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TECHNICAL REPORT
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TITLE: Quantifying the Affect of Temperature on Surface Finish

It is well understood that in spray painting operations, temperature related variations can result in significant quality problems with film build, color match, surface finish, adhesion, etc. A global Tier-1 supplier of interior and exterior components to major automotive manufacturers was experiencing difficulty maintaining consistent finish quality on their painted parts. Working with their Global Paint Manager and staff, we set out to accurately quantify the impact of temperature on surface finish. All measurements were made with a BYK micro-wave-scan, which is well suited to the small, often curved parts painted for customers like Renault, VW and Audi, just to name a few. This provided an industry accepted metric on which to base our analyses and conclusions. The goals and objectives set forth for this project were to:

- Quantify the relationship between paint temperature and surface finish at each step in the painting process
- Demonstrate that controlling temperature can reduce the variation across a group of parts and increase first-pass yield
- Demonstrate that the process is repeatable
- Define a temperature control system that can be installed on the existing robotic paint system with minimal downtime and limited interference with the paint path
- Demonstrate that this approach has a better ROI than other alternatives being examined to address the surface finish issue

THE BASICS

All liquids show some change in viscosity as a function of temperature. Figure 1, taken from an old viscometer data sheet[1], shows that even water goes through a viscosity change of nearly 2:1 between 10°C and 40°C.

Modern paints are no different. Figure 2 shows the viscosity-temperature curve for a selection of common, related paints used in spray painting operations. This shows the typical non-linear relationship associated with these materials over the normal ambient temperature range. It is worthwhile to note that this is shared

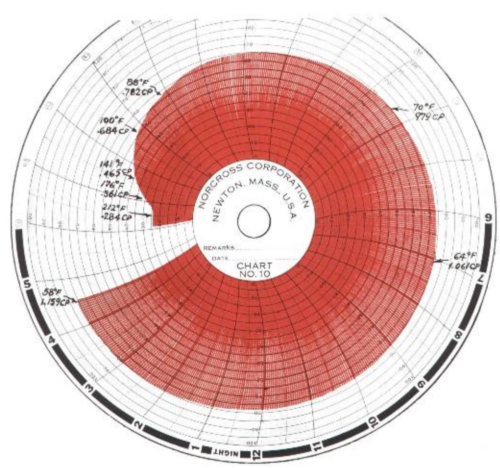

Figure 1: Viscosity vs. Temperature for Water[1]

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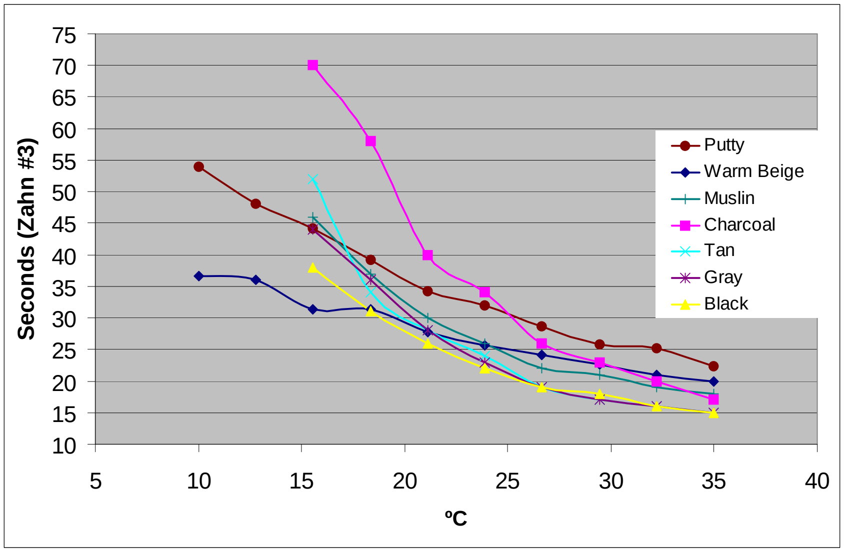


Figure 2: Paint Viscosity vs. Temperature by Color[2]

with virtually all liquids and is a physical property not a defect. As such, this is a parameter that can be exploited to improve the performance of the painting process.

In a spray delivery system, paint viscosity will have a significant impact on system variables such as flow, pressure drop, and atomization; and paint performance properties such as film build and flow out. Each of these will have an impact on the final quality of the finish.

In the paint data sheets supplied for a given formulation, the manufacturer will provide a reference viscosity, often specified at 25°C (77°F). In Figure 2 we see that these colors, all of the same type and formulated for the same operation, display a range of viscosities from 21 to 31 seconds at 25°C (77°F) and each varies differently as a function of temperature. Therefore, in order to obtain acceptable performance from each color there must be either changes in the setup parameters of the spraying system for each color and at each ambient temperature, or the paint must be delivered to the gun at its optimal temperature every time it is sprayed. This then forms the foundation for modern paint temperature control. In fact, one of our past projects with a high-end automotive specialty vehicle and aftermarket supplier showed that their orange peel problems could be eliminated if their paint formulation was sprayed within a consistent 3°F (2°C) window.

THE EQUIPMENT

In order to perform the experiments necessary to establish the impact of temperature on paint finish, it would be necessary to be able to vary the temperature of the paint being sprayed while all other application parameters (flow, gun path, speed, etc.) were held constant. Based on the painting parameters provided, SCS determined that the AT-5900, shown in Figure 3, would be the best TCU (Temperature Control Unit) for the application. This compact unit could provide all of the heating and cooling necessary to control the paint temperature.

Figure 3: AT-5900S TCU

It is essential to provide temperature control all the way to the point of dispense – the gun. We determined that

SCS's new, patent-pending Re-Corable Coax Hose Assemblies would provide the best opportunity for retrofitting the robot. This system surrounds the existing paint carrying tube with a jacket that carries temperature conditioned water, creating a flexible tube-in-tube heat exchanger. Available in configurations for both 1K and 2K paint systems, it is flexible enough to handle the motion of a robotic application and does not alter the existing paint path or paint contact components.

This system was installed on the 2K clearcoat system; requiring just two hours to complete. The result is shown here in Figure 4:

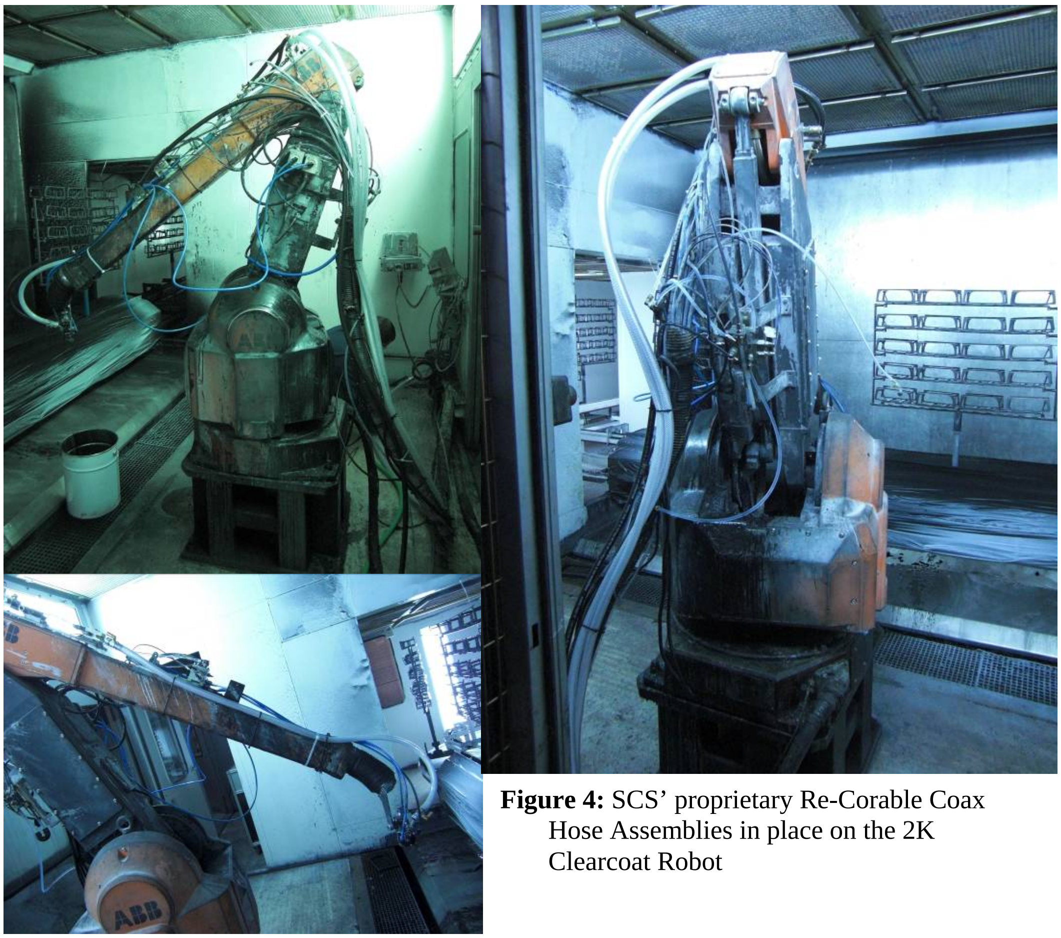


Figure 4: SCS' proprietary Re-Corable Coax Hose Assemblies in place on the 2K Clearcoat Robot

In order to record the temperatures throughout the system, a series of thermocouples and a wireless data collection system were employed. This transmitted temperatures from inside the booth to a computer located outside the intrinsically safe painting area.

THE EFFECT OF CLEARCOAT TEMPERATURE

Using the setup above, the first testing focused on the effect of clearcoat temperature on the surface finish parameters. For this test, the basecoat was applied normally and then the temperature of the clearcoat was varied as shown here in Figure 5:

Here we can see the changes in temperature for each rack as it is being sprayed. This also shows that the system is capable of both changing the temperature of the clearcoat and maintaining it independent of the 22°C (72°F) ambient.

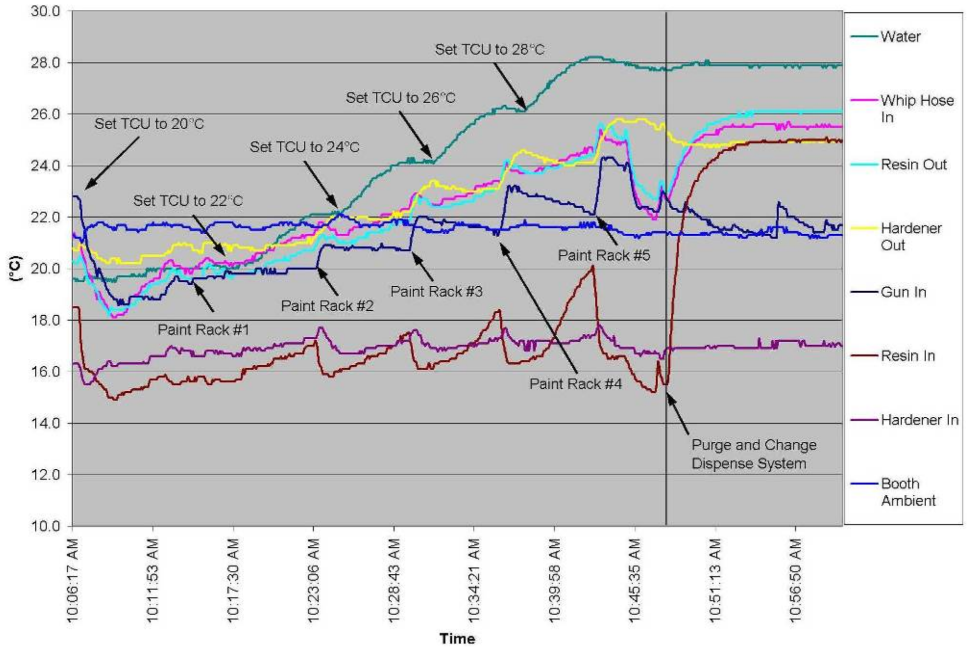
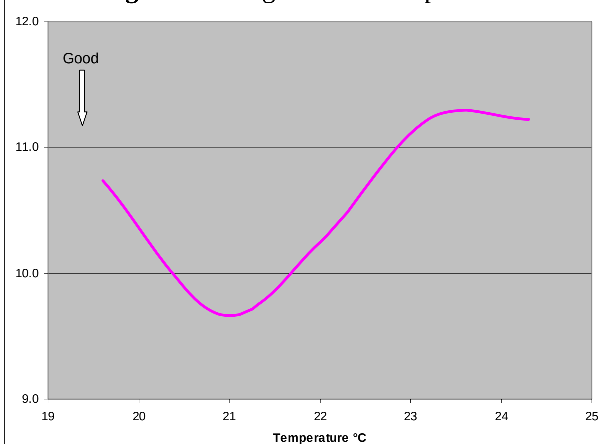


Figure 5: Clearcoat Temperature Testing Data

After baking, the cured parts were measured with a BYK micro-wave-scan and the data analyzed.

The Longwave results are shown at right in Figure 6:

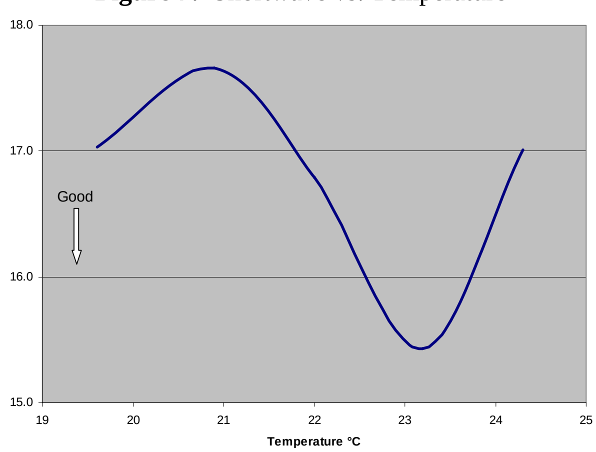
Figure 6: Longwave vs. Temperature



From this graph it is easy to see that the optimal Longwave results with this setup are achieved at about 21.0°C (70°F).

The Shortwave results are shown below in Figure 7:

Figure 7: Shortwave vs. Temperature



Here we can see that the optimal Shortwave results are achieved at about 23.2°C (73.8°F). Looking at these two graphs, it can be observed that the scales on each are equivalent at three points of wave measurement and 6°C (11°F) of temperature variation (25°C – 19°C = 6°C). By placing both on the same dual scale graph and shifting the two plots to coincide with one another, the optimal operating temperature can be quickly determined as shown below in Figure 8:

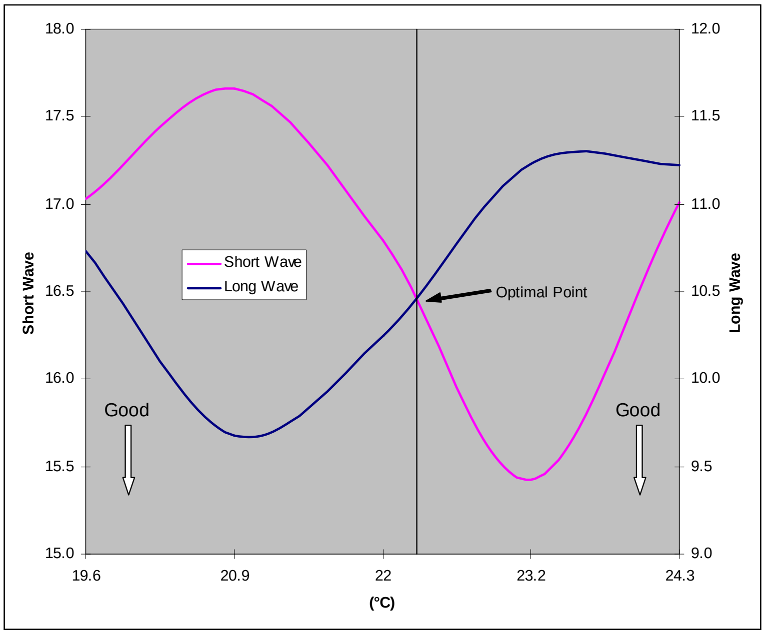
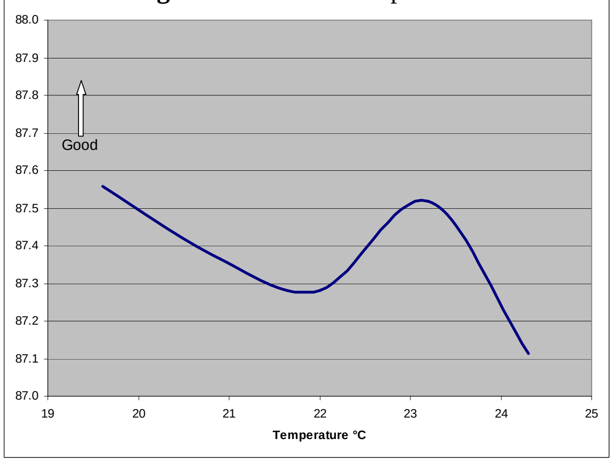


Figure 8: Determining the Optimal Operating Temperature

Figure 8 shows that the best overall balance between Longwave and Shortwave performance is achieved with this setup at the intersection point of 22.2°C (72°F). This also clearly demonstrates how temperature can be used to shift the performance as desired between the two. If it is desirable to optimize Longwave performance over Shortwave, the paint temperature can be lowered down toward 21°C (70°F). Conversely, if it is desirable to optimize Shortwave over Longwave, the paint temperature can be raised up toward 23°C (73°F). This control provides the ability to “fine tune” the process while keeping all other variables constant.

Figure 9: DOI vs. Temperature



The last remaining parameter to be considered was DOI. The results are shown at left in Figure 9:

Here we can see that the optimal DOI results with this setup are achieved at just below 20°C (68°F)and just over 23°C (73°F). For these parts, the minimum value allowed is 86, so the DOI is acceptable at all values between 20°C – 24°C (68°F – 75°F) and therefore will remain in spec regardless of how the long and Shortwave are optimized. This kind of fine tuning allows the best match to the rest of the vehicle to be consistently obtained.

Based on this analysis, it was recommended that a similar experiment be performed on the base coat and the combination of both basecoat and clear coat, to allow the degree of impact that each paint layer has on the overall finish.

THE COMBINED EFFECT OF BASECOAT AND CLEARCOAT TEMPERATURE

For testing both Basecoat and Clearcoat, the decision was made to again focus on the same trim parts painted in the prior experiment (which only use two robots). To facilitate this effort a second set of Re-Corable Coax Hose Assemblies was supplied for the prime booth (applying basecoat in this setup). For this test, the basecoat was applied using the TCU, then the parts were baked and pulled from the line while the TCU was moved to the clearcoat booth to complete the process. A variety of runs were performed to establish the combination of variables and the data was analyzed to determine any relationships between temperature and surface finish.

For this testing, a DeVilbiss Cobra 2 gun was used in each booth due to its fine atomization and fan pattern characteristics. These characteristics allowed the flow rate to each gun to be reduced by 20%, though the rack cycle time was the same. This represents a 20% reduction in paint usage.

The first test was comprised of setting up the temperature control system in the prime booth and spraying 8 racks of parts at different temperatures in the following sequence: 18°C, 20°C, 22°C, 24°C, 26°C, 28°C, 24°C, 20°C. The purpose of reducing the temperature at the end of the test was to determine if the micro-wave-scan parameters would follow the temperature. Once painted and baked, the parts were pulled and inspected to determine the best finish. Because the gloss of the basecoat was below the threshold required for the micro-wave-scan unit, these were judged manually. The result is shown at right in Figure 10:

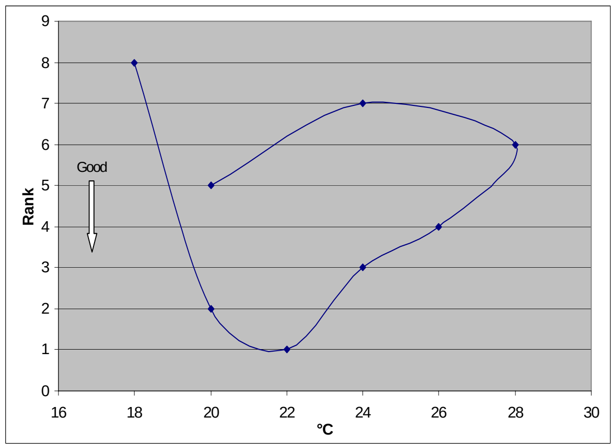


Figure 10: Manual Prime Finish Ranking

This analysis revealed that the best basecoat finish was achieved at 22°C (71.5°F). Multiple racks of parts were then run with a basecoat temperature of 22°C (71.5°F) to use to later test variations in clearcoat temperature. These were also baked and pulled from the line and the TCU was then moved to the clearcoat booth. The temperature data at left in Figure 11 shows the stability of the gun temperature at the end of the trial while these test parts were being run. This is important in assuring that these parts provide a stable base when used in the clearcoat analysis.

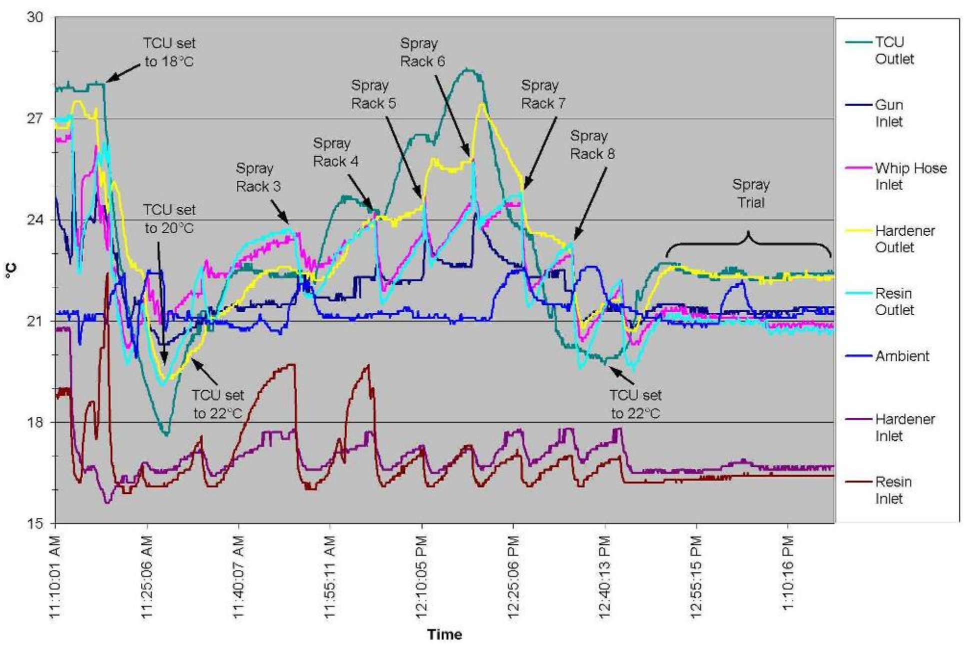
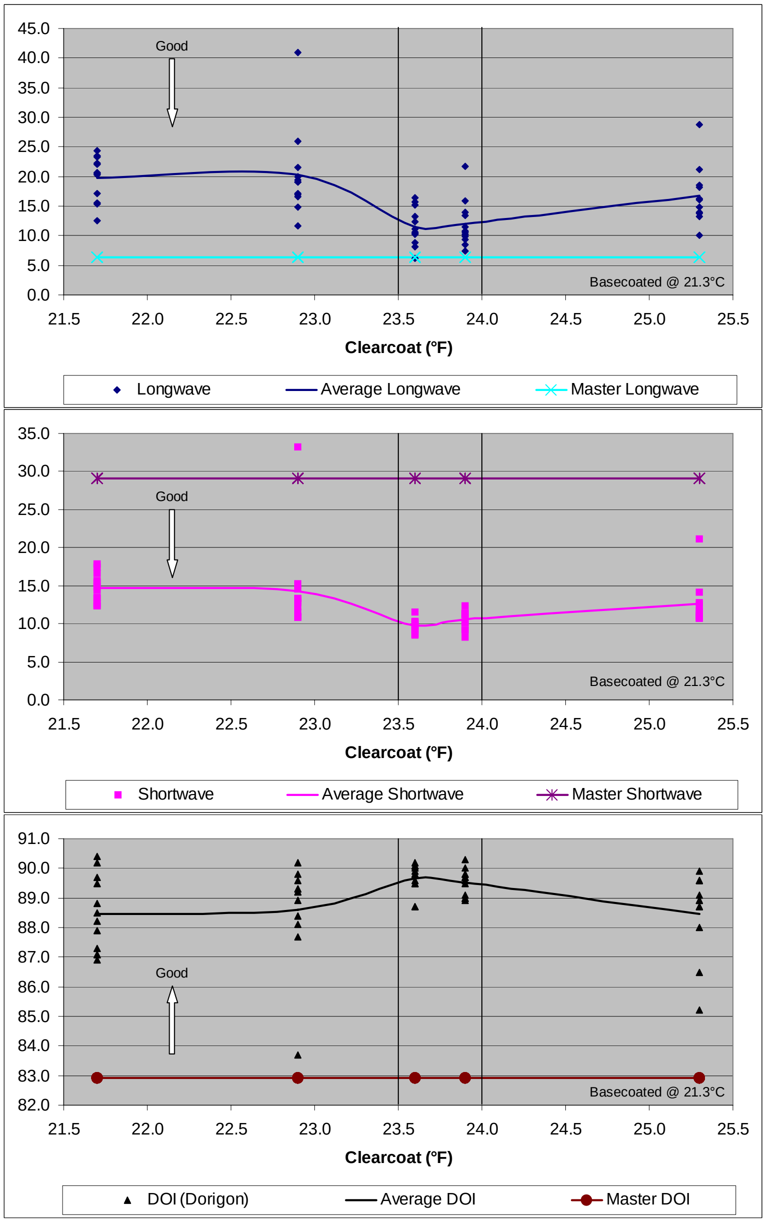


Figure 11: Basecoat Temperature Testing Data

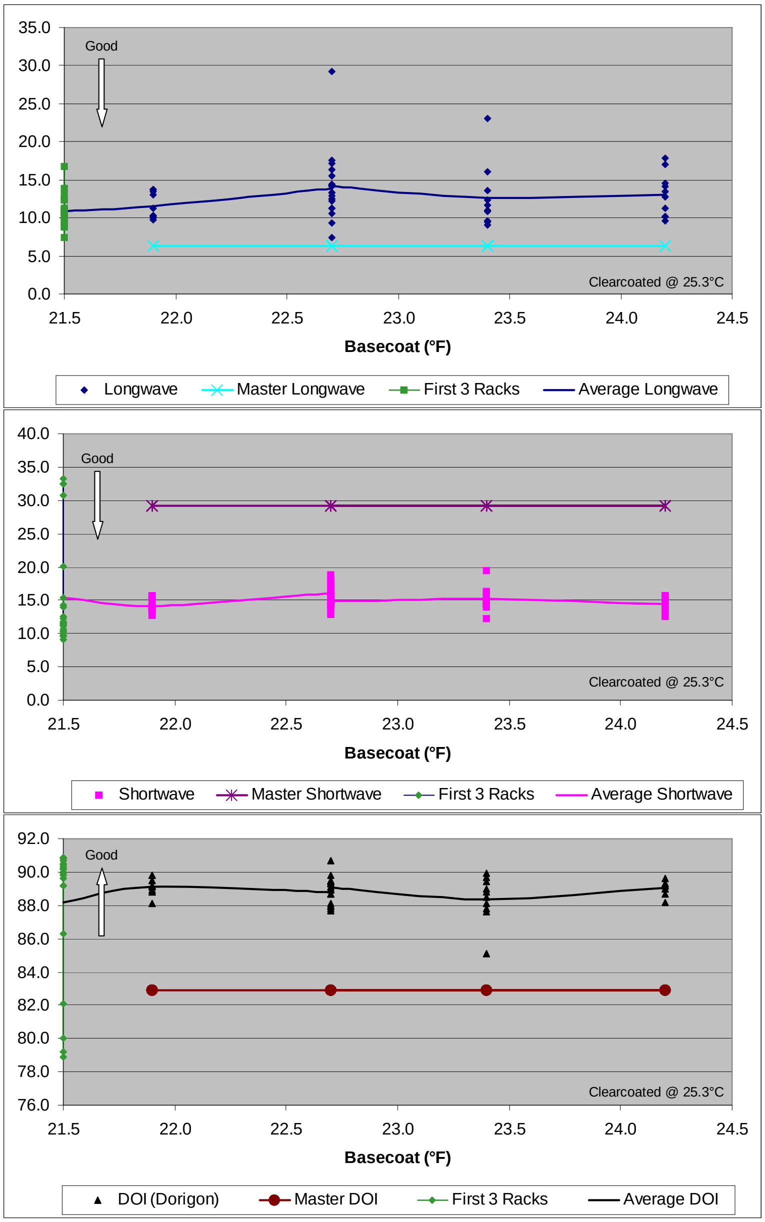
Figure 12: Variable Clearcoat Temperature Testing



The clearcoat testing started with five of those racks basecoated at 22°C (71.5°F) (actual gun temperature 21.3°C (70.3°F). These were then clearcoated at multiple temperatures in sequence (20°C, 22°C, 24°C, 26°C, 28°C) to determine the effect of clearcoat temperature on finish quality with a stable basecoat. The results of this trial are shown at left in Figure 11. Here, all data points are plotted at each temperature such that the actual grouping can be established and the average line is also plotted to show where the mean of the data falls at each temperature. To provide a comparison to the finish goal, the micro-wave-scan readings from the Master Part, approved by the end customer are also shown. These three frames reveal that all three parameters are optimized in the same temperature range – 23.5°C – 24.0°C (74.3°F – 75.2°F). Not only did this achieve the optimal average value in each category, it also produced the lowest variation (tightest groupings). This is extremely important in that lower variation relates to greater first-pass yield. In addition, the DOI and Shortwave are significantly better than the Master and the average of the Longwave is only 5 points off the Master reading. All of this suggests optimal performance with a basecoat spray temperature between 21.0°C – 21.5°C (69.8°F – 70.7°F) and a clearcoat spray temperature between 23.5°C – 24.0°C (74.3°F – 75.2°F). Added to a paint savings of 20%, this will yield significantly better bottom line performance for this trim part than would be achievable without the new gun and temperature control.

The next portion of the test was to load the 8 racks of parts basecoated at varying temperatures from above and clearcoat them at 28°C (82.5°F). It is obvious from the data shown above that this is not the optimal clearcoat temperature for these parts but, as this data had not yet been obtained, the decision was made to move forward based on a visual assessment of wet parts. To complicate matters further, the first three racks were removed from the line and the parts mixed. This means that distinction of the first three of the temperature tests were lost. The data is shown here in Figure 13 with the readings from the first three racks grouped at 21.5°C:

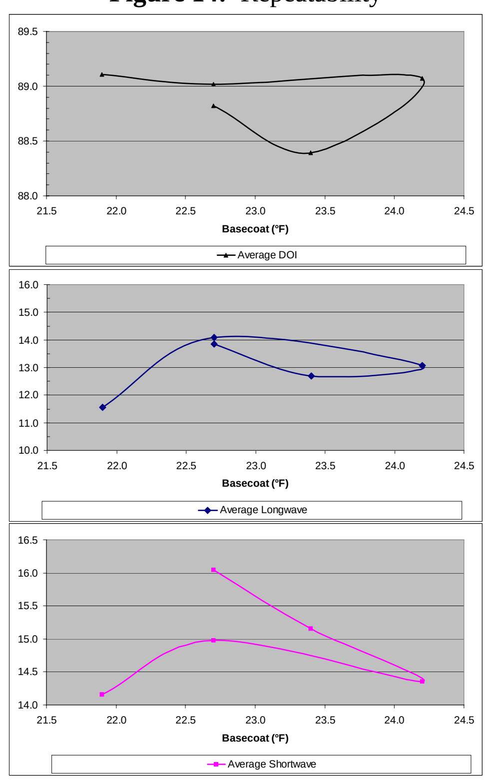
Figure 13: Variable Basecoat Temperature Testing



Due to the limited temperature variation caused by the loss of the first three racks, there is very little variation in the data. What is obvious from this data is that the best performance in all three parameters is in the data just below 22°C (71.5°F). This tends to follow with the data shown above where 22°C (71.5°F) / 21.3°C (70.3°F) was optimal.

Even with the missing data, this experiment was not a total loss. The increase and decrease in temperature allows us to see the repeatability of the data as a function of temperature. This is shown below in Figure 14:

Figure 14: Repeatability



From Figure 14 we see that both DOI and Longwave are virtually repeatable when they return to the 22.7°C (73°F) temperature. Only the Shortwave is a bit askew. This shows us that the effects of temperature are both controllable and repeatable and suggests that we can turn it from an adversary in our quest for quality into a tool we can actively use to improve our quality.

CONCLUSIONS

From this data it is clear that temperature has a significant, measureable impact on surface finish and each coating in the process (prime, base & clear) plays a part. Based on this it is easy to see that temperature can be used as a tool to increase first-pass yield by eliminating variations both within a run and from run-to-run because the effect is repeatable.

The system supplied for the purpose of running these experiments demonstrated how quickly and easily temperature control can be added on an existing system without interfering with the paint path and with minimal downtime.

One proposed alternative to improve first pass yield was to add a robot to each booth. This will be at least 3 – 4 times more expensive and incur days of downtime as opposed to hours for the temperature control system. Furthermore, if the new gun and temperature control system combination can add 5% to the first-pass yield (a very conservative estimate based on past experience), the ROI should be in months as opposed to years. Furthermore, any increase in first-pass yield frees production time that would otherwise be dedicated to rework or additional production which can be used to generate new business – this represents revenue growth which adds to the ROI equation much faster than cost reductions. In every way, this is a fast, sure improvement path with a short term ROI and a long term benefit.

BIBLIOGRAPHY

1 – Water Temperature vs. Viscosity data provided courtesy of Norcross Corporation.

2 – Paint Viscosity vs. Temperature data provided courtesy of Sherwin-Williams Corporation.

Michael R. Bonner is the Vice President of Engineering & Technology for Saint Clair Systems, Inc., a leading supplier of process temperature control equipment for industrial processing systems.