EXAMINATION AND POLISHING OF SURFACE SCRATCHES ON HANDHELD DEVICES

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Resume
Pollution is a current environmental problem. Personal used mobile phones and devices with LCD displays are often thrown away only the optical matter. The renewal of these device surfaces is at the focus of common interest. Our examination was a well-defined micro-scratch test using a special microhardness and scratch tester equipment (MCT). This equipment provides four different means of analyzing the scratch: acoustic emission detection, tangential force measurement, scratch depth measurement, optical observation through a digital microscope. The scratches were made with normal force from 0.5 to 15 N, the same length (20 mm) with the same diamond indenter. The scratches were analyzed with contact and non-contact methods, laser surface topographical analysis, optical microscopic examination, and surface roughness testing. On the LCD display we created specified scratches with the MCT scratch tester and after these scratches had to be repaired by polishing. Three different polishing speeds and loads were used. The measured wear rates show that higher polishing loads result increased wear rates but this trend does not true for the polishing speed.


1. Introduction
Nowadays pollution is one of the highest environmental problem. The handheld devices which are used in everyday life are often thrown away because of the scratches on the surfaces and other optical defects of the surfaces. There is at the heart of common interest to renew these device surfaces. A lot of personal handheld device become unusable and rubbish because of the scratches on the screen. Polishing could be a possible way of repairing scratched surfaces of handheld devices. With our examination we want to investigate the properties of the scratches like scratch depths and which method is the best choice for the examination of scratched surface and compare scratches which created by unknown loads with scratches which made by definite loads. After scratches were made we measured how the scratched surfaces can be repaired with polishing.

2. Materials and methods
Three different parts of handheld devices were analyzed, LCD panel, phone display, and phone cover (Fig. 4.). There are scratched samples, when the scratches created by unknown loads. And there is a part of the measurements when the analyzed scratches made by predefined loads.

2.1 Laser surface profilometer
The surface topography was mapped using an optical sensor within a Rodenstock RM600 surface-measuring instrument. The optical sensor maps the topography of the surface using a laser beam, which is focused on the surface (Fig. 1. a, b). The sample is moved by a CNC table under the optical sensor, enabling automatic scan above the pre-assigned areas. After the scan of the measured area the 3D topography can be sectioned along any line.
and with this sectional profile the surface roughness characteristics and distance of various points of the profile can be calculated.

2.2 Surface roughness analyzer

The Mitutoyo Surftest 301 can measure a 2D profile of the measured surface using piezo electric principle. The device pull a diamond probe-tip across the surface to be measured, and record the vertical displacement of the probe-tip with the function of the horizontal displacement (Fig. 1. c). From the detected profile points the device calculates the characteristics of the surface roughness (Ra, Rz, Rmax).

2.3 CSM Micro Combi Tester

The CSM Micro Combi Tester (MCT) is a special microhardness and scratch test equipment which is widely used for scratch examination [1, 2]. The scratches with predefined load parameters were made by CSM MCT machine. The MCT measures the Ft shear force which is parallel to the displacement, the acoustic emission and the tip penetration depth into the sample. The indenter is lowered onto the sample surface. After reaching a low contact load (0.1 N) defined by the user, the table moves with a constant speed and scans the surface. After the scan, the machine makes a scratch with a load defined by the user. After this step the machine makes another scan from the surface with a low contact load (0.1 N). The residual depth is the difference between the scan before and after the scratch production. The residual depth characterizes the scratch. The scratches were made by a Rockwell indenter with tip radius of 0.05 mm. An example of the measurement was shown in Fig. 2.
2.4 Buehler Beta grinder-polisher machine

The polishing operation was performed on a Buehler Beta grinding and polishing machine (Fig. 3.). The speed of the polishing machine can be controlled, and with the Buehler Vector LC Power Head, we can set different loads to push the sample to the polishing cloth. Polishing operations were performed with 3µm diamond polishing liquid.

The scratches length (up to 80mm) and depth (up to 70 µm) are different. The scratches were shot with a camera with macro objective, but the photographs were not enough to analyze the scratches. Scratches which made by unknown force were analyzed by contact and non-contact surface topography measurements.

Fig. 5. shows the measured scratch depths created by unknown loads. The smallest scratch of the LCD panel was not detectable with RM600 device. The scratches of the phone display were not detectable with the contact and non-contact method. The reason is that the depth of the scratches are very small, barely noticeable, and the laser beam is not, or only very weakly reflected from the glass surface, which makes laser measurement impossible. The results show, that measurements with the stylus tip almost in all cases show higher scratch depths. On the edge of the scratch there is protruding material because of the plastic deformation, and the maximum vertical distance between the profile points are always higher than the distance between the bottom of the scratch and the original surface plane. If the surface material allows, it is practical to measure the scratches with the RM600 surface-measuring instrument.

3. Results and discussions

3.1 Scratches with unknown load of creation

The scratches, when the force of creation was not defined, are shown in Fig. 4. The measured points of the samples are marked. All of the scratches are visible to the unaided eye.
3.2 Scratches with definite load of creation

In case of the LCD panel and the phone display the smallest scratch, created by the smallest 0.5 N load, cannot be detectable with the RM600 and the Mitutoyo contact surface roughness tester. When the loads were higher the scratches were well definable. By optical microscope and surface topography measurements it was stated that plastic deformation dominates during scratches of LCD panel and phone cover. The missing material from scratch tracks made peaks at the edge of scratch valley. In case of phone display, which is a rigid glass, the plastic deformation was not typical during scratch tests. The missing material from the scratch tracks was pitting out, and could be removed from the surface as a glass powder after scratching (Fig. 6.).

The diagrams in Fig. 7. shows the measured scratch depths versus the load. Scratch depths were measured with MCT, RM600 and Mitutoyo Surftest 301. To get the average scratch depth of a scratch, measurements were performed in 3 different points of the sample. The diagrams show the average scratch depths and the deviations in each measuring method. The results show that higher loads result deeper scratches. In case of LCD panel and phone cover the scratch depths increases monotonically. If phone display was examined between 5-8 N loads the scratch depths were not change and at 10 N load increased significantly. This phenomenon can be explained by the rigidity of glass. When the load was 15 N the scratch depths became deeper on the glass surface. In case of LCD panel and phone cover the deviation of the results are low the measurements are well repeatable.

In case of scratches created by the highest load the Mitutoyo contact surface roughness tester measured the largest scratch depths. This is because the deepest scratch tracks create the highest protrusion, burr and this method adds this height to the scratch depth. An exception to this is the phone display because of the pitting the scratch depth are not even. In some points the scratch is deeper than the average depth.
3.3 Polishing of surface scratches

Before the polishing process we measured the scratch depth with Mitutoyo Surftest 301 surface roughness analyzer. Then the samples were placed in the polishing machine and the load settings were adjusted. The scratches of the samples were perpendicular to velocity vector of the polishing cloth. We selected 1 minute intervals for the cycle of polishing and scratch depth measurement. The scratch depths were measured in 5 points and using the average value for further evaluation. The evaluation was performed only for the two deeper scratches because the results of the smallest scratches could not be evaluated properly.

The predefined loads during the polishing were $N_1 = 10 \text{ N}$; $N_2 = 30 \text{ N}$; $N_3 = 50 \text{ N}$. The samples were polished in different positions so the distance between the sample position and the center of the rotating polishing cloth resulted different polishing speeds. The distance between the center of rotation and the samples were $d_1 = 30 \text{ mm}$; $d_2 = 80 \text{ mm}$; $d_3 = 120 \text{ mm}$. The revolution was 200 l/min. The polishing speeds were $v_1 = 0.6283 \text{ m/s}$; $v_2 = 1.6755 \text{ m/s}$; $v_3 = 2.5133 \text{ m/s}$.

For each polishing setting a steady-state wear rate can be easily identified. A straight line can be fitted to the measuring points and the slope of the line represents the wear rate.

The measured wear rates on LCD panel samples were collected in Table 1. It can be seen from the table that lower wear rates can be measured in case of smaller scratches. Clearly visible that the increasing loads increase wear rates too, but on the other hand polishing speeds changes the wear rates differently.

The maximum wear rates were measured at $v_2$ speed. Of course, this does not mean that this speed gives the expected optimum. But the speed which generates the maximum wear rate could be found with a proper resolution experiment around $v_2$ speed.


4. Conclusion

According to the results we can say that the results of MCT is acceptable the best, because the instrument can calculate the depth of the scratch from the scratch tip vertical displacement during the scratch track scanning. If we have to define the depth of an existing scratch the RM600 is recommended because it measures with non-contact method and does not cause other deformations during the measurement process. If the sample surface cannot be measured with laser topography the contact surface roughness measurement could be the solution.

The scratch polishing results in case of LCD panel show that increasing polishing load increase the wear rate. On the other hand the maximum of wear rate is not at the highest polishing speed. The optimal polishing speed is around $v_2$ speed.

Acknowledgements

This research has been supported by the grants of the Highly Industrialized Region in Western Hungary with limited R&D capacity: “Strengthening of the regional research competencies related to future oriented manufacturing technologies and products of strategic industries by a research and development program carried out in comprehensive collaboration”, under grant No. VKSZ_12-1-2013-0038.

References


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Table 1

Wear rates on LCD panel samples