Control of Cleaning Processes to Maximize Sealant Performance

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Introduction

Cleanliness in automotive powertrain manufacture is critical for several reasons. For example, particulates generated in the various casting and machining processes must be effectively removed to prevent both the premature wear of sliding and rotating parts as well as the catastrophic failure of components such as transmission valve bodies. One of the final steps in component manufacture is the cleaning process, and current commercial washer systems can be quite effective at removal of particulate contaminants. In fact, washer system performance is traditionally evaluated based on particulate removal efficiency. Efficiency is typically quantified using tests such as the "Millipore Test". In this test, a cleaned part is thoroughly rinsed with solvent under pressure, the solvent is collected and then filtered to recover any particulates that may have remained on the cleaned part. The mass of the recovered particulates is measured, as this value is used as a parameter to evaluate washer system performance.

In recent years, economic considerations have resulted in automotive powertrain design evolving from using manufactured gaskets (paper, elastomeric, composition) to point-of-use dispensing of RTV silicone sealants onto sealing surfaces. These seals are referred to as Formed in Place Gaskets, or FIPG. Because FIPG performance depends on establishing and controlling surface cleanliness on a chemical, not particulate level, adoption of this technology is forcing a reevaluation of the performance of parts washers. Simply ensuring low particulate levels will not guarantee FIPG adhesion; the chemical composition of the cleaned surface needs to be controlled to ensure FIPG performance.

Quantitative evaluation of washer system performance has implications beyond product performance. Washer system maintenance (water heating, cleaning chemicals, wastewater) represents one of the major expenses of a manufacturing operation. If washing solutions are changed too frequently, costs can increase significantly with no concurrent improvement in product quality. Clearly, a convenient and quantitative measure of washer system performance has significant value to manufacturing operations.

Surface energy is a measure of the density and reactivity of active surface sites. Contaminants consume active sites on a surface and therefore reduce the surface energy. If an adhesive cannot displace the contaminants, these active sites are not available for interaction with the adhesive and a poor interface results: quality of adhesion is directly proportional to surface energy [**1**]. The contact angle established by water on a solid surface is a quantitative measure of the surface energy [**2**]. For low levels of contaminants (e.g. sub micron thicknesses), a water contact angle measurement can rapidly quantify the chemical cleanliness of a surface [**3**].

Cleanliness is a matter of definition. In general, a carefully cleaned metal surface can exhibit a 10 to 20° water contact angle. This corresponds to around 20 at% adventitious carbon when analyzed using X-ray Photoelectron Spectroscopy (XPS). A freshly grit blasted surface will be cleaner: 0 to 5° water contact angle and <10 at% carbon, but will deteriorate within minutes upon air exposure due to oxidation and contaminant adsorption. It is difficult to generate and difficult to maintain a cleaner surface in a laboratory environment, much less a manufacturing facility. Figure 1 shows the water contact angles obtained from machined aluminum surfaces dipped in solutions of 50 wt mineral oil in xylene. The contact angle increases rapidly with small amounts of contaminant; as the thickness of the contaminant layer increases, the rate of change of contact angle decreases. The influence of the underlying surface on the water drop is decreased as its physical separation increases.

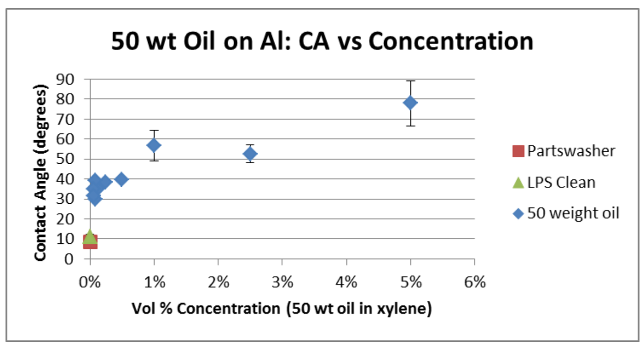

Figure 1. Ballistic water contact angle on machined aluminum with varying amounts of 50 wt oil. Oil applied by dip coating from solutions of carrying concentrations.

The type of relationship shown in Figure 1 holds for a wide range of contaminants and substrates, and permits contact angle measurements to be used for quantifying the performance of a washer system. This paper discusses data obtained during trials of two different washer systems being evaluated for implementation after a machining operation to prepare parts for final engine assembly and sealing using RTV sealants. After cleaning, Ballistic water contact angles were measured at the numbered points using a Surface Analyst™ SA3001 TSF to evaluate both the cleanliness level and the uniformity of cleanliness across the part surface. This instrument returns a contact angle that closely tracks the receding contact angle. It is particularly well suited to evaluation of narrow machined sealing surfaces and is insensitive to part orientation, i.e. that part can be horizontal, vertical, or inverted without affecting the measurement. The small tethered inspection head makes it ideal for use in situations such as an engine assembly line.

Experimental

Figure 2 shows the engine casting used to evaluate parts washer performance. The numbers represent points on the surface that were interrogated with water contact angle measurements after cleaning. The parts were received in an as-machined state, meaning that the surfaces were contaminated with varying amounts of oils and water soluble cutting fluids. Two different types of washers were evaluated. In the first type, multiple parts were loaded into a basket which was then rotated within the machine to expose as much of the surface as possible to the washing and rinsing spray. In the second type, parts were conveyed individually through the wash and rinse zones. Different wash recipes were evaluated in each machine in an attempt to optimize performance.

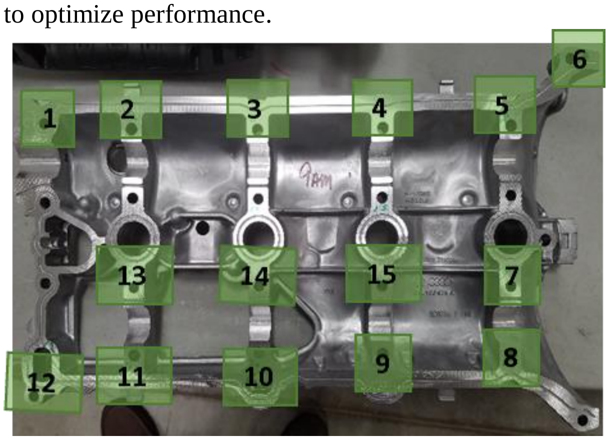

Figure 2. Inspection points on machined engine sealing surfaces evaluated for cleanliness via Ballistic water contact angle measurements.

Performance of the washer systems was evaluated using two metrics: average contact angle, and point-to-point variability.

Results and Discussion

The basket-type washer was evaluated first; the results are shown in Figure 3. Each X axis label indicates a distinct trial on a new part. Each line represents the contact angles measured on a particular point from Figure 2. Trials that resulted in low, tightly grouped contact angles indicate a uniformly well-cleaned part. Contact angles that are high and show larger point-to-point variability indicate a poorer wash process. For example, Test 2 (average of 41°, spread of 27°) compared poorly with Test 3 (average of 25°, spread of 10°).

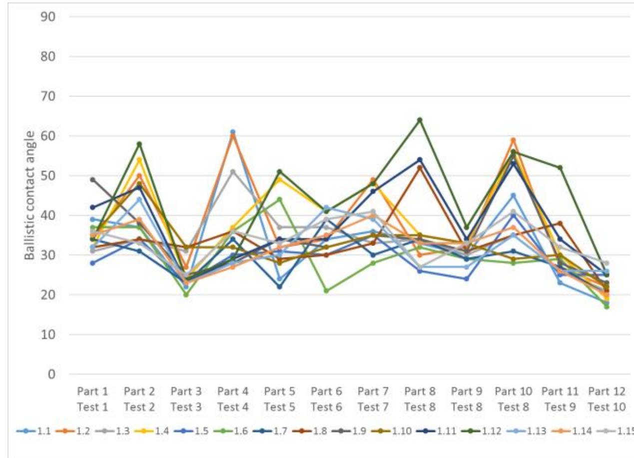

Figure 3. Ballistic contact angle versus washer trial (basket-type). Each X-axis point corresponds to a new washer trial; each line corresponds to a measurement point from Figure 2.

Test 8 (which had 3 parts loaded into the basket at once) showed the effect of loading multiple parts in the washer. Part 8 was next to the back wall of the washer, Part 9 was in the middle of the basket, and Part 10 was adjacent to the front wall. Notice the part in the middle of the basket was cleaner (avg 31° vs 37° and 42°) and showed significantly better point-to-point uniformity (range of 23° vs 38° and 31°) than the parts near the front and back walls of the washer.

Figure 3 also shows that this particular washer had difficulty cleaning certain areas of the parts. Location 12 from Figure 2 (green trace in Figure 3) consistently demonstrated one of the highest contact angles. This kind of data can be used to optimize washer performance by adjusting the configuration of spray patterns and parts loading to minimize variability and avoid product quality issues.

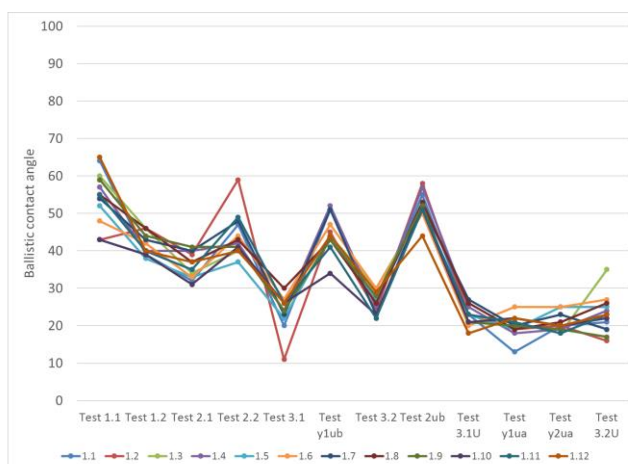

Figure 4. Ballistic contact angle versus washer trial (conveyor type). Each X-axis point corresponds to a new washer trial; each line corresponds to a measurement point from Figure 2.

Similar trials were performed using a different washer design, in which parts were transferred through the wash and rinse zones individually on an endless chain mesh belt. Figure 4 shows the results. Two conclusions are immediately apparent: point-to-point variability was significantly lower than for the basket type washer, and no particular point on the part was more difficult to clean. Test 3.2 showed particularly excellent results, with an average Ballistic contact angle of 26° and a range of 8°. The last four trials shown in Figure 4 were the results of ultrasonic cleaning and showed excellent results as well.

Conclusions

Rapid quantification of washer performance was achieved through contact angle measurements. Data of the type presented in Figures 3 and 4 were used to make a data-based decision on the purchase of a new washer system. The baseline data generated in this investigation provided a benchmark against which future washer performance can be compared, allowing washer maintenance to be performed on the basis of deterioration of a performance metric directly related to the required product performance, in this case adhesion of RTV sealant.

Acknowledgements

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References

1. Andrews, E. H. and Kinloch, A. J., Proc. Roy. Soc. A332, 385 (1973).
2. A.D. Gilpin, B.R. Oakley, R.G. Dillingham, J. Adh Sci. Tech. **29** 9 890-895 (2015).
3. M.L. White, in *Clean Surfaces: Their preparation and characterization for interfacial studies*, G. Goldfinger, ed. (Marcel Dekker, Inc., NY 1970) pp. 361-373.