



Specifying Stainless Steel Surfaces for the Brewery, Dairy and Pharmaceutical Sectors

Jan Elkjaer Frantsen, Troels Mathiesen
FORCE Technology
Park Alle 345
DK-2605 Brøndby, Denmark
jef@force.dk

Abstract

The paper gives an overview of the standards, guidelines (e.g. ASME BPE-2007, 3-A SSI, EHEDG, EN, ISO) and sector-typical requirements that are used to specify the stainless steel surfaces for process equipment in the brewery, dairy and pharmaceutical sectors. Moreover, by means of a case history the paper describes some often occurring problems and disputes related to the subsequent control of the actual delivered surfaces.

Keywords: Surface treatment, Mechanical, Polish, Ground, Chemical, Electropolish, Pickling, 2B, Finish, Specification, Accept criteria, Roughness, Weld post treatment, Brewery, Dairy, Pharmaceutical

Introduction

In the brewery, dairy and pharmaceutical sectors, the process equipment is almost entirely made from stainless steel. However, having made other basic engineering decisions such as dimension and design there are still many decisions to be made regarding sub-task issues such as stainless steel grade, welding requirements, surface treatment and finish, NDT control etc. Moreover, many decisions have to be taken about packaging, transport, on-site erection and final cleaning etc. The preparation of requested documentation material including all the listed issues and for instance the compulsory approval of equipment for pressure purposes can also be a rather comprehensive and time-consuming task.

Among the above-mentioned issues, this article focuses on the challenges related to specifying the surface treatment and finish including a control procedure and an exact acceptance criterion. It is the authors' experience that in the routine task of specifying new process equipment this issue is often handled quite vaguely despite the fact that it in addition to any technical justification also has a great economical impact. Moreover, it is worth keeping in mind that in some cases an incorrect surface quality can result in irreversible damage. By way of example; there is no repair procedure for a process tank delivered with a cold-rolled, bright finish (2B finish, ASTM A 480 / A 480M) that exceeds a specified maximum Ra value.

Criteria used to specify surface quality

Ideally the required surface quality should in every case be carefully considered with respect to hygiene, corrosion resistance and economical aspects. The details on the corrosion aspects are dealt with in another paper [1]. However, it is the authors' postulate that this is not the standard procedure in real life. Quite often the most predominant decision factors seem to be inexpedient use of history and various standards, guidelines and sector-typical requirements. The term inexpedient is used because a history consisting of old drawings, contracts etc. is not always in accordance with the present technical state-of-the-art or cost-optimum solution. Standards and guidelines are also history-based and given specifications are by default very general. Company-specific requirements are usually a very good tool. However, to remain a good tool they shall be reviewed/updated on a regularly basis. In addition, it is not an unfamiliar phenomenon that the term company-specific requirements is enlarged to include not only requirements decided in the decision makers own company but also requirements borrowed from what is regarded as competent information from other relevant companies.

Moreover, the required surface quality is often specified in a non-measurable way (e.g. polishing to grit 220). In these cases it becomes irrelevant that there is also a wide ignorance as to the exact meaning of the specified accept criterion, for instance the difference between $Ra \max 0.6 \mu\text{m}$ and $Ra \leq 0.6 \mu\text{m}$.

Systematic control of the surface quality of the actual delivered process equipment is quite often omitted. This is partly for pure economical reasons as the control procedure represents an expense and partly because many decision makers do not understand the need for control and/or do not know how to specify, undertake and evaluate the control results, e.g. surface roughness measurements. The latter is of course also quite a challenge if there is no specified acceptance criterion. A typical example is repair of polished areas (e.g. after external welding of leg support to a tank) to which the decision makers only in very rare instances remember to specify an acceptance criterion.

With the exception of the use of history-based material such as old drawings, contracts etc. to specify the surface quality for new process equipment, all the aforementioned issues will in the following be commented in detail and a case history will be presented.

ASME BPE-2007

It is the authors' impression that the ASME BPE standard (Bioprocessing Equipment, latest edition from 2007 [2]) in recent years has gained status as the most vital tool for the pharmaceutical sector when new process equipment is to be ordered.

The standard deals with a whole range of important issues such as design for sterility and cleanability, material joining, equipment seals etc. The standard also contains a so-called part SF "Stainless Steel and Higher Alloy Product Contact Surface Finishes" in which "the objective is to describe an acceptable product contact surface finish on selected materials of constructing to enhance their cleaning, sterilization, and corrosion resistance". Initially, this objective is pursued by listing relevant process equipment applications (water-for-injection, purified water etc.), constructing materials (tubes, sheets, fittings etc. according to various ASTM standards), inspection techniques (visual, borescopes, liquid penetrant, profilometer etc.) and surface conditions (machining, mechanical polishing, electropolishing etc.). This is definitely relevant information but it should all be well-known stuff for the decision makers in this business. More importantly, the standard has also three tables with more substantial information:

Table SF-1: "Acceptance Criteria for Stainless Steel and Higher Alloy Mechanically Polished Product Contact Surface"

Table SF-2: "Acceptance Criteria for Mechanically Polished and Electropolished Product Contact Surface Finishes"

Table SF-3: "*Ra* Readings for Product Contact Surfaces"

The tables SF-1 and SF-2 list in details the acceptance criteria for a number of flaws, e.g. pits, cluster of pits, dents, scratches, surface cracks, surface inclusions, blistering, end grain effect, cloudiness, haze etc. The tables are good tools, especially in case of a dispute. However, for the flaw types that is accepted in small number, depth or unit of area, the acceptance criteria are not suited for routine on-site control.

It is beyond the scope of ASME BPE-2007 to define *Ra* max or *Ra* upper limits (\leq) for individual pieces of process equipment. However, the way table SF-3 operates with seven different surface designations ranging from SF0 to SF6 gives a very strong hint about the *Ra* max limits that ASME BPE-2007 thinks acceptable. SF0 represent the "no finish requirement" but among the six other surface designations, SF3 specifying *Ra* max 30 μin . (0.76 μm) is the leanest requirement, see table 1 (a replication of table SF-3 from ASME BPE-2007).

ASME BPE-2007 has three significant general notes to the *Ra* max limits in table 1:

- A. All *Ra* readings are taken across the lay, wherever possible
- B. No single *Ra* reading shall exceed the *Ra* max value in this table
- C. Other *Ra* readings are available if agreed upon between owner/user and manufacturer, not to exceed values in this table

It is the authors' view that ASME BPE-2007 is the best standard available when it comes to specify a surface quality. Still the standard has some shortcomings for which reasons it is advisable to specify some additional requirements when new process equipment is to be ordered. We refer to the pitfalls mentioned in the previous paragraph in this article. See also the case history later on in this article.

3-A SSI

On their web page, 3-A Sanitary Standards, Inc. (3-A SSI) introduces itself as “a non-profit association representing equipment manufacturers, processors, regulatory sanitarians and other health professionals. Through many decades of cooperation, these groups have established a comprehensive inventory of 3-A Sanitary Standards and 3-A Accepted Practices now known around the world for dairy and food processing equipment and systems. 3-A SSI today is committed to advancing the state of art for hygienic equipment design to meet the fast-changing needs of the food, beverage and pharmaceutical industries”.

The great number of 3-A Sanitary Standards and 3-A Accepted Practices contains a huge amount of detailed recommendations for a long list of equipment. However, as regards the product contact surface finishes the common specification is:

- All product contact surfaces shall have a finish at least as smooth as a No. 4 ground finish on stainless steel sheets and be free of imperfections such as pits, folds and crevices in the final fabricated form
- Surface finish equivalent to 150 grit or better as obtained with silicon carbide, properly applied on stainless steel sheets
- A maximum R_a of 32 $\mu\text{in.}$ (0.80 μm) when measured according to the recommendations in ASME B46.1 – Surface Texture is considered to be equivalent to a No. 4 finish (“Finishes for Stainless Steel”, AISI #9012, Committee of Stainless Steel Producers).

Table 2 refers to a few examples of 3-A standards [3] including acceptance criteria for the surface finish.

EHEDG

Their web page states that “The European Hygienic Engineering and Design Group (EHEDG) is a consortium of equipment manufacturers, food industries, research institutes and public health authorities, founded in 1989 with the aim to promote hygiene during the processing and packing of food products. European legislation requires that handling, preparation, processing, packaging, etc. of food is done hygienically, with hygienic machinery in hygienic premises (the food hygiene directive, the machine directive and the food contact materials directive). How to comply with these requirements, however, is left to the industry. EHEDG provides practical guidance on hygienic engineering aspects to help complying to these requirements. As food safety does not end at the borders of Europe, the EHEDG actively promotes global harmonization of guidelines and standards. The US-based organisations NSF and 3-A have agreed to co-operate in the development of EHEDG Guidelines and in turn, EHEDG co-operates in the development of 3-A and NSF standards”.

In September 2008, the EHEDG web page listed 36 guidelines. Two of these guidelines [4] seem to have relevance for the topic of this article, see the references in table 3. As concerns the product contact surface finishes, EHEDG's specifications are:

- Product contact surfaces should have a finish of an acceptable Ra value and be free from imperfections such as pits, folds and crevices (for definition of Ra , see ISO 4287:1997)
- Large areas of product contact surface should have a surface finish of $0.8 \mu\text{m}$ Ra , or better, although the cleanability strongly depends on the applied surface finishing technology, as this can affect the surface topography
- A roughness of $Ra > 0.8 \mu\text{m}$ is acceptable if test results have shown that the required cleanability is achieved because of other design features, or procedures such as a high flow rate of the cleaning agent

It is remarkable that EHEDG specifies the Ra acceptance criterion as an upper limit ($Ra \leq 0.8 \mu\text{m}$) whereas 3-A SSI by comparison specifies the Ra acceptance criterion as a maximum permissible value ($Ra \text{ max. } 0.80 \mu\text{m}$ (32 $\mu\text{in.}$)). This is a difference of great significance, see the later part “EN ISO standards for performing and evaluating surface roughness measurements” in this article. Moreover, contrary to 3-A SSI, EHEDG accepts Ra values $> 0.8 \mu\text{m}$ provided test results have shown the required cleanability.

Of general interest it is worth noting that EHEDG has published a table that shows the relation between the surface treatment of stainless steel and the resultant surface topography, see table 4 (a replication of table 2 from EHEDG Guideline No. 8 “Hygienic equipment design criteria”). It is the authors’ opinion that such a table is very informative but we will underline the fact that the stated Ra values are only approximately values that can vary considerably. See also the case history later on in this article.

Sector-specific requirements for surface quality

For confidentiality reasons company-specific requirements for surface quality cannot be listed. However, the authors are cooperating with many companies in the brewery, dairy and pharmaceutical sectors and we have no problem listing some sector-typical requirements for surface quality.

In the following we are only focussing on the process side. Thus, we are for instance not commenting on the glass-bead blasted surfaces that both the brewery and dairy sectors quite often use as a final surface treatment for the external side of process equipment.

The brewery sector

The majority of stainless steel process equipment in the brewery sector is ordered with a surface quality which is cold rolled, heat treated, pickled and skin passed (2B, EN 10088-2) or hot rolled, heat treated and pickled (2D, EN 10088-2). The 2B surfaces are most frequently specified with acceptance criterion $Ra \leq 0.6 \mu\text{m}$. The same applies for 2D surfaces although for thick-walled material such as for instance fermentation tanks it is also quite common to use the alternative acceptance criterion $Ra \leq 0.8 \mu\text{m}$. Figures 1-2 show the topography of a 2B surface photographed in a scanning electron microscope (SEM).

In the brewery sector, mechanical polishing is a rarely specified surface quality with the exception of weld seams and other areas that for some reasons have to be repair polished. The explanation is a simple cost/benefit consideration. For the same reason the electropolished surface is an almost non-existent surface quality in this sector.

However, at a brewery all the mechanically polished weld seams and repair polished areas make up a significant total area for which reason it is important to specify this surface quality in detail, e.g.:

- How wide a polishing belt is accepted at weld seams?
- How many, how big and what total sum of repair polished areas is accepted on the product contact surface of each piece of process equipment?
- What sort of polishing tools are accepted? Are for instance scuffing wheels accepted? Or are only abrasive belts with increasing fineness of grain (e.g. grit 80 → grit 150 → 220) accepted?
- What subsequent control of the actual delivered surfaces is to be performed?

Unfortunately, it is not unusual that none or only a few of the above-mentioned issues are addressed and that the only specification is a surface roughness acceptance criterion such as $Ra \leq 0.6 \mu\text{m}$ or $Ra \text{ max } 0.6 \mu\text{m}$. As this is also a predominant problem in the dairy and pharmaceutical sectors, this is a subject of the case history later on in this article. Figures 3-4 show the topography of a polished surface photographed in a scanning electron microscope (SEM). The initial surface quality was a 2B surface that subsequently was polished with abrasive belts (grit 80 → grit 120 → grit 180).

The dairy sector

In the dairy sector, the most prevalent surface quality is the cold rolled, heat treated, pickled and skin passed surface (2B, EN 10088-2). However, the mechanically polished surface is also to a great extent used partly for the same reason as aforementioned for the brewery sector (mechanically polished weld seams and areas that for some reasons have to be repair polished) and partly because some dairy process equipment (for instance finish milk tanks) is often ordered with this surface quality. For these two surface qualities, it should be noted that many West European dairies specify the surface roughness acceptance criterion $Ra \leq 0.6 \mu\text{m}$ despite the fact that 3-A SSI and EHEDG specify $Ra \text{ max. } 0.80 \mu\text{m}$ (32 $\mu\text{in.}$) and $Ra \leq 0.8 \mu\text{m}$ respectively.

The hot rolled, heat treated and pickled (2D, EN 10088-2) surface quality is seldom used in the dairy sector as there is only a small need for thick-walled stainless steel material. However, the authors have seen this surface quality at dairies, for instance for washing machines for cheese forms with the surface roughness acceptance criterion $Ra \leq 0.8 \mu\text{m}$.

From a tonnage point of view, the electropolished surface quality is also very rare in the dairy sector. Nevertheless, in recent years the use of electropolished accessories such as rotary spray jets, filters and strainers etc. seem to have increased significantly. As these sorts of accessories are also sold to the pharmaceutical sector, the surface roughness acceptance criterion is usually minimum $Ra \text{ max. } 0.4 \mu\text{m}$ (which is very close to the ASME BPE-2007 surface designation SF4, see table 1). Figures 5-6 show the topography of an electropolished surface photographed in a scanning electron microscope (SEM). The initial surface quality was a 2B surface that subsequently was electropolished.

The pharmaceutical sector

Like the brewery and dairy sectors, the pharmaceutical sector also use a large tonnage of stainless steel with the cold rolled, heat treated, pickled and skin passed surface quality (2B, EN 10088-2). However, this surface quality is mostly used for less critical applications such as

utility (potable water, glycol, condensate, instrument air, cleaning-in-place (CIP) chemicals etc.) and waste systems (bio and process waste etc.).

As regards the critical product contact surfaces, the 2B surface quality is usually rejected because of the risk for surface flaws such as rolling defects, surface pores etc. Instead the electropolished surface quality is specified for the utmost critical process equipment (bio-reactors, water-for-injection (WFI) etc.) and the mechanically polished surface quality for the second most critical process equipment (purified water (WPU), clean steam etc.) It is the authors' experience that these two surface qualities usually are specified almost in accordance with the leanest requirement in ASME BPE-2007, i.e. R_a max. 0.4 μm for the electropolished surface and R_a max. 0.6 μm for the mechanically polished surface, see the ASME BPE-2007 surface designations SF4 and SF6 in table 1.

EN ISO standards for performing and evaluating surface roughness measurements

There are no recommendations in the EN ISO standards as to surface quality of process equipment in the brewery, dairy and pharmaceutical sectors. However, the EN ISO standards EN ISO 4287, EN ISO 4288 and EN ISO 3274 constitute a "trinity" that is eminent when it comes to performing and evaluating surface roughness measurements [5].

Surface roughness measurements can be performed and evaluated according to the following EN ISO standards:

- EN ISO 4287 (1998) Geometrical product specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters (ISO 4287: 1997)
- EN ISO 4288 (1997) Geometrical product specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture (ISO 4288: 1996)
- EN ISO 3274 (1997) Geometrical product specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments (ISO 3274: 1996)

EN ISO 4287 specifies terms, definitions and parameters for the determination of surface texture (roughness, waviness and primary profile) by profiling methods. The most frequently used parameters are:

R_a	Arithmetical mean deviation of profile
R_z	Maximum height of profile
R_q	Root mean square deviation of profile
λ_s	Profile filter cut-off wavelength
λ_c	Roughness cut-off wavelength
l_r	Roughness sampling length
l_n	Roughness evaluation length

EN ISO 4288 specifies the rules for comparison of the measured values with the tolerance limits for surface texture parameters defined in EN ISO 4287. It also specifies the default rules for selection of cut-off wavelength for measuring roughness profile parameters according to EN ISO 4287 by using stylus instruments according to EN ISO 3274. Examples of important parameters mentioned in the standard are:

n	Number (less than 5) of sampling lengths used
σ_5	Evaluation length equal to five sampling lengths

It is worth noting that there is considerable confusion in the use of the above-mentioned terms, especially in handbooks but unfortunately also in the terms for the adjustable parameters written on the stylus instruments (and in the corresponding manuals) and even in the International Standards themselves. By way of example, the roughness cut-off wavelength λ_c is often designated the reference length. Similarly, the roughness evaluation length l_n is often written $n\lambda_c$.

The rules prescribed in EN ISO 4288 for evaluation of surface texture presupposes that the roughness evaluation length is equal to 5 reference lengths, i.e. l_n is equal to $n\lambda_c$ where n is equal to 5. However, in case the number of roughness cut-off wavelengths (reference lengths) is less than 5 the standard prescribes a procedure to taking such changes into account. Anyhow, the roughness cut-off wavelength λ_c shall be selected correctly, i.e. in this connection the standard prescribes no procedure for subsequent correction.

This may seem complicated, however for the brewery, dairy and pharmaceutical sectors it is in general unproblematic. The reason is that these sectors in the main specify Ra values in the interval $0.1 \mu\text{m} < Ra \leq 2 \mu\text{m}$. In this interval, the correct roughness evaluation length l_n is equal to $n\lambda_c$ where n is equal to 5 and the roughness cut-off wavelength (reference length) λ_c is 0.8 mm.

EN ISO 4288 specifies the rules for comparison of the measured values with the tolerance limits. The surface texture for the work piece under inspection can appear homogeneous or be quite different over various areas. This can be seen by visual examination of the surface. In cases where the surface texture appears homogeneous, parameter values determined over the entire surface shall be used for comparison with the requirements specified on the drawings or in the technical product documentation.

If there are separate areas with obviously different surface texture, the parameter values that are determined on each area shall be used separately for comparison with the requirements specified on the drawings or in the technical product documentation.

For requirements specified by the upper limit of a parameter, those separate areas of the surface shall be used which appear to have the maximum parameter value, i.e. if an upper limit is defined for Ra , the measurements shall be performed in the separate area which appears to be most rough.

For requirements specified by the upper limit of a parameter, the surface is considered acceptable if not more than 16% of all the measured values of the selected parameter, based upon an evaluation length, exceed the value specified on the drawings or in the technical product documentation. To designate the upper limit of the parameter, the symbol of the parameter shall be used without the "max" index.

For requirements specified by the maximum value of the parameter during inspection, none of the measured values of the parameter over the entire surface under inspection shall exceed the value specified on the drawings or in the technical product documentation. To designate the maximum permissible value of the parameter, the "max." index has to be added to the symbol of the parameter (for example $Ra \text{ max.}$).

EN ISO 4288 lists a series of basic rules for measuring roughness profile parameters, e.g.

- Determination of cut-off wavelengths (reference lengths) according to specifications – or lack of specifications - on the drawings or in the technical product documentation.
- The work piece shall be positioned so that the direction of the section corresponds to the maximum values of the height of the roughness parameters (R_a and R_z). This direction will be normal to the lay of the surface being measured.

Finally, EN ISO 4288 contains some useful annexes; especially annex A with the title “Simplified procedure for roughness inspection”. At first annex A emphasized the prerequisites for using the simplified procedure, Thereupon it states:

- Where the indicated parameter symbol does not contain the suffix “max” initially, the surface will be accepted and the test procedure stopped if
 - the first measured value does not exceed 70 % of the specified value (indicated on the drawing);
 - the first three measured values do not exceed the specified value;
 - not more than one of the first six measured values exceeds the specified value;
 - not more than two of the first twelve measured values exceed the specified value;

otherwise the work piece is to be rejected. Sometimes, for example before rejecting a high-value work piece, more than 12 measurements may be taken, for example 25 measurements with up to four exceeding the specified value

- Where the indicated parameter symbol does contain the suffix “max”, usually at least three measurements are taken, either from the part of the surface from which the highest values are expected (for example where a particularly deep groove is visible), or equally spaced if the surface gives the impression of homogeneity.
- The most reliable results of roughness inspection are achieved using measuring instruments. Therefore, the inspection of critical details should be performed using measuring instruments from the very beginning.

EN ISO 3274 defines profiles and the general structure of contact (stylus) instruments for measuring surface roughness and waviness, enabling the International Standards EN ISO 4287 and EN ISO 4288 to be applied to practical profile evaluation. It specifies the properties of the instrument that influence profile evaluation and it provides the basics of the specification of contact (stylus) instruments (profile meter and profile recorder).

It is the authors’ experience that many bitter and costly disputes regarding the surface roughness of actual delivered process equipment could have been avoided if the acceptance criterion had been specified according to the “trinity” of the standards EN ISO 4287, EN ISO 4288 and EN ISO 3274. In addition, the control could have been performed easily and rapidly by use of the simplified procedure for roughness inspection given in annex A, EN ISO 4288.

Case History

In 1998 a new “green field” brewery was designed with scheduled construction start just after the turn of the millennium. More than 500 tanks were ordered in all sizes from large

fermentation tanks with a volume of about 600 m³ to small yeast propagation tanks of about 1-2 m³.

The thick-walled fermentation and bright beer tanks were ordered with the following surface quality:

- General process side: 2D, $Ra \leq 0.8 \mu\text{m}$
- All polished areas: $Ra \leq 0.6 \mu\text{m}$

The remaining tanks such as for example all the beer processing tanks were ordered with the following slightly more smooth surface quality:

- General process side: 2B, $Ra \leq 0.6 \mu\text{m}$
- All polished areas: $Ra \leq 0.6 \mu\text{m}$

There were no further specifications to the polishing work to be performed, i.e. the following list of questions which later on in the project became extremely relevant were not addressed in the contract:

- How wide a polishing belt was acceptable at weld seams?
- How many, how big and what total sum of repair polished areas was acceptable on the product contact surface of each piece of process equipment?
- What sort of polishing tools were acceptable? Were for instance scuffing wheels acceptable? Or were only abrasive belts with increasing fineness of grain (e.g. grit 80 → grit 150 → 220) acceptable?
- What subsequent control of the actual delivered surfaces was to be performed?

The contract had a passage that stated that “good craftsmanship in accordance with state-of-the-art was expected in all phases of the project”. However, at the time that the problem with the inadequate specification of the surface quality became evident for everybody involved in the project, that contract passage only helped to fuel an already very heated dispute.

The problem became serious when a few random checks of the polished weld seams in the fermentation tanks showed Ra reading in the interval 0.8-1.0 μm whereupon the brewery instructed the tank manufacturer to repair polish the weld seams to meet the specified surface roughness $Ra \leq 0.6 \mu\text{m}$. The tank manufacturer refused to do this, arguing that according to the EN ISO 4288 standard such a (costly) conclusion could not be made on the basis of only a few random checks. For statistic reasons, more measurements were required. Moreover, according to the same standard 16% of the measurements were allowed to be above the specified upper limit of 0.6 μm .

In response to the tank manufacturer’s refusal to perform the requested repair polishing of the weld seams, the brewery performed a large number of surface roughness measurements in all fermentation tanks and not only on the polished weld seams but also on the repair polished areas and the general process sides. The results were bad. The Ra readings for the polished weld seams were confirmed to be in the interval 0.8-1.0 μm . The same was the case for the repair polished areas. The Ra readings for the general process sides were above 1.0 μm for about one third of the total area whereas the rest of the process side area had Ra readings in

the interval 0.6-0.7 μm . A survey of the fermentation tanks technical documentation showed that the shells were made from coil material from the same steel mill but with four different charge Nos. All R_a readings above 1.0 μm were traced back to one charge No.

As a consequence of these bad results, the brewery decided to perform a large number of surface roughness measurements on many tanks delivered from different manufacturers from several Western European countries. The results were shocking. It was no big surprise that many polished weld seams and repair polished areas did not meet the specified surface roughness $R_a \leq 0.6 \mu\text{m}$ but it was not expected that the same was the case for practically all the 2B process sides. How could this happen when the brewery had contracted many different tank manufacturers who again had purchased stainless steel coils/sheets/plates from different steel mills?

It was straightforward to conclude that the quality control at the tank manufacturers had been very poor. It seemed like the tank manufacturers were confident that if just the weld seams looked "alright" then these would not be subjected to any further on-site control such as for instance surface roughness measurements. It was likewise incomprehensible to experience that none of the tank manufacturers had an adequate receiving inspection program for controlling the surface roughness of the stainless steel deliveries from the steel mills. As expected, all tank manufacturers postulated that they had made a few spot checks with acceptable results. However, for the brewery it was evident that if this really was the case then the term "few" should be taken very literally. In fact, it seems like everybody in the business expected a 2B finish having a R_a value of about 0.3-0.4 μm for which reason there was no reason to make a big deal out of this issue and spend costly time on surface roughness measurements.

Afterwards, the brewery and all other parties involved in the project realized that they were victims of primarily their own naivety but also of a change of procedure that all the leading West European stainless steel mills apparently implemented simultaneously just before the turn of the millennium. Until then it had been common practice that a 2B finish was delivered with a cold-rolled, bright finish according to ASTM A 480 / A 480M [6]. After the change of procedure, a 2B finish was delivered with a cold rolled, heat treated, pickled and skin passed finish according to EN 10088-2 [7]. This was a natural consequence of the fact that in the leading countries in Europe the new common harmonized EN standards had replaced the old national standards.

The definitions of the two types of 2B finishes appeared to be very much the same so what was the difference? A closer investigation into this matter revealed that a 2B finish ordered according to the "old" ASTM A 480 / A 480M standard always had received a final light cold-rolled pass on polished rolls whereas this was not an integrated procedure for the 2B finish ordered according to the "new" EN 10088-2 standard. Consequently, the hard lesson was that a possible R_a acceptance criterion shall be stated explicitly when a 2B finish is ordered according to EN 10088-2. This is likely to cost extra compared to the default 2B finish but otherwise there is no right to complain. In this context it should be stressed that from a legal point of view this is the same for a 2B finish ordered according to ASTM A 480 / A 480M. It might be common practice that a 2B finish is delivered with a R_a value of about 0.3-0.4 μm but it is the steel mill itself that decides when a polished roll is sufficiently smooth. Therefore there is no right to complain if the R_a value of a delivery is higher than usual.

The brewery took the principle decision that no tanks were accepted if the surface quality was in conflict with the criteria specified in the contract. This was indeed a double-edged decision as the contract lacked details about the polishing work to be performed. After a short time the tank manufacturers realized that there was no way to lower the Ra value of a 2B surface finish without changing the surface condition/treatment. However, the solution was straightforward as the contract had no limitations about how many, how big and what total sum of repair polished areas was acceptable on the product contact surfaces of each piece of process equipment. Despite the considerable expenses, the only feasible way to fulfil the contract was to “repair” polish the entire process sides to $Ra \leq 0.6 \mu\text{m}$. Moreover, since the contract had no limitations about the sort of polishing tools that were acceptable, the majority of polishing work was carried out with scuffing wheels instead of abrasive belts with increasing fineness of grain. Figures 7-8 show the topography of a polished surface photographed in a scanning electron microscope (SEM). The initial surface quality was a 2B surface that subsequently was polished with a scuffing wheel.

The overall result was that the tank manufacturers lost an awful lot of money and that the brewery did not get the tanks with the intended process sides, 2B and $Ra \leq 0.6 \mu\text{m}$. Instead the tanks were delivered with a scuffing wheel mechanically polished surface, $Ra \leq 0.6 \mu\text{m}$. With respect to hygiene and corrosion resistance, it is the authors' intuitive conclusion that this was hardly a successful result, see how the topography changes from figures 1-2 (2B) to figures 3-4 (polished with abrasive belts) to figures 7-8 (polished with a scuffing wheel).

Conclusion

In the routine task of specifying new process equipment in the brewery, dairy and pharmaceutical sectors, the challenges related to specifying the surface treatment and finish including a control procedure and an exact accept criterion is often handled quite vaguely. This article reviews the standards, guidelines (e.g. ASME BPE-2007, 3-A SSI, EHEDG, EN, ISO) and sector-typical requirements that are used for this purpose. The conclusion is that ASME BPE-2007 is the best standard available. Still the standard has some shortcomings for which reasons it is advisable to specify some additional requirements when new process equipment is to be ordered.

One recurring problem is that the required surface quality is often specified in a non-measurable way (e.g. polishing to grit 220). In these cases it becomes irrelevant that there is also a wide ignorance as to the exact meaning of the specified accept criterion, for instance the difference between a maximum (e.g. $Ra \text{ max. } 0.6 \mu\text{m}$) and an upper (e.g. $Ra \leq 0.6 \mu\text{m}$) surface roughness limit. This article gives a thorough introduction to this problem and gives a few simple recommendations about how to deal with this issue.

Systematic control of the surface quality of the actual delivered process equipment is quite often omitted. This is partly for pure economical reasons as the control procedure represents an expense and partly because many decision makers do not understand the need for control and/or do not know how to specify, undertake and evaluate the control results, e.g. surface roughness measurements. The latter is of course also quite a challenge if there is no specified accept criterion. A typical example is repair polished areas (e.g. after external welding of leg support to a tank) to which the decision makers only in very rare instances remember to specify an accept criterion. By means of a case history the paper describes some often occurring problems and disputes related to the subsequent control of the actual delivered surfaces.

References

1. ASME Bioprocessing Equipment, ASME BPE-2007
2. 3-A Sanitary Standards and 3-A Accepted Practices:
 - a. Doc. No. 01-07 "Storage tanks for milk and milk products"
 - b. Doc. No. 02-09 "Centrifugal and positive rotary pumps for milk and milk products"
 - c. Doc. No. 33-01 "Polished metal tubing for milk and milk products"
 - d. Doc. No. 12-05 "Tubular heat exchangers for milk and milk products"
3. EHEDG Guidelines:
 - a. Guideline No. 8 "Hygienic equipment design criteria, 2004"
 - b. Guideline No. 19 "Passivation of stainless steel, 1998"
4. EN ISO Standards
 - a. EN ISO 4287 (1998) Geometrical product specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters (ISO 4287: 1997)
 - b. EN ISO 4288 (1997) Geometrical product specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture (ISO 4288: 1996)
 - c. EN ISO 3274 (1997) Geometrical product specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments (ISO 3274:1996)
5. ASTM A 480 / A 480M - 01; "Standard Specification for General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip"
6. EN10088-2:1995; "Stainless steels. Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes"

TABLE 1
Ra readings for product contact surfaces, ASME BPE-2007

Surface Designation	Mechanically polished (Note 1)	
	<i>Ra</i> max	
	$\mu\text{in.}$	μm
SF0	No finish requirement	No finish requirement
SF1	20	0.51
SF2	25	0.64
SF3	30	0.76
	Mechanically polished [(Note 1)] and Electropolished	
	<i>Ra</i> max	
	$\mu\text{in.}$	μm
SF4	15	0.38
SF5	20	0.51
SF6	25	0.64

General Notes:

- A. All *Ra* readings are taken across the lay, wherever possible
- B. No single *Ra* reading shall exceed the *Ra* max value in this table
- C. Other *Ra* readings are available if agreed upon between owner/user and manufacturer, not to exceed values in this table

Note 1: Or any other finishing method that meets the *Ra* max

TABLE 2
Examples of 3-A standards including acceptance criteria for the surface finish

3-A document No.	Equipment	<i>Ra</i> max
01-07	Storage tanks for milk and milk products	32 $\mu\text{in.}$ (0.80 μm)
02-09	Centrifugal and positive rotary pumps for milk and milk products	32 $\mu\text{in.}$ (0.80 μm)
33-01	Polished metal tubing for milk and milk products	32 $\mu\text{in.}$ (0.80 μm)
12-05	Tubular heat exchangers for milk and milk products	32 $\mu\text{in.}$ (0.80 μm)

TABLE 3
Examples of EHEDG guidelines including acceptance criteria for the surface finish

EHEDG Guideline No.	Title	<i>Ra</i> values
8	Hygienic equipment design criteria, 2004	$Ra \leq 0.8 \mu\text{m}$
18	Passivation of stainless steel, 1998	N/A

TABLE 4
Surface treatments of stainless steel and resulting surface topography, EHEDG

Surface treatment	Approx. <i>Ra</i> values (µm)	Typical features of the technique
Hot rolling	> 4	Unbroken surface
Cold rolling	0.2 - 0.5	Smooth unbroken surface
Glass bead blasting	< 1.2	Surface rupturing
Ceramic blasting	< 1.2	Surface rupturing
Micropeening	< 1	Deformed (peened) surface irregularities
Descaling	0.6 – 1.3	Crevices depending on initial surface
Pickling	0.5 – 1.0	High peaks, deep valleys
Electropolishing		Rounds off peaks without necessarily improving <i>Ra</i>
Mechanical polishing with aluminium oxide or silicon carbide		Surface topography highly dependent on process parameters, such as belt speed and pressure.
Abrasive grit number		
500	0.1 – 0.25	
320	0.15 – 0.4	
240	0.2 – 0.5	
180	= 0.6	
120	= 1.1	
60	= 3.5	

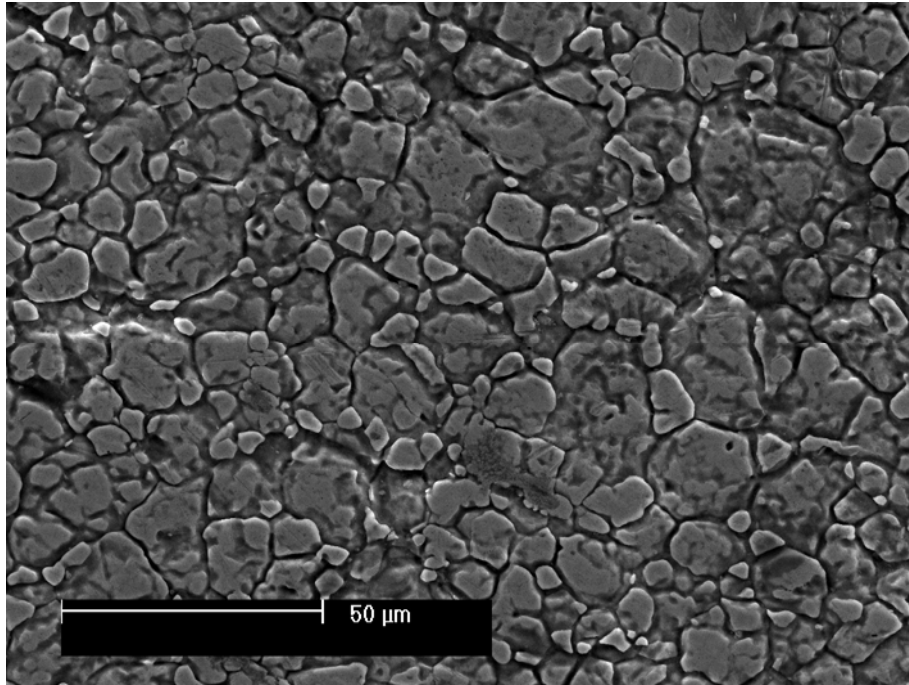


Figure 1: SEM Photo, AISI 316L coil material, WT 1.6 mm, 2B finish according to EN 10088-2 (cold rolled, heat treated, pickled and skin passed), $Ra \approx 0.48 \mu\text{m}$

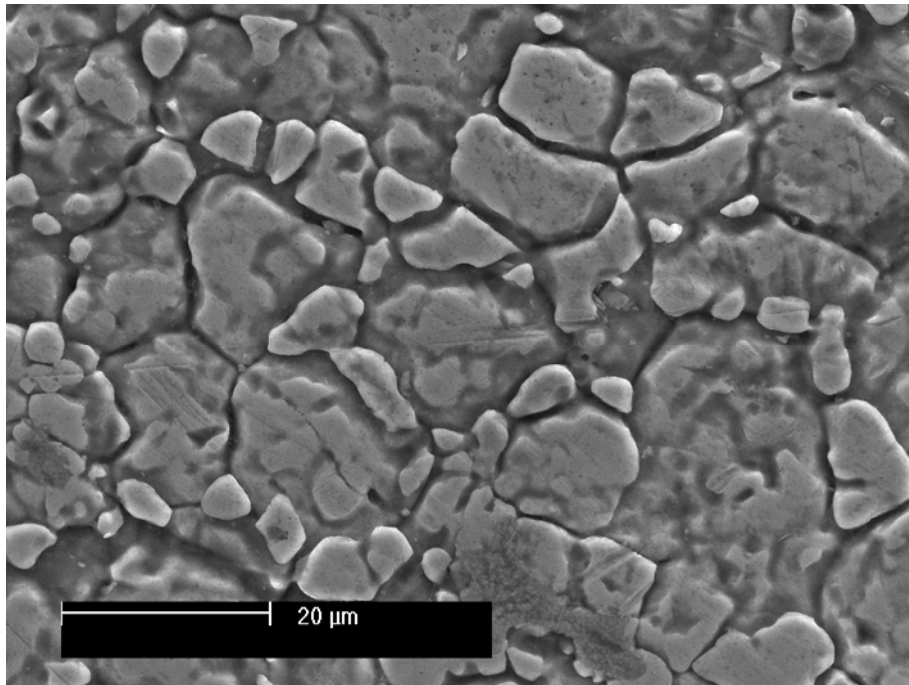


Figure 2: Close-up of figure 1

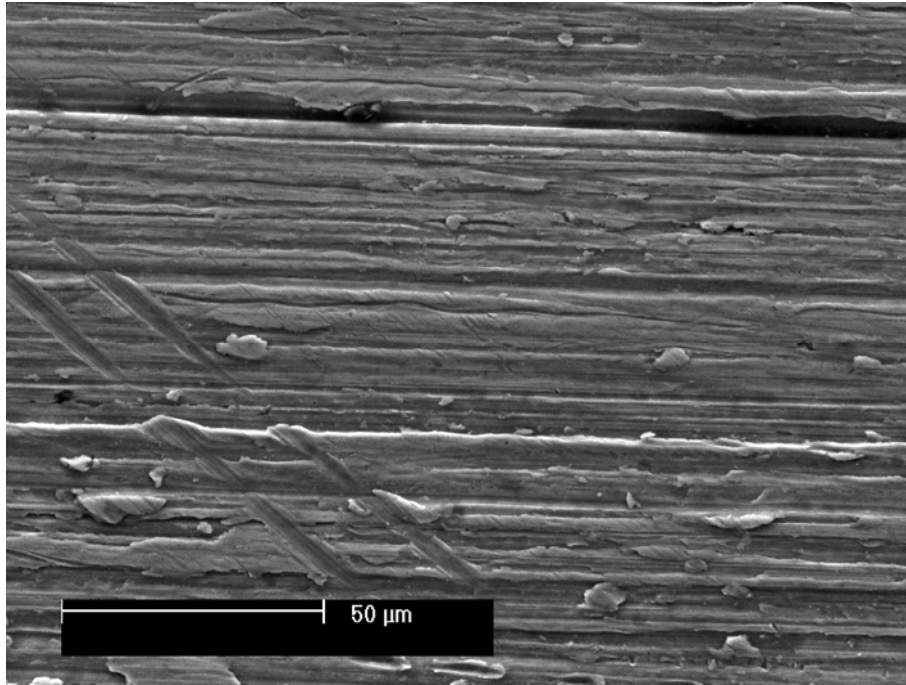


Figure 3: SEM Photo, AISI 316L coil material, WT 1.6 mm, 2B finish (see figure 3) polished with abrasive belts (grit 80 → grit 120 → grit 180), $Ra \approx 0.54 \mu\text{m}$

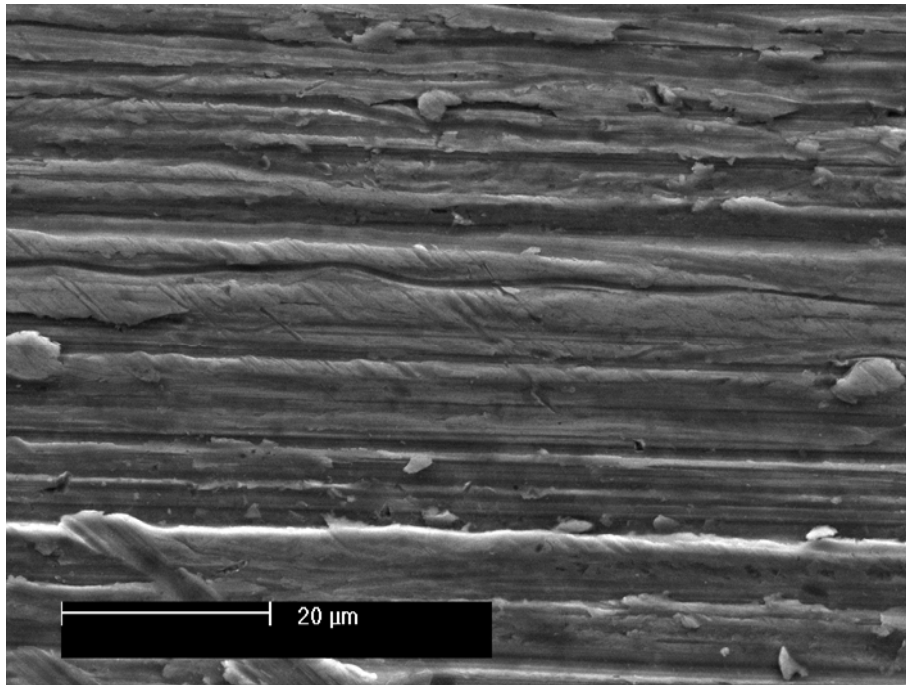


Figure 4: Close-up of figure 3

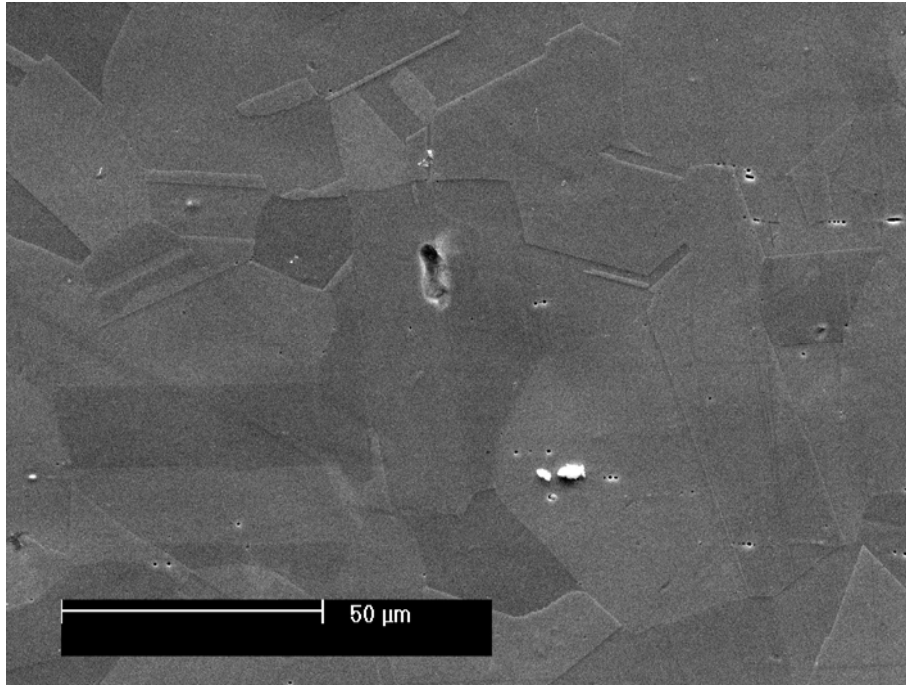


Figure 5: SEM Photo, AISI 316L coil material, WT 1.6 mm, Electropolished, $R_a \approx 0.21 \mu\text{m}$

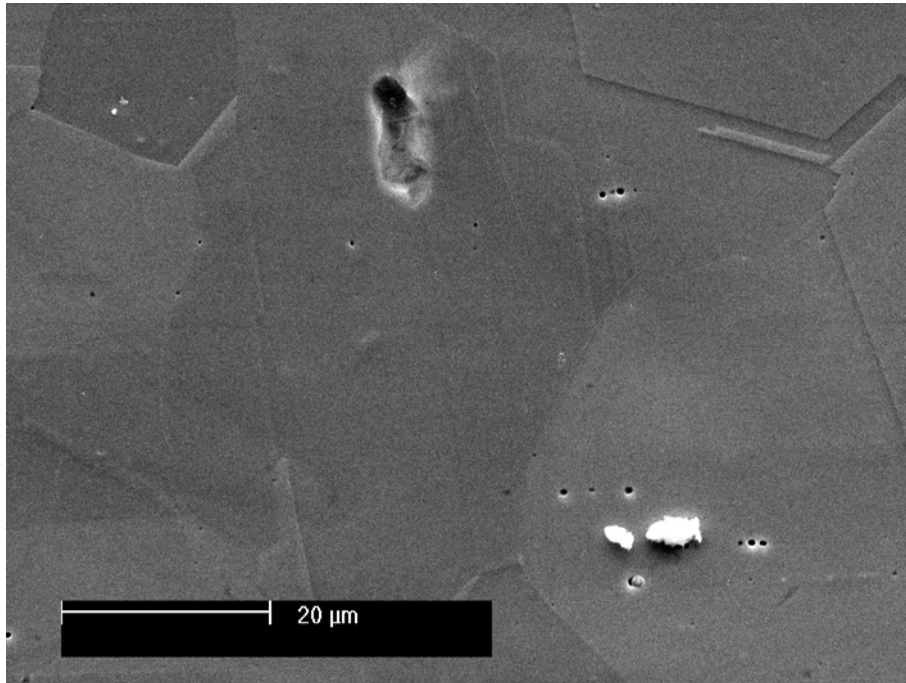


Figure 6: Close-up of figure 5

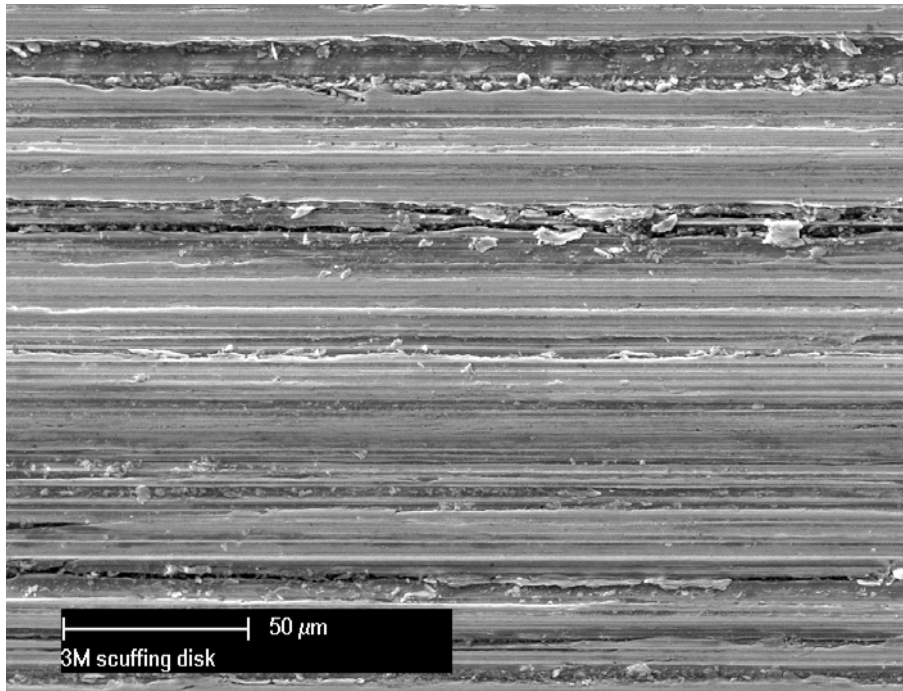


Figure 7: SEM Photo, AISI 316L coil material, WT 1.6 mm, 2B finish (see figure 3) polished with a scuffing wheel, $Ra \approx 0.51 \mu\text{m}$

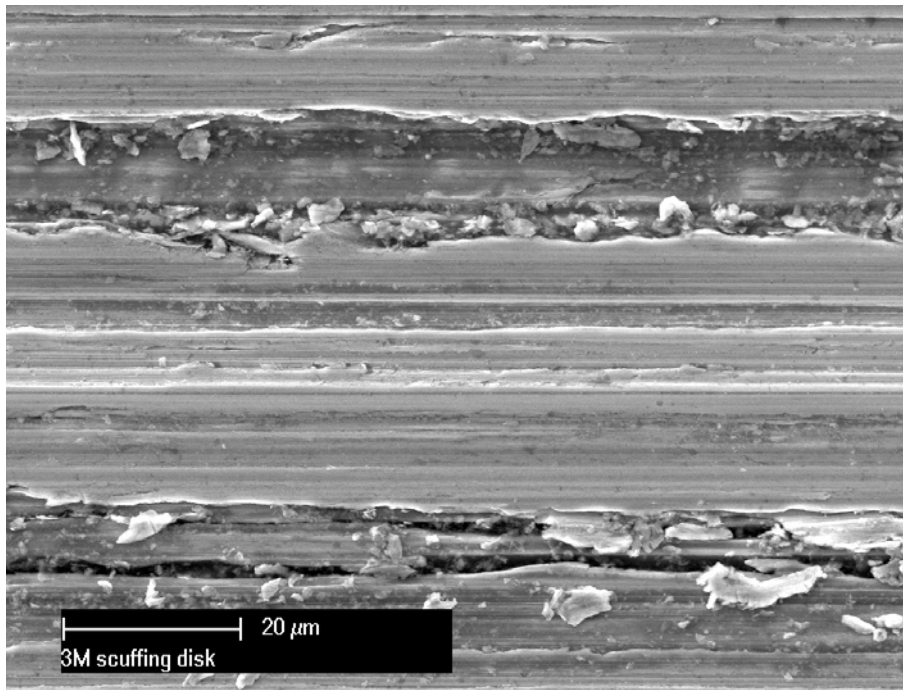


Figure 8: Close-up of figure 7