EVALUATION OF AN AUTOMOTIVE FLUID LINE ASSEMBLY USING ACOUSTIC MICROIMAGING

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ABSTRACT

A unique application of AMI for inspection of a mechanical assembly is presented. This case study involves an automotive fluid line assembly that was failing due to fluid leakage at a sealed joint. Using a good assembly as a calibration standard, an AMI technique was developed to image the seal area. Failed parts were shown to exhibit a poor seal. The method was then used to evaluate joints assembled using various levels of torque in order to determine whether a correlation existed between poor seals and the amount of torque used. Results of subsequent destructive analysis are presented which provided confirmation of the AMI findings.

INTRODUCTION

Acoustic microimaging (AMI) is well known as an excellent means of evaluating package quality in microelectronics. Epoxy molding compound adhesion within plastic encapsulated microcircuits, flip-chip underfill, and die attach evaluation are a few examples that are tailor-made for the scanning acoustic microscope. Measurement of various material properties is another frequent application of AMI.

Acoustic microimaging is a versatile tool that can be applied to unconventional problems as well. In this case, a brake line assembly was failing due to fluid leakage at a sealed joint. The geometry of the assembly was not conducive to acoustic microscopy. However, by preparing the sample in a partially destructive manner, an AMI technique could be developed that allowed inspection of the seal. The technique was then used as part of an experimental procedure to confirm a suspected root cause of failure.

INITIAL INVESTIGATION

The brake line assembly was constructed of a double wall steel tube with a flange formed at one end. The flange was mated to a threadsaver and fastened by a nut. By tightening the nut onto the threadsaver, the tube flange was compressed, thus forming the seal between the tube and the thread-saver (figures 1,2). The sealing surface was at a large angle (approximately 45°) with respect to the longitudinal axis of the tube.

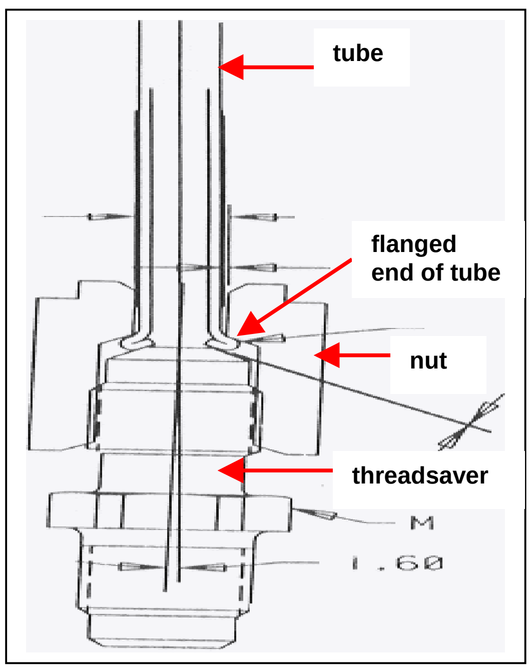


Figure 1 Diagram of assembly showing threadsaver, tube with flanged end, and nut.

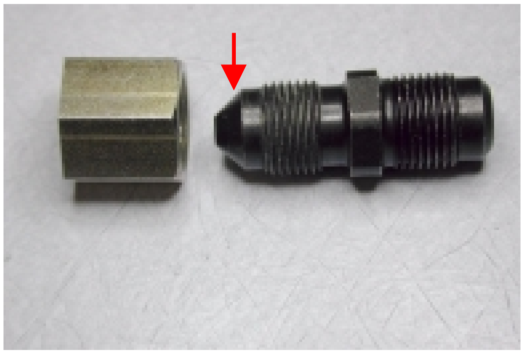


Figure 2 Photo of unassembled nut and threadsaver (tube not present). Note steep angle of mating surface, at arrow.

The original failing unit was known to leak fluid at this connection. However, the cause of the leak was not apparent. Lack of compression at the seal or misalignment of the flared portion of the tube were considered to be possible causes. Without knowing the exact location of the leak site, a metallurgical cross-section was not the most desirable course of action, since there was no way to ensure that the defect would be included in the plane of the cross-section. A method of evaluating the entire circumference of the seal was desired.

The geometry of the assembly provided two obstacles to using acoustic microimaging for evaluation of the seal. The first was the length of tube extending perpendicular to the area of interest. The tube was several inches long and would prevent clearance of the transducer. The second obstacle was the large angle of the sealing surface with respect to vertical. This would tend to reflect the sound waves away from the transducer and would present the added difficulty of collecting information over a relatively large depth of field.

To deal with the first problem, it was decided that the excess length of tube would be cut off flush with the top of the nut. A portion of the nut/tube assembly was then ground away in order to reduce the amount of material that the ultrasound would be required to penetrate in order to reach the seal. This also presented a very flat surface to the transducer. Since the initial objective was simply to identify the cause of failure, the destructive nature of the sample preparation was considered acceptable.

The second obstacle, the severe angle of the interface of interest, presented a greater challenge. The echo return received from the angled interface made it difficult to distinguish exactly which interface was being analyzed: the tube nut to tube interface, or the tube to threadsaver interface, or both. The difficulty in interpreting the echos was probably compounded by the deep focus and the fact that a good seal, by definition, consisted of good compression between the nut, the tube, and the threadsaver. The similarity in acoustic impedance between these metals resulted in a low amplitude echo return that was not well-defined. By contrast, however, areas believed to exhibit a poor seal returned a large amplitude reflection, since an air gap was present between one or both metal-to-metal interfaces.

By setting a wide gate and focusing at a depth estimated to be roughly the center of the desired depth of field, promising results were obtained. Using a 15MHz transducer and a symmetrical, or amplitude, map with gray at the center and yellow/red at both extremes, areas of good contact in the seal region appeared as a uniform gray band. In areas of reduced or no contact, the gray band was thinner or nonexistent as red/yellow encroached into the contact region (figure 3).

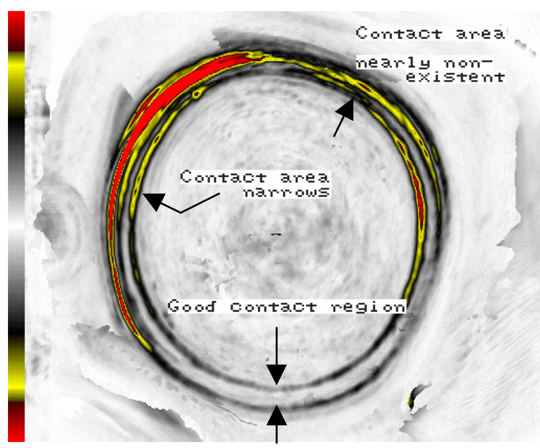


Figure 3 Initial acoustic image of failed assembly, showing seal between tube and threadsaver.

TECHNIQUE REFINEMENT

It should be noted that the conclusions regarding the initial failed sample were based solely on the acoustic microimaging results, with no first hand observation of the part's construction. To increase confidence in the AMI technique, a "calibration standard" was developed using a stock tube nut. The top portion of the tube nut was ground off and polished in order to simulate the sample preparation used on a completed assembly, as described previously (figure 4). The nut was then imaged under the assumption that it would be the ultimate "bad" sample – no contact at all to the tube flange, since no tube was present.

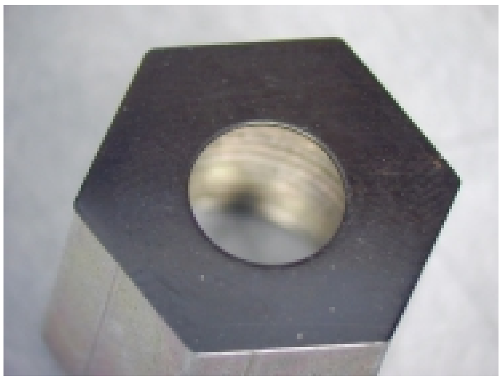


Figure 4 Modified tube nut used as calibration standard.

Using that standard, considerable improvement to the AMI technique was obtained, along with increased confidence in the results. First, it was observed that machined grooves were present on the underside of the tube nut (figure 5). The grooves were quite deep and were very apparent in the images. It was reasoned that in a well-bonded case, where the tube nut had tightly compressed the tube against the threadsaver, the grooves would be less visible, since they would be compressed or filled with material.

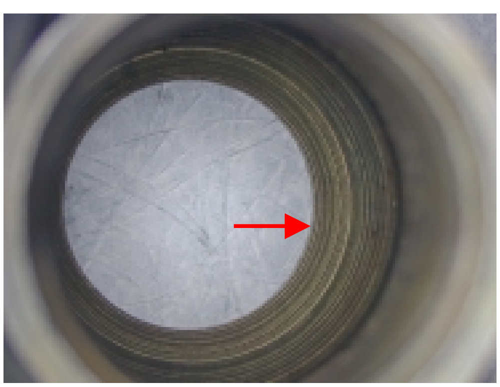


Figure 5 View of tube nut from bottom side. Machining grooves present on angled mating surface (at arrow).

Second, it was concluded that it was impossible to cover the entire angled surface of the tube nut in one scan. Although the gate could be set wide enough to encompass the entire surface, only a portion of it could be kept in focus due to its large Z component. This effect is illustrated in the following sequence of images (figure 6). The middle image was obtained with a

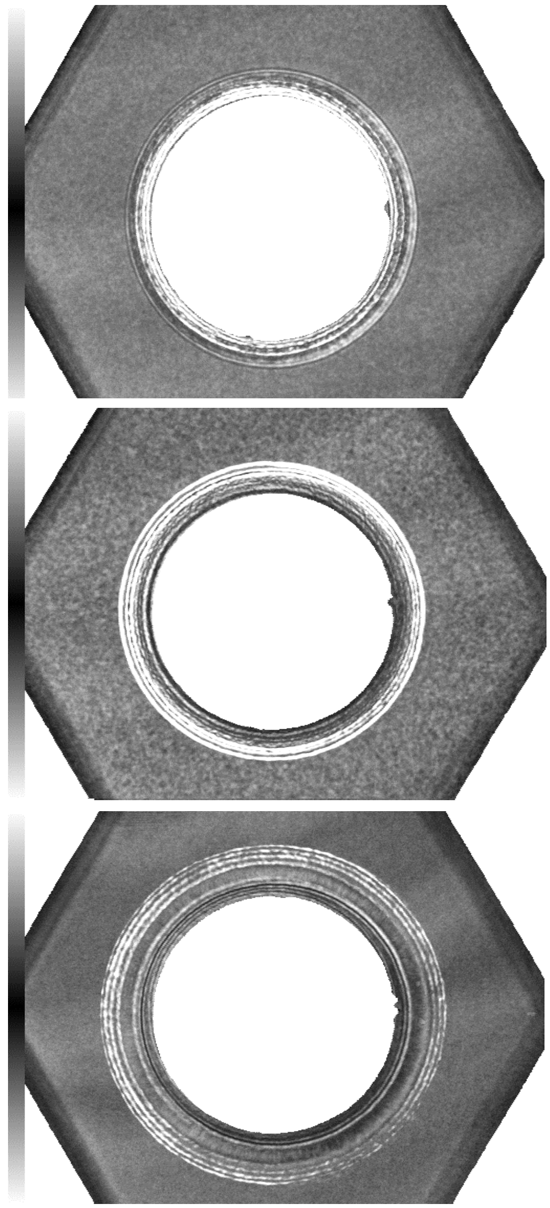


Figure 6 Acoustic images of calibration nut obtained with different focus depths. Top image—shallowest focus (near top of angled surface). Middle image--focused near center of anticipated seal region. Bottom image—deepest focus (near bottom of angled surface).

focus depth corresponding to the center of the anticipated seal area. While the machining grooves tend to detract from the image quality, the portion of the angled mating surface that is visible in this image appears primarily white, due to the large negative reflection from the nut/water interface, as expected. By comparison, the top image resulted from a focus near the inner diameter of the nut (top end of the angled surface), while the bottom image was obtained by focusing near the bottom end of the angled surface. The same wide gate was used in all three images.

Clearly, the difference in appearance between the three images is significant. In particular, it was noted that in the image with the deepest focus (bottom image), a uniform gray band is present in much of what would be the expected seal region. This emphasized the importance of choosing a focus depth near the center of the anticipated seal area, in order to ensure accurate imaging over as much of the seal as possible. In addition, a very large gain was used in order to maximize the amount of information obtained from the echo returns at the extreme ends of the gate.

It should be noted that once these parameters were established using the tube nut calibration standard, subsequent imaging of complete assemblies required individual adjustment. Recall that preparation of an assembly for imaging required removal of excess material from the top of the nut by cutting and grinding. This resulted in variable thicknesses from the top surface to the area of interest, so that it was necessary to locate the proper gate position and focal point on an individual basis. This was accomplished by first locating the gap at the bottom of the angled surface and then raising the focus a predetermined distance to the center of the area of interest (figure 7).

Additional refinement included the selection of a different color map, as shown in the previous images. A symmetric gray scale map that is darkest in the center and lightest at the extremes was chosen in favor of the original map that displayed yellow/red at the extremes. Experimentation with several color maps showed that the gray scale map provided an image that was more easily

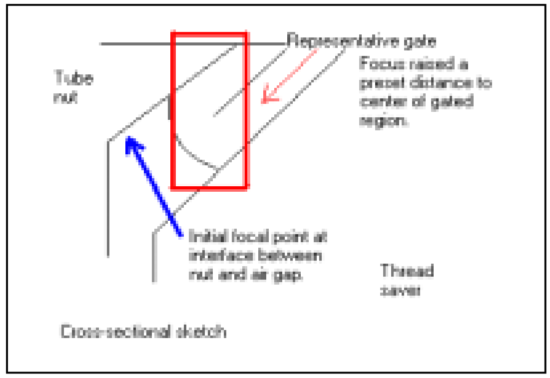


Figure 7 Cross-sectional sketch of seal area

interpreted. In addition, it was found that a 50MHz transducer could be used, which provided increased resolution.

Finally, when the refined AMI technique was applied to actual assemblies, it was concluded that the images represented general seal quality; that is, a lack of compression returned a large reflection, regardless of the interface reflecting the signal. Because of the large angle, the individual interfaces could not be adequately separated out.

EXPERIMENTAL RESULTS

The customer suspected that inconsistent torque values were being used when attaching the tube nut to the threadsaver during production, and that insufficient torque may have been resulting in the leaky assemblies. It was also theorized that side loading of the tube with respect to the threadsaver during assembly may have resulted in misalignment that contributed to the leakage problem. To test these hypotheses, 13 assemblies were constructed using varying amounts of torque, as shown in Table 1. These assemblies were then prepared and imaged, along with one additional failed unit.

Quantity	Torque Force	Side Loaded
2	10 Nm	No
2	10 Nm	Yes
1	17.5 Nm	No
1	17.5 Nm	Yes
3	22.5 Nm	No
1	22.5 Nm	Yes
2	27.5 Nm	No
1	27.5 Nm	Yes

Table 1 Experimental assemblies

Good correlation was observed between the amount of torque used and the quality of the seal. Where a good seal was present, a relatively uniform gray band was visible in the image. Where compression was not as good, the machined grooves on the underside of the nut began to be evident, resulting in more white color within the seal region.

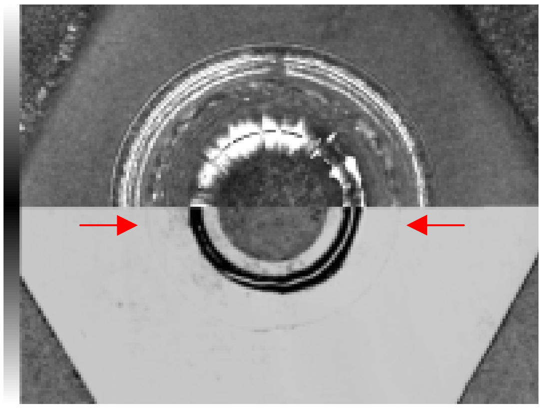


Figure 8 Hybrid image showing seal area image on top and surface image on bottom. Demarcation line on surface image (at arrows) identifies interface between tube and tube nut. Area of interest is from this point outward.

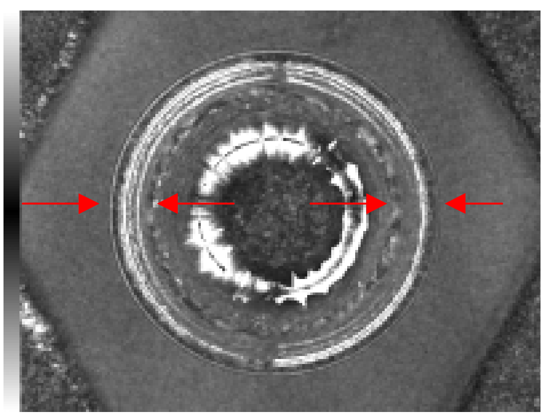


Figure 9 Acoustic image of 10Nm sample, showing entire seal area (bounded by arrows). Poor seal is identified by white bands within the seal area.

Figures 8 and 9 show acoustic images of one of the samples torqued to 10Nm. Figure 8 is a hybrid image in which the top half is the image of the seal area, while the bottom half is a surface image. This is an instructional image intended as an aid in locating the seal region. Figure 9 shows the entire seal for this sample. Note that a portion of the seal appears well-compressed, as evidenced by a uniform gray band (between arrows on right). Much of the rest of the seal area contains white bands, indicating a large signal reflection and, hence, poor compression of the nut/tube/threadsaver system.

By comparison, samples from the 27.5Nm group exhibited good compression around the entire seal, appearing as a uniform gray band due to the low amplitude reflections received from good metal to metal contact (figure 10). At the opposite extreme, the failed sample appeared to exhibit a near complete lack of compression (figure 11). Samples from the 17.5Nm and 22Nm groups exhibited better seals than those from the 10Nm group, but were not as good as those from the 27.5Nm group. Side loading during torquing appeared to further degrade seal quality.

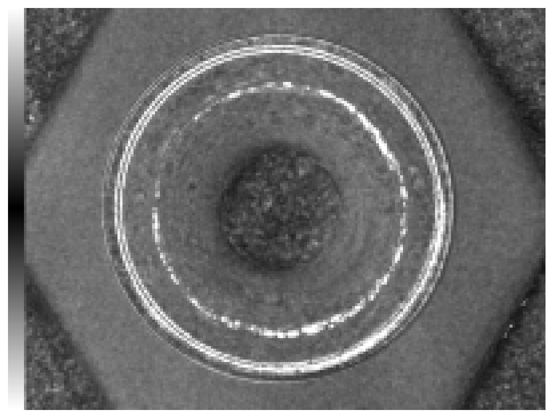


Figure 10 Acoustic image of 27.5Nm sample showing uniform gray band throughout seal region.

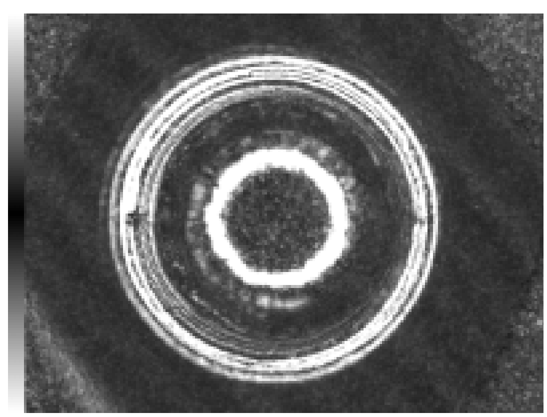


Figure 11 Acoustic image of failed assembly showing near complete lack of seal, as evidenced by white bands within seal area.

DESTRUCTIVE CORRELATION

Three samples – one torqued to 10Nm, one torqued to 27.5Nm, and the failure – were microsectioned vertically and polished for inspection using standard metallographic techniques. The 27.5Nm sample was verified as having good compression of the tube flange, as was seen in the acoustic image (figure 12). The 10Nm sample exhibited a point of contact near the inner diameter, but a wedge shaped separation extended from that point to the outer edge of the seal area (figure 13). The failed unit exhibited a large, wedge shaped separation between the tube and threadsaver. This is similar in appearance to that observed in the 10Nm sample, but to a greater degree. Additionally, a significant gap was present between the tube and tube nut, suggesting that the tube was never adequately compressed (figure 14).

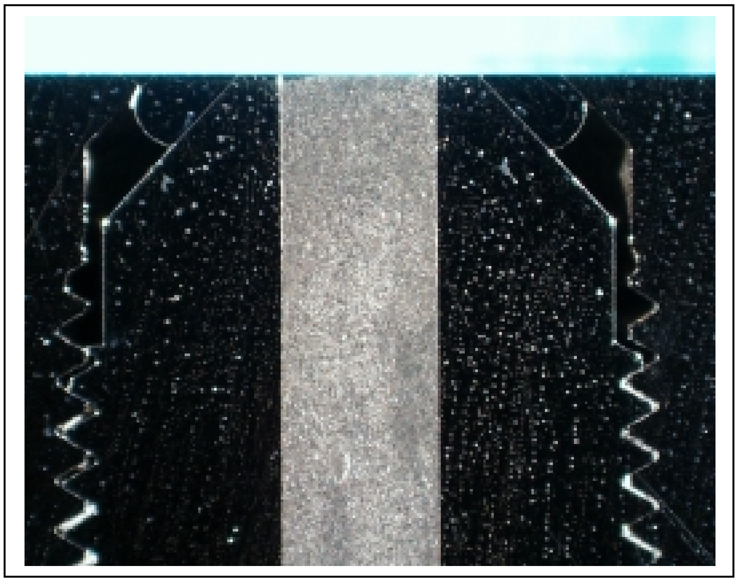
CONCLUSION

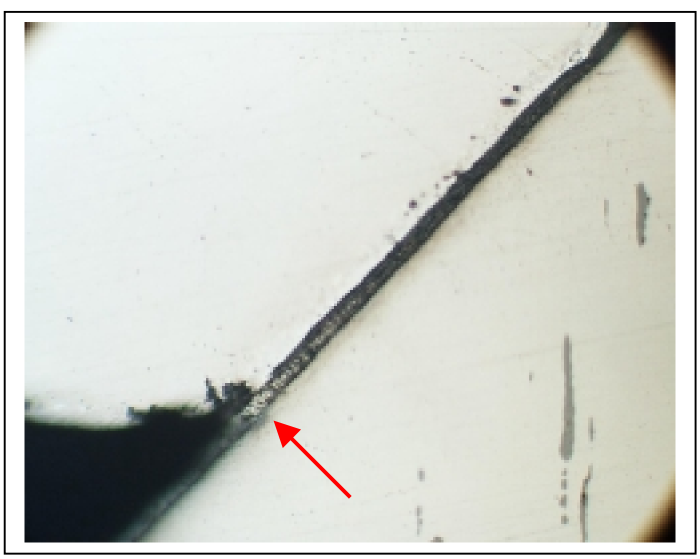
Acoustic microimaging was used to confirm that failing brake line assemblies were leaking due to inadequate compression of the seal. Subsequent destructive analysis validated the AMI results and provided physical evidence of the failure mechanism. Evaluation of experimental samples added confirmation of the root cause of failure, insufficient torque in tightening the nut.

In this study, acoustic microimaging was demonstrated to be a valuable tool for failure analysis in a nontraditional application. In such a situation, calibration studies and a thorough understanding of part construction are often necessary for obtaining an accurate interpretation of AMI results. Guided by accurate AMI data, destructive correlation can then provide valuable insight into the physical nature of the defects.

Figure 12
27.5Nm sample

Cross-section showing an overall view and higher magnification views of the seal area on each side of the section.

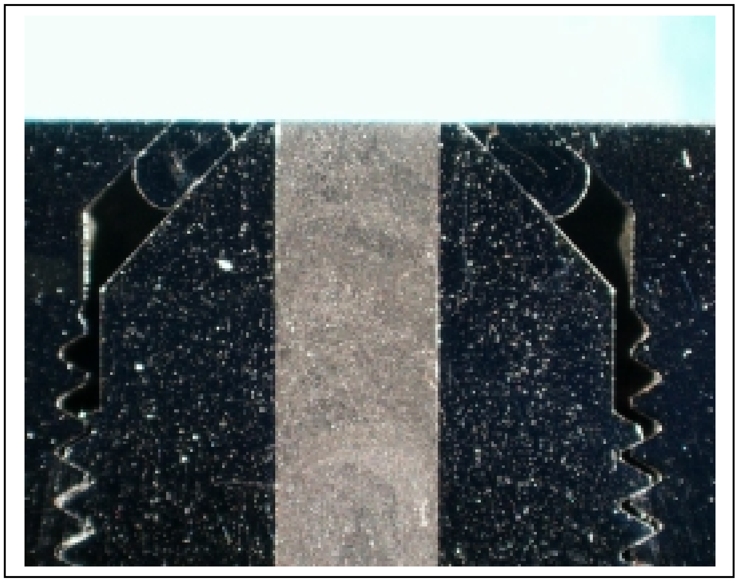




This view of the tube/threadsaver interface shows that what may appear as a separation between the two in the above image is, in fact, a plating layer not visible at the lower magnification. Note that the plating becomes less obvious toward the upper right corner of the photograph; this is a result of preferential polishing of the plating material during the sectioning process.

Figure 13
10Nm sample

Cross-section showing an overall view and higher magnification views of the seal area on each side of the section.



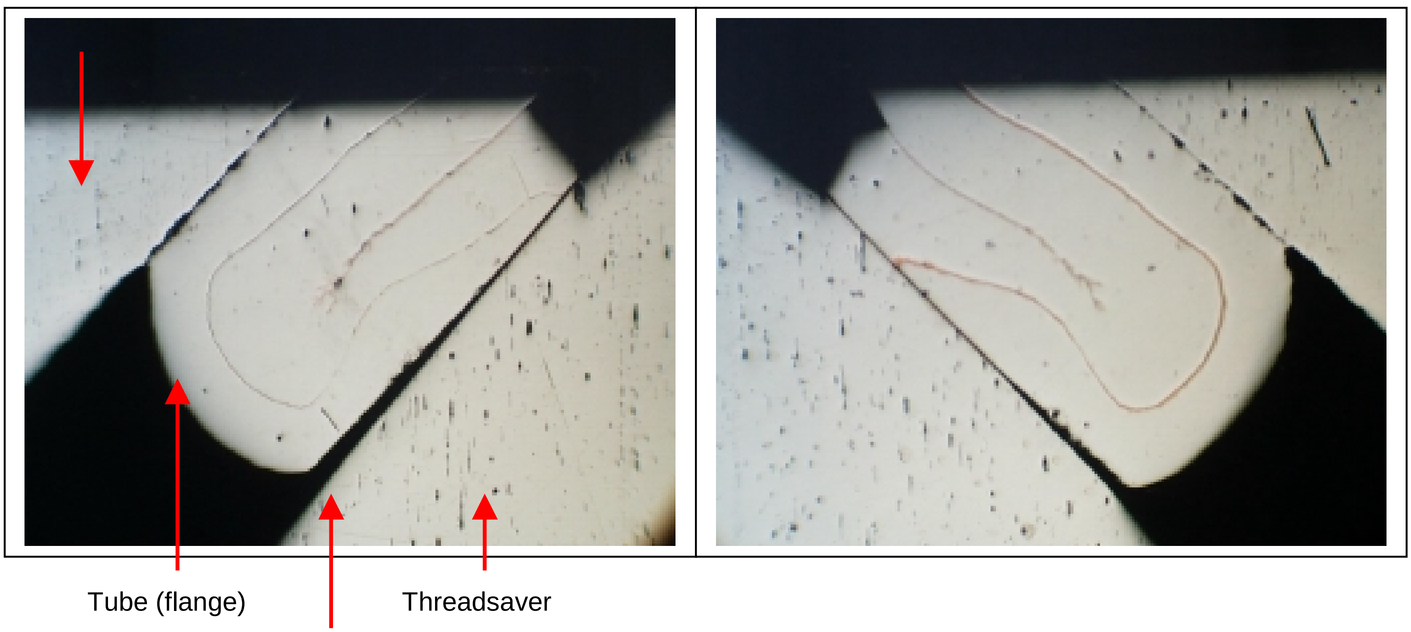


Figure 14
Failed sample

Cross-section showing overall view and higher magnification views of seal area on each side of the section.