

The optimisation of stainless steel surfaces

Over the decades researchers have searched for optimal and efficient techniques to adequately recondition the surface of stainless steel after it has been subjected to various processes. This article examines the various processes currently used and the surface conditions achieved. An independent study has shown that water jet blasting may offer the best solution in terms of both the degree of smoothness achieved and the avoidance of using chemical products.

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Welding is one example of a process that results in the need for surface treatment in stainless steels. Tarnishing caused by welding and heat treatments must be thoroughly removed because such zones and surfaces are microporous as the darkened areas, making it easy for aggressive chlorides to penetrate. A normal healthy oxide layer is only 10 to 15 nanometres thick and consists of several ultra-thin layers. These layers will swell during the oxidation process. Due to the mutual differences in expansion coefficient, these layers will cause extra microporosity in temperature variations. Moreover, the underlying metal is more burned chrome than iron, also resulting in reduced corrosion resistance. In other words, tarnishing caused by welding and/or atmospheric glowing should always be removed, especially if the area shows signs of corrosion afterwards. Reconditioning aims to obtain sufficient corrosion resistance of the stainless steel surface.

Pickling and passivation

One of the best known surface treatment methods is pickling and passivation, which has proven to be a good solution over the years. During pickling and passivation the damaged, burned, and/or contaminated oxide layer is stripped away in order to be built up again; in other words passivation occurs. Although this method is a good solution to restore weakened chromium oxide film to optimum condition, there are also drawbacks. Apart from the environmental impact, the process often required the goods to be sent to specialised pickling companies, which is disruptive to the internal logistical production flow of the manufacturing companies. This has prompted companies to look for alternatives and

the development of mechanical grinding or the use of glass bead blasting. These operations, however, typically provide a surface condition which is not suitable for food applications. In time ceramic bead blasting was developed, which provides a better result as the ceramic pellets last much longer than glass. Glass beads shatter sooner, causing sharp edges which are detrimental to the surface condition. All these methods are designed to treat the material to achieve acceptable corrosion resistance.

Polishing

More specialised methods are anodic and electro-polishing, which create a particularly smooth, high-quality oxide layer. In addition, during this process, more iron atoms disappear than chromium and nickel atoms, which results in a better corrosion resistance. The positive potential of the oxide layer is almost twice as high during electropolishing. This decreases again with respect to an as-delivered finish slightly when grinding or glass bead blasting is applied to the surface. This is because of the rough surface that is created and the negative impact of dirt deposits which then lead to an 'under deposit attack'. This is a form of corrosion that takes place under dirt deposits, particularly in the presence of chlorides. Chlorides can penetrate deeper under dirt deposits than the relatively large oxygen molecules, which eventually compromise the material. Chlorine is one of the halogens and these are salt-formers. Stainless steel actually needs oxygen to maintain its passivity, but under dirt deposits there is insufficient oxygen present for this to occur. Therefore, stainless steel is not maintenance-free and has to be cleaned regularly. It will become clear that

polished surfaces have an advantage because the chances of contamination that may occur will be considerably smaller. Therefore, the corrosion resistance of a wet blasted surface is better than that of the original semi-finished product, but it is somewhat lower than in case of electro-polishing.

The surface condition

The corrosion resistance of stainless steel is not only dependent on the type of alloy, but also on its surface condition. For example, a parking pole constructed of AISI316 stainless steel at a beach will corrode because of marine aerosols. However, this deterioration only occurs on the vertically arranged grinded pipe while the polished cap of the same alloy remains in excellent condition. This proves that grinding has a negative influence on the corrosion resistance, although this effect decreases if one uses a finer abrasive grain. Pickling is often still an ideal compromise in terms of capability and size. Moreover, it is advisable to leave pickling to specialised companies because the chemicals pose health risks to humans and the environment. Companies operating pickling lines must comply with stringent rules to avoid putting their employees at risk of injury, both internally and externally.

About the author

Ko Buijs is a recognized metallurgical/corrosion specialist for stainless steels as well as special metals. He is also a lecturer for several organizations such as stainless steel associations, Technical High Schools and innovation centres. He has published over 150 papers in a number of technical magazines.



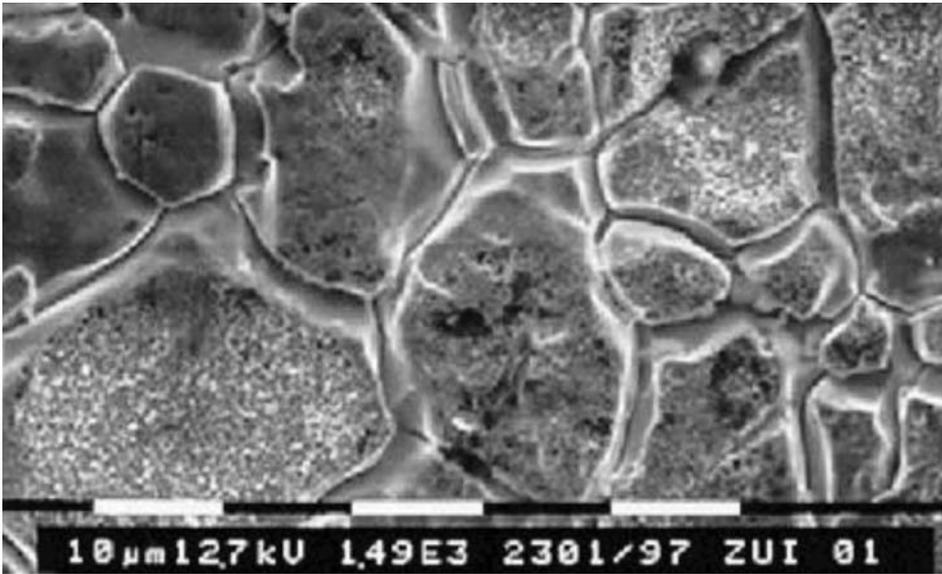


Figure 1. Pickled stainless steel AISI 316 ($V=1500\times$) whose grain boundaries are affected preventively (source Dockweiler).

It will become clear that these measures complicate the business process. However, the motivation to keep products in-house provides benefits such as not disturbing the internal logistics and saving on transportation costs. It is also of great importance that staff in the pickling plant are equipped with the right media, parameters, and inhibitors in order to avoid, for example, over-pickling. A particular risk is that the less resistant grain boundaries can be compromised relatively quickly, leading to a roughening of the surface. In Figure 1, one can see a clear preferential degradation of the grain boundaries in austenitic stainless steel. It goes without saying that these grain

boundaries provide space for all kinds of contamination and microbial deposition. This latter can quickly lead to the dreaded microbially induced corrosion (MIC) and other bacterial 'infections'. Therefore, the eye is not always the optimal instrument to assess an indicative roughness because many rough areas are not always visible to the naked eye. Generally, one can argue that a cut surface is 2.5 to 4 times larger than a polished surface. It is important that a surface is smooth, but also not too smooth; when the surface roughness is below $R_a = 0.2\ \mu\text{m}$, accelerated bacteriological contamination may arise because the adhesion forces between the surface and bacteria have become larger. This can



Figure 4. The right half is treated with the PureFinish process (photo Rösler).

be seen schematically in Figure 2, where the degree of ability to clean is displayed in dependence of the roughness of the surface. In other words, the rule "the smoother the surface, the better the ability to clean" does not always seem to be true in practice, when it concerns bacteria and micro-organisms. Figure 3 shows how this removal of bacteria on a surface takes place schematically.

A topographical survey by TNO showed that the glass bead blasting delivers a particularly rough surface. Such a surface was found to have an average roughness of about $R_a = 1.3\ \mu\text{m}$. A surface treated by wet blasting, however, reached a value of 0.25 and $0.60\ \mu\text{m}$.

Water jet blasting

In recent years the method of water jet blasting with an abrasive additive has received quite some attention and it is expected that this surface treatment will be increasingly used because one can achieve interesting benefits. For example, the company Rösler has

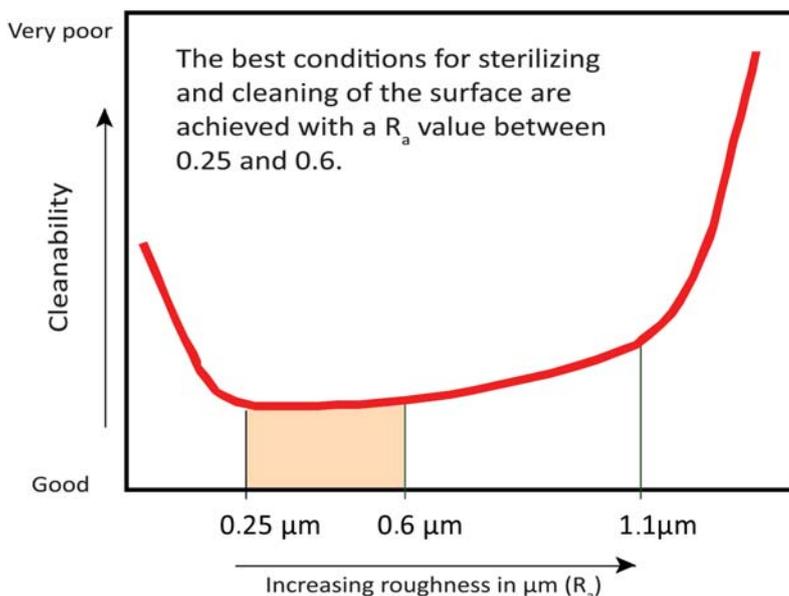


Figure 2. The cleaning of stainless steel is best done with a roughness of between 0.25 and $0.6\ \mu\text{m}$ (source Leser Hamburg).

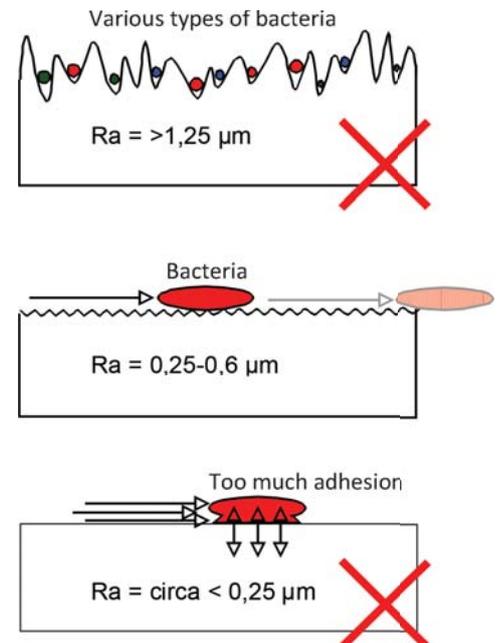


Figure 3. When a surface is too smooth bacteria are difficult to remove due to vacuum and adhesion (source Leser Hamburg)



Figure 5: Housing of a “rotating clean flow” (source Goudsmit).

treated parts for the aviation sector with water jet blasting with an added spheroidal abrasive agent for many decades; for convenience, they call this process – including the medium used - ‘PureFinish’. Customers such as Rolls Royce and Airbus prefer this surface treatment. The water with additive forms a suspended medium which is sprayed at pressure onto the surface. This results in an attractive finish and also creates a certain pressure build-up on the surface; this is also known as “peening”.

The idea arose to also use this finishing technique for the improvement and reconditioning of stainless steel with the aim of achieving a more hygienic and easy-to-clean surface. Furthermore, the abrasive action of the additives means that this process can replace pickling and passivation, because it also removes discoloration and oxidations that are the result of welding or heat treatment. This can easily be seen in Figure 4, where the half of the part has not been taped during this treatment. However, certain conditions must be met in order to achieve good results.

Independent research carried out by TNO determined interesting facts on the basis of an SRI provision. SRI stands for Soil Retention Index and this value gives practical information on how many contaminants remain on the surface after a cleaning process. From this provision it appears that the said surface meets all requirements in terms of hygiene and ability to clean, demanded by the EHEDG for the purpose of serving food and the pharmaceutical industry. This reproducible SRI value even surpasses the existing surface technique, which

is partly explained because the roughness is between 0.25 and 0.60 μm and that appears to be ideal to obtain such results (Figure 2). The European Hygienic Engineering & Design Group (EHEDG) demands a roughness of $R_a \leq 0.8 \mu\text{m}$ and the surface amply meets these requirements. Figure 7 shows a housing of a “rotating clean flow” of AISI316 stainless steel before and after treatment with PureFinish.

In collaboration with customers Rösler’s laboratory carried out the necessary tests to identify the optimum process parameters. For example, one can choose what type of water you want to work with. Options range from ordinary tap water to water that has been treated with deionised or reverse osmosis. Drinking water can sometimes contain a relatively high content of chloride, which can lead to staining as soon as

the oxide skin is stripped. Chlorine is one of the halogens or salt formers that want to form metal salts and this is the explanation for the formation of a stain. This then calls for the use of demineralised water.

The benefits of this surface treatment are:

- Defined, homogeneous and reproducible surface structure which also has a higher overall resistance to corrosion;
- High resistance under ‘deposit attack’;
- It can replace pickling and passivation which often must be done by specialised companies;
- Discoloration, coarsening and heavy oxidations caused by the welding process are removed;
- A very easy to clean surface that meets sanitary and aseptic requirements;
- Hardly any tiny spots where food residue can remain behind;
- Shorter cleaning times which improves the production yield;
- Light pressure build-up on the surface which reduces the risk of stress corrosion cracking;
- Microscopic fine notches in the surface, which are also called artefacts are ‘hammered’ closed;
- No deformation because the material remains cool during the treatment, in contrast to glass-bead blasting. In particular, austenitic stainless steel has a high coefficient of expansion, thus deforms quite quickly as soon as the temperature rises only slightly, as is the case with bead blasting;

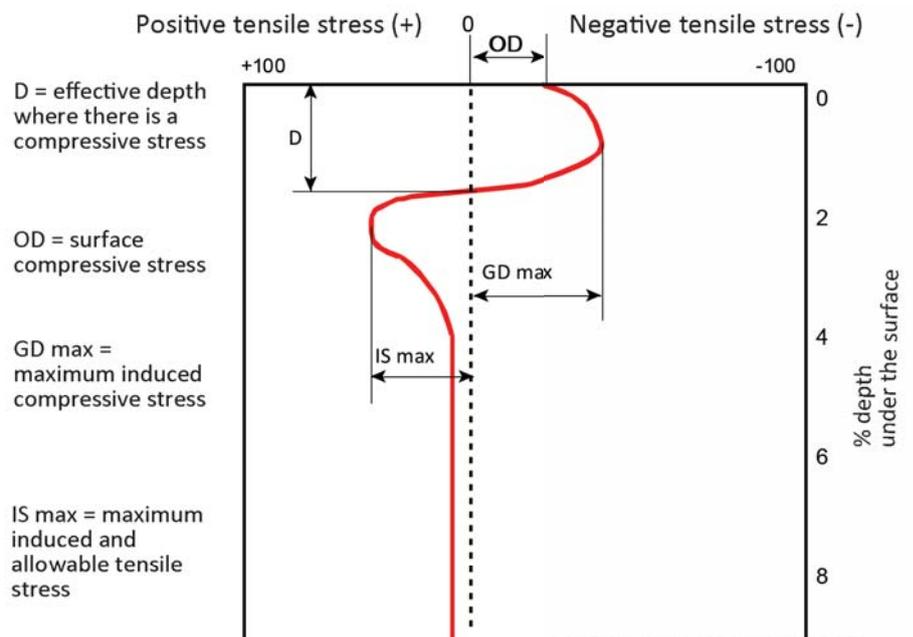


Figure 6: Schematic representation of pressure build-up on the surface.

[SURFACE FINISHING]

- Surface is hydrophobic, thus producing less adhesion of moisture and other substances;
- PureFinish installations can be integrated into existing production lines with the customer;
- The water film somewhat protects the surface against hard impacts of the abrasive agent which is beneficial to the quality of the corresponding surface;
- Significantly less environmental impact, since it means one is basically working without chemicals;
- The process is easy to mechanise or robotise; one can even scan the geometry of a part and, after conversion, control the process by computer. The great advantage of this unmanned work is that the human factor, with all its limitations, for a large part is removed.

As stated, the pressure build-up in the surface will lead to a decrease in the stress corrosion cracking susceptibility of austenitic stainless steel. This form of corrosion occurs in stainless steels due to a combination of mechanical tensile stress, elevated temperature ($> 40^{\circ}\text{C}$) and the presence of chlorides. The result is a dangerous form of trans-crystalline corrosion which is difficult to detect. The material can suddenly fail, potentially with serious consequences. For example, in swimming pool environments deaths and injuries have been caused by stainless steel suspension systems suddenly failing. If one can apply a



Figure 7: A closed PureFinish system (source Rösler)

compressive stress on the surface, such as during the PureFinish process, the degree of compressive stress will reduce the tensile stress. This is shown graphically in Figure 6. One of the few disadvantages of the PureFinish process is that one must work in a very clean manner during the production of the stainless

steel components. This is because, for example, iron contamination in the stainless steel surface will be insufficiently removed during this treatment. The presence of these particles can be the result by the usage of, for example, steel tools, folding machines, etc. During pickling, these particles will probably disappear, provided that they are not too far into the surface due to the anodic formation of such contaminations.

This means, for example, that the press brake knives must be fitted with a tape to prevent iron absorption. If this is not easy to control, then one will have to acidize the critical places for the water jet process so to remove the free iron as much as possible. The saying 'prevention is better than cure' also applies here.

Another disadvantage is that the process generates a lot of noise (around 80 dB) and one has to take measures concerning this. However this noise is reduced to an acceptable level when using a closed blasting cabinet.

The equipment

There are blasting cabinets which are operated at a comfortable height with a working area of 700 x 700 mm up to

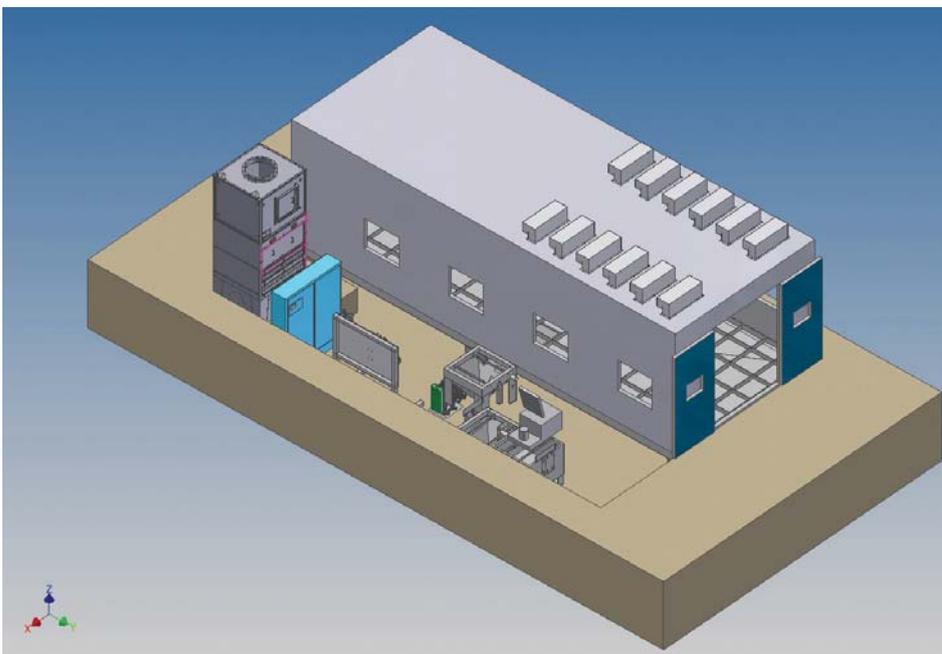


Figure 8: A closed PureFinish system 10 x 4 meters (source Rösler).

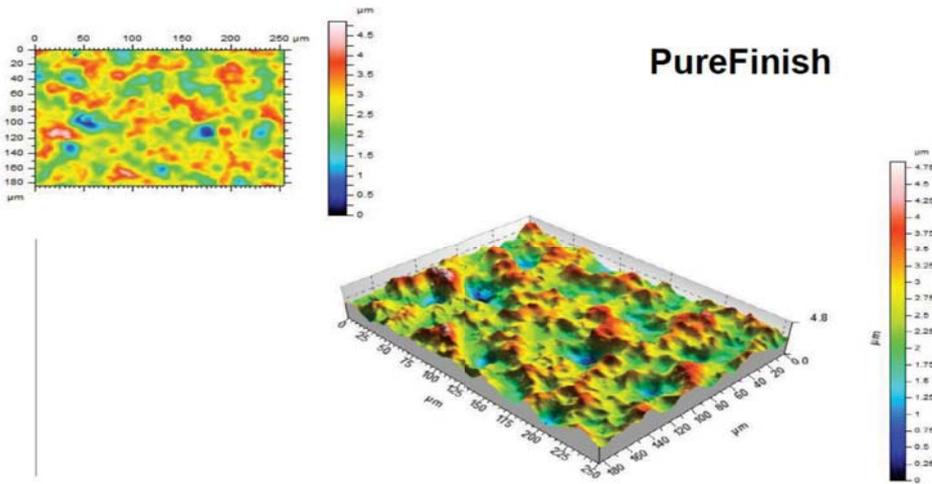


Figure 9: Topographical images of a PureFinish surface in thousands of millimetres (source TNO)

2000 x 2000 mm (Figure 7). Open and closed systems can vary concerning workspace, from between 6,000 x 4,000 up to 10,000 x 8,000 mm (Figure 8). The spray nozzles are available in various diameters. The shape of the beam is determined by the nozzle shape and that is of great importance in order to get a good distribution of the abrasive, which gives a uniform finishing of the surface. We are working with a lightly elevated pressure so that the operator can manually work quite easily. All systems feature a closed water system and, thanks to a sophisticated recycling system, water and abrasive consumption is kept to a minimum.

The SRI value

The Soil Retention Index is a test developed by TNO that measures the attachment and detachment of

a particular protein on a stainless steel surface. The method takes into account the amount of open spaces in the deeper portions of the roughness, creating a new defined value. It is the value resulting from the multiplication of the number of peaks, the percentage of open spaces in the valleys and the average surface roughness. It goes beyond the average roughness value which cannot always explain a particular attachment behaviour. SRI provision forms the basis for describing and assessing the ability to clean a surface to the microbial level, and thus provides an important indication as to what extent, after a certain cleaning, unwanted substances were left behind on the surface. Therefore, this parameter provides, in practice, the best relationship between surface structure, contamination and ability to clean.

Reliance on the roughness value only indicates the average roughness and produces virtually no absolute information about highs and lows on the surface. The lower the SRI value, the lower the shear forces to clean the surface, which plays an extra role when the surface needs to be cleaned on site in a guaranteed manner; the so-called "Cleaning In Place" (CIP). In Figure 9 is a topographic survey in thousands of millimetres of a PureFinish surface designed by TNO. On such a small scale one sees a hilly landscape, so to speak, which is created by this treatment.

If we made a recording of a glass bead blasted surface, it would look like an Alpine region.

Figure 10 shows the clear difference between a 2B finishing and PureFinish surface with regard to the remnants of contamination. On a cut or blasted surface, however, these values are even worse than with a 2B finishing. Hence the latter finishing is not as good compared to PureFinish. 2B is a standard finishing on the market for cold rolled sheet which, in itself, feels very smooth. Therefore, it is TNO's conclusion that such a surface offers the best opportunity to rid a surface area of undesirable substances in the most optimal way.

Passivation

As stated earlier, one can achieve an excellent passivation of the surface at the end of the water jet process due to the oxygen in the air. However, this means that the material should have some time to form a new oxide layer of the desired thickness (10 to 15 nm). This new oxide layer, moreover, is formed immediately during the blasting process, but the final thickness is reached after approximately 4 hours. It is of great importance that people to not touch the material during this time, in order to prevent fingerprints. Besides the fact that those would be unattractive spots in those places, it also undermines the corrosion resistance. One can measure the increase in passivity by means of a so-called Oxyliiser. A surface which has just been treated is in a passive condition but it is not yet in its optimum condition. If one does not have the time to wait 4 hours then an oxidative agent can be used; this is usually a solution of nitric acid.

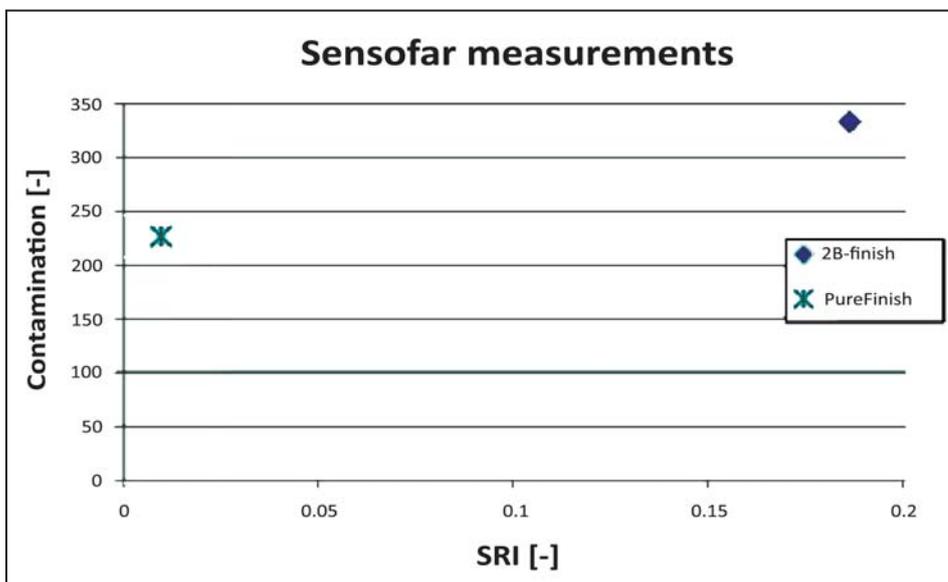


Figure 10: Contamination measurements SRI vs. Ra (source TNO)

For more information: www.innomet.nl and info@innomet.nl