Fine Powder Investigation for Optimum Imperial 008004 Solder Paste Printing: Part I

Authored by: Adam Murling, Meagan Sloan, and Miloš Lazić, Indium Corporation; and Ed Nauss and Mike Butler, ITW EAE.

Abstract

Miniaturization has been, and continues to be, a challenge for the electronics industry. Assemblies are getting more complex, component spacing is decreasing, and circuit board real estate is quickly becoming a premium commodity. Board assemblers are currently investing many resources to prove that circuit boards for future challenges can be built. The 1990s revealed the 0402, the 2000s created the 0201 component, and the 2010s introduced the 01005; all of this yielded the 008004, with each new component saving more and more space. Currently, the mobile communications market is using these small components and other industries are quickly catching up. As component size decreases, material suppliers have to develop next generation materials and processes to meet the industry's needs. This paper will investigate the effect of powder size on the transfer efficiency of solder paste. Five different powder sizes will be homogeneously mixed within the same flux vehicle to yield five different solder paste systems. Each system will be evaluated to provide the optimum print conditions for the 008004 apertures and pad design. All of the powder sizes will then be compared to each other to determine the appropriate powder size distribution.

Introduction

As the implementation of the next level of component miniaturization in the form of the 008004 (0201 metric) is presently being examined, printed circuit pad and stencil aperture designs are becoming clearer. Requirements for equipment that need to be adapted to these miniature components have little room for compromise. Increased stencil printer accuracy, enhancements to the optics of the SPI, specific nozzles and feeders for the placement system, and a nitrogen atmosphere in the reflow process reflect the requirements needed to successfully implement miniature components. However, based on previous introductions of reduced component sizes, there is a reluctance to adhere to the recommendations of decreasing the powder size in the solder paste. This reluctance is often motivated by increased cost, familiarity with the existing material, or availability of finer powder sizes from their present vendor. In anticipation of this trend, this paper explores what effects the different powder sizes have on 008004 (0201 metric) aperture sizes and surrounding larger aperture sizes, and to understand where the limits are in order to successfully implement a successful and repeatable 008004 (0201 metric) process.

ADAM MURLING

Adam Murling, Assistant Engineering Manager – Technical Support, assists in the vision, strategy and long-term goals for the Americas-based technical support engineering department, as well as providing technical support to the Midwest region. He is also responsible for coaching, supporting, and supervising project work performed by technical support teams. He is an active blogger, has authored technical papers on wave solder fluxes and solder preforms and was the moderator for Indium Corporation's inaugural InSIDER Series webinar.

Murling has a bachelor's degree in chemical engineering from Clarkson University. While at Clarkson, he worked as a researcher for the Partech Research Group where he converted biomass into fuel oil using a Parr high-pressure reactor. Murling also interned at the Air Force Research Laboratory in Rome, NY, where he performed nanotechnology research.

email: amurling@indium.com
Full biography: www.indium.com/biographies

When 0402 (01005 metric) components were first entering mainstream production, the predominant powder size being used was Type 3 powder. This component required, as did many components to come, the use of Type 4 powder. However, many who continued to use Type 3 powder had negative results such as inadequate volume, non-wet opens, and clogged apertures. The reason for most not switching to Type 4 powder was either being unaware of the powder requirement, not wanting to incur increased material costs, or having to manage multiple materials on the production floor. Another scenario was in automotive, medical, and military applications where processes would be signed off with a specific material, and then a new and additional unknown material would be introduced to the process.

History and The Five-Ball Rule

Back in the 1980s, a “rule of thumb” was developed where a correlation between ball size and the width of an aperture opening could be used to determine if there was a match between the two. The rule is simply to take the largest ball size that was specified for that powder type and multiply it by a factor of 5 to determine the minimum aperture width that would exhibit good, repeatable paste transfer (Figure 1). For example, the largest ball size for Type 6 is 20µm (0.00078"). Multiply this by 5 and we get 100µm (0.00393"), so roughly our minimum aperture size is determined to be 100µm (0.00393"). Using this as a guide, rectangular apertures should use area ratios greater than 1.5, and circular apertures should use area ratios greater than 0.66.

Table 1 shows the differences between the different powder sizes. For years, the dominant powder size was Type 3. As apertures continued to be reduced, Type 4 became the dominant powder size now used in the SMT market today. Improvements in powder yields and industry demand have made the availability of Type 4 and Type 5 powders more prevalent in the marketplace. Traditionally, yields for Type 6 and Type 7 powders have remained constant and small compared to the larger sizes and thus are less available and potentially more

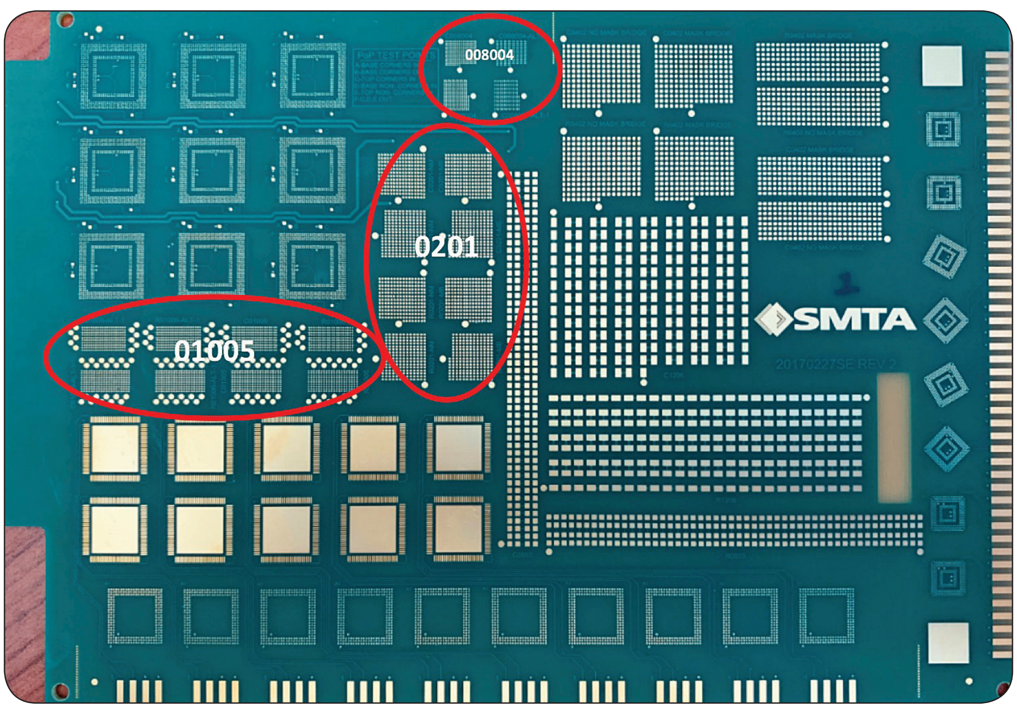


Figure 1. SMTA test vehicle.

MEAGAN SLOAN

Meagan Sloan is a Technical Support Engineer II based at the Indium Corporation’s headquarters in Clinton, NY, USA.

Meagan provides leading edge technical support to customers and potential customers all over the Northeast. She is responsible for resolving complex solder process challenges, and takes a direct role in project-related activities in the SIM Lab.

Meagan earned her master’s degree in chemical engineering from Syracuse University and her bachelor’s degree in Chemistry with a concentration in Pre-engineering through a dual program between Le Moyne College and Syracuse University. She has helped author technical papers. She is a member of the American Chemical Society and the Surface Mount Technology Association (SMTA), holds a leadership position in the SMTA Empire Chapter as vice president of Young Professionals, and is the new chair for the 5-24A Flux Specification Task Group. She also earned numerous awards from the American Institute of Chemists and the American Chemical Society.

email: msloan@indium.com
Full biography: www.indium.com/biographies

Table 1. Powder sizes.

Powder Type	Mesh Size	Micron Range	Average Ball Size (µm)	Largest Ball Size (µm)
Type 3	-325/+500	25–45µm	35	45
Type 4	-400/+635	20–38µm	30	38
Type 4.5	-450/+635	20–32µm	25	32
Type 5	-500/+635	20–25µm	20	25
Type 5.5	-550/+635	15–25µm	15	22
Type 6	+635	<20µm	10	20
Type 7	N/A	2–11µm	5	11

expensive. Availability and lead time along with an increase in material costs begs the question, "What is the minimum powder size that can be used and are the results within specifications and repeatable?"

Once the powder is formed, the process of separating the spheres by size involves using a mesh process. If the powder passes through the mesh, it is designated with a minus sign and if it is caught by that mesh, it is designated with a plus sign. The mesh number indicates how many mesh lines cross a square-inch area. For example, a typical Type 4 is a -400/+635. With each deduction in mesh, the yield drops off, thus the increase in cost. Paste is packaged equally with metal and flux, with the weight based on the percentage of metal. Typical metal percentages for Type 4 is 88–92% where Types 5 and 6 will have metal percentages in the 85–90% range. The percentages are based on the alloy densities. With the reduction of particle size, another consideration comes with the increase in surface area of the total solder spheres. When comparing the surface area of 1kg of material using the average solder ball size of the powder, the surface area is increased by roughly 20% from Type 3 to Type 4. The same comparison between Type 3 and Type 5 is an increase of 75%, where Type 6 sees an incredible 350% increase in surface area. This requires different chemistries to be employed in the paste formulation to address this issue. This also affects the shelf life of the solder paste and material handling needs to be addressed. Time that the material is present on the stencil, or stencil life, needs to be observed and regulated as this will affect the printing as well as the reflow process due to its exposure to the environment.

As the miniaturization of components continued, hybrid powder sizes were developed to widen the manufacturing process window of SMT lines. This is where the powder specifications were split in order to compromise on the area ratio requirement where, for example, an aperture size that would best case require a Type 5, a Type 4.5 was developed to bridge this gap. A specific powder size can be optimized for any customer's application.

Design of Experiments (DOE)

The purpose of this DOE is to show different solder paste printing limitations and capabilities of five different powder sizes on the 008004 (0201 metric) component. Each aspect of the DOE was carefully laid out to minimize the data from being skewed due to any equipment, materials, and process anomalies. From the equipment standpoint, the printer was qualified by passing a CeTaQ print capability test and a Gage R&R was performed on the solder paste inspection (SPI) machine prior to any testing. The printer was set up the same, with a 2.4mil-thick laser cut, stainless steel nanocoated stencil, 55-degree surgical steel squeegee blades, and dedicated tooling with vacuum for all five tests. The SPI

MILOŠ LAZIĆ

Miloš Lazić, Product Development Specialist at Indium Corporation's headquarters in Clinton, NY, USA, works with the cross-functional Thermal team to launch fully-scaled, marketable products and their associated assembly processes, for Indium Corporation's expanding portfolio of Thermal Interface Materials (TIMs).

Miloš joined Indium Corporation in 2018. He attended the University of Nis, School of Electronics Engineering, where he received his Master's degree in Electronics Engineering and Bachelor's degree in Electrical Engineering. Miloš is a founder of the non-profit organization, "Urban Youth Forum," which successfully encourages students to plan, develop, and execute projects involving environmental protection through the recycling of electronic waste. Miloš is fluent in English, Serbian, Croatian, and Bosnian.

email: mlazic@indium.com

Full biography: www.indium.com/biographies

was set up to use an optimal threshold for the board being scanned. To factor out any noise, a bare board teach (BBT) was also performed using the boards from the actual test to set an accurate base plane for each pad. To limit the effects of the materials anomalies, such as board stretch, all 10 boards were labeled to ensure they were printed in the same order for the five different powder sizes. This was done to help normalize the data across the five different powder sizes. The print parameters for all five tests were the same. The print pressure was 15lbs for the 10-inch squeegee blades, with a print speed of 1.5 inch/second. Stencil release distance was set to 0.100, with a speed of 1 second and a wipe sequence of Dry/Vac/Vac was performed after each printed board. To condition the stencil to optimum performance and paste to working viscosity, the test started by printing four boards and then the 10 test boards were printed. The 10 test boards were scanned by two different SPI machines and every second and tenth board were manually inspected under the microscope.

As previously stated, the SMTA test vehicle was used (Figure 1). The areas of concern for the board are circled in red for reference. Table 2 references the sizes of the component pads and their corresponding apertures.

Table 2. SMTA board pad and aperture designs.

Component	Pad	Aperture
0201	12 x 15 rectangle (9mil gap)	10.8 x 13.5
01005	8 x 8 square (7mil gap)	8 x 8
01005 – ALT 1	8 x 8 square (8mil gap)	8 x 8
008004	7 x 6 rectangle (4.7mil gap)	7 x 6
008004 – ALT 1	5.1 x 6.3 rectangle (6.7mil gap)	5.1 x 6.3

Both the 01005 and the 008004 components had alternate pads and corresponding apertures. These are reflected in the data as separate tables.

Results

The different powder sizes were coded with letter designations to help separate the data: T5A, T5B, T6A, T6B and T6C. All of the volumetric data was analyzed by using JMP® Statistical Software from SAS. That data was separated using the Variability/Attribute Gauge Chart function by the following characteristics:

- Solder Paste Stencil
- Solder Paste
- Powder Size
- Board Number

Each graph was then separated from each other by using:

- Part Number
- Aperture Size
- Area Ratio

The data in the variability charts has the stencil, solder paste, powder size, and board number positioned on the x-axis while the volume percent is on the y-axis. These charts also share the plot of each box plot's standard deviation of each board.

There is an anomaly with powder Type 6A. Board 6 for T6A consistently has large volume percentages across the different apertures. This is hypothesized to be contamination or foreign debris since the same 10 boards were used in every powder condition. Figures 2 through 13 show the variability charts for 008004 (aperture size and orientation), 01005 (component type and aperture size), and 0201 (component type, aperture size, and orientation).

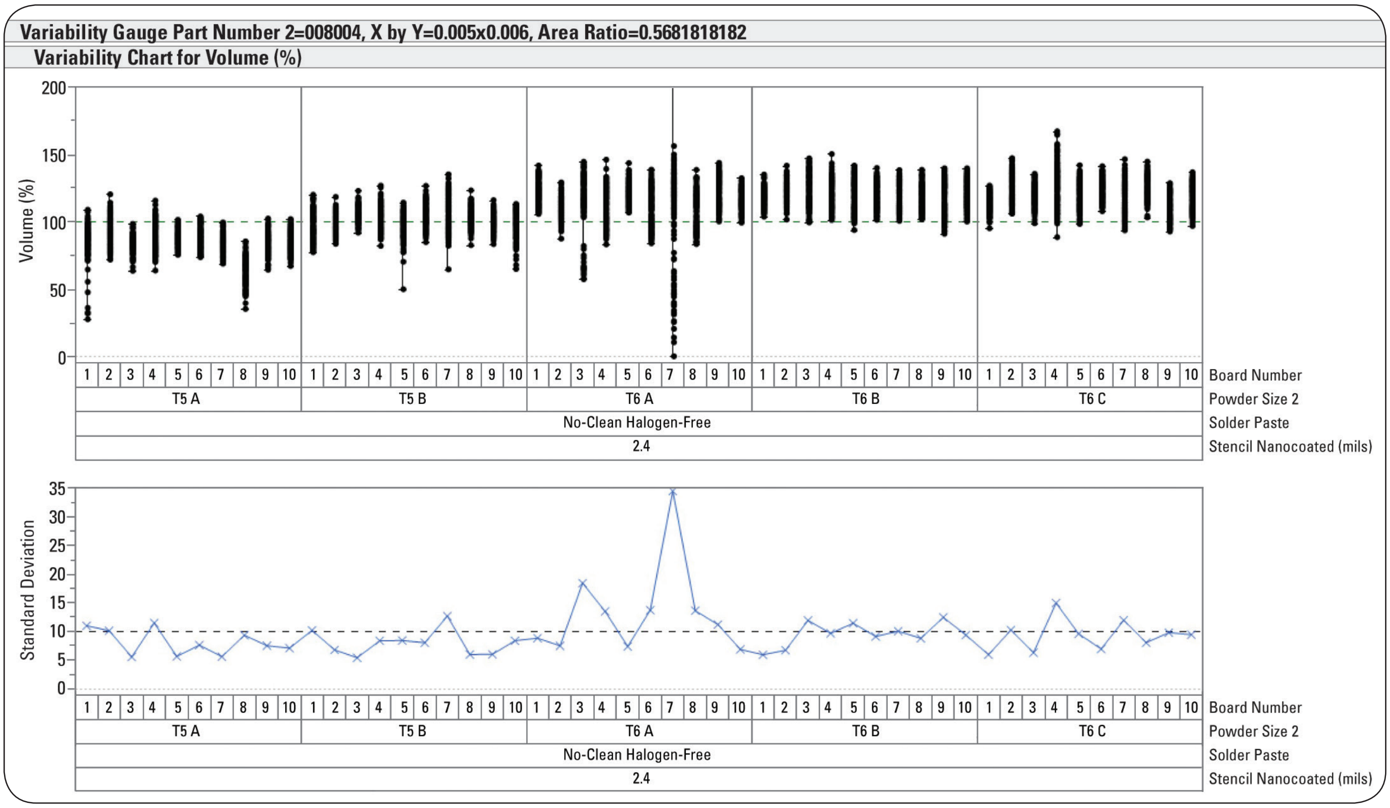


Figure 2. Component: 008004; Aperture: 0.005 by 0.006; Area Ratio: 0.568.

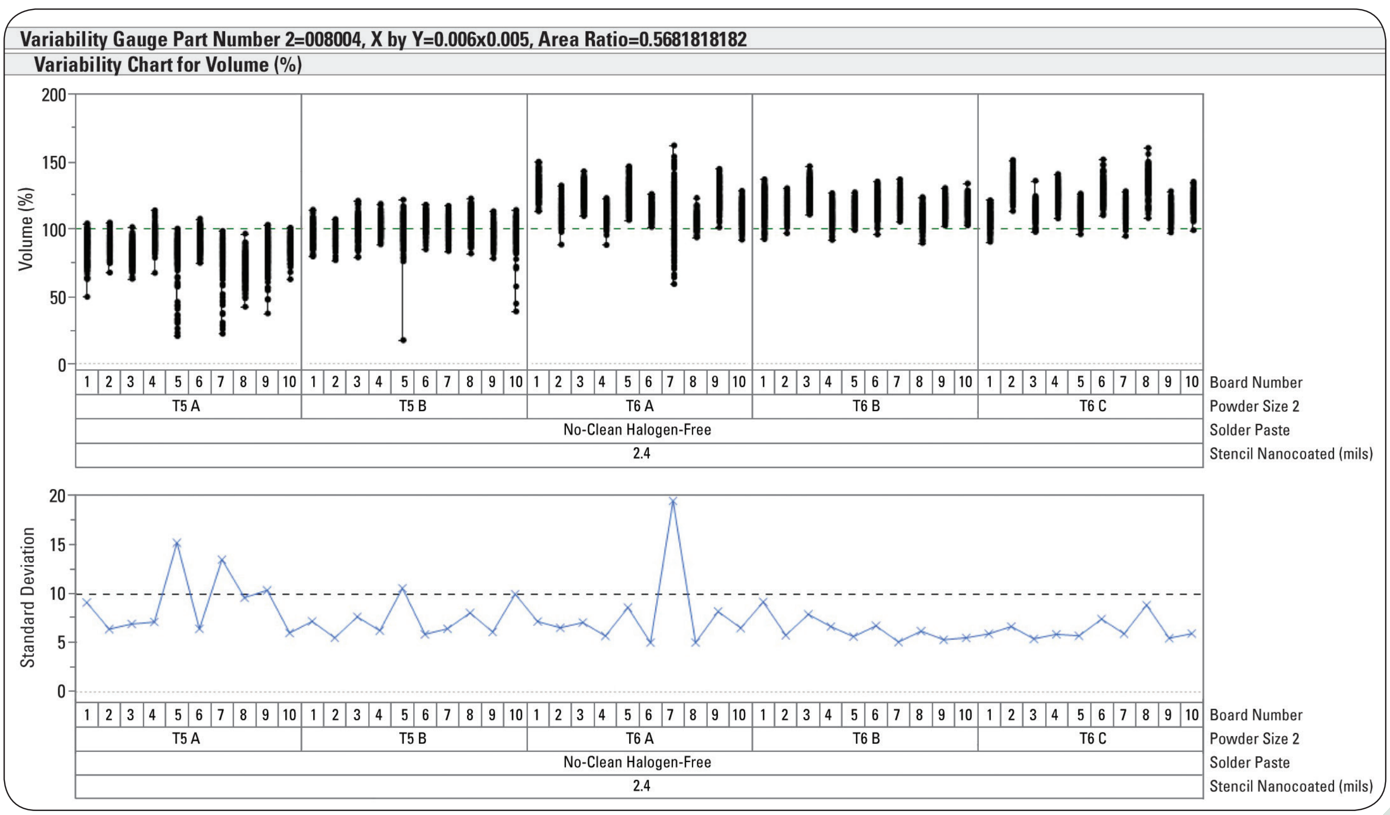


Figure 3. Component: 008004; Aperture: 0.006 by 0.005; Area Ratio: 0.568.

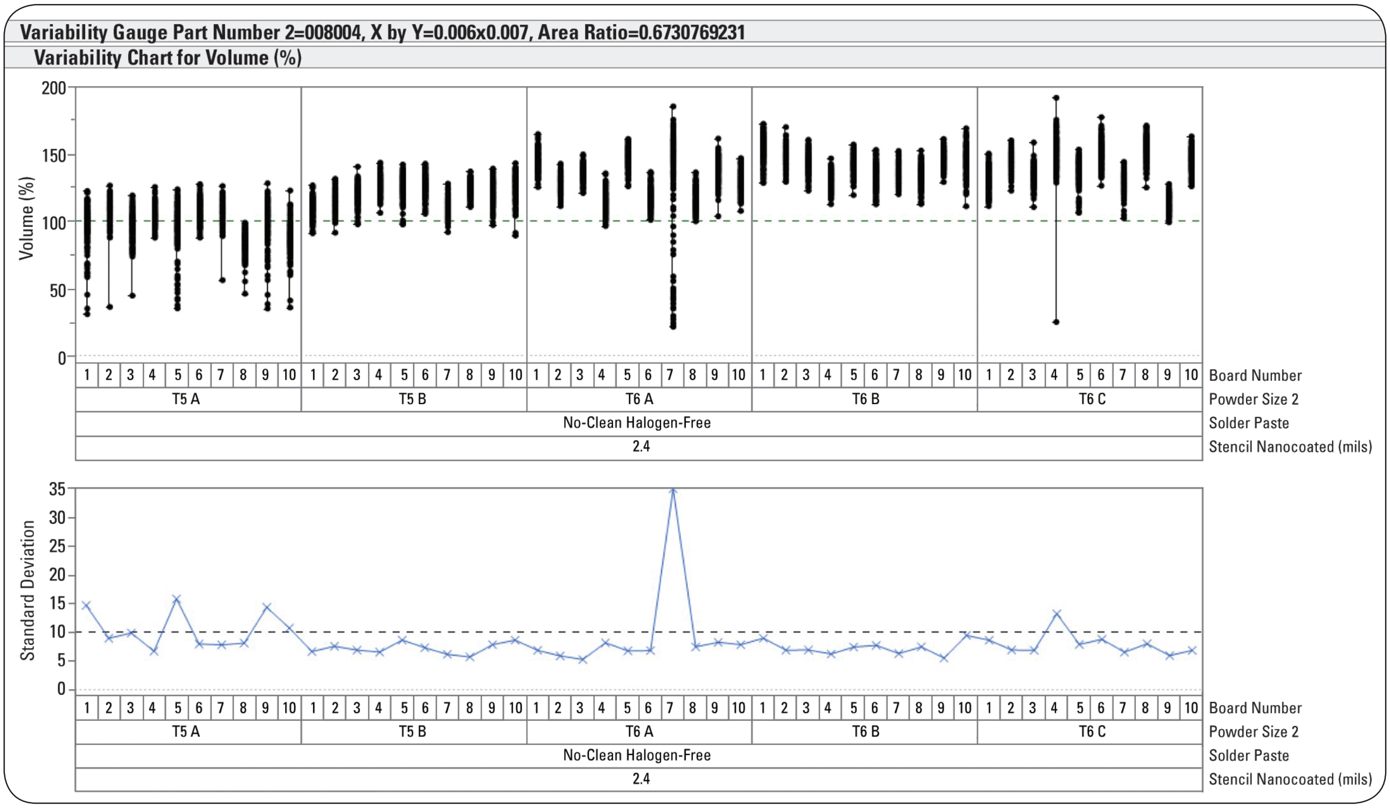


Figure 4. Component: 008004; Aperture: 0.006 by 0.007; Area Ratio: 0.673.

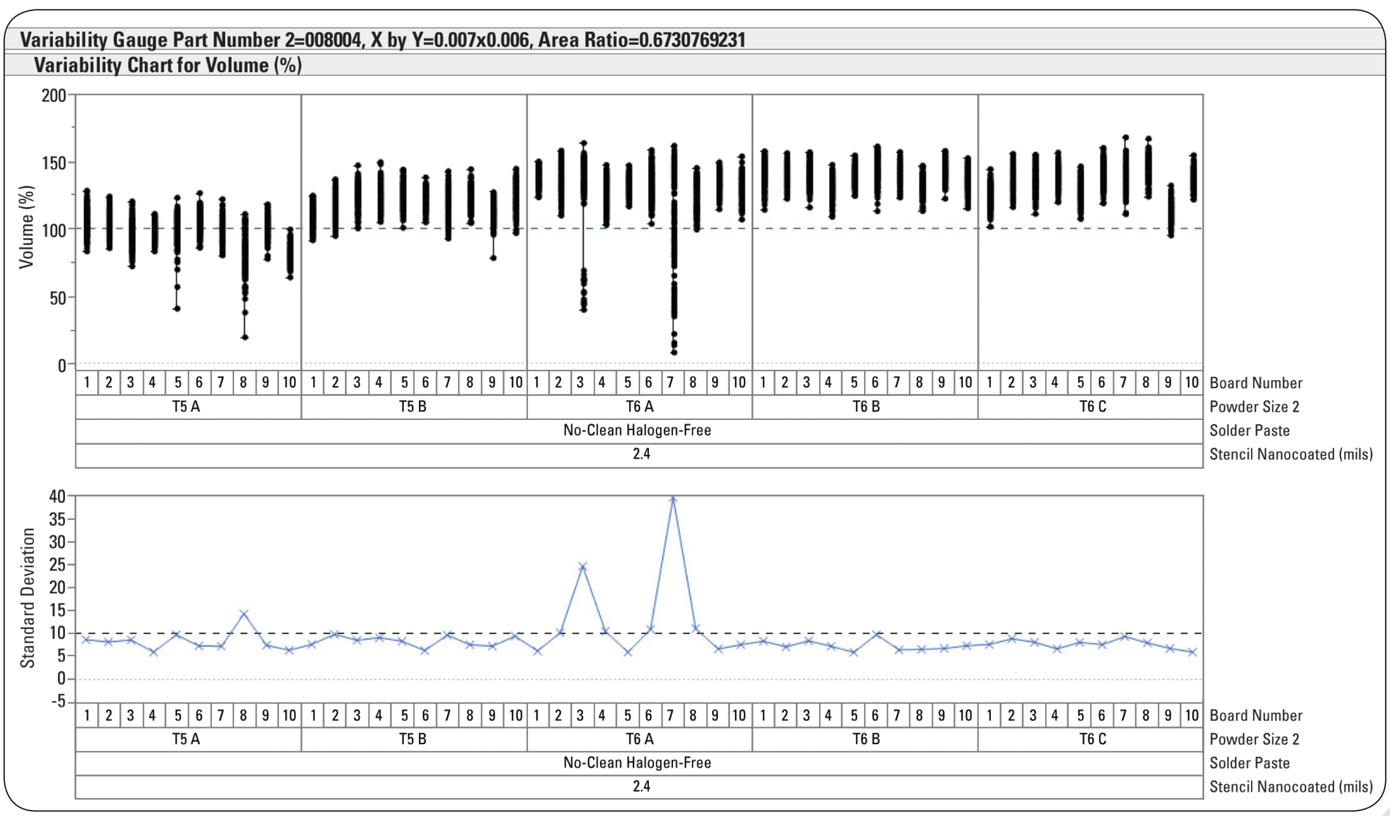


Figure 5. Component: 008004; Aperture: 0.007 by 0.006; Area Ratio: 0.673.

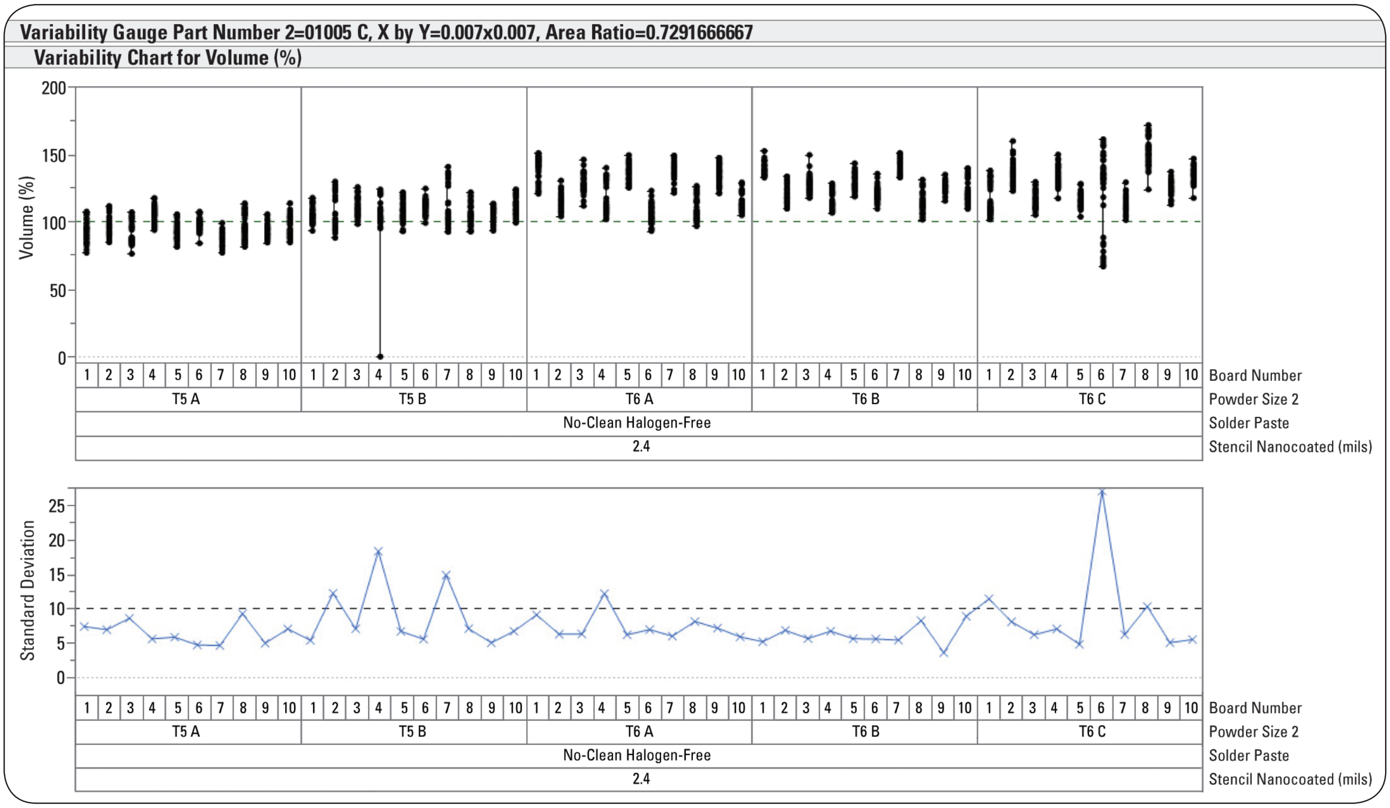


Figure 6. Component: 01005 C; Aperture: 0.007 by 0.007; Area Ratio: 0.729.

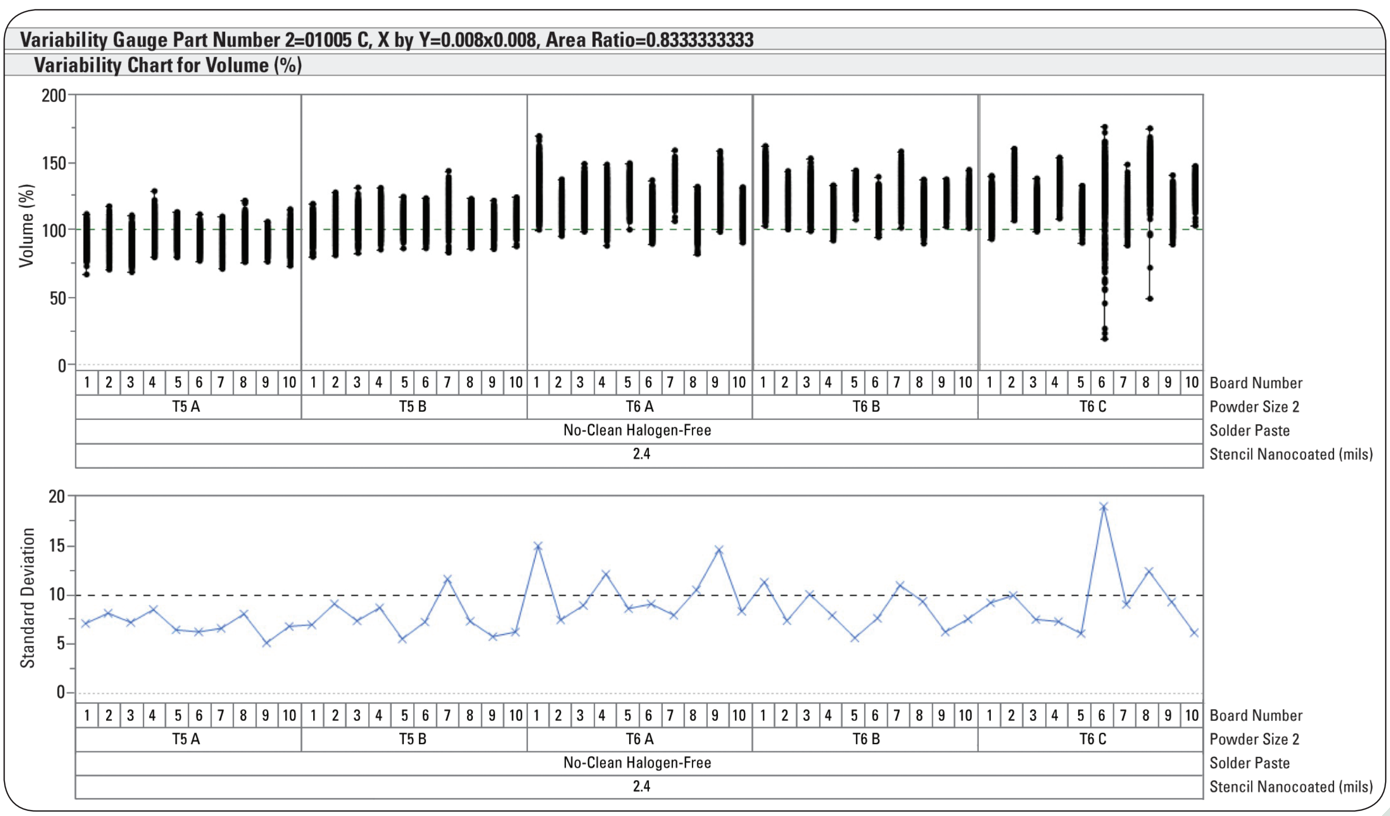


Figure 7. Component: 01005 C; Aperture: 0.008 by 0.008; Area Ratio: 0.833.

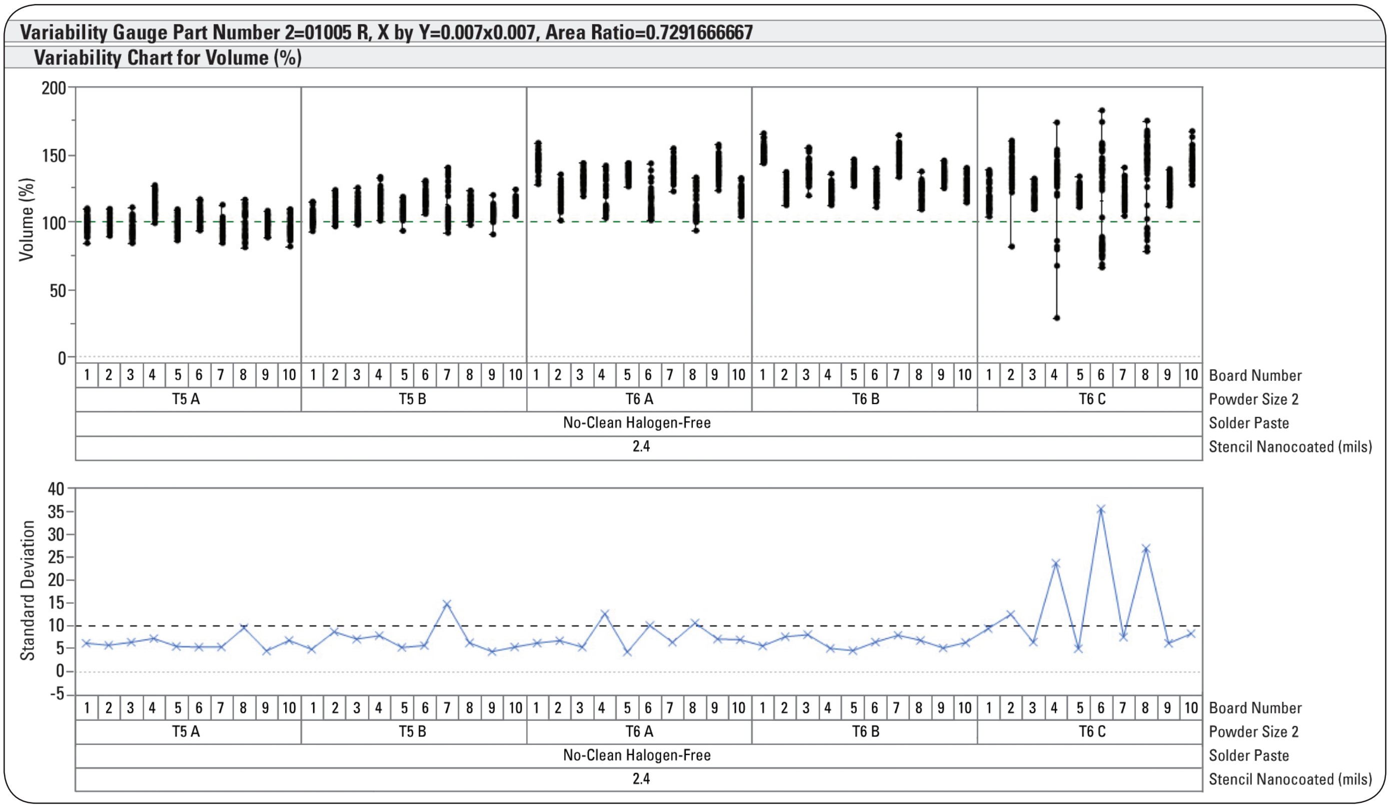


Figure 8. Component: 01005 R; Aperture: 0.007 by 0.007; Area Ratio: 0.729.

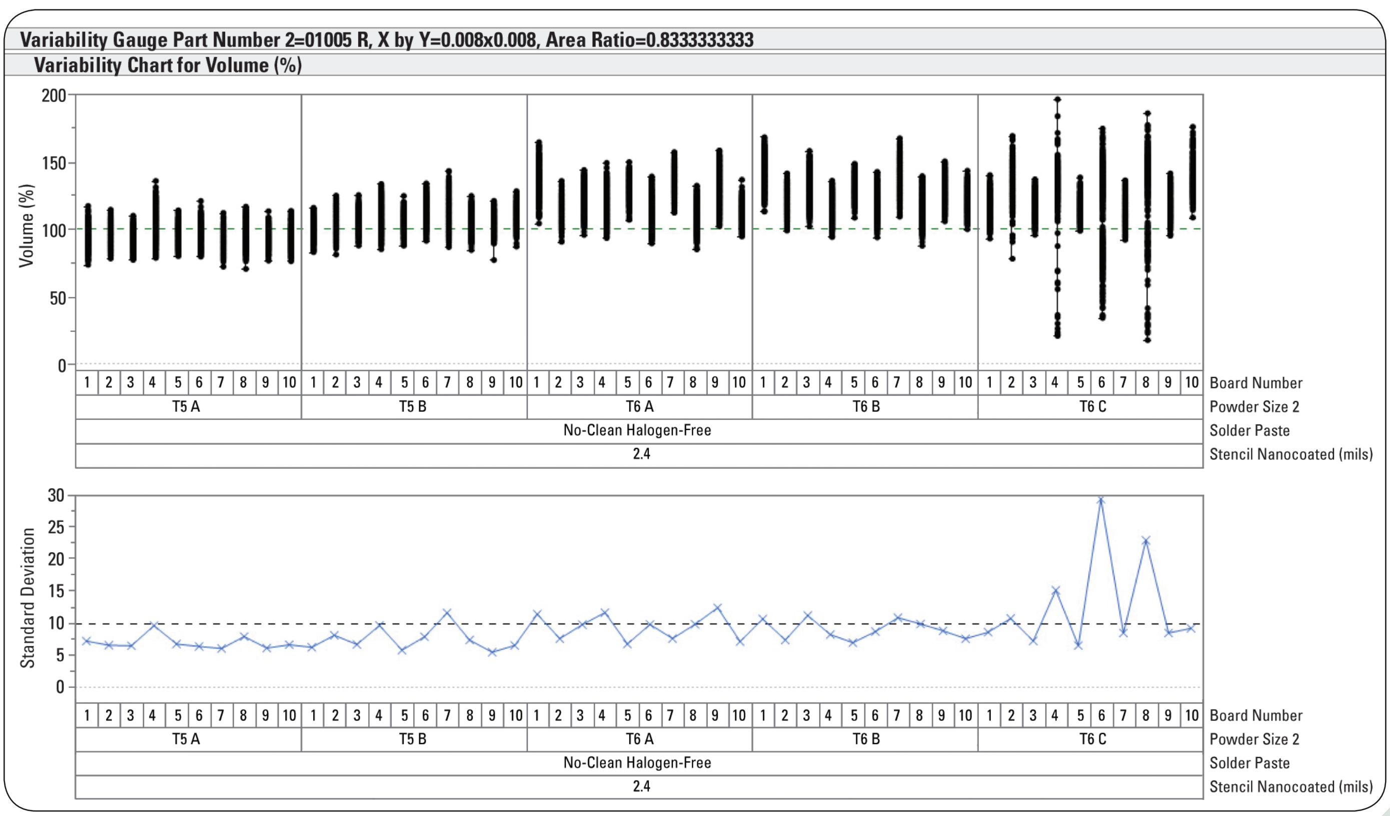


Figure 9. Component: 01005 R; Aperture: 0.008 by 0.008; Area Ratio: 0.833.

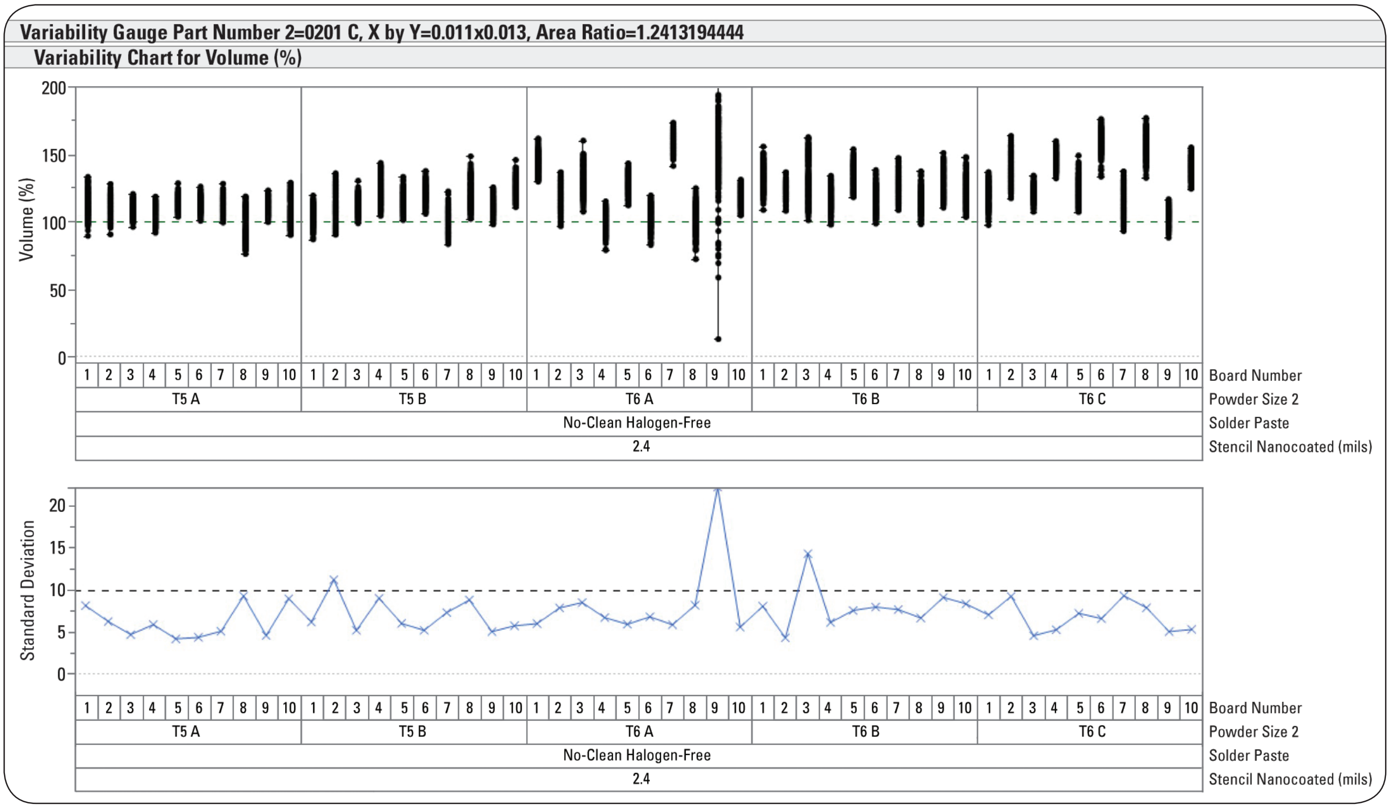


Figure 10. Component: 0201 C; Aperture: 0.011 by 0.013; Area Ratio: 1.241.

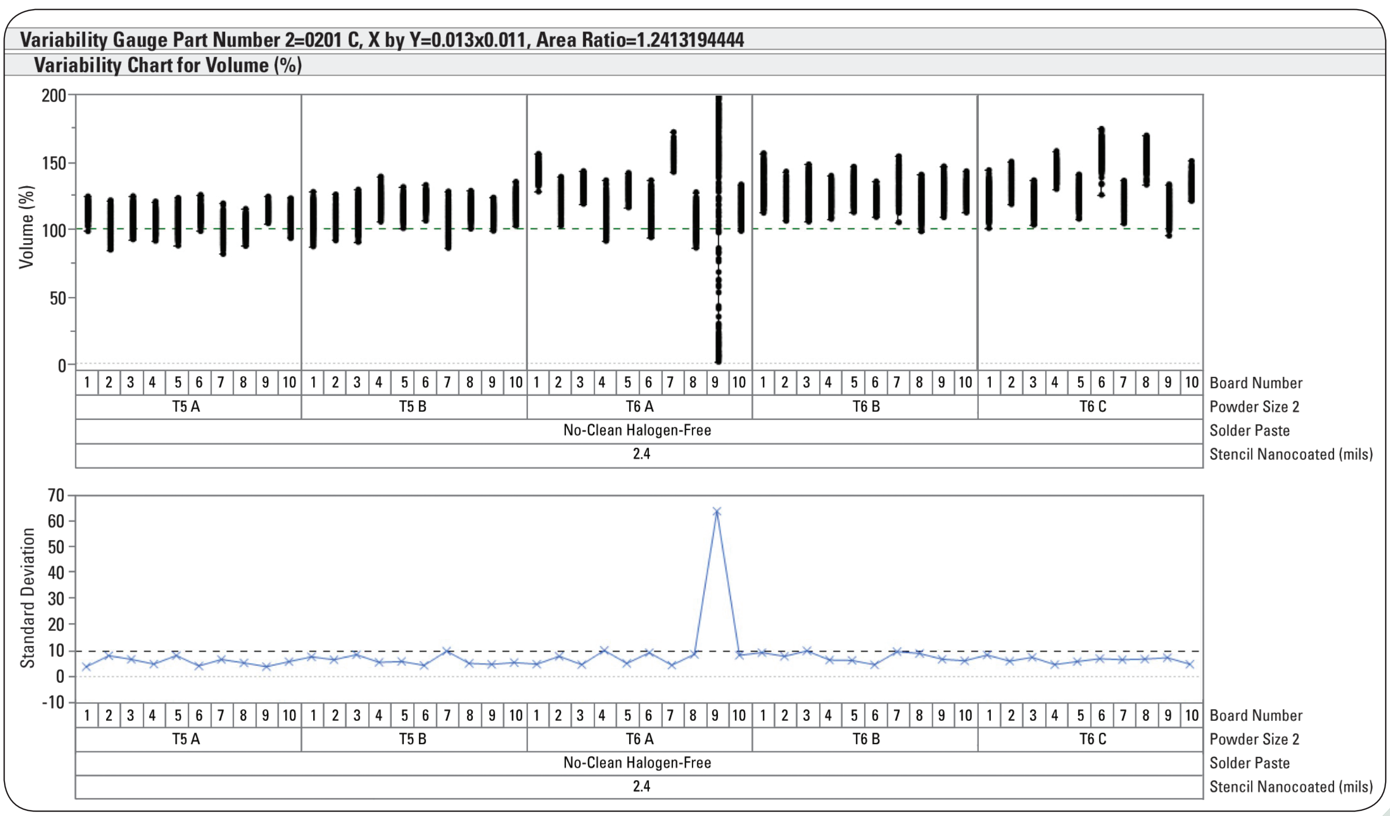


Figure 11. Component: 0201 C; Aperture: 0.013 by 0.011; Area Ratio: 1.241.

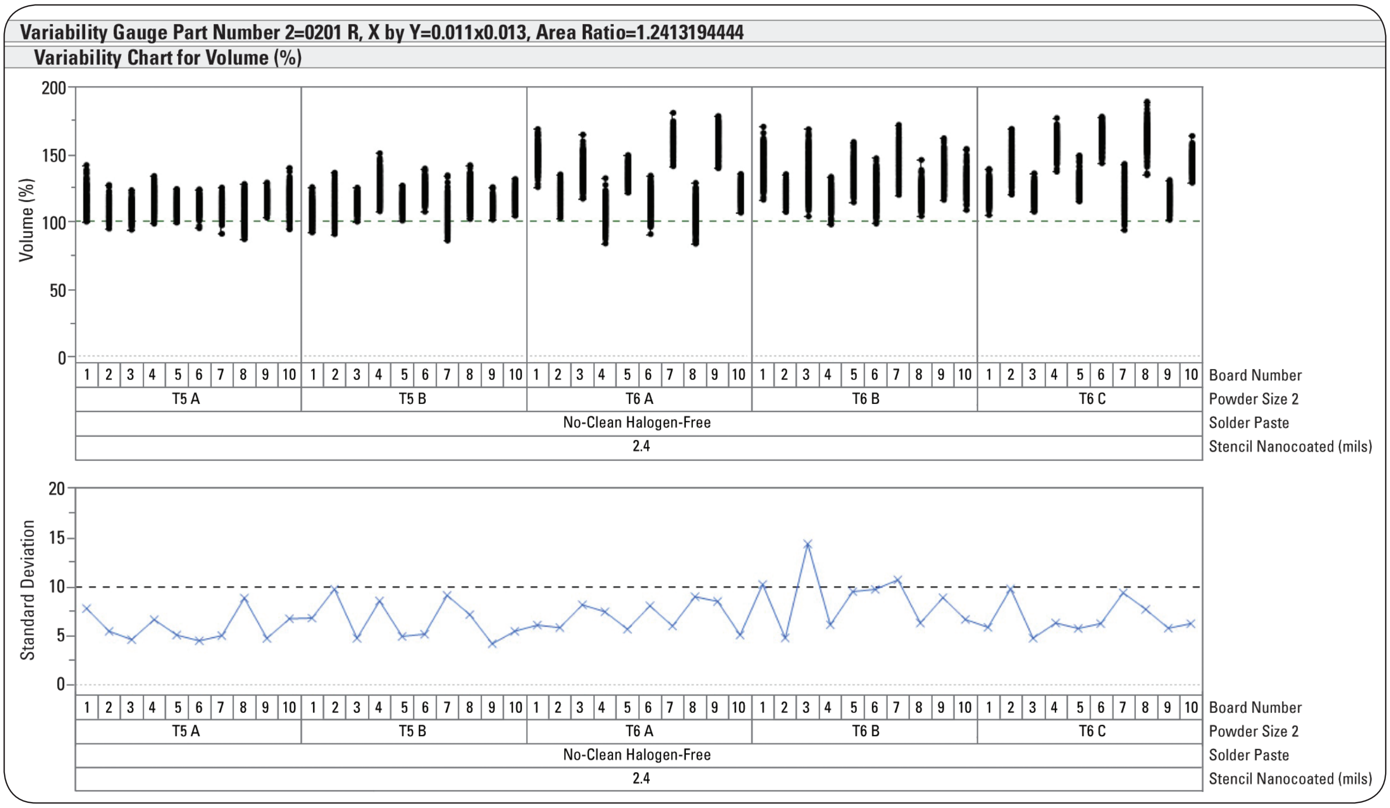


Figure 12. Component: 0201 R; Aperture: 0.011 by 0.013; Area Ratio: 1.241.

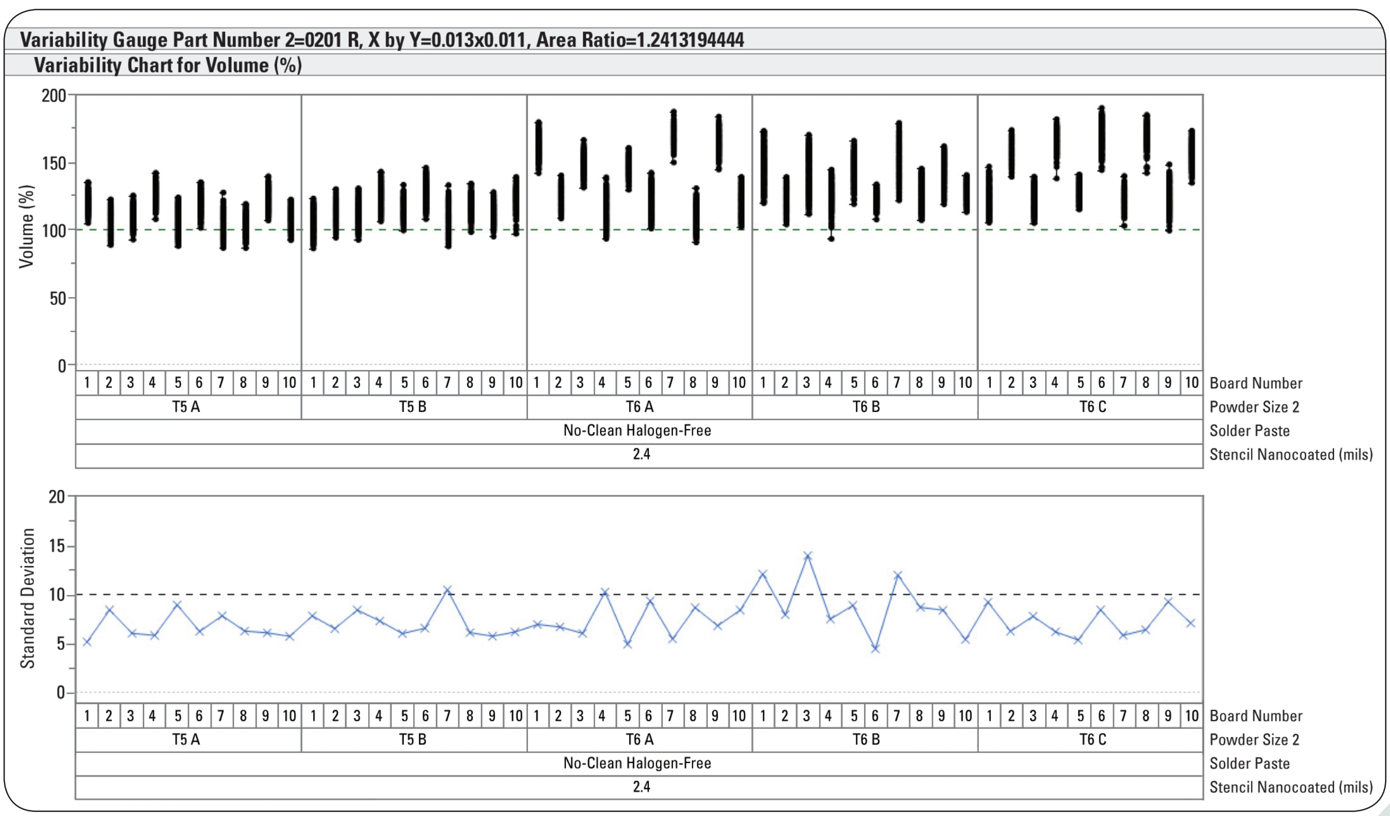
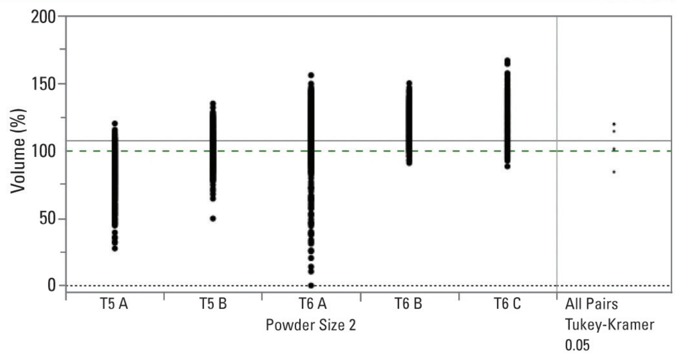


Figure 13. Component: 0201 R; Aperture: 0.013 by 0.011; Area Ratio: 1.241.

The powder sizes were then compared to each other using a one-way analysis of volume percent with the Tukey-Kramer method. This determines if the data is statistically different from each other. The data is broken up using a connecting letter report which shows that levels not connected by the same letter are significantly different. Figures 14 through 25 expand on the data set.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 008004, X by Y=0.005x0.006, Area Ratio=0.5681818182



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72827	0.05

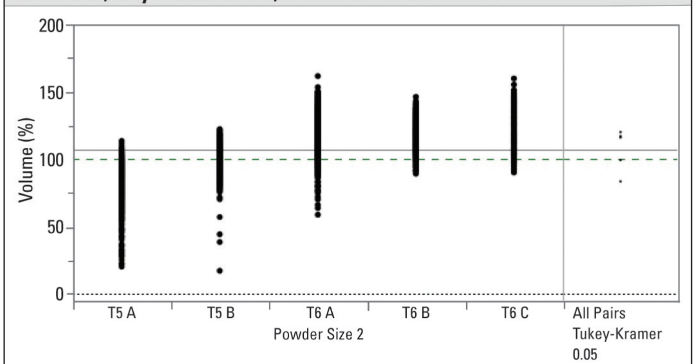
Connecting Letters Report

Level					Mean
T6 C	A				119.81246
T6 B	A				119.56581
T6 A		B			114.36131
T5 B			C		101.31779
T5 A				D	84.26886

Levels not connected by same letter are significantly different.

Figure 14. Component: 008004; Aperture: 0.005 by 0.006; Area Ratio: 0.568.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 008004, X by Y=0.006x0.005, Area Ratio=0.5681818182



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72827	0.05

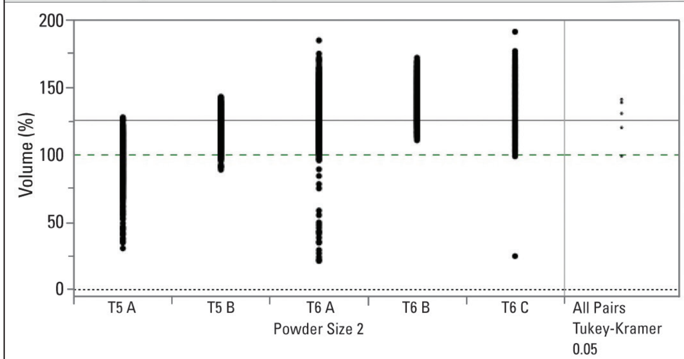
Connecting Letters Report

Level						Mean
T6 C	A					120.06492
T6 A		B				117.01985
T6 B			C			116.00619
T5 B				D		99.26463
T5 A					E	83.50410

Levels not connected by same letter are significantly different.

Figure 15. Component: 008004; Aperture: 0.006 by 0.005; Area Ratio: 0.568.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 008004, X by Y=0.006x0.007, Area Ratio=0.6730769231



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72827	0.05

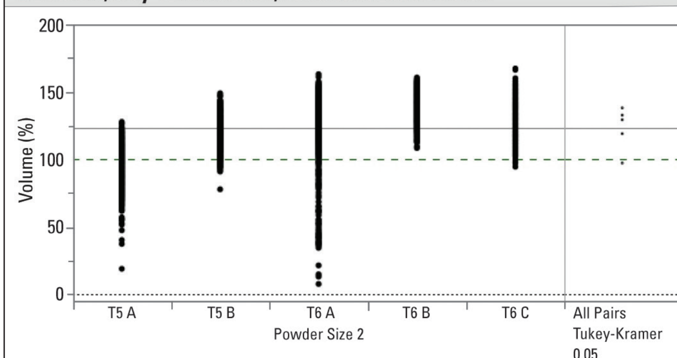
Connecting Letters Report

Level						Mean
T6 B	A					140.85765
T6 C		B				138.58794
T6 A			C			130.46803
T5 B				D		120.05750
T5 A					E	98.86000

Levels not connected by same letter are significantly different.

Figure 16. Component: 008004; Aperture: 0.006 by 0.007; Area Ratio: 0.673.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 008004, X by Y=0.007x0.006, Area Ratio=0.6730769231



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72827	0.05

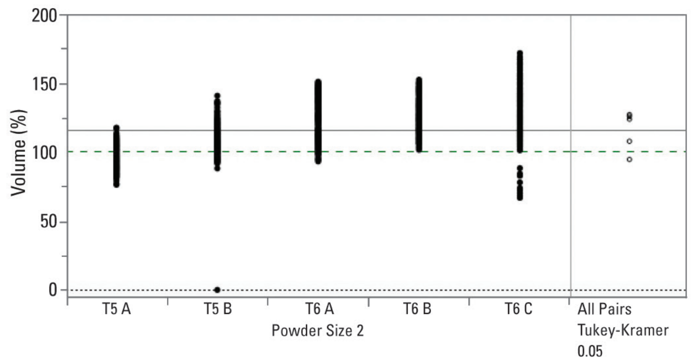
Connecting Letters Report

Level						Mean
T6 B	A					138.08179
T6 C		B				132.67524
T6 A			C			129.23964
T5 B				D		118.99061
T5 A					E	97.29930

Levels not connected by same letter are significantly different.

Figure 17. Component: 008004; Aperture: 0.007 by 0.006; Area Ratio: 0.673.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 01005 C, X by Y=0.007x0.007, Area Ratio=0.7291666667



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72999	0.05

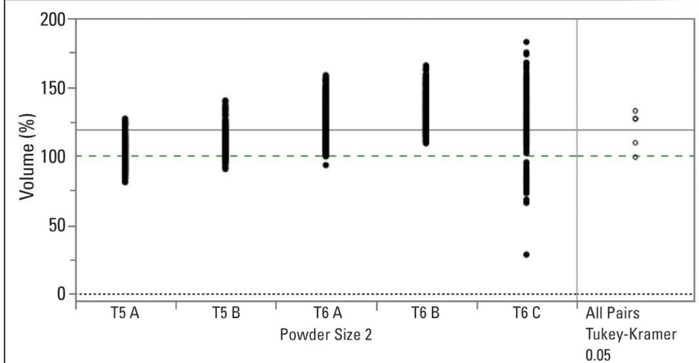
Connecting Letters Report

Level					Mean
T6 C	A				126.61918
T6 B	A	B			125.24402
T6 A		B			123.16781
T5 B			C		107.27828
T5 A				D	94.17534

Levels not connected by same letter are significantly different.

Figure 18. Component: 01005 C; Aperture: 0.007 by 0.007; Area Ratio: 0.729.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 01005 R, X by Y=0.007x0.007, Area Ratio=0.7291666667



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72974	0.05

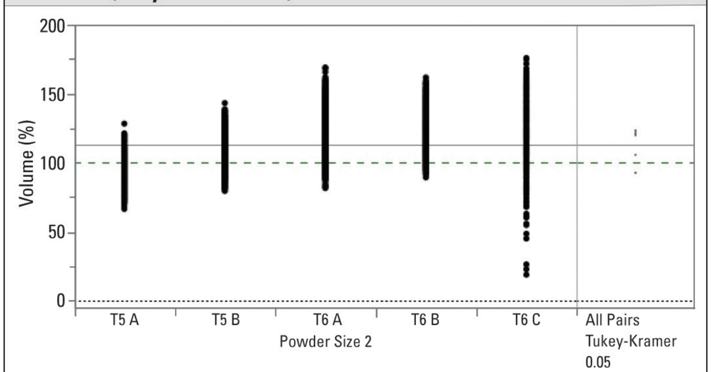
Connecting Letters Report

Level					Mean
T6 B	A				132.37574
T6 C		B			126.80010
T6 A		B			126.68158
T5 B			C		109.34160
T5 A				D	98.94462

Levels not connected by same letter are significantly different.

Figure 20. Component: 01005 R; Aperture: 0.007 by 0.007; Area Ratio: 0.729.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 01005 C, X by Y=0.008x0.008, Area Ratio=0.8333333333



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72791	0.05

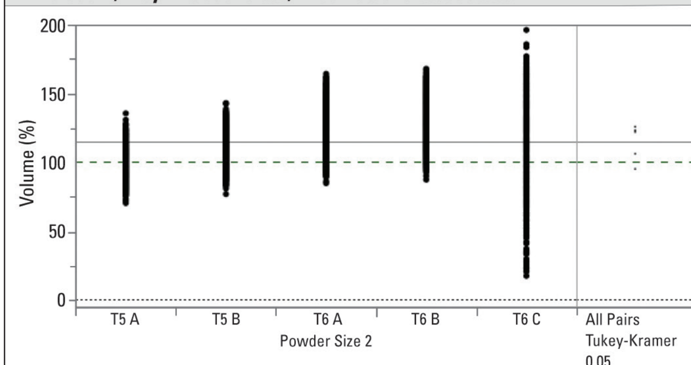
Connecting Letters Report

Level						Mean
T6 C	A					123.20907
T6 B		B				121.46333
T6 A			C			119.85672
T5 B				D		105.51563
T5 A					E	92.66890

Levels not connected by same letter are significantly different.

Figure 19. Component: 01005 C; Aperture: 0.008 by 0.008; Area Ratio: 0.833.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number 2 = 01005 R, X by Y=0.008x0.008, Area Ratio=0.8333333333



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72791	0.05

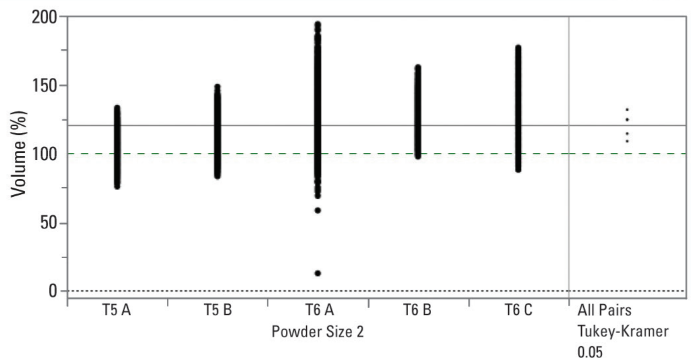
Connecting Letters Report

Level						Mean
T6 B	A					125.51720
T6 C		B				122.99336
T6 A			C			121.71142
T5 B				D		105.93942
T5 A					E	94.94261

Levels not connected by same letter are significantly different.

Figure 21. Component: 01005 R; Aperture: 0.008 by 0.008; Area Ratio: 0.833.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number
2 = 0201 C, X by Y=0.011x0.013, Area Ratio=1.2413194444



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72802	0.05

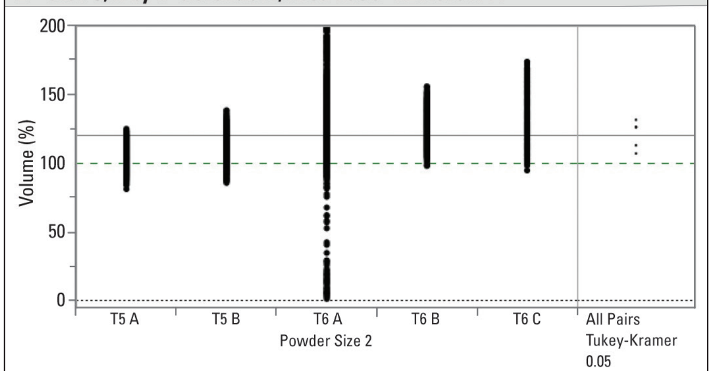
Connecting Letters Report

Level					Mean
T6 C	A				131.86109
T6 A		B			124.57923
T6 B		B			124.38947
T5 B			C		114.36998
T5 A				D	108.84679

Levels not connected by same letter are significantly different.

Figure 22. Component: 0201 C; Aperture: 0.011 by 0.013; Area Ratio: 1.241.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number
2 = 0201 C, X by Y=0.013x0.011, Area Ratio=1.2413194444



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72802	0.05

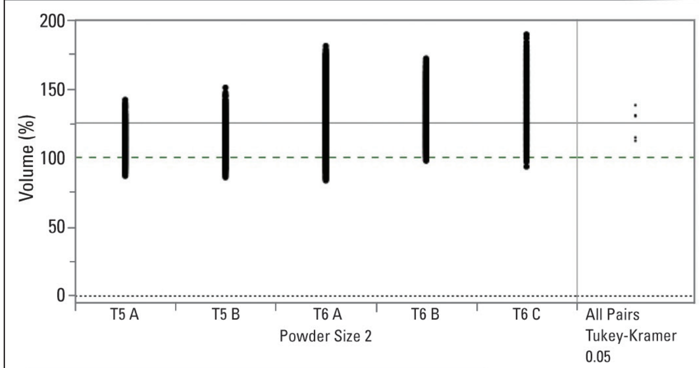
Connecting Letters Report

Level					Mean
T6 C	A				131.57865
T6 A		B			126.38429
T6 B		B			126.21994
T5 B			C		112.98738
T5 A				D	107.11499

Levels not connected by same letter are significantly different.

Figure 23. Component: 0201 C; Aperture: 0.013 by 0.011; Area Ratio: 1.241.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number
2 = 0201 R, X by Y=0.011x0.013, Area Ratio=1.2413194444



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72802	0.05

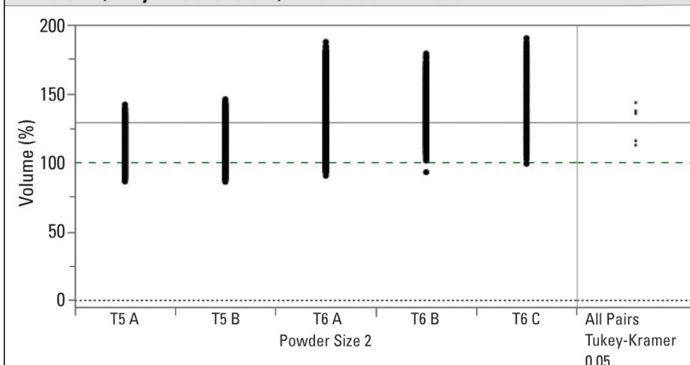
Connecting Letters Report

Level					Mean
T6 C	A				137.43918
T6 A		B			130.08470
T6 B		B			129.48867
T5 B			C		114.16674
T5 A				D	111.71939

Levels not connected by same letter are significantly different.

Figure 24. Component: 0201 R; Aperture: 0.011 by 0.013; Area Ratio: 1.241.

Oneway Analysis of Volume (%) By Powder Size 2 Part Number
2 = 0201 R, X by Y=0.013x0.011, Area Ratio=1.2413194444



Mean Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

Confidence Quantile

q*	Alpha
2.72802	0.05

Connecting Letters Report

Level						Mean
T6 C	A					143.36735
T6 A		B				137.25010
T6 B			C			135.53419
T5 B				D		115.71436
T5 A					E	112.52429

Levels not connected by same letter are significantly different.

Figure 25. Component: 0201 R; Aperture: 0.013 by 0.011; Area Ratio: 1.241.

Conclusion

The transfer efficiency of solder paste is used on many factory floors as a pass/fail criterion for circuit board assembly. It is important to have the correct materials, machines, and process to guarantee favorable results. Miniaturization and the introduction of the 008004 (0201 metric) has brought with it many challenges in all of these areas. From a materials perspective, the data is clear that the powder size in solder paste is instrumental in determining adequate transfer efficiency. The process window for producing consistent uniform solder paste deposits of this size is narrow and the process needs to be well-controlled to maintain adequate volumes.

The 2.4mil laser-cut nanocoated stencil used in this study coupled with the consistent process variables has determined that a T5 particle size makes printing possible for the 5mil x 6mil, and 6mil x 7mil 008004 apertures. The variability charts coupled with the Tukey-Kramer analysis show that both T5 solder powders remained statistically different than their T6 cousins and were closer to the target 100% with lower variation.

The stencil thickness is also an important variable for the processing of 008004 components. Stencils that were 3mil- and 2mil-thick were used in this study to determine if any interaction between the powder sizes and stencil thickness would improve the efficiency of the solder paste deposits. Stay tuned for Part II of this study where we will analyze the data and conclusions for stencil and powder size interactions.

First presented at the SMTA International Virtual Conference, September 28–October 23, 2020.