

Surface Finish Effects on Vacuum Pump-down Time

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There are many strongly held opinions regarding how the surface finish in a vacuum chamber affects the pump down time. Throughout vacuum literature, we see numerous articles that mention the importance of surface preparation, but there is a limited amount of test data that is presented. For this reason, we created a controlled setup to compare the different pump down rates of various surface finishes.

Rough, High and Ultra High Vacuum

Although there are no absolute technical definitions for the different vacuum ranges, the gas flow properties change as the vacuum level is increased. For our purposes, the rough vacuum range is between 10.0 to 1×10^{-3} mbar, high vacuum range is 1×10^{-3} to 1×10^{-8} mbar and the ultra-high range is less than 1×10^{-8} mbar.

In the rough vacuum range there is viscous flow, meaning that the air molecules push against one another in such a way that they rapidly move to a location where there is a lower pressure.

In the ultra-high vacuum range, the density of air molecules is so low that they have minimal interaction with one another. There is no force that compels them toward the vacuum pump, so they can wander about inside of the chamber and rest on the chamber surfaces a long time before they find their way to the pump.

The high vacuum range starting at 1×10^{-3} mbar is the transition toward the molecular flow range. At higher pressures (low vacuum), the molecules still interact and are easier to pump, but as the pressure is lowered it becomes increasingly difficult to expel them from the vacuum chamber.

The surface finish of a vacuum chamber has a different effect on the vacuum pumping speed depending on the pressure range. When the majority of the gas load involves evacuating the air volume inside the chamber, the surface finish has little effect. Most of the atoms are not touching the chamber surfaces. In the higher vacuum ranges, however, most of the free molecules have already been evacuated, so the molecules that are breaking free from the surfaces are a significant contributor to the gas load.

The view that outgassing is higher from a rougher surface has been questioned and refuted by several studies. In 1969, Youngⁱ demonstrated that the outgassing of 304 stainless steel was the same regardless of whether the surface was glass bead blasted or electropolished, after the surfaces were baked out at 250° C.

Water Vapor

In the rough vacuum range, the composition of the gasses that are being evacuated from the vacuum chamber is a mixture similar to ratios of gasses in air. However in the high vacuum range, this changes. Provided that the vacuum chamber is properly cleaned and free from surface hydrocarbons, the gas load that remains in the chamber is primarily water vapor. This is because the water molecules tend to adhere more strongly to the surface of the chamber than other molecules.

A water droplet will tend to separate more easily from a rough surface than a smooth surface (the texture also plays a significant role)ⁱⁱ. Water vapor, on the other hand, behaves differently than a water droplet. The size of a water molecule is about 3 angstroms (0.3 nano meters, or 3×10^{-10} meter). Consequently these molecules can reside in every little nook on the surface of the vacuum chamber (and anything else in the chamber). They have both cohesive (water molecule to water molecule) and adhesive bonds (water molecule to a different surface)ⁱⁱⁱ thus the water molecules like to form a thin film over all of the vacuum chamber surfaces. It is this characteristic that makes them the predominant gas at pressures below 1×10^{-4} mbar.

One commonly held belief about the surface finish of a vacuum chamber is the total surface area must be measured at the microscopic scale. If you have a stainless steel plate that is 12 inches square, the surface area as seen by the water vapor is not 144 square inches, but rather one would need to measure the surface of all of the peaks, hillsides and valleys with a profilometer stylus that is 3 angstroms in diameter (size of a water molecule) to determine the actual amount of exposed surface. Consequently, the smoother the surface and more highly polished it is, the less total surface area there will be.

While this seems logical, a mirror-like polished surface will have a surface finish of 0.1 micrometers.^{iv} In other words, this is 1000 angstroms or over 300 times the diameter of a water molecule. As a comparison, The One World Trade Center building is 1776 feet tall, or 300 times taller than a person who is 5 feet 11 inches tall. Thus what we would see as a beautiful, smooth surface would still have peaks that are huge when compared to a water molecule.

The Test Setup

To perform the test, we built a rectangular vacuum chamber from 304L stainless steel with the inside dimensions of 15 x 15 x 15 inches. All of the gages and ports were sealed with conflat (copper gasket) seals except that the baseplate seal is a baked out O-ring made from FKM (VitonTM). The inside surface of the vacuum chamber was 1,350 square inches plus what is added by the ports. Also inside the vacuum chamber is a material stand that has a surface area of

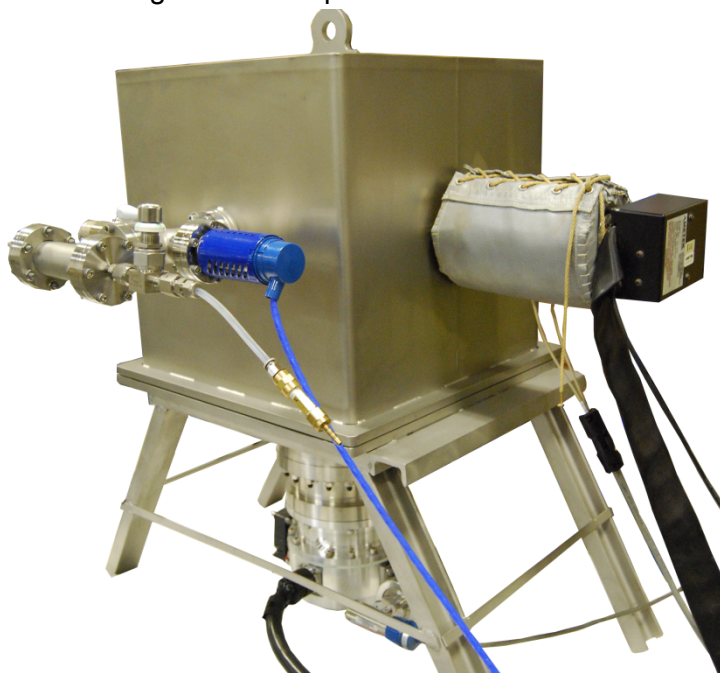


Figure 1. Test Chamber Setup

104 square inches. These items are constants through the testing process. The components and instruments used are shown in Table 1.

Inside the chamber we placed 12 surface area samples. Each plate is 304L, 0.250 inches thick with a surface area of 300 square inches. The total surface area of the samples was 3,600 square inches. We started first with as-purchased 2B plate and then changed the surface finish through common vacuum chamber finishes: 2B, #4 grained finish, grained and electropolished, and bead blasted. The surface finish roughness is shown in Table 2.

Table 1. Equipment List		
Component	Model	Manufacturer
Turbo Pump	MagLev TG420MCAB	Osaka
Pressure Gauge	Stabil Ion 360	Granville Phillips
RGA	LC 100	Dycor/AMETEK
Roughing Pump	Drystar GV 80	Edwards

Test Results

To prepare the test chamber, it was cleaned baked out at 125 degrees Celsius and evacuated until the pressure inside reached 2.7×10^{-8} mbar.

Figure 3 shows the pressure vs time curves for the different surface finishes. After the initial pump-down to high vacuum, the chamber was back-filled with dry nitrogen to bring the inside back to atmospheric pressure. The chamber was re-evacuated to compare how it pumped in a dry, clean condition.

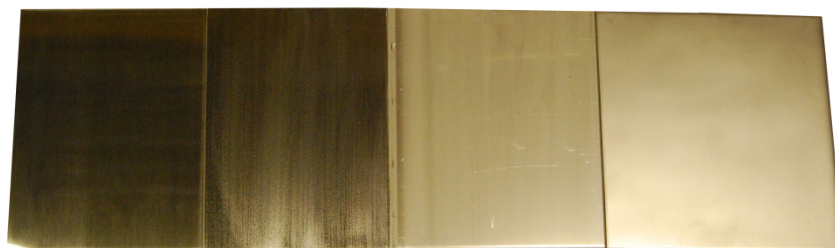


Figure 2. Surface Finish Test Samples

Conclusions

1. All of the pump-down curves are very similar from ambient pressure to 1×10^{-6} mbar. As long as the system has adequate pumping capacity in this pressure range, the surface finish has a minimal influence on the pumping time. This is not to say that some processes which operate in this pressure range do not need a chamber with an improved surface finish. In some cases, a few seconds of reduced pumping time could be important. However for many applications, the surface finish improvements have a negligible effect on pumping speed in this pressure range.
2. If a chamber is clean and baked out (or otherwise dry), the surface finish is not as significant. The surface finish is more important when the chamber is repeatedly vented and exposed to atmospheric moisture.

Table 2. Test Article Surface Roughness	
Surface Preparation	Surface roughness $\mu\text{in } R_a$
2B Finish	20
Grained	41
Electropolished	38
Bead blasted	28

3. The pump-down time is not entirely dependent upon the measured surface roughness. In our example, the bead blasted plate, as measured by a profilometer, had a smoother surface than the grained plate. However, the pump-down time for the bead blasted plate is longer than that of a grained plate.
4. A plate that was grained and then electropolished had a very similar pump-down time as compared to just a grained plate. The electropolishing did not make a dramatic improvement in the pump-down time.
5. The greatest benefit of an improved surface finish is in the pressure range lower than 1×10^{-6} mbar. For example, it will take 25% longer to evacuate a chamber that has a bead blast finish as compared to a chamber with a grained finish in this pressure range.
6. For a chamber that is re-pumped without opening it to atmospheric moisture, the evacuation is rapid until 2.5×10^{-8} mbar, then there is an immediate slowing of the pumping speed.

Summary

There are many reasons to select a certain vacuum chamber finish. Three common reasons are: 1) aesthetic appeal, 2) ease of maintenance, and 3) the speed of pump-down. After a chamber is exposed to the atmosphere, the surface finish inside does affect the pump-down time, but a shinier looking surface is not always the best choice. A smoother surface is typically more costly to produce and for a large number of vacuum system applications a less polished surface is more than adequate to meet the process requirements.

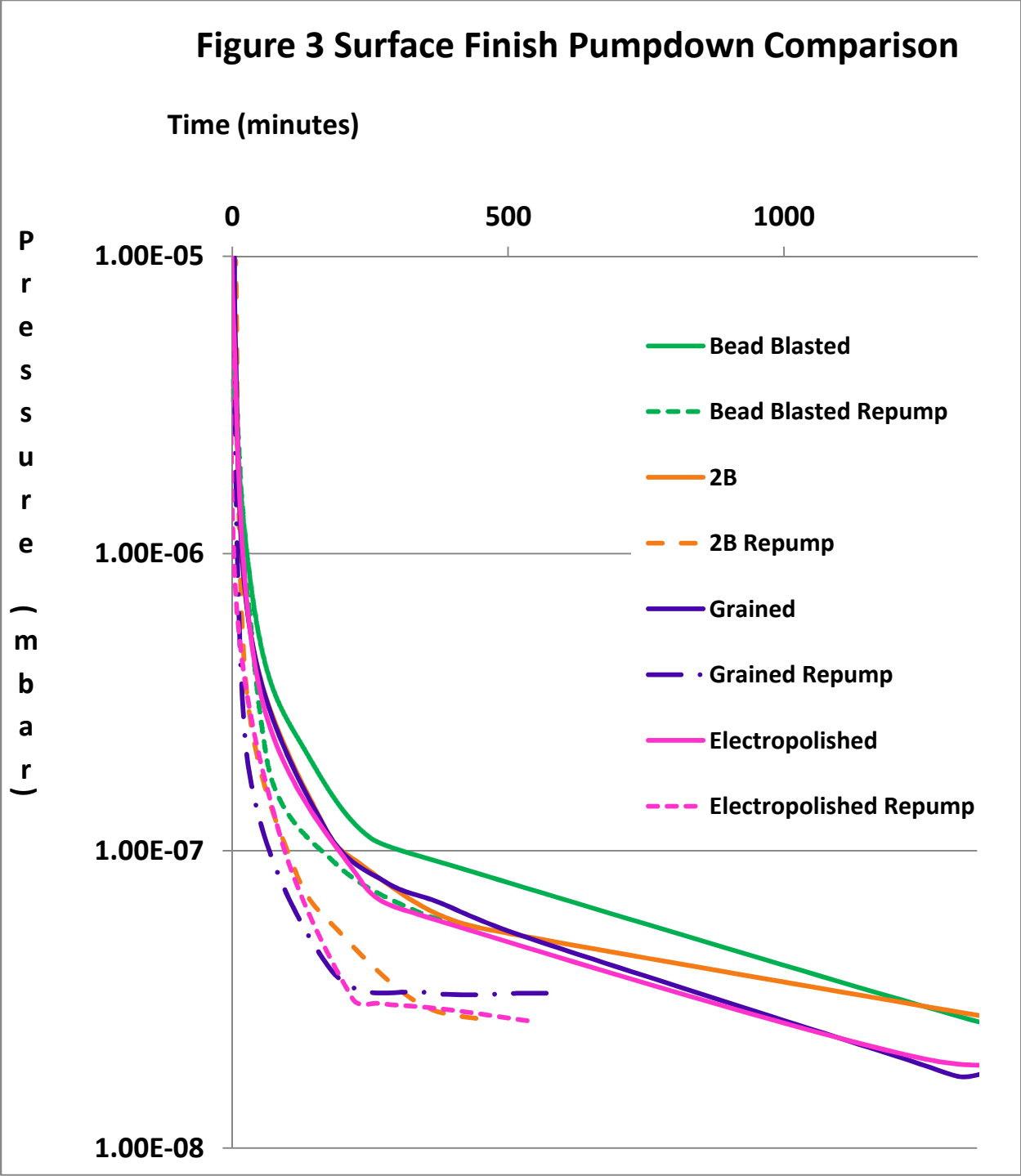


Figure 3. Pump-Down Curves

ⁱ Young J R, *Outgassing Characteristics of Stainless and Aluminum with different Surface Treatments*, Journal of Vacuum Science and Technology 6(3), 1969 pp. 398-400.

ⁱⁱ David L. Chandler, MIT News Office, *That's the way the droplets adhere*, June 7, 2013, <http://web.mit.edu/newsoffice/2013/droplet-surface-adhesion-0219.html>

ⁱⁱⁱ Perlman, Howard, U.S. Geological Survey, *Adhesion and Cohesion of Water*, January 10, 2013, <http://water.usgs.gov/edu/adhesion.html>

^{iv} Maryland Metrics, *Surface Roughness Tables*, Version P1A/T3J, <http://mdmetric.com/tech/surfruff.htm>