

Investigation and Evaluation of Methods for Measuring Surface Texture on Worktops and Kitchen Fronts

Aniol Salvador Soy & Christian Öhrström

*Division of Machine Design • Department of Design Science
Faculty of Engineering LTH • Lund University • 2013*



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Preface

This Master Thesis has been conducted at the Department of Design Sciences, Faculty of Engineering LTH, Lund University in collaboration with IKEA of Sweden AB, between February and June of 2013.

We would like to thank everyone at IKEA who has taken the time to answer our questions and provided invaluable information to our project. Especially we would like to thank our supervisor Markus Malmén at IKEA of Sweden for his constant support and motivation, as well as Peter Lantz and Ted Kollevik for their help and input.

We would also like to thank our supervisor at LTH Karl-Axel Andersson and our examiner Giorgos Nikoleris for interesting discussions and valuable guidance. Special thanks as well to our opponent Ivi Kalyvioti, who took the time to go through our thesis report and contributed with helpful comments.

I després de tantes hores angleses, una mica de llengua materna: donar les gràcies als tres mosqueters, Jordi, Gemma i Coral, pels seus ànims incondicionals, i també a les iaies, per ser prou valentes per venir-me a veure tan lluny. Finalment, dedicar la tesi a l'amic Owen; si estiguessis aquí ho celebrariem junts.

Ett stort tack till våra vänner i ex-jobbs rummet, ni har sett till så att ingen dag varit den andra lik. Tack också till Karin för din ständiga uppmuntran och för att du under hela våren lyssnat eller i alla fall låtsats lyssna på mina långa utläggningar om yttextr.

Lund, June 2013

Aniol Salvador Soy & Christian Öhrström

Abstract

In this Master Thesis different methods for measuring and evaluating surface textures have been investigated and evaluated. A method for digitizing textures called photometric stereo have also been studied. The purpose has been to find methods that can replace or supplement the current method of visual inspection used for surface texture studies by IKEA of Sweden. The suggested methods are going to be used by the company for securing that the surface textures on laminate worktops and pigment lacquered kitchen fronts are both consistent between different suppliers and matching the original reference sample.

The thesis work has been written in three phases. First a background study of surface texture measurement methods has been carried out as well as a market research about what instruments are used for surface texture measurements. The next step has been an investigation of what problems IKEA is experiencing and finding the cause of these problems. This includes studies of the manufacturing process for laminates, the tools used for giving texture to laminates and how textures patterns are developed. The manufacturing process of the kitchen front has been also studied. In the last step the different methods have been tested and evaluated based on the needs of IKEA of Sweden.

Keywords: Surface Texture, Surface Roughness, Texture Pattern, Laminates, Profilometer.

Sammanfattning

Den här rapporten sammanfattar ett examensarbete utfört som en avslutande del av civilingenjörsutbildningen på Lunds Tekniska Högskola. Arbetet har utförts i samarbete med IKEA of Sweden AB under våren 2013. Målet med arbetet har varit att undersöka olika metoder för att mäta och kvantifiera yttexturer på bänkskivor i laminat och på målade köksfronter. Detta för att kunna ersätta eller komplettera IKEAs nuvarande kontrollmetod som endast består i visuell bedömning och jämförelse med referensprov. En metod för att digitalisera yttexturer som kallas photometric stereo har också undersökts.

Grunden till projektet är att IKEA idag inte kan ge sina leverantörer klara specifikationer på hur yttexturen på olika produkter ska se ut. IKEA kan heller inte på ett objektivt sätt kontrollera att en textur stämmer överens med den textur som finns på referensprovet. Metoden med visuell bedömning anses alltför subjektiv och har också visat sig otillräcklig i flera fall.

Arbetet har utförts i tre faser. I den första fasen har olika metoder för att undersöka och mäta yttextur studerats. Även de mätinstrument som finns tillgängliga på marknaden idag har undersökts.

I den andra fasen låg fokus på att identifiera vilka problem relaterade till yttexturer som IKEA upplevde och att hitta och förstå orsaken till dessa. I detta arbete studerades tillverkningsmetoderna för både laminatbänkskivor och köksfronter. Fabriksbesök genomfördes hos Supplier K som tillverkar laminat och hos Swedwood Älmhult AB som tillverkar köksfronter.

Tre problem relaterat till texturen på laminatbänkskivor har identifierats:

- Skillnader i makrotextur på produkter tillverkade av olika leverantörer.
- Variationer i mikrotextur och glansnivå på produkter tillverkade av olika leverantörer.
- Variationer i både makro- och mikrotextur samt glans på produkter tillverkade av samma leverantör.

Skillnader i makrotextur mellan olika leverantörer bedöms vara det problem som ger störst effekt på det slutgiltiga utseendet hos produkten. Om en kund köper två exemplar av samma bänkskiva men har otur och får exemplar tillverkade av olika leverantörer kan utseendet skilja sig markant åt. Grunden till det här problemet är att leverantörerna använder olika texturmönster, något som har sin grund i att leverantörerna inte haft tillgång till samma original ritning av mönstret när

produktionen startat. Leverantörerna har istället fått försöka skapa en kopia av originalet eller använda sig av ett liknande mönster.

Variationerna i mikrotextur och glansnivå mellan leverantörerna kan bero både på att korrekta värden inte funnits att tillgå från början så att fel använts eller på förslitning av de verktyg som används för att ge textur på laminaten.

De variationer som finns på produkter från samma leverantör beror antingen på processvariationer vid tillverkningen såsom temperatur, tryck, tjocklek på pappret samt fukthalt eller på grund av verktygsförslitning. En av de metoder som används för att ge textur till laminat är att använda något som kallas release paper. Detta är ett papper som fått laminattexturen präglad på sig och som sedan läggs ovanpå laminatet så att laminat ytan formar sig efter papprets textur under tillverkningen.

Utifrån dessa identifierade problem har slutsatsen att fyra olika parametrar måste kontrolleras för att säkerställa att laminatens textur är enhetlig. Dessa fyra parametrar är:

- Textur mönstret
- Texturens djup
- Mikrotexturen på ytan
- Ytans glansnivå

Två problem kopplade till texturen på köksfronter identifierades:

- Skillnader i ytfinhet mellan olika områden på köksfronten
- Förekomst av apelsinskalseffekt på vissa av de tillverkade köksfronterna

Skillnaderna i ytfinhet mellan olika områden på köksfronten uppstår på grund av materialvalet och tillverkningsmetoden. Köksfronterna är tillverkade av MDF-skiva och bearbetade genom fräsning. Både fräsningen och det faktum att densiteten på MDF-skivan minskar ju längre från dess ursprungliga yta man kommer bidrar till att det blir en lägre ytfinhet på de områden som bearbetats.

Apelsinskalseffekt är något som uppkommer under spraymålningen av köksfronterna, om lösningsmedlet i färgen avdunstar så snabbt att färgen inte hinner flyta ut ordentligt kan färgen stelna i ett mönster som liknar det hos ett apelsinskal. Detta problem relaterat till målningen kan klassas som ett texturproblem och inte som en lokal defekt då det kan uppstå över större ytor.

Utifrån dessa identifierade problem har slutsatsen att tre olika parametrar måste kontrolleras för att säkerställa att köksfronternas textur är enhetlig. Dessa tre parametrar är:

- Texturen på köksfrontens olika områden
- Mängden apelsinskalseffekt
- Ytornas glansnivå

I den tredje fasen har de metoder som funnits intressanta och varit tillgängliga testats och utvärderats för att se om de kan leverera användbara resultat till IKEAs

användningsområden. Tester med Mitutoyo SJ-400 profilometer, GFM3D MikroCAD, Optimap PSD och BYK Wave-Scan dual har utförts.

Från testerna som gjordes på laminatbänkskivorna har författarna dragit slutsatsen att med korrekt valda mätparametrar kan profilometern användas för att ge mätvärden på de olika parametrar som författarna bedömde viktiga.

Av testerna som gjordes på köksfronten bedöms även där profilometern vara det bästa instrumentet för att mäta ytfinheten på de olika områdena. För att mäta apelsinskalseffekt och ytans visuella egenskaper anses Optimap PSD vara det bästa instrumentet.

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1 Introduction

In this chapter a brief overview of IKEA's history is given. The background, aims and delimitations of the thesis are described.

1.1 History of IKEA

IKEA was founded in 1943 by the then 17 years old Ingvar Kamprad. The name IKEA is derived from his initials (IK) and the first letters in Elmtaryd (E) and Agunnaryd (A). Elmtaryd was the farm where Ingvar Kamprad was born and Agunnaryd the village he grew up in. In the beginning IKEA was selling small items like pens, wallets, picture frames and watches. The products were sold door to door by Ingvar Kamprad himself and later through mail order. The business model was simple: buying large quantities from the manufacturer for a low price and selling them piece by piece to the customer for a price lower than the competitors [1].

In 1948 furniture was introduced into the range, advertised in the local newspapers and sold by mail order. The response from the customers was very positive and in 1951 the first IKEA catalogue was released. In 1953 the first furniture showroom opened in Älmhult, so the customers were able to see and touch the furniture before ordering it. It was during this time that IKEA started to design its own line of furniture and also when the flat package was born. Since the furniture was sold by mail order, the flat package was both cheaper and less prone to become damaged during the transport. This meant that the customer had to do the final assembly at home. In 1958 the first IKEA store opened in Älmhult and in 1960 the first IKEA restaurant was added to the store [1].

By then, many of the IKEA's foundations that are known today were in place: the catalogue, the store with showrooms for all the products, the restaurant for hungry customers and the iconic flat package that enabled cheap and efficient transport.

In the 1960s and 1970s many of IKEA's now classic products such as POÄNG, KLIPPAN and the bookcase BILLY were introduced. IKEA also expanded into Scandinavia and northern Europe with stores in Denmark, Norway, Austria, Germany, Switzerland and the Netherlands. Stores were also opened in Australia and Canada [2].

In the 1980s IKEA's expansion continued with stores opening in France, Belgium, USA, United Kingdom and Italy. IKEA had then more than 60 stores and 10.000 co-workers. Products like the LACK table and MOMENT sofa were added to the range [2].

In the 1990s the rapid expansion continued: new stores were opened in Spain, Hungary, Czech Republic, Poland and China. A greater focus on environmental issues was taken with the first environmental policy as well as co-operations with Greenpeace. IKEA became member in the global Forest Stewardship Council. Children's IKEA was launched with a whole range of furniture specially made for children as well as the first IKEA PS collection, a designer collection with creatively designed items which are renewed every third year. IKEA 365+ was also launched as a collection of functional and attractive products for everyday cooking and eating [2].

In the 2000s IKEA continued to expand into new markets such as Japan and Russia. The bedroom and kitchen range was increased and IKEA Food was launched; under this label IKEA sells food products based on Swedish recipes and tradition. New environmental projects were developed and several social projects started [2].

In 2012 IKEA's range consisted of approximately 9500 products sold through 298 stores in 26 different countries operated by the IKEA Group and another 40 stores operated by other franchisees [2], [3]. The IKEA Group employs 123.000 people in 25 different countries and has 1084 home furnishing suppliers in 53 countries [4].

1.2 Problem description

IKEA sells many different types of worktops and kitchen fronts in the kitchen range. They are made of different materials, produced in different ways and by different suppliers. Today IKEA is working with reference samples to explain the surface texture of the different products. This method has several drawbacks. First of all it is a very subjective method since it is based on people's opinion about the surface texture. People have different points of view and one person's opinion may also change over time. Secondly this method makes it hard to get objective and quantifiable values of the surface texture. One can only put "relative values" on the surface texture compared to a reference sample, and conclude that the surface texture is rougher, smoother, or the same as the reference sample. But also these "relative values" are very subjective since one person may judge a surface to be rougher than the reference sample while another person thinks the surface is the same or smoother than the reference sample. IKEA have identified several situations when the current method is inadequate and there is a need for a more reliable and objective method.

When starting a new supplier for an existing product it is important to validate that the product delivered from the new supplier is as similar as possible to the products delivered from existing suppliers. If a customer already has a product and decides to buy another one, the new item must precisely match the old one. In this situation it is very important that color, surface texture and gloss level are matching those on the existing products, especially if the products are to be placed side by side in the customer's home.

A new method is also needed to control the products delivered by existing suppliers. Both to see that the surface texture of the delivered products does not change over time and that they are matching between different suppliers.

With some manufacturing techniques there can be fluctuations of the surface texture in the running production. IKEA has today no method of putting tolerances on the surface textures to decide when a product is approved and when it is not. That is currently judged from time to time by different people making the process subjective and increasing the risk of unsatisfied customers.

1.3 Aims

The aim of this project is to investigate what different methods exist for measuring and characterizing surface textures.

To identify what problems related to surface textures IKEA are having and find their causes.

To evaluate the measuring methods and find the best methods for IKEA's needs.

1.4 Delimitations

The thesis will focus on finding a method for measuring and characterizing the surface texture of IKEA's laminate worktops and pigment lacquered kitchen fronts. The work will focus on two different worktop textures that have different suppliers and are sold in high volumes as well as on one kitchen front (ZZ) made from MDF board. These surfaces are good examples of the different surfaces in IKEA's kitchen range and also the surfaces that IKEA finds the most interesting to study.

Since measuring surface textures is a very complex subject, the focus will be on investigating existing methods rather than inventing new ones. The authors started to look into image analysis as a possible method, but due to the fact that it did not seem to have a good potential and the lack of knowledge of the writers in this field, they decided not to proceed with it. It was not possible to test samples using the Cruse scanner equipment (one of the suggestions in chapter 7) because of time limitations.

Finally, the supplier's names as well as the name of the different products studied have been removed due to confidentiality issues.

2 Method

In this chapter the structure of the report and the different steps followed are described.

2.1 Work layout

The work has been carried out at Lunds Tekniska Högskola, in Lund, with visits to IKEA of Sweden, in Älmhult, for meetings with supervisor Markus Malmén and other IKEA employees. Trips to Malmö, Halmstad and Gothenburg were also done to meet with resellers of different measuring instruments and to visit a trade fair. A factory visit to Supplier K in Pustków, Poland, was carried out to study the laminate process and the quality control process of laminates. Swedwoods factory, in Älmhult was also visited to study the manufacturing process of kitchen fronts.

The project started out as a very open project without any predefined structure. IKEA's request was that they had several different problems and they wanted a solution to these problems. The project plan has therefore developed during the course of the project but can roughly be divided into three different stages. The background research phase, the market research and concept development phase, and finally the concept evaluation and testing phase. These stages have overlapped in some parts but they describe what have been the main activities during the different stages of the project.

2.1.1 Background research

The authors had limited knowledge about surface textures and surface texture measurements. Therefore the project started with a background research phase where methods for surface roughness measurements, the problems IKEA was having and the production processes for the relevant surfaces were studied.

2.1.2 Market research and concept development

As the project evolved the next logical step was a market research phase where the different technologies for measuring surface textures were explored. Also during this phase the different parameters that need to be measured in order to specify a texture were decided and different concepts for measuring them were developed.

2 Method

2.1.3 Concept evaluation and testing

During this phase the different methods for measuring the needed parameters were tested and evaluated to see if they were able to deliver the needed results. The test results were discussed and conclusions drawn about what methods were the best for IKEA's needs.

3 Background research

In this chapter the frame of reference is developed, analyzing the evolution of surface texture and metrology through history, different methods to characterize surfaces, how other industries work with this topic, the laminate manufacturing process and the kitchen front manufacturing process.

3.1 History of surface texture and surface metrology

Surface texture has become the most critical factor and functionality indicator in the performance of high precision devices. The interest in this field started to increase during the Second World War to control the manufacture of armaments and, since that time, the production of domestic goods and appliances. Surface metrology is the discipline that characterizes the surface texture.

Surface metrology is the science of measuring small-scale geometrical features on surfaces, i.e. the surface topography. The origin of this discipline started centuries ago, with the investigation into the friction between surfaces carried out by da Vinci, Amontons and Coulomb. Along the history, this field has been important due to its association with other disciplines such as quality of optical components, tribology, surface engineering and manufacturing processes. Several issues have always surrounded this complex discipline: is current surface metrology adequate? Can surface metrology be used as a simple quality control in industry or should it be used to gain a deeper understanding of the surface? During the lifetime of the surface metrology as a discipline, there have been different historical shifts [5].

3.1.1 The instrumentation shift

For many years the only way to assess surface textures was using the thumbnail and the eye. Obviously both methods were completely subjective and effective only if used by an experienced practitioner. When applying these methods, a basic problem in surface measurement appeared which is present even today for modern contact instrumentation: whether to measure normal to the surface or across it. One aspect was clear: the need to develop methods to quantitatively assess surfaces. Hence, instrumentation started to be used in order to magnify normal to the surface.

One of the first methods was using a galvanometer incorporating a mirror to give a magnification around 30X. Then the first optical methods appeared (simply projecting a line of light across the surface at an angle), but manufacturers considered optical

methods too sensitive for in-line measurements or to be used near machine tools. Therefore, simple tactile methods were the chosen ones (around 1933): stylus held in a pick-up, connected to a transducer, amplifier and meter. In the first serious measurements with a stylus instrument the transducer was a hot wire and the meter only read the root mean square (r.m.s.) value. The reading was difficult to verify owing to the fluctuations. It was soon realized that a measure relative to a mean line was preferred and the output of the transducer was divided by a factor: the result was called arithmetic average AA (it would later become R_a). In the second half of the 1930s the first commercial instruments showing a chart with the roughness profile appeared in the market, and the term “profilometer” started to be used. Not all these instruments, however, used a stylus: capacitance and pneumatics methods were also employed [5].

At this point is when the utilization of roughness parameters started. The initial idea was, by using just one parameter, assessing the surface in a scale from “goodness” to “badness”. Some differed from this method since they considered it simplistic: what parameter should be used? For this reason the profile shape itself gained importance as a way to characterize the surface. Therefore, one method offered too little data whereas the other one represented the surface by too much data. Here the solution was developed by Dr. Abbott (during the 1930s), with the Abbott & Firestone curve, also known as the material ratio curve or the bearing curve, where the surface profile was converted into a curve that was a function of the profile depth. This curve is still used today [5].

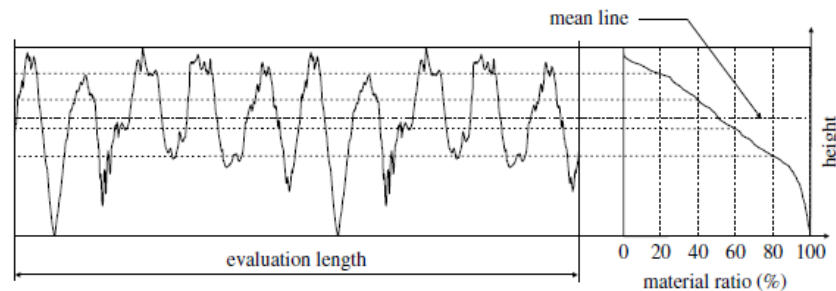


Figure 3.1 Abbott-Firestone curve [5]

Thanks to this curve the relation between function and parameters was simple enough to control manufacturing. However, two basic problems were present: it did not give any spatial information on the surface and the curve should start at the highest peak of the surface.

During the 1940s and the 1950s, important books were published regarding surface texture and metrology, describing the different components of texture: form (due to the design), waviness (because of the machine tool effect) and roughness (owing to the manufacturing process). All this components could form a periodic or random structure.

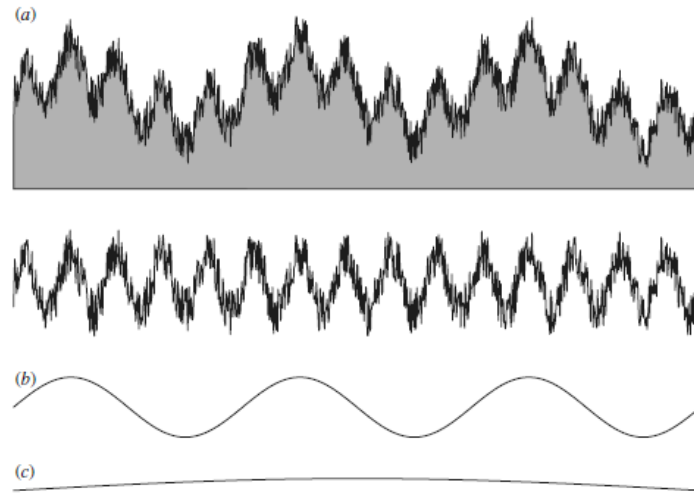


Figure 3.2 Geometric components of a surface: (a) roughness, (b) waviness and (c) form [6]

The studies also decomposed the components according to wavelength bands: form and waviness were considered long-wavelength components whereas roughness was short-wavelength. The main problem with this issue was where the wavelength boundary between the waviness and the roughness bands should be placed. Several attempts were carried out in order to remove the waviness component of the surface texture (to be able to study the roughness): one was using electrical filters in the meter circuit and the other one was mechanical, simulating the contact of a converse surface (such as a large circle rolling across the profile). During the sixties, with the appearance of computer systems and theoretical improvements to both the analogue and digital filters, the first attempt succeeded over the second.

3.1.2 Shift to the digital age

The need of observing what happened between two surfaces in contact lead to the use of computers in order to simulate this contact after mapping the surfaces digitally. This field studying the behavior of interacting surfaces in relative motion is called tribology; it includes lubrication, contact mechanics, friction, wear, surface damage and coatings [7]. Thus, at the end of the 1960s, tribology was the first science/engineering related to surface texture claiming for the use of digital equipment.

One of the most significant digital progresses was the simulation in the computer of the waviness filter. From that point, it was possible to implement any parameter in software: every process engineer developed his own roughness parameters, making standardization a difficult goal to achieve.

Simultaneously to the digital revolution in surface metrology, two other advances were made. First of all, the realization that surface texture could be represented not only as periodic signals derived from operations such as turning or milling, but also as random signals derived, for example, from abrasive processes. The second advance was the progress made in the tribology field (i.e. friction, wear, lubrication and mechanical contact). With these two improvements and the help of phase-corrected filters, digital characterization could be used to produce more realistic images of surfaces and, therefore, to go forward in the surface metrology field.

3.1.3 Separating form and texture and improving the vertical-range

The first surface texture instrument that actually could measure both surface texture and form with a single profile measurement had its origin in an MSc Thesis (1977). The instrument was commercially available in 1984; before that, surface texture instruments had only a dynamic range from 100 to 300 μm , in contrast to this new equipment that had a usable vertical range of 2 mm with a resolution of 5 nm. The reason of this improvement was not only the new revolutionary transducer (the device that converts the mechanical movement of the stylus to electrical signals) but also the correction of nonlinearities thanks to the enhanced movement of the lever holding the stylus. At the same time, this was due to the creation of mathematical optimization algorithms that could calculate the calibration constants automatically, ensuring a precise Cartesian coordinate system in the measurement plane. This coordinate system allowed the separation between form and texture through mathematical algorithms: any shape that was mathematically defined could be removed from the profile with the corresponding algorithm.

Different transducers have been continuously developed; currently (2007) the vertical range of some surface texture instruments with very good transducers can reach up to more than 20 mm with a resolution of 0,1 nm [5]. However, the standard vertical range of a stylus instrument normally varies from 0,5 mm to ± 2 mm; this means that the sensor located inside the pick-up of the instrument can measure down to -1,5 mm and up to 2,5 mm [8]. As an example of a modern profilometer, the Mitutoyo SJ-400 that IKEA uses was bought in 2011 and has a resolution of 0,125 nm and a vertical range of 800 μm .

Apart from the historical shifts (developed above) the surface metrology discipline is currently experiencing changes as well. This is due to the need of measuring and qualifying micro- and nanometer scale manufactured components commercially available. These components, such as implantable medical devices or semiconductor surfaces, require a specification of surface form with precision up to levels approaching atomic magnitude. The most significant change that is currently happening is the shift from profile to areal characterization [5].

The first areal measurements of surface texture were done at the end of the 1960s, using conventional stylus systems along parallel traces. The first two dimensions (x and z) were realized when the 2D profile was traced, and the third dimension (y) generated as each trace scan was obtained [8].

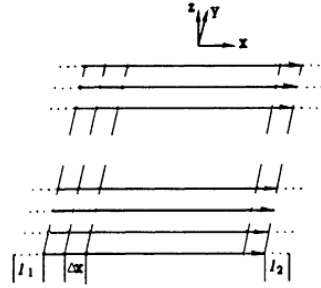


Figure 3.3 Coordinates of raster scan [8]

However, it was not until the appearance of the personal computer in 1980s when the areal characterization started to become useful. This is due to the fact that a lot of data was involved in these processes, being really difficult to handle without the help of computers. The first commercially available areal surface instruments appeared in the early 1990s, based on optical interferometry. Nowadays there are several techniques to acquire areal measurements, such as phase-shifting interferometry, white-light interferometry, confocal microscopy, chromatic probe microscopy, structured light techniques, scanning electron microscopy, scanning tunneling microscopy and atomic force microscopy.

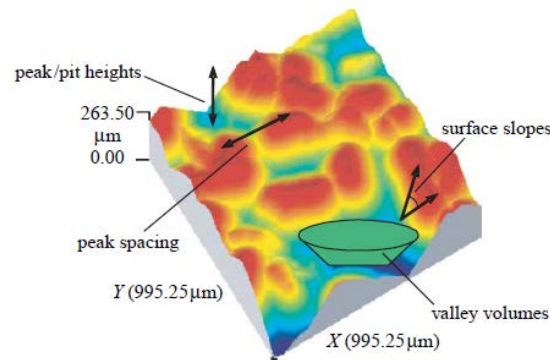


Figure 3.4 Some simple attributes used to characterize areal surface texture [6]

The biggest development in areal characterization came in 1990 with the BCR research program *An integrated approach to 3D surface measurement* [9], supported by the European Community. This program stated the first definitions for the parameter set called *Birmingham 14 parameters* [8]. In 1997 the same European Community asked for a standardization of areal surface characterization; the research program called *The development of a basis for three-dimensional surface roughness*

standards [10], also known as *SurfStand*, formed the basis for these standards in 1998. Consequently, in 2002, the ISO/TS 25178 series (areal surface texture standards) started to be developed.

3.2 Methods of describing and characterizing surfaces

3.2.1 Visual

The easiest way to investigate a surface is by looking at it. The human eye is very good at detecting differences in color, texture and gloss, especially when comparing two samples side by side. How small objects the human eye can see is a rather complex optical discussion. The human eye can see objects of any size as long as they reflect enough light to trigger the detector cells in the eye. For example the star Deneb, which has an angular diameter of 0,0024 arcseconds, can be seen by the naked eye. A light-emitting object perceived to have the same size, when viewed at a distance of 15 cm from the eye would be 1,75 nanometers wide. Also smoke particles can be seen even though the particles are too small to be seen one by one. The real limit of the human eye is how close two objects can come before they blur into one. In practice objects as small as 0,04 mm wide can be resolved when viewed from a distance of 15 cm [11]. What is visible and not is dependent on several factors such as light conditions, the objects reflectiveness, color and size. In general terms, one could say that the macro texture of objects can be seen but the micro texture cannot.

To aid the visual study and the capture of images of surface textures different methods have been investigated.

3.2.1.1 USB – microscope

An USB-microscope (Figure 3.5) is a compact microscope with a built-in digital camera. It is connected through a USB-connection to a computer, which displays the magnified object; then images can easily be captured through the bundled software. It uses incident light from LED-lights placed around the lens. The magnification is usually in the range between 20x and 200x. The price range is from 25€ for simple models up to 700€ for higher quality models with high-resolution image sensors and solid construction [12]. The image resolution varies from 0,3 Mpx on the cheapest versions up to 5 Mpx on the high-end models. USB-microscopes provide an easy method for magnifying surface textures and capturing images of them.



Figure 3.5 USB-microscope [13]

3.2.1.2 Macro photography

One way of capturing magnified pictures of surface textures is by using a macro lens mounted to a digital camera. The output is the same as with an USB-microscope but the image quality is better. The optical quality of a macro lens is higher than the lenses found in USB-microscopes and a digital camera is able to capture higher resolution images. The downside of macro photography is a higher cost, heavier and more complex equipment, which is also less user-friendly.



Figure 3.6 Camera with macro lens and extra flashes [14]

3.2.1.3 GelSight

GelSight is a new type of sensor (Figure 3.7) that can be used to record surface shape and texture. It consists of a piece of transparent elastomer covered on one side with a reflective coating. When pressed against an object the elastomer deforms and takes the shape of the object's surface, which can be viewed through the elastomer. In this basic way it can provide a better image of a surface texture by removing color and gloss [15]. In Figure 3.8 human skin can be seen photographed through the GelSight sensor.

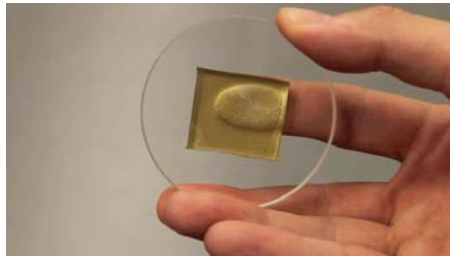


Figure 3.7 GelSight sensor



Figure 3.8 Skin photographed through a GelSight sensor

The elastomer can also be fitted to a camera and, by using different lighting angles and a photometric stereo algorithm, a 3D image of the surface can be captured [16]. In Figure 3.9 a 3D rendered image of letters printed by a laser printer can be seen.

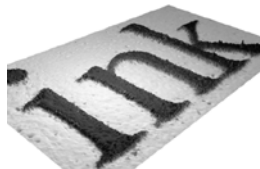


Figure 3.9 Laser printed letters on paper. Geometry rendered with a color texture map [17].

The technique is still in an experimental stage but can provide a cheap and efficient way of studying and recording surface texture if developed into a commercial product.

3.2.1.4 Photometric Stereo

Photometric stereo is a technique used to estimate the surface normals of an object by photographing it under at least three different lighting conditions [18]. From these images a 3D image can be calculated. The information is stored in an image called a Normal Map; it is an ordinary 2D digital image in a format such as JPEG or TIFF.

The RGB-values of each individual pixel are used to store the XYZ-coordinate of the point of the surface represented by that pixel. In practice, the steps for acquiring a height map are: taking at least three (often four) images (as can be seen in Figure 3.10) with the light coming from different angles. Then these photos are merged in a graphics-editing program such as Adobe Photoshop to obtain the Normal Map [19]. Figure 3.11 is an example of a Normal Map.



Figure 3.10 Pictures taking with the light coming from four different angles [20]



Figure 3.11 Normal Map [20]

From the normal map a Height Map can be calculated. A Height Map is a grey scale image where every grey level represents a height. In this way three dimensions can be stored in a two dimensional image by using the color (grey level) to store information about the third dimension. A lighter shade of grey means a higher point and a darker shade represents a lower point. Thus, a bitmapped image that uses 8 bits to indicate the color of a single pixel (8 bpp) can have $2^8=256$ different grey levels. In Figure 3.12 a Height Map image can be seen and in Figure 3.13 the same Height Map is shown after being rendered in 3D. These methods are commonly used in computer graphics.

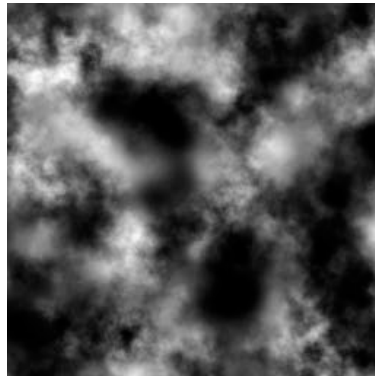


Figure 3.12 Height Map

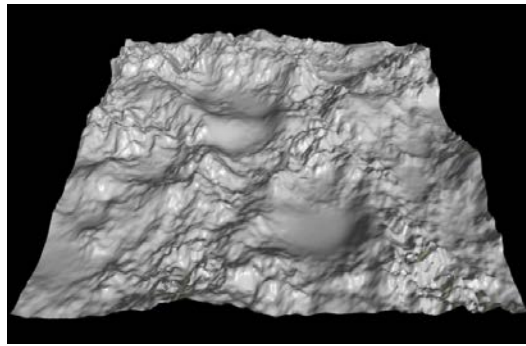


Figure 3.13 Rendered Height Map

3.2.2 *Visual appearance measurements*

The visual appearance of a surface is closely linked to the texture of the surface and has therefore been studied.

3.2.2.1 *Gloss*

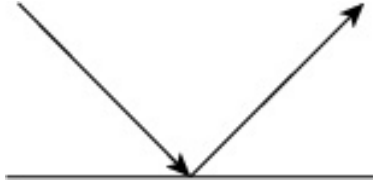

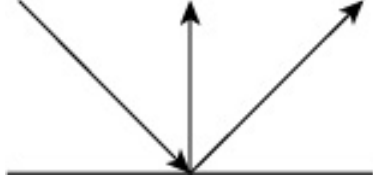
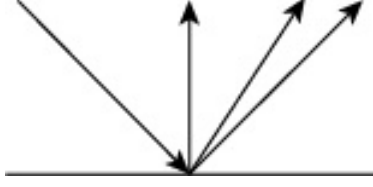
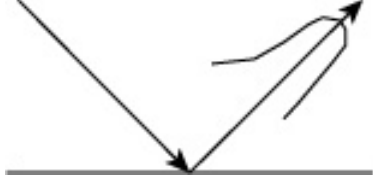
Visual appearance can be described in several ways and, apart from color, the most common property is gloss. In 1934 Hunter designed a gloss meter to study how different materials reflected light at 45° to the surface normal. He identified six different criteria that could be used to measure the appearance of gloss on a surface [20].

The six criteria are:

- Specular gloss: the ratio of the light reflected from a surface at the same angle as the incident light but on the opposite side of the normal surface.
- Sheen: the gloss at grazing angles of incidence and viewing.
- Contrast gloss or luster: the ratio of the specularly reflected light to that diffusely reflected normal to the surface.

- Absence-of-bloom: a measure of the absence of haze or the ‘milky’ appearance adjacent to the specularly reflected light.
- Distinctness-of-image (DOI): the sharpness of the specularly reflected light.
- Surface uniformity: a measure of the freedom from surface non-uniformities such as texture.

Table 3.1 Hunter's different types of gloss [20]

| Type of gloss | Visual evaluation | Reflectance function | Types of surfaces |
|-----------------------------|---|--|--|
| Specular gloss | Shininess, brilliance of highlights |  | Medium-gloss surfaces of book paper, paint, plastics, etc. |
| Sheen | Shininess at grazing angles |  | Low-gloss surfaces of paint, paper, etc. |
| Contrast gloss or luster | Contrast between specularly reflecting areas and other areas |  | Low-gloss surfaces of textile fiber, newsprint, etc. |
| Absence-of-bloom gloss | Absence of haze adjacent to reflected highlights |  | High- and semi-gloss surfaces in which highlights may be seen. |
| Distinctness-of-image gloss | Distinctness and sharpness of mirror images |  | High-gloss surfaces of all types in which mirror images may be seen. |
| Surface-uniformity gloss | Surface uniformity, freedom from visible non-uniformities such as texture | Not a function of reflectance | Medium-to-high-gloss surfaces of all types. |

3.2.2.1.1 Specular gloss

The most common type used in gloss measurement is specular gloss. Specular gloss describes the surface's ability to reflect light into the specular direction, which is the direction with the same angle as the incoming light ray but on the opposite side of the surface normal. A glossy surface reflects most of the incident light into the specular direction, but a matte surface scatters most of the light into different directions as seen in Figure 3.14.

Factors that affect specular gloss are the angle of incident light, the refractive index of the material, and the surface topography. Objects with smooth surfaces reflect more light into the specular direction and appear glossy, such as mirrors and polished metals. On the contrary, objects with rough surfaces reflect less light into the specular direction and appear matte.

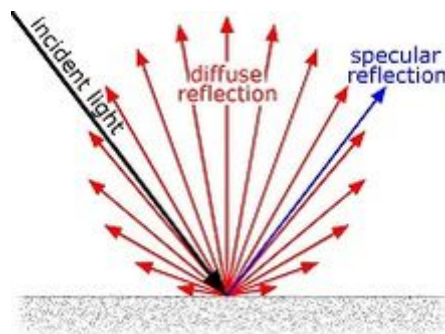


Figure 3.14 Illustration of diffuse and specular reflection

3.2.2.1.2 Distinctness of image and Haze

A surface with a high reflectance at the specular angle can appear very shiny, but an image reflected in the surface can still appear dull or with low contrast. This is characterized by the distinctness-of-image (DOI) and haze (the inverse of absence-of-bloom) or by the contrast gloss. In Figure 3.15, samples with different DOI values can be seen. DOI is measured on a scale from 1-100, where 100 is a surface with a mirror-like reflection. Two samples with different amounts of haze can be seen in Figure 3.16.

An effect often measured with distinctness of image is the orange peel effect: the painted surface gets a texture that resembles the surface of the skin of an orange. It occurs when the solvent in the paint evaporates so fast that the paint does not have time to flow out evenly. It is more prone to occur on rough surfaces where it takes more time for the paint to flow out evenly, as well as vertically painted surfaces.



Figure 3.15 Samples with different DOI values [21]



Figure 3.16 Samples showing different amounts of haze [21]

3.2.2.1.3 Gloss meter

Specular gloss is measured with a gloss meter. An example can be seen in Figure 3.17. It's an instrument that shines a known amount of light onto a surface at a predetermined angle and quantifies the reflection. The angle used is dependent on the anticipated gloss level of the measured surface. Table 3.2 explains how to choose the correct measuring angle. The three measurement angles, as seen in Figure 3.19 (20° , 60° , and 85°), are specified to cover most types of surfaces. Usually 60° is used, but for high and low gloss surfaces it should be changed to 20° and 85° respectively. For example, if the measurement made at 60° is greater than 70 GU, the measurement angle should be changed to 20° to optimize measurement accuracy.

Two more angles are specified to be used on certain materials: an angle of 45° for measuring ceramics, textiles and anodized aluminum, and an angle of 75° for paper and printed materials [22].



Figure 3.17 Gloss meter [23]

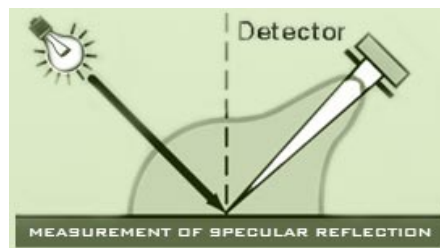


Figure 3.18 Gloss meter principle

Table 3.2 Gloss measuring angles

| Gloss Range | 60° Value | |
|--------------|------------|---|
| High Gloss | >70 GU | If measurement exceeds 70 GU, the test setup must be changed to 20° |
| Medium Gloss | 10 – 70 GU | If measurement is in between 10 and 70 GU, the 60° angle is the right one |
| Low Gloss | <10 GU | If measurement is less than 10 GU, the test setup must be changed to 85° |

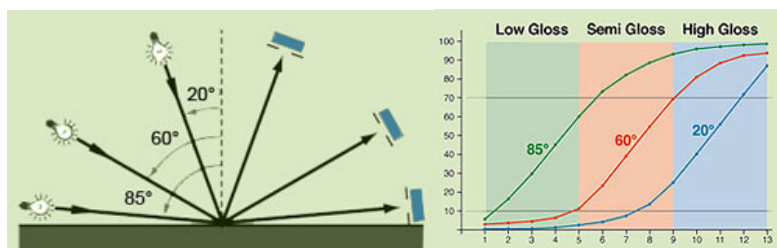


Figure 3.19 Gloss measuring angles

3.2.2.1.4 Gloss Unit (GU)

Gloss is measured in a unit called Gloss Unit (GU). It is defined based on the reflected light from a black glass standard with a defined refractive index. The gloss meter is calibrated so the measurement value for this defined standard is equal to 100 GU and the result from a completely matte surface is equal to 0 GU. Materials with a higher refractive index can have a measurement value above 100 GU. Polished metals can reach as high as 2000 GU and transparent materials can also reach very high measurement results due to the reflection inside the material. When very high GU values are reached, the measurement result is usually reported in % reflection of the illuminated light [11].

3.2.2.1.5 Goniophotometric curves

The amount of light reflected by a surface can vary depending on at what angle the surface is observed. A Goniophotometric curve, as seen in Figure 3.20, shows how the amount of light that is reflected or transmitted by an object varies as the viewing direction changes. A Goniophotometric curve is created by fixing a light source at a specific angle and measuring the reflectance at various viewing angles [10]. The peak value of the Goniophotometric curve is called *Rspec*.

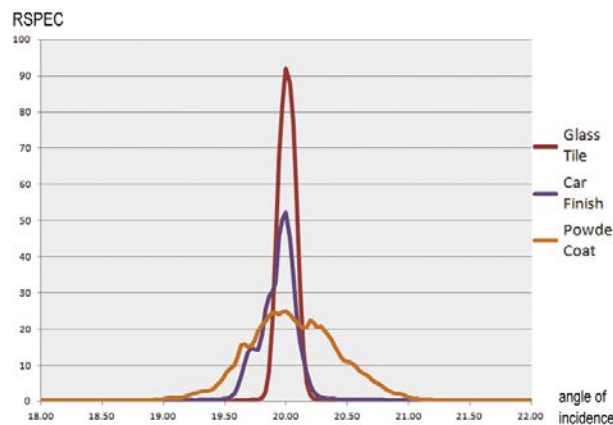


Figure 3.20 Goniophotometric curve

3.2.2.2 Wave-Scan

Wave-Scan and Wave-Scan Dual (Figure 3.21) are two instruments developed by BYK-Gardner, trying to simulate the visual perception of humans and quantifying it. The instruments have been developed in cooperation with the car industry and are mostly used to measure the paint coating on cars. The price is relatively high, listed at 21700€ and 24.750€ respectively [24]-[27].

The Wave-Scan can only be used on high gloss surfaces, and it is rolled across the surface for 5-20 cm. It uses a laser to scan the surface and a CCD sensor to measure the reflection.

The Wave-Scan Dual can be used on both high and medium gloss surfaces. It uses both a laser and an infrared LED to scan the surfaces. The optical profile recorded by the CCD sensor is band-pass filtered into five different wavelengths (BYK uses the letter W to refer to these wavelengths ranges). Dullness that comes from structures smaller than 0,1 mm is also measured [25].



Figure 3.21 Wave-Scan Dual from BYK – Gardner [13]

Table 3.3 Wavelength ranges

| Range | Wavelength (mm) |
|-------|-----------------|
| du | < 0,1 |
| Wa | 0,1 to 0,3 |
| Wb | 0,3 to 1 |
| Wc | 1 to 3 |
| Wd | 3 to 10 |
| We | 10 to 30 |

3.2.2.3 Phase Stepped Deflectometry (PSD) principle: Optimap

The measuring equipment that uses this technique is called Optimap PSD, from the company Rhopoint Instruments. This optical technique uses white light to project a periodic pattern with sinusoidal waveform on a surface. The pattern is produced by a high-resolution display, and a CCD sensor (high-resolution camera) captures the reflection of the image on the surface. This method requires no movement of the measuring equipment over the surface.

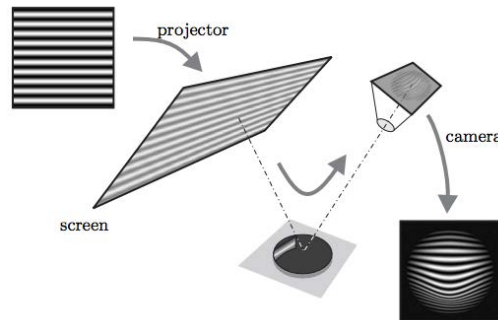


Figure 3.22 PSD performance [28]

The pattern acts like a ruler across the surface, allowing the co-ordinates of the surface to be mapped. By stepping the waveform phase of the pattern and by using the geometric relationship between the display, surface and camera, each point on the surface is spatially modeled to calculate its curvature.

An appearance defect can be defined as a fast variation in a surface profile across a short distance being dependent on its amplitude and wavelength. Therefore curvature, which is the first derivative of the slope and the second derivative of the amplitude, combines both parameters making it suitable to measure appearance.

Once the wavelength band is selected from the waviness scale (Rhpoint refers to them as K-bands instead of W-bands) the correlated value of waviness (curvature) is calculated (m^{-1}). By applying standardized equations to this curvature values, the texture values are obtained ($T_a - T_e$) [29].

Table 3.4 Wavelength ranges

| Range | Wavelength (mm) |
|-------|-----------------|
| Ka | 0,1 to 0,3 |
| Kb | 0,3 to 1 |
| Kc | 1 to 3 |
| Kd | 3 to 10 |
| Ke | 10 to 30 |

This optical method is more suitable for analysing the appearance of a surface rather than carrying out a deep study on the surface roughness. This is due to the following reasons:

- It does not provide R or S-parameters (both used to study roughness). The texture values obtained ($T_a - T_e$) give more information on the appearance than on the roughness of the studied surface.

- A large area is mapped in a single operation (Optimap: 95x70 mm²). This means that a bigger area can be studied compared to the optical methods providing S-parameters, allowing a more representative measurement. However, it also means that the vertical resolution is lower (Optimap: 75 µm).
- It allows measurements in a large variety of surfaces: from semi matt surfaces to polished mirrors (high gloss surfaces).

Thus, the Phase Stepped Deflectometry technique can be placed in between the optical methods providing roughness parameters and the traditional visual/tactile tests.

3.2.3 Roughness parameters

3.2.3.1 Profile measurements (2D)

This method has been the most traditional and common one to study surface texture in history. The parameters obtained are measured within a 2D profile, even though surface topography is three-dimensional in nature (it will always give an incomplete description of the reality) [8]. The length of the profile is called evaluation/measured length (L_n) and it is the part of the traversing length from where the values of the surface parameters are determined. At the same time, this evaluation length is composed of n sampling lengths (usually $n=5$); the sampling length is the reference for roughness evaluation [30]. In total, the traversing length is the evaluation length plus the start-up length (approach travel and pre-travel) and the trailing length (post-travel). In the Figure 3.23, each sampling length (l) is equal to the cutoff filter λ_c (explained more deeply in this section).

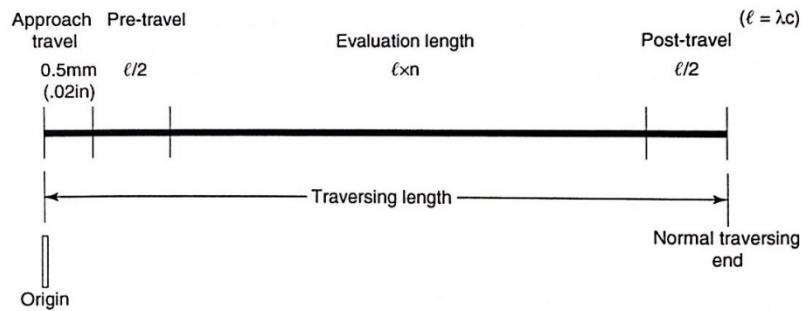


Figure 3.23 Lengths used in the measurement [31]

The stylus method is the most used 2D measurement; it has been used for 80 years and it is still utilized. It consists in a driving unit running a stylus (which is in contact with the surface all the time) along the profile. The distance between the pick-up (part of the device holding the stylus) and the surface remains constant, and the motion of

the lever is converted into electrical signals which are filtered by different sorts of filters depending on what kind of profile is going to be displayed.

There are as well non-contact methods based on focus detection. They consist in detecting the focus position of the incident light using a focus detector that analyses the light reflected from the surface. The lens movement follows the surface contour and it is measured by a transducer. Because of the similarities in the realization of movement, the horizontal resolution and range of the focus detection method is comparable to the stylus one [8].

The operating procedure of the profilometer consists in, first of all, removing the unwanted small-scale lateral components of the surface such as measurement noise. This is done using a low-pass filter (cutoff wavelength λ_s) that will delete the short-wave profile parts (shorter than λ_s). The operation that follows is called fitting and it consists in removing the underlying geometry of the surface (form removal process). This is done through an F-operator: the operator firstly uses optimization to determine a best fit to the nominal form, and then removes the fitted form from the surface [32]. Once these steps are executed, the primary profile of the surface can be obtained. The parameters extracted are identified by P and evaluated within the sampling length, which is defined by the cutoff wavelength λ_s .

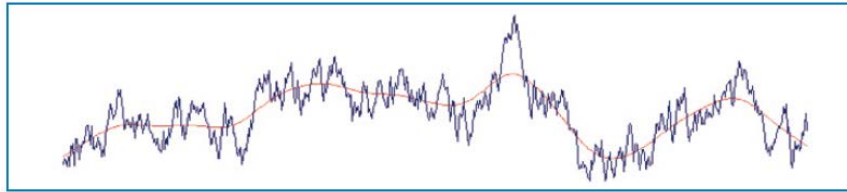


Figure 3.24 Primary profile after λ_s low-pass filtering [31]

The filtering operation comes after the low-pass filtering and the fitting processes. It consists in using different kinds of filters depending on what profile will be studied (i.e. roughness or waviness profile). To obtain the roughness profile a high-pass filter is used (cutoff wavelength λ_c). In doing so, the long-wave profile parts -longer than λ_c - are cut-off. The evaluation length (L_n) is divided into several sampling lengths (L_r) and each sampling length is equal to the cutoff wavelength of the filter used (λ_c). The parameters obtained are called R-parameters, and most of them are relative to a reference or mean line of the profile, calculated as the line that has equal material-filled areas above and material-free areas below.

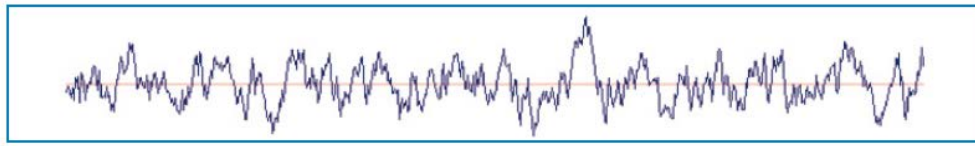


Figure 3.25 Roughness profile after λ_c high-pass filtering [33]

To obtain the waviness profile two different filters are needed: a low-pass filter (cutoff wavelength λ_c) to delete the short-wave profile parts (shorter than λ_c), and a high-pass filter (cutoff wavelength λ_f) to remove the longest wavelengths that are not even considered waviness. Here the sampling lengths (L_w) correspond to the cutoff wavelength λ_f and the parameters obtained are called W-parameters.



Figure 3.26 Representation after λ_c low-pass filtering [33]



Figure 3.27 Waviness profile after λ_c low-pass filtering and λ_f high-pass filtering [33]

3.2.3.1.1 R-parameters

Table 3.5 R-parameters and their description and characteristics [31], [34]

| R-parameter | Description | Characteristics |
|-----------------------------|--|--|
| Amplitude parameters | | |
| Ra | Arithmetic average of all the absolute profile values. | It is not sensitive to exceptional peaks or valleys due to the mean value formation from all profile values (not good for sealing faces). Its significance is rather low. No information on the profile shape. |
| Rq | Root mean square (RMS) | Largely replaced in Europe by Ra (normally it is 25% greater than Ra). It is slightly more sensitive to exceptional peaks or valleys than |

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| | | |
|---|--|--|
| | | Ra. |
| Rp | Maximum profile peak height (from the mean line) within a sampling length Lri. | |
| Rv | Maximum profile valley depth (from the mean line) within a sampling length Lri. | |
| Rzi | Maximum height of the roughness profile: $R_p + R_v$ within a sampling length Lri. | Good for measuring surfaces sensitive to exceptional peaks; less affected by waviness components. |
| Rz1max | Maximum surface roughness: largest of the Rzi-values over the total evaluation length Ln. | For surfaces where individual deviations heavily affect their function (e.g. sealing surfaces). |
| Rz | Surface roughness depth: mean value of the n Rzi-values from the n sampling lengths Lri over the evaluation length Ln (normally $n=5$). | For all the surfaces as a rule (general use), determinable from the profile graph, easy to understand. It is used to assess random surfaces. No information on the profile shape. |
| Rc | Mean height of profile elements: mean value of the profile element heights (distance from peak to the adjacent valley) within a sampling length Lri. | It is a very stable parameter. |
| Rpm | Mean value of the measurements from the highest peak to the mean line in each sampling length Lri. | Reliable information on the profile shape. |
| Zp | Highest peak of the profile (the whole evaluation length). | |
| Zv | Lowest valley of the profile (the whole evaluation length). | |
| Rt (Ry) | Total height of the profile: $Z_p + Z_v$ within the evaluation length Ln. | For random surfaces (non-periodic profiles). It is extremely sensitive to exceptional peaks or valleys. |
| Spacing parameters* | | |
| RSm | Mean width of the profile elements: mean value of the width of the profile elements Smi within a sampling length. | Used for periodic profiles. |
| Bearing area / Material ratio curve parameters** | | |
| Rmr(c) | Material ratio of the profile as a function of the section height c . | For guide and sealing surfaces moving against each other. |
| AFC | Abbott-Firestone Curve or material ratio curve. | It characterizes the profile shape: - Gentle curve slope: bumpy profile (smooth with single scratches), good wear resistance. - High curve slope: spiky profile, poor wear resistance. |
| Rk | Core roughness depth: depth of the roughness core profile. | It is the roughness of the profile without the highest peaks and the lowest valleys. It is considered to be a stable parameter. |

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| | | |
|---|---|--|
| Rpk | Reduced peak height: average height of protruding peaks above roughness core profile. | |
| Rvk | Reduced valley depth: average depth of valleys projecting through roughness core profile. | |
| Mr1 | Material portion 1: level in % determined for the intersection line which separates the protruding peaks from the roughness core profile. | |
| Mr2 | Material portion 2: level in % determined for the intersection line which separates the deep valleys from the roughness core profile. | |
| A1 | Peak area | |
| A2 | Valley area | |
| Hybrid parameters | | |
| RΔq | Root mean square slope: root mean square value of the ordinate slopes (dZ/dX) within a sampling length Lri. | It is the way of measuring the local slope. |
| Surface height distribution parameters | | |
| Rsk | Skewness of profile: quotient of mean cube value of the ordinate values Z(x) and cube Rq within a sampling length Lri. | It is the measure of the asymmetry of the surface height distribution. Rsk will be 0 if it is normal distributed (totally symmetric). |
| Rku | Kurtosis of profile: quotient of mean quartic value of the ordinate values Z(x) and quartic Rq within a sampling length Lri. | It is the measure of the “peakedness” of the surface height distribution. If the distribution has a large “peakedness” Rku will be a high value. |
| Local parameters | | |
| R3z | Mean value of the distances between the third highest peak and the third lowest valley of each sampling length Lri. | It does not take into account exceptional profile peaks or valleys. Minimum statistical dispersion: good for porous surfaces. |

*The spacing parameter RSm calculates the mean value of the width of the profile elements S_{mi} within a sampling length. The width of a profile element is the length of the x-segment intersecting with profile peak and the adjacent profile valley. A profile peak is a portion projecting upward over the given upper count level and a profile valley is a portion projecting downward below the given lower count level. The count level is adjusted to be a percentage of the parameter Rz (over and under the mean line).

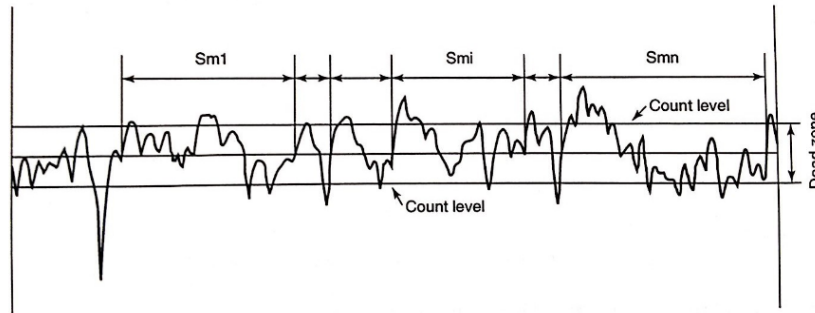


Figure 3.28 RSm parameter [31]

**The bearing area curve (BAC or AFC) parameters are calculated from the curve. A straight line is calculated for the central region of the material ratio curve which passes through two points (A and B) different in the material ratio by 40% and having the smallest gradient. The core roughness R_k is the vertical distance between the ordinate values of the straight line intersecting two lines at $mr(c) = 0\%$ position (C) and $mr(c) = 100\%$ position (D), respectively. Parameters R_{pk} and R_{vk} are calculated as the height of the right-angle triangle (CHJ and DEG) which is constructed to have the same area as the “peak area A1” and “valley area A2” respectively. The triangle corresponding to the “peak area A1” has $Mr1$ at its base, and that corresponding to the “valley area A2” has $Mr2$ at its base [31].

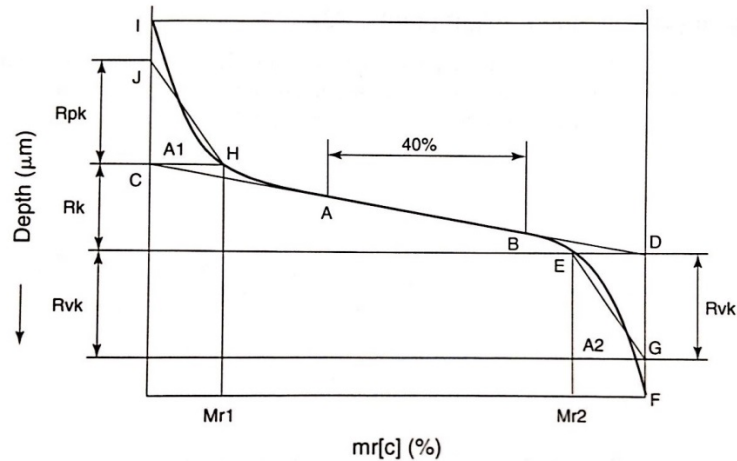


Figure 3.29 Material Ratio Curve [31]

A gentle material ratio curve slope comes from a bumpy profile (smooth with single scratches) with good wear resistance. On the other hand, a high material ratio curve slope comes from a spiky profile, with poor wear resistance.

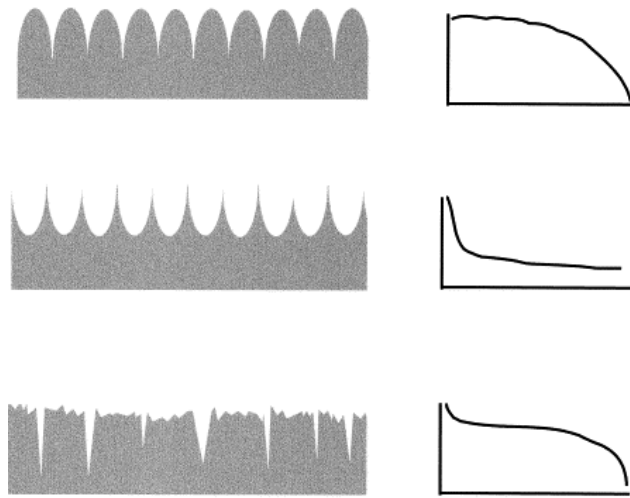


Figure 3.30 Relation between Material Ratio Curve and roughness profile [35]

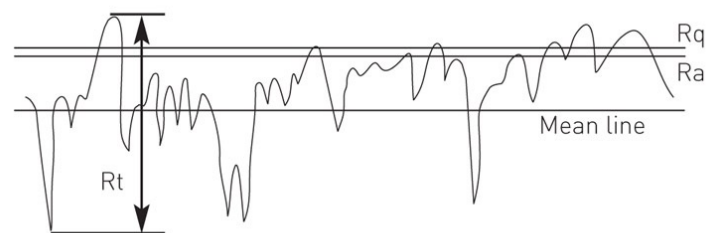


Figure 3.31 Ra, Rq and Rt parameters [36]

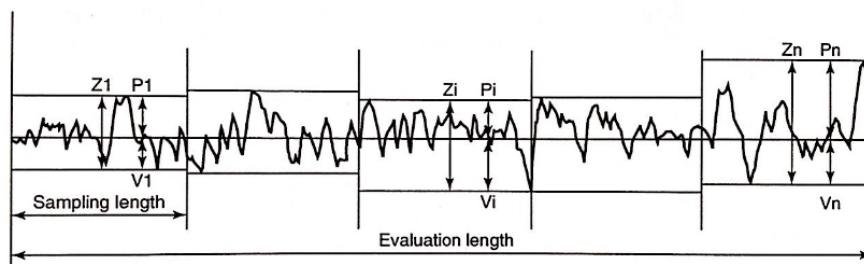


Figure 3.32 Rz parameter [31]

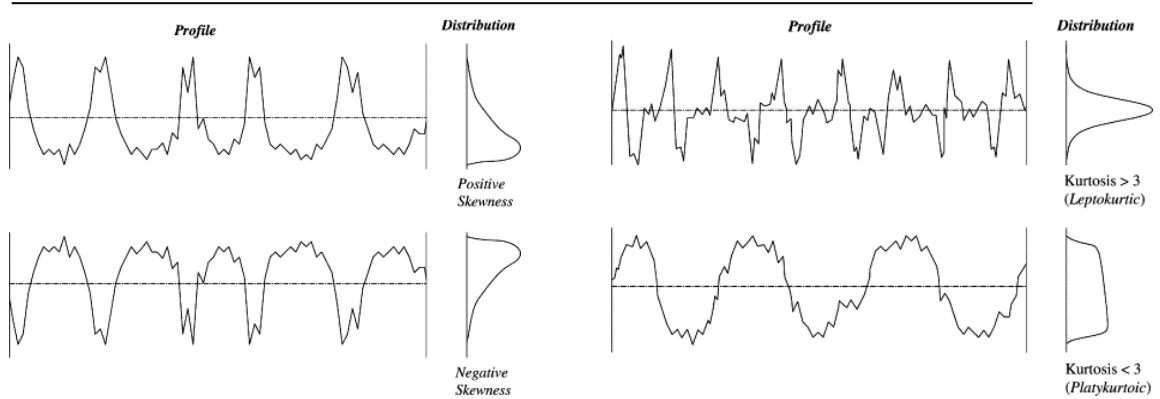


Figure 3.33 Rsk and Rku parameters [37]

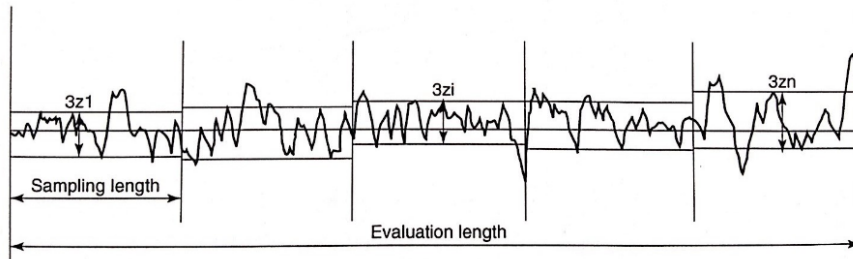


Figure 3.34 R3z parameter [31]

3.2.3.2 Measurement conditions (ISO 4288)

The Figure 3.35 shows the measurement conditions for roughness measurements. It indicates the maximum stylus tip radius and the cutoff wavelength λ_c , as well as the evaluation and the traversed length depending on the value of the different roughness parameters.

| Non-periodic profiles | | Periodic profiles | Measuring conditions according to DIN EN ISO 4288 and DIN EN ISO 3274 | | | |
|--|------------------|--------------------------------|---|--|-------------|-------------|
| Grinding, honing, lapping, eroding ↓ or ↓ | | Turning, milling, planing ↓ | r_{tp} l_r l_n l_t | Maximum stylus tip radius Single measured length Total measured length Traversed length (measured length plus start-up and trailing length) | | |
| R_t, R_z μm | R_a μm | R_{Sm} mm | r_{tp} μm | $\lambda_c = l_r$ mm | l_n mm | l_t mm |
| > 0.025...0.1 | > 0.006...0.02 | > 0.013...0.04 | 2 | 0.08 | 0.4 | 0.48 |
| > 0.1...0.5 | > 0.02...0.1 | > 0.04...0.13 | 2 | 0.25 | 1.25 | 1.5 |
| > 0.5...10 | > 0.1...2 | > 0.13...0.4 | 2*) | 0.8 | 4 | 4.8 |
| > 10...50 | > 2...10 | > 0.4...1.3 | 5 | 2.5 | 12.5 | 15 |
| > 50...200 | > 10...80 | > 1.3...4 | 10 | 8 | 40 | 48 |

Figure 3.35 Measurement Conditions [33]

3.2.3.3 Evaluation of measurements (ISO 4288)

Roughness measurement values (especially the amplitude parameters) have a spread between -20% and +30%. Therefore a single measurement value cannot provide a complete statement concerning the observance of the permissible parameter tolerances.

When a limit value is specified (for example in a drawing symbol) ISO 4288 Appendix A states the following procedure:

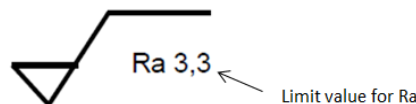


Figure 3.36 Limit value for Ra

- Max-rule: this rule is applied to all roughness parameters with the addition “max”. It states that when measuring at least three points on the surface where the highest values are to be expected, the limit value must not be exceeded at any point.

- 16%-rule: applied to all roughness parameters without the addition “max”. It states that when measuring the most critical surface, if not more than 16% of all value based on sampling length exceed the limit value, this value is considered to be acceptable. If more than 16% exceed it, the following procedure should be done:

- Another measurement must be done; if this measured value is smaller than 70% of the limit value, the latter is considered to be observed.

- Otherwise two further measurements at other points on the surface must be done. If all three are smaller than the limit value, the latter is considered to be observed.
- Otherwise nine further measurements at other points on the surface must be done. If no more than two of them exceed the limit value, the latter is considered to be observed.

3.2.3.4 Areal measurements (3D)

This method consists in characterize an area of the surface instead of just a profile. The profile measurements are not able to assess the functionality of a surface directly. Thus, areal measurements are not simply an extension from profile measurements, but also they try to characterize the surface functionality [6].

The irregularities of a surface can be classified into three different groups: roughness, generated by the material removal mechanism (e.g. tool marks), waviness, caused by the imperfect operation of a machine tool, and form error, generated by distortions such as thermal or gravity effects. The surface texture refers to the roughness and the waviness, as well as the lay (the direction of the predominant pattern of the surface irregularities). With measurements based on a profile, the coordinate systems are different when it comes to surface texture and form error. This is because a texture profile is specified to be orthogonal to the lay (to ensure the consistency of the irregularities), whereas a form error profile is specified to be parallel to the datum of the surface. Therefore, surface texture and form error cannot be together in a coherent specification [6].

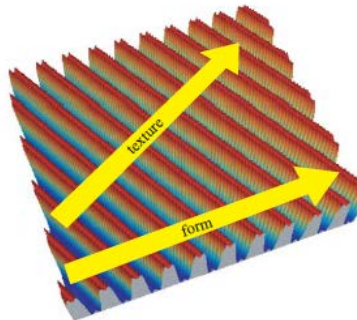


Figure 3.37 Two different coordinate systems for texture and form [6]

This problem is solved with the areal surface methods, since they are no longer based on profile measurements. In this way, the coordinate system does not have to be related to the lay and surface texture and form error can be defined with a unified coordinate system, called geometrical product specification (GPS). With this kind of measurements all the three different irregularities can be studied in the same system, from roughness as the smallest scale to form error as the largest one.

Another difference with the 2D measurements is that areal characterization does not need the three different groups of parameters related to each surface component (i.e. P for the primary profile, W for the waviness and R for the roughness). Only S-parameters are defined, and their meaning depend on the so-called scale-limited surface used. A scale-limited surface is determined by the filters or operators used, and it is controlled by the nesting index of those filters (extension of the concept cut-off wavelength suitable for all types of filters) [6].

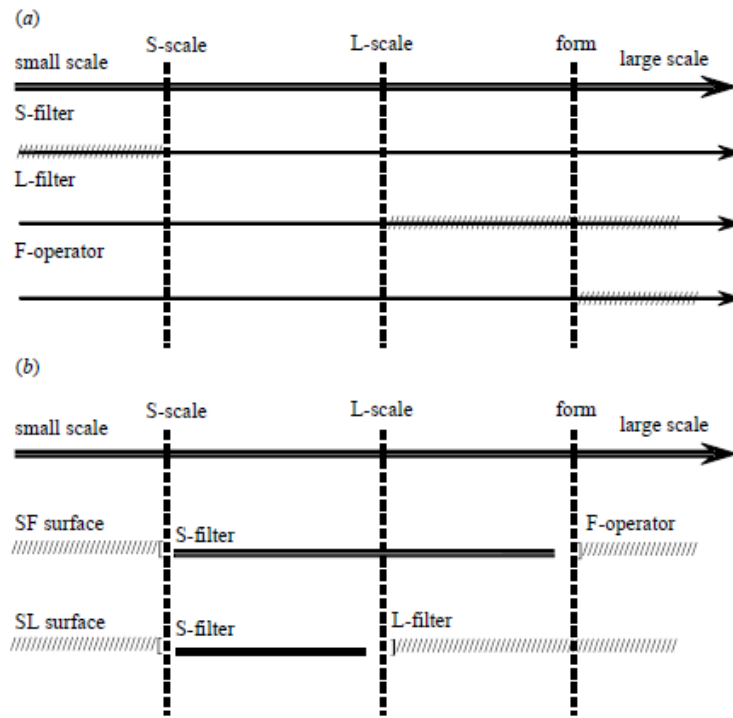


Figure 3.38 (a) S-filter, L-filter and F-operator, (b) scale-limited surface (SF and SL surface) [6]

The S-filter removes the undesirable small-scale components of the surface, such as noise, and the L-filter deletes the large-scale components that are not wanted. Finally, the F-operator is in charge of removing the nominal form, using optimization to determine a best fit to the nominal form and then removing it from the surface. The SF scale-limited surface is obtained by using an S-filter and an F-operator, whereas the SL scale-limited surface is gotten by adding an L-filter to an SF surface [6].

Making the comparison between profile and areal measurements, the primary profile is equivalent to the SF surface, with the profile λ_s filter equal to the areal S-filter. The roughness profile is equivalent to the SL surface, with the profile λ_s filter equal to the areal S-filter, and the profile λ_c filter equal to the areal L-filter. Finally, the waviness profile is equivalent to the SF surface, with the profile λ_c filter equal to the areal S-filter.

3.2.3.4.1 S-parameters

As seen in the previous section *History of surface texture and surface metrology*, a set of parameters called *Birmingham 14 parameters* was developed at the beginning of the 1990s. Although this set of parameters was widely accepted, it had both practical and theoretical lack of definition. Some mathematical descriptions were ambiguous and the parameters had insufficient practical evidence for its applicability [38]. With the research program known as *SurfStand* [10], and thanks to the work carried out by both academia and industry, the parameters for areal measurements were redefined and improved according to the geometrical properties of the surface. They were called field parameters and were based on statistics (averages and deviations), extremes and specific features from a continuous surface.

The field parameters set is divided into S-parameters and V-parameters. There are 12 S-parameters, and they describe amplitude and spatial characteristics. At the same time, these parameters are divided into different groups depending on what kind of information they provide [6].

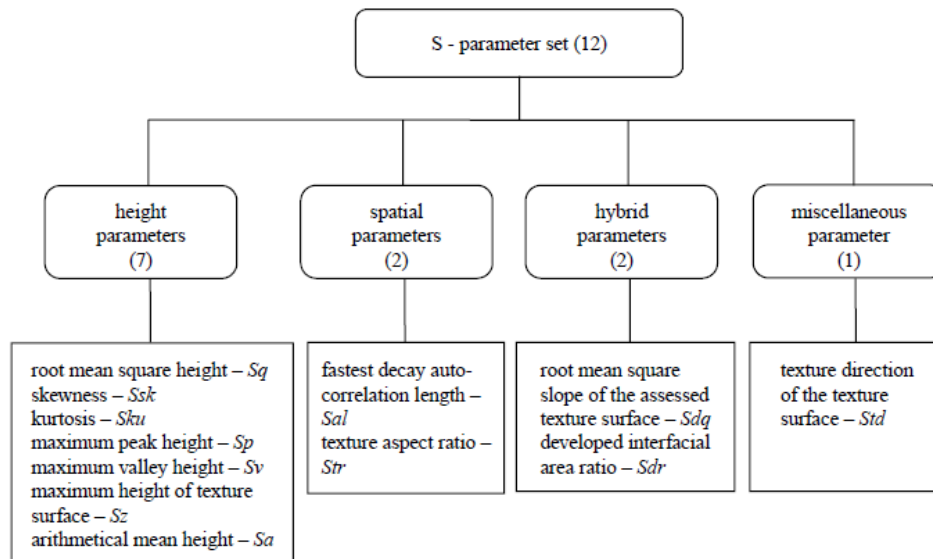


Figure 3.39 The S-parameter set [6]

The **height parameters** are equivalent to the profile amplitude ones (R_p , R_v , R_z , R_q , R_a ...), describing properties related to amplitude deviation (average and extreme properties), since those parameters have been the preferred ones for the different industries involved in surface roughness.

The **spatial parameters** refer to the spatial properties of the surface, i.e. density of summits, texture strength and uniformity of the texture in all directions. They are

particularly useful in distinguishing between highly textured and random surface structures [39]. These kind of parameters require the surface to be quadratic ($N \times N$) [40].

The **hybrid parameters** are based on both amplitude and spatial characteristics (reflecting slope gradients). These parameters become relevant in the study of contact properties (i.e. thermal, electrical, sealing, wear and optical reflectance properties), since they contain information about peak flanks, where most contact occurs.

The miscellaneous parameter Std provides information in the texture direction (the lay of the surface texture).

The V-parameters (or **functional parameters**) are used to define the functional topographical features of the surface through analyzing the material volume and void volume. The aim of these parameters is to split the material ratio curve into three different height zones: the peak (corresponding to initial running-in wear), the core (to wear throughout the lifetime of the component) and the valley zone (to lubricant retention under heavy conditions) [6]. In other words, they characterize the bearing and the fluid retention properties of the surface [40].

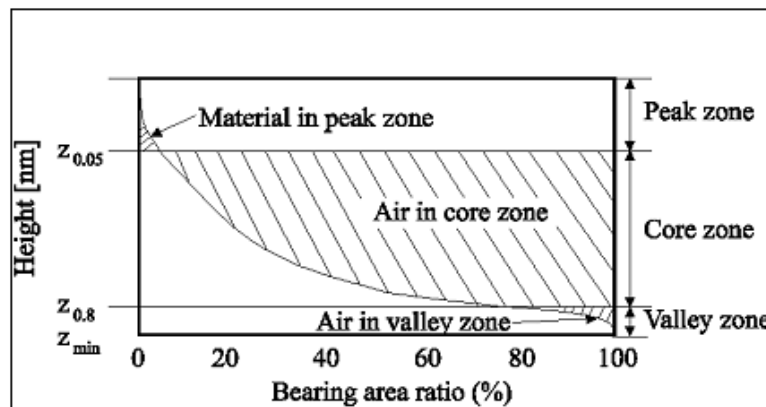


Figure 3.40 Characterization of the bearing and the fluid retention properties [40]

3.2.3.5 Comparison between 2D and 3D measurements

Over the past two decades the use of 3D measurement of surface has increased rapidly in many industrial companies thanks to the development of the technology in general (i.e. powerful microcomputers and advanced measurement techniques). The 3D measurements are able to provide complete information about surface topography whereas the 2D measurements are not. This is because of the fact that 2D measurements only give information about a profile (a line along the surface) being necessary to take several measurements in order to have reliable results. However, 2D profile measurements and their analysis are still playing an important role in the surface measurement field, above all in optical and mechanical engineering areas,

because of the shorter time needed for the whole measurement and the lower cost of the instrument.

These are the main advantages of the 3D analysis over the 2D one:

- Surface topography is three-dimensional in nature. Thus, a 3D measurement can define its natural characteristics whereas 2D measurements cannot. This aspect appears not only in qualitative identification (such as lay and anisotropy) but also in quantitative calculations such as size, shape and volume of the specimen.

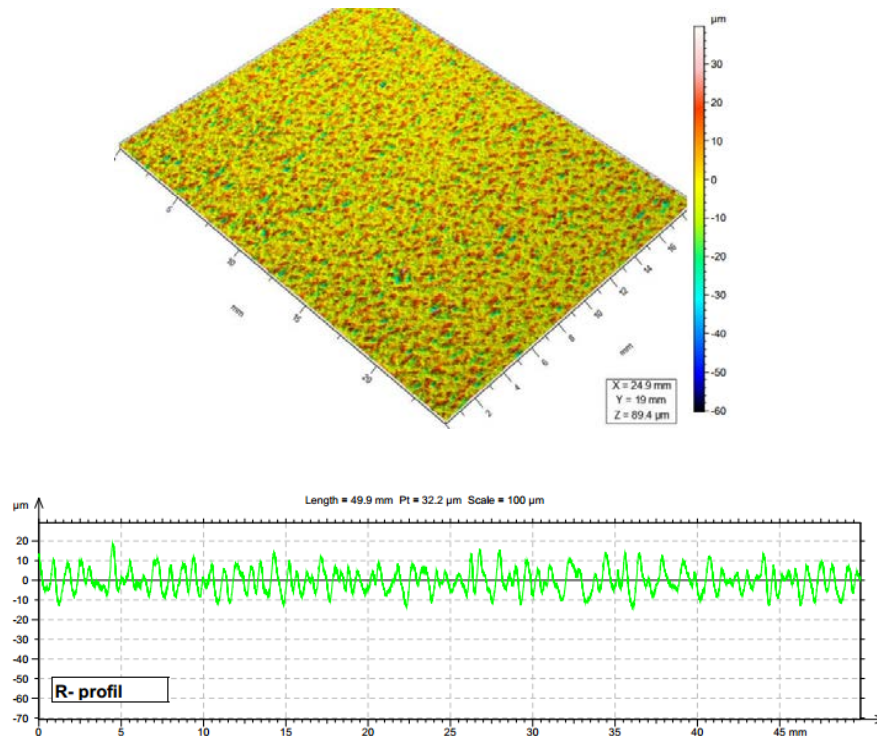


Figure 3.41 Measurements in the same surface done in Toponova (using MikroCAD GFM3D and Mitutoyo profilometer respectively)

- The extreme parameters obtained with the 2D measurements are only approximate indications of the real values, since the profile is the intersection of a vertical plane with the measured surface, and may not cross the real summits or valleys. This problem is solved with 3D measurements, since the real summits and valleys can be found.
- The 3D measurement can provide more parameters than the 2D one cannot. For example, spatial parameters (such as density of summits or texture strength), and hybrid parameters, which are very useful in the study of contact properties.

- Concerning statistics, the statistical analysis of 3D surface topography is more reliable and representative than the 2D analysis. This is because of the larger volume of data obtained, and consequently its increased independence. Thus, 3D measurements can reduce the variance of parameters.
- A really important feature of 3D topography analysis is that the result is visualized in a computer. Thus, image-processing techniques can be applied, such as grey-scale mapping, and more significant information can be obtained rather than just a profile.
- Finally, most of the 3D measurement devices are based on digital systems, whereas the profilometers use analogue systems. Comparing both systems, the digital ones are more user-friendly and really powerful when it comes to data processing and storage.

On the other hand, not everything is positive when analyzing the 3D measurements. The cost of the equipment can still be considered too high compared to the cost of a profilometer, and the time for preparing each measurement can as well be an important drawback.

It is believed that the use of 3D measurements will keep rising, being applied to a wider range of products, as well as developing, enlarging the ratio of range to resolution [6].

3.2.3.6 Optical methods and their principles

Optical systems are the most used ones in the 3D topography field. In this kind of measurements, no physical contact is made with the surface, avoiding damage. However, the main advantage of the optical techniques is that they can define a surface completely. On the other hand, the most important drawback is the reduction of the measurement area with high vertical resolutions.

Depending on the optical principle they are based on, the 3D measurement instruments can provide quantitative (S-parameters) and/or qualitative (e.g. visual) information. The most typical optical principles that can provide quantitative measurements are divided into focus detection methods and interferometric methods:

3.2.3.6.1 Phase shifting interferometry (interferometric method)

This principle has proven to be extremely powerful. It consists in measuring the phase shift between the beam (monochromatic light) reflected from the surface and a reference beam as the sample is scanned in z. This phase shift is directly proportional to the path length travelled by the light (to and from the reflecting surface), which means that it is proportional to the surface height as well [8]. The interferometric systems have a high vertical resolution (on the order of 0,1 nm) but a limited dynamic vertical range: the height difference between two adjacent data points must be less than the fourth of the incident light wavelength ($\lambda/4$) [41].

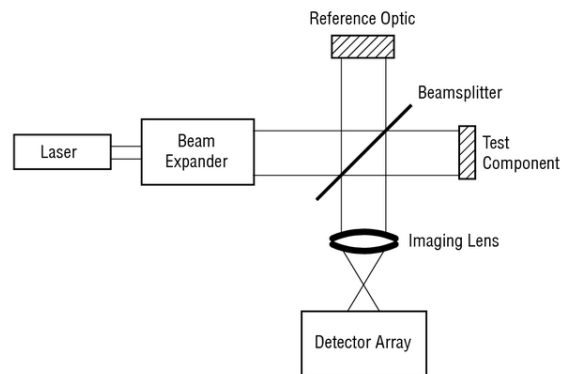


Figure 3.42 Phase shifting interferometry performance [42]

3.2.3.6.2 Scanning white light interferometry (interferometric method)

This principle is used in order to overcome the dynamic vertical range limitation in phase shifting. As seen in the Figure 3.43, the upper beam splitter directs white light (instead of monochromatic light) from the light source towards the objective lens. The lower beam splitter in the objective lens splits the light into two separate beams: one is directed towards the sample and the other towards an internal reference mirror. Then the two beams recombine (interference fringes are produced) and this recombined light is sent to the CCD sensor. Interference takes place when the path length to the sample and the reference are the same. The resolution limit for white light interferometry is about $0,5 \mu\text{m}$ because of diffraction effects [41].

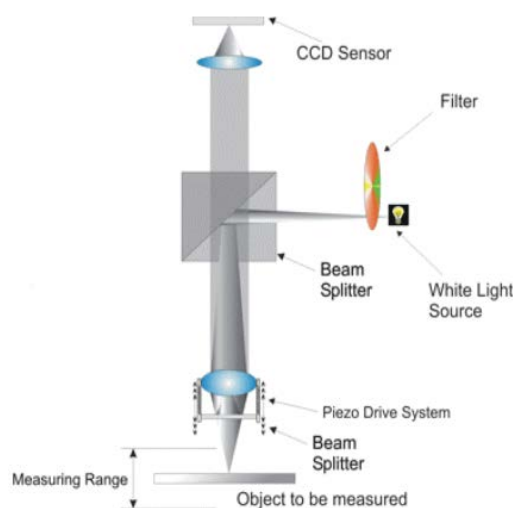


Figure 3.43 Scanning white light interferometry performance [41]

3.2.3.6.3 Confocal laser scanning (focus detection method)

Principle based on excluding most of the light from the specimen that is not from the microscope's focal plane. Thus, a confocal microscope creates sharp images of the specimen that would appear blurred when viewed with a conventional microscope. The method consists in a laser light that reflects off a dichroic mirror and hits two mirrors which are used to scan the laser across the sample. Dye in the sample fluoresces and emits light that passes through the same mirrors. This light goes through the dichroic mirror, is focused onto a pinhole and it is measured by a detector. In practice, the best horizontal resolution of a confocal microscope is about $0,2\text{ }\mu\text{m}$ and the best vertical resolution is about $0,5\text{ }\mu\text{m}$ [43].

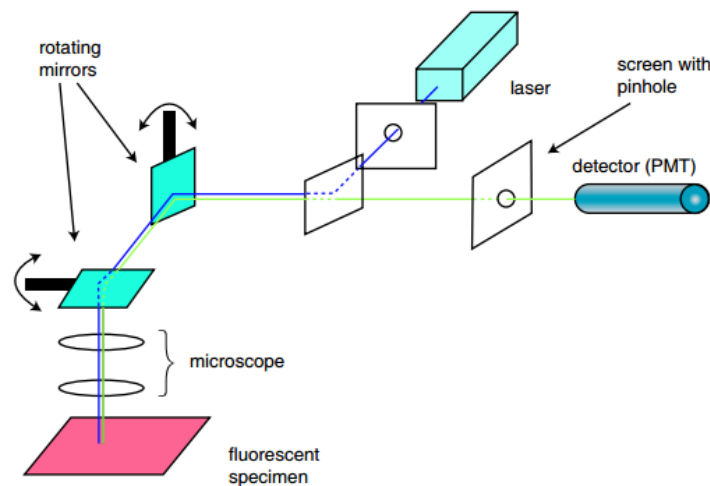


Figure 3.44 Confocal laser scanning performance [43]

3.2.3.6.4 Focus variation (focus detection method)

Light emerging from a white light source is inserted through a beam splitting mirror into the optical path of the system and focused onto the specimen via the objective. The rays emerging from the specimen and hitting the objective lens are gathered by a light sensitive sensor behind the beam splitting mirror. The equipment's optics has a small depth of field, sharpening only small regions of the object; thus, to acquire full depth of field, the precision optics is moved vertically along the optical axis, while continuously capturing data from the surface (i.e. each region of the object is sharply focused). The results are obtained by analyzing this variation of focus along the vertical axis. The precision optics component contains different objectives with various lens systems and its vertical resolution depends on the chosen objective and can be as low as 10 nm . The vertical range can reach up to more than 20 mm [44].

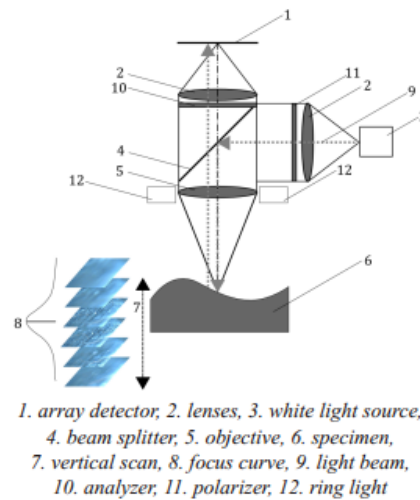


Figure 3.45 Focus variation performance [44]

An example of an optical principle that can only provide qualitative information is:

3.2.3.6.5 Light-scattering

Principle based on the scattering property of rough surfaces. The surface is illuminated by a beam of infrared rays and a fraction of the radiation is scattered back, depending on the surface structure. Then, using a photodiode array, a cross-section is made through this scattered beam and the intensity distribution is measured as a function of the angle of dispersion. Light-scattering instruments produce relative parameters instead of the absolute height of the surface roughness [8].

3.2.3.7 Comparison between optical and stylus methods

The stylus instruments have a large vertical range and a high vertical resolution (to sub-nanometer level). The large ratio of range to resolution in the horizontal direction allows this kind of instruments to integrate many features of the geometry into one measurement (e.g. form, waviness and roughness). For this reason they are the best suited to measure engineering surfaces at micron or sub-micron scale [8].

The interferometers have the highest vertical resolution (to sub-nanometer level) but a lower horizontal resolution than the stylus instruments. Their main problem is the limitations in the vertical range due to the wavelength of the incident light. However, the scanning white light interferometer improves this aspect. These instruments are mainly suitable for measuring fine surfaces (e.g. optical and electronic circuits on the nanometer scale) [8].

The focus detection instruments have a slightly inferior resolution to the stylus instruments in both vertical and horizontal directions. Their large dynamic range in both directions makes them suitable for measuring surfaces similar to the ones

measured by stylus instruments, but with the advantage of its non-contact mode, particularly useful where use of the stylus could lead to damage of the sample and/or the stylus itself [8].

The most obvious advantage of the optical methods over the stylus ones is that they are non-contacting and hence, non-destructive. Apart from that, they also have a higher measuring speed than contacting techniques. However, optical methods are subjected to a number of surface characteristics that can affect the accuracy of the obtained results: surface reflection properties, deep valleys in which multiple scattering may occur and surface features that cause diffraction. Stylus techniques are not affected by these surface peculiarities [45].

This table compares the most significant aspects of the three different methods:

Table 3.6 Comparison between three different methods [8]

| | Stylus | Interferometer | Focus detection |
|---------------------------------------|---------|----------------|-----------------|
| Vertical resolution | 2 | 1 | 3 |
| Vertical range | 1 | 3 | 2 |
| Horizontal resolution | 1 | 3 | 2 |
| Horizontal range | 1 | 3 | 2 |
| Measurement mode | Contact | Non-contact | Non-contact |
| Time for preparing measurement | 1 | 2/3 | 2/3 |
| Time for measurement | 3 | 1/2 | 1/2 |
| Cost of instrument | 1 | 2/3 | 2/3 |
| Influenced by reflectivity of surface | No | Yes | Yes |
| Damages in the surfaces | Easily | No | No |

| | Resolution | Range | Time | Cost |
|---|------------|----------|----------|----------------|
| 1 | Highest | Largest | Shortest | Cheapest |
| 3 | Lowest | Smallest | Longest | Most expensive |

There is an important aspect to have in mind when analyzing the relation between resolution and range: the higher the vertical resolution the smaller the horizontal range (measurement area) that can be measured. Thus, when using a screen to visualize a measured area, if the vertical resolution of the measurement is increased, the area that will appear in the screen will be smaller and consequently less surface of the specimen will be studied. This could be a problem when the aim of the measurement is more the general appearance of the surface rather than the high-tech properties of a tiny component. It is mainly for this reason that the development of the roughness measurements (above all the 3D ones) is focused on enlarging the range to

resolution ratio. This means being able to increase the vertical resolution while keeping a large enough measurement area.

3.3 How other industries work with surface texture

As a part of the background research, it has been investigated how different industries work with surface textures. The aim has been to gain knowledge of different methods already used.

3.3.1 Stainless steel industry

For stainless steel there is an ISO standard (EN 10088-2) that defines how different surfaces should look like [46]. Unlike many other standards this standard isn't definitive, the EN 10088-2 standard describes the methods (process routes) for achieving the different finishes. The different surface finishes are abbreviated with a number and a letter for example 1C. Where the number denotes whether the steel is hot rolled or cold rolled and the letter what other process steps have been used. In the ISO standard it is described what process has been used, a note that gives some information about what applications the surface finish is suitable for and sometimes a general description of the surface. In some cases there is also an approximate Ra value specified [47].

Table 3.7 ISO standard EN 10088-2

| Hot Rolled Finishes | | | |
|---------------------|---|---|-----------------|
| Abbreviation | Finishing Process Route | Notes | Typical Ra [μm] |
| 1C | Hot rolled, heat treated, not descaled | Surface covered with mill scale. Finished parts may be suitable for heat (oxidation) resisting applications as supplied, but should be descaled to optimize corrosion resistance. | - |
| 1E | Hot rolled, heat treated, mechanically descaled | Free of mill scale by shot blasting or grinding. This finish can also limit the crevice corrosion resistance. | - |
| 1D | Hot rolled, heat treated, pickled | Most common 'hot rolled' finish available. Most corrosion resistant hot rolled finish specified. | 4-7 |
| 1U | Hot rolled, not heat treated, not descaled | Surface is left covered with rolling (mill) scale. Surface suitable for products intended for further working eg strip for re-rolling. | - |

In this standard it is also stated that “Within each finish description the surface characteristics can vary and more specific requirements may need to be agreed between manufacturer and purchaser (e.g. grade of grit or surface roughness)”. Peter Davis, the managing director of Professional Polishing Services Limited, calls that sentence a catch-all that says to the specifier “here is a standard but ignore it and negotiate your own requirements to ensure you get what you want” [48].

The measurements being made to characterize the surface finish on stainless steel are usually Ra measurements done with a stylus instrument. Sometimes when non-reflective or highly reflective surfaces are required, the light reflectance of the surface is measured with a gloss meter [48].

To summarize, the stainless steel industry has a standard that describes different surface finishes but it is not specified well enough to guarantee that different manufacturers produce products that are indistinguishable from each other. For example, if you order a steel plate with surface finish 1C from two different manufacturers the steel plates will probably not look exactly the same. The advice given is that if you want the same finish on all the steel plates being used, you should order them from the same manufacturer. The measurements that are usually being done are Ra measurements for surface roughness and gloss measurements for surface reflectivity.

3.3.2 Paper and cardboard industry

Surface roughness has always been an important parameter in paper production. The surface of the paper is very important when using it for printing. In paper industries a number of methods called air leak measurements have been used over the years. The basic principle is to measure how much air leaks out between the paper and the measuring device placed on the paper. The rate of air leak determines the surface roughness of the paper.

Many other methods have also been used to study and measure the topography of paper surface and the results have been presented in the classic 2D R-parameters and lately the more modern 3D S-parameters [49].

3.3.3 Wood industry

In the studied literature concerning measurements of surface roughness on different wood and wood based products, all measurements have been done using the different R- and S-parameters. It is also often specified what type of processing method should be used, for example sandpaper with a specific grit. Some methods to detect and characterize surface defects are also available; however, these methods just measure the defects and not the texture of the whole surface [50], [51].

3.4 Laminates

A laminate is a material that consists of several layers which are stacked on top of each other and fused together. The laminates used for furniture, worktops and flooring usually consist of a protective layer, a decorative layer, and several layers of kraft paper [52].

The protective layer, also called overlay, is a transparent fine quality alpha-cellulose paper sheet. It's impregnated with thermosetting resins with abrasive material (abrasive particles with a mean size between 5 and 30 μm). It is the hard transparent top layer which protects the laminate against scratches, stains and general wear. In the protective layer is where the texture is engraved.

The decorative layer is an alpha-cellulose paper sheet impregnated with thermosetting resins. This layer gives the laminate its appearance; often a wood or stone imitation is printed on the decorative layer but it can also be a solid color or an artistic pattern.

After the process, the cellulose fibers of the papers plus the cross-linked bonding of the resins offer a very homogenous material with a non-porous surface.

The kraft paper layer is the base which gives stability to the laminate, prevents the telegraphing of defects to the decorative sheet and improves the impact resistance qualities of the laminate.

3.4.1 Resins

Melamine-formaldehyde resin is used for impregnating the top layers; it becomes both hard and transparent when cured. It has excellent resistance to mechanical wear as well as chemical solvents and corrosives. Phenol formaldehyde is used for the kraft paper layers; it becomes brown and elastic. The thermosetting resins are in a liquid state when uncured and at room temperature. Once cured, the process cannot be reversed or reformed, since a chemical reaction takes place: the curing process transforms the resin into plastic by a cross linking process that bonds one polymer chain to another. Thus, its recycling process is extremely complicated.

Laminates are often divided into three groups depending on the manufacturing process. These are High Pressure Laminates (HPL), Continuous Press Laminates (CPL) and Low Pressure Laminates (LPL).

3.4.2 High Pressure Laminates (HPL)

This manufacturing process consists in pressing different layers at a high pressure (between 8 and 10 MPa) and a temperature between 100 and 250°C during a suitable pressing time. The higher the pressure and/or temperature used the shorter the pressing times. This process allows production of laminates thicker than 2 mm and high-gloss surface finishes, laminates as thick as 10mm can be achieved with this method [53]. An illustration of the HPL process can be seen in Figure 3.46.

HPL

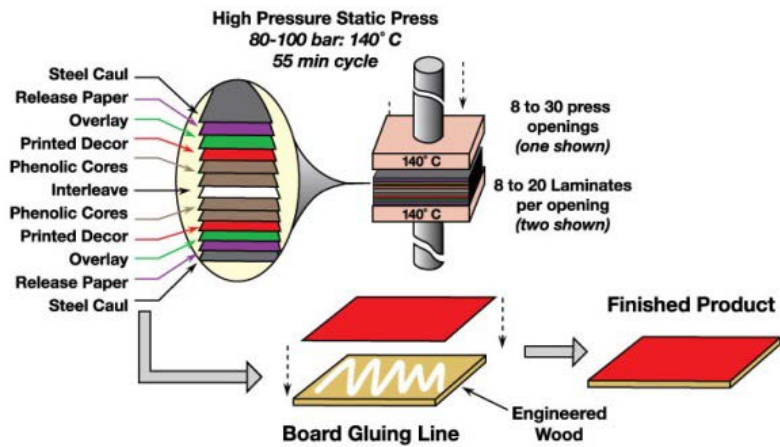


Figure 3.46 High pressure laminate process [54]

3.4.3 Low Pressure Laminates (LPL)

In this process lower pressure is used (around 3 MPa). Only two layers are used for the laminate, the protective overlay and decorative layer. These are saturated with resin and are merged with the substrate in the pressing process. An illustration of the LPL process can be seen in Figure 3.47.

LPL

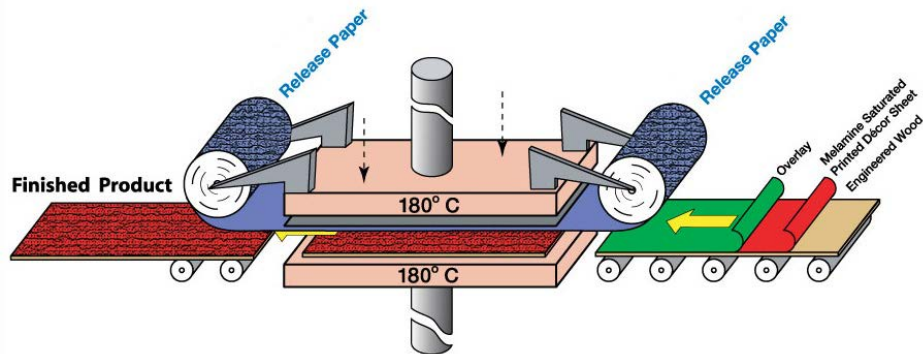


Figure 3.47 Low pressure laminate process [54]

3.4.4 Continuous Press Laminates (CPL)

In this manufacturing process the laminates are produced in a continuously operating double-belt press, applying a pressure between 2,5 and 5 MPa with a temperature between 150 and 170°C. The feed rate can vary a lot from 8 m/min to 30 m/min. This method requires a big startup investment and it is best suited for large scale production, for example in laminate flooring and other high volume products. An illustration of the HPL process can be seen in Figure 3.48.

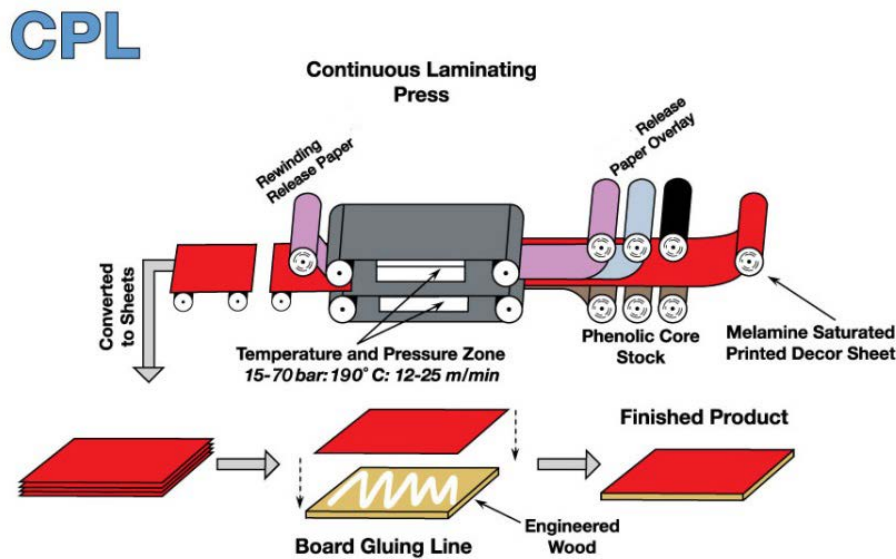


Figure 3.48 Continuous press laminate process [54]

3.4.5 How texture is given to the laminates

Texture is given to the laminates by three different methods. One method is to use textured press plates or press belts. These are pressed against the laminate during the curing process imprinting the texture onto it. The other method is to use a textured release paper; this paper has the desired texture embossed and it is inserted between the top layer and the steel roller of the press. The texture is imprinted onto the top layer during the pressing process regardless of the method.

The press plates and press belts are made of steel and can be chrome plated for extra durability. The textures can be imprinted onto them in several ways. For simpler textures mechanical processing can be used, but the most common method is chemical etching. During the etching process some areas of the steel plate are protected by a lacquer and do not get affected by the acid in the etching bath. The unprotected areas are burnt away by the acid. This lacquer can be applied in several ways: a method similar to inkjet printing can be used where a print head applies lacquer to the steel surface; lacquer can be also applied to the plate/belt by using a printing roller in the same way as newspapers are printed. Another method consists in using litho film: light will project the texture onto the litho film which will solidify and protect the areas of the steel plate/belt during the etching process. More recently, direct laser engraving has also been used to give texture to the texture plates/belts.

There are two kinds of release paper, thermosetting release paper and electron beam cured release paper. Thermosetting release paper is impregnated with a thermosetting plastic, it is wrapped around a hot textured steel roll which gives the release paper its texture and solidifies the plastic. The electron beam cured release paper gets a liquid

coating and is then wrapped around a textured steel roll. The liquid coating is then polymerized using a high energy electron beam while still being in contact with the textured roll [55], [56] and [57].

3.4.6 How texture patterns are developed

The process of designing and developing a texture pattern varies between different companies and also depending on what type of pattern is being designed.

Often the design process starts with a piece of the material that one wishes to mimic, for example a piece of real wood or stone. This is then digitally scanned either in 2D or 3D. For the 2D scans the image is manipulated to fit all the required parameters such as depth and size of the pattern.

For the 3D scans, special software is used to filter out the different steps of the texture. This data is needed to create masks that are used when adding the lacquer that protects areas of the plates/belts during the etching process. These masks are stored as 2D images in the .TIFF file format. The etching process is done in several steps with a new mask of lacquer applied between each etching. In this way the textures are deepened step by step until it receives its final depth.

Typically a small pilot roller is created to test the concept texture. This may have several zones on it with different depth variations and/or gloss levels. This allows the texture to be proofed before the manufacturing of a production plate/belt or roller.

Often deep textures are desirable but they are difficult and costly to produce, both in press plates and release paper as well as in the final laminate. Deep textures require a lot of resin to accommodate the thickness which is the highest cost component in lamination. The digital artwork also has to be adjusted for the linear dimensions, either a step and repeat or folding of the initial pattern to create the size desired and to blend any seams.

The whole process is a close collaboration between the texture pattern designer and the steel engraver. Experience and skilled craftsmen is the key to a good result [55, 57-59].

3.5 Manufacturing process of the ZZ kitchen fronts

3.5.1 Material and milling process

The ZZ kitchen front is made from Medium Density Fiberboard (MDF). It's a board material made from wood fibers which are glued and pressed together. The board is cut to the correct size and then material is removed through a milling process to achieve the desired design. The surface is then sanded to remove marks from the milling process and makes the surface smoother [60].

3.5.2 UV lacquering

The backside of the kitchen front is painted by using a technique called UV-lacquering. The paint is transferred onto the surface from rollers and cured under UV lamps [60].

3.5.3 Pigment lacquering

The front and sides of the ZZ kitchen front cannot be painted with the UV-lacquering method because the surface is not flat. Instead of this, a method called pigment lacquering, or in more general terms spray painting, is used. The method is based on compressed air to spray paint through the air onto the surface, and it is done by robots. It is a good method for applying paint in a fast and uniform way [60].

4 Problem analysis

In this chapter the samples that are going to be analyzed in chapter 5 are described and the problems related to worktops and the kitchen front are explained. Finally what needs to be measured and specified is stated.

During the course of the thesis work the studied surface textures have been divided into two categories. The first category is where the surface has a designed texture pattern. This designed texture pattern can be a symmetrical pattern or a more natural looking pattern, as seen in Figure 4.1. These textures are a deliberate choice by the designer/manufacturer. Their primary function is to give the surface a pleasing visual and tactile appearance. The texture also hides small scratches and dents that otherwise would make the surface look worn and unappealing. These textures can be viewed as three-dimensional objects and have specific measurements in the x, y and z directions. These measurements should be the same for every instance of the surface produced with the same texture pattern. The studied worktops fall into this category.

The other category is where the surface texture is not a designed pattern but more of a result from the manufacturing process. These textures are semi-random, there are no drawings of them and it is not specified how each point of the surface should be. The studied kitchen front falls into this category.

4.1 Studied surfaces

The two worktop textures that have been used in this study will be referred to as YY – stone and XX – wood grain. YY has many small bumps which appear to be randomly spread across the surface; the texture doesn't have any clear orientation. The texture is perhaps trying to imitate the surface texture of stone. XX is imitating a wood texture with small indentations oriented in the same direction looking like wood grain.

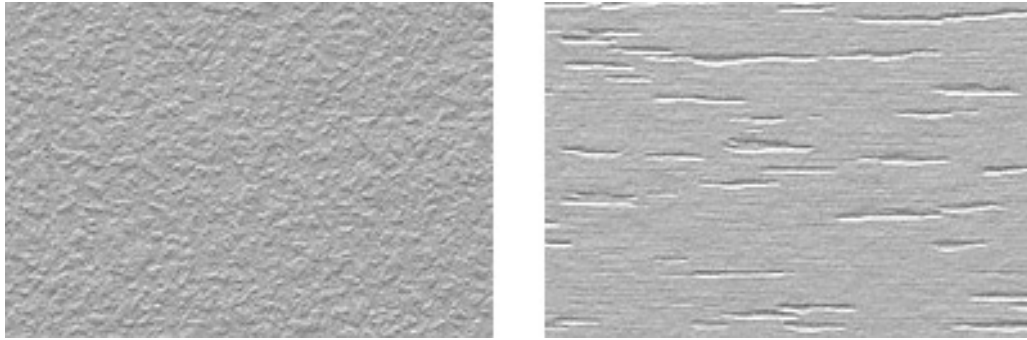


Figure 4.1 YY-stone texture (left) and XX-wood grain texture (right) [61]

Regarding the kitchen front, three different zones of the same sample have been studied: the milled and the non-milled areas, and the lateral side.

4.2 Problems related to worktops

For the studied worktops, three different problems have been identified.

- Inconsistency in surface macro texture between different suppliers.
- Inconsistency in micro texture and gloss level between different suppliers.
- Variations in micro and macro texture as well as gloss level from the same supplier.

4.2.1 Inconsistency in surface macro texture between different suppliers

Figure 4.2 shows two worktop samples sold as the same product but produced by different suppliers [29]. When comparing the samples side by side, even with the naked eye it can be easily seen that the two samples differ quite clearly from each other.

This problem occurs because of the fact that the two suppliers are using different original texture patterns, and it should come as no surprise that the end result differs when using different blueprints for the same product.

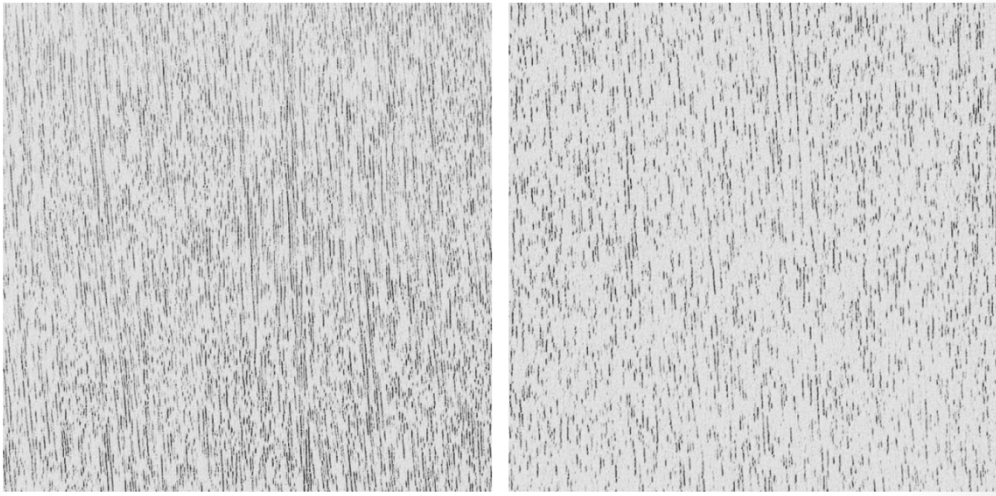


Figure 4.2 XX-wood grain texture samples produced by different suppliers: Supplier A (left) and Supplier S (right) [62]

The explanation on why the suppliers are using different texture patterns lies in the supply chain structure of the laminate industry and the history of IKEA's kitchen range. When a new worktop with a new surface texture has been introduced into the range it has been manufactured by only one supplier. If this worktop has been sold in high enough volumes more suppliers of the same worktop have been added. There can be several reasons for this: sometimes a single supplier cannot deliver enough volumes of the product or it can also be that with two suppliers prices can be kept lower because of the competition between them. Apart from that, if one supplier is experiencing manufacturing difficulties the other supplier can increase its deliveries and the demand can be met.

The problem with adding more suppliers is, as explained earlier, to get the new supplier's products to match the already existing ones. The texture patterns used today have not been designed by IKEA and thus the company does not own them. This means that IKEA has no copies of the original pattern, no drawings, no CAD files and no roughness values. What IKEA has is a master sample, which is a piece of worktop, to which other samples are visually compared.

The texture patterns used today have been designed and are owned by the laminate suppliers or by the suppliers of the press plates, press belts or release paper. So when IKEA has started to work with a new supplier, it has not been able to send them a copy of the original drawings for the texture pattern or any other clear specifications of the texture. Therefore, either a new texture pattern has had to be designed with the aim of looking identical to the original texture, or a texture pattern that was similar to the original has been chosen. The new design or the chosen texture pattern has not been, in some cases, a close enough match to the original.

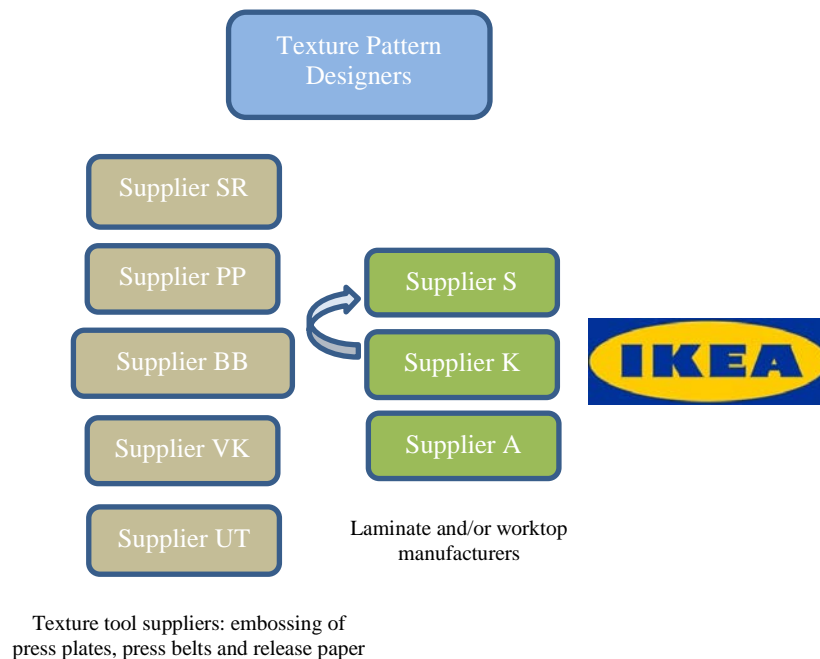


Figure 4.3 Flow chart of the supply chain

This flow chart explains graphically the supply chain and who the different actors are. Concerning the worktop manufacturers, it is good to know that Supplier K owns Supplier S: the first one only produces laminates and the second one only manufactures worktops; therefore all the laminates that Supplier K produces for IKEA are sent to Supplier S.

Regarding the texture tools suppliers they produce either press plates (also called texture plates), press belts (also called steel belts) or release paper. Supplier PP and Supplier SR are release paper manufacturers; Supplier BB produces steel belts; Supplier VK manufactures both press plates and steel belts; Supplier UT produces rollers and press plates. They can either offer already designed textures or design the new texture that the laminate supplier is asking for. For example, Supplier UT has a service called "Design Service for Printing and Embossing". Apart from that, Supplier PP and Supplier SR have as well some roller supplier (e.g. Supplier UT), since they need to emboss the texture to the release paper.

Therefore it is not easy to know in which step of the chain the texture pattern designers are to be placed. For example, Supplier K has its own texture designers for press plates, but for press belts and release paper it chooses between already designed textures from the texture tools suppliers (Supplier BB and Supplier PP respectively).

4.2.2 Inconsistency in micro texture and gloss level between different suppliers

The gloss level of the laminate is tightly connected to the micro texture on the laminate. The micro texture varies between different worktop manufacturers because they are using different press plates and different suppliers for the release paper. Because of this, the micro texture and gloss level of the laminates can vary.

4.2.3 Variations in micro and macro texture as well as gloss from the same supplier

This problem is caused by the manufacturing process of the laminates. The causes can be split into:

- Texture tool wear (either the release paper, the press belt or the press plate)
- Process variations (the several factors affecting the curing process of the resins such as the pressure, the temperature, paper thickness...)

4.2.3.1 Texture tool wear

This problem concerns the release paper in a very short term, and the press belts and the texture plates in a very long one.

The release paper can be cured in two different ways:

- Thermosetting cured: its lifetime is set by the quality inspection of the laminates since it does not rip. For example, Supplier K is using it 5 times (see Appendix E).
- Electron beam cured: after using it a certain amount of times it rips. More sophisticated textures can be embossed to this kind of release paper. For example, Supplier K is using it 11/12 times (see Appendix E).

The press belts and the texture plates are made of steel. Therefore their deterioration is much slower and difficult to quantify in terms of times that have been used. They can be used to give texture to the laminates for several years before they need to be replaced or refurbished.

4.2.3.2 Process variations

During the whole laminate process two curing reactions take place: one for the melamine-formaldehyde resin present in the overlay, and the other one for the phenol formaldehyde resin present in the kraft paper. Pressure and temperature are two factors that affect directly these curing reactions. Thus a slight variation of these factors can cause variations in the process. Apart from the resins, the laminate process is as well subjected to the amount of layers used.

4.3 Problems related to ZZ kitchen front

Swedwood (the manufacturer of ZZ kitchen fronts) is currently using visual comparison in the quality inspection process. They have exposed three samples of each product manufactured: one has a green distinction (accepted), another has a yellow one (depending on the kind of defect it can be either accepted or not), and finally the red one (not accepted). They take one kitchen front from each batch and compare it with the graded samples. Thus visual inspection is already being used to check the kitchen front defects. In this thesis the surface problems related to the kitchen fronts have been split into two different matters:

- Differences in surface roughness between different parts of the kitchen front
- Occurrence of orange peel effect on some of the manufactured kitchen fronts

Differences in the surface roughness appear in the front surface of the kitchen front, between the milled and the non-milled parts. They are caused by variations in the surface density of the substrate. The substrate used for ZZ is Medium Density Fiberboard (MDF): a material made from wood fibers which are glued and pressed together to form a board. The density of the board can vary between 600-800kg/m³ [63]. The density also varies in the z-direction because of the pressing process, which makes the board denser on the surface than in the middle. This has implications on the surface texture when the board is milled. The milled parts become rougher than the non-milled parts both because of the milling process and because of the lower density in the surface that is exposed after the milling.

Occurrence of orange peel effect is caused by the painting process and it appears mainly in the lateral surfaces of the kitchen front. Several types of problems can be related to the painting process; some of the most common are stripes, pinholes and the so-called orange peel effect. Of these problems only the orange peel effect can be considered to be a problem related to the surface texture, since the other defects are local defects which does not affect big areas of the surface. Orange peel effect has this name because the painted surface gets a texture that resembles the surface of the skin of an orange. It occurs when the solvent in the paint evaporates so fast that the paint does not have time to flow out evenly, drying into a bumpy surface. Some reasons of the orange peel appearance might be spraying at an angle other than perpendicular or applying excessive paint. It is more prone to occur on rough surfaces where it takes more time for the paint to flow out.

The final texture on the kitchen front is a result of the substrate material as well as the milling and painting processes used. Even though the texture is a result from the manufacturing process and not a chosen texture pattern, it is just as important as on the worktops. Kitchen fronts are almost always used side by side in the customer's kitchen. This makes it very important that they all look the same in terms of surface texture, color and gloss. Mismatches between the kitchen fronts will inevitably lead to unsatisfied customers.

4.4 What needs to be measured and specified

The identified problems have led the authors to conclude that there are several different parameters that must be controlled in order to specify a surface texture and make sure that the suppliers deliver products with a consistent look.

4.4.1 Worktops

Four parameters have been identified for the worktop textures. These are:

- The texture pattern
- The depth of the texture pattern
- The micro texture of the surface
- The gloss level of the surface

The most important parameter is the texture pattern. If the suppliers are not using the same texture pattern or at least similar texture patterns where it is hard to see a difference between, the final worktops will not look the same.

The depth of the texture pattern should be the same for a consistent look. If two samples with the same texture pattern have different texture depth, it is very likely that the sample with the deeper texture appears rougher and with a denser texture pattern. It is also possible that this sample appears glossier because of the deeper texture [64]. The deeper texture gives darker shadows which makes the contrast greater between the shadows and the highlights.

The micro texture is connected to the gloss of the surface. A smoother micro texture on the surface gives more specular reflection which is perceived as gloss. A rougher micro texture will scatter more of the reflected light making the surface appear duller.

Gloss is not only affected by the micro texture on the surface but also by other factors such as the material properties and the macro texture of the surface. So even if the micro texture is the same on two samples the overall gloss level should also be measured.

4.4.2 ZZ kitchen front

For the kitchen front three parameters have been studied:

- Differences in surface texture of the substrate
- Orange peel effect from the paint
- Gloss level of the surface

For the ZZ kitchen front, the surface texture differs between different areas of the front surface and, if this difference is too big, it will have a negative impact on the kitchen fronts look. The different textures are a result of the material used and the milling process carried out in the manufacturing process of the kitchen fronts (Figure 4.4).

Orange peel effect can appear because of the painting process. It is more prone to occur on the rougher milled parts of the surface and the sides (lateral surfaces) of the kitchen front which are painted in a vertical position (Figure 4.5). A certain amount of orange peel effect can be desirable for a more rustic/classic look. The amount of orange peel effect should be the same for the kitchen fronts to have a uniform appearance.

The gloss level on the kitchen fronts is connected to the paint and the painting process. This issue is already controlled today so it is not believed to be a problem.



Figure 4.4 Milled area on the left and non-milled area on the right



Figure 4.5 Orange peel effect on the side of the ZZ kitchen front sample

5 Test and evaluation of measurement methods

In this chapter the methods explained in the background research (3.2) will be evaluated for each parameter that needs to be controlled in both, worktops and kitchen fronts (4.4). The aim is to find the most suitable method to describe and characterize the studied surfaces.

5.1 Tested samples

Regarding the worktops, the samples on which the tests have been performed are from two worktop suppliers (Supplier S and Supplier A) and from a laminate manufacturer (Supplier K). Concerning the ZZ kitchen front all the tests have been performed on a sample from Swedwood (Figure 5.1).

The samples marked with an S in Figure 5.2 and Figure 5.3 are from Supplier S and the samples marked with an N are from Supplier A. The samples marked as S5 and N5 have the texture called “XX – wood grain” and the samples marked as S11 and N11 have the texture called “YY – stone”. These samples will, from now on, be referred to as Supplier S XX, Supplier A XX, Supplier S YY and Supplier A YY.

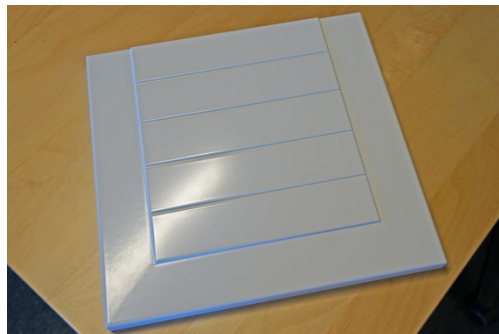


Figure 5.1 ZZ kitchen front sample



Figure 5.2 XX-wood grain texture samples

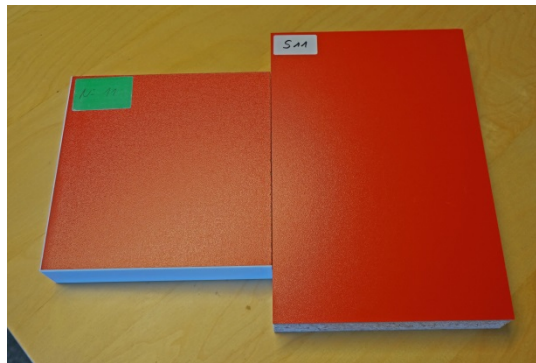


Figure 5.3 YY-stone texture samples

5.2 Worktops

5.2.1 The texture pattern

The problem with different suppliers using different texture patterns cannot be solved only by measuring and specifying values for a surface. However, measurements can still give valuable information about the texture and can be used to give quantifiable values which can be compared and give an indication of how similar or different the texture patterns on different surfaces are.

5.2.1.1 Profilometer measurements

A test using the Mitutoyo SJ-400 profilometer has been carried out with the aim of showing the significant differences in texture pattern between the two suppliers. An explanation about the parameters obtained from the profilometer is needed:

- YY – stone texture: due to the symmetric shape of its profile the standard followed is ISO 4287 (profile R). The first three parameters used are the most

characteristic amplitude parameters and the fourth one is to give spatial information:

- **Ra**: arithmetic average of all the absolute profile values
 - **Rq**: root mean square
 - **Rz**: mean value of the Rzi-values from the different sampling lengths
 - **RSm**: mean width of the profile elements within a sampling length
- **XX** – wood grain texture: due to the asymmetric shape of its profile the standard followed is DIN 4776. This is because the surface texture has the peculiar “scratches” of the wood (seen as deep valleys in the profile). The parameters used are the ones related to the material ratio curve, which is the aim of the study when analyzing asymmetric profile shapes:
- **Rpk**: average height of protruding peaks above roughness core profile
 - **Rvk**: average depth of valleys projecting through roughness core profile
 - **Rk**: depth of the roughness core profile
 - **Mr1**: level in % determined for the intersection line separating the protruding peaks from the roughness core profile
 - **Mr2**: level in % determined for the intersection line separating the deep valleys from the roughness core profile
 - **A1**: peak area
 - **A2**: valley area

A deeper explanation on how to select all the settings and parameters, how the previous mentioned standards work and how to take the measurements depending on which texture is being studied can be read in Appendix A.

Two samples with the texture called XX – wood grain (Supplier S XX and Supplier A XX) and two samples with the texture called YY – stone (Supplier S YY and Supplier A YY) have been compared.

Settings used:

- Standard: ISO'97
- Profile: R (YY – stone texture) / DIN4776 (XX – wood grain texture)
- Filter: Gauss
- N (number of sampling lengths): 5
- λ_c : 2,5 mm
- λ_s : 8 μ m
- L_n (evaluation length): 12,5 mm ($\lambda_c \times N$)
- Count level (used by RSm): 10% of the parameter Rz (over and under the mean line)

Table 5.1 Test results

| | XX – wood grain texture | | | | | | | |
|-----------------|-------------------------|-------|-------|-------|--------------------|-------|-------|-------|
| | Supplier A XX (N5) | | | Mean | Supplier S XX (S5) | | | Mean |
| Rpk [μm] | 2,80 | 3,40 | 2,70 | 2,97 | 3,10 | 2,70 | 2,40 | 2,73 |
| Rvk [μm] | 33,1 | 32,0 | 32,1 | 32,4 | 25,4 | 23,8 | 19,2 | 22,8 |
| Rk [μm] | 7,30 | 6,80 | 5,10 | 6,40 | 10,1 | 10,0 | 9,50 | 9,87 |
| Mr1 | 9,00% | 9,90% | 9,20% | 9,37% | 7,00% | 6,40% | 5,90% | 6,43% |
| Mr2 | 81,6% | 81,1% | 87,0% | 83,2% | 86,1% | 86,7% | 85,2% | 86,0% |
| A1 | 12,5 | 16,7 | 12,6 | 13,9 | 11,0 | 8,64 | 6,89 | 8,85 |
| A2 | 304 | 303 | 208 | 272 | 177 | 158 | 142 | 159 |

Table 5.2 Test results

| [μm] | YY – stone texture | | | | | | | |
|------------|---------------------|------|------|------|---------------------|------|------|------|
| | Supplier A YY (N11) | | | Mean | Supplier S YY (S11) | | | Mean |
| Ra | 7,05 | 7,04 | 8,29 | 7,46 | 4,61 | 5,15 | 4,03 | 4,60 |
| Rz | 29,1 | 28,7 | 32,3 | 30,0 | 22,3 | 21,8 | 21,4 | 21,8 |
| Rq | 8,31 | 8,17 | 9,35 | 8,61 | 5,56 | 6,04 | 5,07 | 5,57 |
| RSm | 801 | 732 | 1041 | 858 | 797 | 889 | 791 | 826 |

Focusing on the results from the XX texture it can be easily seen that in this kind of profiles the valleys (“wood grain”) are much more significant than the peaks: Rvk, Mr2 and A2 are much higher than Rpk, Mr1 and A1 respectively.

When comparing the R-parameters from the different suppliers, there are no significant differences regarding Rpk; this is because of the lack of protruding peaks in the XX texture. The parameter Rvk is significantly rougher in the sample from Supplier A, which means that it has deeper valleys projecting through the roughness core profile. However, Rk is rougher in the sample from Supplier S. The Rk parameter is an indicator of the surface roughness without considering the deep valleys that characterize this kind of texture. Thus, the sample from Supplier S is rougher if the “wood grains” are not taken into account. For these reasons it is difficult to conclude which sample is rougher.

The parameter A2 differs a lot even between measurements of the same sample. This is because it depends on the amount of “wood grains” that are included in each measurement. Therefore, it can be concluded that the sample from Supplier A has more wood grains than the one from Supplier S (A2, which is the valley area, is higher in the sample from Supplier A).

Concerning the comparison of the YY texture, the results are conclusive and indicate that the sample from Supplier A is rougher than the one from Supplier S: all the three amplitude parameters (Ra, Rz and Rq) are higher. The roughness is also more spaced, which can be seen on the higher RSm value.

5.2.1.2 3D measurements obtaining S-parameters

This analysis has been carried out using a 3D measuring instrument from GFM3D called MikroCAD, based on projected fringe technology. The measurement area of this equipment is 25x19 mm and it has a vertical resolution of 1,6 μm . The vertical range is 5 mm and the horizontal resolution 16 μm . The S-parameters obtained from the analysis are equivalent to the R-parameters that are called in the same way, but measured over an area instead of a profile (e.g. Sa gives the same information as Ra over an area).

Each test consists in a 2D image that gives information about the texture pattern and the texture depth by using a color graded scale. It also provides the material ratio curve of the studied area, with the S-parameters related to the curve (Sk, Spk, Svk, Mr1, Mr2, A1 and A2) as well as Sa and Sxp (extreme peak height). Finally, a 2D image of the surface is displayed split into motifs (repeated patterns), pointing out the number of motifs, its mean height and its mean area. The whole analysis with all the tests can be found in Appendix B.

A comparison between the S-parameters and the R-parameters obtained from the profilometer analysis above has been done. These tests provide the same parameters (mentioned above) for both the XX – wood grain texture and the YY – stone texture; this means that the XX samples comparison will be more extensive than the YY samples one (which only has Sa/Ra in common).

Table 5.3 Test results

| [μm] | Supplier A XX (N5) | | [μm] | [μm] | Supplier S XX (S5) | | [μm] | |
|------|--------------------|-------|------|------|--------------------|-------|-------|-----|
| Spk | 5,26 | 2,97 | Rpk | | Spk | 6,68 | 2,73 | Rpk |
| Svk | 23,4 | 32,4 | Rvk | | Svk | 20,6 | 22,8 | Rvk |
| Sk | 17,2 | 6,40 | Rk | | Sk | 15,4 | 9,87 | Rk |
| Mr1 | 7,42% | 9,37% | Mr1 | | Mr1 | 10,2% | 6,43% | Mr1 |
| Mr2 | 79,8% | 83,2% | Mr2 | | Mr2 | 84,9% | 86,0% | Mr2 |
| A1 | 19,5 | 13,9 | A1 | | A1 | 34,1 | 8,85 | A1 |
| A2 | 237 | 272 | A2 | | A2 | 155 | 159 | A2 |

Table 5.4 Test results

| [μm] | Supplier A YY (N11) | | [μm] | | [μm] | Supplier S YY (S11) | | [μm] |
|-------------------|---------------------|------|-------------------|--|-------------------|---------------------|------|-------------------|
| Sa | 6,73 | 7,46 | Ra | | Sa | 5,90 | 4,60 | Ra |

As seen in the Table 5.3 and Table 5.4, all the parameters are significantly different when comparing profile measurements to area measurements. The authors believe that the S-parameters are more reliable since they are measured over an area (25x19 mm) which means that the measured region of the sample is pretty larger than the one measured with the profilometer (12,5 mm).

Another comparison has been carried out facing the S-parameters obtained between the different suppliers:

Table 5.5 Test results

| [μm] | XX – wood grain texture | | [μm] | YY – stone texture | |
|-------------------|-------------------------|-----------------|-------------------|--------------------|------------------|
| | Supplier A (N5) | Supplier S (S5) | | Supplier A (N11) | Supplier S (S11) |
| Spk | 5,26 | 6,68 | Sa | 6,73 | 5,90 |
| Svk | 23,4 | 20,6 | | | |
| Sk | 17,2 | 15,4 | | | |
| Mr1 | 7,42% | 10,2% | | | |
| Mr2 | 79,8% | 84,9% | | | |
| A1 | 19,5 | 34,1 | | | |
| A2 | 237 | 155 | | | |

Regarding the XX texture, as well as in the profilometer analysis, the parameter Svk is rougher in the sample from Supplier A, which means that it has deeper valleys projecting through the roughness core profile. Sk is higher in the Supplier A sample, so its texture is as well rougher in between the wood grains. This last result differs from the profilometer analysis, which stated that Supplier S had rougher texture in between the valleys. Looking at the A2 parameter (valley area), it can be easily seen that the sample from Supplier A has more wood grains than the one from Supplier S (as supported by the profilometer analysis).

Concerning the YY texture, as explained before just one parameter is used from the MikroCAD analysis: Sa. This is because the material ratio curve is not used for describing this kind of texture. Thus, if focusing just on this parameter, the sample from Supplier A is rougher than the one from Supplier S (which was as well the conclusion from the profilometer analysis).

5.2.1.3 Optimap PSD measurements

As explained in the background (3.2.2.3), the aim of this method is quantifying the appearance of a surface. Thus, these measurements do not provide S- or R-parameters but curvature parameters ($K_a - K_e$), which are related to the visual appearance. From these curvature parameters it calculates the texture values ($T_a - T_e$) by applying standardized equations. The authors believe that this method provides good 2D images where the texture can be appreciated.

The tests have been done on the same samples as in the profilometer analysis. The data obtained from each test consist, first of all, in a general analysis of the surface: both 2D and 3D images of the area studied and the profile shape (in the x and the y directions). Then, 2D images are provided for each wavelength band ($K_a - K_e$); the curvature values that are positive indicate a protrusion from the surface whereas the negatives ones indicate a depression into the surface. Finally the K- and the T-values are displayed in two different graphs. The whole analysis with all the tests can be found in Appendix C.

These are the graphs showing the T-values of the XX – wood grain texture samples for both suppliers:

Supplier A N5:

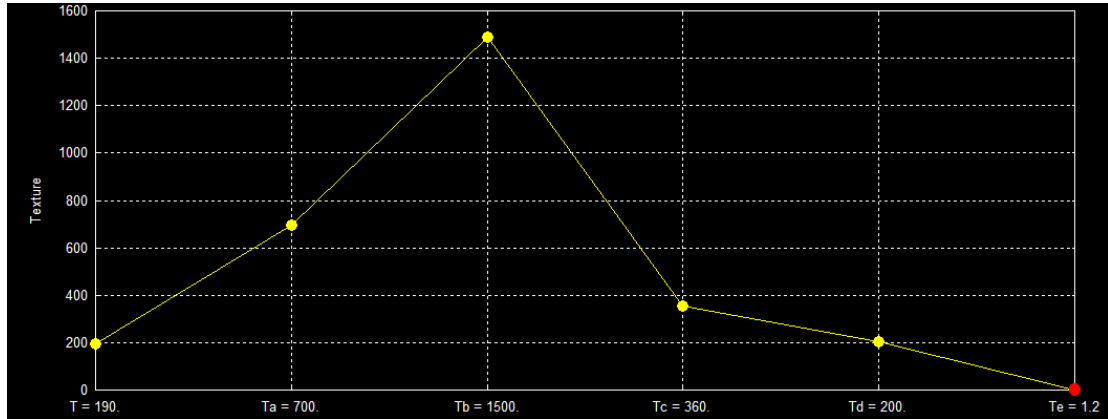


Figure 5.4 T-values of the XX-wood grain texture for N5

Supplier S S5:

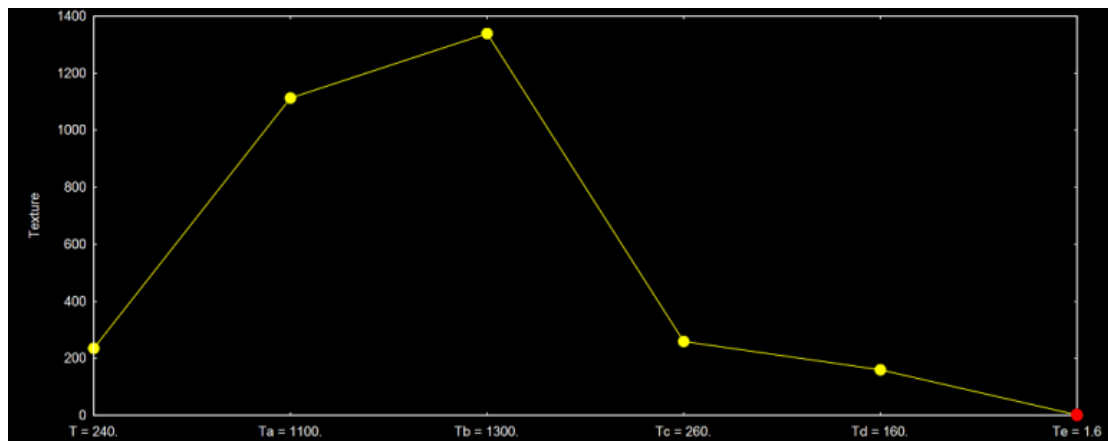


Figure 5.5 T-values of the XX-wood grain texture for S5

It can be seen in the graphs above (Figure 5.4 and Figure 5.5) that in both samples the biggest amount of structures present on the surface have a wavelength range Kb (0,3 – 1,0 mm). The sample from Supplier A has its texture more concentrated at this specific wavelength band (Tb = 1500) whereas the sample from Supplier S has its texture more spread between this one and Ka (0,1 – 0,3 + 0,3 – 1,0 mm): Tb = 1300 and Ta = 1100. Trying to relate these results to the profilometer analysis, the sample from Supplier S had a higher depth of the roughness core profile (Rk), which means that its texture between wood grains is rougher. Considering that the main texture of these XX samples is the wood grain valleys, the fact that S5 has as well a meaningful

roughness between them could explain the longer wavelength range where the significant amount of texture is located.

These are the graphs showing the T-values of the YY – stone texture samples for both suppliers:

Supplier A N11:

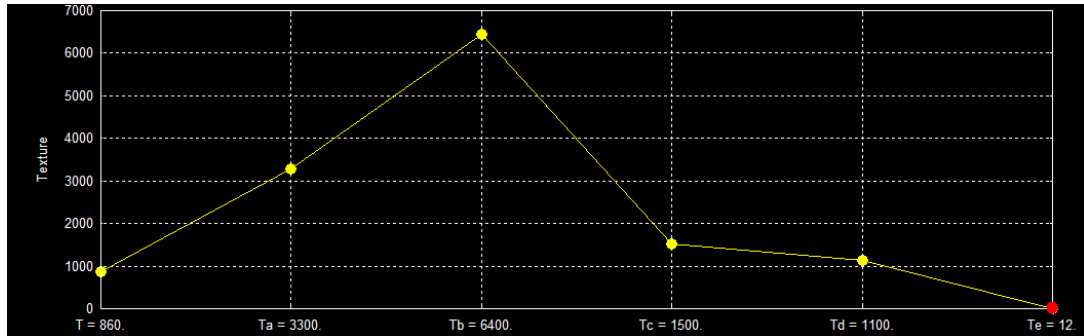


Figure 5.6 T-values of the YY-stone texture for N11

Supplier S S11:

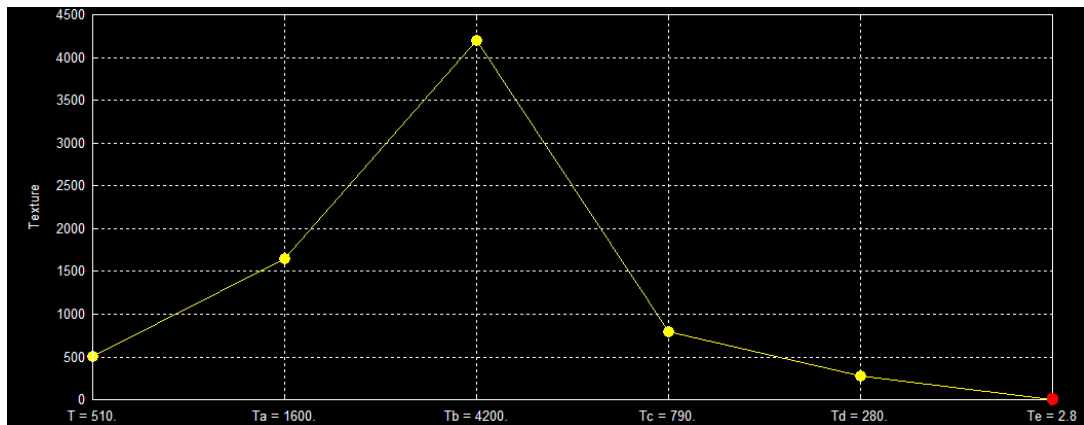


Figure 5.7 T-values of the YY-stone texture for S11

The measurements carried out on the Supplier A N11 sample did not work properly, as it can be seen in the first 2D and 3D images, as well as in the profile shapes. However, if the texture graphs are considered anyway, in both samples the biggest amount of structures present on the surface has as well a wavelength range Kb (0,3 – 1,0 mm). The sample from Supplier A (Tb = 6400) is considerably rougher than the Supplier S one (Tb = 4200); this makes sense when comparing it to the profilometer results, which showed that N11 was rougher than S11 too. Nevertheless, if these two graphs are compared to the micro texture analysis developed in section 5.2.3.1, the results differ. This mentioned analysis states that S11 has a rougher micro texture

than N11, which is not supported by the Optimap analysis: at the shortest wavelength band the texture in N11 ($T_a = 3300$) is higher than the texture in S11 ($T_a = 1600$).

5.2.2 The depth of the texture pattern

In order to test the differences in the depth of the texture pattern between surfaces, the previous test carried out with the profilometer to compare texture patterns could be used. However, the authors believe that if two surfaces have different texture patterns, it has no sense to analyze the difference in the texture depth, since the first problem overtakes the second one. This means that if two surfaces have different texture patterns it does not really matter the depth of these textures. For this reason the test carried out in this section is using samples from the same supplier (Supplier K).

A test using the Mitutoyo SJ-400 profilometer has been carried out to compare three different samples with XX texture and two samples with YY texture. The explanation of the parameters used is exactly the same as in section 5.2.1.1.

Settings used:

- Standard: ISO'97
- Profile: R (YY – stone texture) / DIN4776 (XX – wood grain texture)
- Filter: Gauss
- N (number of sampling lengths): 5
- λ_c : 2,5 mm
- λ_s : 8 μm
- L_n (evaluation length): 12,5 mm ($\lambda_c \times N$)
- Count level (used by RSm): 10% of the parameter R_z (over and under the mean line)

Table 5.6 Test results

| | XX – wood grain texture (Supplier K) | | | | | | | |
|------------------------------|--------------------------------------|-------|-------|-------|---------|-------|-------|-------|
| | A558 XX | | | Mean | S135 XX | | | Mean |
| Rpk [μm] | 3,10 | 2,70 | 2,10 | 2,63 | 1,80 | 2,20 | 2,20 | 2,07 |
| Rvk [μm] | 31,4 | 21,6 | 24,4 | 25,8 | 26,9 | 30,7 | 22,7 | 26,8 |
| Rk [μm] | 10,0 | 10,0 | 9,30 | 9,77 | 9,90 | 9,50 | 9,80 | 9,73 |
| Mr1 | 6,60% | 5,70% | 5,50% | 5,93% | 3,60% | 7,00% | 3,50% | 4,70% |
| Mr2 | 86,9% | 85,9% | 87,8% | 86,8% | 86,6% | 79,4% | 84,6% | 83,5% |
| A1 | 10,1 | 7,54 | 5,60 | 7,74 | 3,27 | 7,88 | 3,88 | 5,01 |
| A2 | 205 | 152 | 149 | 169 | 180 | 316 | 175 | 223 |

| XX – wood grain texture (Supplier K) | | | | |
|--------------------------------------|----------|-------|-------|-------|
| | 17712 XX | | | Mean |
| Rpk [μm] | 2,70 | 2,90 | 2,40 | 2,67 |
| Rvk [μm] | 21,4 | 15,7 | 26,3 | 21,1 |
| Rk [μm] | 8,50 | 8,30 | 8,90 | 8,57 |
| Mr1 | 8,30% | 6,80% | 4,60% | 6,57% |
| Mr2 | 83,9% | 86,7% | 86,9% | 85,8% |
| A1 | 11,1 | 9,69 | 5,55 | 8,77 |
| A2 | 173 | 104 | 172 | 150 |

Table 5.7 Test results

| YY – stone texture (Supplier K) | | | | | | | | |
|---------------------------------|--------|------|------|------|---------|------|------|------|
| [μm] | 430 YY | | | Mean | C618 YY | | | Mean |
| Ra | 4,04 | 4,65 | 5,10 | 4,60 | 4,86 | 4,47 | 4,92 | 4,75 |
| Rz | 21,9 | 26,9 | 24,9 | 24,6 | 24,2 | 22,4 | 24,0 | 23,5 |
| Rq | 5,12 | 5,79 | 6,18 | 5,70 | 5,84 | 5,36 | 5,95 | 5,72 |
| RSm | 775 | 772 | 653 | 733 | 640 | 599 | 673 | 637 |

As seen in the Table 5.6 and Table 5.7, 3 measurements have been done for each sample. The authors had 3 samples with the XX – wood grain texture and 2 with the YY – stone texture. Regarding the XX texture samples, as in the test carried out to compare samples from different suppliers, the valleys (“wood grains”) are much more significant than the peaks (Rvk, Mr2 and A2 are much higher than Rpk, Mr1 and A1 respectively).

The significant roughness parameter in this texture analysis is Rvk (information on the valleys projecting through the roughness core profile) since it is the one directly related to the depth of the wood grains. Thus, looking at this roughness parameter it can be concluded that the first two samples have a very similar wood grain depth. However, in the third one the wood grains are shallower.

The authors believe that the tool wear and the process variations affect more the micro texture than the macro texture. Thus, the explanation of why the third sample has shallower wood grains cannot be based on the tool wear / process variations problem. Since the laminates that Supplier K produces for IKEA are done through CPL processes using release paper as a texture tool, the explanation of the shallower wood grains could be the use of a different release paper roller.

As well as with the previous test, the parameter A2 differs a lot even between measurements of the same sample. This is because it depends on the amount of “wood grains” that are included in each measurement. However, in this test the variation just depends on where the stylus has been placed to take each measurement,

since the samples are from the same supplier and the texture pattern is the same, having the same amount of wood grains.

Concerning the YY – stone texture, all the amplitude parameters are significant in this texture analysis (Ra, Rz and Rq) since all of them give information on the texture depth. It is not possible to conclude from the results which one is rougher, since the one that has a higher Ra on one hand, has a lower Rz on the other. However, it can be seen that the differences between both samples are far from being significant.

5.2.3 The micro texture of the surface

The micro texture of the surfaces has been studied by using the Mitutoyo SJ-400 profilometer. Two tests have been done: the first one on the four samples named Supplier S XX, Supplier A XX, Supplier S YY and Supplier A YY (different suppliers), and the second one on samples from the same supplier (Supplier K).

The micro texture profile of all the studied surfaces has a more symmetric shape rather than an asymmetric one. Thus the same parameters as with the YY – stone texture analysis have been used, but with a shorter cutoff wavelength λ_c (even shorter wavelength components must be filtered out). A deeper explanation on how to select all the settings and parameters, how the previous mentioned standards work and how to take the measurements depending on which texture is being studied can be read in Appendix A.

5.2.3.1 Micro texture comparison between different suppliers

Settings used:

- Standard: ISO'97
- Profile: R
- Filter: Gauss
- N (number of sampling lengths): 5
- λ_c : 0,08 mm
- λ_s : 2,5 μ m
- L_n (evaluation length): 0,4 mm ($\lambda_c \times N$)
- Count level (used by RSm): 10% of the parameter Rz (over and under the mean line)
 - o RSm = L-P: it means that there are not profile peaks (projecting over the upper count level) adjacent to profile valleys (projecting below the lower count level).

Table 5.8 Test results

| [μm] | Micro texture: XX – wood grain texture | | | | | | | |
|------------|--|------|------|------|-----------------|------|------|------|
| | Supplier A (N5) | | | Mean | Supplier S (S5) | | | Mean |
| Ra | 0,35 | 0,29 | 0,51 | 0,38 | 0,30 | 0,37 | 0,39 | 0,35 |
| Rz | 1,60 | 1,30 | 2,00 | 1,63 | 1,40 | 1,90 | 1,80 | 1,70 |
| Rq | 0,43 | 0,35 | 0,61 | 0,46 | 0,36 | 0,46 | 0,46 | 0,43 |
| RSm | L-P | 34,1 | 48,0 | - | 33,5 | 35,7 | 34,2 | 34,5 |

Table 5.9 Test results

| [μm] | Micro texture: YY – stone texture | | | | | | | |
|------------|-----------------------------------|------|------|------|------------------|------|------|------|
| | Supplier A (N11) | | | Mean | Supplier S (S11) | | | Mean |
| Ra | 0,14 | 0,12 | 0,18 | 0,15 | 0,30 | 0,19 | 0,20 | 0,23 |
| Rz | 0,70 | 0,60 | 0,70 | 0,67 | 1,20 | 1,00 | 0,90 | 1,03 |
| Rq | 0,17 | 0,15 | 0,22 | 0,18 | 0,34 | 0,23 | 0,24 | 0,27 |
| RSm | L-P | L-P | L-P | - | 36,2 | L-P | L-P | - |

The comparison between the XX texture samples shows that the micro texture can be considered pretty similar in both suppliers, since the three amplitude parameters (Ra, Rz and Rq) do not show significant differences.

However, in the YY texture comparison it can be concluded that the sample from Supplier S has a rougher micro texture than the one from Supplier A, since the three amplitude parameters are higher. This result is rather interesting, since the analysis of the texture pattern (macro texture) gave the opposite conclusions (the sample from Supplier A was rougher than the sample from Supplier S).

The results regarding the spacing information (RSm parameter) are inconclusive since a big part of the measurements did not have profile peaks adjacent to profile valleys in the predetermined count level.

5.2.3.2 Micro texture comparison in the same supplier

Settings used:

- Standard: ISO'97
- Profile: R
- Filter: Gauss
- N (number of sampling lengths): 5
- λ_c : 0,08 mm
- λ_s : 2,5 μm

5 Test and evaluation of measurement methods

- Ln (evaluation length): 0,4 mm ($\lambda_c \times N$)
- Count level (used by RSm): 10% of the parameter Rz (over and under the mean line)
 - o RSm: L-P means that there are not profile peaks (projecting over the upper count level) adjacent to profile valleys (projecting below the lower count level).

Table 5.10 Test results

| [μm] | Micro texture: XX – wood grain texture (Supplier K) | | | | | | | | | | | |
|------------|---|------|------|------|---------|------|------|------|----------|------|------|------|
| | A558 XX | | | Mean | S135 XX | | | Mean | 17712 XX | | | Mean |
| Ra | 0,38 | 0,39 | 0,35 | 0,37 | 0,36 | 0,46 | 0,36 | 0,39 | 0,35 | 0,41 | 0,40 | 0,39 |
| Rz | 2,00 | 2,00 | 1,60 | 1,87 | 1,60 | 2,10 | 1,90 | 1,87 | 1,90 | 1,90 | 1,80 | 1,87 |
| Rq | 0,47 | 0,48 | 0,43 | 0,46 | 0,42 | 0,55 | 0,46 | 0,48 | 0,44 | 0,49 | 0,48 | 0,47 |
| RSm | 26,4 | 35,7 | 33,1 | 31,7 | 26,1 | L-P | 35,6 | - | 34,7 | L-P | 40,6 | - |

Table 5.11 Test results

| [μm] | Micro texture: YY – stone texture (Supplier K) | | | | | | | |
|------------|--|------|------|------|---------|------|------|------|
| | 430 YY | | | Mean | C618 YY | | | Mean |
| Ra | 0,21 | 0,22 | 0,27 | 0,23 | 0,51 | 0,28 | 0,14 | 0,31 |
| Rz | 0,70 | 0,90 | 1,20 | 0,93 | 2,10 | 1,30 | 0,70 | 1,37 |
| Rq | 0,25 | 0,26 | 0,33 | 0,28 | 0,62 | 0,35 | 0,18 | 0,38 |
| RSm | L-P | L-P | L-P | - | L-P | L-P | L-P | - |

The micro texture comparison between the three XX samples shows that the roughness values are almost exactly the same. On the other hand, in the micro texture comparison between the two YY samples, the second one is significantly rougher.

As stated above, it is believed that the tool wear and the process variations affect more the micro texture than the macro texture. For this reason this is the suitable test to focus on these issues. Although it was not possible for the authors to find out how many times the release paper had been used when the different samples were manufactured, it can be concluded that in the XX samples it is not possible to appreciate the differences in roughness due to either the tool wear or the process variations. However, in the YY samples it can be said that either the first one was manufactured with a more worn out release paper than the second one or the two of them were manufactured with slightly different conditions (such as temperature or pressure).

The results regarding the spacing information (RSm parameter) are inconclusive since a big part of the measurements did not have profile peaks adjacent to profile valleys in the predetermined count level.

5.2.4 Gloss level of the surface

The gloss values of the samples are taken from a report commissioned by IKEA from the Institut für Holztechnologie Dresden GmbH (IHD) and the measurements were performed according to DIN EN 13722.

Table 5.12 Test results

| Sample | Measurement angle | M1 (GU) | M2 (GU) | M3 (GU) | M4 (GU) | Mean (GU) | Std. deviation |
|-----------------------------|-------------------|---------|---------|---------|---------|-----------|----------------|
| Supplier A XX-texture (N5) | 60° | 7,20 | 6,40 | 7,50 | 7,30 | 7,10 | 0,5 |
| | 85° | 19,1 | 17,6 | 20,0 | 18,8 | 18,9 | 1,0 |
| Supplier S XX-texture (S5) | 60° | 5,70 | 5,70 | 5,60 | 5,50 | 5,60 | 0,1 |
| | 85° | 21,6 | 21,5 | 20,5 | 21,0 | 21,2 | 0,5 |
| Supplier A YY-texture (N11) | 60° | 11,8 | 13,1 | 13,4 | 13,7 | 13,0 | 0,8 |
| Supplier S YY-texture (S11) | 60° | 16,5 | 14,5 | 16,9 | 14,2 | 15,5 | 1,4 |

The gloss of the XX samples (N5 and S5) measured at 60° was lower than 10 GU. Thus, another measurement was needed using an angle of 85°.

Focusing on the profilometer test carried out on these samples regarding the texture pattern analysis (macro texture), it could be seen that the S5 sample had lower Rvk but higher Rk than the N5 one. Looking at the gloss measurements S5 is glossier than N5. Therefore, the facts of having less deep valleys projecting through the roughness core profile and/or having a higher roughness in-between the valleys could make S5 to have a higher gloss level than N5. It could be seen as well that the roughness in N11 was higher than S11, as well as more spaced. Because of the fact that the gloss measurements done on S11 are higher than the ones on N11, it can be said that a smoother and less spaced YY – stone texture could give a higher gloss level.

Focusing on the profilometer test carried out on these samples regarding the micro texture analysis, it could be seen that N5 and S5 had a pretty similar micro texture; however, S11 was rougher than N11. S11 is as well glossier than N11, so this test states that rougher YY micro textures give higher gloss levels.

The authors think it is important to point out that the gloss measurements not always reflect the visual perception of gloss. An example is the comparison between YY – stone textures (N11 and S11): the sample from Supplier A (N11) looks glossier than the one from Supplier S (S11) although the gloss meter says the opposite.

5.3 Kitchen front

The sample where the analysis has been carried out is a sample that has passed the quality inspection in Swedwood. It shows no signs of orange peel effect on the front or the backsides but it does on the lateral sides. A difference in surface texture between the milled and non-milled areas can be seen.

5.3.1 Differences in surface texture

5.3.1.1 Profilometer measurements

To study the texture on the milled and non-milled parts of the kitchen front, several measurements using the Mitutoyo SJ-400 profilometer have been carried out. All the available cutoff lengths (λ_c) of the Gauss high-pass filter have been tested.

The texture of both the milled and the non-milled surfaces has a more symmetric profile than an asymmetric one. Thus the same parameters as with the YY – stone texture analysis have been used. A deeper explanation on how to select all the settings and parameters, how the previous mentioned standards work and how to take the measurements depending on which texture is being studied can be read in Appendix A.

Settings used:

- Standard: ISO'97
- Profile: R
- Filter: Gauss
- N (number of sampling lengths): 5
- λ_c : depending on the measurement (all the possible ones)
- λ_s : depending on the measurement (automatically set)
- L_n (evaluation length): depending on the measurement ($\lambda_c \times N$)
- Count level (used by RSm): 10% of the parameter R_z (over and under the mean line)
 - RSm = L-P: it means that there are not profile peaks (projecting over the upper count level) adjacent to profile valleys (projecting below the lower count level).

Table 5.13 Test results

| [μm] | $\lambda_c = 0,08 \text{ mm}$ | | $\lambda_c = 0,25 \text{ mm}$ | | $\lambda_c = 0,8 \text{ mm}$ | | $\lambda_c = 2,5 \text{ mm}$ | |
|------------|-------------------------------|-------------|-------------------------------|-------------|------------------------------|-------------|------------------------------|-------------|
| | n-m | m | n-m | m | n-m | m | n-m | m |
| Ra | 0,07 | 0,06 | 0,20 | 0,17 | 0,28 | 0,26 | 0,31 | 0,52 |
| Rz | 0,30 | 0,30 | 1,30 | 1,10 | 1,70 | 1,70 | 2,10 | 3,40 |
| Rq | 0,08 | 0,08 | 0,25 | 0,21 | 0,34 | 0,34 | 0,39 | 0,65 |
| RSm | L-P | 18,8 | 73,3 | 43,5 | 219 | 187 | 314 | 662 |
| Ra | 0,08 | 0,08 | 0,14 | 0,15 | 0,22 | 0,31 | 0,29 | 0,45 |
| Rz | 0,40 | 0,40 | 0,80 | 0,90 | 1,60 | 2,00 | 2,10 | 3,00 |
| Rq | 0,09 | 0,09 | 0,18 | 0,19 | 0,28 | 0,39 | 0,36 | 0,57 |
| RSm | L-P | 35,5 | 60,3 | L-P | 168 | 228 | 285 | 552 |
| Ra | 0,11 | 0,08 | 0,17 | 0,18 | 0,27 | 0,38 | 0,31 | 0,49 |
| Rz | 0,50 | 0,40 | 0,90 | 0,90 | 1,80 | 2,10 | 2,70 | 3,00 |
| Rq | 0,13 | 0,10 | 0,21 | 0,22 | 0,35 | 0,46 | 0,39 | 0,61 |
| RSm | L-P | 28,3 | 107 | 89,1 | 139 | L-P | 216 | 432 |
| | Mean | Mean | Mean | Mean | Mean | Mean | Mean | Mean |
| Ra | 0,09 | 0,07 | 0,17 | 0,17 | 0,26 | 0,32 | 0,30 | 0,49 |
| Rz | 0,40 | 0,37 | 1,00 | 0,97 | 1,70 | 1,93 | 2,30 | 3,13 |
| Rq | 0,10 | 0,09 | 0,21 | 0,21 | 0,32 | 0,40 | 0,38 | 0,61 |
| RSm | - | 27,5 | 80,2 | - | 175 | - | 272 | 549 |

n-m: non-milled surface / m: milled surface

Table 5.14 Test results

| [μm] | $\lambda_c = 0,8 \text{ mm}$ | | |
|-----------|------------------------------|--------|-----------|
| | Non-milled | Milled | % Rougher |
| Ra | 0,26 | 0,32 | 23,0% |
| Rz | 1,70 | 1,93 | 13,5% |
| Rq | 0,32 | 0,40 | 25,0% |

Table 5.15 Test results

| [μm] | $\lambda_c = 2,5 \text{ mm}$ | | |
|-----------|------------------------------|--------|-----------|
| | Non-milled | Milled | % Rougher |
| Ra | 0,30 | 0,49 | 63,3% |
| Rz | 2,30 | 3,13 | 36,1% |
| Rq | 0,38 | 0,61 | 60,5% |

As seen in the Table 5.13, 24 measurements have been done (each measurement providing the 4 different parameters): 3 measurements in the milled part and 3 in the non-milled part for the 4 different cutoff lengths (λ_c) available in the profilometer. The fact that the milled surface is rougher than the non-milled one is not possible to be appreciated with cutoff lengths of 0,08 and 0,25 mm. However, the results show that with 0,8 mm the milled surface is rougher, and with a cutoff length of 2,5 mm (the longest one in this Mitutoyo SJ-400 model) the differences in roughness are even more significant (seen in Table 5.14 and Table 5.15).

These results lead to the following analysis: the differences in roughness between the milled and the non-milled surfaces can be appreciated only with the two longest cutoff lengths of the filter. Thus, the micro texture of both parts of the kitchen front is similar, and only the macro texture is different. This verifies that the “unwanted” texture of the milled surface is caused by the manufacturing process (the cutting forces of the milling machine tool affect the macro texture) and not because of the painting (which it is believed to affect the micro texture).

The results regarding the spacing information (RS_m parameter) are inconclusive since a big part of the measurements did not have profile peaks adjacent to profile valleys in the predetermined count level.

5.3.1.2 3D measurements obtaining S-parameters

This analysis has been carried out using the same 3D measuring instrument as in section 5.2.1.2 (GFM3D MikroCAD). The only S-parameters obtained in the analysis are S_a (arithmetic mean height) and S_{xp} (extreme peak height); this is due to the fact that the authors did not have complete access to the equipment and could not ask for a deeper study. What is most interesting about this analysis is how it improves the visual comparison (Figure 5.8).

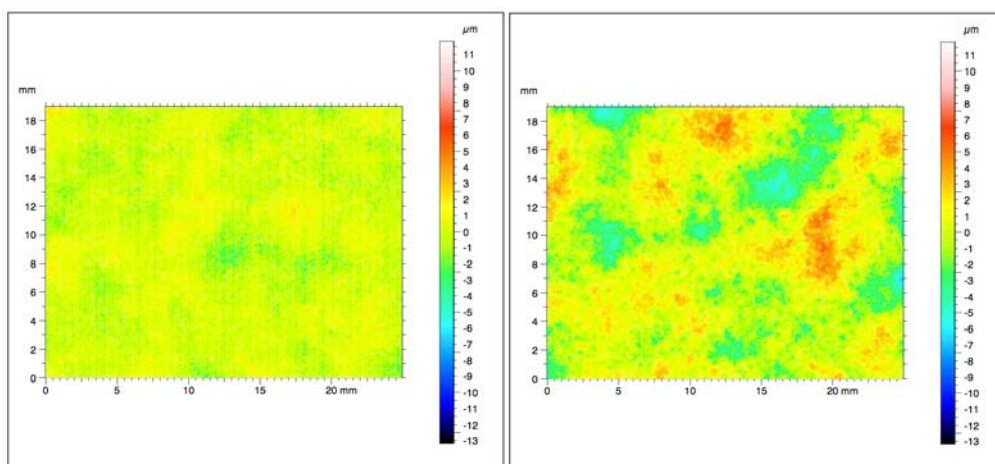


Figure 5.8 Non-milled area (left) and milled area (right) of the kitchen front

Table 5.16 Test results

| [μm] | Non-milled | Milled | % Rougher |
|-------------------|------------|--------|-----------|
| Sa | 0,71 | 1,45 | 104% |
| Sxp | 4,01 | 8,79 | 119% |

As it can be seen in Table 5.16, the milled surface is much rougher than the non-milled one (the parameters are more than twice as high). This test states that the differences between both areas are higher than the differences confirmed by the tests carried out with the profilometer with all the possible cutoff lengths. S-parameters give information over an area, thus the authors think that they are more reliable than the R-parameters. Therefore, it can be concluded that the differences in roughness between the milled and the non-milled surfaces of the ZZ kitchen front are really significant.

5.3.1.3 Optimap PSD measurements

The first test carried out on the kitchen front sample has provided neither K- nor T-values. This is because it has been measured both the milled and the non-milled areas at the same time, in order to visualize the differences. Thus, the stripe that can be seen in all the images is caused by the difference in height between both areas, and it would spoil the numerical results. The zone over the stripe is the milled surface, and the zone under it is the non-milled surface.

Although these measurements are considered to be appearance measurements, in the first three wavelength bands (Ka, Kb and Kc) it can be easily appreciated the differences in texture between both parts: the milled area has long grains caused by the milling process whereas the non-milled area has a more homogeneous and symmetric structure.

5 Test and evaluation of measurement methods

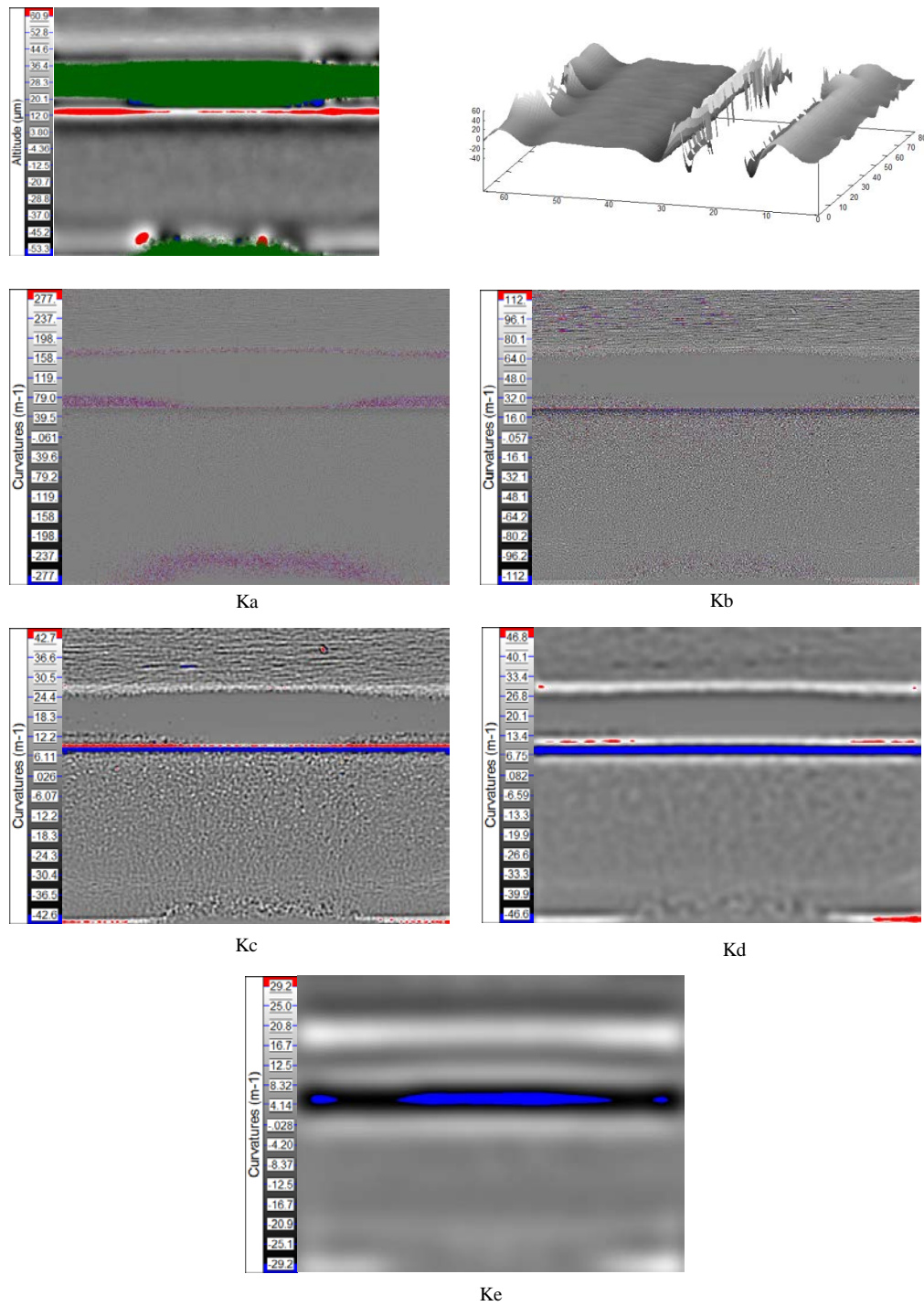


Figure 5.9 Optimap measurements: first test

In the second Optimap analysis carried out on the kitchen front sample an area of the non-milled part has been selected. In this way it has been possible to get the K- and T-values that were missing in the first test.

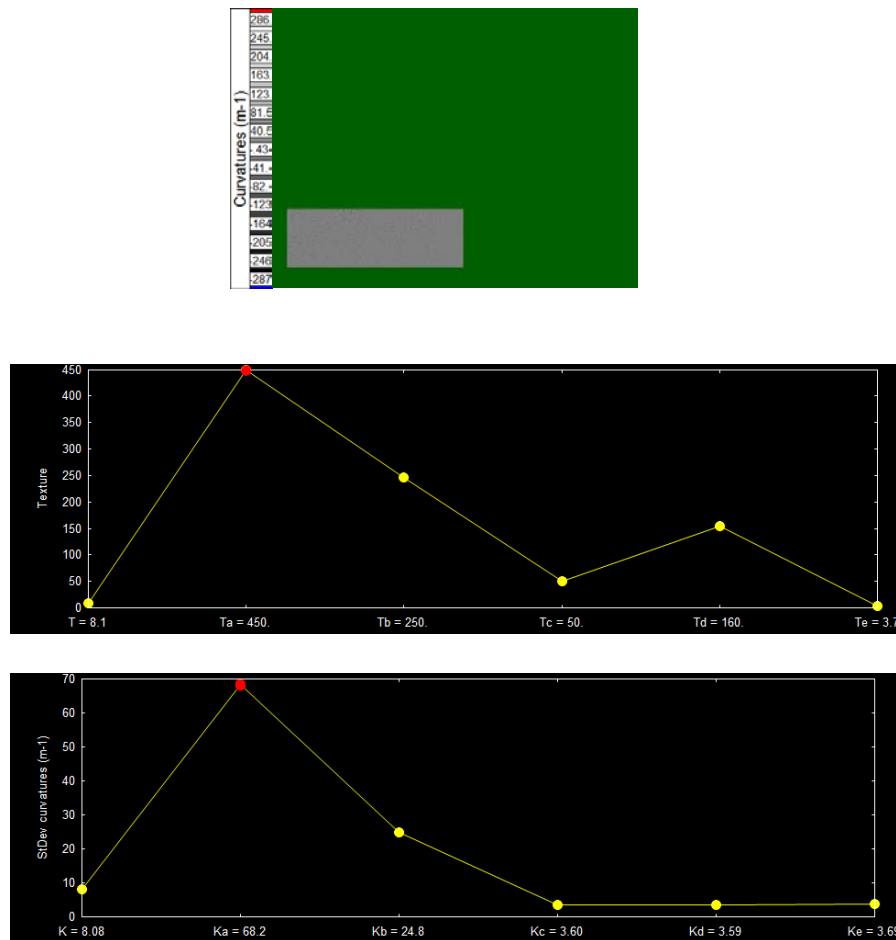


Figure 5.10 Optimap measurements: second test

Therefore, it can be seen in this test that it is possible to get values even if there are some parts of the measurement area that are not fine. The biggest amount of texture in the non-milled part has a wavelength between 0,1 and 0,3 mm ($T_a = 450$).

5.3.1.4 Wave-Scan measurements

The test has been carried out with a Wave-Scan Dual instrument, from the company BYK-Gardner. As explained in the background (3.2.2.2), this equipment uses a laser and an infrared LED to scan the surface and a CCD sensor to measure the reflection. The optical profile recorded by the CCD sensor is band-pass filtered into five different wavelengths (Wa – We).

These measurements are considered to be appearance measurements. They have been done on the backside and on the milled area of the front side, since the non-milled area of the sample was not measurable as the “image forming qualities” were too low. This means that the area was not brilliant enough to be able to take measurements with Wave-Scan equipment.

Table 5.17 Test results

| | | Wa | Wb | Wc | Wd | We |
|--------------------|-------------|------|------|------|------|------|
| Backside | M1 | 78,6 | 63,8 | 26,1 | 23,6 | 16,9 |
| | M2 | 77,0 | 60,2 | 26,9 | 25,4 | 22,0 |
| | M3 | 79,5 | 63,4 | 26,6 | 18,0 | 15,9 |
| Milled area | M1 | 74,5 | 60,7 | 30,5 | 34,2 | 20,0 |
| | M2 | 76,6 | 58,7 | 26,3 | 33,5 | 29,5 |
| | M3 | 78,8 | 60,7 | 30,7 | 34,2 | 32,1 |
| Mean | Backside | 78,4 | 62,5 | 26,5 | 22,3 | 18,3 |
| | Milled area | 76,6 | 60,0 | 29,2 | 34,0 | 27,2 |

Comparing the two tested surfaces, there is a significant difference in the Wd and the We wavelengths, since the ones from the milled area are higher. This means that the differences between the backside and the milled area are significant when the profile is filtered into long wavelengths (from 3 to 30 mm).

5.3.1.5 Gloss and DOI measurements

These measurements have been used for the orange peel problem. It is believed that with this problem the visual inspection is the right way to proceed, since it is more considered an appearance matter rather than a roughness one. However, measuring the gloss and the DOI is a way to quantify this appearance.

After a conversation with Peter Håkansson, sales technician at AkzoNobel Wood Finishes & Adhesives, the authors received test results from a test conducted by him using an instrument called Rhopoint IQ. The Rhopoint IQ measures gloss at three angles as well as DOI, Haze and Rspec. The tests were performed on pigment lacquered kitchen front samples which had been judged to have different amounts of orange peel effect. The results from the test can be seen in Table 5.18. The results are

inconclusive and cannot be used to quantify the amount of orange peel effect on the samples. A theory is that the samples have too low gloss values for the instrument to detect differences in the amount of orange peel effect. Because of these results no further investigations into the usage of DOI measurements to evaluate orange peel was done.

Table 5.18 Test results

| Sample | Characterization of surface | Gloss at different measuring angles (GU) | | | DOI | Haze | R |
|--------|--------------------------------------|--|------|------|------|------|-----|
| | | 20° | 60° | 85° | | | |
| V2 | High amounts of orange peel effect | 12,2 | 53,7 | 73,3 | 23,6 | 448 | 2,2 |
| V3 | Medium amounts of orange peel effect | 11,3 | 51,3 | 73,9 | 24,5 | 427 | 2,0 |
| V4 | Low amounts of orange peel effect | 12,4 | 54,7 | 76,1 | 24,9 | 448 | 2,2 |
| V5 | Smooth surface | 11,9 | 52,9 | 74,7 | 23,0 | 431 | 2,1 |

6 Digitalization of texture patterns using photometric stereo

In this chapter three different instruments are studied in order to digitalize texture patterns already existing.

IKEA is rather interested in finding a way to acquire a texture already existing in order to make easier the processes of starting to work with new suppliers and developing new worktops. Therefore, in this chapter three different methods to reach this purpose have been developed and analyzed: the first two have already been studied at ICOM, and the third one is being developed in this thesis (although it has not been enough time to test it).

6.1 Methods to acquire the texture pattern

6.1.1 Flatbed scanner

A flatbed scanner allows for the conversion of paper documents or photos into a digital form. Its resolution is composed of two numbers: the small one indicates the optical resolution of the CCD sensor and the big one the possible positioning of the carriage stepping motor (the motor is pulsed to move in steps). For example, a 1200x2400 dpi (dots per inch) scanner will scan 1200 pixels per inch horizontally (the width of the scanned object) and the motor will be able to move vertically 1/2400 inches each step or pulse. Thus, the large number indicated in the resolution does not contribute to the optical resolution [65]. Normal resolutions are, for example:

- 300 dpi for photo prints
- 600 dpi for line art documents
- 1200 or 2400 dpi for scanning film



Figure 6.1 Flatbed scanner [65]

Pros:

- The procedure of implementing the process is quick [66].
- Accessible and cheap equipment.
- Higher resolution than a camera.

Cons:

- The resolution is not as good as other measurement instruments. If the CCD sensor has a resolution of 1200 dpi (which is one of the highest) it means that the horizontal resolution is around 20 μm . A flatbed scanner does not have vertical resolution since it does not give depth information.
- If depth information is required, image processing (e.g. photometric stereo method explained in section 3.2.1.4) is needed after the scanning process.
- When scanning a sample some distortion of the image appears. The lens correction of the scanner is supposed to solve that, but cheap flatbed scanners do not achieve accurate corrections. Thus the results are not repeatable and traceable [66].
- Limited measurement area.

6.1.2 Camera

The camera that IKEA Communications has available currently is a Hasselblad H3DII-39MS. It is a medium-format camera with the following settings [67]:

- Focal lens: 120,0 mm
- Photo dimension: 7212x5412 pixels
- Resolution: 300 dpi



Figure 6.2 Hasselblad H3DII-39MS [67]

Pros:

- IKEA already has this equipment available.
- Bigger measurement areas than the flatbed scanner: up to 100x100 cm [66].

Cons:

- Lower resolution than a flatbed scanner. 300 dpi is equal to a horizontal resolution of 85 μm approximately.
- The procedure of implementing the process is slow [66].
- If depth information is required, image processing (e.g. photometric stereo method explained in section 3.2.1.4) is needed after taking the images.

6.1.3 Cruse scanner

A SD (Surface Detecting) Cruse scanner is engineered to record large sized originals in premium quality, getting both RGB image (using a CCD sensor) and 3D data simultaneously. This is possible thanks to 5 different 2D scanning processes that scan the object with different viewing angles. The result is a height map encoded as greyscale (TIFF format) coming from a bitmapped image using 16 bits per pixel (i.e. 65536 grey levels). This height map can then be converted into triangulated surface data (STL format). The resolution in both vertical and lateral directions is, in practice, close to 20 μm , and some of the models can scan up to a 200x300 cm area [68].



Figure 6.3 Cruse scanner [69]

Pros:

- Individually constructed according to the requirements of each customer.
- Really large measurement areas: up to 200x300 cm.
- Height map obtained directly, without the necessity of the photometric stereo method; big amount of grey levels to give information about the third dimension (depth).
- Lens correction problem of the flatbed scanners is no longer a problem for a Cruse scanner.
- Higher resolution than a camera.
- Supplier VK's suppliers (press plates and steel belts) are already using a Cruse scanner to reproduce an existing texture [55].
- Supplier SR and Supplier UT (texture tools suppliers) are already using a Cruse scanner. However, it is not used for acquiring texture: Supplier SR uses it for the decor layer and Supplier UT to take the RGB/CMYK information from an original [70], [71].

Cons:

- The resolution (20 μm) is not as good as other measurement instruments such as a profilometer or a phase shifting interferometer.
- Expensive equipment, IKEA does not have it.

6.2 Relation between measured area and resolution

An important aspect to have in mind when trying to achieve both large measurement area and high resolution is that they are inversely proportional: the higher the resolution the smaller the horizontal range or measured area. Thus, when using a screen to visualize a measured area, if the vertical resolution of the measurement is increased, the area that will appear in the screen will be smaller and consequently less surface of the specimen will be studied. It is mainly for this reason that the development of the roughness measurements is focused on enlarging the range to resolution ratio. This means being able to increase the vertical resolution while keeping a large enough measurement area.

Table 6.1 Ratio calculation

| | Measured area (cm^2) | Resolution (μm) | Range to resolution ratio ($\text{cm}^2/\mu\text{m}$) |
|-----------------|------------------------------------|---------------------------------|--|
| Flatbed scanner | 29,7x42,0 (A3 size) | 20 (1200 dpi) | 62,37 |
| Camera | 100x100 | 85 (300 dpi) | 117,65 |
| Cruse scanner | 200x300 | 20 | 3000 |

If the range to resolution ratio is calculated for each of the three methods, the Cruse scanner ratio is 25 times larger than the second largest ratio (which is the camera). Therefore, if only the resolution and the measured area are taken into account, the best way to digitalize a texture pattern is pretty obvious.

7 Conclusions, recommendations and future work

In this chapter the authors present their conclusions and recommendations regarding the measurement of surface textures on IKEA's worktops and the ZZ kitchen front.

7.1 Worktops

In the problem analysis the authors identified four parameters connected to the surface texture on worktops which they believe need to be measured and controlled in order to specify a surface texture.

7.1.1 Texture pattern

The first and biggest problem connected to the surface texture on worktops is that different suppliers are using different texture patterns when producing the same product. This makes the products look different depending on which supplier has manufactured them. This problem is not something that can be solved simply by measuring and specifying a parameter. The solution consists in ensuring that the suppliers are using the same texture pattern or at least texture patterns where the customers cannot see a difference between: the suppliers must have the same drawings in order to be able to produce matching products. Today IKEA does not own or have access to the drawings of the texture patterns. The authors believe that IKEA would benefit from taking a more active role in the development of its texture patterns; by developing their own collection of texture patterns or securing the rights for the texture patterns used today, IKEA would gain the control needed to ensure consistent looking textures between different suppliers. If IKEA could gain this control over the texture patterns, whenever the need for starting a new supplier arises IKEA could provide the correct drawings and parameters from the beginning and in this way increase the chance for a good result.

Therefore, the texture pattern problem can be considered to have two different kinds of solutions: on one hand, the first one could be called “reactive” solution since it consists in finding out the right parameters to compare textures already produced. On the other hand, the second one could be called “proactive” solution since it consists in being able to specify the right texture to the supplier from the beginning.

Looking into the “reactive” solution, when comparing texture patterns to control if they are similar enough, the authors have shown that by choosing the correct parameters, the differences and the similarities in the texture pattern can be seen both by measuring with a profilometer and by measuring with more advanced 3D roughness methods. The authors believe that the use of a profilometer for measuring the suggested parameters is preferable: the results obtained are accurate, a profilometer is relatively easy to use and it is based on international standards for surface roughness measurements. Apart from that, the fact that IKEA already has the equipment makes it the best choice. The larger measured area providing more reliable parameters of the GFM3D instrument does not make up for the higher price, the lack of portability and the fact that it is more difficult to request the suppliers to purchase this measuring equipment. Concerning the Optimap PSD analysis, the authors believe that this is not the most suitable method to measure the texture pattern of the laminates. The parameters obtained are not based on international standards for surface roughness measurements, complicating the communication with the different suppliers. Apart from that, the results do not really reflect the differences between suppliers.

Focusing on the “proactive” solution, it is important to know how the texture tools suppliers design and/or obtain new texture patterns. The information received from them points out that they use different techniques in order to manufacture press plates, steel belts or release paper. Some of them use 2D images/drawings of the textures, but others use 3D scanning of a piece of real wood or stone, filtering out the different steps of the texture as explained in the background (3.4.6).

Concerning the first way of manufacturing the texture tools, the photometric stereo method, which provides height-mapped 2D images, could be the right one in order to digitalize the texture. This method is already being used by IKEA Communications (ICOM) for the renderings in IKEA’s catalogue, and the procedure has been recorded in a report by Anton Karlsson [66]. Today the procedure is quite time consuming and not very user friendly. There are also limitations regarding the size of the sample that can be digitized. As seen in chapter 6, the use of a Cruse scanner would enable the digitization of larger samples in a much faster and easier way, and with good enough resolution. Regarding the second way of manufacturing the texture tools, a real 3D scanner is needed. The authors have not been able to obtain more detailed information about what scanners are used or how textures are scanned and processed before being etched onto the texture tool, due to the corporate secrets surrounding this matter of the various companies that have been contacted.

The authors think that the purchasing of a Cruse scanner could be interesting for IKEA if the aim is getting good quality images of the texture. This could improve visual comparison between suppliers delivering images that clearly show the textures, making visual comparison more objective and enabling images to be sent electronically instead of shipping physical samples. Apart from that, this scanner could also be used by IKEA Communications for acquiring textures for their renderings, speeding up the process considerably. Thus, if the idea of purchasing a Cruse scanner moves forward, the authors recommend a continued cooperation between IKEA of Sweden and IKEA Communications in further testing and

evaluation of this equipment and its ability to create height-mapped images of surface textures. Nevertheless, it is important to have in mind that one of the ways the texture tools suppliers are using to acquire the texture is 3D scanning, and the photometric stereo method does not give a real 3D image of it. Therefore, the authors believe that further investigation in 3D scanning should be done, since the time period for this thesis has not been enough to look deeply into this issue (see Appendix F).

It is important to have in mind that one solution does not exclude the other. Thus, the measurements developed in the “reactive” solution can be used to verify that the acquired texture in the “proactive” solution is the right one. Apart from that, they can be used as well when the supplier shows different texture samples to IKEA requesting approval for one of them. Then the measurements should be used in a proactive way ensuring that the chosen texture is close enough to what IKEA wants.

7.1.2 Texture depth and micro texture

The authors believe that the issues related to the texture tool wear and/or process variations are not as significant as the one developed above. It has no sense to focus on this problem if the texture pattern differences are not solved before. However, when the pattern is not a problem anymore, the texture depth and micro texture need to be measured in order to guarantee the right appearance and touch of the surface.

In order to measure the depth and the micro texture, it is as well recommended the use of a profilometer, for the same reasons previously stated and because the results of the different tests carried out were conclusive.

7.1.3 Gloss

For measuring the gloss level on the laminate surfaces the continued use of gloss meters is recommended. The authors must strongly advise IKEA to not only measure at a 60° angle, since some of the laminate samples are not glossy enough to be measured at this angle but should be measured at 85° for reliable results.

7.2 ZZ kitchen front

In the problem analysis three parameters were identified: difference in surface texture, orange peel effect and gloss. In the evaluation of methods the authors tested different equipment in order to quantify the differences in surface texture and the appearance of the ZZ kitchen front.

Concerning the differences in surface texture, the profilometer is believed to be the right way in order to quantify it. With long cutoff lengths of the filter, the differences between the milled and the non-milled parts are really important and can be easily measured. For the same reasons stated above, the larger measurement area giving

more reliable parameters of the GFM3D instrument does not make up for the higher price and lack of portability compared to the profilometer.

Regarding the appearance measurements, the Optimap PSD equipment can be used to have a good visual comparison between both areas (the texture differences could be well-appreciated in the test). However, the Wave-Scan gave some problems because of the surface properties (this kind of equipment is thought to perform better in more shiny surfaces). Finally, focusing more on the orange peel effect, the gloss and the DOI measurements were totally inconclusive since the differences between measurements of high and low amounts of orange peel were too insignificant.

As a final suggestion, the authors believe that the profilometer is the right way to quantify differences in texture between the milled and the non-milled parts. Apart from that, the Optimap PSD instrument has great potential regarding appearance measurements. It has only been possible to use it on a kitchen front in two tests because of the lack of samples, but further investigation should be done if problems such as orange peel appearance need to be solved.

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Appendix A: Procedure to take measurements with Mitutoyo SJ-400

A.1 Characteristics of the equipment

- Vertical range: 800 μm
- Vertical resolution: 0.125 nm
- Horizontal range: 0.1 to 25.4 mm
- 36 kinds of roughness parameters.

A.2 Description of the equipment

- A standard stylus (2 μm radius) and a stylus-ball. In the measurements concerning this thesis only the standard stylus will be used.
- Skidless nosepiece and skid-attached nosepiece. In the measurements concerning this thesis only the skidless nosepiece will be used.
- Detector unit: it holds the nosepiece and the stylus.

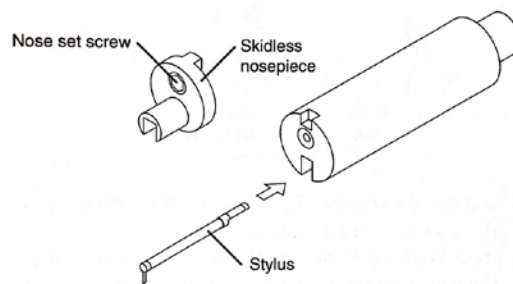


Figure A.1 Detector unit, nosepiece and stylus [31]

- Drive unit: where the displacement of the stylus is converted into electric signals through the detector unit.
- Height / tilt adjustment unit: it corrects the position of the drive unit.
- Display unit: where the electrical signals generated by the stylus displacement are subjected to various calculation processes and the results are

displayed on the touch panel. It has a printer incorporated as well as printer paper.

- Precision reference specimen: it is a reference surface used to check if the instrument is working properly. The user must check that the measurement is done perpendicular to the cutter mark of the specimen.
- Three Allen keys (nominal 3, 1.5 and 0.9) and a flat-blade screwdriver. The smallest Allen key (nominal 0.9) is placed in the display unit.

A.3 Preparation of the measurements

Before doing the measurement, the most important things that the user should check are:

- The surface must be clean.
- One of the most common problems that cause wrong measurements is having a broken tip. Sometimes the precision reference specimen is not able to detect that problem; thus, the user should check the tip in a microscope.
- The tilt and the height of the drive unit must be adjusted through the knobs in the height/tilt adjustment unit. Concerning the tilt adjusting knob, the user must check that the drive unit is not supporting the equipment (i.e. the drive unit is not touching the surface). Regarding the up/down motion knob, the user must check it in the “Home” screen (the black square must be in the middle of the vertical bar once the stylus is touching the surface).



Figure A.2

- The stylus must properly contact the measured surface (i.e. being parallel to the measured surface). The user should check it looking at the detector unit from the front, and should adjust it loosening the screw which fixes the drive/detector unit to the height/tilt adjustment unit and tightening it again in the right position.

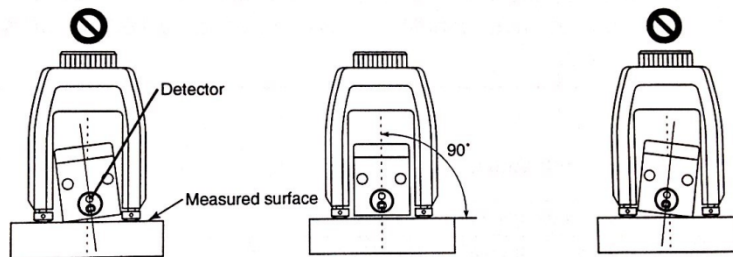


Figure A.3 Tilt adjustment [31]

A.4 Measurements execution

The primary profile -P-profile- (obtained after filtering out the nominal shape and the measurement noise) provides important information about the amplitude, wavelength and frequency of the surface. It has a big relevance since it will show what kind of further measurements and calculations are needed. Concerning the needs of this thesis, there is a different way of measuring the texture for each different surface (i.e. the YY – stone texture surface and the XX – wood grain texture one), following different standards:

A.4.1 YY – stone texture surface: ISO 4287

This standard is used for profiles that have a more symmetric shape rather than an asymmetric one. For this reason it is the suitable way to measure the YY – stone texture surface. It calculates amplitude and spacing parameters using a Gauss filter to get the mean line and the desired profile (P, R or W).

In the “Condition menu, Page 1/3” screen select:

- Standard: ISO'97
- Profile: P, R or W depending on which one is needed. In this thesis the measurements have been done on the roughness profile (R).
- Filter: Gauss

In the same screen the user has to select the cutoff lengths of the different filters as well as the number of sampling lengths (N) that will form the evaluation length (the standard is 5 sampling lengths, and if another number is used, it must be indicated). The theoretical explanation about the cutoff lengths of the filters is developed in the report (3.2.3.1 Profile measurements (2D)). Thus, if what is being studied is the macro texture, and the interesting profile is the roughness one (Profile: R), the settings should be:

- λ_c : 2.5 mm (evaluation length: $N \times 2.5 = 12.5$ mm)
- λ_f : not needed for the roughness profile
- λ_s : it is automatically set (8 μ m)

In order to select the parameters that the user is interested in, go to the “Condition menu, Page 2/3” screen and select “Custom”. There are 5 different groups of parameters (P1-P5) and they are activated or not depending on the profile selected before (P, R or W). In this thesis the parameters used for the YY – stone texture surface have been (all of them in the P1 group):

- **Ra**: it is the arithmetic mean of the absolute values of the profile deviations (Y_i) from the mean line. This parameter is defined over the entire evaluation length.
The main reason for using Ra is that it is the most widespread in Europe. The user must have in mind, though, that it does not give information on the profile shape and it is not good to measure exceptional peaks or valleys.
- **Rq**: it is the square root of the arithmetic mean of the squares of profile deviations (Y_i) from the mean line. This parameter is defined over the entire evaluation length.
Rq is the most widespread parameter in the USA. It is approximately equivalent to Ra, but it is slightly better for sensitive surfaces (with exceptional peaks or valleys).
- **Rz**: it is the mean value of the Rzi-values of the entire evaluation length. Rzi is the distance from the highest peak to the deepest valley in each sampling length.
Rz is the second most common parameter. It is good to complement the previous parameters since it is related to the extreme structure depth.
- **RSm**: it is the mean width of the profile elements within a sampling length. Whereas the other parameters give information on the profile height (amplitude), this one does it on the profile x-direction (it is a spacing parameter).

On the other hand, if what is being studied is the micro texture, the high-pass filter (λ_c) must filter out parts of the profile with even shorter wavelengths. Thus, the settings should be:

- λ_c : 0.08 mm (evaluation length: $N \times 0.08 = 0.4$ mm)
- λ_s : it is automatically set (2.5 μ m)

The parameters used are the same as with the macro texture study.

When the aim has been measuring the surface of the **kitchen front (ZZ)**, the measurement procedure has been the same as with the YY – stone texture surface one.

A.4.2 XX – wood grain texture surface: ISO 13565 or DIN 4776

This standard is used for profiles that have an asymmetric shape. For this reason it is the suitable way to measure the XX – wood grain texture, since its profile has deep valleys but not significant peaks. It calculates the parameters related to the material

ratio curve (bearing area curve or Abbott-Firestone curve) using a double Gaussian filter. The first filter removes the valleys and the second one fits the profile without the valleys (removing the slope). Finally the valleys are relocated to the fitted profile.

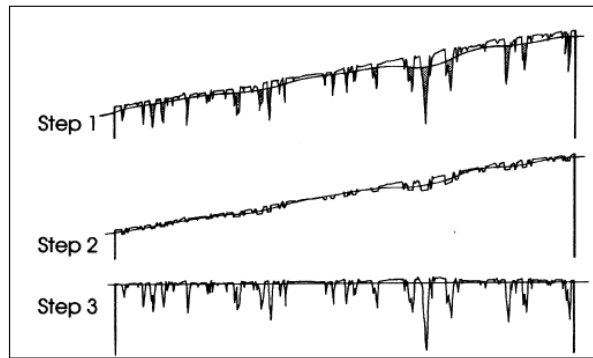


Figure A.4 Fitting process of the profile [72]

This standard is only used to calculate the macro texture of the surface, since the micro texture (the texture between the “wood” scratches) is considered to have a more symmetric profile rather than an asymmetric one. When measuring the macro texture, the direction of the measurement must be perpendicular to the “wood” scratches direction. In the “Condition menu, Page 1/3” screen select:

- Standard: ISO'97
- **Profile: DIN4776**
- Filter: Gauss
- λ_c : 2.5 mm (evaluation length: $N \times 2.5 = 12.5$ mm)
- λ_f : not needed for the roughness profile.
- λ_s : it is automatically set (8 μ m)
- N: 5

In order to select the parameters, go to the “Condition menu, Page 2/3” screen and select “Custom”. Only the group P4 is activated, since it is the one that contains the parameters related to the material ratio curve. In this thesis the parameters used when looking into the macro texture of the XX – wood grain texture have been:

- **Rpk**: reduced peak height. It is the average height of the protruding peaks above the roughness core profile.
- **Rvk**: reduced valley depth. It is the average depth of the profile valleys projecting through the roughness core profile.
- **Rk**: core roughness depth. It is the depth of the roughness core profile.
- **Mr1**: material portion 1. It is the level in % determined for the intersection line which separates the protruding peaks from the roughness core profile.
- **Mr2**: material portion 2. It is the level in % determined for the intersection line which separates the deep valleys from the roughness core profile.

- **A1**: peak area
- **A2**: valley area

The relation between this parameters and the material ratio curve is deeply explained in the report (3.2.3.1 Profile measurements (2D)).

If what is being studied is the micro texture, the measurement should be done parallel to the “wood” scratches direction and avoiding them, since in this case the wanted texture is the one between scratches (if the measurement is done perpendicular to the scratches direction, it is too difficult to find a distance long enough to avoid them). The user should follow the same way of measurement as with the YY – stone texture surface regarding the settings and the parameters used:

- Standard: ISO'97
- **Profile: R**
- Filter: Gauss
- λ_c : 0.08 mm (evaluation length: $N \times 0.08 = 0.4$ mm)
- λ_s : it is automatically set (2.5 μm)
- N: 5
- Parameters: Ra, Rq, Rz, RSm.

When all the settings are ready and the parameters are selected, press the “START/STOP” button under the screen to begin with the measurement.

A.5 Measurement conditions (ISO 4288)

The following table shows the measurement conditions for roughness measurements. It indicates the maximum stylus tip radius and the cutoff wavelength λ_c , as well as the evaluation and the traversed length depending on the value of the different roughness parameters.

| Non-periodic profiles | | Periodic profiles | Measuring conditions according to DIN EN ISO 4288 and DIN EN ISO 3274 | | | |
|--|----------------------|--------------------------------|---|--|-------------|-------------|
| Grinding, honing, lapping, eroding ↓ or ↓ | | Turning, milling, planing ↓ | r_{tip} l_r l_n l_t | Maximum stylus tip radius Single measured length Total measured length Traversed length (measured length plus start-up and trailing length) | | |
| Rt, Rz μm | Ra μm | RSm mm | r_{tip} μm | $\lambda_c = l_r$ mm | l_n mm | l_t mm |
| > 0.025...0.1 | > 0.006...0.02 | > 0.013...0.04 | 2 | 0.08 | 0.4 | 0.48 |
| > 0.1...0.5 | > 0.02...0.1 | > 0.04...0.13 | 2 | 0.25 | 1.25 | 1.5 |
| > 0.5...10 | > 0.1...2 | > 0.13...0.4 | 2*) | 0.8 | 4 | 4.8 |
| > 10...50 | > 2...10 | > 0.4...1.3 | 5 | 2.5 | 12.5 | 15 |
| > 50...200 | > 10...80 | > 1.3...4 | 10 | 8 | 40 | 48 |

Figure A.5 Measurement conditions [33]

In this thesis the cutoff wavelength (and consequently the sampling length) selected for the study of macro texture has been $\lambda_c = 2.5$ mm, since the R-parameters obtained match inside the specified intervals. On the other hand, the cutoff length selected for the micro texture study has been $\lambda_c = 0.08$ mm, since it is the smallest wavelength that the high-pass filter (λ_c) is able to filter out. The tip radius of the stylus was $2 \mu m$, which fits with both macro texture and micro texture measurement specifications (the number in the table is the maximum radius allowed).

A.6 Evaluation of measurements (ISO 4288)

In this thesis all the R-parameters used do not have the addition “max” (i.e. mean values from the 5 sampling lengths). This means that if there is any limit value specified for one of the roughness parameters, the 16%-rule should be followed:

When measuring the most critical surface, if not more than 16% of all value based on sampling length exceed the limit value, this value is considered to be acceptable. If more than 16% exceed it, apply the next procedure:

- Another measurement must be done; if this measured value is smaller than 70% of the limit value, the latter is considered to be observed.
- Otherwise two further measurements at other points on the surface must be done. If all three are smaller than the limit value, the latter is considered to be observed.
- Otherwise nine further measurements at other points on the surface must be done. If no more than two of them exceed the limit value, the latter is considered to be observed.

A deeper explanation about the measurement evaluation rules can be found in the report (3.2.3.1 Profile measurements (2D)).

A.7 Visualization of the profile and printout

To visualize the profile wait until the measurement is completely done and select the profile button in the “Home F.1” screen in order to enter to the “Measured Profile” screen. Here it is possible to zoom-in and zoom-out depending on the interests of the user.

To printout the profile, first of all the printing scale must be adjusted. Go to the “Home F.2” screen and select “I/O”. Once in the “I/O Menu” screen select “Printer”. Here is where the vertical and horizontal printing scales are defined:

- For a macro texture measurement: Ver. = 500; Hor. = 10
- For a micro texture measurement: Ver. = 20K; Hor. = 500

When the scale is properly adjusted, press the “PRINT” button under the screen.

Appendix B: MikroCAD 3D analysis

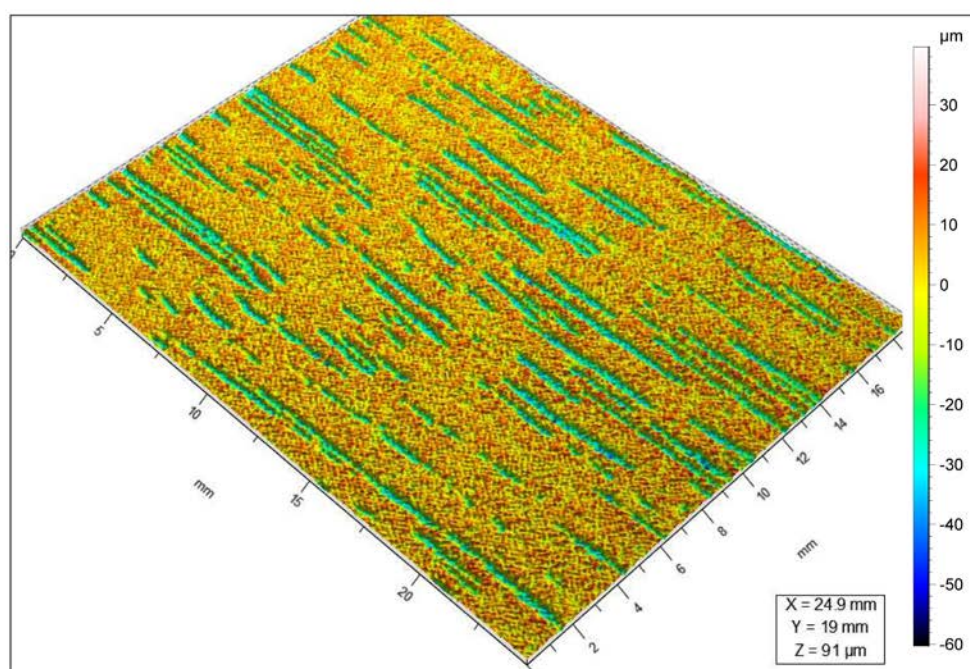
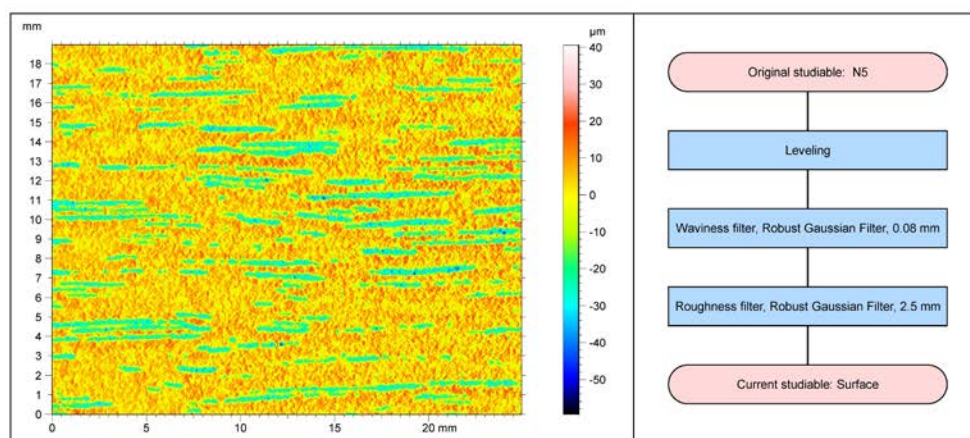
B.1 XX – wood grain texture: Supplier A N5



Name: N5

2013-05-14

1 / 3

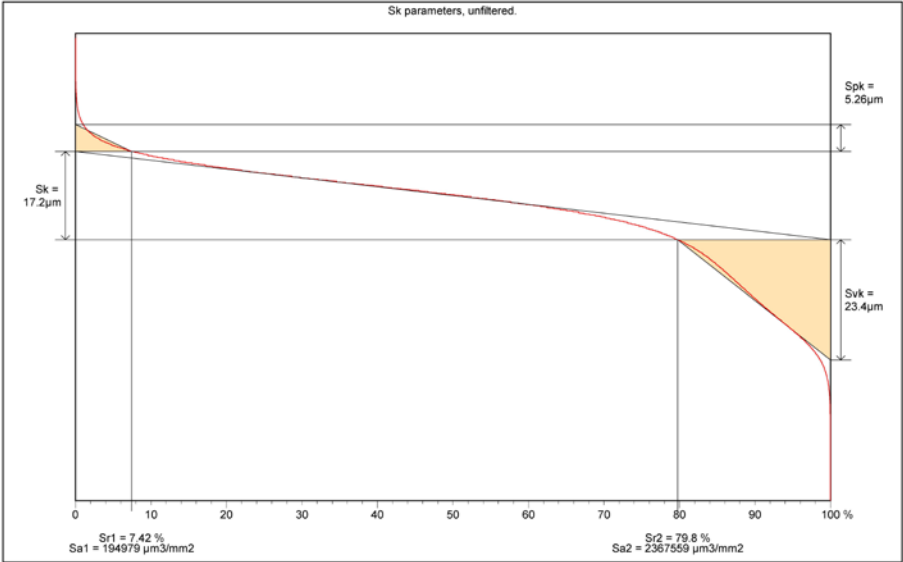


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www.toponova.se | info@toponova.se | +46 35 169200
Org nr: 556547-3930 | VAT no: SE556547393001

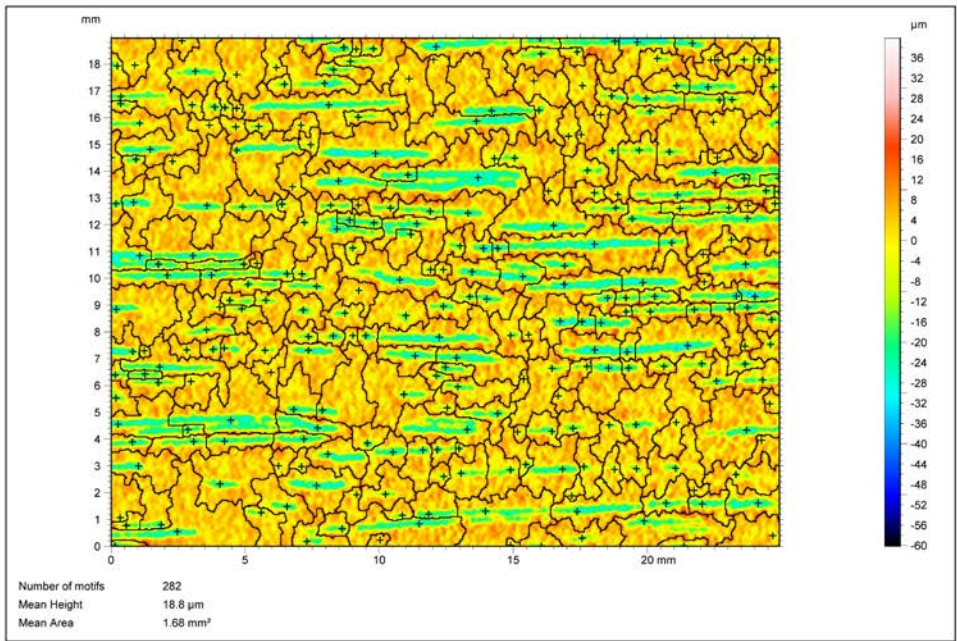
MountainsMap® Premium 6.2.6466



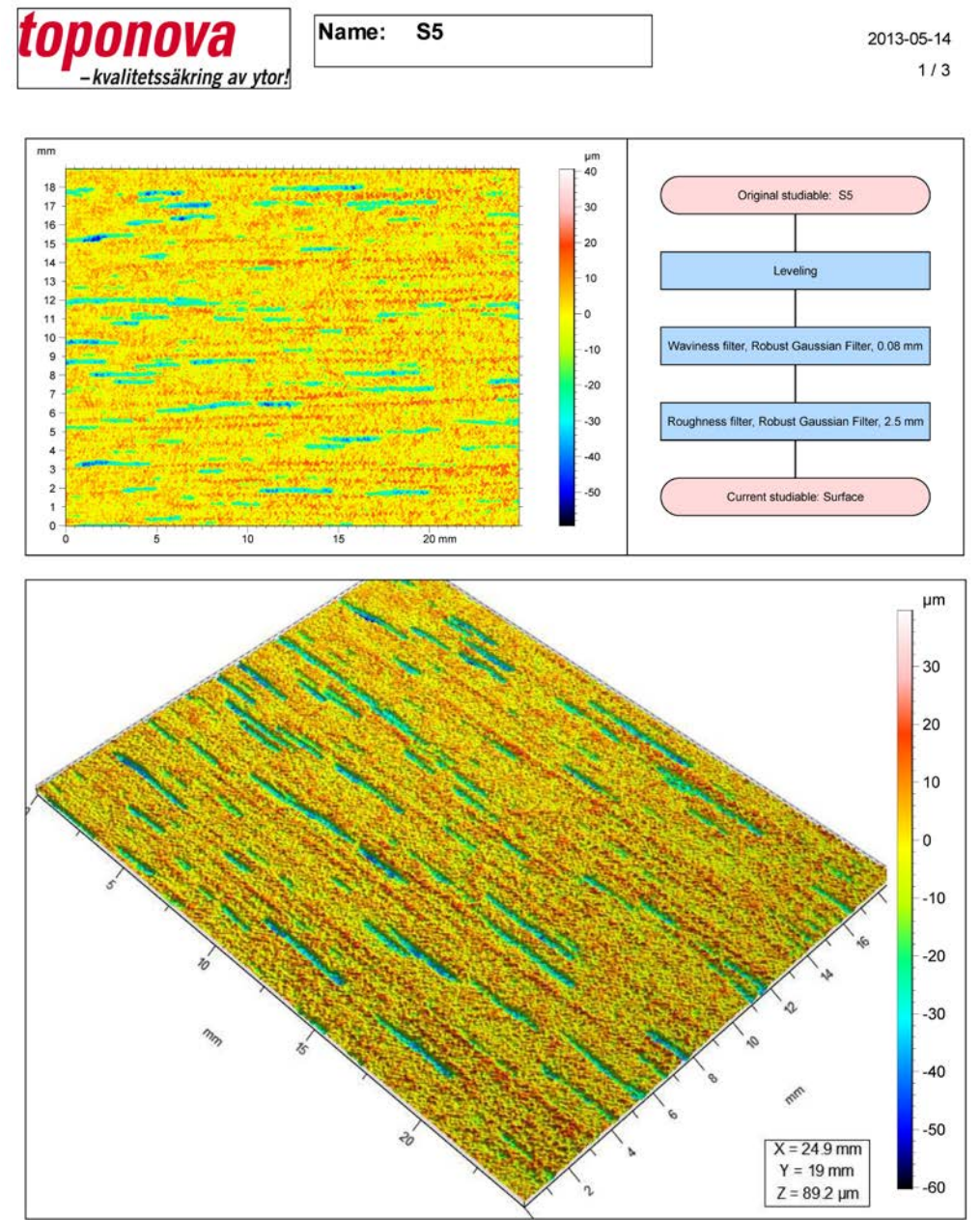
2013-05-14
2 / 3



| ISO 25178 | | | | |
|-----------------------|------|----|-----------------|------------------------|
| Height Parameters | | | | |
| Sa | 7.93 | µm | | Arithmetic mean height |
| Functional Parameters | | | | |
| Sxp | 46.8 | µm | p = 1%, q = 99% | Extreme peak height |

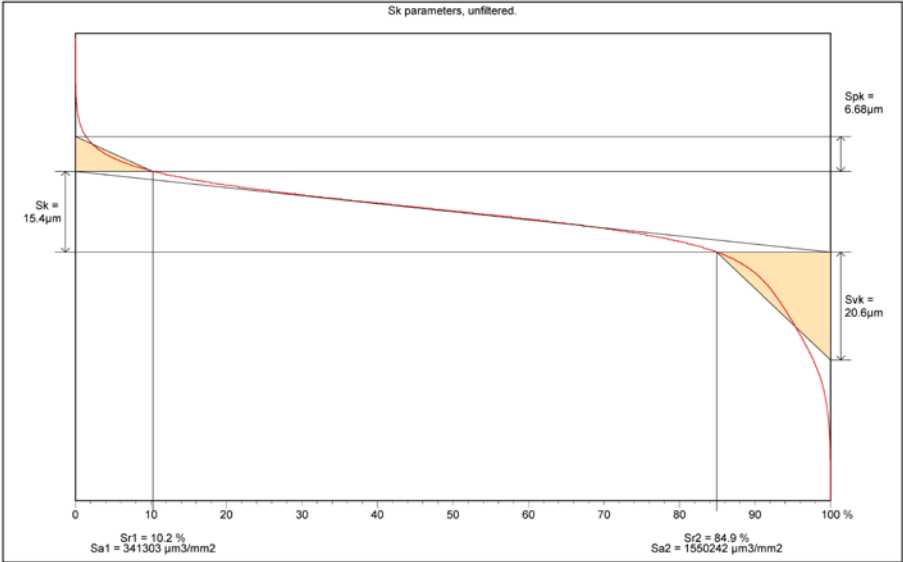


B.2 XX – wood grain texture: Supplier S S5





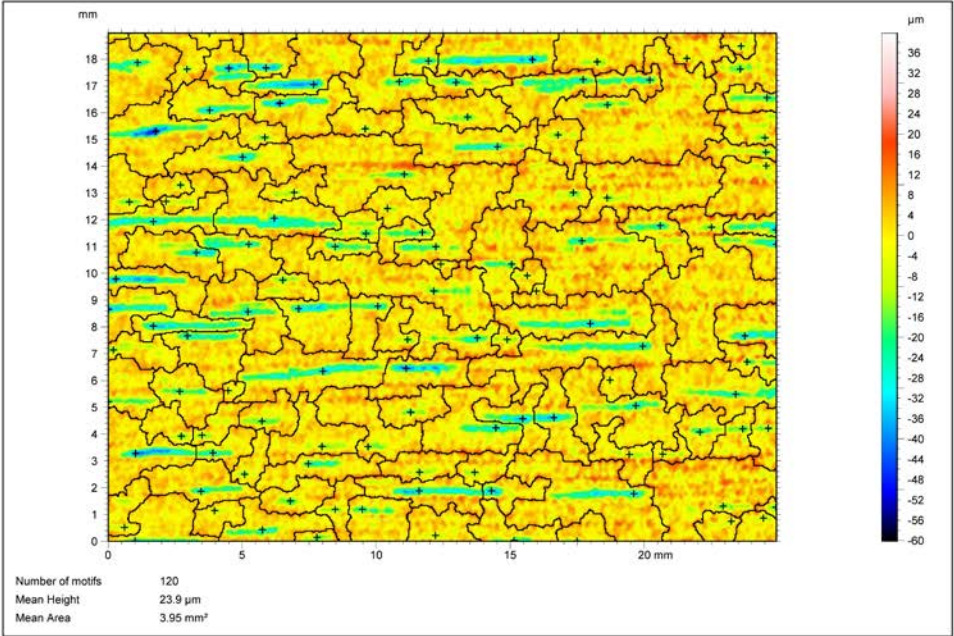
2013-05-14
2 / 3



| ISO 25178 | | | | |
|-----------------------|------|----|-----------------|------------------------|
| Height Parameters | | | | |
| Sa | 6.38 | µm | | Arithmetic mean height |
| Functional Parameters | | | | |
| Sxp | 48.7 | µm | p = 1%, q = 99% | Extreme peak height |



2013-05-14
3 / 3



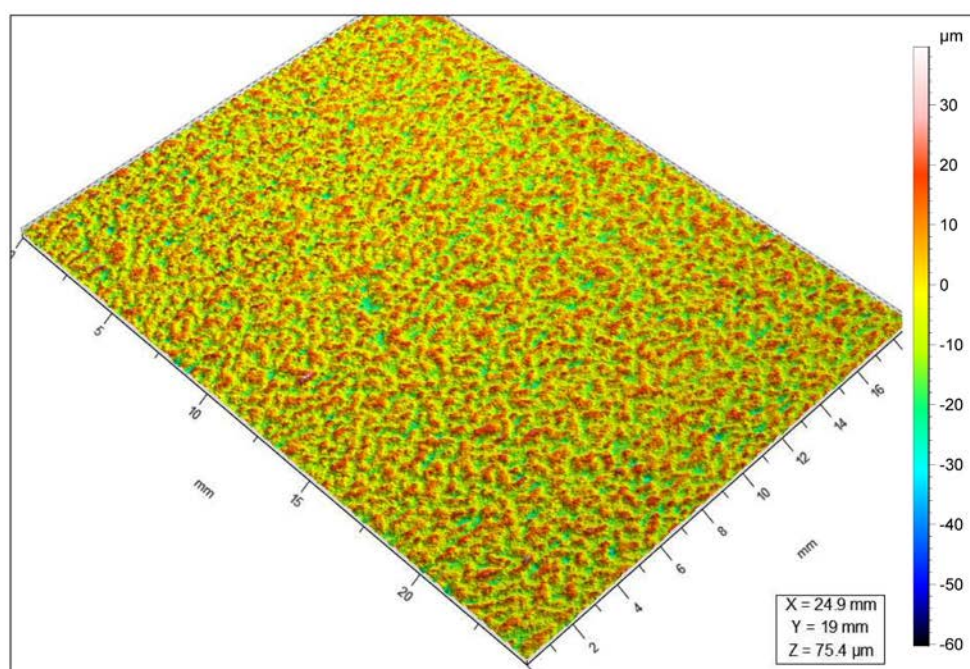
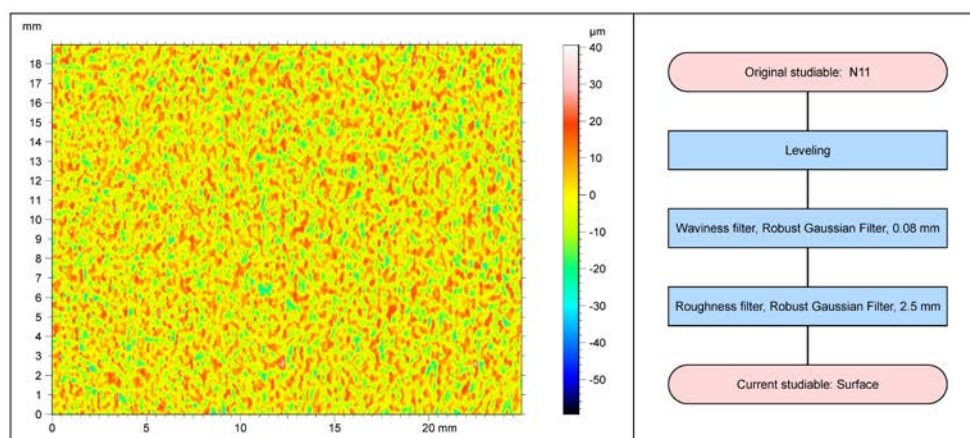
B.3 YY – stone texture: Supplier A N11



Name: N11

2013-05-14

1 / 3

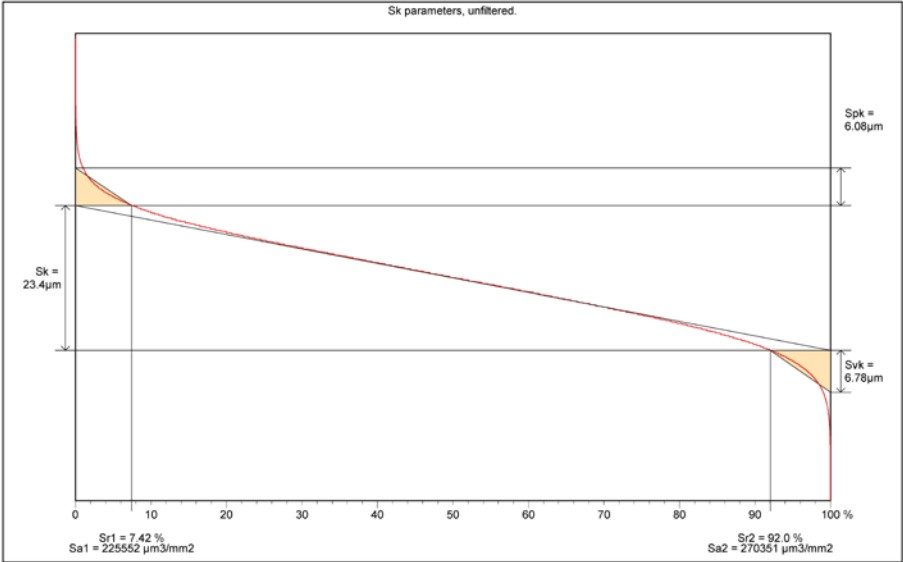


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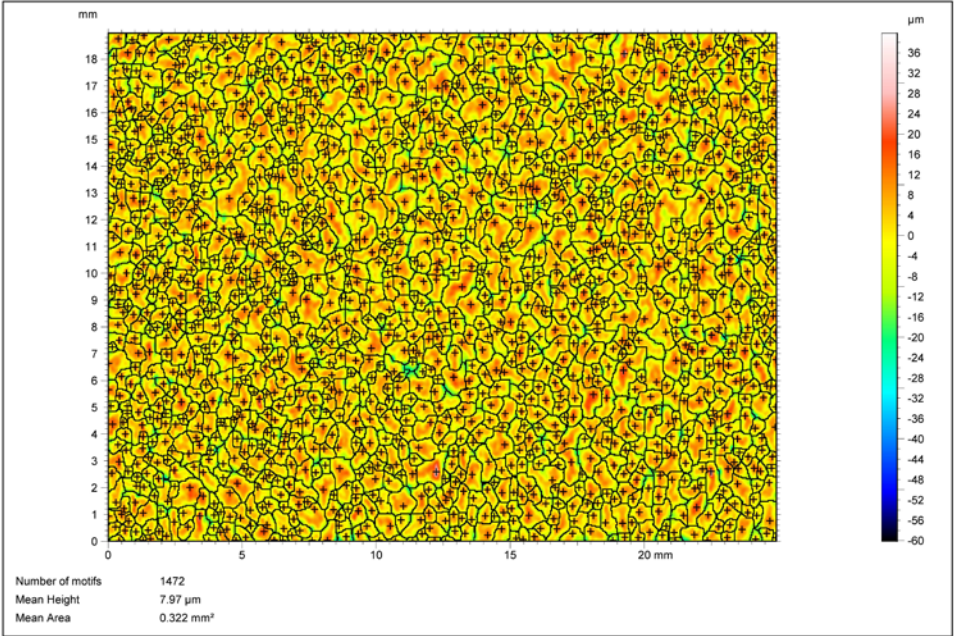
2013-05-14
2 / 3



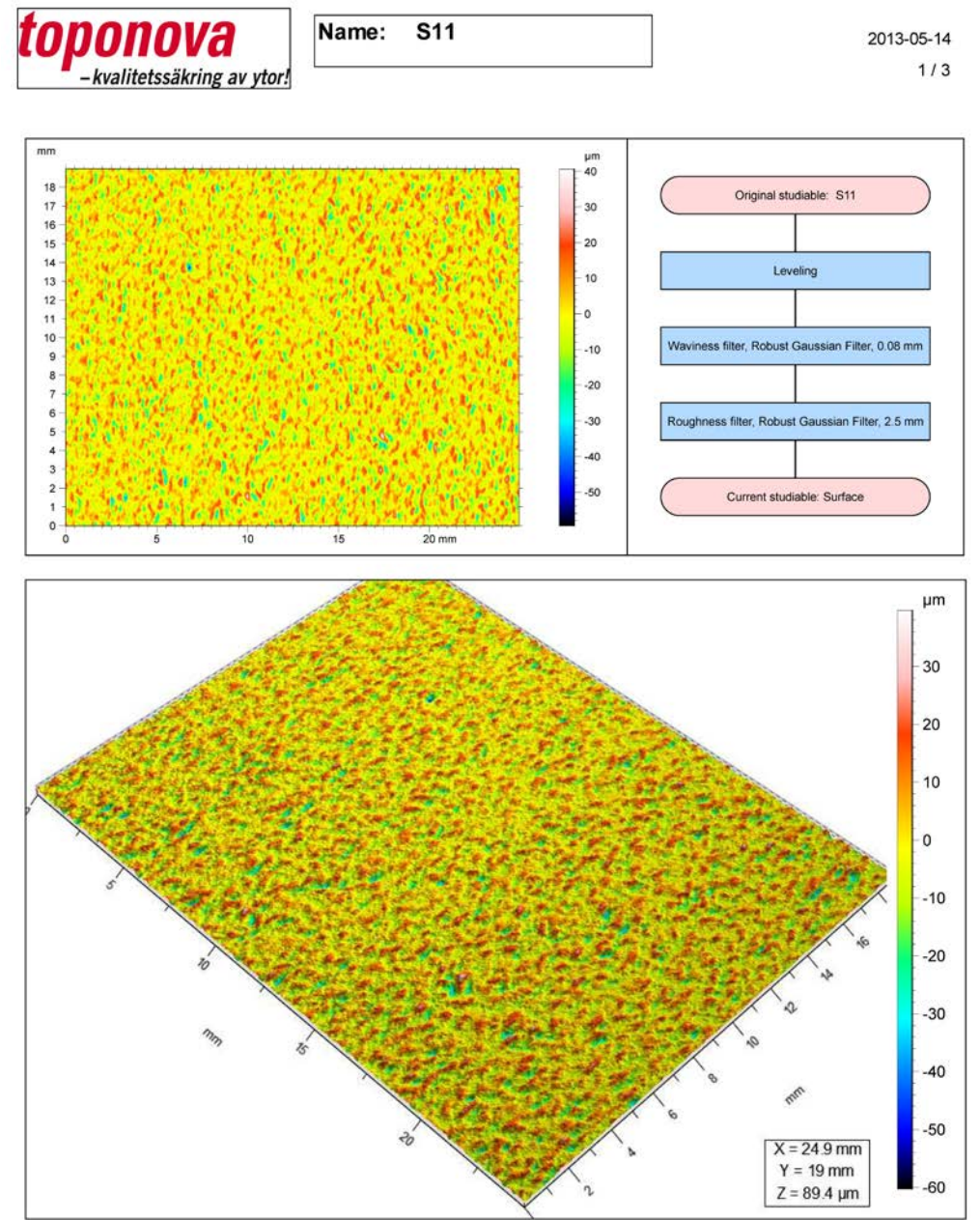
| ISO 25178 | | | | |
|-----------------------|------|----|-----------------|------------------------|
| Height Parameters | | | | |
| Sa | 6.73 | µm | | Arithmetic mean height |
| Functional Parameters | | | | |
| Sxp | 36.1 | µm | p = 1%, q = 99% | Extreme peak height |



2013-05-14
3 / 3

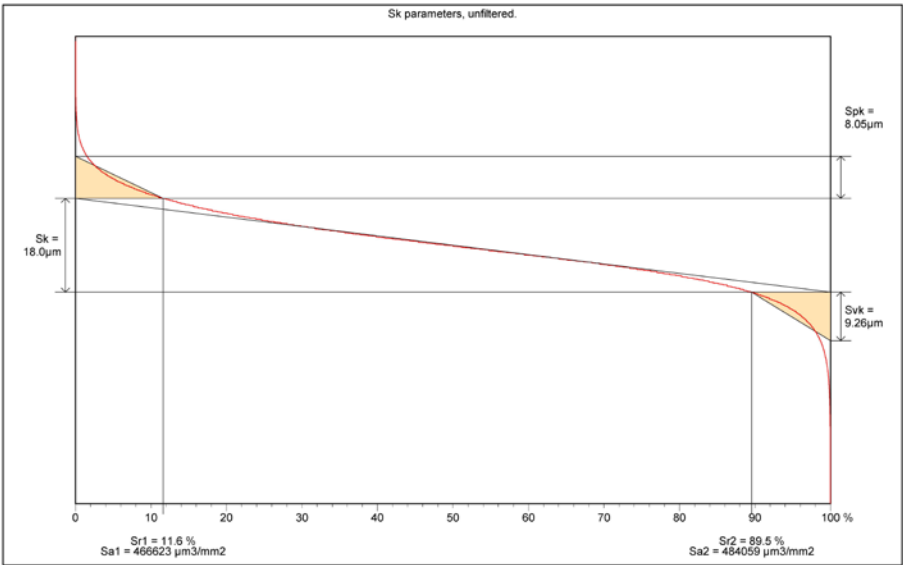


B.4 YY – stone texture: Supplier S S11





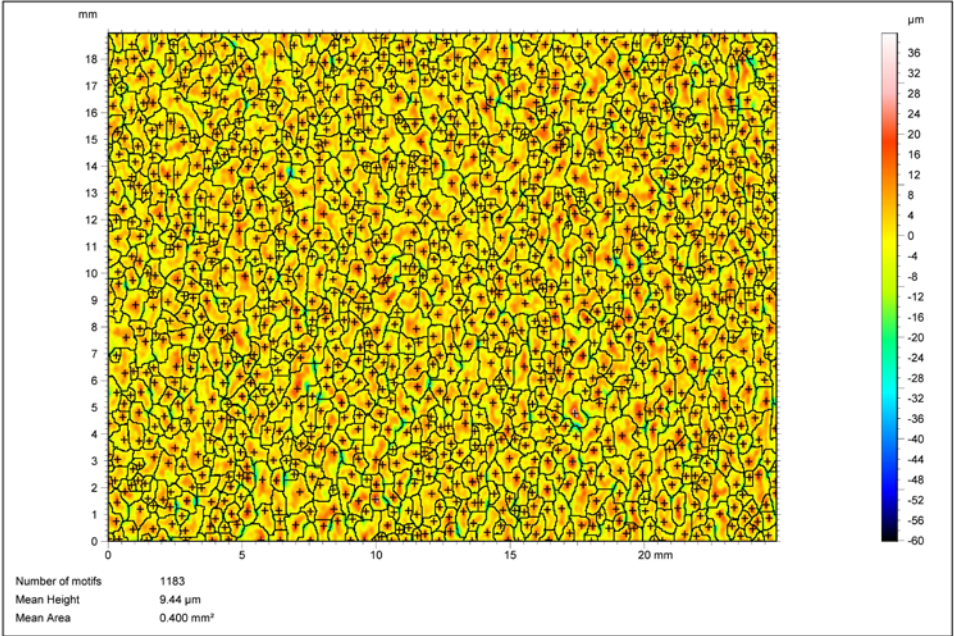
2013-05-14
2 / 3



| ISO 25178 | | | | |
|-----------------------|------|----|-----------------|------------------------|
| Height Parameters | | | | |
| Sa | 5.90 | µm | | Arithmetic mean height |
| Functional Parameters | | | | |
| Sxp | 37.8 | µm | p = 1%, q = 99% | Extreme peak height |



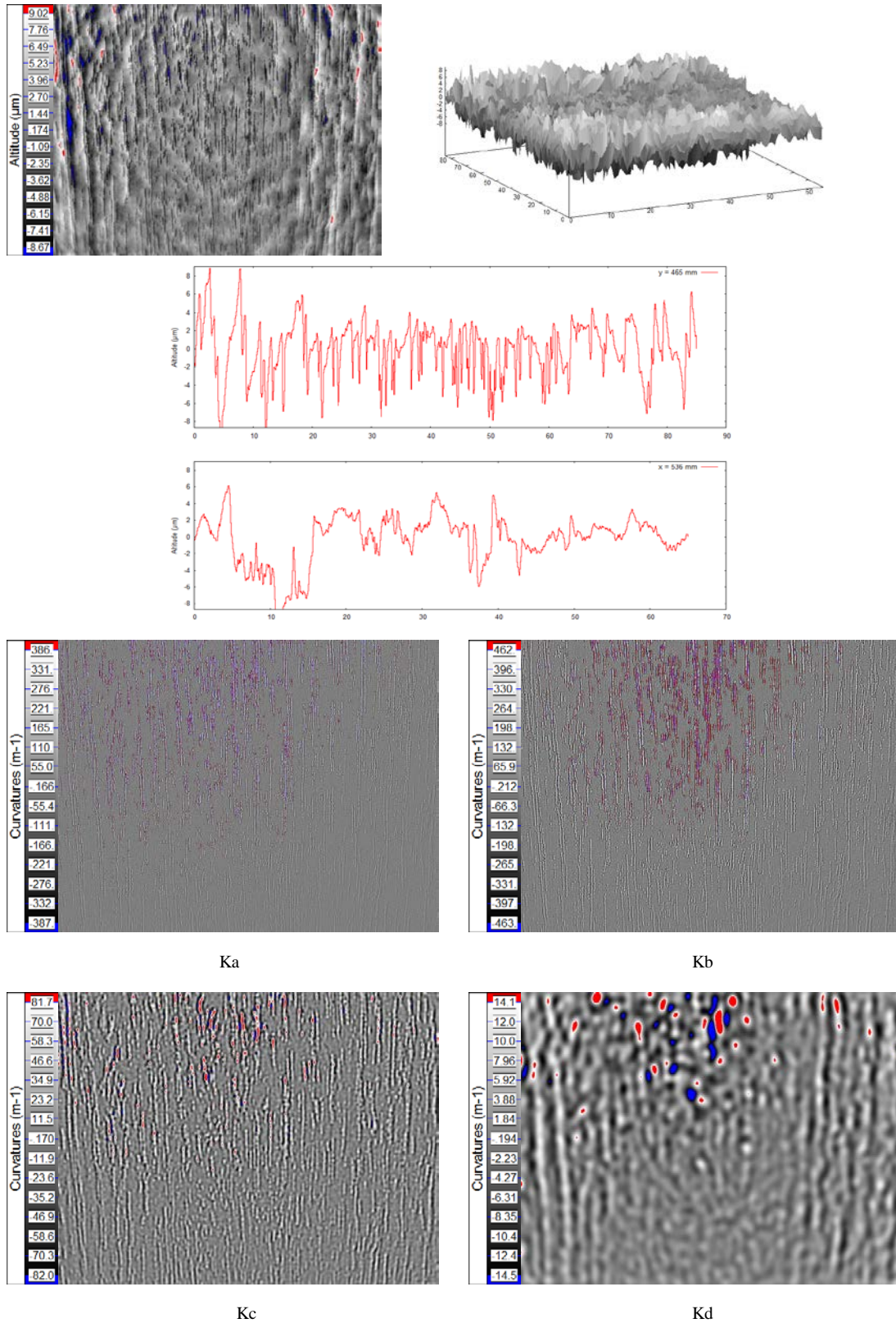
2013-05-14
3 / 3

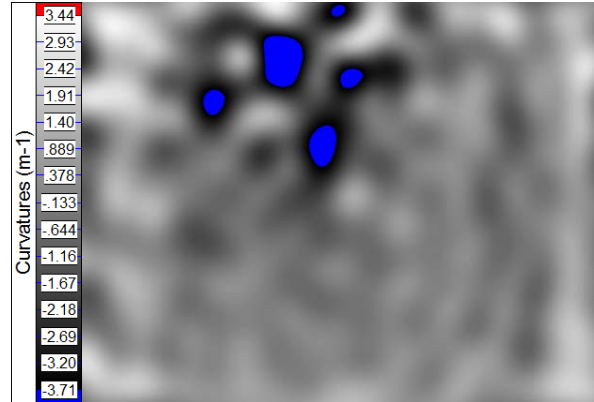


Appendix C: Optimap PSD analysis of the worktops

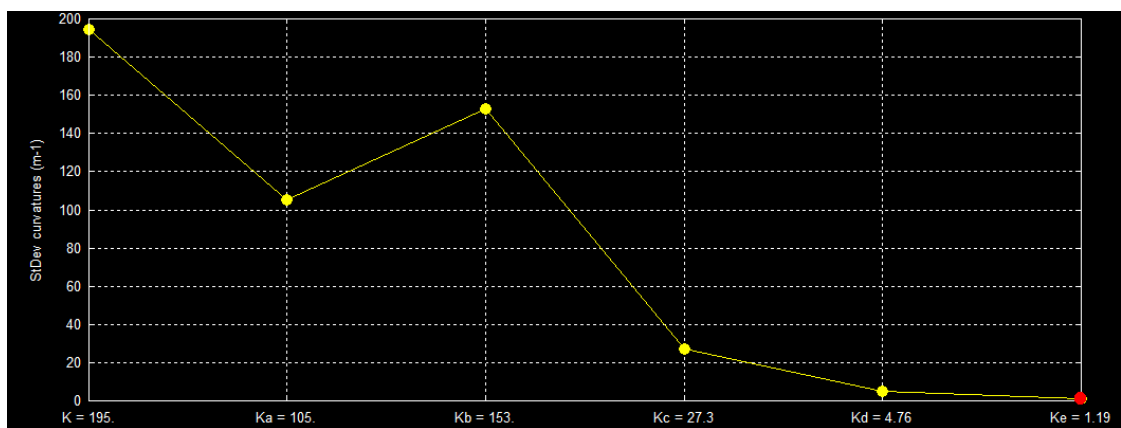
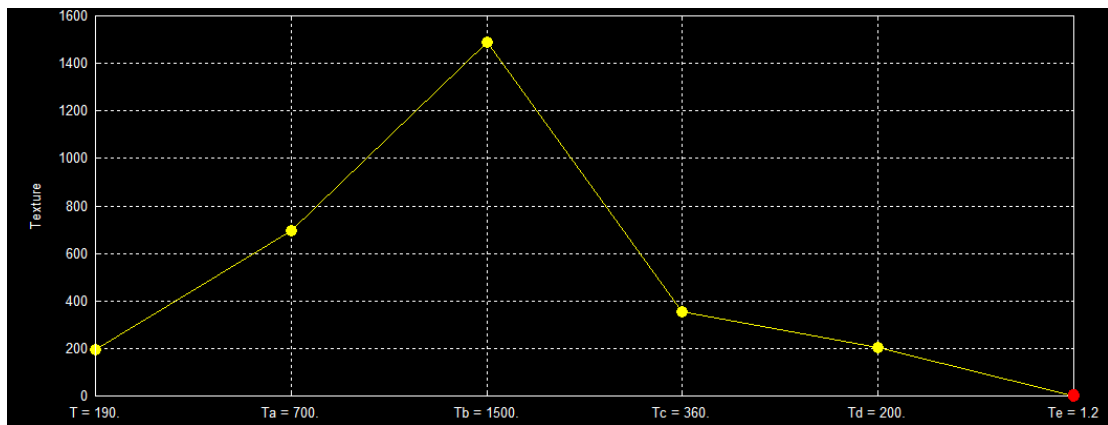
Appendix C: Optimap analysis

C.1 XX – wood grain texture: Supplier A N5

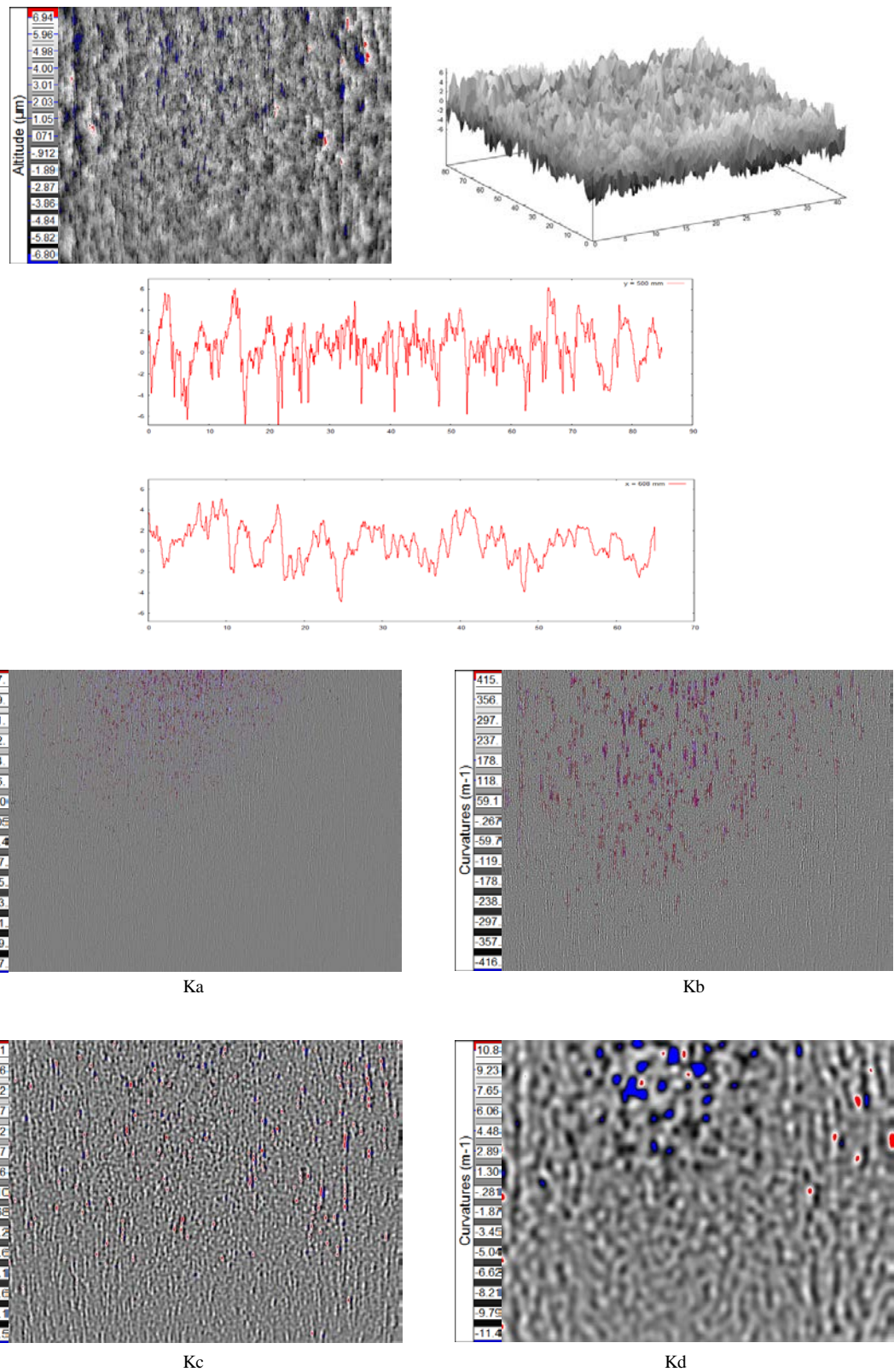


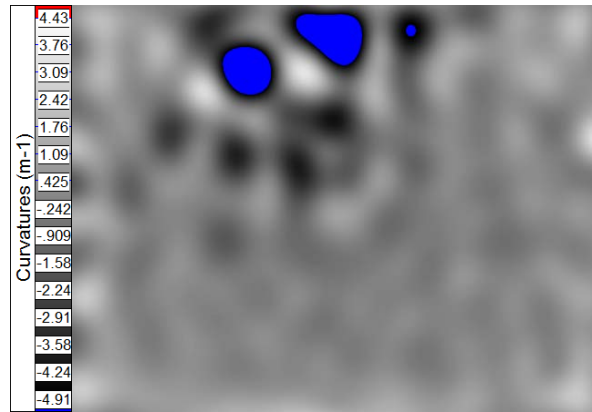


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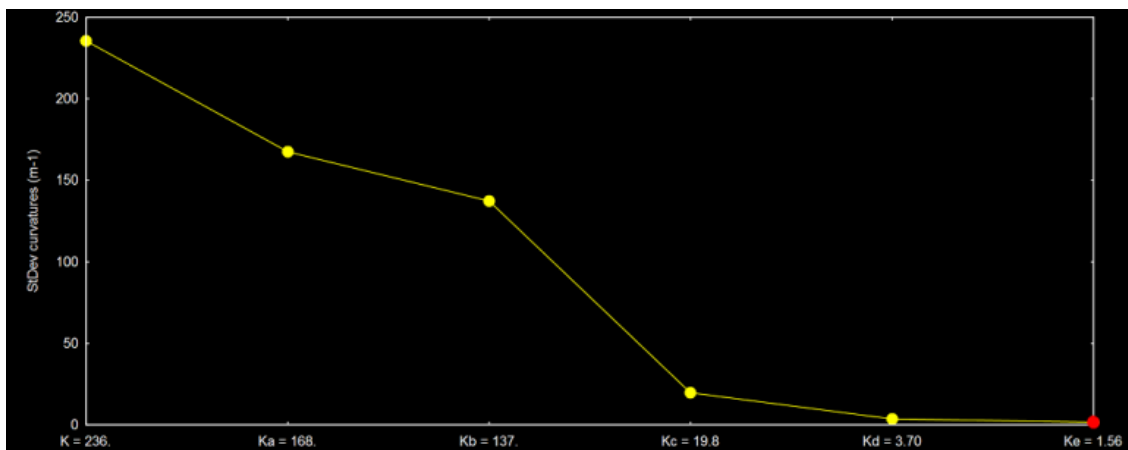
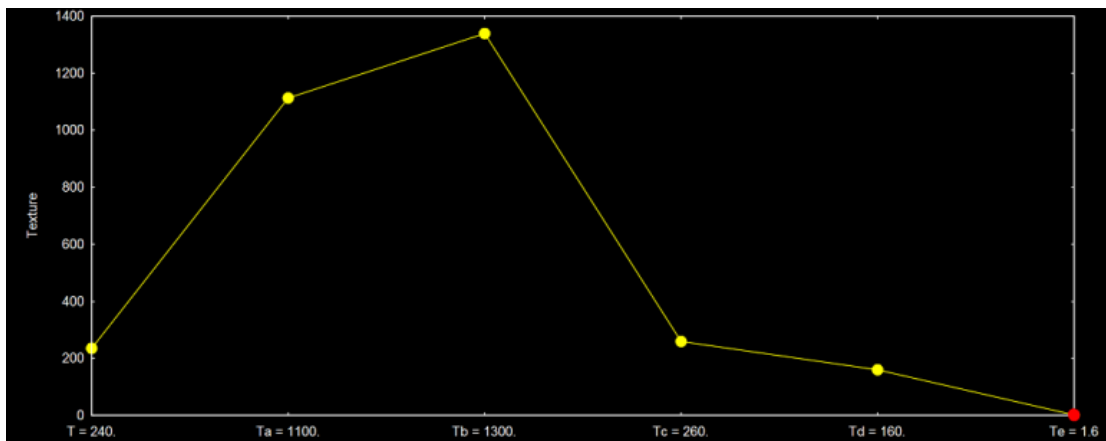


C.2 XX – wood grain texture: Supplier S S5

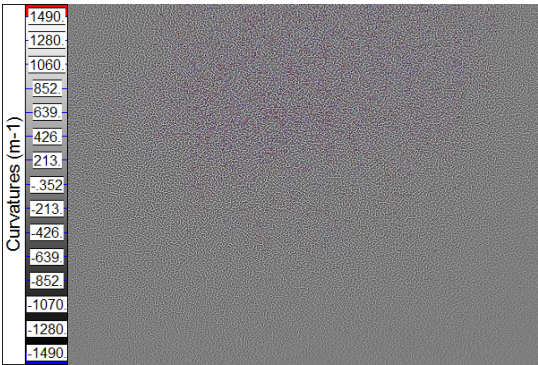
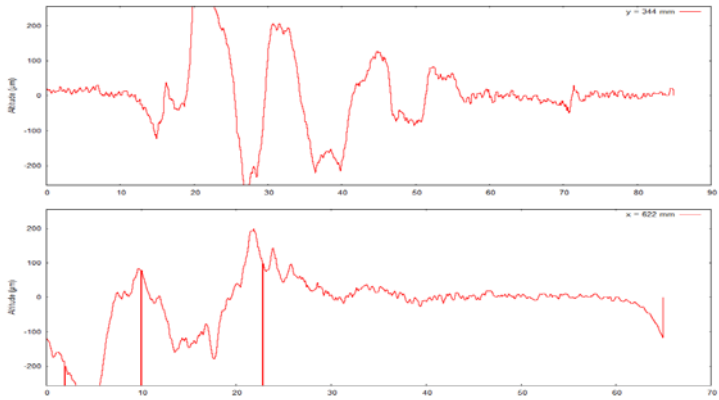
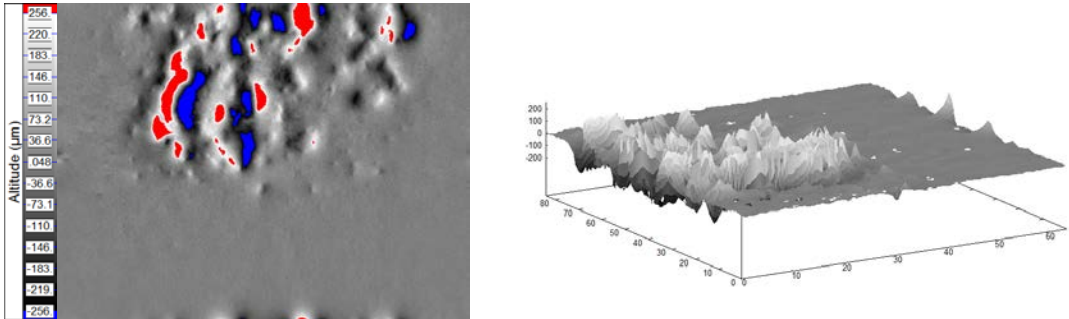




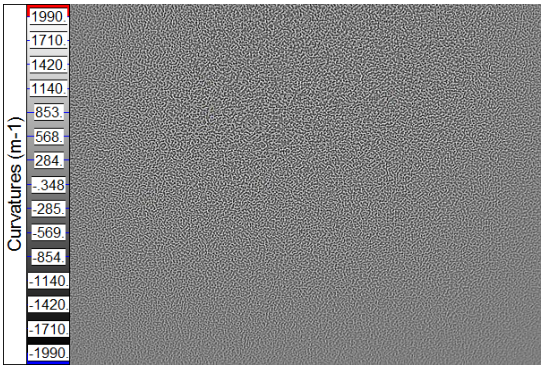
Kc



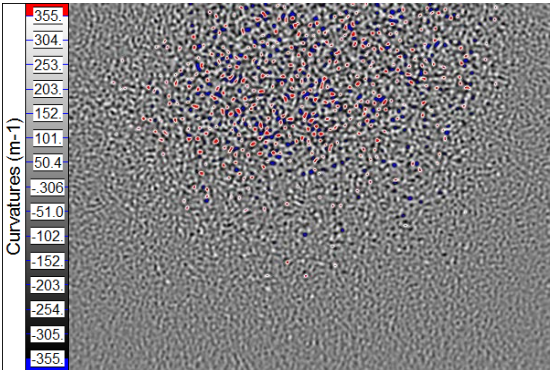
C.3 YY – stone texture: Supplier A N11



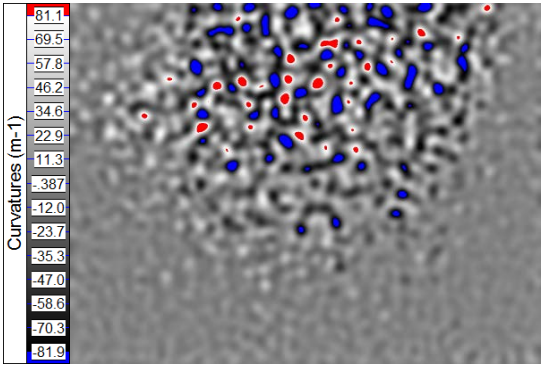
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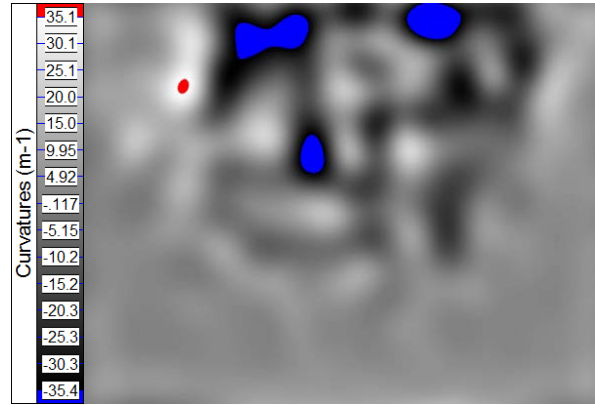
Kb



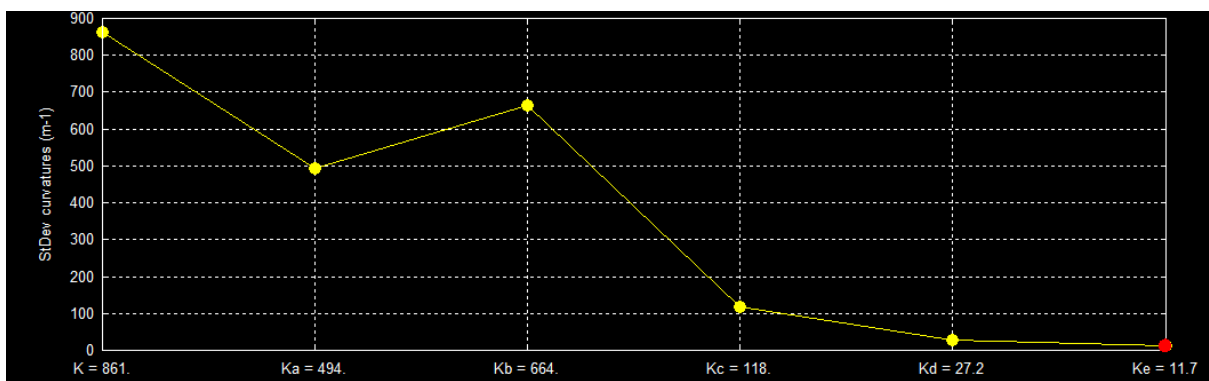
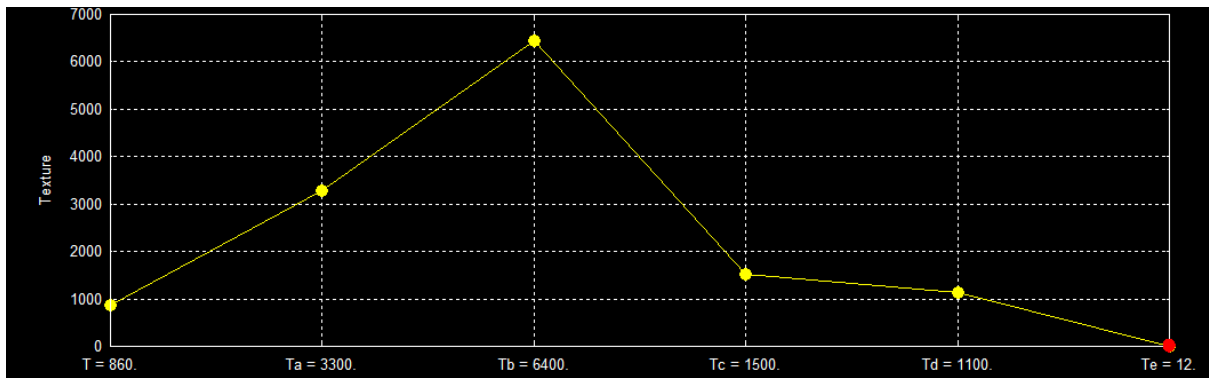
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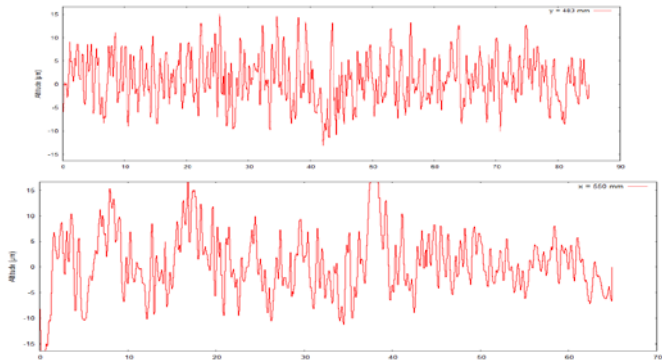
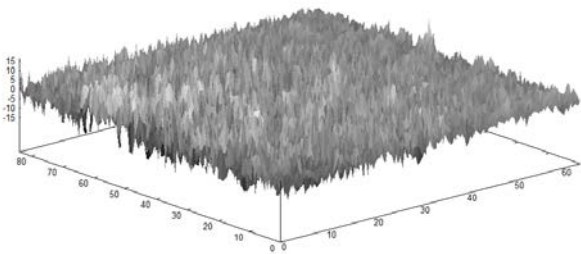
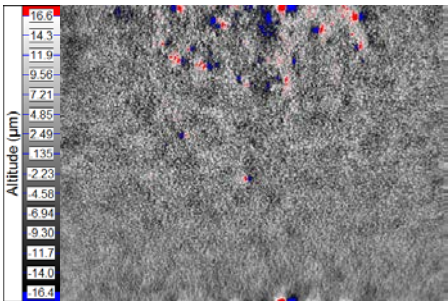
Kd



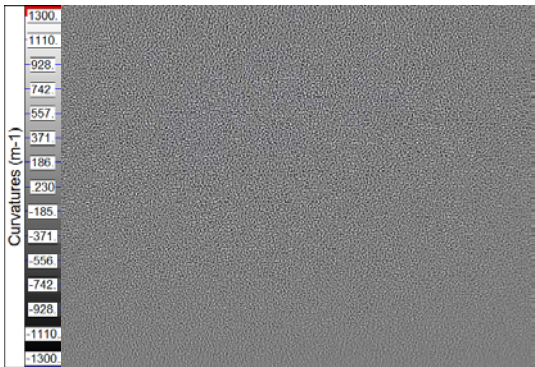
Ke



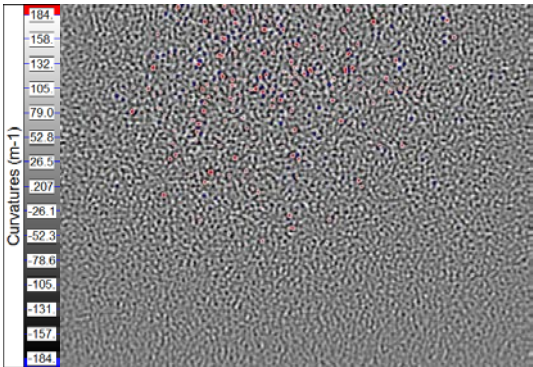
C.4 YY – stone texture: Supplier S S11



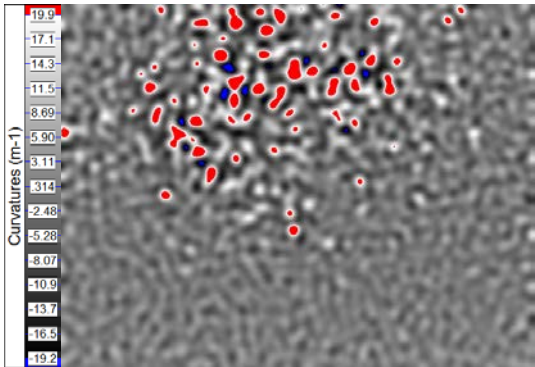
Ka



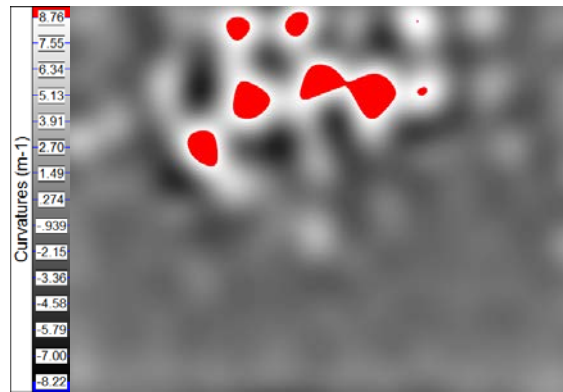
Kb



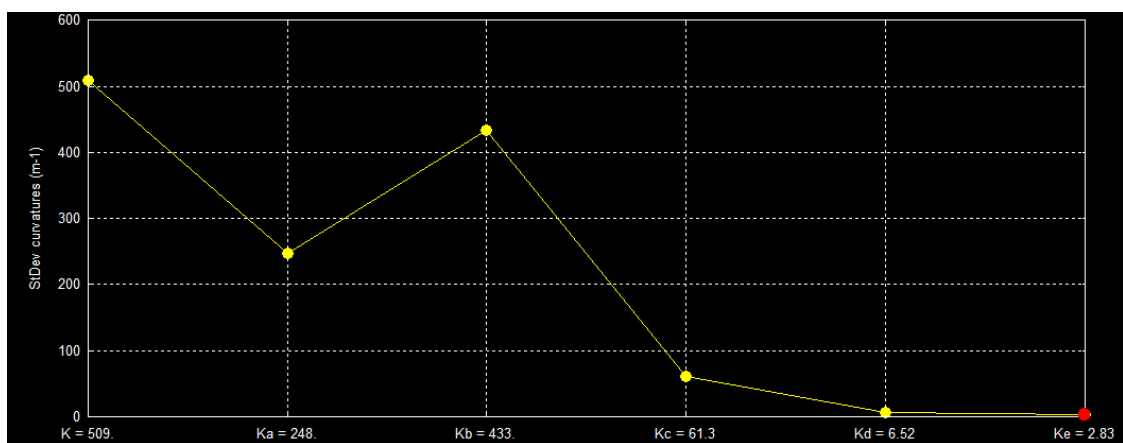
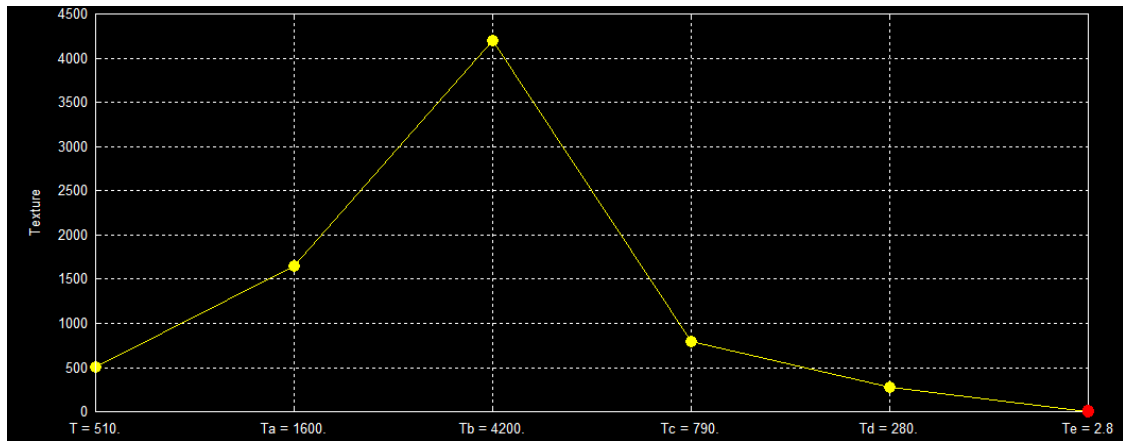
Kc



Kd

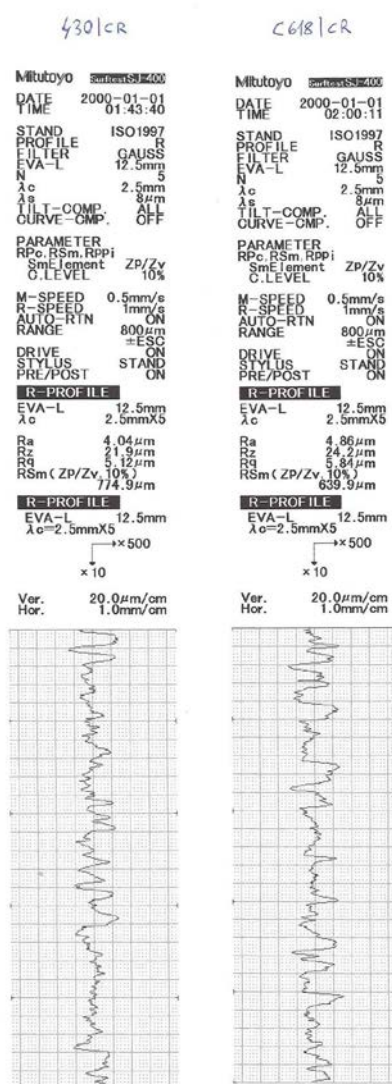


Ke



Appendix D: Scanned results

D.1 Supplier K YY

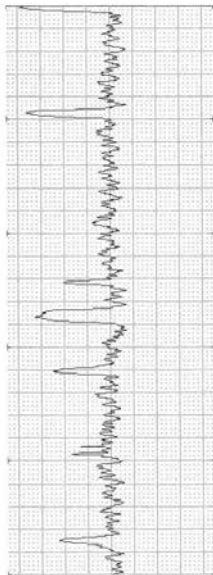


Appendix D: Scanned results

D.2 Supplier K XX

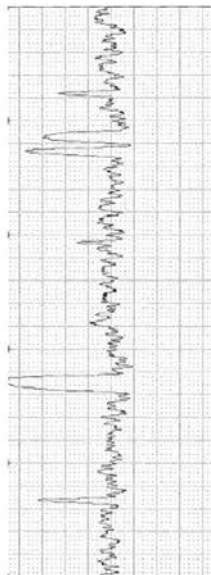
17712 FP

Mitutoyo Surftest SJ-400
 DATE 2000-01-01
 TIME 00:38:46
 STAND ISO1997
 PROFILE DIN4776
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP ALL
 CURVE-CMP OFF
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC ON
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
DIN4776
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Rpk 2.4 μ m
 Rvk 26.3 μ m
 Rk 8.9 μ m
 Mr1 4.6%
 Mr2 86.9%
 A1 5.551
 A2 171.86
DIN4776
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 500$
 $\times 10$
 Ver. 20.0 μ m/cm
 Hor. 1.0mm/cm



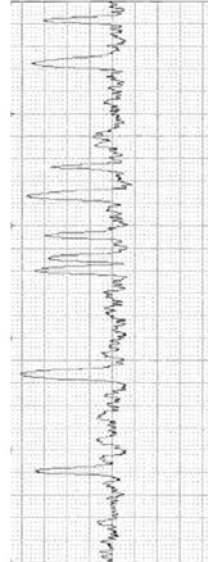
19558 FP

Mitutoyo Surftest SJ-400
 DATE 2000-01-01
 TIME 00:27:40
 STAND ISO1997
 PROFILE DIN4776
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP ALL
 CURVE-CMP OFF
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC ON
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
DIN4776
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Rpk 3.1 μ m
 Rvk 31.4 μ m
 Rk 10.0 μ m
 Mr1 6.6%
 Mr2 86.9%
 A1 10.089
 A2 205.03
DIN4776
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 500$
 $\times 10$
 Ver. 20.0 μ m/cm
 Hor. 1.0mm/cm

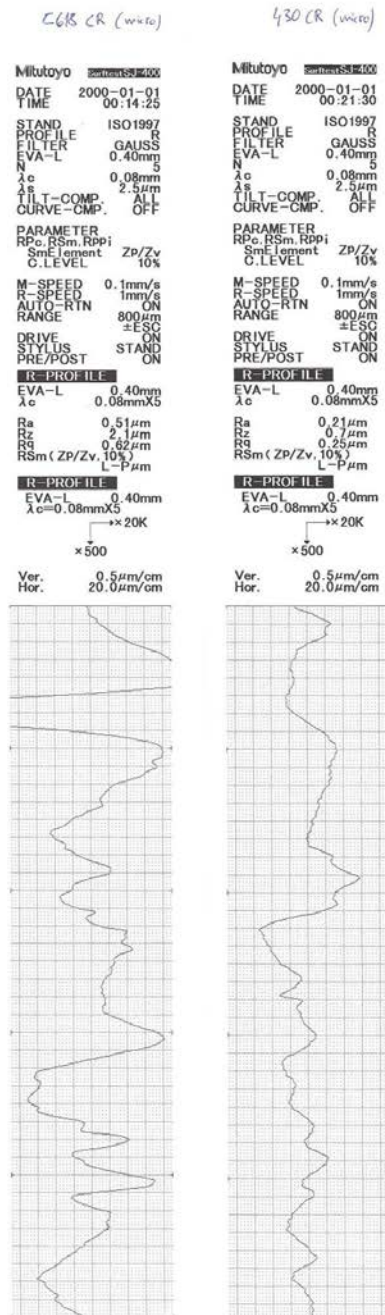


5135 FP

Mitutoyo Surftest SJ-400
 DATE 2000-01-01
 TIME 00:36:28
 STAND ISO1997
 PROFILE DIN4776
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP ALL
 CURVE-CMP OFF
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC ON
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
DIN4776
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Rpk 2.2 μ m
 Rvk 30.7 μ m
 Rk 9.5 μ m
 Mr1 7.0%
 Mr2 79.4%
 A1 7.884
 A2 315.81
DIN4776
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 500$
 $\times 10$
 Ver. 20.0 μ m/cm
 Hor. 1.0mm/cm

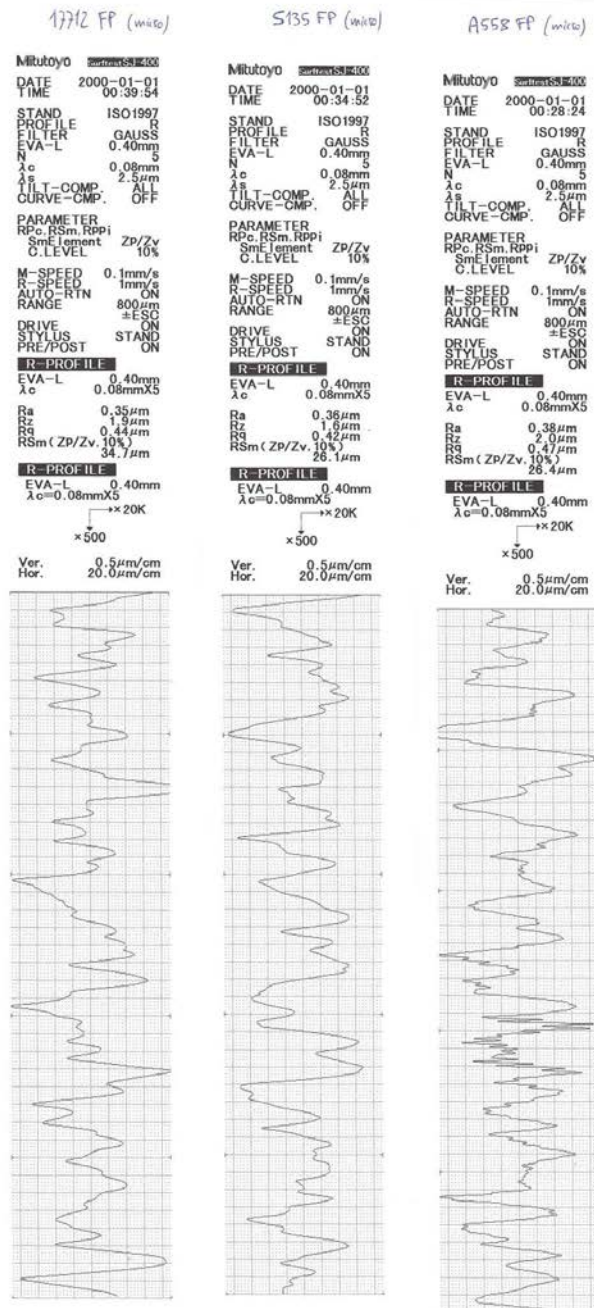


D.3 Supplier K micro texture YY

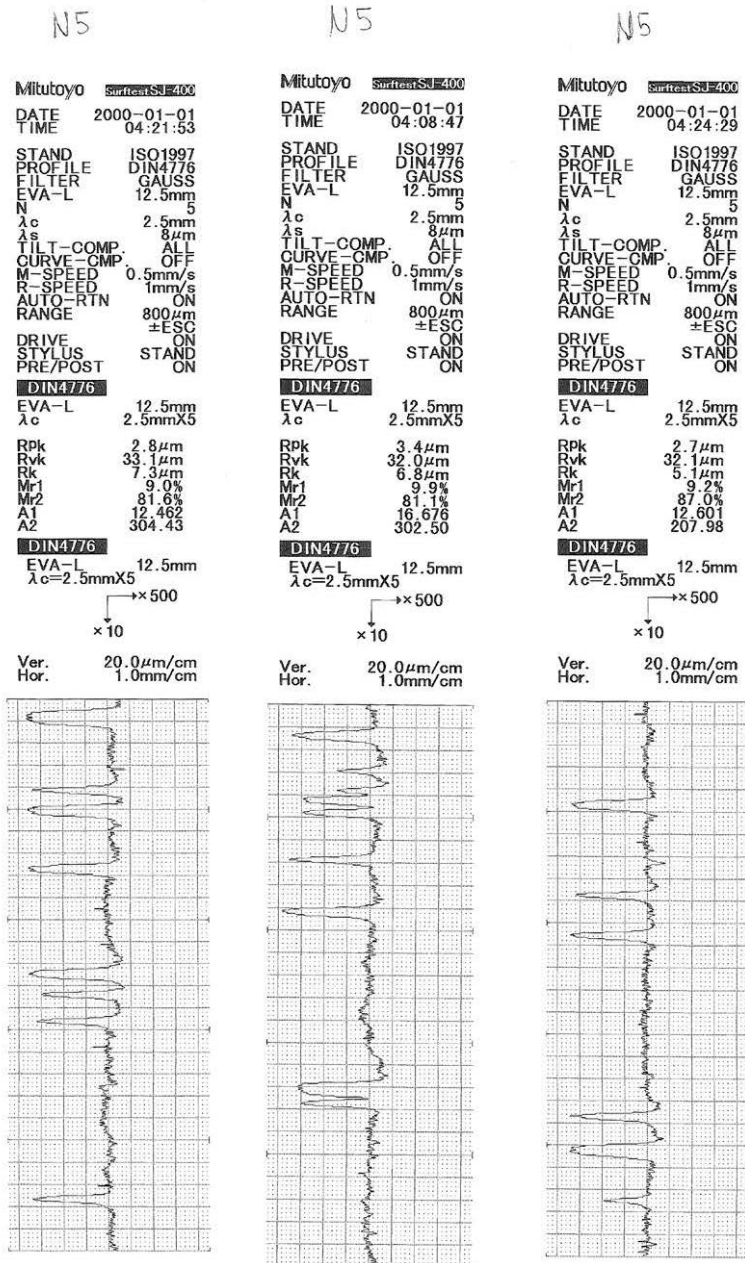


Appendix D: Scanned results

D.4 Supplier K micro texture XX

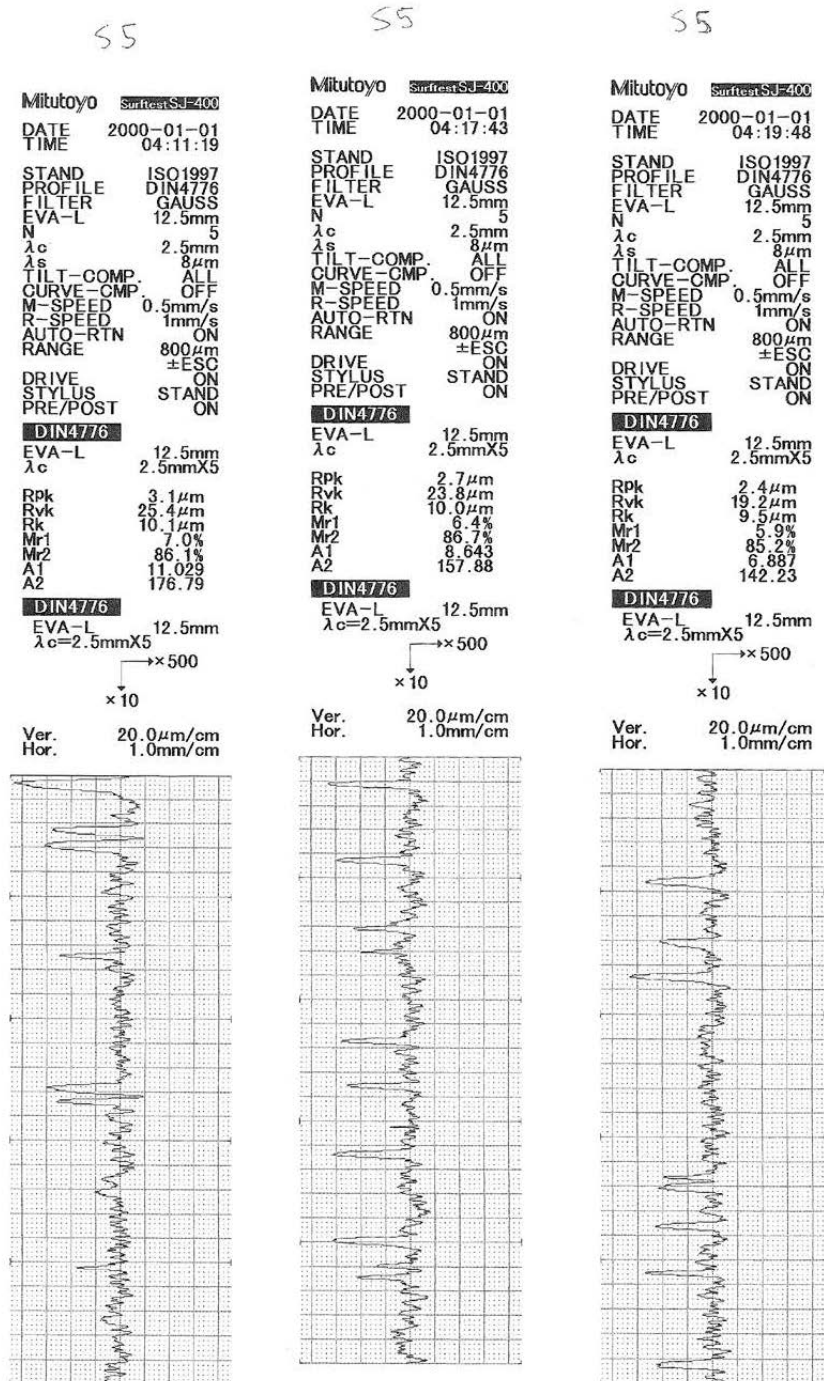


D.5 N5



Appendix D: Scanned results

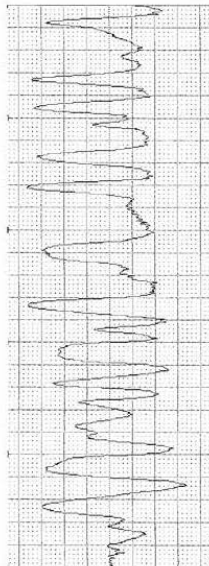
D.6 S5



D.7 N11

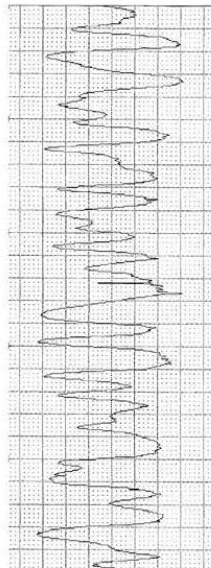
N11-1

Mitutoyo Surtest SJ-400
 DATE 2000-01-01
 TIME 02:14:47
 STAND ISO1997
 PROFILE R
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP. ALL
 CURVE-CMP. OFF
 PARAMETER
 R ρ_c , RSm, R ρ_{pi}
 SmElement Zp/Zv
 C.LEVEL 10%
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Ra 7.05 μ m
 Rz 29.1 μ m
 Rq 8.31 μ m
 RSm (Zp/Zv, 10%) 801.1 μ m
R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 1K$
 $\times 10$
 Ver. 10.0 μ m/cm
 Hor. 1.0mm/cm



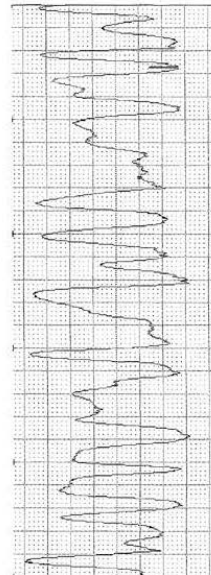
N11-2

Mitutoyo Surtest SJ-400
 DATE 2000-01-01
 TIME 02:30:10
 STAND ISO1997
 PROFILE R
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP. ALL
 CURVE-CMP. OFF
 PARAMETER
 R ρ_c , RSm, R ρ_{pi}
 SmElement Zp/Zv
 C.LEVEL 10%
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Ra 7.04 μ m
 Rz 28.7 μ m
 Rq 8.17 μ m
 RSm (Zp/Zv, 10%) 731.5 μ m
R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 1K$
 $\times 10$
 Ver. 10.0 μ m/cm
 Hor. 1.0mm/cm



N11-3

Mitutoyo Surtest SJ-400
 DATE 2000-01-01
 TIME 02:32:09
 STAND ISO1997
 PROFILE R
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP. ALL
 CURVE-CMP. OFF
 PARAMETER
 R ρ_c , RSm, R ρ_{pi}
 SmElement Zp/Zv
 C.LEVEL 10%
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Ra 8.29 μ m
 Rz 32.3 μ m
 Rq 9.35 μ m
 RSm (Zp/Zv, 10%) 1040.9 μ m
R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 1K$
 $\times 10$
 Ver. 10.0 μ m/cm
 Hor. 1.0mm/cm

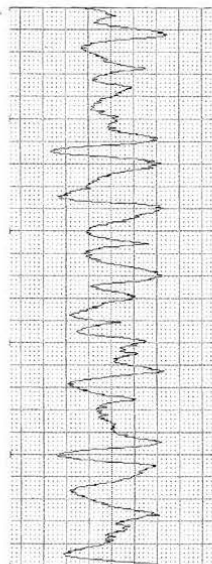


Appendix D: Scanned results

D.8 S11

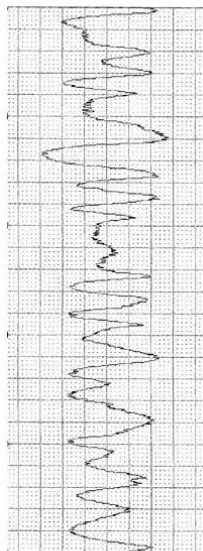
S11:1

Mitutoyo Surtrac SJ-400
 DATE 2000-01-01
 TIME 02:18:17
 STAND ISO1997
 PROFILE R
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP. ALL
 CURVE-CMP. OFF
 PARAMETER
 R_{Pc}, R_{Sm}, R_{Pp}
 S_m Element Zp/Zv
 C.LEVEL 10%
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
 R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Ra 4.61 μ m
 Rz 22.3 μ m
 Rq 5.56 μ m
 RSm (Zp/Zv, 10%)
 796.7 μ m
 R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 1K$
 $\times 10$
 Ver. 10.0 μ m/cm
 Hor. 1.0mm/cm



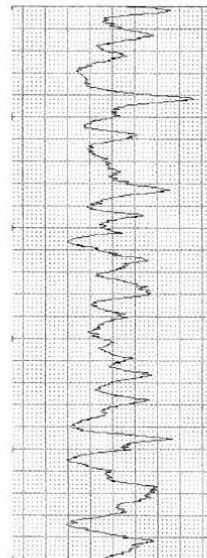
S11:2

Mitutoyo Surtrac SJ-400
 DATE 2000-01-01
 TIME 02:24:52
 STAND ISO1997
 PROFILE R
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP. ALL
 CURVE-CMP. OFF
 PARAMETER
 R_{Pc}, R_{Sm}, R_{Pp}
 S_m Element Zp/Zv
 C.LEVEL 10%
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
 R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Ra 5.15 μ m
 Rz 21.8 μ m
 Rq 6.04 μ m
 RSm (Zp/Zv, 10%)
 889.2 μ m
 R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 1K$
 $\times 10$
 Ver. 10.0 μ m/cm
 Hor. 1.0mm/cm

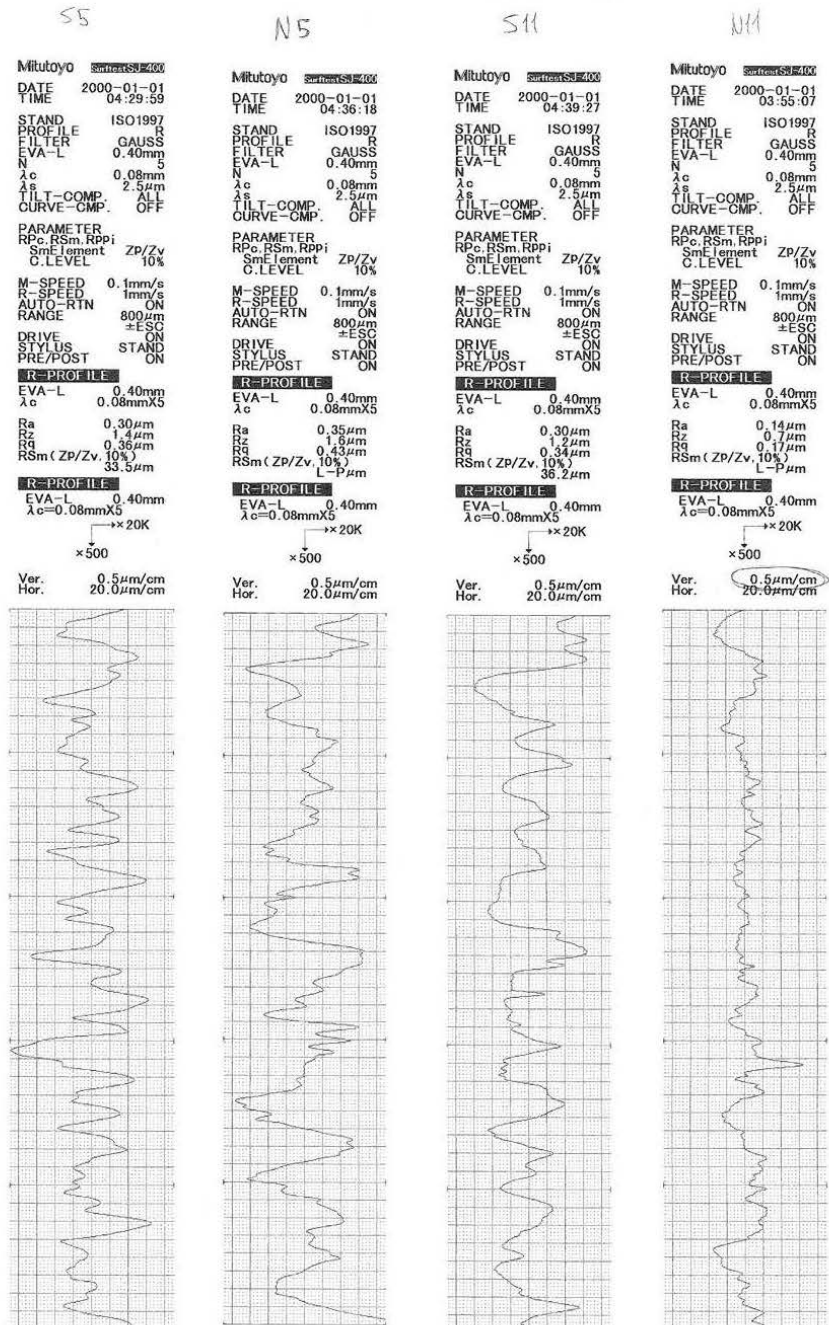


S11:3

Mitutoyo Surtrac SJ-400
 DATE 2000-01-01
 TIME 02:27:05
 STAND ISO1997
 PROFILE R
 FILTER GAUSS
 EVA-L 12.5mm
 N 5
 λ_c 2.5mm
 λ_s 8 μ m
 TILT-COMP. ALL
 CURVE-CMP. OFF
 PARAMETER
 R_{Pc}, R_{Sm}, R_{Pp}
 S_m Element Zp/Zv
 C.LEVEL 10%
 M-SPEED 0.5mm/s
 R-SPEED 1mm/s
 AUTO-RTN ON
 RANGE 800 μ m
 \pm ESC
 DRIVE ON
 STYLUS STAND
 PRE/POST ON
 R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 Ra 4.03 μ m
 Rz 21.4 μ m
 Rq 5.07 μ m
 RSm (Zp/Zv, 10%)
 790.5 μ m
 R-PROFILE
 EVA-L 12.5mm
 λ_c 2.5mmX5
 $\times 1K$
 $\times 10$
 Ver. 10.0 μ m/cm
 Hor. 1.0mm/cm

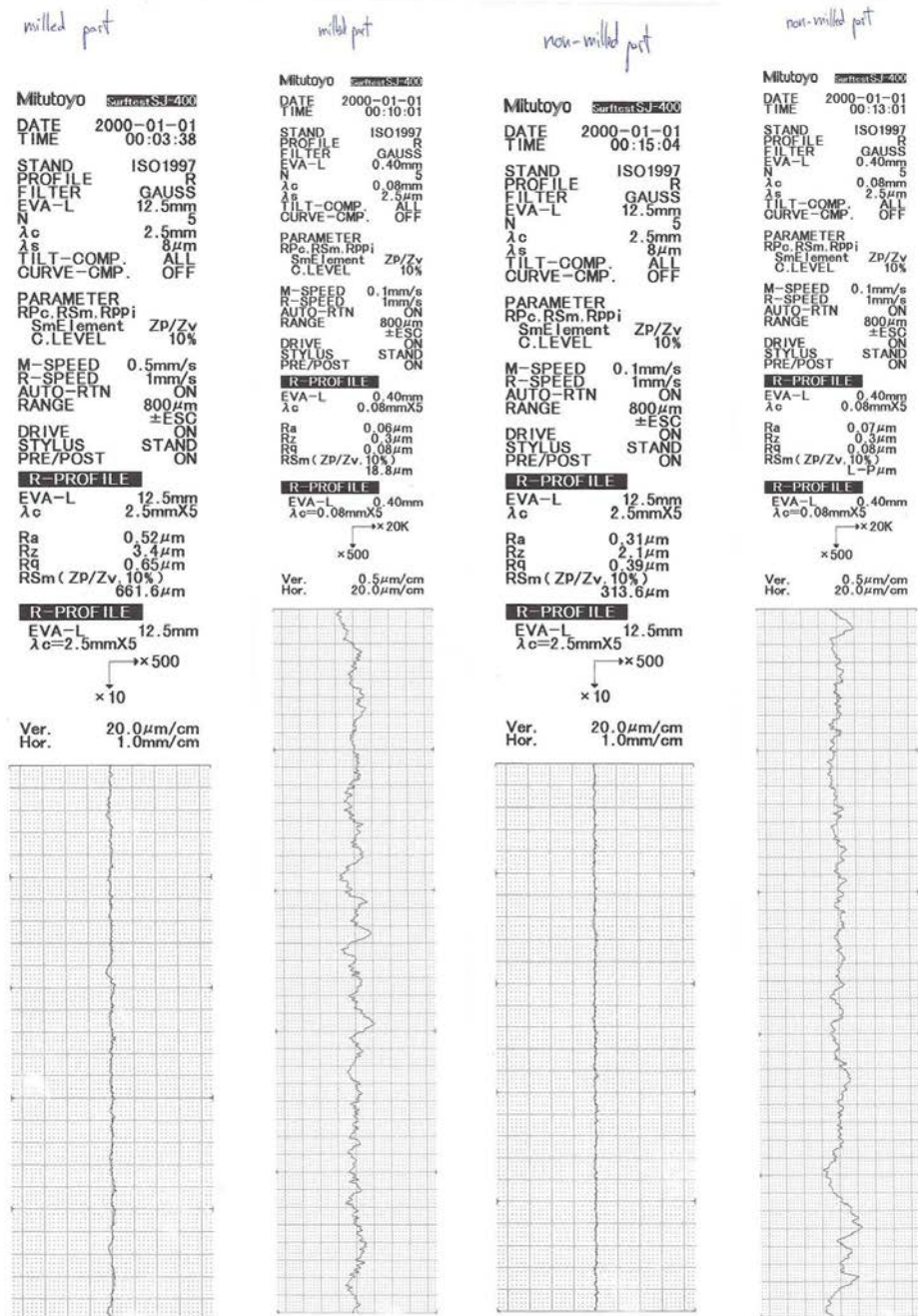


D.9 Micro texture



Appendix D: Scanned results

D.10 ZZ kitchen front



Appendix E: Visit to Supplier K

E.1 CPL process

- Pressure: 35 bar
- Laminates: from 0.2 to 0.8 mm thickness

All the laminates that Supplier K is producing for IKEA are manufactured through Continuous Press Laminate processes.

Using release paper to give the texture:

- Problem: batch to batch differences
- Thermosetting cured release paper: can be used 5 times. Gloss sets the lifetime, there are no texture differences.
- Electro beam cured release paper: can be used 11/12 times, after that it rips. Is used to emboss more sophisticated textures to the release paper.

Using a steel belt to give the texture:

- Problems: up to the operator's mistakes
- High cost texture tool: 400.000€/steel belt
- Used for really high volume
- 11.3 m long

Steps in the process:

- First of all the kraft paper, the decorative layer and the overlay are pressed together with the release paper or the steel belt to give texture to the overlay. This is done in a continuous process through different rollers. When the decorative layer consists in just one uniform color, the overlay is not used and the texture is given directly to the decorative layer.
- Once the release paper or the steel belt is released, the cooling process starts. It consists in different rollers with cold water flowing inside. This process is only carried out with thick laminates.
- After leaving the cooler, the laminate goes through the sanding process, in order to both fit the expected thickness of the laminate and give roughness to the back side of the laminate. This roughness is needed to manufacture the worktop: it facilitates the gluing process between the laminate and the fiberboard.

E.2 HPL process

- Pressure: 90 bar
- Laminates: from 0.7 to 20 mm thickness
- A silicone paper is used on the top just to avoid stickiness with the texture plate.

This process uses texture plates to give the texture to the laminates.

E.3 Quality inspection

Related to surface texture:

- Visual inspection
- Gloss level

Concerning the surface texture, the only objective measurement that the quality control department is doing consists in just checking the gloss of the laminates in order to approve or reject the batches. A profilometer or any other roughness measuring instruments are not used at all.

E.4 Texture pattern design

Supplier K has its own texture designers concerning texture plates. However, with the release paper and the press belts they choose between the already designed textures that the suppliers offer (Supplier PP and Supplier UT respectively).

Appendix F: Contact information

For further research on topics related to this Master Thesis, these contacts could be useful:

| Topic | Writers of the Master Thesis |
|--------|------------------------------|
| Name | Christian Öhrström |
| Major | Mechanical Engineering |
| E-mail | christian.ohrstrom@gmail.com |
| Name | Aniol Salvador Soy |
| Major | Industrial Engineering |
| E-mail | aniol.salvador@gmail.com |

| Topic | Scanning and height-mapping large surfaces |
|----------------|--|
| Equipment | Cruse scanners |
| Company | Cruse Digital Imaging Equipment |
| Place | Germany |
| Website | www.cruseScanner.com |
| Contact person | Klaus Karcher |
| E-mail | kk@cruseScanner.com |
| Position | Head of R&D |

| Topic | Consulting company in surface texture |
|----------------|---------------------------------------|
| Equipment | GFM3D MikroCAD and profilometer |
| Company | Toponova AB |
| Place | Halmstad |
| Website | www.toponova.se |
| Contact person | Stefan Rosén |

Appendix F: Contact information

| | |
|-----------------|--------------------|
| E-mail | stefan@toponova.se |
| Position | CEO |

| | |
|-----------------------|--|
| Topic | Appearance measurements |
| Equipment | Optimap PSD, Rhopoint IQ and glossmeters |
| Company | Rhopoint Instruments |
| Place | United Kingdom |
| Website | www.rhopointinstruments.com |
| Contact person | Nigel Rose |
| E-mail | nigel.rose@rhopointinstruments.com |
| Position | Technical Sales Director |

| | |
|-----------------------|--|
| Topic | Appearance measurements |
| Equipment | Wave Scan and Wave Scan Dual |
| Company | BYK Gardner |
| Place | Germany |
| Website | www.byk.com/en/instruments/products/appearance-measurement.html |
| Contact person | Friedhelm Fensterseifer |
| E-mail | friedhelm.fensterseifer@altana.com |
| Position | Product Manager Appearance |

| | |
|-----------------------|--|
| Topic | 3D scanning and reverse engineering |
| Equipment | 3D scanners |
| Company | Cascade Computing AB |
| Place | Gothenburg |
| Website | www.cascade.se |
| Contact person | Börje Larsson |
| E-mail | borje.larsson@cascade.se |
| Position | Managing Director |