How Clean is Clean? Defining Acceptable Cleanliness Levels.

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Abstract

A key to surface finishing is a "properly" prepared surface. Defining and maintaining the surface preparation at "proper" levels is at best subjective. Often the failure of surface preparation processes is not discovered until problems, such as poor adhesion, occur down stream resulting in non-conformance due to poor surface cleanliness. To assure consistent quality of surface cleanliness, it is important not only to specify a desirable level of surface cleanliness but also to specify a method of cleanliness verification for that level to have meaning.

This generally leads to the question, what do we mean by "clean"? How clean is "clean"? Even so called clean parts have a certain amount of contamination, even if it is microscopic level. With advances in technology, more and more applications are moving towards the need for higher levels of cleanliness. Hence it is important to select an appropriate surface cleanliness verification technique. This paper will discuss various methods available for monitoring surface cleanliness, their advantages and disadvantages, criteria for selecting an appropriate technique, approaches to establishing an acceptable level of cleanliness including optimum cost approach and introduce Optically Stimulated Electron Emission (OSEE) for quantitatively measuring surface cleanliness. Some typical OSEE application results will also be discussed.

Introduction

Surface cleanliness is becoming a major issue for more and more applications in industry as customers demand higher and higher quality and performance from products. In the march towards achieving this goal, manufacturers are faced with several issues, such as how to measure surface cleanliness, what are the choices available for monitoring techniques and how to define what is an acceptable level of cleanliness.

There are no national or international standards for acceptable level of cleanliness, as a result it is left up to each individual to define the acceptable level. In addition to presenting information on the most common surface cleanliness techniques, general approaches to help establish such limits are discussed herein.

Types of Contamination

There is several type of contamination that can be present on part surface that are undesirable for product performance. Some of the common types of contaminants are listed below.

> **Particle Contaminants -** Contaminants present in the form of foreign particles on the surface, such as dust, hair, fibers, and metallic micro-fragments.

Thin Film Contaminants - Contaminants present in the form of a thin film on the surface. This type of contamination includes both organic and inorganic thin film contamination, such as skin oil, greases, processing fluids, surfactant / chemical residues, rinsing residues, oxides and other unwanted thin films on surfaces.

Microbial Contaminants - Contaminants present in the form of microbes on the surface, such as spores, bacilli etc.

There are other types of contaminants, such as radioactive, heavy metal etc. Discussion of these types of contaminants is beyond the scope of this chapter. The primary focus of this paper is thin film contaminants.

Most common verification / measurement methods

All of the cleanliness verification/monitoring method can be categorized as Indirect Method, Direct Method or Analytical Method. Indirect method does not measure cleanliness directly from the surface of interest, whereas direct methods measure cleanliness directly from the surface. Both of these types of methods give a qualitative or quantitative measure of surface cleanliness and also do not identify the species i.e. the type of contamination. In contrast, analytical techniques are those that generally give a quantitative measure of surface cleanliness and identify the species of contamination. Analytical methods can be indirect or direct. Some of the most common indirect, direct and analytical methods are presented below. This list is by no means exhaustive but merely lists the most commonly used techniques.

Indirect methods - Most indirect methods of cleanliness measurement depend on a solvent of some type to dissolve any contaminants left on the part and the solvent is then analyzed for contamination. This requires that the solvent used be stronger than the solvent that was originally used in the cleaning process so it can remove any residual the original cleaning solvent was not able to remove. Historically, these methods use solvents that are the type many manufacturers are trying to eliminate from their cleaning processes. Recently, more environmentally benign alternatives have begun to be evaluated for this class of measurement methods.

Indirect methods that use solvents to extract contamination are usually only practical for small parts due to the large volume of extraction solvent that would be needed for larger parts. Still, this method can analyze larger parts than some direct methods, such as contact angle, where the parts must actually be able to fit in the equipment. Also, when extraction is used none of the geometric limitations exist as they do for contact angle and some other direct methods.

1. **Net Volatile Residue (NVR) -** This method uses a volatile chemical to flush the part. The container that is used to collect flushed chemical is weighed before collecting the chemical. The container is weighed again after the flushed chemical has volatilized. The difference in the before and after weight is the weight of the contaminant that was left on the part surface. The amount of contamination can be defined in units of weight or weight per unit area if the surface area of the flushed surface is known. NVR detects only organic contamination, it is cumbersome and not suited to measuring low levels of

contamination.

2. **Ultraviolet (UV) Spectroscopy -** This method has been used in the electronics industry to measure flux residue left on printed circuit boards, and has also been adapted to detect oils and greases on metal parts. This method requires the use of extraction equipment and an UV spectrometer, which are moderately expensive. In addition, the method requires that the contaminant to be analyzed has a unique absorption wavelength that can be identified in the ultraviolet spectrum. A calibration curve then is created by measuring samples of the solvent containing known concentrations of the contaminant at the unique wavelength. This curve can then be utilized for measuring contamination on unknown parts.

3. **Optical Particle Counter (OPC) -** Uses a light source to shine a beam of light through a flow channel. One method uses the blocking of light by the particles that pass through the light beam.. The blockage of light creates an electrical pulse that is proportional to the particle size. A microprocessor counts and sorts the pulses according to size. Light extinction can measure particles as small as one micron. Another method measures light scattering. This method is a more sensitive method that measures the light "scattered" by a particle as it passes through a light beam. Light scattering detects particles as small as 0.1 micron or even smaller but does not work for particles larger than about 25 microns. The sensitivity of OPC comes at a price. OPC is good only for particulate contamination.

Direct Methods (See Table 1) - Direct methods actually measure cleanliness on the part of interest by analyzing the surface of the part directly. Direct methods, therefore, avoid many of the problems inherent in collecting contaminants off the part to be analyzed indirectly. However, since the part is being analyzed directly, there may be a limitation on the size or geometry of the parts that can be checked with some direct measurement equipment. It is preferred, wherever possible, to measure the cleanliness of the part directly, since the inspected surface of the part is the one that is of direct interest.

1. **Magnified Visual Inspection -** Visual inspection using a magnifying glass or low-power microscope can be used to look at a part made of any material directly and observe any gross contamination that may not be visible to the naked eye but is still larger than the micron range. This is a subjective and labor intensive approach to checking surface cleanliness and is not suited to detecting low levels of contamination.

2. **Black Light -** This test requires a dark room and black light source for direct visual inspection of parts. This method is a pass / fail test that is useful in detecting any contaminant that fluoresces under black light, provided the part itself does not fluoresce. The operator simply places the part under the black light and visually inspects the part. Experience shows that the detection capability, even for the best operator, is limited to contamination of more than to10,000 angstroms. This level of contamination is generally too much for precision cleaning requirements. Therefore, this method is only good for detecting gross fluorescing contaminants. It is however a very low cost method.

3. **Water Break Test -** This simple method takes advantage of the fact that many contaminants of interest are hydrophobic. In this pass/fail test, which is typically used for metal surfaces, water is flowed over the part. If it sheets off the surface evenly, the part is "clean." If the water channels or beads on certain areas the part is rejected or sent for additional cleaning. It is a low cost, qualitative method that works well for detecting contaminants that are hydrophobic in nature.

4. **Contact Angle -** This method also takes advantage of the fact that most contaminants cause water to bead up due to their hydrophobic nature. The test is done by applying a distilled water droplet of reproducible size to the test surface. After waiting a couple of minutes for the drop to equilibrate, the droplet is examined using the goniometric technique and angle of contact the drop makes with the surface is recorded. A perfectly clean metal surface would have a contact angle of 0°, which is impossible to obtain in laboratory air. A contaminated metal part would have a high contact angle, such as 90° or more. Some parts, such as plastics, have positive contact angles even when "clean" so the method is not typically used for cleanliness analysis for these materials.

5. **Optically Stimulated Electron Emission (OSEE) -** A probe illuminates the surface to be tested with ultraviolet light of a particular wavelength. This illumination stimulates the emission of electrons from the metal surface. These electrons are collected and measured *as current* by the instrument. If the surface is clean, it gives high electron emission. If there is any organic or inorganic contamination it reduces the electron emissions and, therefore, the measured current. OSEE is probably the only technique that can detect both organic and inorganic contamination and can be adapted for on-line monitoring of surface cleanliness.

6. **Measurement and Evaluation of Surfaces by Evaporative Rate Analysis (MESERAN) -** This technique involves measurement of the rate of evaporation or desorption of an added radioactive high boiling material which is deposited onto the surface being tested and then monitored as it evaporates into the atmosphere. The greater the contamination on the surface the slower the observed evaporation. The radioactive material is very weak in nature and requires no special license, but adds small expenditure to on-going cost of using the technique.

7. **Direct Oxidation Carbon Coulometer (DOCC) -** Also known as **Total Organic Carbon (TOC)** uses oxygen gas in a combustion chamber at a set temperature to combust carbon-based contaminants into carbon dioxide that is then detected by CO_2 coulometer detection. Suitable for small parts and parts that can withstand high temperature.

Analytical Methods (See Table 2) - Analytical methods are those that analyze the part surface or a small piece of the part surface, by studying the species of contaminants on the surface. Generally this type of technique utilizes high vacuum for operation, and provides information about the type of contaminant on the surface, which can not be provided by any of the indirect or direct methods. All of these techniques are laboratory techniques and cannot be used on the shop floor. The samples have to be sent to the laboratory for analysis. Testing time, in most cases, is quite long, thus limiting the

number of samples that can be tested. The cost of this type of equipment is very high, generally in the range of $60,000 to high six figures. A very high skill level is required to operate the system and interpret the results. These techniques are very powerful and very useful in determining the type of contaminants present on the surface. The knowledge of the type of contaminants on the surface can be very useful in locating and possibly eliminating the source of contamination.

Some of the most common analytical techniques are listed below.

1. **Auger Electron Spectroscopy (AES) -** Also known as **Scanning Auger Microscopy (SAM)** - The Auger electrons, named after the discoverer of the process, are ejected when the surface is bombarded with electrons. The energy level of Auger electrons gives the information about the species of contamination.

2. **Electron Dispersive X-Ray (EDX)** – Also known as **Wavelength Dispersive X-Ray (WDX).** Bombardment of a surface with electrons generates X-rays which are characteristic of the elemental constituents comprising the sample. Both techniques generate a spectrum in which the peaks correspond to specific X-ray lines and the elements can be easily identified. While the WDX technique has always been appreciated for its higher resolution and trace element capability, it has been traditionally viewed as more complex to set up, and WDX data more tedious to obtain and interpret than EDX.

3. **Electron Spectroscopy for Chemical Analysis (ESCA)** - is often called **X-Ray Photoelectron Spectroscopy** (**XPS**). This highly sophisticated and expensive measurement method uses special equipment to bombard the surface of interest with x-rays under vacuum conditions, causing electrons to be released from the surface. Since each type of element (i.e. carbon, oxygen, etc.) releases a unique amount of electrons under these conditions the actual elemental composition of the surface can be quantified.

4. **Secondary Ion Mass Spectrometry (SIMS - Dynamic)** - is inherently a profiling technique. It uses O_2 or Cs ions to bombard a surface in high vacuum. This technique identifies masses according to a gated arrival time at a detector. From the arrival time the species of masses can be identified.

5. **Secondary Ion Mass Spectrometry (SIMS - Static)** - often called **TOF SIMS (Time-of Flight Mass Spectrometry).** It uses pulses of gallium ions to bombard a surface in high vacuum. This technique identifies masses according to a gated arrival time at a detector. From the arrival time the species of masses can be identified.

6. **Scanning Electron Microscopy (SEM)** - is a surface imaging technique, but with Energy Dispersive X-ray **(EDS)** it can identify elements in the near surface region. This technique is most useful for imaging particles.

7. **Fourier Transform Infra-Red Spectroscopy (FTIR)** - uses infra-red light focused on the part surface and absorption of specific light frequencies is detected. This information can be used to detect what type of organic materials is

on the surface.

8. **Attenuated Total Reflectance Fourier Transform Infra-Red Spectroscopy (ATR-FTIR)** – This mode of FTIR spectroscopy is a powerful tool for characterizing organic thin films and surface contamination on polymers. It can also be used to determine the compositions of thick samples, the construction of multiplayer polymer films, and the type of surface treatment applied to a polymeric system

9. **Raman Spectroscopy (RS)** – uses strong monochromatic light source (usually a laser) to irradiate a surface. The radiation excites the molecule, distorting the shape of the molecule's electron cloud. When the electron cloud returns to its original shape, the light energy in the molecule may have increased or deceased slightly, changing the energy of scattered radiation. Viewed in terms of energy levels, the electrons reside in the ground vibrational and electronic states before excitation. The position and intensity of the features in the vibrational spectrum can be used to study molecular structure or determine the chemical identity of the sample.

10. **X-Ray Fluorescence (XRF)** – is a bulk characterization technique for the rapid, simultaneous, and non-destructive detection of all elements heavier than fluorine. The sample is irradiated with x-rays and re-emits x-rays characteristic of its composition. Thin layers of contamination, especially heavy metals, can often be detected.

Factors to consider for selecting a suitable cleanliness measurement method

As we can see there are a wide variety of cleanliness measurement methods. To determine which method is right for a given application, many issues must be considered. Some of the issues that affect the choice of method are:

! **Type of contaminants to be monitored.** The method selected must be able to detect the contaminants of interest. For example, some methods will detect only organic contamination and not inorganic contamination. In general, it is better to have a method that can detect both organic and inorganic types of contamination and not be restricted to certain type of contamination.

! **Type of substrate being checked.** Any potential method must be compatible with the substrate being measured, i.e. should not damage the substrate. For example, certain cleanliness measuring methods deposit some type of "measuring media" on the surface to measure the cleanliness. Care should be taken to make sure that the "measuring media" deposited on the surface is not going to effect the performance of the part and does not deposit contaminants on the part surface.

! **Contamination range that must be detected.** The method must be able to detect the contaminants at the minimum and maximum level of interest.

! **Accuracy and precision required.** Some methods provide gross estimates of contamination, even if they can detect contamination at very low levels, while others provide very precise data for evaluation. The method selected must be appropriate for

the application.

! **Measurements speed.** The method selected must be able to make analyses at the desired rate to keep up with production.

! **Budgetary limitations.** The more precise and automated measurement systems are the more expensive they tend to be. The cost / benefit of the measurement method must be evaluated.

! **Skill level required.** The required skill level to utilize the technique and interpret the results varies a lot among various methods available. The ongoing cost of operation is higher for the more sophisticated techniques.

For a given cleaning process, it may be possible that more than one method is required to verify / measure all of the parameters of interest. There are many measurement methods that can be used to evaluate cleanliness in a manufacturing environment.

Cost Impact of Cleanliness Levels

For every level of cleanliness, there is a corresponding level of failure / non-conformance. There is cost associated with achieving certain level of cleanliness just as there is cost associated with failure / non-conformance. These two cost components can be combined to assess "total cost" of cleaning. An acceptable level of cleanliness is the one that minimizes the "total cost". The "total cost" can only be minimized by balancing the cost of incremental cleaning with the reduced cost of corresponding failure/non-conformance rate.

Experience shows that the higher the desired level of surface cleanliness, the greater the cost of cleaning. Hence surface cleaning cost is directly proportional to the surface cleanliness level. Experience also shows that the higher the surface cleanliness level, the lower the failure/non-conformance rate due to surface cleanliness, thus the lower the cost due to failure/non-conformance. Hence the rate of failure/non-conformance is directly proportional to the cleanliness level and inversely proportional to cost. The acceptable level of cleanliness is the one that minimizes the "total cost". The "minimum total cost" will result in the "OPTIMUM" level of cleanliness. Since all processes have some variation, there is bound to be some variation in the level of cleanliness achieved. An acceptable variation around the "OPTIMUM" level of cleanliness minimum cost would define the "Acceptable Level" level of cleanliness.

Procedures for defining acceptable ("optimum") level of cleanliness

Two ways of defining the "Acceptable Cleanliness Level" are discussed here, namely "Benchmark Testing" and "Desired Success Level of Subsequent Operation".

Benchmark Testing – A cleanliness measuring method must be used to establish the level of cleanliness achieved by the current cleaning process, and determining and recording the rate of product failure or non-conformance that is attributed to surface contamination. If the failure/ non-conformance rate is too high, the surface cleanliness level will have to be improved in order to reduce the failure rate. On the other hand, no failures or a very low failure rate implies that the surface *may be* "over-cleaned." It may be desirable to optimize the cleaning process by comparing the cost of non-conformance with the cost of cleaning the surface. Generally, increasing the level of surface cleanliness will result in increased cleaning cost. An increased

level of cleanliness should lower the rate of non-conformance, which in turn reduces the non-conformance cost. As long the reduction in non-conformance cost more than offsets the increased cost of cleaning, it would be cost effective to increase the achieved level of surface cleanliness. When the decrease in non-conformance cost fails to offset the increase in the cleaning cost, then an optimum or "acceptable level of cleanliness has been achieved.

Desired "success level" of subsequent operation

Another way to define the "acceptable level of cleanliness" is to perform a controlled experiment. For example, if two parts are to be bonded together then achieving the desired bond strength would be considered "success". The bond strength measurements can be correlated to surface cleanliness. If the parts are to be coated after cleaning, then the adhesion strength of the coating should be correlated to surface cleanliness. For the purpose of discussion, let us assume that the parts are to be coated and that the adhesion of the coating is measured by the peel strength. Achieving the desired peel strength (target peel strength), in this case, would be considered **"success".** As a minimum, this experiment would involve preparing parts with different levels of cleanliness, measuring the surface cleanliness of each part, and correlating a measure of the "success" of the subsequent operation to the level of part surface cleanliness.

Parts with various degrees of cleanliness can be prepared by either altering some factors of the cleaning process or by applying known amounts of contamination to clean parts. After the parts have been prepared, surface cleanliness measurements for each part should be taken and recorded. If possible, make several measurements per part. The next step is to apply the coating on to these parts. After the coating has been applied and cured/dried, as many measurements as possible should be made of the peel strength for each part, and these values recorded.

The mean surface cleanliness reading for these parts should be correlated with the mean measurement of peel strength. Figure 1 depicts, graphically, the typical result of correlating the peel strength of coating adhesion to the surface cleanliness level. The cleanliness level that correlates with the minimum level of adhesion strength measurement then becomes the required *minimum* level of surface cleanliness. Since there is variation in every process, then the lower limit of the "Acceptable Level" of cleanliness will be the *minimum* level of cleanliness established through this experiment. The upper limit can be established based on the cost of incremental cleaning.
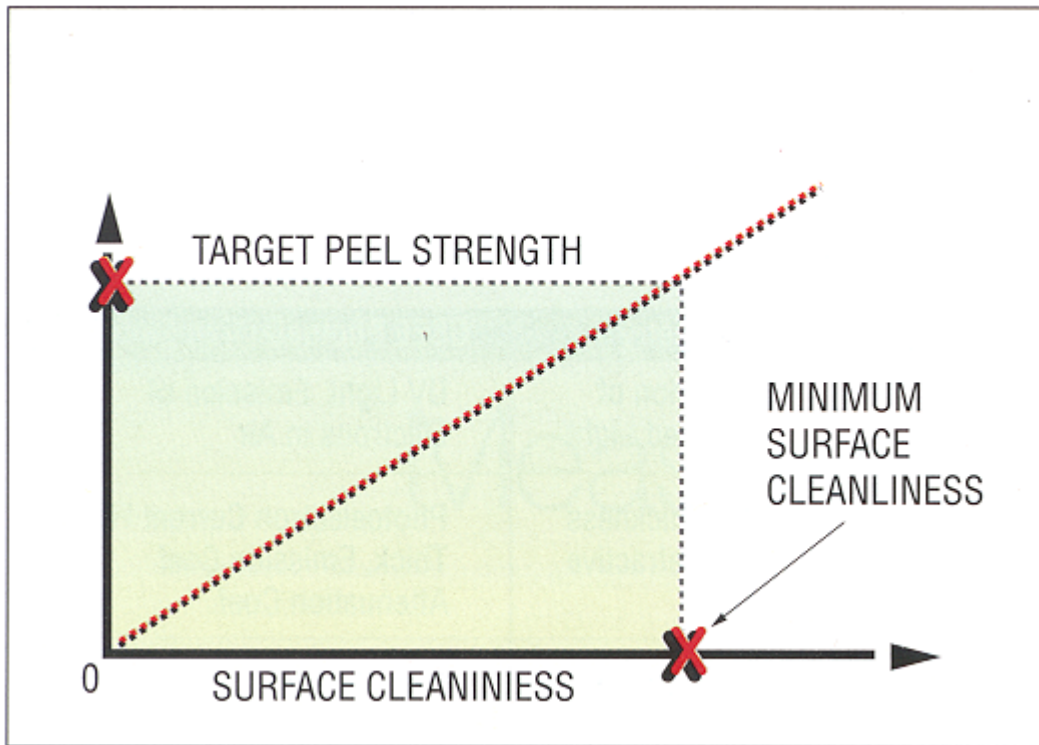
Surface Cleanliness vs. Peel Strength
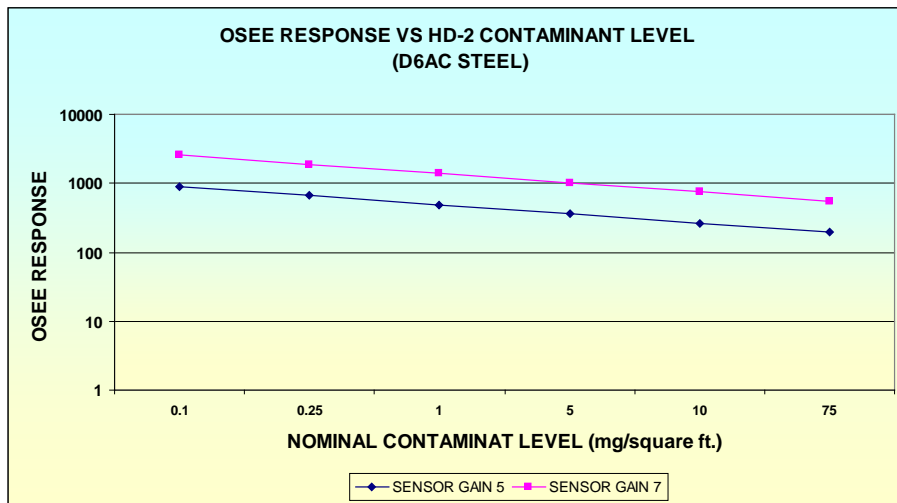**Figure 1**

Cleanliness monitoring of Solid Rocket Motor (SRM) Case using OSEE

The SRM case is made up of several segments of D6AC steel, approx. 13 feet diameter and 10 feet long. Segments are mechanically fastened to each other with a groove/tongue/ring arrangement. This joint also houses the infamous "O" ring that was considered responsible for the 1986 space shuttle disaster. Once the segments are mechanically joined together, a asbestos/rubber lining is bonded to the inside surface of the SRM case. This lining also covers the segment joints. Solid propellant is then cast into the SRM case. During the launch of the space shuttle, the propellant burns and generates intense heat which is transferred through the lining to the steel case and then to the atmosphere. In the 1986 disaster, subsequent testing determined that the failure was initiated by poor bonding of the lining to the casing. The normal heat transfer could not take place. So the heat and gases burned through the lining, traveled between the lining and the steel case and arrived at the segment joint that houses the "O" ring. The "O" ring material had also frozen due severe weather. The joint could not contain the pressure and an explosion resulted.

Three distinct steps were taken to rectify this design flaw. First the joint was redesigned to make it mechanically stronger. Second, the "O" ring material and cross-section was changed for better performance under severe weather. Third, the surface cleanliness method was reviewed and found to be inadequate. Several techniques were evaluated and Optically Stimulated Electron Emission (OSEE) was selected for implementation in production.

It was established that peel strength of 150 pounds per linear inch (PLI) was the desired bond strength target. In order to establish a correlation between bond strength and surface cleanliness a controlled experiment was performed as follows:

1. Several approx. 1' x 1' sections of D6AC steel were prepared with varying degree of surface cleanliness measured in mg/ft^2.
2. Surface cleanliness of these samples was measured with OSEE and recorded.
3. Next, the lining was bonded to the samples using the standard process.
4. Peel tests were performed to measure and record the bond strength of these samples.
5. A correlation between the OSEE readings and surface contamination level was established. This relationship is shown as a graph in Figure 2 below.
6. A correlation between the surface contamination level and peel strength was also performed. This relationship is shown as a graph in Figure 3 below.
7. Given the target peel strength of 150 PLI, the maximum allowable contamination was established at 5 mg/ ft^2. This level of contamination represented an OSEE reading of 900. Hence this level of cleanliness was established as the minimum level of cleanliness for production.

OSEE Response vs. Contamination Level
Figure 2

Currently every inch of the inside surface of the SRM case is monitored for surface cleanliness using OSEE prior to bonding the lining to the casing. The steel case is coated with HD2 grease for protection against environment during storage prior to processing. HD2 grease fluoresces as a result the surface was previously inspected visually with a black light. With this controlled experiment, it was determined that even the best visual inspectors could detect contamination level no less than 100 mg/ ft^2. This level of contamination gave bond strength of 50 PLI at best. So the desired level of maximum contamination was a factor of 20 lower than the best visual inspection could detect.
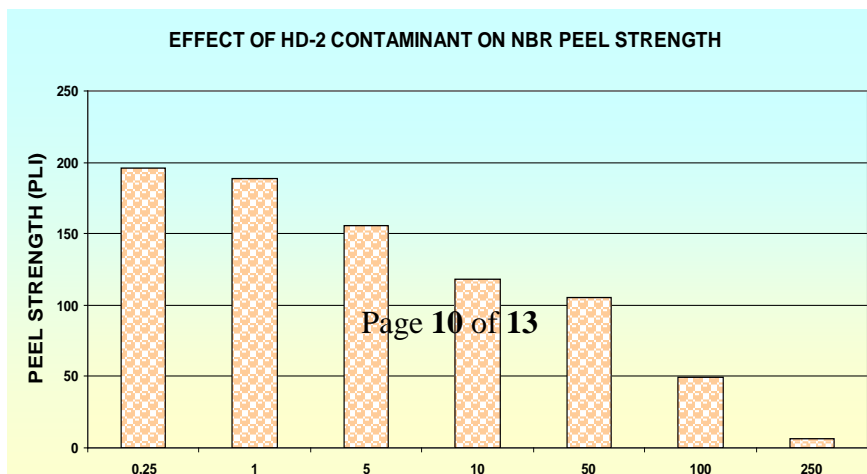
Peel Strength vs. Contamination Level
Figure 3

On-going surface cleanliness monitoring

Once the "optimum" cleanliness level has been established, surface cleanliness measurement system must be used to monitor the process and assure that the desired cleanliness level is being achieved on an on-going basis. By monitoring the surface cleanliness to an established level of cleanliness, the non-conformance due to surface contamination can be minimized or eliminated.

Another advantage of on-going, in-process monitoring of surface cleanliness is that replenishment of chemicals or cleaning agents will only be done when needed, and not done according to a pre-determined, somewhat arbitrary schedule. This replenishment schedule is usually time-dependent. ***In reality, the amount of contamination can vary considerably from part to part. In addition, the number of parts being cleaned during a given time frame can also vary considerably.*** Thus, a time-dependent replenishment schedule is not the best way of controlling the cleaning process. The required level of cleaning agent concentration in the cleaning solution can be objectively determined and maintained by implementing a surface cleanliness monitoring system.

A surface cleanliness measuring system can be very useful to, not only establish a "acceptable cleanliness level", but also in evaluating alternative cleaning processes for achieving the desired cleanliness level. Changes can also be made to the cleaning process and the expected impact on non-conformance can be assessed by measuring surface cleanliness achieved by an alternate cleaning process or by the changes made to the existing cleaning process.

Table 1 - Comparing Salient Features of Common Direct/Indirect Methods of Cleanliness Verification / Measurement.

METHOD	Type of Contaminant Detected	Type of Method	Relative Cost	Measurement Time	Quantitative	Part Geometry Limitation	Operator Skill Level	Non-Contact	Non-Destructive	Area Inspected	Limitations
NVR	Organic	Indirect	Low	Few Minutes	Yes	Some	Low	No	Yes	Limited	Generally Small Parts
UV Spectroscopy	Some organic	Indirect	High	Few Minutes	Yes	Yes	High	Yes	Yes	No Limit	Fluorescing contaminants only
Optical Particle Counter	Particulate	Indirect	High	Few Minutes	Yes	Yes	High	No	Yes	No Limit	Large particle contamination only
Magnified Visual Inspection	Organic	Direct	Low	Few Seconds	No	Yes	High	Yes	Yes	No Limit	Only gross level of contamination detected
Black Light	Some organic	Direct	Low	Few Seconds	No	No	High	Yes	Yes	No Limit	Only Fluorescing gross contaminants
Water Break Test	Organic	Direct	Low	Few Minutes	No	Some	Low	No	Yes	No Limit	Only detects Hydrophobic contaminants
Contact Angle	Organic	Direct	Medium	Few Minutes	Yes	Flat Surface	Medium	No	Yes	Small	Only detects Hydrophobic contaminants
OSEE	Organic and Inorganic	Direct	Medium	Few Seconds	Yes	No	Low	Yes	Yes	No Limit	Does Not Detect Particle Contamination
MESREN	Organic	Direct	Medium	Few minutes	Yes	Flat Surface	Medium	No	Yes	Limited	Does not detect inorganic Contamination
Total Organic Carbon (TOC) or (DOCC)	Organic	Direct	Medium	Few Minutes	Yes	No	High	Yes	Yes	Limited	Subjects the part to high temperature

Table 21 - Comparing Salient Features of Common Analytical Methods of Cleanliness Verification / Measurement.

Technique	Surface, < 10 nm 100 Angstroms	Near Surface < 2µm	Bulk, > 10µm	Depth Profiling Available	Used to identify interfaces	Quantitative	Elemental	Chemical	Used to identify Organics	Used to identify Inorganics
	No depth profiling									
AES/SAM	Yes	No	No	Yes	Yes	Yes	Yes	Some	No	Yes
EDX/WDX	No	Yes	No	No	Some	Yes	Yes	No	No	Yes
ESCA (XPS)	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dynamic SIMS	Yes	No	No	Yes	Yes	Yes	Yes	Some	No	Yes
SSIMS	Yes	No	No	No	No	No	Some	Yes	Some	Some
TOF SIMS	Yes	Some	No	Yes	Yes	With Standards	Yes	Yes	Yes	Yes
VASE	Yes	Yes	Some	No	Yes	With Standards	Yes	No	No	No
FTIR	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Some
ATR FTIR	No	Yes	Some	No	Yes	Yes	No	Yes	Yes	Some
RS	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
XRF	Some	Yes	Yes	NO	Some	Yes	Yes	No	No	Yes