Forensic examination using a nondestructive evaluation method for surface metrology

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Abstract
The objective of this paper is to describe the use of a new technique of optical profilometry in a nondestructive, non-contact fashion for the comparison of two metallic surfaces, one hard and one soft. When brought in contact with one another, the harder material (i.e. the tool) will impress its surface roughness onto the softer. It is understood that the resulting set of impressions left from a tool tip act in a manner similar to a photographic negative, in that it leaves a reverse, or negative impression on the surface of a plate. If properly inverted and reversed, measurements from the softer material should be identical to the harder indenting object with regard to surface texture and roughness. This assumption is inherent in the area of forensics, where bullets, cartridge cases, and toolmarked surfaces from crime scenes are compared to similar marks made under controlled conditions in the forensic laboratory. This paper will examine the methodology used to compare two surfaces for similarities and dissimilarities, and comment on the applicability of this technique to other studies.

Keywords
nondestructive testing, acoustic tomography, optical testing, QNDE, Materials Science and Engineering

Disciplines
Materials Science and Engineering | Structures and Materials

Comments
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FORENSIC EXAMINATION USING A NONDESTRUCTIVE EVALUATION METHOD FOR SURFACE METROLOGY

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ABSTRACT. The objective of this paper is to describe the use of a new technique of optical profilometry in a nondestructive, non-contact fashion for the comparison of two metallic surfaces, one hard and one soft. When brought in contact with one another, the harder material (i.e. the tool) will impress its surface roughness onto the softer. It is understood that the resulting set of impressions left from a tool tip act in a manner similar to a photographic negative, in that it leaves a reverse, or negative impression on the surface of a plate. If properly inverted and reversed, measurements from the softer material should be identical to the harder indenting object with regard to surface texture and roughness. This assumption is inherent in the area of forensics, where bullets, cartridge cases, and toolmarked surfaces from crime scenes are compared to similar marks made under controlled conditions in the forensic laboratory. This paper will examine the methodology used to compare two surfaces for similarities and dissimilarities, and comment on the applicability of this technique to other studies.

Keywords: Forensics, Optical, Profilometry
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BACKGROUND

Visual inspection of materials and parts has been an important part of nondestructive evaluation from the beginning of the science. Initial methodologies of visual inspection were dependent upon a person’s visual acuity for accuracy of any measurements. Although this method could be performed rather quickly and relatively inexpensively, the reliability and repeatability was not as certain as was needed in more scientific work.

Because of the uncertainty of visual inspection, there has been an increased demand for a more quantitative and reliable method of analysis for surface features due to wear and material removal. Over time, there have been several methods developed which increased
the potential for a higher accuracy of surface measurements, such as interferometers, laser profilometers and stylus profilometers. It has not been until the more recent development of optical profilometers that the ability to measure surface features on increased slopes at angles greater than 45 degrees with any repeatable accuracy has been possible. Such a capability has the potential to greatly expand the use of optical profilometers in many areas of nondestructive evaluation.

**Experimental Approach**

In this experiment, a series of marks were made on lead plates using standard flat screwdriver tips. These tips were produced in succession and obtained directly from a manufacturer of screwdrivers. This was done in order to analyze the differences between tips that should be as nearly exactly the same as possible. The plates were made from standard lead acquired from a materials supplier. Once the tips and plates were acquired, they were placed into a device constructed to hold a modular screwdriver at three distinct angles (30, 60 and 85 degrees) against the plate of lead. When the screwdriver was securely held in the device, the tip of the screwdriver was dragged across the surface of the lead plate with a moderate pressure applied to the holding device, as seen in the Figure 1 above.

The result of this motion created a mirrored impression of the tip as the screwdriver was pressed into the softer lead plate (see Fig 2). The impression procedure was completed for both sides of the flat tip (labeled side A or B) and onto four separate sections of lead plate at all three angles to determine repeatability of the process.

Once all tip and plate impressions were produced, the analysis process could proceed. In order to analyze the edge of the flat tip, a corresponding device similar to the screwdriver bracket was machined to hold the tip at the proper angle for scanning with an optical profilometer. The specific device used was an Alicona InfiniteFocus optical 3D measuring device using a 2 megapixel camera with a motorized stage in the x, y and z directions.

When the setup is completed, a scan of the tip contact area is conducted. The theory behind performing the scan is that the area of the tip that came in contact with the plate is directly perpendicular to the beam of light shown through the objective lens of the microscope, and will reflect the greatest amount of light.
This factor is important in the next section where we discuss the analysis of the scan, but is imperative in the experimental setup and approach to ensure the proper data is collected. The length of the scan will depend on the magnification of the objective lens used.

For this experiment, the magnification was set at 10X, which resulted in a 9 image scan of approximately 7 millimeters in length. There are several different magnification settings available, but it was felt that 10X magnification would be sufficient for image analysis for both the tip and the plate.

Scans of the plate were obtained in a similar fashion to the tip with regards to the exposure and contrast settings. Since the plate is a flat object, there is no reflective area to concentrate on in the setup, so all that is primarily needed is to have an image of good quality and to ensure the scan is of similar length to that of the tip.

Results and Data Analysis

Analysis involves comparing the optical scans of both the tip and the plate corresponding to a particular angle. Each resulting scan produces a two dimensional graph, representing the length of the scan in the x direction, and the height (or depth) of the surface roughness in the z direction (see Fig. 3). When two corresponding scans have been created, they are matched together to determine overall similarities between peaks and valleys. In order to match the individual scans from the tips and plates, one of the scans will need to be inverted and reversed in order. This step is necessary to have the proper sides match up with one another. If this is not done, as an example, the right hand side of the tip would be compared to the impressions created by the left side of the tip. And, since the plate acts as a negative impression of the tip, the z values need to be inverted so a peak on the tip scan will correspondingly be represented by a peak on the plate scan. After one of the two scans has had the order inverted and reversed, scans may appear to be nearly identical, as in Fig. 4 below, but quantitative analysis is required to confirm the accuracy of the match.
To derive quantitative data, a computer-based search/match algorithm created by Dr. Max Morris at Iowa State University [1] that delivers a numerical number describing the quality of comparison was employed. The algorithm mimics a visual comparison in that it compares two data sets, looking for the regions that show the best agreement, or “match”. After finding the region of greatest similarity, the algorithm provides a mathematical measure of the quality of that matched region when compared to background values [2]. If a proposed match between two specimens is real, numbers of comparisons generated beyond the region of the proposed match are also expected to have high mathematical values. This idea is known as the verification step, and it is illustrated in Fig 5.

FIGURE 3. A two dimensional profile of an area of examination. The red line in the image represents the area where the profile was taken, and the graph below shows the profile in the Z direction from the scan.

FIGURE 4. Line scans of a tip and a plate combined one on top of the other to illustrate the closeness of the comparison on the match.
If the proposed match is just coincidental, there is a low probability that a rigid translation will also match. In effect, the proposed match will break down outside the initial region. For validation, the correlation of the verification step is compared to randomly chosen test segments. This essentially determines a reference background and calibrates the system so a numerical measure of the validity of a match can be determined. Figure 6 shows the randomly selected comparison windows taken during the validation step for a proposed match shown in red.

FIGURE 5. Verification of proposed match of tip and plate.

FIGURE 6. Validation of proposed match of tip and plate. (the unit index refers to the position along the scanned surface).
TABLE I. Statistical comparison of Match to Non-Match.

<table>
<thead>
<tr>
<th>Correlation Window, Validation Window, Number Pairs</th>
<th>Tool Side B Plate Side B (Match) T Statistic</th>
<th>Tool Side A Plate Side B (Non Match) T Statistic</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>150,75,90</td>
<td>8.31389</td>
<td>-2.60347</td>
<td>10.91736</td>
</tr>
<tr>
<td>500,250,90</td>
<td>11.172</td>
<td>1.23879</td>
<td>9.93321</td>
</tr>
<tr>
<td>600,300,90</td>
<td>11.03465</td>
<td>4.47916</td>
<td>6.55549</td>
</tr>
<tr>
<td>750,375,90</td>
<td>11.37513</td>
<td>4.24278</td>
<td>7.13235</td>
</tr>
<tr>
<td>800,400,90</td>
<td>11.58111</td>
<td>3.04119</td>
<td>8.52992</td>
</tr>
<tr>
<td>1000,500,90</td>
<td>11.40088</td>
<td>4.09402</td>
<td>7.30686</td>
</tr>
</tbody>
</table>

The correlations from the verification step and the validation step are compared to one another in the regions of the matched areas. If a match between a tip and a plate exists, the correlations of the verification step should tend to be larger than the correlation from the validation step. This would not be true for the case for non-matching areas.

Table I shows one the results obtained when a lead plate obtained by marking with side B of a specific screwdriver is compared to the measured results obtained from the tooltip for side A versus side B. The values shown in Table I present T statistic results, which is what is used to compare the data sets in the algorithm developed by Morris et al. A low or negative number indicates a non-match or a very low probability of a match. A high number indicates a high probability of a match between tip and plate scans. The second column representing tool side B and Plate side B represent a good match with high T values, whereas the third column representing Tool side A and Plate side B represent low T values and a non-match condition.

CONCLUSIONS

In developing a new statistical system of comparing tool and plate marks in forensic sciences, there are several conditions that must be recognized and met for proper assessment to occur. Foremost is that the angle which the tip is held at the plate to replicate the mark is important for statistical comparison to occur. It has been found that a tip held at a shallow angle will result in a mark showing very little similarity to a mark made at a high angle, which will result in a non-match. Tips are unique in surface profile, not only from tip to tip, but from side to side as well. Side A of a tip is different in profile from Side B. Although initial efforts have produced encouraging results, further work is needed in both the method of scanning the tip or plate, and the algorithm used for determination of a match versus a non-match. In time, however, this nondestructive method will be an important tool in providing a quantitative determination in crime scene investigation.
REFERENCES
