Substrate Cleanliness Study in the Screen Printing of Thick Film Ceramic Substrates

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Report No. 98T-011

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Abstract

To build highly reliable thick film products, it is essential to achieve excellent adhesion between the deposited film and substrate. Little information on the effect of substrate surface cleanliness during screen printing has been reported. In this study, two experiments were conducted to determine the effect of the substrate surface cleanliness. In the first experiment, the ceramic substrates were divided into four groups according to different treatments: (1) smeared with a thin film of grease (NYE Instrument Grease 706C), (2) contaminated with ceramic dust, (3) untreated, and (4) ultrasonically cleaned in 70% isopropyl alcohol for 5 minutes. After printing and firing, visual inspection was chosen as the basis for rating each experimental group since the results were so apparent. In this experiment it was shown that the printing quality was improved with increasing substrate surface cleanliness.

In the second experiment, 3 different cleaning solvents were compared to an untreated group. The solvents were denatured alcohol, 190 proof ethyl alcohol, and DIUF water. In this experiment, the results were not as apparent, so the substrates were ranked and a statistical approach was used to test whether any of the solvents provided a better result than the others. While untreated substrates and those cleaned with denatured alcohol had better than average rankings, there was no statistically significant difference found in the methods at the 95% confidence level.

Key Words: Screen Printing, Substrate, Cleaning, Thick-film, Adhesion

Introduction

Substrate cleanliness is an important factor in the production of thick-film ceramic circuits. Impurities on the surface can affect the adhesion of the paste during the printing process or after the paste has been fired. This paper presents the results of 2 experiments designed to determine the effect of substrate cleanliness on screen printing quality. It does not address the adhesion after the substrates have been fired.

Several references deal with the subject of cleaning and substrate cleanliness. Davis [1] presents a general analysis of adhesive bonding to substrates. Veeramasuneni [2] discusses the particle adhesion with respect to silicon wafers. O'Brien [3] develops a mathematical model for cleaning silicon substrates. Manchester [4] presents more practical solutions to problems encountered in cleaning electrical substrates. Little work has been published on the cleaning of alumina substrates for thick-film. This research reports on how ceramic substrate cleanliness affects the screen printing process.

Experimental Setup

Both experiments use the same test pattern for the printing process. The pattern is shown in Figure 1. Other variables common to both experiments are as follows:

Paste: Metech Ag/Pd conductor
Screen: 325 mesh
28 μm (1.1 mil) wire diameter
7.6 μm (0.3 mil) emulsion
Substrate: Coors 96% alumina
Screen Printer: Presco MSP 873
Drying oven: Vitronics

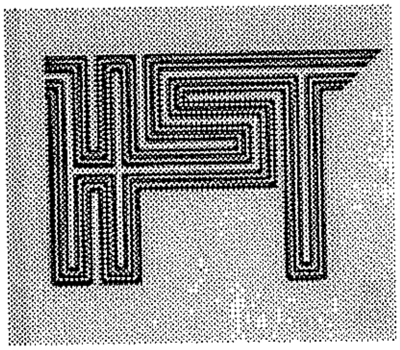

Figure 1. Sample Test Pattern.

First Experiment

This first experiment was designed to determine the effects of printing on a contaminated substrate versus a clean substrate. Two types of contamination were tested along with one method of cleaning and a control group. The 4 groups are as follows:

Group 1 was intentionally contaminated with a light coating of ceramic dust. Ceramic dust from the substrates was lightly brushed onto the surface with a small, soft brush.

Group 2 was intentionally contaminated with a light coating of NYE Instrument Grease 706C.

Group 3 was ultrasonically cleaned in a 70 % isopropyl alcohol solution for 5 minutes.

Group 4 was untreated. They were used as packaged by the manufacturer, Coors.

The experiment included four replicates in each group. After printing, the substrates were dried. Figure 2 shows the 4 substrates from Group 1 that were contaminated with ceramic dust. Figure 3 shows the 4 substrates from Group 2 that were contaminated with instrument grease. Figure 4 shows the substrates from group 3 that were cleaned with isopropyl alcohol. Figure 5 shows the Group 4, the control group of untreated substrates. From these figures it can be observed that all the contaminated substrates (Groups 1 and 2) were unacceptable. The cleaned substrates (Group 3) and untreated substrates (Group 4) were acceptable. The only difference between the untreated substrates and those cleaned by isopropyl alcohol was that there were some areas on the untreated surfaces that seemed to be lighter.

From this experiment it was clear that contamination on the substrate surface caused poor printing quality. Isopropyl alcohol seemed to clean the surface quite well. It was not known whether other solvents would work as well. Therefore, the second experiment was designed to try to this address this topic.

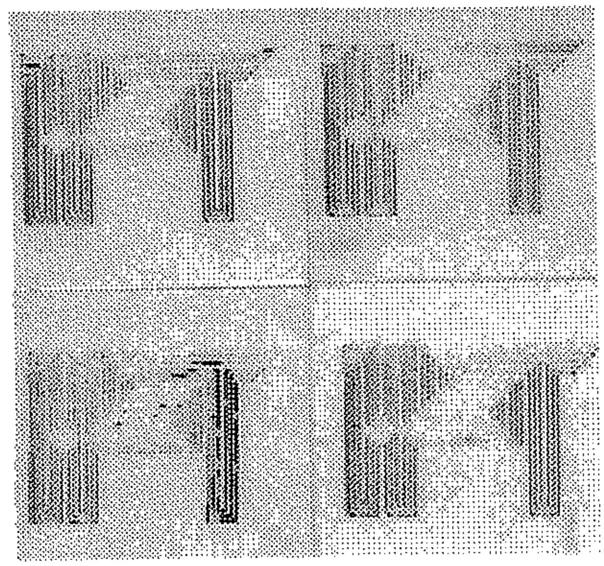

Figure 2. Group 1 Samples Contaminated by Ceramic Dust.

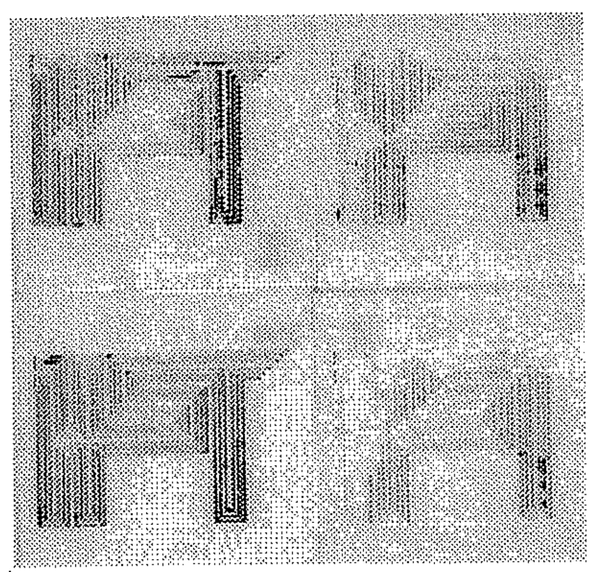

Figure 3. Group 2 Samples Contaminated by Instrument Grease.

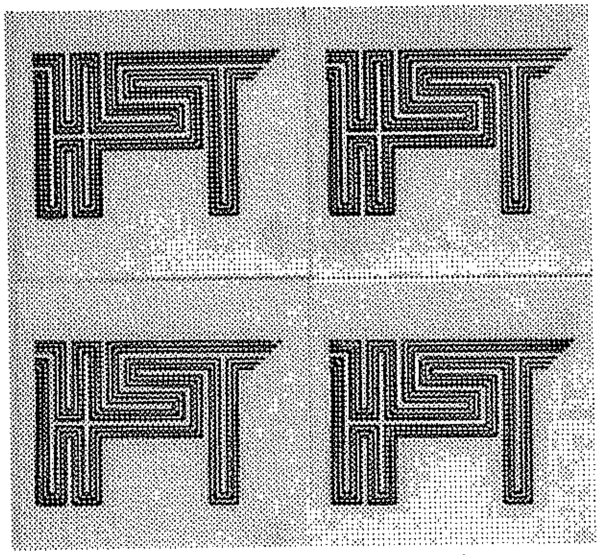

Figure 4. Group 3 Samples Cleaned with Isopropyl Alcohol.

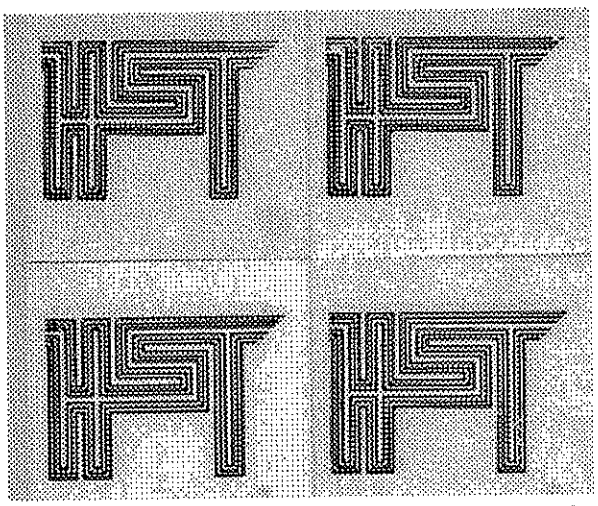

Figure 5. Group 4 Samples that Were Untreated.

Second Experiment

The purpose of this experiment was to determine if different solutions used to clean the substrate surface affected the screen printing quality. In order to generate comparative data on different substrate surface preparations, the printing process parameters were held constant. The following parameters were set for this experiment:

Paste:	Metech Ag/Pd conductor
Screen:	325 mesh
	28 µm (1.1 mil) wire diameter
	7.6 µm (0.3 mil) emulsion
Squeegee	70 shore type A polyurethane squeegee at 45 degree angle
Snap-off distance	1.25 mm (50 mils)
Squeegee speed	127 mm/s (5 inch/sec).
Substrate	51mm x 51mm (2 x 2 inch) 96% alumina Manufactured by Coors

A statistically designed experiment was developed with four different substrate treatments and six replications. The four treatments were as follows:

Group 1 was cleaned ultrasonically using denatured alcohol.

Group 2 was cleaned ultrasonically using 190 proof ethyl alcohol

Group 3 was cleaned ultrasonically using DIUF (deionized ultra-filtered) water.

Group 4 was untreated. These substrates were used as packaged by the manufacturer.

For groups 1, 2 , and 3, the ultrasonic cleaning time was 5 minutes. After cleaning, all substrates were dried 5 minutes at 200°C. The next step was to randomize the order of the treatments. It should be noted that the randomization of the order of treatments is the cornerstone underlying the use of statistical methods in experimental design. The assumption that the observations are independently distributed, random variables is usually valid when the experiments are properly randomized.

One way to rate the quality of the printed substrates is to rank them. Two researchers ranked the substrates from best to worst. Ties were allowed. Each sample received a score according to its rank with 1 being the best and 24 being the worst. If a group of samples was tied, each member of the group received the average of the tied rankings. For example if there were 2 samples tied for the best, each would receive a score of 1.5. Table 2 summaries the randomized trials and ranks for the samples in the experiment. Figures 6, 7, 8, and 9 show the samples from Group 1, 2, 3, and 4, respectively. These images are smaller than actual size to allow them to fit in the paper format.

Table 1. Groups and Ranks for the Experiment.

Sampl	Group*	Rank	Rank	Sampl	Group*	Rank	Rank
1	4	3	1.5	13	3	8	8
2	1	2	5.5	14	3	23	21.5
3	1	1	1.5	15	2	16	12
4	3	13.5	21.5	16	4	6	5.5
5	1	5	3.5	17	4	24	21.5
6	4	10.5	16.5	18	4	7	8
7	2	4	3.5	19	1	13.5	16.5
8	2	10.5	16.5	20	3	19	12
9	3	9	8	21	4	21.5	12
10	3	12	16.5	22	2	19	21.5
11	1	16	12	23	2	19	21.5
12	2	16	21.5	24	1	21.5	12

* 1 = denatured alcohol 2 = 190 proof alcohol
3 = DIUF water 4 = untreated

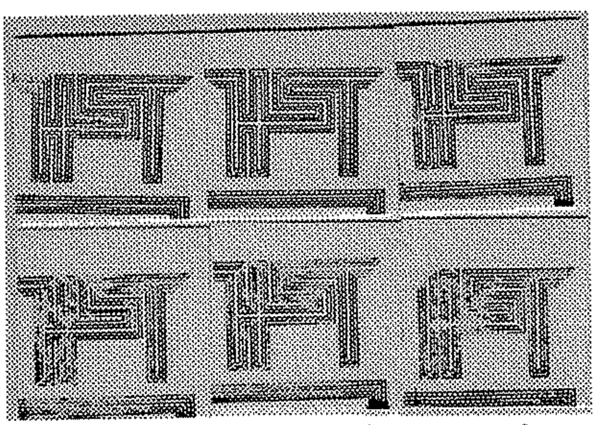

Figure 6. Group 1 Samples Using Denatured Alcohol.

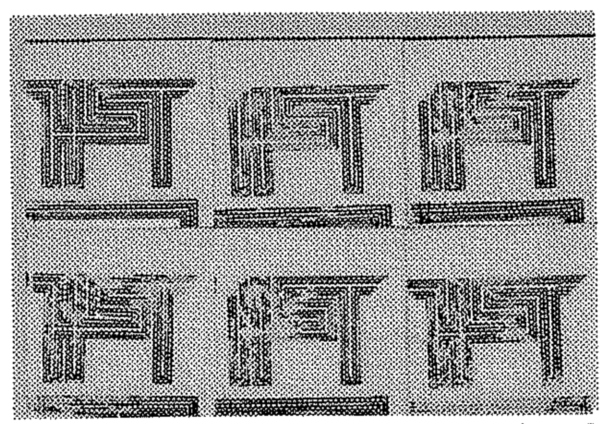

Figure 7. Group 2 Samples Using 190 Proof Ethyl Alcohol

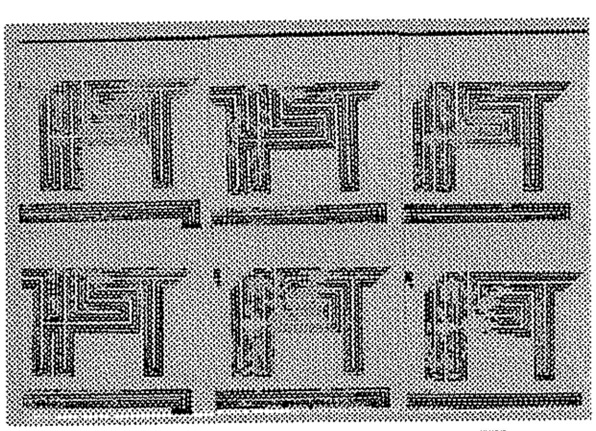

Figure 8. Group 3 Samples Using DIUF Water.

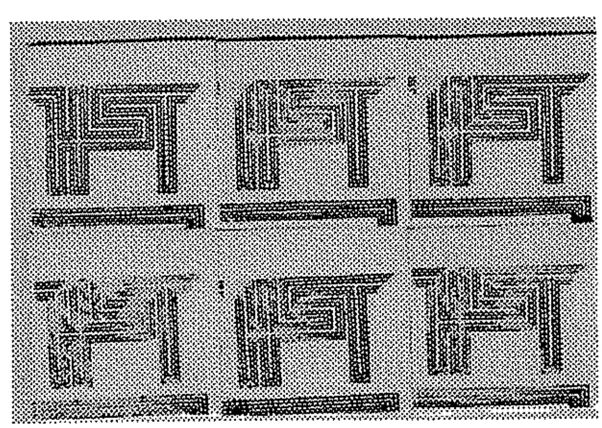

Figure 9. Untreated Group 4 Samples.

The null hypothesis was that all of groups had the same mean or average ranking, so the Kruskal-Wallis test was applied. Table 2 shows the results of the Kruskal-Wallis test for the average rank of each group. Since the p-value of the Kruskal-Wallis test is 0.395, the null hypothesis was not rejected at a 95 percent confidence level and it was concluded that there is no significant difference between different cleaning solutions.

Table 2. Kruskal-Wallis Test for Average Rankings by Group.

Group	Sample Size	Average Rank
1	6	9.08
2	6	14.92
3	6	14.83
4	6	11.17
Test statistic = 2.9748 P-Value = 0.395523		

Conclusions

Based on the first experiment, it can be determined that cleaning is an important part of thick-film ceramic substrate preparation. Contamination can cause errors in the printing process that result in scrapped modules.

In the second experiment it was found that the type of cleaning solution (of the types tested) does not affect the quality of the screen printing samples at the 95% confidence level. While the mean ranking for denatured alcohol and untreated samples (groups 1 and 4, respectively) was better, it was not at a statistically significant level. With a larger number of samples, the cleaning solution could be significant. Further tests are required in order to determine the level of significance.

Acknowledgments

The authors wish to acknowledge funding from the AT&T Foundation and NSF ILI #9552137 program for equipment to perform the experiments. Funding from the US Army CECOM and the General Electric Corporation provided materials and supplies.

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Biography

Gregory L. Tonkay is Associate Professor in the Department of Industrial and Manufacturing Systems Engineering at Lehigh University. He is the Director of the Electronics Manufacturing Laboratory and Associate Director of the George E. Kane Manufacturing Technology Laboratory. He was the IIE Outstanding Young Engineer in 1995 and has received the College of Engineering and Applied Science Teaching Excellence Award and the IMSE Department Teaching Award. He is a member of IMAPS, IIE, and ASEE and is also the advisor of the IMAPS student chapter. He has authored or coauthored over 25 technical papers. His areas of interest are manufacturing, automation, electronics manufacturing, and engineering education.

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Kannachai Kanlayasiri received a Master of Engineering degree in Industrial Engineering from Lehigh University in 1998. Prior to that he received a Bachelor of Engineering in Mechanical Engineering from King Mongkut's Institute of Technology in Thailand. He is currently a Ph.D. student at Texas Tech University.