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Aesthetics and gloss of ground surfaces – A review on measurement and generation

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ABSTRACT

Visual appearance of an object significantly influences a consumer's choice and largely controls the market economy. The perceived quality of products are governed by surface's optical properties (reflection, refraction, etc.), geometrical properties (roughness, waviness, etc.) and chemical properties (oxide layer formation, thermal variation, etc.). Surface shininess attracts researchers from many different disciplines, in particular manufacturing, metrology, psychology, physiology, and computer science. Unfortunately, there are still huge knowledge gaps on characterizing and appraising shiny surfaces in a reproducible way. This paper introduces the main definitions and physics of shininess and gloss, methods of gloss sensing, and relates these definitions and methods to surface generation by grinding. Automated gloss measurement is difficult in particular for free form surfaces and optical quality is still often evaluated by human workers. Gloss models are often based on the bidirectional reflection distribution function (BRDF) of the surface, but the models are commonly not connected with the manufacturing process. This study proposes to consider the geometrical features (defects, waviness, lay, and roughness) of metal surfaces as well as the physical and chemical features (grain structure and micro layers) to understand surface

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appearance and manufacturing in a holistic way. Preliminary tests show that 2D roughness measurements are not connected well with measured gloss units and subjective, perceived quality. More fundamental research on the generation and measurement of surface appearance is needed and would benefit many industries.

KEYWORDS: surface appearance, gloss, gloss measurement, finishing, grinding

INTRODUCTION

Consumers focus increasingly on the visual appearance of product features and often evaluate the product quality and performance based on this [1]. The success of products in the market is defined by perceived quality in addition to product function. Examples are the exteriors of electronics (shiny laptop or cell phone cases), or textures in car interiors.

A big portion of marketing policy relies on shiny surfaces irrespective from its surface functionality. For example, parts get rejected because of visual surface marks even though these marks do not have direct impact on surface properties. Surface shininess attracts researchers from many different disciplines, in particular psychology, physiology, computer science, manufacturing, and metrology. Psychological and physiological studies are interested in how the visual perception of gloss works: for example how surface structures at different scales interfere [2] or how highlights and binocular vision change gloss perception [3]. So far, the perceptions of object shape and contour have drawn more attention of researchers than the perception of the object material [4].

The knowledge about shininess is also essential to computer scientists who work on object rendering and visualization [4, 5]. Realistic surface appearance is not only needed for computer aided design and manufacturing, but also for computer graphics in the entertainment industry. Purely physics-based models do not seem to have realistic results, so quantitative studies of gloss perception must be included [5].

Although the human eye is still the most capable instrument, automated gloss measurement is needed for quantitative and reliable quality control in industrial settings [6]. First applications in gloss control were for paint and paper [7]. Later on, gloss was also monitored for construction materials such as stones and tiles [8], plastics [9], coatings [10], sheet metals [11], and finished metal surfaces at household appliances, consumer electronics, or optical molds [12]. Gloss is also highly important for dental materials [13] and the food industry [14, 15]. In industry, standardized glossmeters are applied to measure the surface reflectivity, but they give a unidimensional metric (gloss units), which is not sufficient to ensure a certain cosmetic appearance [16]. Clearly, more fundamental research on the generation and measurement of surface appearance would benefit many industries. This paper introduces the main definitions and physics of shininess and gloss, methods of gloss sensing, and relates these definitions and methods to surface generation by grinding.

LIGHT INTERACTION WITH SURFACES

Light interaction with objects can be explained by different effects happening at the surface, mainly reflection and diffraction and effects happening inside the object material such as refraction, absorption, scatter. When a beam of light strikes a boundary surface separating by two media, part of the light is reflected and part enters into the second medium [17, 18]. The light entering the second medium can be absorbed, refracted, or scattered, which is particularly important for coatings or paint, which have been studied intensively [10] [19].

For specular or flat mirror-like surfaces (Fig. 1 a) follows the law of reflection, where the angle of reflection and angle of incidence, α, are equal with the normal line [18]. In contrast, Lambertian surfaces show ideal diffuse reflection (Fig. 1 b), whereas most surfaces exhibit a mixed reflection behavior (Fig. 1 c).

Generally, metal surfaces have multiple layers such as oxide layers on top of the metal, which change the incident light wave propagation and reflection. Reference [20] shows the impact of oxide layers on steel by considering roughness change and the optical properties of the oxide components (hematite and magnetite).

Gloss is a function of the directional reflectance properties of surfaces [5], but is also influenced by the subjective assessment of the observer [6, 7]. There is a nonlinear relation between gloss perception and instrumental specular gloss values. For example a person`s sensitivity for gloss is higher at extreme values than in middle ranges [16]. The relationship between perceived and measured gloss still undergoes research.

In 1937, Hunter defined six types of gloss, namely specular gloss, contrast gloss, sheen, absence-of-bloom gloss, distinctness-of reflected-image gloss, and absence-of-surface-texture-gloss [21]. The distinction between the gloss types however has been questioned as they are not independent from the illumination environment [4]. Commonly people use multiple, subjective terms for describing reflection appearance, such as matte, shiny, glossy, mirror-like, lustre, metallic [4, 22]. Clearly interdisciplinary research on perceived gloss and surface appearance of metal surfaces is needed.

GLOSS MEASUREMENT

High gloss metal surfaces are challenging to optical measurements, for example scratch detection [23] or dimension measurement [24]. In industry, glossmeters are used to measure the surface shininess. The glossmeter consists of a white light source and a photo detector arranged under specific angles (Fig. 2 left). The gloss standard is highly polished black glass [25] and should give a gloss reading of 100 gloss units (GU). International standards specify incident angles for different materials and different types of gloss, e.g. 20° incident angle for high gloss surfaces, 60° for medium gloss and 85° for sheen, i.e. shininess at grazing angle [4] [25]. Gloss units give an estimate of perceived shininess.

Glossmeters work best on flat surfaces and have a high sensitivity for geometric misalignments [12, 26]. In addition, the probing area has a minimum dimension (often several square millimeters), therefore the inspection of tiny surface areas is usually a problem for glossmeters [26]. Laboratory setups such as the “diffractive optical element based glossmeter” can obtain information on the gloss also from curved metal surfaces [9, 26].

A more comprehensive metric with four dimensions and spatial information is the bidirectional reflection distribution function (BRDF). BRDF is the ratio of the reflected radiance (L_r, luminance) in the exiting direction to the irradiance (E_i, illuminance) in the direction of incident light (Equation 1 and Fig. 2, right) [4, 7]. Radiance is the light energy at a point; irradiance defines how much light power reaches a certain area.

$$f_f(\omega_i, \omega_o) = \frac{dL_r(\omega_o)}{dE_i(\omega_i)} \tag{1}$$

With f_r =BRDF, L_r = radiance, E_i = irradiance, ω_i = incoming light direction, ω_o = outgoing light direction (Fig. 2, right)

BRDF considers only the reflective scatter of the bidirectional scattering distribution function (BSDF). BSDF is standardized in ASTM E2387-05 and contains the bidirectional transmittance distribution function (BTDF) in addition to BRDF.

BRDF is measured with a gonioreflectometer, which consists of light source and detector moveable in relation to the sample surface [27]. The challenges lie within having a high angular resolution, dense sampling of the visible wavelength spectrum, and rapid operation as measurements can take hours [27]. Researchers often rely on self-built gonioreflectometers or customized optical systems. For example, Deinhammer and Brandner developed a dynamic sensing system with a 2D camera [12].

BRDF plots show the intensity of the scattered beam over the beam angle. If the plot contains sharp peaks this indicates regular defects on the surface. Peak number and intensity relate to the defect shape; general intensity height relates to the random roughness. [28]

GLOSS MODELING

For photo-realistic computer graphics, reflectance models based on BRDF are used. Additional illumination models are needed in the case of light coming from more than a direct individual light source, but will not be discussed here.

The **Phong Model** is one of the oldest BRDF models and still very commonly used [29]. It is based on ray optics and assumes that incoming light tends to leave the surface distributed around the direction of perfect reflection. Variants of this model with faster computation have been developed [30, 31]. **Physically-based models** take the micro geometry of surfaces into account, for example through microfacets in the shape of V-cavities [32] [33] or small cylindrical scratches to model anisotropic surfaces [34]. **Empirical models** use directly measured model parameters, fitted BRDF measurements from gonioreflectometers, or dense BRDF measurements [35] [36]). Matusik et al. introduced a new method with measured isotropic BRDF data and added perceptually-based or user-specific data [36].

The quality of the BRDF models can be evaluated by comparing the results with measured BRDF data [37]. Perceived gloss however goes beyond BRDF. Recent research shows that the human observer needs both mesoscale textures ("bumps", waviness) and microscale roughness for a realistic shininess [2]. Qi proposes therefore to simulate surfaces with a full conjoint measurement model of mesoscale and microscale roughness [4].

Simpler gloss models outside of computer graphics try to understand changes in gloss. For example, Hunt et al. estimate gloss as a function of roughness and pigment particle distribution for the weathering of paint [19]. Their 2D simulation is purely based on the assumption that gloss is primarily dependent on surface roughness. Gloss models are commonly not connected with the manufacturing process.

SURFACE GENERATION IN GRINDING

Grinding is an abrasive process, also called machining with geometrically undefined edges, and represents a key technology with high performance, process stability, and part quality [38, 39]. In grinding, abrasive grits engage with the workpiece to form chips. The tool bonding has to hold the grits until they become blunt and release them to let new, sharp grits engage.

Chip formation

Modeling

Researchers have tried to model the grinding process for many decades, but the models still inherit many uncertainties or empirical measurements [40, 41]. The individual and combined grit engagements with the workpiece affect the chip formation process. However, a purely topographic characterization of wheel and workpiece surfaces does not give direct correlations [42].

Although some models are close to simulating the real workpiece surface roughness, the resulting surface integrity is less understood. Surface integrity of the rim zone includes geometrical parameters (e.g., surface finish, topography), physical parameters (e.g., microhardness, residual stresses, microstructure), and chemical parameters (e.g., chemical reactions, affinity, chemisorption, polarization) [43, 44]. The metal surface consists of more than the idealized surface roughness, because several microlayers sit on top of the bulk material, such as oxide layers [45]. If metals undergo mechanical machining this commonly leads to a deformed layer of heavily deformed base material and oxides [44]. In addition, water vapor, debris and other contamination materials build up on top.

Existing models in grinding do not focus on the surface appearance or gloss. Even if existing roughness models are taken for computational surface modeling, they might not be sufficient because they do not include microlayers and surface integrity, which should be addressed in future research.

METAL SURFACE MODEL AND INITIAL TESTS

The surface features affecting surface appearance are plentiful. For metal surfaces, we propose to focus on the features shown in Fig. 3. Defects (scratches, cracks, etc.), waviness, lay and roughness are geometrical properties that act mostly on light reflection and diffraction. Grain structure and micro layers on the surface count as chemical and physical properties that impact mainly light scatter, absorption, and refraction.

It can be assumed that reflection is the dominating factor for shininess of uncoated metals, thus surface topography has to be studied. Preliminary tests on surface characterization were conducted with different surfaces on a Surface Roughness Standards Set (SPI- Rubert Composite Pocket Set, No. 30-695-1, Rubert & Co. Acru Works, Cheshire). Fig. 4 shows pictures of six different finished surfaces, two made by lapping, one by reaming, and three by grinding. The lapped surfaces denoted with Ra = 0.05 µm and 0.2 µm have a crosswise texture which differentiates them from the reamed and the ground surfaces. The texture might change the subjective surface appearance but is not related to the denoted profile roughness.

Row 1 and 2 (Fig. 4) show the images of surfaces taken by light microscope and laser scanning confocal microscope (Zeiss LSM 700) respectively. LSM 700 was used to measure the surface roughness. Rows 3 and 4 depict the average surface roughness Ra and average peak-to-valley height Rz respectively. It can be seen that the measured Ra values do not match with the specified Ra values well. For the roughest reamed and ground surfaces, the values have the highest scatter, which might be due to wear of the roughness scale.

The gloss units in row 5 were measured by ZGM 1120 Glossmeter (60°, 20°) from Zehntner GmbH Testing Instruments. The gloss units under a 60^o angle are always higher than under 20°, but neither the ratio nor the difference between these values is constant. Rougher surfaces have lower gloss units, but the gloss units do not linearly depend on the roughness values.

The perceived quality in row 6 was obtained from surveying ten human subjects. The participants were asked to rank the sample surfaces based on their perception of surface roughness and shininess. The ranks range from 1 to 10 where 1 considered as the lowest quality and 10 as the best. The results show that higher surface roughness decreases the perceived quality of shininess and roughness, which matches the expectations. There is however one outlier for the reamed surface of Ra = 0.8 µm, where the surface shininess was evaluated with a high rank despite of its high surface roughness.

These preliminary tests show clearly how difficult it is to describe finished surfaces distinctly by measured parameters (roughness or gloss units). The measured shininess does not have a linear correlation with measured or perceived roughness. More research is needed to quantify the impact of geometrical surface properties and on physical and chemical surface characteristics in addition.

CONCLUSION

Appearance of manufactured surfaces is highly important to both consumers and manufacturers. However, automated gloss measurement is difficult in particular for free form surfaces and human workers often evaluate optical quality. Knowledge gaps exist between surface generation, surface characterization, and perception of surface quality. Therefore, the gloss models need to be linked to manufacturing. We propose to consider the geometrical features (defects, waviness, lay, and roughness) of metal surfaces as well as the physical and chemical features (grain structure and micro layers) to understand surface appearance and optimize manufacturing in a holistic way. Preliminary tests show that 2D roughness measurements are not connected well with measured gloss units and subjective, perceived quality. Comprehensive investigations on 3D topography and surface integrity are needed to enable an efficient production of shiny metal surfaces. Future research should take interdisciplinary approaches to utilize knowledge from metrology on measurement, computer graphics on surface modeling, manufacturing science on process modeling, marketing research on perception, and such to generate a better understanding of targeted gloss generation.

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NOMENCLATURE

a_e	depth of cut
C_{stat}	statical cutting edge density
d_{eq}	equivalent grinding wheel diameter
E_i	irradiance
f_r	bidirectional reflection distribution function (BRDF)
$h_{cu,max}$	Undeformed maximum chip thickness
k	material constant
L_r	radiance
v_{gr}	grinding wheel speed
v_{wp}	workpiece speed
α	Incidence angle
κ	cutting edge angle
ω_i	incoming light direction
ω_o	outgoing light direction

REFERENCES

[1] Du, P., and MacDonald, E. F., "Eye-Tracking Data Predicts Importance of Product Features and Saliency of Size Change," Proc. ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.
[2] Ho, Y.-X., Landy, M. S., and Maloney, L. T., 2008, "CONJOINT MEASUREMENT OF GLOSS AND SURFACE TEXTURE," Psychological science, 19(2), pp. 196-204.
[3] Kerrigan, I. S., and Adams, W., 2013, "Highlights, disparity, and perceived gloss with convex and concave surfaces," Journal of Vision, 13(1):9, pp. 1-10.
[4] Qi, L., 2012, "Measuring Perceived Gloss of Rough Surfaces," PhD
[5] Ferwerda, J. A., Pellacini, F., and Greenberg, D. P., "Psychophysically based model of surface gloss perception," pp. 291-301.
[6] Kigle-Boeckler, G., 1995, "Measurement of Gloss and Reflection Properties of Surfaces," Metal Finishing(May 1995), pp. 28 - 31.
[7] Whitehouse, D. J., Bowen, D. K., Venkatesh, V. C., Lonardo, P., and Brown, C. A., 1994, "Gloss and Surface Topography," CIRP Annals - Manufacturing Technology, 43(2), pp. 541-549.
[8] Ozcelik, Y., Careddu, N., and Yilmazkaya, E., 2012, "The effects of freeze–thaw cycles on the gloss values of polished stone surfaces," Cold Regions Science and Technology, 82, pp. 49-55.
[9] Myller, K., Juuti, M., Peiponen, K. E., Silvennoinen, R., and Heikkinen, E., 2006, "Quality inspection of metal surfaces by diffractive optical element-based glossmeter," Precision Engineering, 30(4), pp. 443-447.
[10] Farrier, L., 2006, "Influence of Surface Roughness on the Specular Reflectance of Low Gloss Coatings Using Bidirectional Reflectance Measurements, AFRL-ML-WP-TM-2007-4019," Air Force Research Laboratory.
[11] Shih, T.-S., Wei, P.-S., and Wu, C.-L., 2008, "Effect of abrasives on the glossiness and reflectance of anodized aluminum alloys," J Mater Sci, 43(6), pp. 1851-1858.
[12] Deinhammer, C., and Brandner, M., "Advanced Gloss Sensing for Robotic Applications," Proc. Proc. SPIE 8495, Reflection, Scattering, and Diffraction from Surfaces III, 84950T (15 October 2012).
[13] Fernandez-Oliveras, A., Costa, M. F. M., Yebra, A., Rubino, M., and Perez, M. M., "Gloss measurements and rugometric inspection in dental biomaterials," Proc. Proc. SPIE 8785, 8th Iberoamerican Optics Meeting and 11th Latin American Meeting on Optics, Lasers, and Applications, 8785E0 (18 November 2013).
[14] Ward, G., and Nussinovitch, A., 1996, "Gloss Properties and Surface Morphology Relationships of Fruits," Journal of Food Science, 61(5), pp. 973-977.
[15] Briones, V., Aguilera, J. M., and Brown, C., 2006, "Effect of surface topography on color and gloss of chocolate samples," Journal of Food Engineering, 77(4), pp. 776-783.
[16] Obein, G., Knoblauch, K., and Vienot, F., 2004, "Difference scaling of gloss: Nonlinearity, binocularity, and constancy," Journal of Vision, 4, pp. 711-720.
[17] Trezza, T. A., and Krochta, J. M., 2001, "Specular reflection, gloss, roughness and surface heterogeneity of biopolymer coatings," Journal of Applied Polymer Science, 79(12), pp. 2221-2229.
[18] Tipler, P. A., 1991, Physics - For Scientists and Engineers, Worth Publishers, New York.

[19] Hunt, F., Galler, M., and Martin, J., 1998, "Microstructure of weathered paint and its relation to gloss loss: Computer simulation and modeling," Journal of Coatings Technology, 70(880), pp. 45-53.
[20] Goossens, V., Stijns, E., Van Gils, S., Finsy, R., and Terryn, H., "Measuring and modelling the appearance of coated steel surfaces," Proc. Proc. SPIE 7390, Modeling Aspects in Optical Metrology II, 73900M (June 15, 2009).
[21] Hunter, R. S., 1937, "Methods of determining gloss, Research paper RP958,=," Journal of Research of the National Bureau of Standards, 18(Jan. 1937), pp. 19-39.
[22] Adelson, E. H., "On Seeing Stuff: The Perception of Materials by Humans and Machines," Proc. Human Vision and Electronic Imaging VI, Proceedings of SPIE Vol. 4299 (2001).
[23] Böhm, J., Bianchi, D., Jech, M., Brodman, R., and Vellekoop, M., "DETECTION OF NM-SCALE SCRATCHES ON HIGH GLOSS METAL SHEETS BY A LIGHT SCATTERING METHOD," Proc. STLE/ASME International Joint Tribology Conference IJTC2008, ASME.
[24] Sato, M., Shimamoto, R., and Mizoguchi, M., "3-D IMAGE MEASUREMENT SYSTEM FOR SMALL MACHINE PARTS WITH GLOSSY METAL SURFACES," Proc. ASME/ISCIE 2012 International Symposium on Flexible Automation ISFA2012, ASME.
[25] ASTM, 2014, "D523 − 14 -Standard Test Method for Specular Gloss."
[26] Peiponen, K.-E., Myllylä, R., and Priezzhev, A. V., 2009, Optical Measurement Techniques, Springer Berlin Heidelberg.
[27] Li, H., Choong Foo, S., Torrancei, K. E., and Westin, S. H., 2005, "Automated three-axis gonioreflectometer for computer graphics applications," Proceedings of SPIE 5878, pp. 5878 -5829.
[28] Schmitt Measurement Systems, I., 1994, "Interpreting light scatter measurements," company brochure, Schmitt Measurement Systems, Inc.
[29] Phong, B. T., 1975, "Illumination for computer generated pictures," Commun. ACM, 18(6), pp. 311-317.
[30] Blinn, J. F., 1977, "Models of light reflection for computer synthesized pictures," SIGGRAPH Comput. Graph., 11(2), pp. 192-198.
[31] Whitted, T., 1980, "An improved illumination model for shaded display," Commun. ACM, 23(6), pp. 343-349.
[32] Torrance, K. E., and Sparrow, E. M., 1967, "Theory for Off-Specular Reflection From Roughened Surfaces," J. Opt. Soc. Am., 57(9), pp. 1105-1112.
[33] Cook, R. L., and Torrance, K. E., 1982, "A Reflectance Model for Computer Graphics," ACM Trans. Graph., 1(1), pp. 7-24.
[34] Poulin, P., and Fournier, A., 1990, "A model for anisotropic reflection," SIGGRAPH Comput. Graph., 24(4), pp. 273-282.
[35] Kurt, M., and Edwards, D., 2009, "A survey of BRDF models for computer graphics," SIGGRAPH Comput. Graph., 43(2), pp. 1-7.
[36] Matusik, W., Pfister, H., Brand, M., and McMillan, L., 2003, "A data-driven reflectance model," ACM Trans. Graph., 22(3), pp. 759-769.
[37] Ngan, A., Durand, F., and Matusik, W., "Experimental Analysis of BRDF Models," Proc. Eurographics Symposium on Rendering (2005), K. B. a. P. Dutre, ed., The Eurographics Association.

[38] Klocke, F., 2009, Manufacturing Processes 2 – Grinding, honing, lapping, Springer.
[39] Marinescu, I. D., Hitchiner, M., Uhlmann, E., Rowe, W.B., Inasaki, I., 2007, Handbook of Machining with Grinding Wheels, CRC Press.
[40] Tönshoff, H. K., Peters, J., Inasaki, I., and Paul, T., 1992, "Modelling and Simulation of Grinding Processes," CIRP Annals - Manufacturing Technology, 41(2), pp. 677-688.
[41] Brinksmeier, E., Aurich, J. C., Govekar, E., Heinzel, C., Hoffmeister, H. W., Klocke, F., Peters, J., Rentsch, R., Stephenson, D. J., Uhlmann, E., Weinert, K., and Wittmann, M., 2006, "Advances in Modeling and Simulation of Grinding Processes," CIRP Annals - Manufacturing Technology, 55(2), pp. 667-696.
[42] Terry, A. J., and Brown, C. A., 1997, "A Comparison of Topographic Characterization Parameters in Grinding," CIRP Annals - Manufacturing Technology, 46(1), pp. 497-500.
[43] Brinksmeier, E., Lucca, D. A., and Walter, A., 2004, "Chemical Aspects of Machining Processes," CIRP Annals - Manufacturing Technology, 53(2), pp. 685-699.
[44] Davim, J. P., 2010, Surface Integrity in Machining, Springer, London.
[45] Brinksmeier, E., and Walter, A., 2000, "Generation of Reaction Layers on Machined Surfaces," CIRP Annals - Manufacturing Technology, 49(1), pp. 435-438.

Figure Captions List

Fig. 1	Light reflection on a surface
Fig. 2	Principles of glossmeter and BRDF
Fig. 3	Features of the metal surface that affect surface appearance
Fig. 4	Characterization of surfaces by microscope pictures, measured roughness, perceived quality, and measured gloss units

Figures

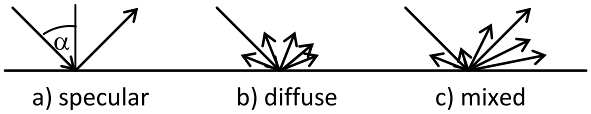

Fig. 1.

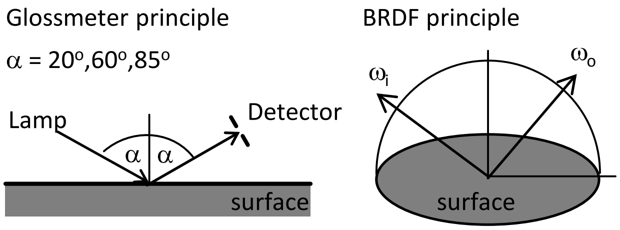
Glossmeter principle
α = 20°,60°,85°
Lamp
Detector
α
α
surface
BRDF principle
ω_i
ω_o
surface

Fig. 2.

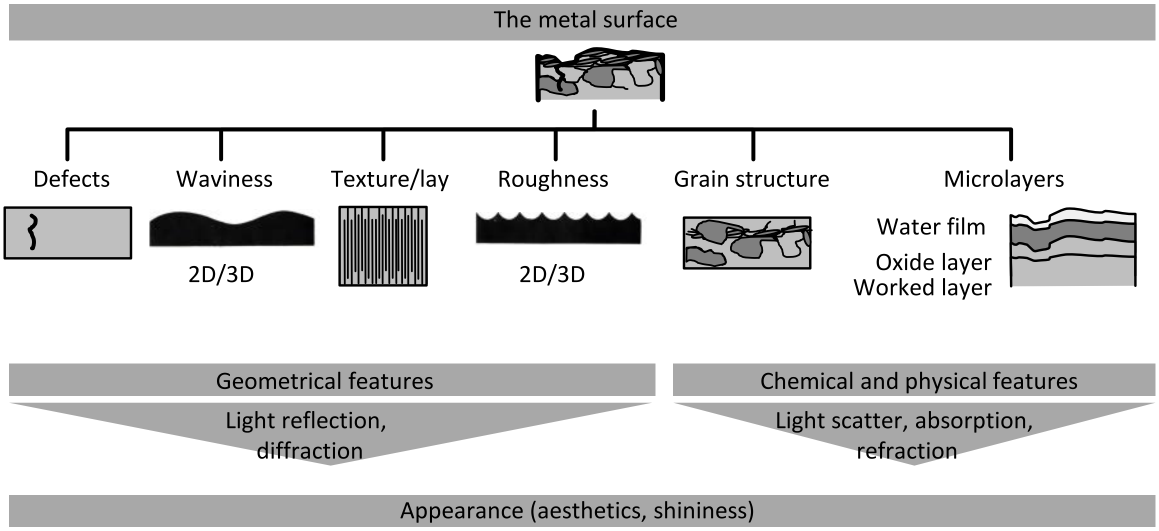
The metal surface
Defects
Waviness
2D/3D
Texture/lay
Roughness
2D/3D
Grain structure
Microlayers
Water film
Oxide layer
Worked layer
Geometrical features
Light reflection, diffraction
Chemical and physical features
Light scatter, absorption, refraction
Appearance (aesthetics, shininess)

Fig. 3.

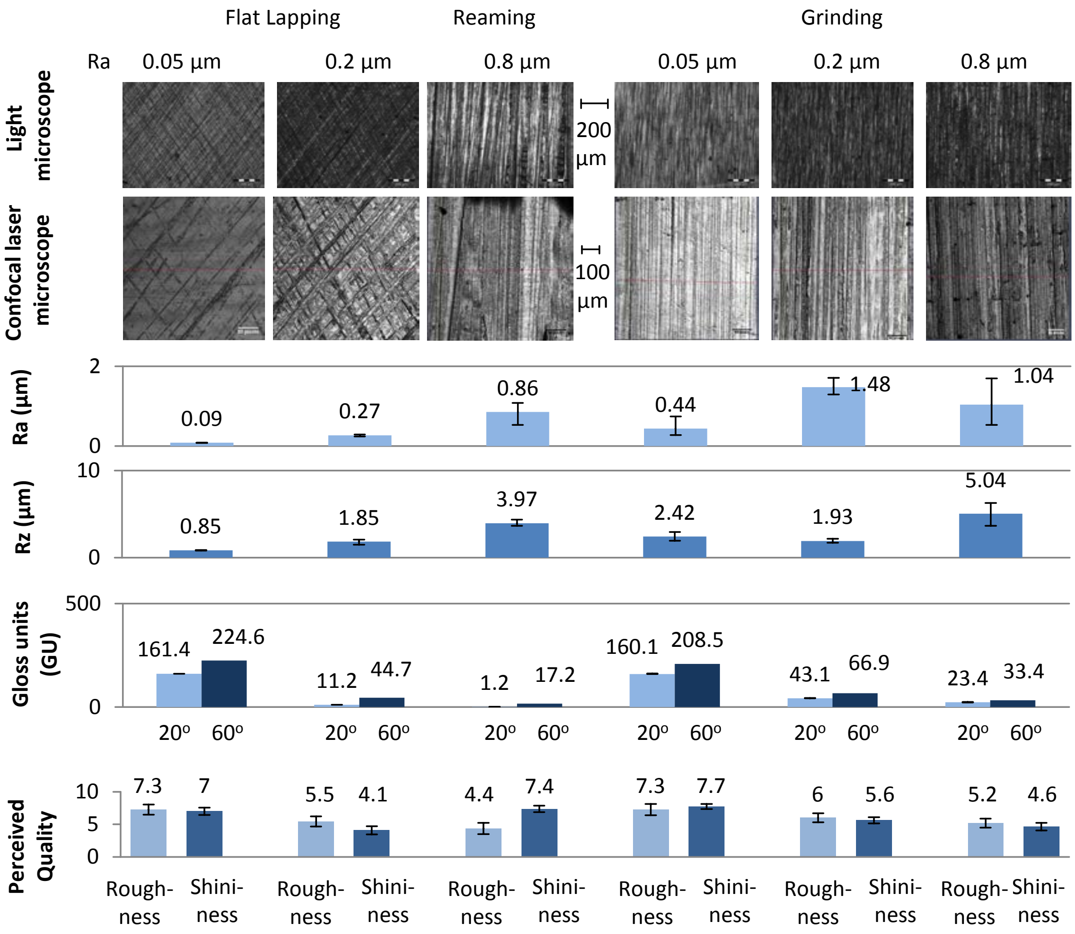
Flat Lapping
Reaming
Grinding
Ra
0.05 µm
0.2 µm
0.8 µm
0.05 µm
0.2 µm
0.8 µm
Light microscope
200 µm
Confocal laser microscope
100 µm
Ra (µm)
2
0
0.09
0.27
0.86
0.44
1.48
1.04
Rz (µm)
10
0
0.85
1.85
3.97
2.42
1.93
5.04
Gloss units (GU)
500
0
161.4
224.6
11.2
44.7
1.2
17.2
160.1
208.5
43.1
66.9
23.4
33.4
20°
60°
Perceived Quality
10
5
0
7.3
7
5.5
4.1
4.4
7.4
7.3
7.7
6
5.6
5.2
4.6
Rough-ness
Shini-ness

Fig. 4.