Surface Roughness, Appearance and Identification of AGFA-Gevaert Photograph Samples

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W. (Bill) Wei and S. Stigter

The age of digital imaging is rapidly pushing traditional photographic methods into the background. Furthermore, the replacement of discolored analogue photographic prints has become museum display policy, as it is seen as a solution in conservation, and is sometimes promoted by artists. There is therefore an urgent need for methods to characterize photographic materials while they are still available and/or in relatively good condition. Surface properties are some of the most important because they determine the appearance and perception of photographs as works of art. These properties are also valuable for identification and authentication purposes. In particular, the micro-roughness of the surface of a photograph determines the glossiness, but also affects the perception of color. Moreover, a surface's physical character situates the print in time.

A study is being conducted by the Cultural Heritage Agency of the Netherlands (RCE) and the University of Amsterdam (UvA) on the relationship between the surface properties of photographic papers, micro-roughness and gloss, and their appearance. The surface micro-roughness and gloss of photographic paper samples from an Agfa-Gevaert photographic sample book (1972 or 1973) was measured using standard industrial equipment, a confocal white light profilometer, and a gloss meter respectively. The results were related to the perception of a number of conservators, other museum professionals and students who were asked to judge the appearance of the samples in terms of glossiness.

The results of this research thus far have shown that the surface of photographic papers can be well-characterized quantitatively using confocal white light profilometry. However, when identifying photographic materials or making judgments about their condition, it is important that one considers both the "objective" values of surface properties such as roughness in relation to time and possibilities of the photographic industry, and the "subjective" interpretation of the conservator and observer.

1. INTRODUCTION

Decisions concerning the conservation and restoration of objects of art and cultural heritage are based on a number of factors which all have their roots in the principles of modern conservation ethics. These factors include (in alphabetical order) aesthetics, appearance, artist's intent, authenticity, context, history, originality, significance and value, as well as the background of the viewer. How these aspects are brought into the decision making process, and eventually any kind of treatment, determines how viewers "interpret" and "perceive" what they "see".

What a viewer sees depends, however, on technical parameters such as color (reflectance spectra), texture (macro- and micro-roughness) and gloss. This is especially important when making decisions about the conservation strategy for photographic works of art or mixed-media objects containing analogue photographs. As with any other type of object, one needs to be able to identify the types of materials one is dealing with before making a treatment decision. In the case of analogue photographs, one would like to be able to identify the photographic process and paper without needing to take a sample. Furthermore, in some cases an option is to actually replace the photographic part of the work. One must then not only identify the technical characteristics of the original photographic paper, but must also consider the appearance of the work as a whole if the photograph is replaced with a new reproduction, even using the same type of paper.

An example of such a case was the replacement of discolored and aged chromogenic photographic paper of *The wider the flatter* (1972), a work by the Dutch artist, Ger van Elk (1941-2014), in the collection of the Kröller-Müller Museum, Otterlo, The Netherlands, see figure 1a. For the reinstallation, chromogenic photographic paper had to be selected with a similar surface structure, figure 1b, to produce the desired sheen (degree of matteness/gloss) [1]. At the time, this had to be performed based on the visual judgment of the conservator, photographer and the artist.

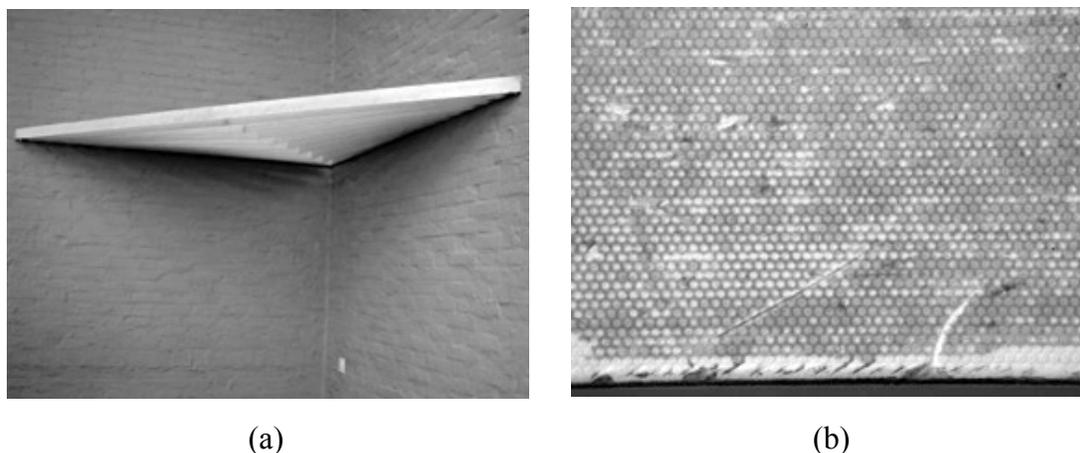(a)   (b)

Fig. 1 - Ger van Elk, *The wider the flatter* (1972), chromogenic prints on aluminum, 6 x 270 x
          134 cm. Collection Kröller-Müller Museum (Images: S. Stigter / UvA)
          a - Work as installed in the Kröller-Müller Museum, Otterlo, The Netherlands
          b - Detail of abraded chromogenic RC-print showing silk screen surface structure

There has been much work conducted on the identification of photographic papers by a number of groups using techniques based on edge reflection analysis and the technique of polynomial texture mapping developed by Hewlett Packard, see for example [2-5]. Initial studies have also been conducted to determine how the human observer sees and perceives properties such as gloss, and how this relates to the technical measurements and calculations [5-6].

The Cultural Heritage Agency of the Netherlands (RCE) has been using standard industrial non-contact micro-roughness measurement techniques to directly measure the surface texture of objects [7-10]. This technique has been shown to be useful for the identification and

protection of objects against illegal trafficking [7-8], and for studying the effect of treatments *in situ* on surface texture and appearance [9-10]. The RCE and the University of Amsterdam Department of Conservation and Restoration are now studying the use of these techniques along with gloss measurements to assist conservators in identifying photographic papers and processes, and if necessary, selecting materials for conservation treatments. The results of initial testing of papers in an Agfa photographic paper sample book are presented here.

2. EXPERIMENTAL PROCEDURE

This study was conducted on 25 professional photographic papers presented in an AGFA-Gevaert sample book from around 1972-1973, see figure 2. Roughness and gloss measurements were conducted on each of the samples in the book. Simple perception tests were then carried out to determine how observers perceived the gloss of the samples.

Fig. 2 - Front and back of the AGFA-Gevaert sample book used in the current study, from around 1972-1973 (Image: W. Wei / RCE).

2.1 ROUGHNESS MEASUREMENTS

The roughness measurements were conducted using a μSurf™ confocal white light profilometer manufactured by NanoFocus AG, Oberhausen, Germany. The principles of this roughness measurement technique have been described in detail elsewhere [11-13] and are only briefly summarized here. A confocal white light profilometer is, in principle, an optical micro-scope, which has been adapted for the application. The reader probably has had the experience that it is not possible to focus on all areas of a rough surface at once under the microscope. One therefore moves the objective lens up and down to focus on specific regions of interest. This up and down movement is, in fact, a height measurement. By using special optics and micro-mechanical motion controllers, the microscope can focus stepwise "through" the surface of the specimen, and thereby create a topographic map of the surface based on real height data..

(a)   (b)
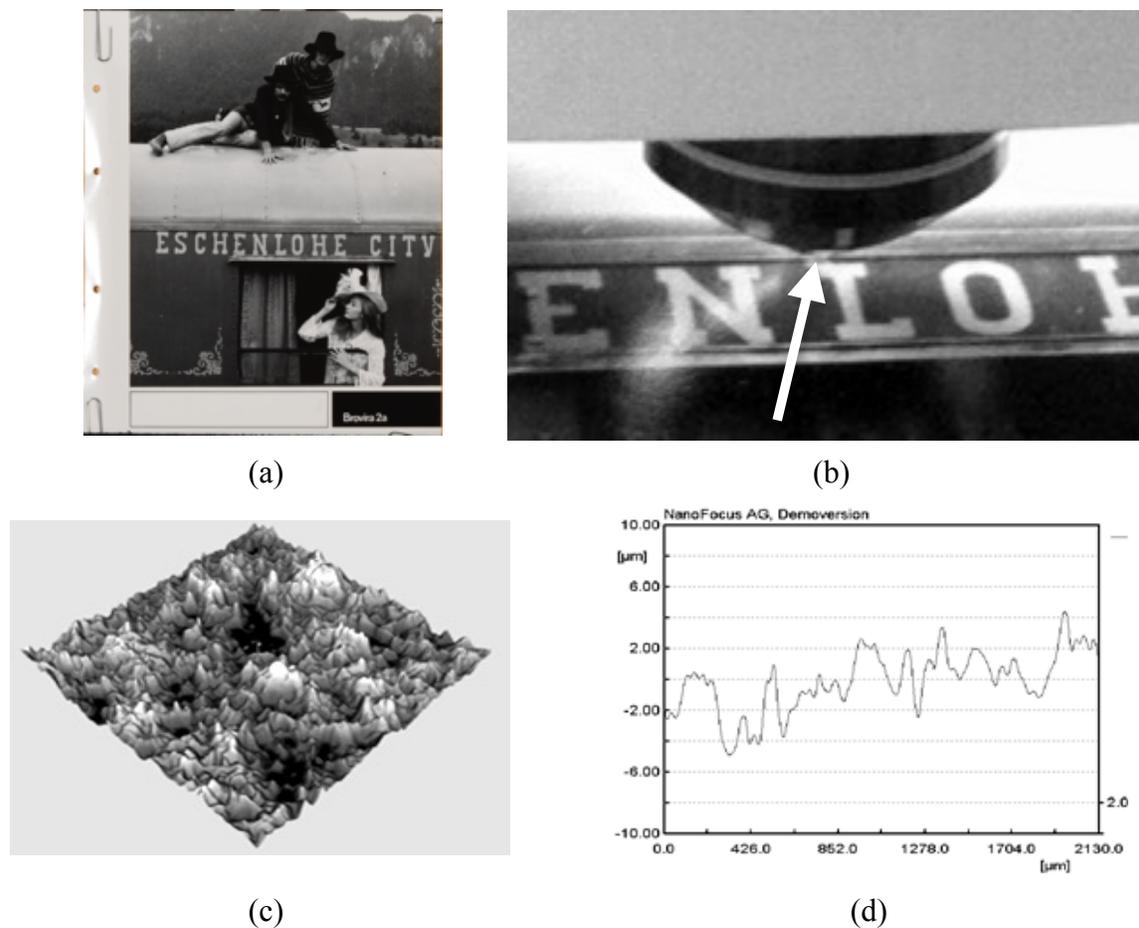

(c)   (d)

Fig. 3 - Typical roughness measurement using a confocal white light profilometer (Images: W. Wei / RCE)

    a - AGFA-Gevaert photograph paper sample (Brovia 2a)

    b - Positioning of objective lens above the measurement area (arrow)

    c - Topography of the 2 x 2 mm measurement area in false gray scale: the difference between white and black is approximately 10 μm

    d - Typical 2 mm long line profile through the area shown in c)

An example of how this kind of measurement is performed is shown in figure 3. The objective lens is positioned above a sample of photographic paper, figure 3a, at the point of interest indicated by the arrow under the objective lens, figure 3b. A three-dimensional (3D) topographic map for this measurement spot is obtained and can be displayed, for example, in false color, much like a National Geographic™ topographic map, where yellow and red areas are higher and green and blue are lower. These could not be reproduced in this black and white publication, so one sees an example of a topographic map in false gray levels in figure 3c. In

either case, these topographic maps are based on the real height/roughness data. In figure 3d one sees a cross-section two-dimensional (2D) profile along a randomly selected line through the topographic map shown in figure 3c. One can think of this as the equivalent of the mountain racing profiles one sees in the newspaper during the Tour de France bicycle race every year.

Furthermore, values for standard industrial roughness parameters can be calculated from the 2D and 3D roughness information such as the average roughness, designated as R_a or S_a, and the root mean square roughness (rms), designated as R_q or S_q, as well as waviness, see e.g. [14]. Such information is also useful for characterizing and identifying photographic paper surfaces. In this paper, the rms roughness, S_q, will be used, and further work is being conducted to determine what other roughness parameters would be useful for this application.

For this study, a 20x/0.6 magnification objective lens was used, which measures an area of 0.8 x 0.8 mm in size. The lateral (x, y) resolution was 1.4 μm (typical for normal optical micro-scopy), and the vertical (roughness) resolution was 0.06 μm (60 nm). The profilometer was set up to automatically measure a matrix of 3 x 3 adjacent areas and stitching the results together. The measurement time was approximately two to three minutes. This resulted in 2.14 x 2.14 mm topographic maps, an example of which was shown in figure 2c. S_q values were calculated over this area, or along line profiles using NanoFocus' μSoft™ analysis software.

2.2 GLOSS MEASUREMENTS

The gloss of the photographic paper samples was measured on the white edges of the emulsion (e.g. left and bottom areas in figure 2a) using a Sheen Tri-Glossmaster 20/60/85, figure 4a. The gloss meter works on the principle that a perfectly glossy surface, essentially a perfect mirror, will reflect all light coming in at a given angle, θ, at exactly the same angle, figure 4b. The Sheen instrument directs light at a flat surface at three angles of 20°, 60° and 85° from the vertical. Detectors are placed at the corresponding angles opposite the light sources, and the amount of reflected light is measured in arbitrary gloss units. If the surface is perfectly glossy, the instrument measure 100% gloss (2000 gloss units). If the surface is rough or dusty, some of the incoming light gets scattered at other angles and does not enter the detectors, figure 4c. Less light is then detected and a lower level of gloss is measured.
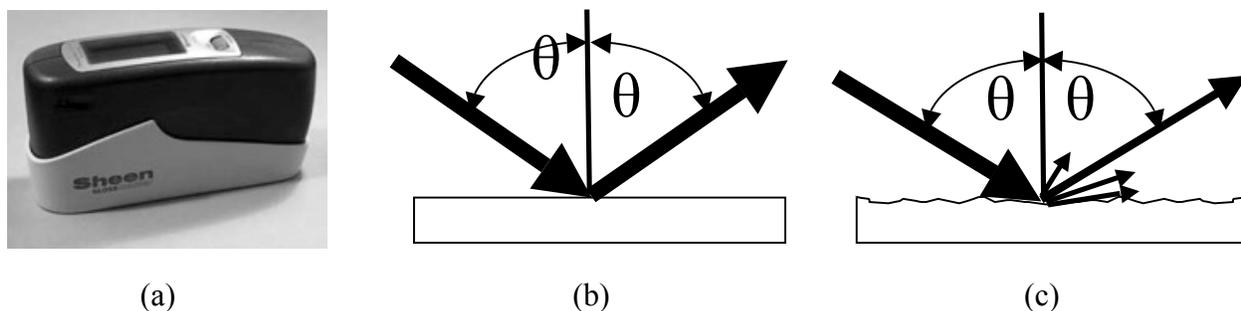

(a)   (b)   (c)

Fig. 4 - Principles of gloss measurements.
     a - Sheen Tri-Glossmaster 20/60/85
     b - Reflection of light from a perfectly glossy surface
     c - Reflection of light from a rough (matte) surface

For this study, only the values for the measurement angle 85° were recorded. This was based on experience performing studies of dust deposition in museums, which show that this measurement angle is the most sensitive to changes in surface texture [15]. Values in the Results section are reported in gloss units. Note that what is important for this study is the relative difference in gloss units between photographic paper samples, and not the absolute values of gloss.

2.3 PERCEPTION TESTING

It was found that the photographic paper samples could be categorized in five groups based on the results of the roughness measurements. Perception testing was therefore conducted using sets of six unmarked samples, one from each of four of the groups and two from a fifth. Subjects were asked to rank them in order of glossiness in office settings at the RCE laboratories in Amsterdam, or in the Department of Conservation and Restoration of the University of Amsterdam. The use of six samples per set resulted in six relative categories from most glossy to least glossy. The final result of the perception test was a count of how many times a particular group was listed as most glossy, second most glossy, etc. During testing, the subjects were allowed to move around and/or hold the photograph samples in any way they wanted. Some subjects used existing lighting, while some moved closer to windows to obtain lighting conditions, which made it easier for them to see the differences in glossiness. A total of 41 subjects participated in the testing, including cultural heritage professionals and students.

## 3. RESULTS

3.1 ROUGHNESS MEASUREMENTS

Typical results for the roughness measurements are shown in figure 5. Images of the corresponding photographic paper samples from the Agfa-Gevaert book are shown in figure 6. The results of the roughness measurements of the 25 photographic papers could be divided into five groups based on a visual comparison of the both the topographies of the 2.14 x 2.14 mm measurement areas, and the roughness profiles shown in figure 5. The original versions of the topographies shown in the left-hand column of figure 5 were in false color. In this black and white publication, white and light grays are higher than areas in darker shades of gray to black. In the figure it can be seen that topographies of the samples in Group 1 appear to be very smooth, whereas Group 5 shows a matrix of regularly spaced nodules. The differences between Groups 2, 3 and 4 range from a very fine structure (Group 2), through a mixed fine and coarse structure (Group 3), to a coarser structure (Group 4).

The differences between the five categories, and in particular, Groups 2, 3 and 4 can be more easily seen by comparing the roughness profiles in the right-hand column of figure 5 taken through the corresponding topographic maps. Note that the profile for Group 3 has a slightly larger vertical scale (-18 to +12 μm) than the other four groups (-10 to +10 μm). The profiles confirm that Group 1 photographic papers are very smooth. Groups 2 and 3 appear to have the same sort of fine structure, but that fine structure is superimposed on a broad wavy structure in Group 3. Group 4 has less fine structure, but also shows waviness, though not as strong as for Group 3. The nodular structure of Group 5 is clearly visible in the profile.

Group 1
(Brovira 111)
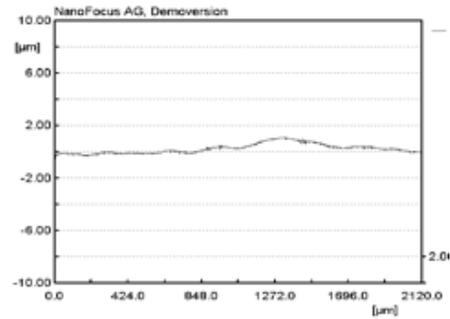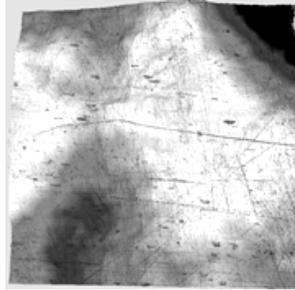
Group 2
(Brovira 122)
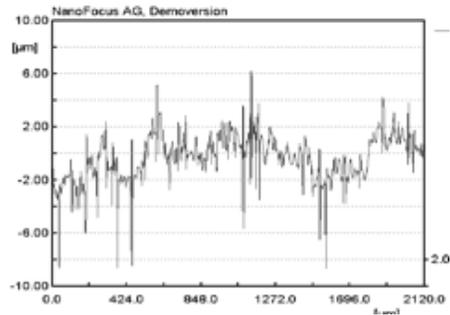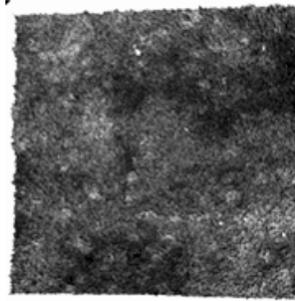
Group3
(Record-Rapid 118)

Group 4
(Record-Rapid 119)

Group5
(Agfacolor MCN 317)

Fig. 5 -   Topographic maps (2.14 x 2.14 mm) with typical roughness profiles (2.14 mm long) for five different types of roughness found for the Agfa-Gevaert photographic papers. Those papers named in parentheses are shown in figure 6. Note that the vertical scale for Group 3 is 30 μm, and for the others, 20 μm.
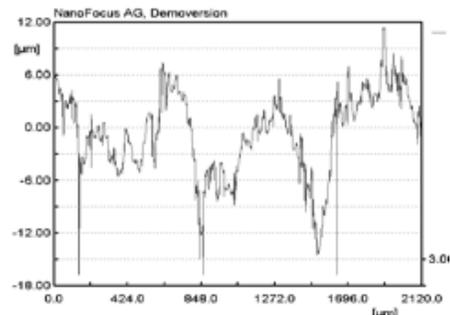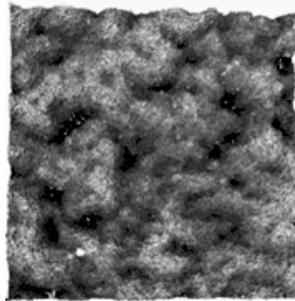
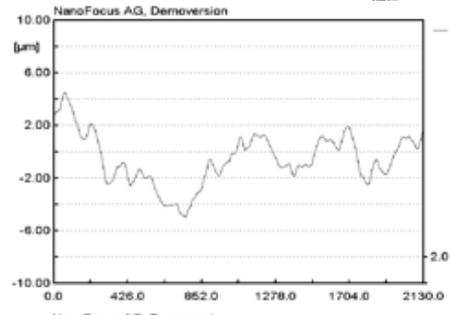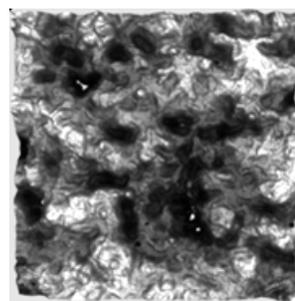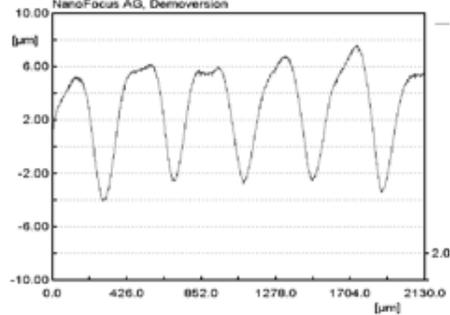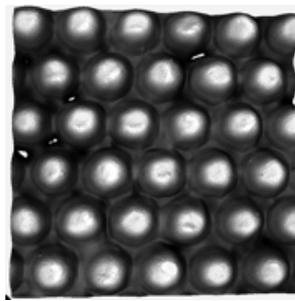1 (Brovira 111)   2 (Brovira 122)   3 (Record-Rapid 118)

4 (Record-Rapid 119)   5 (Agfacolor MCN 317)
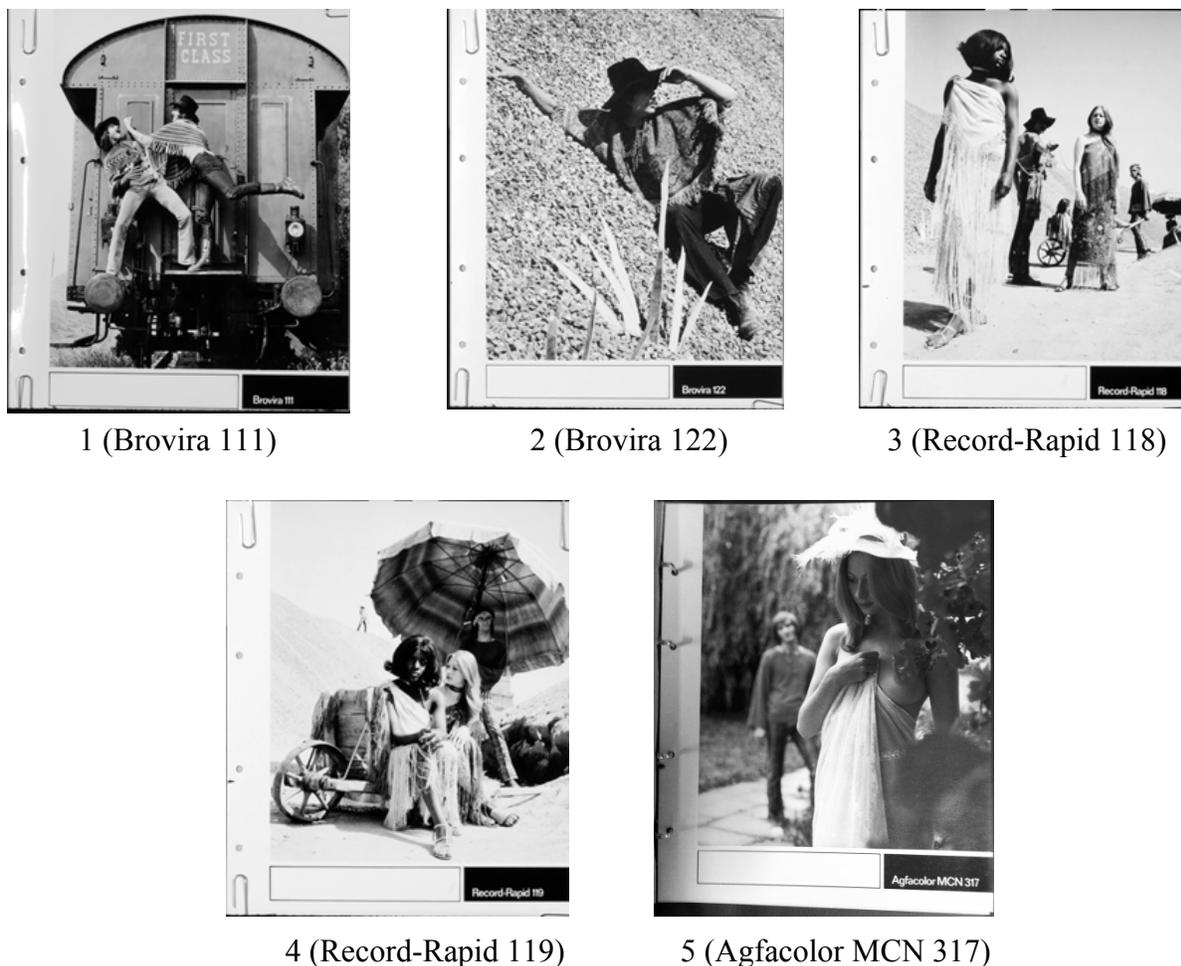
Fig. 6 - Photographic paper samples grouped according to the roughness measurement results
shown in figure 5

Calculated values for the rms roughness, S_q, for each group are shown in the second and third columns in table 1. In the second column, S_q, was calculated over the entire 2.14 x 2.14 measurement area for each photographic paper. What is shown in table 1 is the mean and standard deviation of S_q for all of the papers in a group. Since S_q was calculated over the whole measurement area, the values in this column include not only the fine micro-roughness structures of the papers, but also the waviness. The column is thus labeled S_{qw}.

In order to remove the effect of the waviness, the S_q values were calculated for level segments of the 2D profiles. The mean and standard deviation of all of these values for each group are shown in the third column of table 1. These values of micro-roughness are clearly lower than the values which include waviness. When looking at the data this way, Groups 1 and 5 have low values of micro-roughness, and Groups 2 and 3 have the highest values of micro-roughness.

TABLE 1

SUMMARY OF THE RESULTS OF ROUGHNESS AND GLOSS MEASUREMENTS,

Group	S_{qw} (rms roughness)[a] including waviness	S_q excluding waviness[b]	Gloss units
1	0.17 ± 0.04	0.02 ± 0.01	80 ± 30
2	1.88 ± 0.32	0.96 ± 0.35	8 ± 4
3	4.68 ± 0.46	$0,81 \pm 0.03$	5 ± 0.6
4	1.81 ± 0.27	0.20 ± 0.14	33 ± 10
5	4.00 ± 0.61	0.07 ± 0.01	46 ± 45

a - Calculated over entire 2.14 x 2.14 mm topographic map, average of all samples in a group
b - Calculated for short pieces of single profiles, average of all samples in a group

3.2 GLOSS MEASUREMENTS

The average values of the gloss measured per group are shown in the fourth column of Table 1. One could expect that with higher micro-roughness, the gloss would decrease. This relationship can be confirmed by comparing the gloss values with the S_q values without waviness (third column in table 1). Group 1 with the lowest micro-roughness has the highest gloss value followed by Groups 4 and 5. Within the scatter of the values, Groups 2 and 3 have higher micro-roughness values than the other groups and thus the lowest gloss. On the other hand, the S_{qw} values including waviness in the second column of Table 1 do not correlate well with the gloss measurements. Based on those results, the Group 5 papers with a high S_{qw} value should have a low gloss value, and the Group 2 and 4 papers with intermediate S_{qw} values should have some intermediate gloss value.

3.3 PERCEPTION TEST RESULTS

The results of the perception tests are shown in figure 7. The figure shows six relative levels of glossiness from right to left, most glossy to most matte. At each level, one sees the total number of subjects who placed a particular group at that level. It is clear that all 41 subjects agree that Group 1 photographic papers had the highest gloss, the gloss level at the far right of the diagram. Group 4 was considered by 36 subjects to be the next most glossy paper, and the third in order was Group 5, the nodular paper. For the subjects it was, however, difficult to distinguish differences in gloss between Groups 2 and 3, indicated by the fact that the votes for each Group are spread throughout the lower three categories of relative glossiness. Recall that there were two of Group 2 samples in each set, which is why there are twice as many responses for that group than for the other groups.
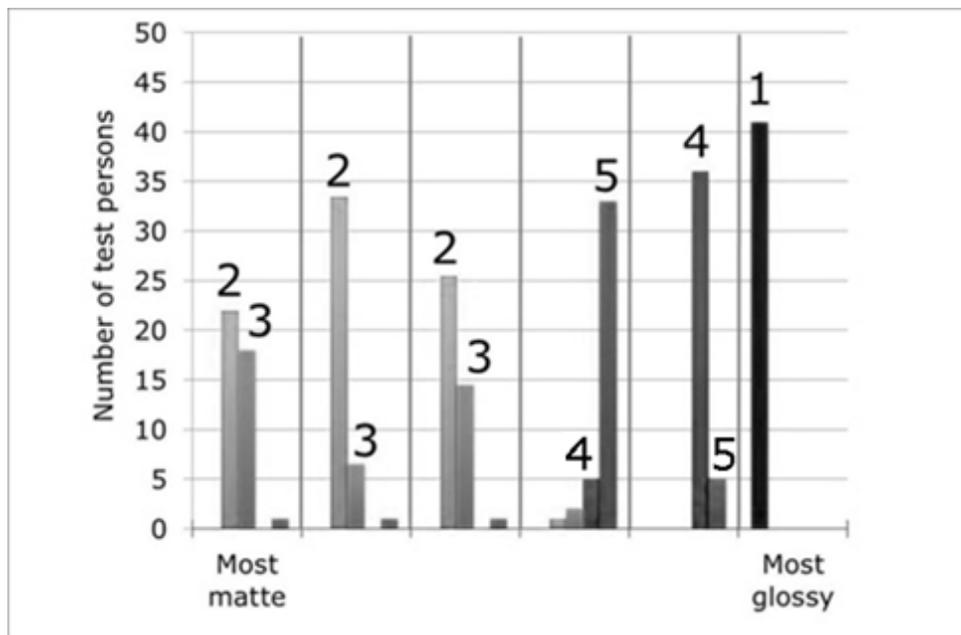
Fig. 7 -   Results of perception testing on sets of photographic papers samples including one each from Groups 1, 3, 4, and 5, and two from Group 2.

4. DISCUSSION

The technical results of this project to date show that the micro-texture of photographic papers can be characterized easily and quickly at sub-micron resolution using standard non-contact roughness measuring equipment available in industry, so-called confocal white light profilo-meters. Three-dimensional topographic maps and two-dimensional line profiles along with statistical analysis of the surface roughness provide much more useful, quantitative information than current raking light / polynomial texture mapping techniques for characterizing and differ-entiating between papers. If necessary, higher depth resolution on the order of 10 nm is possible, as is slightly better spatial resolution to under 1 μm. The roughness information measured from profilometers alone is better than current methods for characterizing photographic papers, and can thus be of great use in helping identifying papers, by comparing the roughness of the photo-graph paper to be identified with a database of roughness measurements on reference papers.

The gloss of photographic papers can also be measured using standard industrial instru-ments. However, it should be noted that gloss measurements depend on the color of the object being measured. All of the Agfa-Gevaert sample pages had white margins, which were part of the photographic emulsion. However, the papers, being older, had slightly varying levels of mild yellowing. This may have been the cause of some of the scatter in the results shown in table 1.

TABLE 2

RANKING OF GLOSSINESS BY GLOSS MEASUREMENTS AND BY HUMAN SUBJECTS

Rank	Rank in glossiness	Group no. (gloss meter)	Group no. (human)
1	Most	Group 1	Group 1
2		Group 5	Group 4
3		Group 4	Group 5
4		Group 2	Groups 2-3
5	Least	Group 3	Groups 2-3

While identifying photographic papers is of great importance in photograph conservation, the motivation for this and other work in this area has been to find ways to assist conservators in with the selection of photographic papers for conservation treatments. This requires a way to relate technical measurements to appearance and what the conservator or other professional sees and perceives. Table 1 appears to show that gloss as measured by the gloss meter is determined in large part by the micro-roughness. This results in a ranking of the paper groups as shown in the second column of table 2. Note that the gloss meter finds that the nodular structure of Group 5 with low micro-roughness to be glossier than Group 4.

A comparison of the rankings based on the gloss measurements with the results of rankings based on perception testing in table 2 shows the difficulty in relating technical measurements to appearance and perception, let alone trying to automate it as described in [5]. Most of the perception testing subjects had difficulty deciding if the nodular structure of Group 5 was glossier than the coarse Group 4 structure, and how to describe the difference. Although the micro-roughness of Group 5 papers was almost as low as for the glossiest Group 1 papers, and lower than the Group 4 papers, most subjects ultimately found the Group 5 papers to give a less glossy impression because the nodular structure was visible to the naked eye.

The subjects in the perception test were also divided in their judgment as to whether Group 2 papers or Group 3 were glossier. Statistically, the mean micro-roughness values of the two groups shown in table 1, were not significantly different. It will be interesting to have the subjects examine the exact same individual photographic papers, as opposed to a random selection of one paper out of a group. Work is continuing in this area.

In this project, it thus appears that the technical characteristics of the photographic papers do not correlate well with what human subjects perceive in terms of gloss, in particular, at the level which is required for selecting replacement materials. For pure identification purposes, roughness measurements are a simple but rigorous way to identify historic papers. However, identifying papers on the basis of appearance, or selecting materials for a conservation treatment, using only texture and eventually gloss data can be very difficult.

Other research with the goal of identifying papers using raking light and polynomial texture mapping techniques have also been confronted with this problem [5-6]. While there has

been some success, there is the problem of terminology when trying to describe what one sees and then match that with technical data. Furthermore, both research groups indicate that there is still much work to be done to improve the automated techniques so that they can predict paper types and appearance as well as the human expert. This is an issue, which will continue to plague the conservation world where subjectivity plays a significant role. The identification techniques described in this communication will certainly make photographic paper identification easier for the conservator. However, for materials selection, the conservator and art historian will continue to have to make the final - subjective - decision.

5. CONCLUSIONS

A project is being conducted to characterize the surface texture and gloss of photographic papers in order to assist in their identification, and to help conservators select materials for reprinting photographs a as conservation strategy. The three-dimensional surface micro-topography and gloss of photograph paper samples from an Agfa-Gevaert sample book (1972-1973) were directly measured using a standard industrial non-contact confocal white light profilometer with sub-micron height resolution, and a standard industrial gloss meter respectively. Perception testing was conducted to see if the surface properties could be correlated with how human subjects judge the relative glossiness of the different papers.

The results show that photographic papers can be easily characterized in high resolution using confocal white light profilometry, with statistical information about the surface roughness better than current techniques for characterizing papers. The technique can thus be used for identifying papers. Gloss measurements can also be easily taken, but are subject to subtle changes in color of aged papers. It was shown that while the roughness measurements and data correlate with the gloss measurements, what humans considered glossy, did not always correspond to technical measurements. Thus, for the selection of papers for conservation treatments, the eye and perception of the conservator or other professional will always be necessary and invaluable.

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