PWB Solder Wettability After Simulated Storage

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ABSTRACT

A new solderability test method has been developed at Sandia National Laboratories that simulates the capillary flow physics of solders on circuit board surfaces. The solderability test geometry was incorporated on a circuit board prototype that was developed for a National Center for Manufacturing Sciences (NCMS) program. The work was conducted under a cooperative research and development agreement between Sandia National Laboratories, NCMS, and several PWB fabricators (AT&T, IBM, Texas Instruments, United Technologies/Hamilton Standard and Hughes Aircraft) to advance PWB interconnect technology. The test was used to investigate the effects of environmental prestressing on the solderability of printed wiring board (PWB) copper finishes. Aging was performed in a controlled chamber representing a typical indoor industrial environment. Solderability testing on as-fabricated and exposed copper samples was performed with the Sn-Pb eutectic solder at four different reflow temperatures (215, 230, 245 and 260°C). Rosin mildly activated (RMA), low solids (LS), and citric acid-based (CA) fluxes were included in the evaluation. Under baseline conditions, capillary flow was minimal at the lowest temperatures with all fluxes. Wetting increased with temperature at both baseline and prestressing conditions. Poor wetting, however, was observed at all temperatures with the LS flux. Capillary flow is effectively restored with the CA flux.

INTRODUCTION

Solderability is a property of electronic and other components that is crucial both to manufacturing efficiency and product reliability. While wettability can be directly measured, it is more difficult to quantify solderability and its relationship to board level defects. While several methods are available to evaluate soldering using controlled test methods, a key aspect of this testing is the direct measurement of wettability. These methods range from the simple dip test to the quantifiable wetting balance (Ref. 1). A test vehicle developed recently at Sandia National Laboratories (Ref. 2) is especially representative of the wetting process for surface mount assembly. One of the objectives of this study was to quantify solder wettability before and after simulated storage.

There is often a considerable time interval between the initial fabrication of a component and its use at the assembly level. Parts are often stored under a variety of conditions, usually not controlled. The wettability can soon deteriorate during storage and in the extreme case, the part will not wet. Perhaps the most common cause of solderability difficulties is related to the loss of wettability as a component ages before actual assembly. Accelerated aging tests can predict the effect of storage on wettability. An accelerated aging treatment is designed to reduce the solderability of a component at a rate that can be directly correlated to the reduction of solderability by natural aging. With such surfaces as Cu, wettability deteriorates as an oxide or corrosion film develops on the surface (Ref. 1). Environmental stressing is a very discriminating way to assess the effects of materials and processing on solder wettability. The capillary flow test vehicle (CFTV) used in this study is especially sensitive to evaluating different processing conditions. As previously noted (Ref. 2), the CFTV's geometry is a metal strip of width δ, connected to a circular base pad, having radius r. Theoretical and experimental analyses suggest that a line width to pad radius ratio (δ/r) of 0.5 or greater is normally necessary for solder to flow onto the strip (Ref. 3).

Although flux type is an important environmental concern, wetting is essential to the soldering process. Solder fluxes are used to promote wetting by allowing the solder to come into intimate contact with the base metal forming a true metallurgical bond (Ref. 4). A variety of fluxes have been evaluated for solder wettability. Based on current industry needs and trends, the effectiveness of a rosin mildly activated (RMA) flux, a low solids (LS) flux, and a citric acid-based (CA) flux were selected for this investigation. There is considerable interest in evaluating low solids and no-clean fluxes that are environmentally friendly and minimize hazardous chemical use.

Flux residues are also a concern, since most solvents used to remove them are typically environmentally hazardous. Washing or cleaning printed circuit boards is necessary to remove flux residues which are left after soldering. The need for cleaning is closely related to the choice of flux. Flux residues may remain on the board or must be removed. The major constituent in a solder flux that contributes to residue on a board is the percentage of solids in the flux. The solids in the flux are the rosin and the activator (Ref. 5). Organic solvents are often necessary to remove RMA flux residues. They are not biologically degradable and have potential environmental effects on both ground water and the atmosphere (Ref. 6). The CA flux, which has recently been developed for microelectronic soldering, is water soluble and can be removed with hot water.

Since flux type affects the solderability of different PWB surface finishes, Sandia National

Laboratories' Center for Solder Science and Technology has been characterizing solder flow on as-fabricated (baseline) and pre-stressed test coupons with different fluxes and reflow temperatures.

MATERIALS AND TEST PROCEDURE

Accelerated aging was performed in a flowing mixed gas (FMG) chamber. The test simulates corrosion and oxidation of electronic contact and connector materials (Ref. 6). A Class II environment was chosen for the study that closely simulates exposure to a typical indoor industrial environment. The atmosphere consists of 10 ppb H_2S, 200 ppb NO_2, and 10 ppb Cl_2 at 35°C and 70% relative humidity. The Class II environment produces chloride-driven pore corrosion of thin films and is especially suitable on oxidation and sulfidation-sensitive Cu (Ref. 7). Samples were exposed to the Class II atmosphere to simulate an eighteen month shelf life (real time aging of 48 hrs).

The capillary flow test vehicle was fabricated using conventional PWB materials and fabrication technologies. The CFTV substrate was an epoxy resin laminate, 0.060" thick, reinforced with glass fiber cloth (FR-4). Copper patterns (0.5 oz.) were printed and etched per the specified "lollipop" test geometry. Additional copper was electrodeposited on the vendor-etched Cu to a final conductor thickness of 35 µm (1 oz. Cu).

Latex gloves were used when handling individual specimens to minimize contamination from oils, greases and other foreign debris. Teflon coated tweezers were used to transport all samples.

The CFTV design is illustrated below in Figure 1.

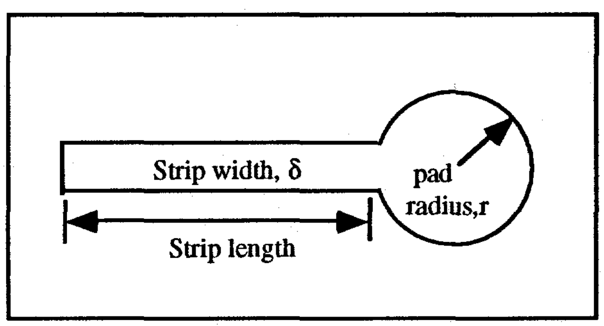

FIGURE 1. Capillary flow test geometry for controlling solder wetting. The ratio of linewidth to pad radius (δ/r) can be varied to control solder spreading from the metal base or pad onto the connected metal strip.

The substrate has duplicate test patterns with line width-to-pad ratios (δ/r) of 0.25, 0.50, 0.75 and 1.0. The pad radius is a constant 0.040" with line widths of 0.010, 0.020, 0.030 and 0.040". The maximum line length, or possible capillary flow is 1.5" (or 38 mm). One millimeter reference marks were also patterned onto the test board as measurement datums. An azole-based organic solderability preservative (OSP) was deposited onto the bare copper surfaces to retain solderability during subsequent storage and handling prior to testing.

The substrates were pre-cleaned by degreasing in trichloroethylene followed by an isopropyl alcohol rinse. A commercially available OSP was applied to the test coupons by the manufacturer at the time of fabrication and was not removed for this study in order to assess the effects of environmental aging on solderability. Capillary flow experiments were conducted with eutectic Sn-Pb (Sn63-Pb37, wt.%) solder pellets. As noted earlier, three types of fluxes were selected for the study based on current industry needs and trends. The RMA flux was diluted with isopropyl alcohol to 25% solids for this study.

Test boards were coated with flux immediately following the cleaning procedure. A Q-tip was used to apply the flux. Solder pellets of known weight were dipped in flux and placed on the center of the flux-coated pads. Based on previous experiments, the flux was allowed to dry for 30 minutes prior to testing, since a preheat was not incorporated into the original test procedure. This significantly improved the capillary flow results by permitting the alcohol carrier in the flux to volatilize (Ref. 9).

Capillary flow tests were conducted by floating samples on a standard thermostatically controlled solder pot. Test temperatures of 215, 230, 245 and 260°C ± 2°C were used for this experiment. The CA flux was tested only at 245°C. CFTV's were floated for 90 seconds to capture the complete wetting event. Samples were then carefully removed from the solder bath, minimizing agitation of the molten solder on the test pads and strips. RMA and LS flux residues were removed by ultrasonically cleaning in trichloroethylene and isopropyl alcohol. The CA flux residue was removed with flowing hot tap water followed by a flowing deionized water rinse.

Capillary flow data were analyzed from recorded video images. A black and white, charged-couple device (CCD) camera and professional video tape recorder with time code generator was used to record the capillary flow test images. The solder flow images were recorded on video tape and stored on a hard disk attached to a personal computer. Digital image analyses were then conducted with a PC-based image processor and commercial image analysis software. Data were taken at 30 frames per second.

RESULTS AND DISCUSSION

Capillary flow experiments were conducted under baseline and class II aging conditions. The effects of temperature and flux type were investigated. Wetting results are summarized in Table 1.

Under baseline (unaged) conditions, capillary flow was minimal at the lower test temperatures with all fluxes. Wetting increased with temperature at all linewidths for both the baseline and pre-stressing conditions. The RMA flux had the best wettability, although repeatability was somewhat diminished from sample to sample. Poor wetting and poor repeatability were observed with the LS flux at all temperatures. The CA flux showed moderate wetting but good repeatability from sample to sample. Baseline results for all conditions are shown in Figure 2. The Class II aging results are illustrated in Figure 3.

Wetted distances were generally sensitive to test temperature, especially on the finer 20 mil strip. The variability in the 20 mil test results made the data particularly difficult to analyze. The 30 mil line best reflects the capillary flow trends, as predicted by the linewidth to pad radius ratio (δ/r) relationship described earlier. The 10 mil lines had negligible solder flow and are not included in the data. The 40 mil lines, on the other hand, have a much larger surface area and the amount of solder needed to sustain solder flow is quickly depleted. The maximum wetted distance generally peaked on the 30 mil line at a test temperature of 230-245°C. The 30 mil linewidth data is summarized at baseline and Class II conditions in Figure 4.

Under Class II conditions, even with an OSP coating on the Cu, wetted distances substantially decreased with the RMA flux. This was particularly true for the baseline-RMA capillary flow tests. Figure 5 illustrates baseline versus Class II wetting with RMA flux for the 30 mil linewidth. Only 10-30% of the baseline wetting distance was recovered.

Minimal wetting was observed with the LS flux before and after aging. The wetting peaks remain fairly constant at approximately 5 mm with the LS flux before and after aging. The bar graphs noted in Figure 6 illustrate not only poor wetting behavior but also high variability from sample to sample with this flux.

The wetting decrease due to aging was less pronounced with the CA flux. Although capillary flow was somewhat diminished, good wetting was still obtained. The aged 30 and 40 mil lines yielded approximately 60% of the baseline flow distance, while the 20 mil line results were almost equivalent (Fig. 3). 30 mil linewidth data is illustrated in Figure 7 at both baseline and Class II conditions. The improved flow results after aging were attributed to the higher activity of the CA flux. Similar results were observed on wrought copper coupons (Ref. 6).

Temperature effects on wetting were also observed. Increasing the test temperature on the aged coupons typically improved solder flow. In addition, wetting distances decreased after aging across all temperature ranges, regardless of flux. The baseline condition most sensitive to test temperature was the 20 mil line, RMA flux condition. This was due, in part, to the higher surface energy associated with the finer linewidth. Increasing the test temperature directly contributed to initiating and sustaining solder flow.

A direct comparison of the test conditions at 245°C is shown in Figure 8. The results clearly show that the CA flux is most effective on both the baseline and the aged surfaces.

CONCLUSIONS

Experiments demonstrated that solder flow was sensitive to reflow temperatures, flux type and pre-stressing. The best flow results were obtained with a citric acid-based flux. Environmental aging generally degraded capillary flow.

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Table 1: CFTV Solderability Wetted Distances (mm)

Flux Type	Linewidth (mil)	215°C	230°C	245°C	260°C
BASELINE (unaged)					
RMA	20	0.9 ± 0.3	7.8 ± 9.9	14.5 ± 9.9	27.6 ± 4.2
RMA	30	13.8 ± 8.3	25.9 ± 2.5	25.0 ± 4.3	30.3 ± 8.4
RMA	40	13.1 ± 4.0	20.8 ± 2.1	13.5 ± 6.8	28.3 ± 1.7
LS	20	1.8 ± 1.5	2.9 ± 2.0	3.1 ± 1.9	4.5 ± 2.4
LS	30	4.1 ± 1.9	4.6 ± 1.4	5.6 ± 1.1	5.1 ± 3.0
LS	40	4.0 ± 1.6	6.0 ± 1.8	6.9 ± 1.9	6.3 ± 2.8
CA	20			18.0 ± 12.7	
CA	30			34.0 ± 4.2	
CA	40			28.5 ± 3.5	
48 Hr. CLASS II (aged)					
RMA	20	0	2.6 ± 4.6	10.4 ± 10.3	3.8 ± 6.8
RMA	30	0.8 ± 0.3	3.5 ± 3.7	6.0 ± 7.0	8.9 ± 8.8
RMA	40	3.4 ± 3.2	6.9 ± 0.8	9.9 ± 3.7	13.8 ± 3.9
LS	20	0.3 ± 0.3	1.3 ± 2.2	2.1 ± 2.3	1.3 ± 2.5
LS	30	1.1 ± 1.9	3.0 ± 2.2	3.5 ± 2.6	2.8 ± 3.2
LS	40	2.3 ± 1.5	3.4 ± 1.4	3.3 ± 3.0	6.3 ± 1.3
CA	20			17.3 ± 5.3	
CA	30			19.5 ± 4.9	
CA	40			16.5 ± 4.9	

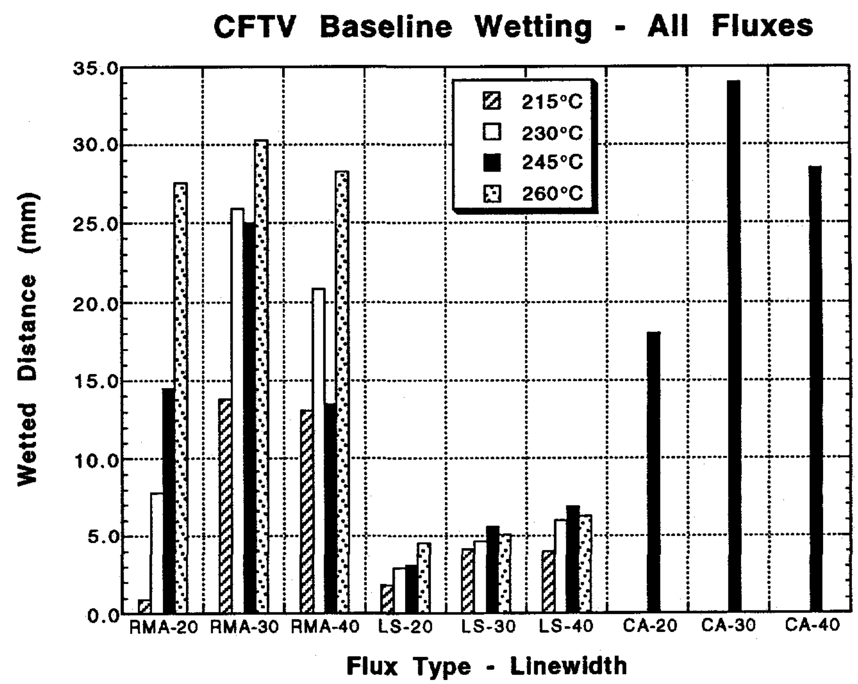

FIGURE 2. Wetted distance as a function of test geometry (line width, mm) and flux type, and test temperature under baseline conditions.

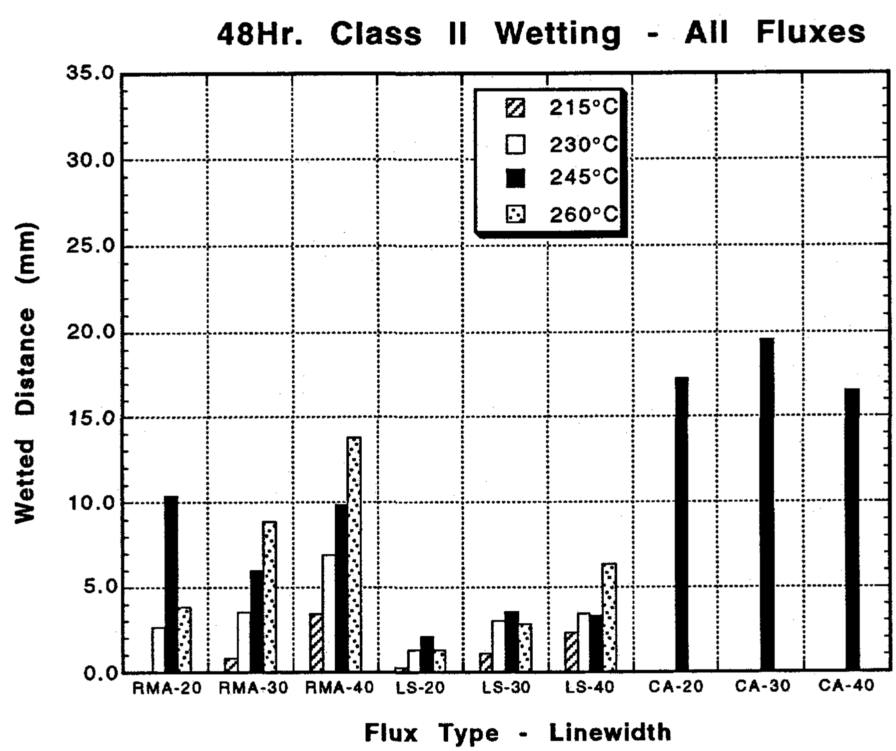

FIGURE 3. Wetted distance under Class II aging conditions.

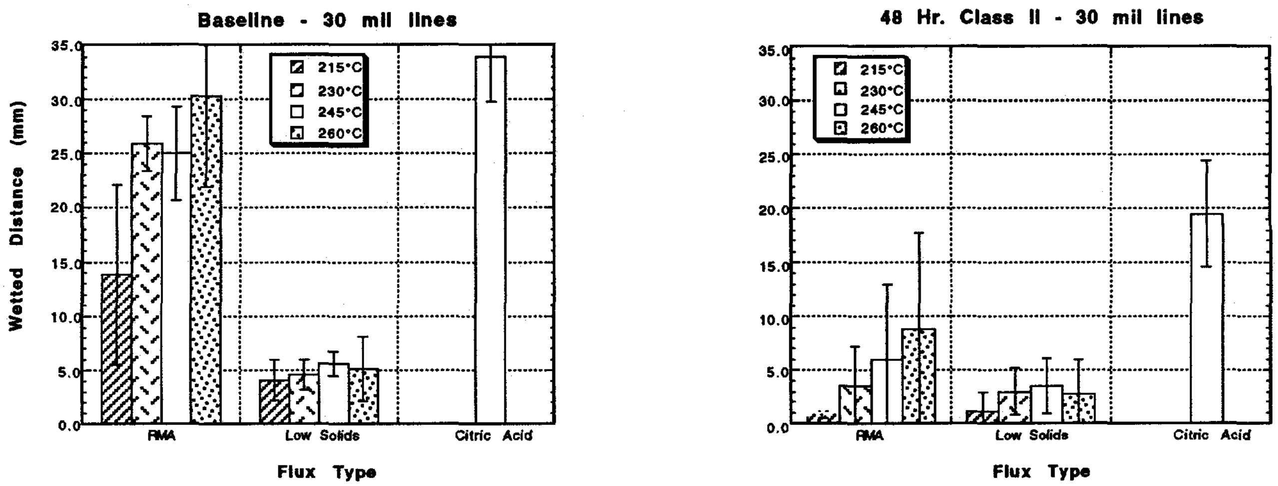

FIGURE 4. 30 mil linewidth data summarized for all fluxes and temperatures under baseline and aging conditions.

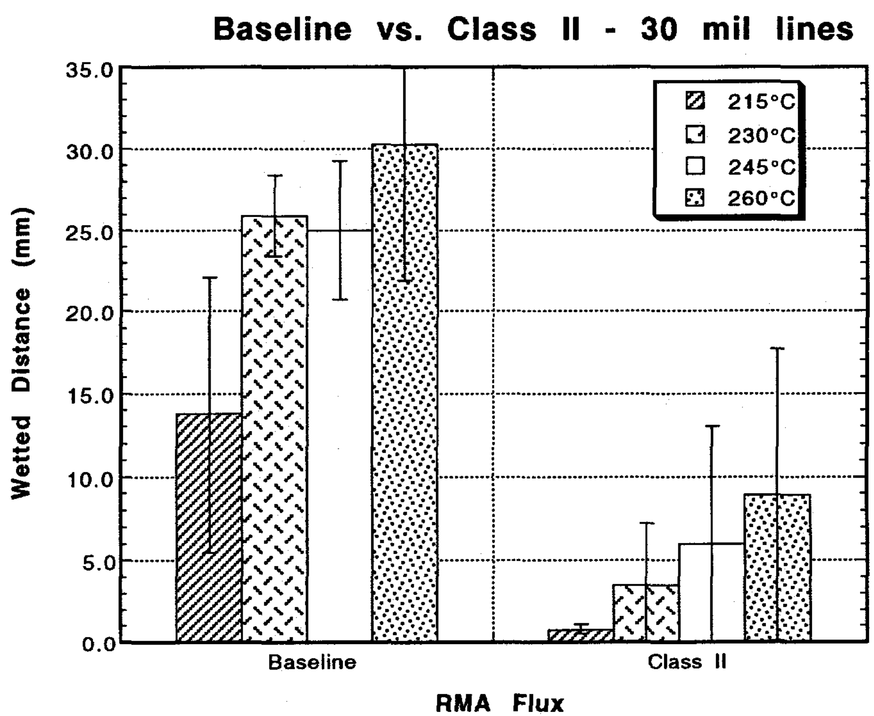

FIGURE 5. Comparison of capillary flow on a 30 mil line with a RMA flux before (baseline) and after aging (Class II).

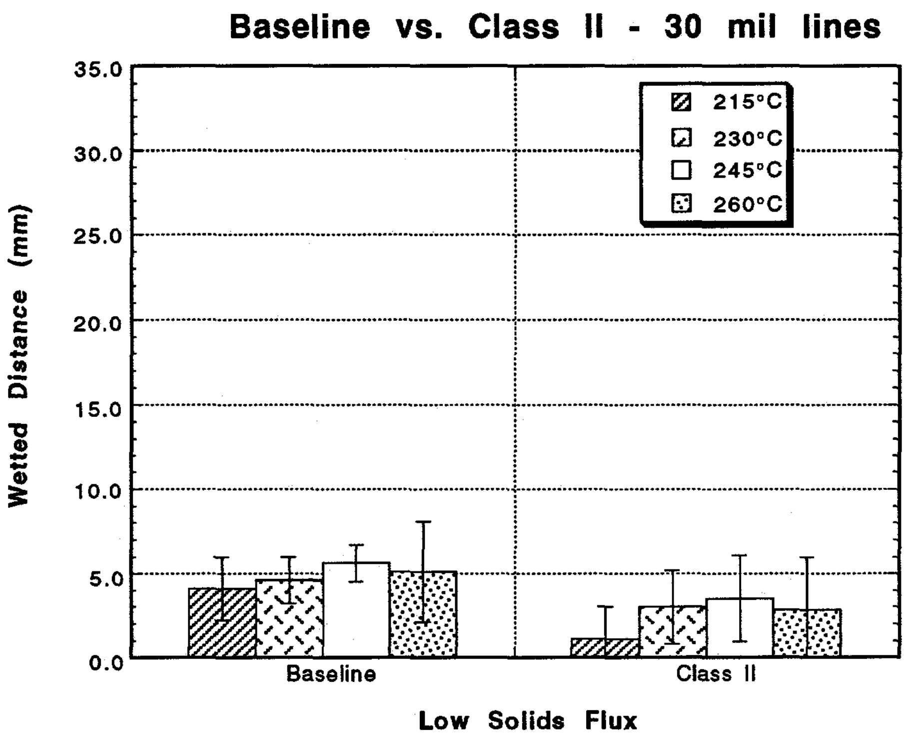

FIGURE 6. Capillary flow comparison with a LS flux.

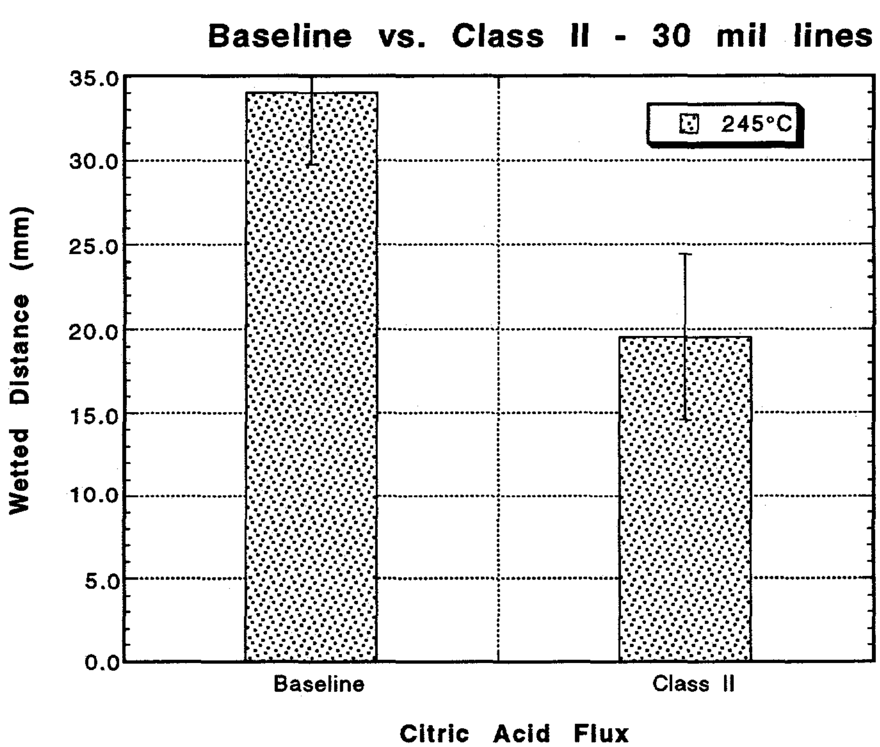

FIGURE 7. Capillary flow comparison with a CA flux.

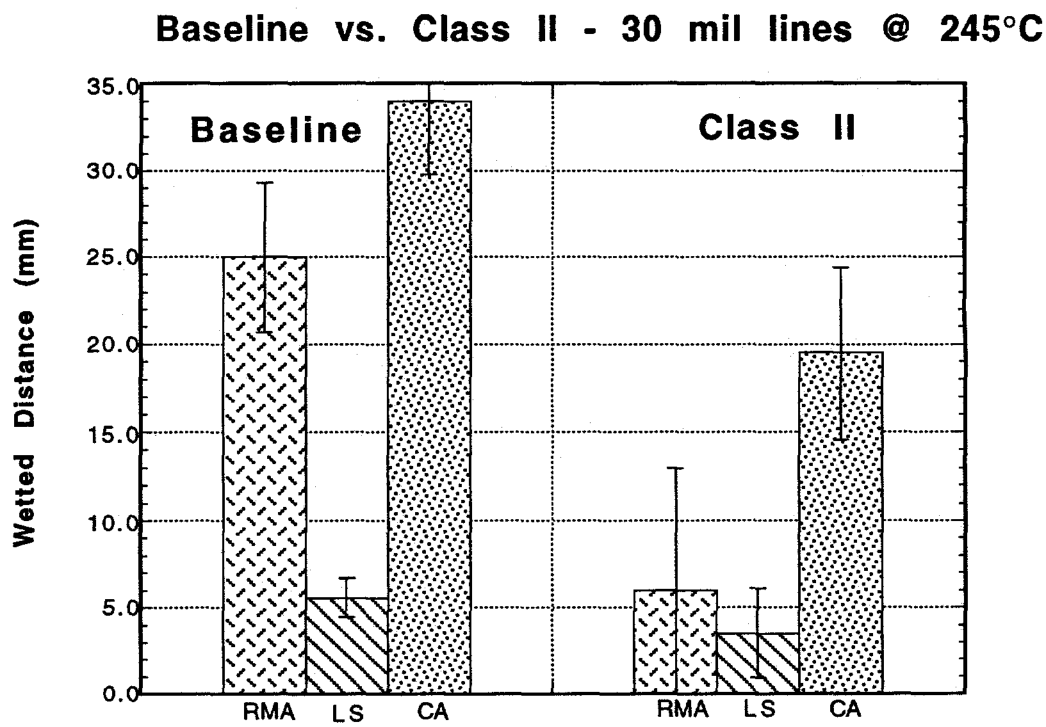

FIGURE 8. Comparison of 30 mil lines for all fluxes at 245°C.