316L stainless steel in resisting weld-induced sensitization and the concomitant pitting when exposed to an ASTM B117 salt spray corrosion test. However, several issues have been identified that the NCPC should consider in their evaluation.

1. The performance of the two sets of samples in resisting pitting corrosion were quite different, with the second set of submitted samples performing significantly better. However, the observation that the weld penetration in the second set of samples appearing to be less than the first, coupled with the lack of comparable information regarding the welding power settings introduces a question as to whether they were fabricated under the same conditions. Reducing the power used to form the weld can be an effective means in controlling sensitization, but generally at the expense of weld penetration depth and perhaps strength. A comparison of the welding power settings used should be performed before any conclusions are drawn when comparing the first and second set of samples.

2. As has been stated several times by NIST, the mechanical performance of the joint under wind and vibrational loading is as or more important a parameter in selecting the materials to use in this application as the corrosion resistance properties of the base metal. A full spectrum of mechanical tests of the welds (fabricated under the power settings to be used in production) is called for, both straight tensile and shear strength of the joints and also fatigue testing of select sections of the design in biaxial tension, replicating the conditions of wind and self loading as closely as possible.

3. Also as previously stated, the welding and salt spray performance of the braided yarn materials has yet to be investigated, and due to their non-monolithic structure (ie not a single cylinder wire), the variability of the welding conditions due to how the individual strands are arranged and make contact, along with the tendency of braided yarns to accumulate materials such as water and debris, and hold it for longer than single wires, may lead these welds to perform differently than welded single wire joints. This should be investigated both for corrosion and mechanical performance.

4. The ASTM B117 salt fog test with the modifications introduced in the present study is severe, and subjects the material to conditions that are far more intense than those expected in service in an attempt to accelerate the test. These results should be used to compare materials and fabrication techniques relative to one another, and not to attempt to extrapolate the test results to predict actual performance. Such an extrapolation would be of dubious value and subject to large errors.

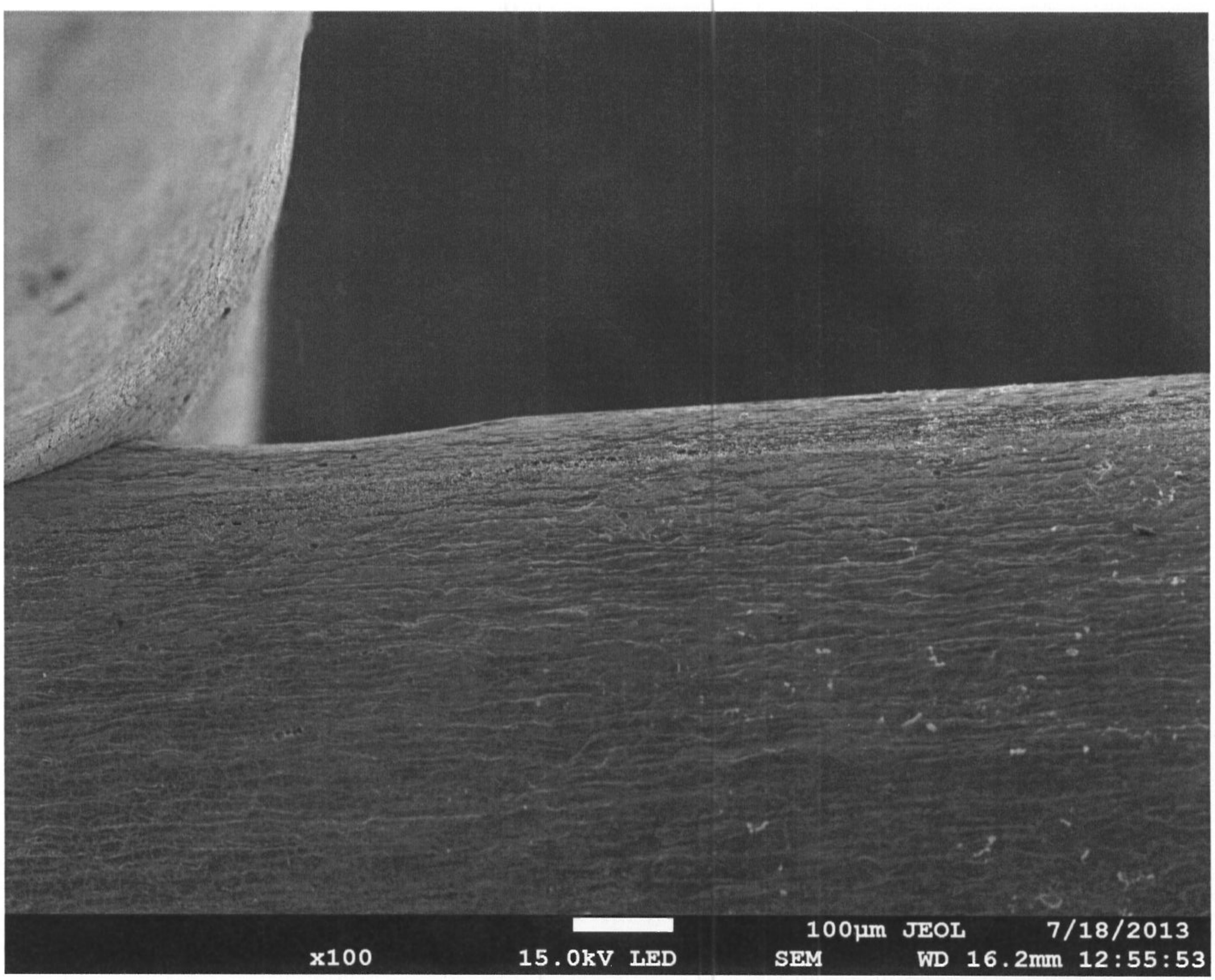

Figure 1 – Low magnification view of sensitization zone in sample #6 (316L). Weld is to the left.

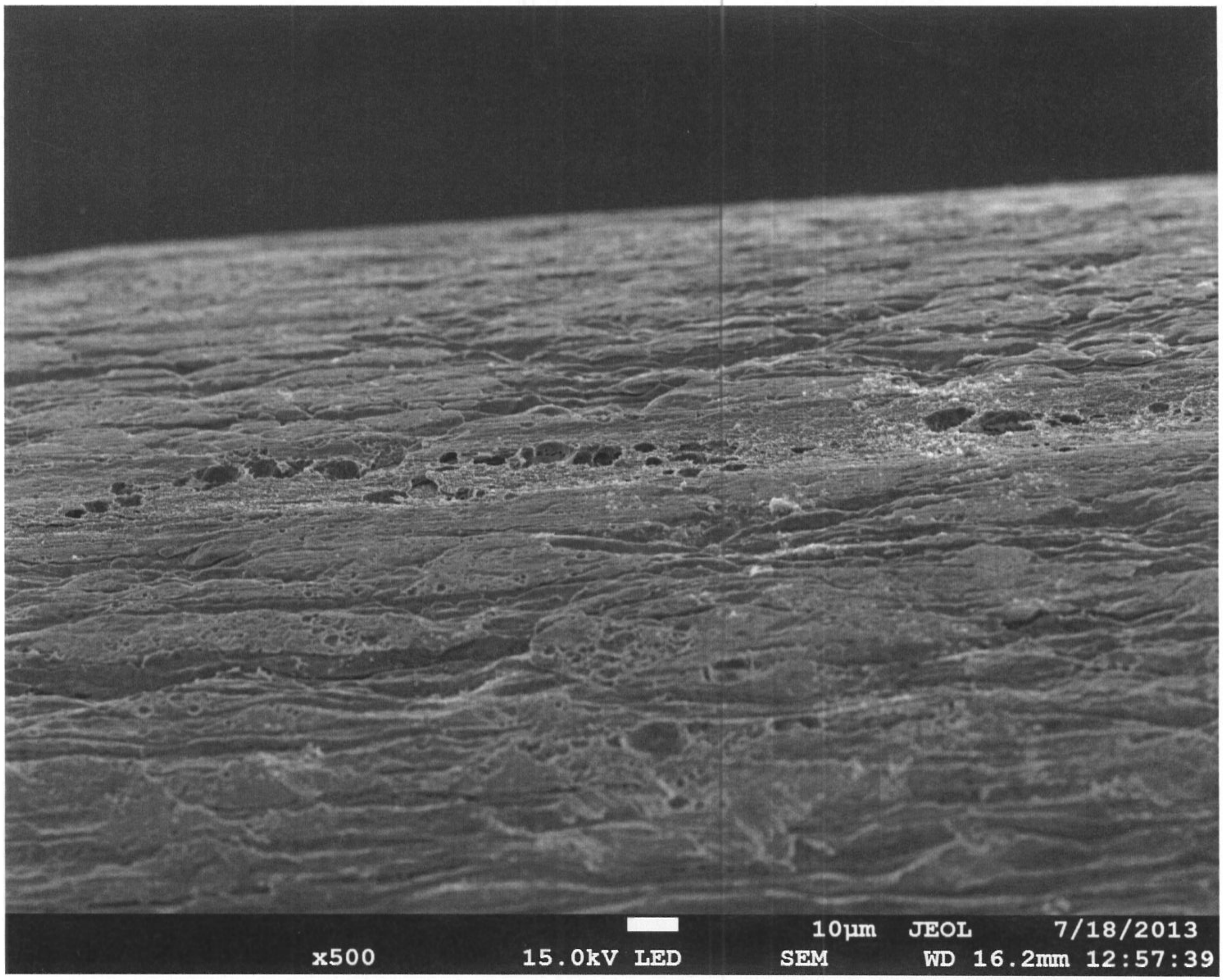

Figure 2 – Higher magnification of the sensitization zone near the weld in sample #6, showing a row of small corrosion pits.

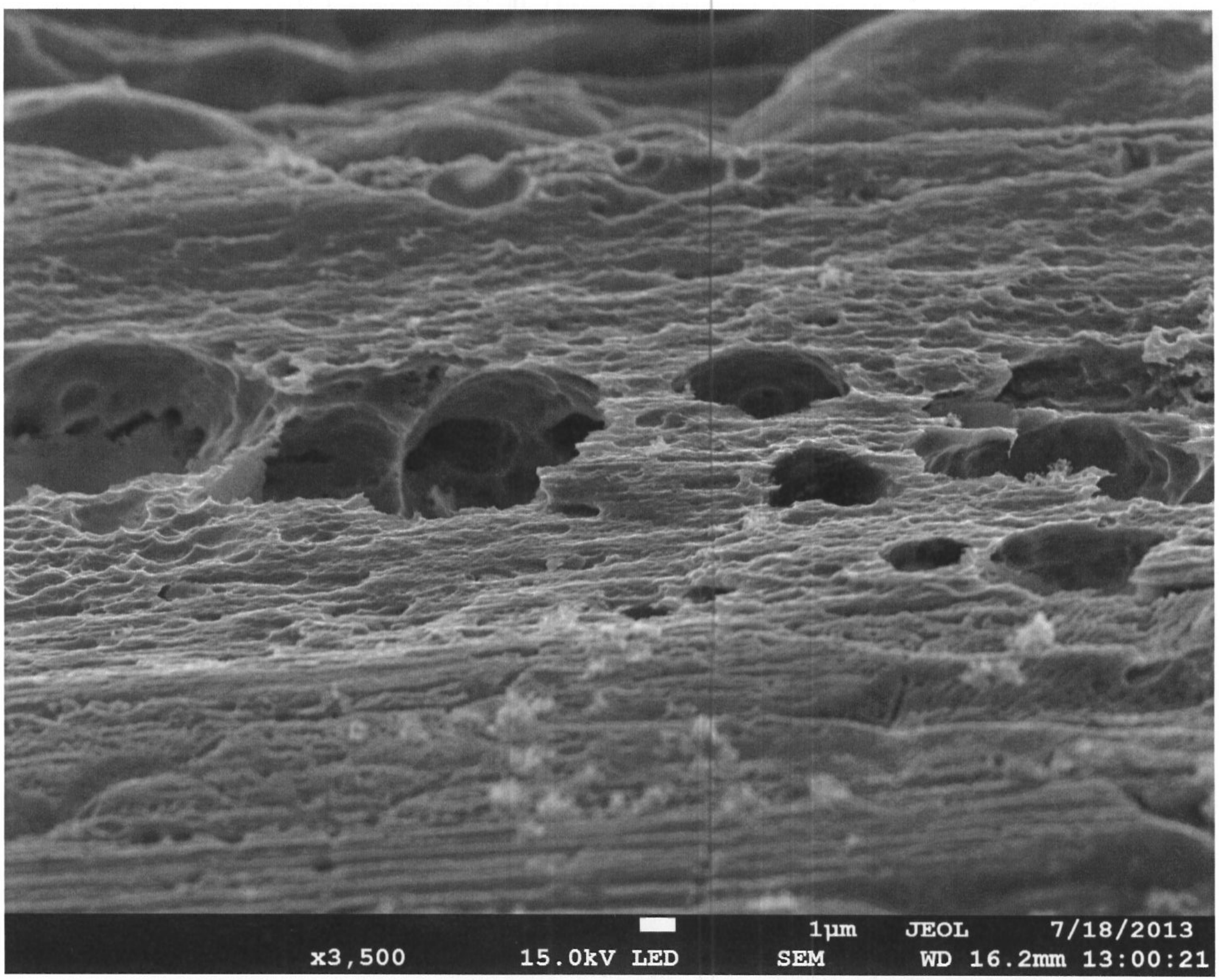

Figure 3 – A high magnification of the sensitization zone near the weld in sample #6, showing corrosion pits. Pits range from 2-10 microns in diameter, and are roughly hemispherical.

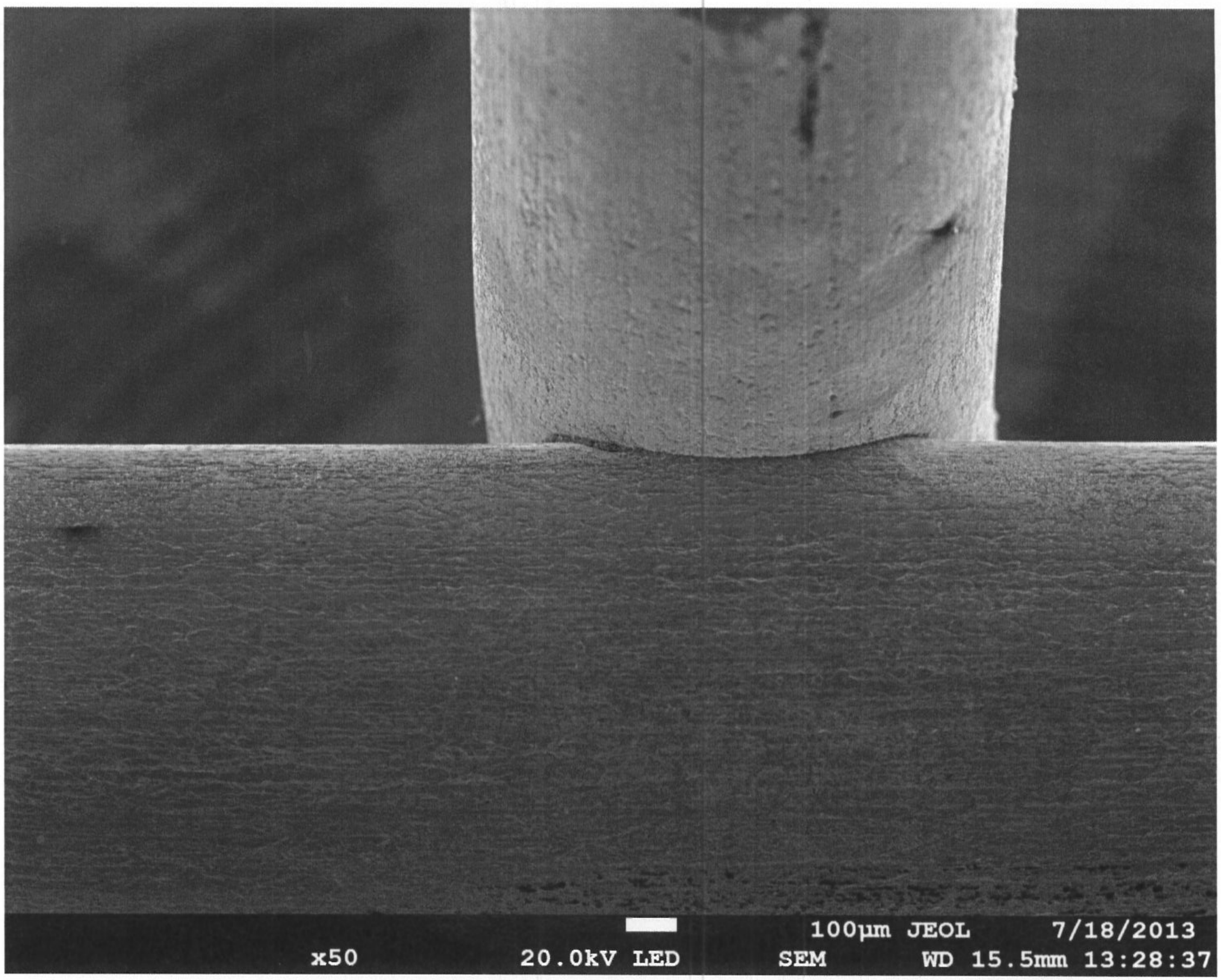

Figure 4 – Low magnification view of sensitization zone in sample #13 (317L). Weld is at center.

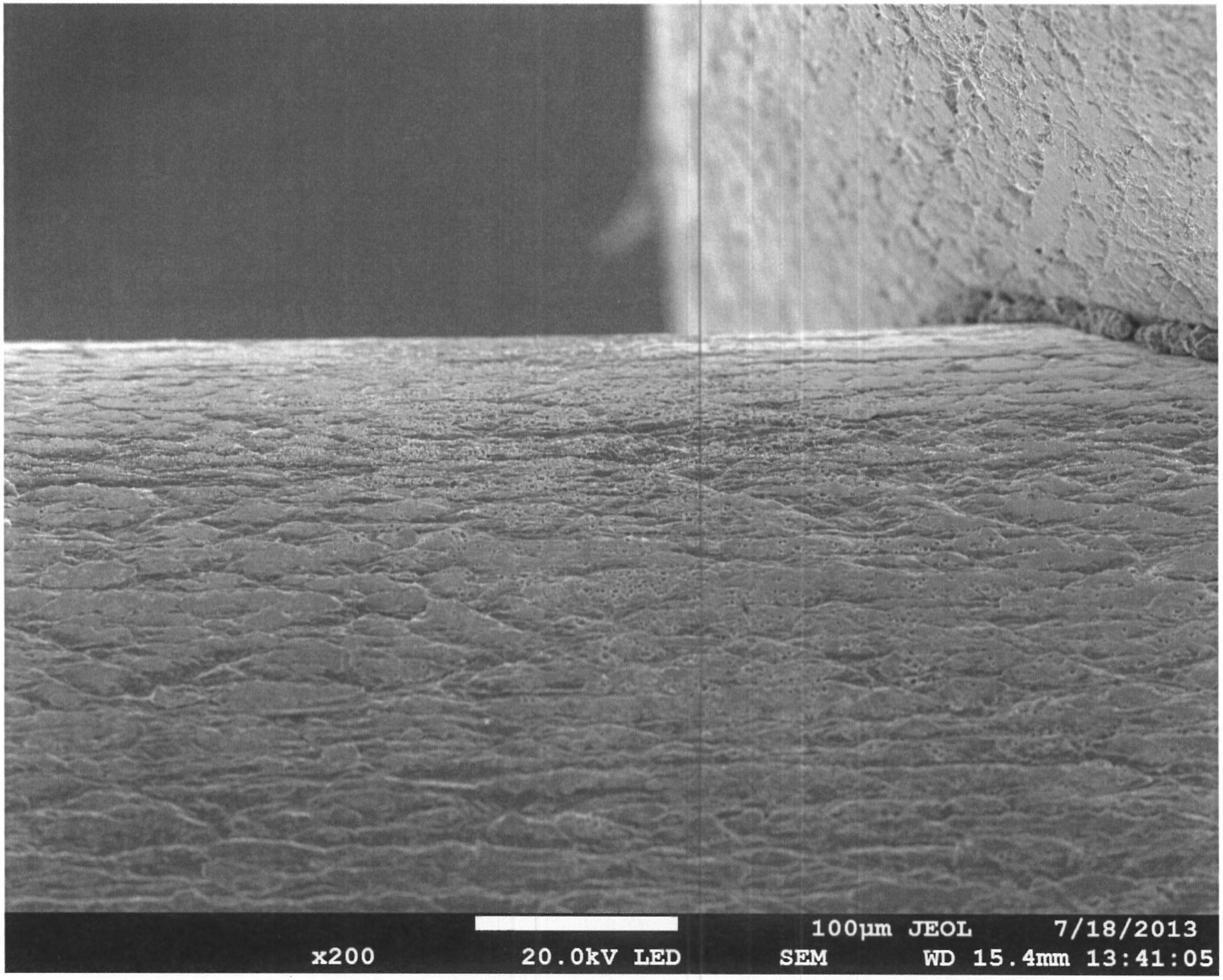

Figure 5 – Higher magnification of the sensitization zone near the weld in sample #6, showing a scattering of small corrosion pits.

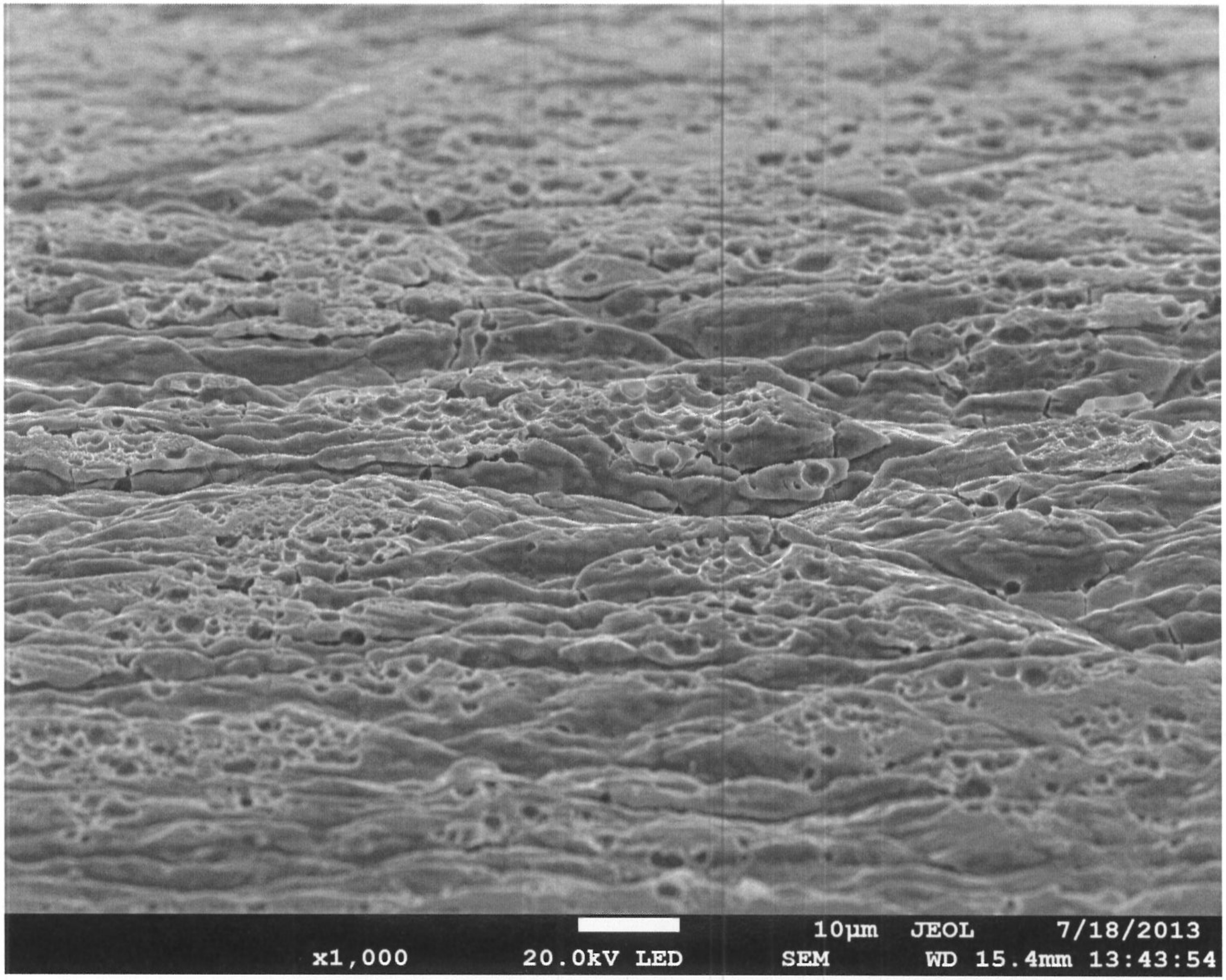

Figure 6 – A high magnification of the sensitization zone near the weld in sample #6, showing corrosion pits. Pits average approximately 1 micron or less in diameter, and are roughly hemispherical.

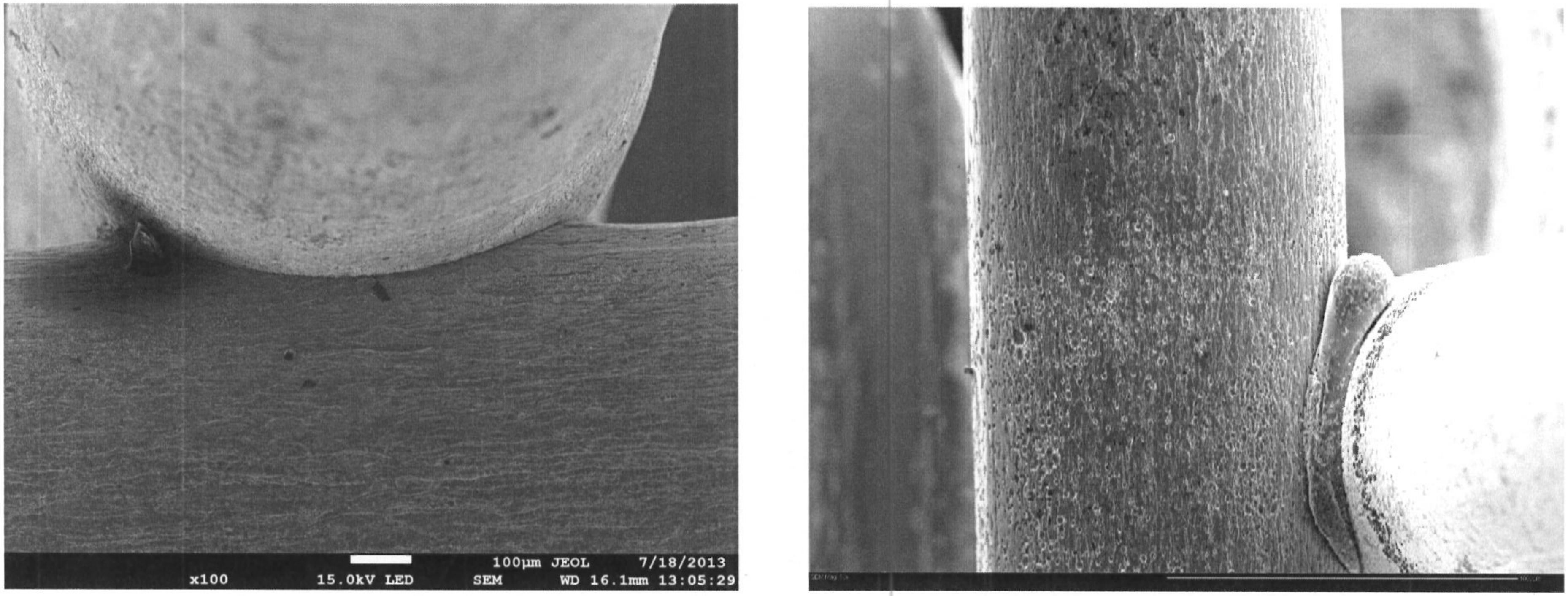

Figure 7: Low magnification images of the welds of 316L wire samples from the current (left) and previous (right) submission. Note the exuded melted metal in the joint and the higher amount of interpenetration of the wires in the previous submission to the right, and the higher degree of pitting (dark band on the horizontal light tinted wire just beyond the exudate). These lead to the conclusion that the previous samples were welded with more power and were hotter, leading to more sensitization.