New Findings in Not-So-New Wrinkling

A primary culprit is heat

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The fabrication of rigid-flex products has always presented more than its share of problems. This study identifies a major flaw in the manufacture of such products and suggests ways to solve the problem.

In a recent experiment, the formation of wrinkles on the inside bend radius of the flex layers of rigid-flex boards was observed as flex circuits were processed through fabrication and baking operations. The flex circuits studied were made up of polyimide sheet, modified acrylic adhesive, and 1-oz. or 2-oz. rolled annealed copper. Flex bend radius, flex layer thickness, and temperature were the variables in the study that determined that wrinkling is due to compressive loading on the inside cover sheet.

Wrinkling doesn't easily develop at room temperature, but heating a bent flex section to 85°C for 15 minutes did result in rapid wrinkling, with larger wrinkles forming laminate voids in the acrylic adhesive. The adhesive showed a reduction in mechanical strength at elevated temperature, allowing the cover sheet to buckle under the compressive load induced by flex bending. As the peaks of the cover sheet wrinkle exceed the 200 to 300% maximum elongation of the acrylic, a laminate void forms, reducing the dielectric between the conductors.

Flex Circuit Construction

The rigid-flexes under study were designed in accordance with Mil-Std-2118 and fabricated per Mil-P-50884. The flex circuits in the bend area consisted of individual single- or double-sided flex layers. The 10-layer flex portion comprised two external etched copper layers in the rigid area and eight etched copper layers that extended from one rigid area to the other. In the flexible area, copper layers were laminated together to form a double-sided flex layer.

The Nature of the Voids

Categories of deformations were defined as follows:

- waves = gentle waves
- wrinkles = wrinkles that bridge copper conductor lines
- microvoids = small voids 1 to 2 roils in diameter, mostly over copper runs
- voids = air bubbles trapped in the acrylic adhesive layer.

Flex circuits with smaller wrinkles did not have voids in the acrylic adhesive. As the wrinkle size increased, voids formed between the polyimide cover sheet and the copper conductor. Also, as the bend radius decreased, cover sheet deformations progressed to form wrinkles, long wrinkles, microvoids, and voids.

The wrinkles formed during the study were generally discontinuous across the flex circuit. The voids first appeared as microvoids directly over the etched copper conductor line, compromising the dielectric between the conductors and also possibly exposing the copper to the external environment. In many cases, wrinkles with voids progressed to the edges of the flex circuit, forming a void condition that would allow contaminants to wick through the voids to the copper conductors.

Band Radius and Temperature

On a rigid-flex product with four individual double-sided layers in its flexible portion, wrinkles formed on the inside radius of the flex bend after the flex circuit was installed in a chassis. Half of the assemblies with wrinkles also had voids.

At room temperature, single- and double-sided flex circuits could be bent to a radius 10 times the layer thickness without forming wrinkles. Significant wrinkling and void formation was observed when the circuit was held at 85°C for 30 minutes.

The acrylic adhesive has very good flexibility and excellent copper adhesion, but some of its strength is sacrificed for these characteristics. It has a low Tg, a very high thermal coefficient of expansion, and a low modulus. In a flex bend, the polyimide cover sheet on the inside of the bend radius is in compression. As the bend radius decreases, the cover sheet buckles under compression, forming a wrinkle. When the peak of the cover sheet wrinkle increases beyond the 200 to 300% elongation limit of the acrylic adhesive, a void is formed.

Flex circuit materials are rated to 125° C. For this evaluation, temperatures of 85 and 115°C were established to encompass conditions seen during the fabrication process. At the elevated temperatures occurring during presolder bake, conformal coating curing, and adhesive curing, the flex is bent to a radius different from the final configuration to facilitate connector soldering. The bend radius range chosen for this evaluation was 40t (40 times the individual layer thickness) to 2t.

Determination of Bend Radius

The flex circuits that experienced wrinkles during processing had “free-form” bends. Regardless of whether the bends were of pull or pinched radius, the resultant shapes were parabolic. Once a flex was pinched, the plastic deformation of the copper retained the small radius locally, even if the sample was later installed in a configuration that allowed a larger radius.

Decreasing bend radius and increasing temperatures are the key factors in wrinkle and void formation.

The radius-to-thickness ratio presented proved to be the ideal radius in cases where a complete semicircle was formed. Since the flex shape was parabolic, the true radius was slightly less than the reported one (as verified by a radius gauge). The test was focused on free-form flex bending because it is desirable to reduce any radius preforming operation.

Test Procedure

Samples of single- and double-sided flex circuits were cut into 1“ strips and uniformly bent and installed in a bend test fixture. In the case of the 2-02. over 1-oz. double-sided layer, the 2-02. copper was placed toward the inside of the bend. After being baked at 85°C for 30 minutes, the flex circuits were returned to the baking chamber and re-inspected periodically over 60 hours of baking.

Results

Decreasing bend radius and increasing temperatures are the key factors in wrinkle and void formation. The tighter the bend radius, the greater the degree of wrinkling/voiding. Raising the temperature to soften the acrylic adhesive allows the wrinkles to form more readily. Smaller wrinkles do not form voids. A bend radius of 40t will not form wrinkles under any condition. For double-sided flex layers, a bend radius of 20t will form wrinkles with some voiding.

Conclusions

The bend radius rules presented in Mil-Std-2118 are not broad enough to prevent the formation of wrinkles with laminate voids. The mil-spec addresses flexibility considerations at room temperature only and does not account for laminate performance at higher temperatures. Testing has shown that flex circuit wrinkles form easily when the bent flex is heated. Keeping bend radii greater than 30 to 40t will generally eliminate the formation of wrinkling on double-sided flex layers. Single-sided flexes can be bent to 20 to 30t without wrinkling. The formation of wrinkles does not necessarily mean that voids are present; a difficult and lengthy inspection process is required to determine the presence of voids.

The reduction of acrylic in the coverlayer tended to reduce the magnitude of wrinkling. Radius control or fixturing is necessary if the possibility of pinching exists during the manufacturing cycle. When a flex was pinched to a tight radius, a wrinkle always formed at that point, even if the flex radius was allowed to open up later. It is preferable to do most flex circuitry thermal processing, such as baking, soldering, and adhesive curing, with the flex in a flat condition. FAB

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Acknowledgements

I would like to thank Guy Yali and Richard Smalling of Martin-Marietta (Johnson City, NY) for their contributions to this article.

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This paper was originally presented at the IPC Printed *Circuits Expo, April 25-27,* 1994, Boston, MA.