Can direct, 3D, defect measurement mitigate the risks and limitations of replica materials?

by Jared Wheeler, 4D Technology Application Engineer

Measurements of Various Defects and Their Replicas Using the 4D InSpec

The 4D InSpec is a handheld surface gauge designed to quantify defects and fine-scale surface features in three dimensions on components made of metal, ceramic, composite, plastic, rubber, and other materials. Despite its small size and ability to employ fold mirrors to access tight spaces, some locations are still inaccessible for measurement, such as in narrow holes or deep into various recesses. In such cases, replication is needed. A rubber-like paste is applied to the surface feature, allowed to solidify, then it's peeled off and a negative of the feature replicated for measurement; this process is essentially the same as a dentist uses to create a mold of a tooth. The replicate is often measured using a 2D stylus trace, or the feature is cross-sectioned with a razor, and then the cross-section is viewed on a shadowgraph or optical comparator to estimate the feature height or depth.

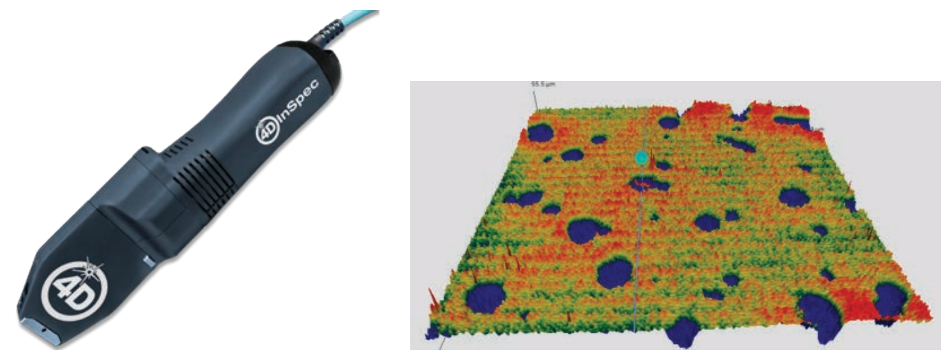

Figure 1: 4D InSpec surface gage (left) and a false-color 3D measurement (right) of pitting on a surface, as taken with the 4D InSpec

Any production-qualified measurement device should analyze the replicated feature just as accurately as measuring the surface feature directly. This application note will:

- Confirm that overall, data from direct 3D surface measurements match measurements of the replicated features—within the noise floor of the 4D InSpec gauge, or to about 0.0001" (2.5 µm)
- Compare 3D measurements of various surface defects and their replicas, and discuss limitations with the replication method.
- Show how using 2D-trace measurement techniques (as opposed to full 3D analysis of the surface) can lead to measurement errors.

As anyone with replication experience knows, there are limitations and costs to replication methods. A significant drawback is when the replication material does not penetrate all the way to the bottom of steep or deep features, leaving voids which ultimately mask the deepest parts of the feature. Compared to an optical measurement of a few seconds for acquisition and automated pass/fail analysis, the replication process takes a significant amount of time: curing normally takes 10 minutes or more, followed by an intensive measurement process that can add up to an hour before results are known. As a consumable item, replication material costs add up quickly; large manufacturing houses report spending hundreds of thousands of dollars per year, ordering replication material.

Matching direct measurements to replica casts

A variety of pits and scratches were replicated. The 4D InSpec was then used to measure both the replica and the feature itself. Feature heights ranged from 0.001" (25µm) deep to 0.007" (178 µm) deep to provide a range of heights over which to evaluate the system. The correlation of the depth measurements is very close. The slope is 0.998 with an R^2 value of 0.9989 and an offset of less than 8 micro-inches (0.2 µm). The maximum deviation of any of the replicated measurements versus the direct measurement was .0001" (2.5µm), which is within the noise floor of the 4D InSpec. Results are shown in Figure 2.

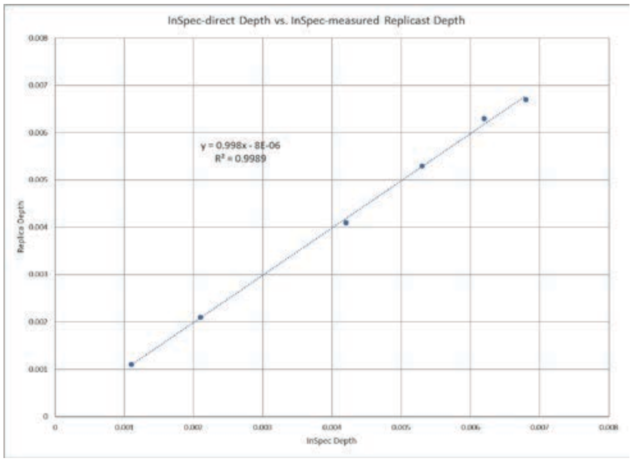

Figure 2: Depth of directly measured features versus replicated surface features using the 3D InSpec analyses

Example 1: Measurement of a 0.001” scratch

An approximately 0.001” (25 µm) deep scratch on a visual reference standard (Figure 3), used for defect assessment, was replicated. The scratch itself was measured directly with the 4D InSpec and the replica’s negative impression was measured as well. Results of the actual surface measurement and measurement of the replication are shown in Figures 4 and 5.

Figure 3: 0.001” scratch on visual comparison standard

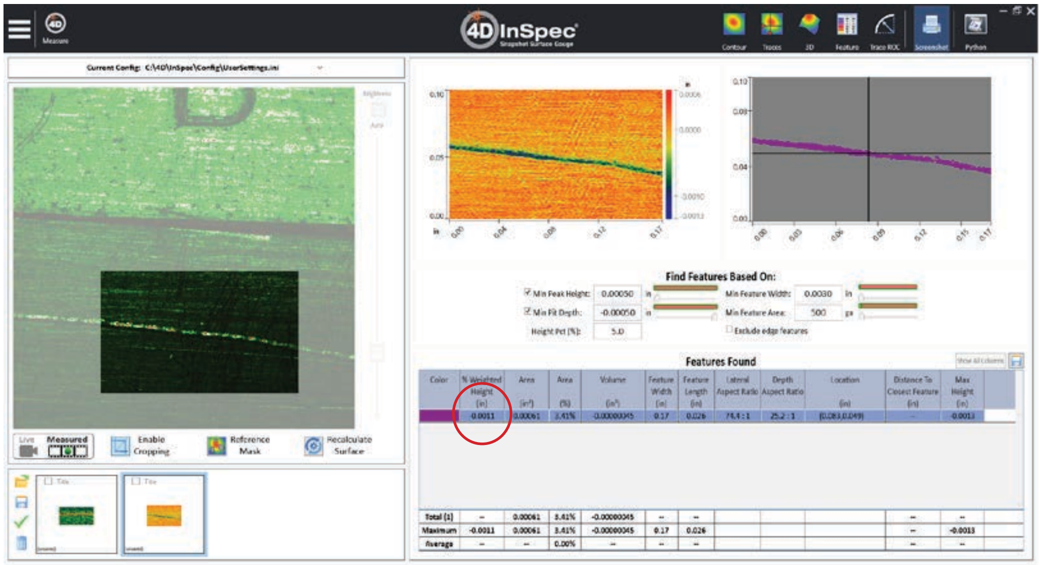

Figure 4: Direct measurement showing bright-field image of scratch (left picture), false-color height map from measurement (center picture) and automatic defect finding and analysis (upper right picture and table below).

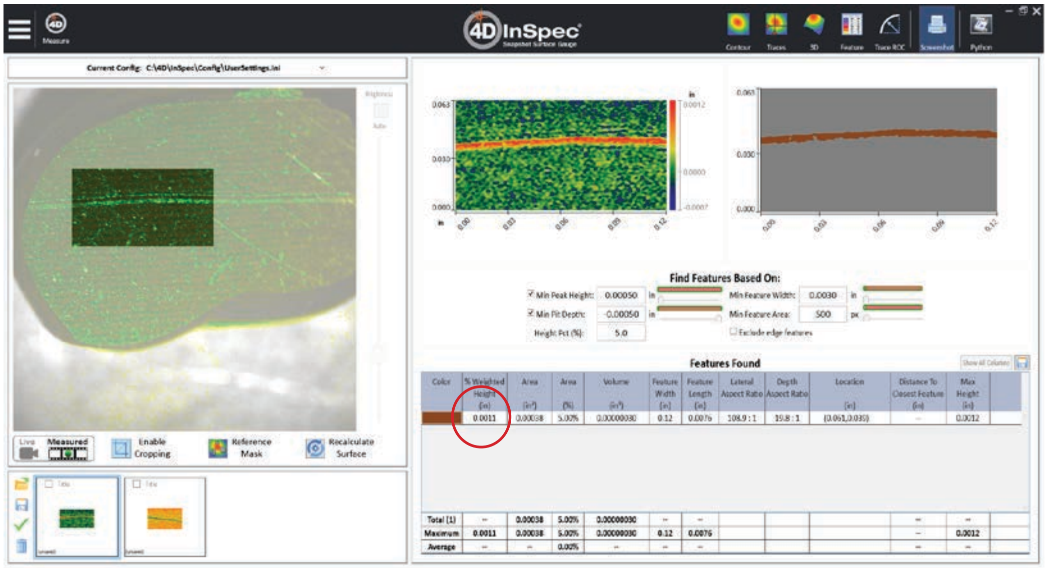

Figure 5: Replicated measurement showing bright-field image of scratch (left picture), false-color height map from measurement (center picture) and automatic defect finding and analysis (upper right picture and table below).

In this example, automatic analysis of the scratch depth and replicated scratch depth match exactly. Thus, for this example, the errors associated with the different materials (and making of the replica) are lower than the precision of the gauge, and are negligible.

Example 2: Pit depth measurements

Four different pits and their replicas (figure 6) were measured with the 4D InSpec. The pits were close enough together to fit within a single field of view of the instrument, which is 0.3" x 0.3" (8 mm x 8 mm). This allows all four pit depths to be calculated simultaneously. Differences between the results from measuring the original aluminum surface and the replica are within the noise floor of the instrument (0.0001", 2.5 μm). Figures 7 and 8 detail the data using the 4D InSpec Feature Analysis tool.

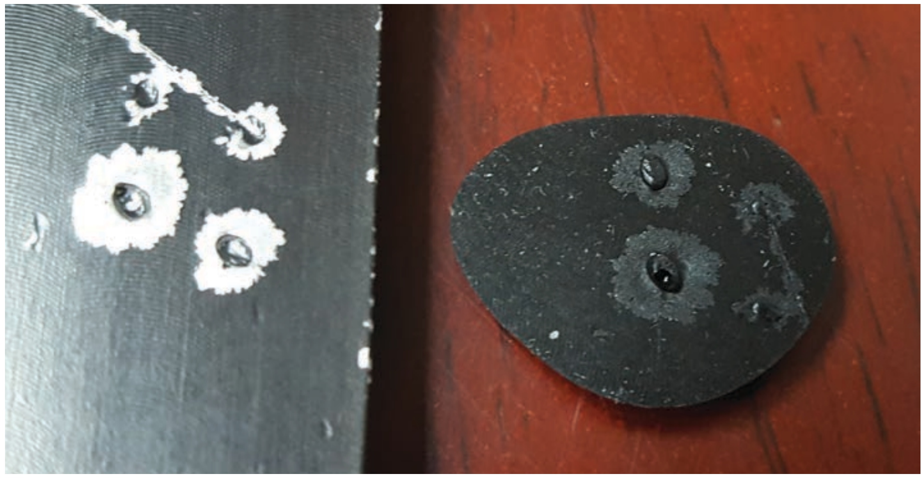

Figure 6: Pitted aluminum sample (left) and its replica (right).

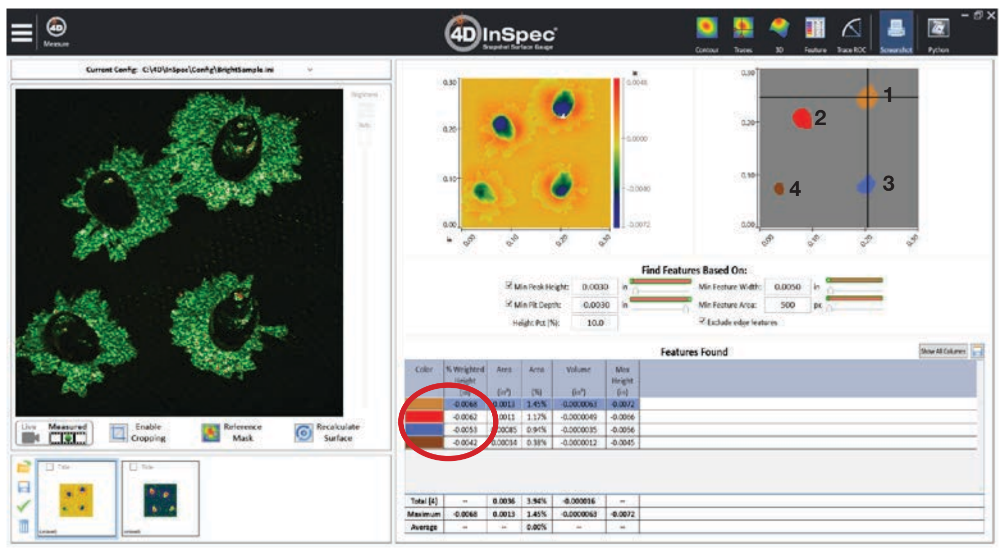

Figure 7: Direct measurement showing bright-field image of pits (left picture), false-color height map from measurement (center picture) and automatic defect finding and analysis (upper right picture and table below).

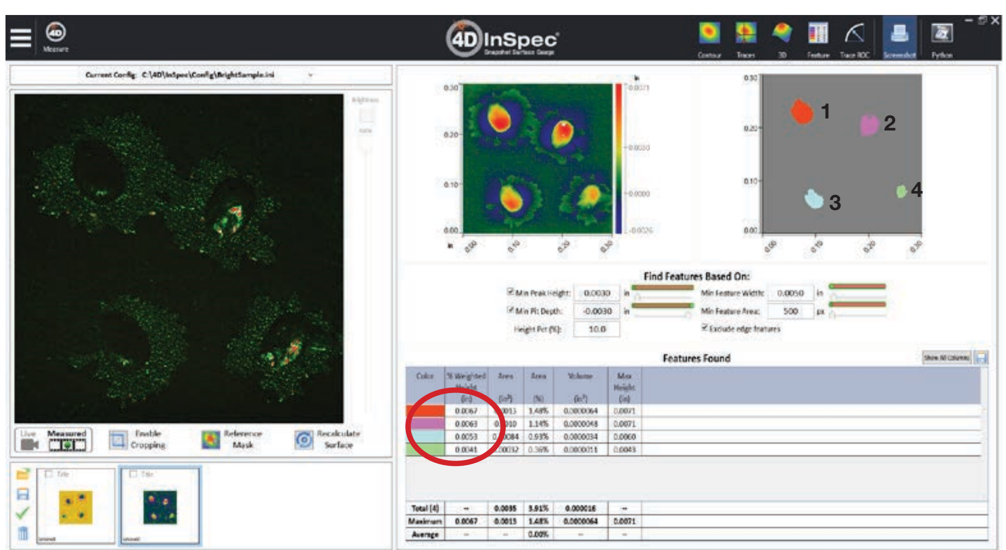

Figure 8: Replica measurement showing bright-field image of pits (left picture), false-color height map from measurement (center picture) and automatic defect finding and analysis (upper right picture and table below).

Limitations of the replication method and 2D analysis of defects

Voids

One major issue with replication of defects is that the replica material does not always penetrate to the lowest part of pits and scratches. One primary cause of this is when the material is too viscous, and thus does not flow all the way to the bottom of the feature. For this reason, many companies that employ replication have a variety of formulations with different viscosities and try to pick the best one for different types of parts and defects. However, it is expensive to maintain multiple materials and also can lead to variability in results if the proper material isn't used. Another cause of an incorrect replica is that sometimes air bubbles become trapped under the material and prevent it from flowing all the way to the bottom. This can occur despite the viscosity of the material as it is highly dependent on the surface properties of the material with the defect.

An example of an improper replica is shown in Figure 9. A pit with a relatively flat bottom, ~0.026" (66µm) deep was directly measured and a replica produced. Figure 10 shows the direct measurement of the pit and Figure 11 shows the measurement of the replica. The replicated surface has a depression in the top where the material did not penetrate all the way to the bottom of the pit. Thus, any measurement of pit depth based upon this replica would be inaccurate.

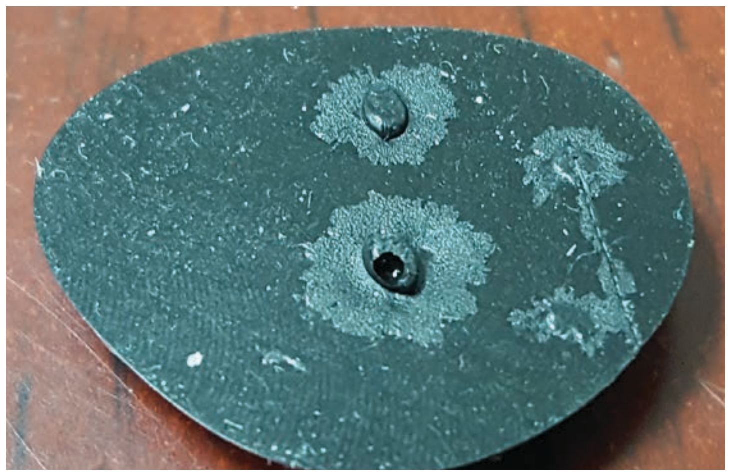

Figure 9: .0026" (66µm) pit in aluminum surface

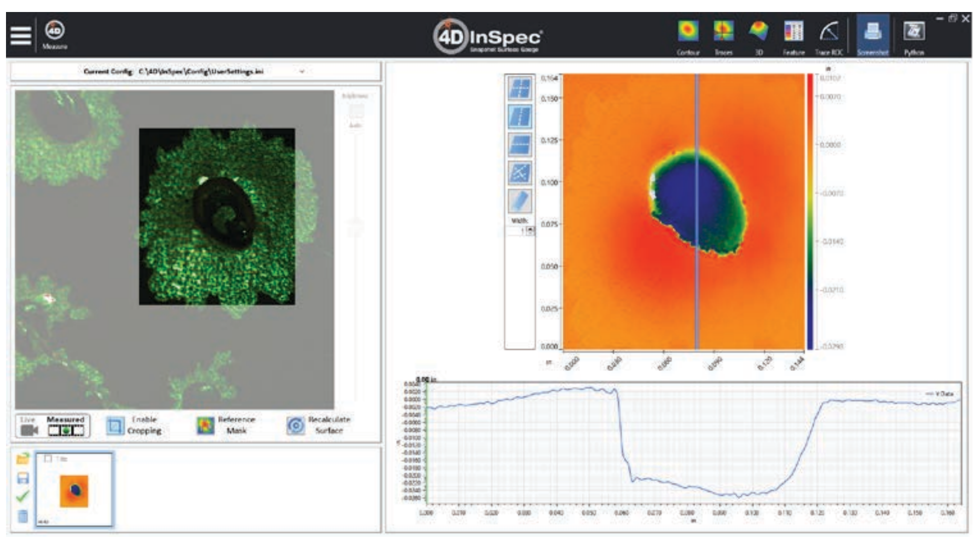

Figure 10: Direct measurement of the pit with 2D cross-section showing a flat bottom.

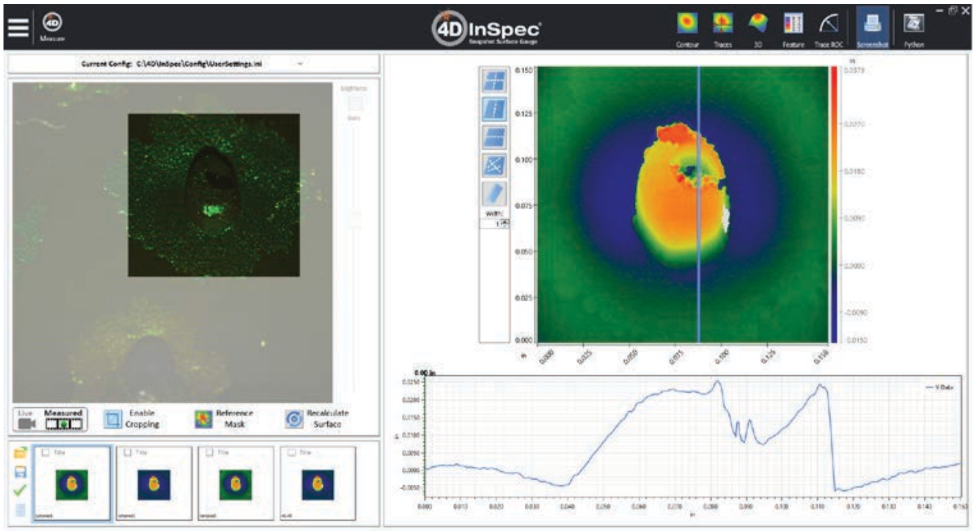

Figure 11: Measurement of the replica with 2D cross-section. The depression in the replica is from the replication material not penetrating all the way down the defect.

The void was confirmed as a replica error and not a feature by several means. First, the 4D InSpec measured the pit before and after the replica was created and did not see a feature to explain the void. The feature was easily accessible to the 4D InSpec and the data are reliable. Second, visual inspection did not show any raised area in the bottom of the pit that could account for the replica shape. Third, a sharp point was run through the pit and no raised feature was felt. Several of the replicas used to create the correlation graph had to be redone due to improper replication of the surface, suggesting that this is not an uncommon occurrence. Since the replication process is quite time consuming—taking about 10 minutes to apply the material and cure it—having to remake replicas can be costly in terms of turnaround time, to say nothing of requiring the inspector to recognize something went wrong, and to redo it in the first place.

2D vs. 3D Results

2D tools typically are not ideal for accurately quantifying the height or depth of a feature. Depending on the specific cross-section examined, and where the reference point is chosen from which one measures the height, different results will be obtained. This is briefly illustrated in the following figure.

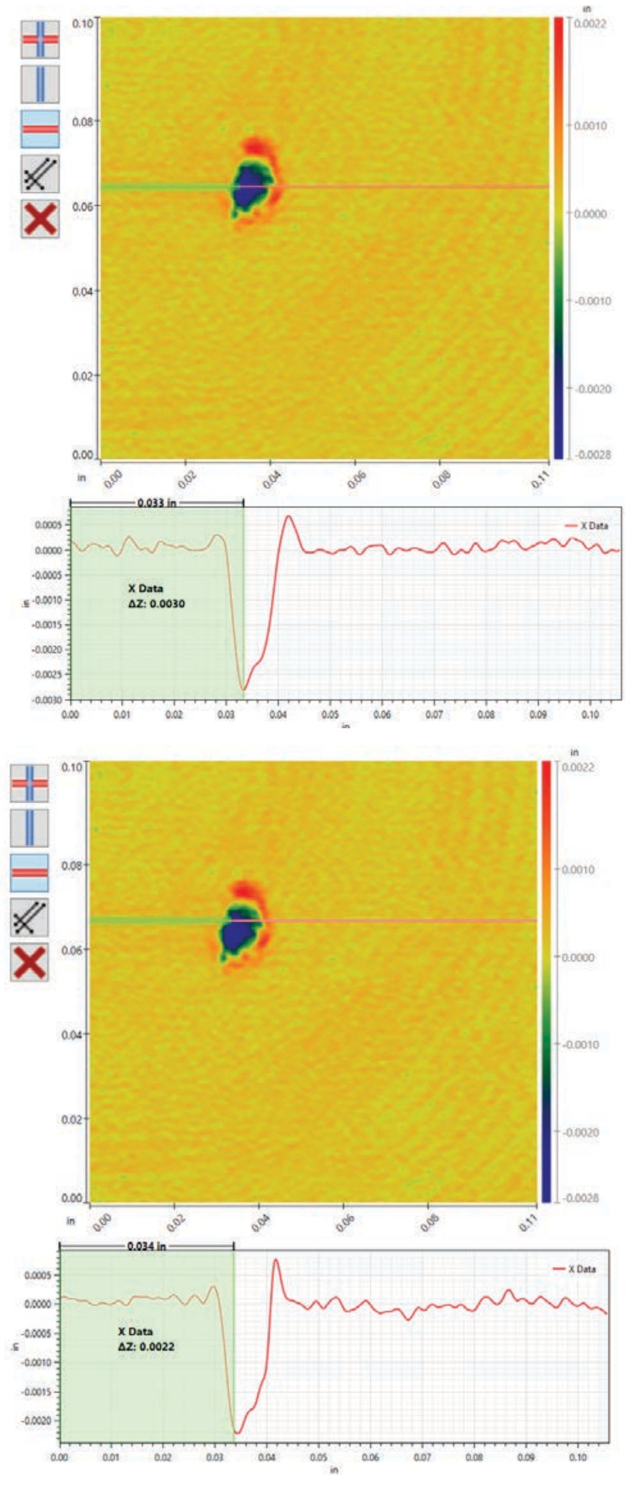

Figure 12: Pit depth measured using 2D cross sections. By slightly offsetting two traces, one gets results that differ by nearly 0.001" (25 µm): the upper result is 0.003" (76 µm) and the lower 0.002"(52 µm).

Such differences are even more pronounced on long features such as scratches. It is nearly impossible to visually judge the deepest part of a scratch, and thus cross-sectioning often leads to highly variable results. With an automated analysis of the entire scratch as captured with the 4D InSpec, the inspector is guaranteed to have an accurate reading of the maximum depth as, the entire surface is considered.

Conclusions

Replication is sometimes necessary when measuring areas which are inaccessible—even to a handheld instrument such as the 4D InSpec. Fortunately, 4D InSpec is equally accurate measuring properly replicated features as it is with direct measurements.

The replication process itself is time consuming, compared to a measurement with a handheld instrument.

Replication can lead to errors in analysis, if the cast does not truly match the defect to be measured.

When replication is used, analysis should always be via examination of the entire 3D defect result rather than using cross-sectioning methods. Cross-sectioning errors can arise depending upon where the 2D cross-section is placed.