Publications

Title: "Surface Defect Inspection - At The Double"

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"The growing importance of surface detail and surface degradation in engineering equipment is reflected by increasing standards in surface inspection. Polymer replication using new silicone-based materials is a powerful surface inspection technique that can provide detailed information in circumstances where conventional techniques are impractical"

by Victor Rollins

Replication is being employed as a means of inspecting critical engineering surfaces. The technique produces an exact copy of the surface which can be peeled away and examined microscopically in the laboratory. Conventional replicating methods, involving acetate film and tape softened with acetone have been used for many years for microstructural replication, but are often tedious, time consuming, unreliable, and cannot be used over large areas, on rough surfaces or applied to remote locations.

New high-resolution, silicone-based replicating polymers, which have been developed and extensively tested during the past 10 years are now showing the way forward for the qualitative, quantitative and chemical non-destructive evaluation of surface defects. One notable development in this field is a new replication technique known as Microset, which uses liquid polymers to replicate large surface areas (up to a square metre) in remote locations quickly and easily in a single operation.

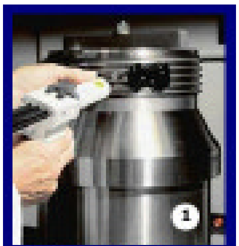
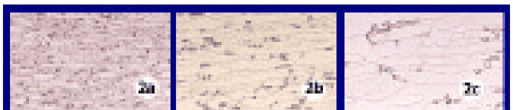


Figure1: Producing a polymer replica using a hand dispensing gun, a twin pack cartridge and a disposable mixing-nozzle.

The materials were initially developed for Rolls Royce plc, which specified the requirements and collaborated in the testing of the efficacy of different formulations for different applications. The objective was to facilitate the identification, assessment and monitoring of surface features at remote locations in critical equipment where previously non-destructive inspection had been thought to be impractical. The technique has proved to be extremely successful, and specialised equipment has been developed for remote surface preparation, remote replication and the examination of large 3-D replicas.

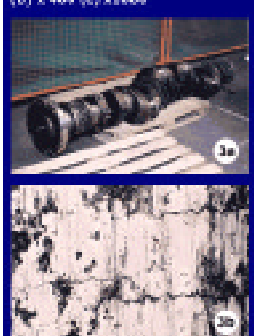
The technique has considerable advantages compared with conventional acetate replication for in-situ metallography applications owing to its simplicity and certainty in achieving quality replicas. In contrast with acetate, replication may be undertaken at largely inaccessible locations remote from the operator. In such circumstances compounds can be pumped along tubes equipped with video cameras and fibre optic viewing systems to sites of suspected corrosion or damage. The flexibility and toughness of these polymers allows the 3-D replication of extreme surface detail within internal engineering features ranging from tube welds and threaded bolt holes to the fine laser drilled cooling holes used in aero-engine components.

Microset polymers are applied ready-mixed from a range of standard twin-pack cartridges using manual or pneumatic dispensers. They are produced in different grades with varying viscosity, curing time and mechanical properties to suit different applications. For example, Thioxotropic grades are used for overhead inspection, while fluid grades are more suitable for internal inspection, horizontal applications or microstructural replication. **Figure 1** shows the 50ml system being used with a Thixotropic grade to replicate the geometry and surface of a thread in an oil-field component. With a chosen curing time typically between 3-60 minutes, a flexible rubber replica is formed, which is then ready for analysis.



Optical micrographs of a Microset 101RF replica of sigma phase formed adjacent to a weld in a duplex stainless steel at (a) x160 (b) x 400 (c) x1000

A range of different techniques can be employed for the examination of Microset replicas. While optical microscopy is appropriate for microstructural evaluation, the assessment of 3-D features is best carried out using macroscopy or scanning electron microscopy.



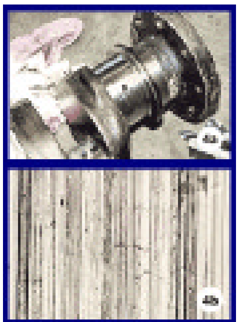
Optical micrograph (3b) of a Microset 101RF replica of heat cracking on the surface of a marine alternator crankshaft journal (3a), magnification x 100

Microset replicas tend to pick up loose deposits present on surfaces and retain them at their original locations, therefore scanning electron microscopy can be used for the chemical analysis of such material during examination to provide important information in failure analysis investigations. **Figure 2** shows a replica of a duplex stainless steel microstructure viewed by conventional metallurgical microscopy.

Currently, hi-tech companies worldwide, particularly in the fields of aerospace, marine engineering and nuclear power, employ Microset polymers in numerous applications such as:

- in-situ metallography
- replication of fracture surfaces
- the verification of internal surface geometry and surface finish
- the indentification of stress raisers exposed by internal machining of critical welded components
- the assessment and monitoring of corrosion, cracking and creep damage at poorly accessiblesurfaces within critical equipment

- the inspection of internal tube welds and threaded bolt holes
- the surface monitoring of critical components such as gears, for the early detection of micro cracking



Optical micrograph (4b) of micro-cracking detected on a crankshaft journal which had suffered heat cracking, been remachined and crack detected using MPI and returned to service (4a), magnification x 100

- the underwater inspection of nuclear components including fuel module geometry
- the undersea inspection of offshore pipeline and ring groove damage.

The materials are designed specifically to be compatible with stainless steels and other engineering alloys and not to compromise future corrosion behaviour should traces of replicas remain after replication. For this reason, constituents containing halides, sulphur compounds and heavy metals are kept at extremely low levels.

One major application for the technique is crack detection, and **Figure 3** shows a replica of thermal cracking detected in an overheated journal of a marine alternator crankshaft. **Figure 4** shows a replica taken from a similarly damaged crankshaft journal that had been re-machined and thought to be free of cracking after testing by magnetic particle cracking detection. The replica clearly shows the presence of residual micro cracking not detected by MPI.

An example of stress corrosion cracking, replicated remotely in an austenitic stainless steel steam tube, is shown at various magnifications in **Figure 5**. In this particular case, the replicating material penetrated into the crack, and part of the fracture surface was replicated and retrieved together with corrosion products removed by the replica. The intergranular nature of the cracking and the presence of concentrations of sulphur compounds in the corrosion products, which was revealed by EDX micro-analysis, provided invaluable information with respect to the cracking process.

It is impractical in most cases to use acetate techniques to replicate fracture surfaces because the detail is usually too coarse and acetate is not strong enough to be pulled from re-entrant detail. Microset polymers do not suffer from these disadvantages as shown in Figure 5. Brittle-fracture surfaces and fatigue striations on aluminium alloy fracture surfaces have also been successfully replicated.

Scanning electron micrographs of a stress corrosion crack in a steam tube, replicated remotely using Microset 101RF material. The material penetrated the crack and replicated the edge of the fracture surface. (The replica was mounted and sputter coated with gold prior to examination)

A major feature of these polymers is their ability to be used for large-scale 3-D replications. One example is the examination of bolt holes for cracking in large austenitic stainless steel casings, which is particularly difficult using conventional methods not only because of the geometry but also because these materials have poor magnetic properties. The use of Microset polymers to examine bolt holes of up to 75mm diameter has now become standard practice.

The technique is not only suitable for the examination of surface defects and fractures - it can be used just as effectively in surface measurement using non-contact laser techniques and interferometry, to determine surface finish and dimensional parameters.

The extreme sensitivity - a resolution better than 0.1 microns - and accuracy together with constant reflectivity properties of Microset replicas, allows them to be used with interferometry for precise surface measurements. For example, tests made on the surface of an optical disc with known groove depths of 50 nanometres, gave Ra values from the original disc and from the replica only 5 nanometres or so either side of the 50 nanometres value, demonstrating the technique's extreme resolution. Practical examples of the combined usage of replication with non-contact measurement equipment include the Harrier Jet inlet compressor blading, in which replicas of surface damage are measured using non-contact laser metrology. Wear to the inside surfaces of marine diesel engine cylinder liners are assessed in a similar way.

Figure 6 relates to the assessment of surface finish on a reconditioned crosshead pin from a large marine engine. The pin was one of eight that had been 'super finished' and installed in the engine with new white-metal bearings. The bearings had overheated and failed within a few hours. 'Super finishing' implies a polished surface with an Ra value of 0.05 - 0.1 microns, but in-situ finish readings indicated that the pin surfaces had Ra values of 0.3 - 0.5 microns. These values were confirmed by Microset replication and laboratory measurement using interferometry.

The applications for this new technique are expanding rapidly because of its ease of use and versatility. It offers a method of non-destructive surface inspection capable of providing greater detail than other methods currently available. The fact that high-resolution replicas can be produced at locations remote from the operator, particularly in hazardous situations has enabled the detailed examination of surface features that previously could only be assessed visually, using video equipment. The ability of Microset polymers to provide a visual microscopic picture of 3-D surfaces and, at the same time, accurate dimensional data, is both remarkable and highly useful as a permanent record for subsequent reference or monitoring purposes.

The accurate measurement of the surface finish of a marine main-engine crosshead pin (6a) by in-situ replication and laboratory assessment by interferometry. (Microset 101RF replica measured uncoated and results presented in '3-D interactive display' mode, figure 6b)