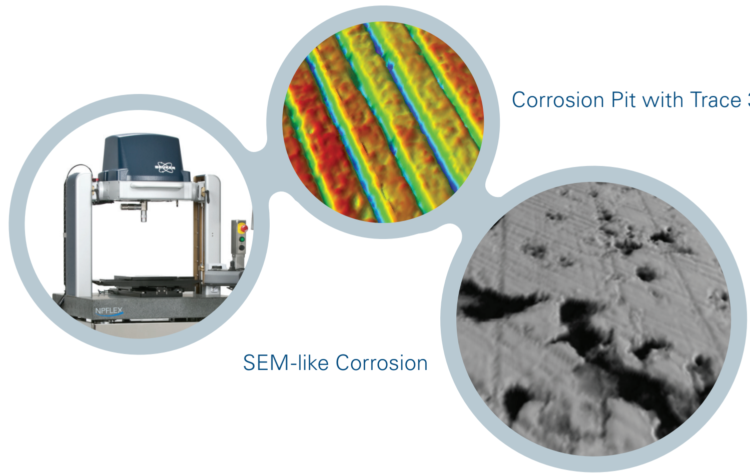

Application Note #556

Corrosion Monitoring with Bruker 3D Optical Microscopes – Fast, Accurate Metrology for Cost Savings in the Refining Industry

Corrosion in the oil transport and refining industry degrades infrastructure and materials at a cost approaching $8 billion annually. Research scientists and engineers interested in oil production materials and additives, as well as how they influence the extent and rates of corrosion, need fast and accurate methods to image and quantify structural damage. High-quality images and accurate metrology enable workers to clearly document and trace changes over time in infrastructure, as well as to enable effective characterization of the influence of additives and other prevention techniques. Bruker's 3D optical microscopes provide excellent large field-of-view images at high resolution, as well as highly accurate vertical scale information for the characterization of damaging corrosion. These imaging and metrology capabilities are exceptional tools for monitoring corrosion in the effort to help control or limit the detrimental effects of this inevitable material and environmental process.

Corrosion Is Inevitable, but Controllable

A key challenge corrosion presents in the oil refining industry is management of local area failures caused by pitting and fracturing in the surfaces. Crude oils under transport do not cause corrosion in the pipelines that deliver them (there are more than 2.5 million miles of pipeline in the United States alone). However, the inevitable presence of trace amounts of water and sediments do cause corrosion, causing leaks or failures over time. Also, heavy crude oil may have a higher acid or sulfur content, which is not problematic in the cool environment of the transportation pipeline, but acid and sulfur can become corrosive in the higher temperatures (200˚C, for example) of the refining environment.

Finding and Fixing Is Not Ideal – How About an Ounce of Prevention?

The pipeline environment is inspected regularly with ultrasonic pulse technologies or with mechanical inspection devices known as "intelligent pigs," which can help detect areas of heavier corrosion, such as that shown in Figure 1.

Figure 1. Internal pipeline corrosion shown. Pits, up to 10mm deep in some cases, can develop.

Although a "find it and fix it" approach can work against corrosion, researchers are continually challenged to develop better materials, additives, and preventive measures to reduce and ultimately control corrosion and its damaging effects.

As shown in Figure 2, the majority of preventive expenditure is on organic coatings to inhibit corrosion. The efficacy of these coatings, and their adherence to surfaces, must be tested on a very small scale using highly accurate measurement instrumentation. Although corrosion in controlled experimentation happens on a very small scale, it can be used to predict functional performance over time for large infrastructures.

Costs of Corrosion Control

Material & Services	Range	Average cost	
	($ x billion)	($ x billion)	(%)
Protective Coatings – Organic – Metalic	 40.2-174.2 1.4	 107.2 1.4	 88.3 1.2
Metals & Alloys	7.7	7.7	6.3
Corrosion Inhibitors	1.1	1.1	0.9
Polymers	1.8	1.8	1.5
Anodic & Cathodic Protection	0.73-1.22	0.98	0.8
Services	1.2	1.2	1.0
Research & Development	0.020	0.02	<0.1
Education & Training	0.01	0.01	<0.1
Total	$54.16-188.65	$121.41	100%

Figure 2. Costs of corrosion preventive measures.

Scanning Electron Microscopy—Accurate but Slow and Limited

One of the methods used for measurement of coatings is scanning electron microscopy (SEM), which is a highly accurate and precise imaging technique. This method is used to measure and test small, localized corrosion pits that are under the effects of material coatings and additives used to reduce or prevent corrosive effects.

Although SEM is a powerful imaging and measurement technique, it requires a somewhat lengthy sample preparation process. This preparation usually includes sectioning the sample and orienting it so that vertical dimensions can be measured along with lateral dimensions, which is important when trying to identify and then quantify the depths and extent of corrosion pitting. Additionally, SEM is generally considered a two dimensional measurement technique—one that can provide information about a cross section of an area of interest or profile information, but not true three dimensional information, which is needed to understand the nature of three dimensional corrosion pitting and defects.

Bruker 3D Optical Microscopes Provide Accurate, Fast Corrosion Metrology

Corrosion can be difficult to quantify. No single measurement can adequately describe the extent to which a surface has corroded. Three dimensional measurement of pitting and other surface degradation, however, provides a sophisticated method to more completely measure, visualize, and quantify corrosion. Optical profiling uses the interference of light to measure surface shape and roughness. This method can resolve surface anomalies from nanometer-scale roughness through millimeter-scale step heights, operating at scales that are typical of

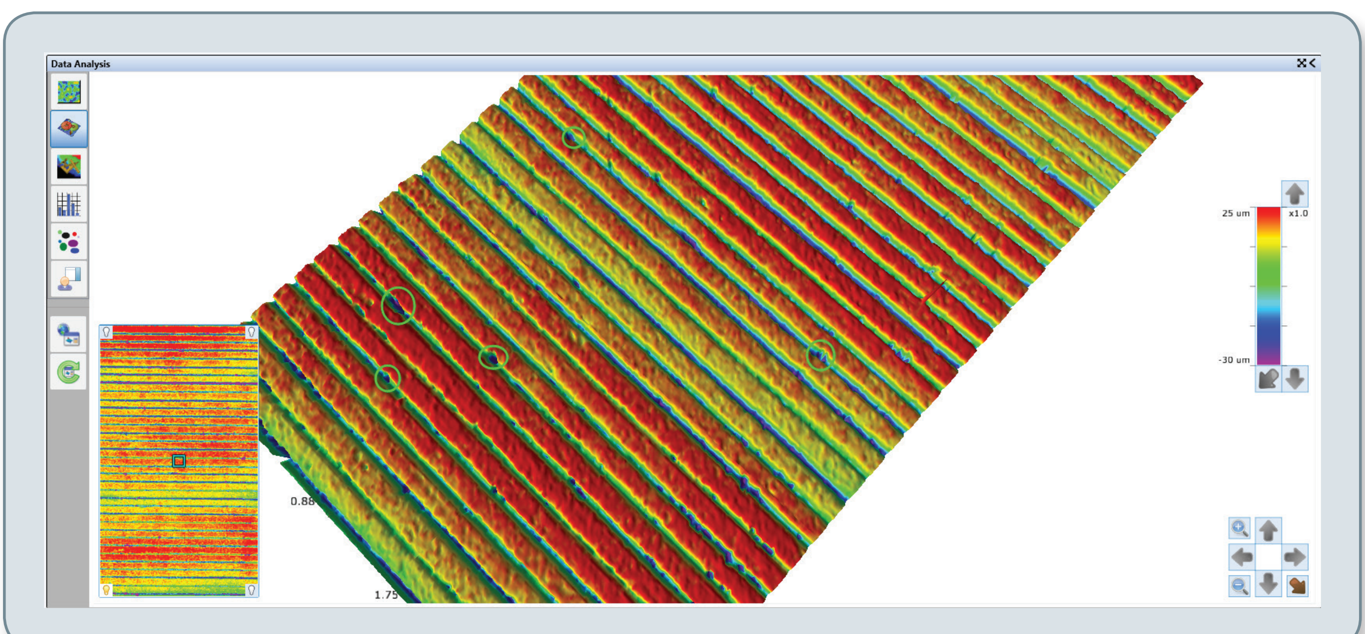

Figure 3. 3D display image of corrosion coupon with representative pits circled in green.

Figure 4. Corrosion coupon samples.

corrosion. With 3D analysis, hundreds of parameters can be calculated to fully describe surface corrosion, including the volume of material lost over time, ratios of peaks to valleys, directionality of corrosion, and so on.

Bruker has developed targeted automation and analysis capabilities for our line of 3D optical microscopes that can mitigate cost and time issues associated with corrosion research and product development within the oil and gas industries. Bruker microscopes can dramatically increase the speed with which engineers and scientists can monitor and prove concepts in their research on both materials and coatings, the two largest portions of corrosion prevention costs.

Figure 5. Bruker's NPFLEX 3D optical microscope. Its large nominal working volume handles small or large sample coupons and multi-sample trays.

Bruker's Vision64® software includes a robust Gaussian filter to flatten images, and its multi-regional analysis pinpoints corrosion pits and quantifies their size and volume.

Corrosion Coupon Measurements

Many pipeline operators use corrosion "coupons" to monitor corrosion. These are usually representative samples of the material from which the pipeline is made. The coupons are usually a strip, disc, rod, or ring, etc., shaped to fit into a testing cell or between pipe joints. They are placed in pipelines in strategic locations and then are periodically removed and tested for corrosion. Corrosion coupons are an inexpensive and simple yet effective tool for providing a quantitative estimate of corrosion rates within a system that is in operation.

The coupons are weighed before and after exposure to determine weight loss, and they generally are examined for pits and cracks, as well. By observing the mils-per-year corrosion rate of an exposed coupon, valuable information can be obtained regarding the material's life expectancy. They also provide a visual indication of the type of corrosion that may be occurring in the system being monitored.

The evaluation of corrosion coupons is a basic and widely used method of corrosion monitoring because they produce some of the most reliable physical corrosion evidence possible. They yield information on average material loss, corrosion rate, extent, distribution of localized corrosion, and the nature of the corrosion. Coupon corrosion results can identify trends that indicate acceptable or unacceptable corrosion protection, gains made by changes to a treatment program, or the need for improvements in protection or inspection programs or processes.

The Bruker NPFLEX™ 3D optical microscope platform (shown in Figure 5) is a 3D metrology instrument that is cost effective and well-suited for corrosion coupon monitoring.

The large working area and XY stage enable the NPFLEX to accommodate large jigs that can hold multiple corrosion coupons for inspection (see Figure 6c). This enables testing of a variety of materials and coatings at the same time under similar conditions.

Smaller optical microscopes provide a challenge for positioning larger samples or imaging internal diameters from an end-on perspective. Bruker's NPFLEX resolves this issue with a large gantry capable of holding larger parts, such as corrosion coupon trays (shown in Figure 6e), or custom multi-coupon jigs, such as those shown in Figures 6c and 6d, to measure multiple coupons with one easy setup.

To speed measurements on small cylindrical coupons, the NPFLEX can be configured with a small roller stage option that allows the mounting of multiple small cylindrical parts at one time (Figure 6d). The roller stage and various multi-coupon holders enable the NPFLEX to acquire data from several coupons in a single measurement run, increasing measurement efficiency and minimizing use of operator time.

An advantage of the NPFLEX is that it also can be used near-line in production. The bridge gantry design is resistant to vibration levels commonly found in near-line industrial environments, and the integrated air table offers further stability for repeatable results in a smaller footprint. The open-gantry bridge design also provides full access from both the front and back for ease of service and support, and the ultra-long working distance objectives enable collection of data from difficult to access areas.

This combination of features enables the NPFLEX to perform multiple, repeatable measurements on multiple samples, even at difficult angles. Metric surface dimensional data is converted easily into standard reports, providing a metric measurement capability that is objective and comparable over time. The system's automatic corrosion pit identification and analysis is of great value during materials and coatings development processes, as well. In the research laboratory, newly developed materials may be measured against current materials in use.

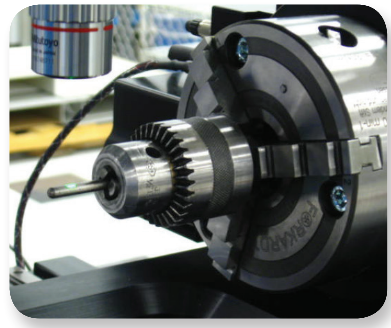

Figure 6a. Measurement of small cylindrical corrosion coupon on an NPFLEX.

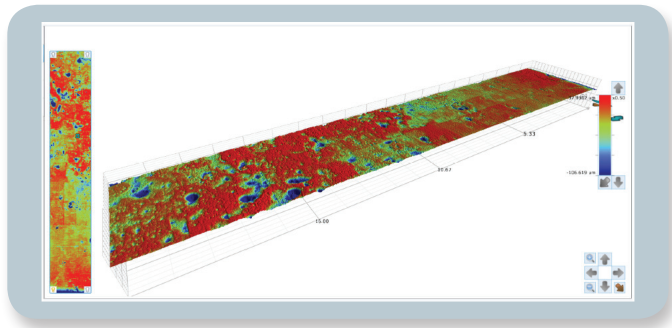

Figure 6b. NPFLEX 3D analysis plot showing corrosion pits. Linear stitched measurement data from a small cylinder coupon was captured with NPFLEX.

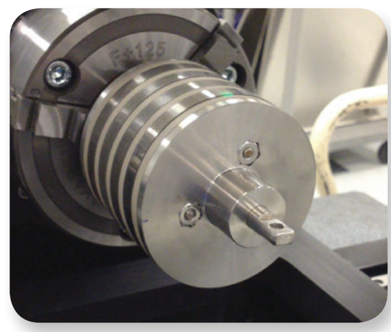

Figure 6c. Metal corrosion coupons mounted on a cylindrical jig on the NPFLEX rotational stage chuck.

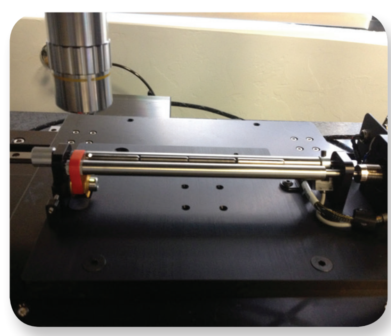

Figure 6d. Multiple small cylindrical corrosion coupons in a multi-coupon jig, ready for measurement on an NPFLEX.

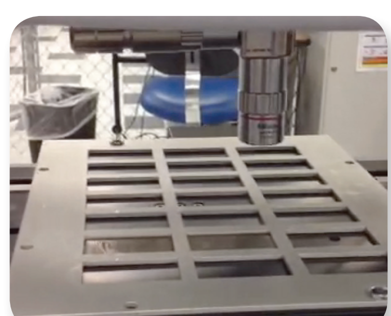

Figure 6e. Automated coupon tray on NPFLEX stage.

Multi-Region Analysis – Automatic Identification and Computation for Analysis

Multiple region analysis (MRA) is a powerful inspection capability offered in Bruker's Vision64 software. This unique software feature enables the automatic detection and analysis of many different interest areas in the acquired image (see Figure 7). For corrosion monitoring and materials and coatings development, this fast, automated technique to identify and track the depths and sizes of corrosion is an important, time saving feature.

The combination of speed and ease with which data can be acquired and then used to understand experiment results represents a significant cost savings for materials science research and the development of improved coatings. Since development of preventive coatings and materials is the area of highest cost in the corrosion prevention process, 3D microscopy from Bruker represents a significant added value for this industry.

Conclusion

Corrosion in the oil and gas industry is a costly and challenging problem, but there are methods in place to address the challenges with an eye toward reducing costs and increasing reliability. Bruker's NPFLEX, with its large sample area, automatic data acquisition, and analysis capabilities is a comprehensive solution for those involved in the development of new corrosion preventive materials and coatings. Bruker's 3D optical microscopes can bring significant metrology and inspection cost savings, both in time and dollars spent, to this important step in the corrosion prevention process.

No	Region	Rv µm	Rv% µm	X Diameter µm	Y Diameter µm
13		-11.27725	-11.27725	22.04821	36.74702
14		-13.36481	-13.36481	36.74702	29.39762
15		-25.18203	-24.32716	95.54226	58.79524
16		-14.82327	-14.82327	14.69881	22.04821
17		-26.79549	-26.79549	22.04821	22.04821
18		-13.06717	-13.06717	44.09643	36.74702
19		-23.65698	-23.65698	36.74702	36.74702
	Avg:	-17.73175	-17.64605	44.87005	35.58659
	Std:	5.52128	5.42963	20.49732	12.67654
	Skewness:	-0.58521	-0.58240	0.86687	0.86001
	Max:	-10.67075	-10.67075	95.54226	66.14464
	Min:	-29.14848	-28.83962	14.69881	22.04821
	Range:	18.47773	18.16887	80.84345	44.09643

Figure 7. MRA analysis results showing computations on corrosion pits and representative sizes and depths.

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