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Flexible Circuit Materials for High Temperature Applications

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Abstract
Many opportunities exist for flexible circuits in high temperature applications (Automotive, Military, Aerospace, Oil and Gas). Flex circuits in these applications have been hindered by a lack of materials that can survive higher temperatures. Some materials, especially some thermoset adhesives, break down over time at higher temperature, becoming brittle or losing adhesion to copper. Polyimides tend to perform much better under high temperature.

The other issue is the lack of good test methods to verify that flex materials can survive higher temperatures. Several methods for testing copper clad laminates exist but there are very few for coverlays and bondplies. We will discuss different test methods for measuring high temperature capability including the new IPC Service Temperature test. We will also report on test results for various flexible materials and our recommendations for the best flexible materials for high temperature applications. This will include development work on new flex materials for high temperature applications.

Introduction
More applications require flexible circuits that must survive high temperature environments. These include automotive applications near the engine, oil and gas down-hole pumps, and aerospace applications near jet engines. There have been limited test methods to determine what temperatures flexible materials can survive.

The damage caused by high temperature environments will mainly fall in three categories: loss of adhesion between copper and dielectric, loss of adhesion between dielectric layers, and embrittlement of the dielectric layers. At the highest temperatures the copper would also become brittle, but in most cases the flexible circuit dielectrics fail first. Thermoset adhesives seem to be most sensitive to embrittlement especially compared to polyimide films which are much more resistant to high temperature.

UL has two different temperature ratings. The RTI (relative thermal index) is based on the temperature aging of base dielectrics. For flex materials this is mainly polyimide films. The RTI is determined by loss of tensile strength (mechanical property) and dielectric strength (electrical property) with long term thermal aging. The RTI tests only measure the degradation of the base film properties. The samples are tested declad (without copper) so it does not capture copper adhesion loss aspects of thermal aging. So RTI by itself is not a good measure of the capability of a copper clad laminate.

The UL MOT ratings are assigned for copper clad laminates and primarily measure the loss of copper adhesion to the adhesive layer. The MOT uses accelerated heat aging. MOT is mainly used for rating copper clad laminates. The UL MOT cannot be higher than the lowest of the mechanical or electrical RTI.

A new IPC Test method has been developed to measure Service Temperature (IPC-TM-650 2.6.21B). This test was originally created to measure Service Temperature for flexible copper clad laminates. It was later revised to allow measurement of service temperature of bondplies and coverlays. The IPC Service Temperature test measures loss of copper adhesion and dielectric strength with high temperature aging. The IPC method does not use accelerated aging; it measures property loss after 1000 hours of aging at the target temperature. The test method is still new and not much data has been reported from this test until now.

Results for Flexible Clad Testing
We have completed testing of flexible copper clad laminates with the IPC Service Temperature test. After testing at multiple temperatures we determined a tentative Service Temperature rating for most of our clads. The IPC Service Temperature test measures peel strength after 1000 hours of aging. If the final peels are more than 50% of the starting peels then the material achieved a Service Temperature rating at that temperature. Table 1 shows the percent drop in peel strength after 1000 hours for multiple clads and aging temperatures. A, L, T and F are all commercial products. X and D are experimental polyimide films that were laminated to form copper clad laminates.

Table 1. Percent of Original Peel Strength After 1000 hours of Thermal Aging

Flex Clad Type	105 C	125 C	150 C	180 C	225 C
A	N/A	N/A	100%	98%	93%
X	N/A	N/A	N/A	109%	92%
D	N/A	N/A	95%	92%	88%
L	76%	64%	58%	<50%	N/A
T	94%	N/A	44%	21%	N/A
F	63%	46%	36%	N/A	N/A

The three all polyimide films all show very high Service Temperature (A, X and D). For all 3 films, copper foil was laminated directly to the polyimide, so no thermoset adhesive is present in these constructions. The samples that used adhesives to bond the copper foil to the polyimide core all had lower performance (L, F and T). Based on all the testing done so far, Table 2 shows the Service Temperature Rating we have tentatively assigned for these products.

Table 2. IPC Service Temperature Rating vs UL Rating (Degrees C)

Flexible Copper Clad	Clad Service Temperature	UL MOT	UL RTI
A	**>225**	**180**	**200**
X	**>225**	**TBD**	**TBD**
D	**>225**	**TBD**	**TBD**
L	**150**	**None**	**200**
T	**140**	**TBD**	**200**
F	**>105 and <125**	**105**	**200**
Service Temperature is determined by the temperature where the peels are 50% of original, or better than AS spec.			

L shows higher values than some might have predicted but this rating is consistent with experience in flex applications. Clearly A has a much higher Service Temperature than the UL rating would suggest. The table shows that RTI ratings are not a good method of predicting Service Temperature. (Service Temperature is mainly determined by peel strength; RTI is done on samples with no copper foil.)

When the flex clads were tested at 250C in an air oven per the IPC Service Temperature test, the copper foil became so brittle that the peel strength could not be measured. So the actual Service Temperature of A, X, and D could be 250C, but we have not been able to measure peel strength because of copper oxidation. A quick test to add ENIG to the copper surface proved unsuccessful because the nickel made the copper too brittle. To measure Service Temperature of high temperature flex clads above 225C will require development of a new technique.

Results for Flexible Bondply and Coverlay Testing

UL does not assign a MOT rating for flexible bondplies and coverlays. In some cases, it is possible to get a MOT rating for a combined package (clad and coverlay for example). The IPC Service Temperature test method was adapted to test bondplies and coverlays. The bondplies and coverlays are laminated to copper to create clads and then tested as if the samples were clads. Our testing so far has shown wide variation in Service Temperature ratings of bondply and coverlays, suggesting that the test method has many issues with reproducibility. Our internal testing shows Service Temperature for coverlays that are well below the accepted performance in the field. This suggests that the present Service Temperature method does not measure the true capability of coverlays and bondplies.

Some of these issues are caused by the process of microetching sheets of copper foil, which get laminated to the coverlay or bondplies to form a clad. This obviously is not easy to process. The other issue is the coverlay sample that is aged in the oven is just coverlay with copper foil on one side. Previous testing has shown that adhesion loss between copper foil and the dielectric is driven by the presence of oxygen. The multiple layers of copper, bondply and coverlay will reduce the amount of oxygen present at the copper interface, which will prolong the life of the flex circuit at higher temperatures.

We are designing a new internal method to measure Service Temperature for coverlays that captures all of the possible failure modes. This method makes a simple flexible circuit with coverlay(s) laminated over circuit lines designed for bend testing. Temperature aging of these circuits should show reduced bend performance if any of the 3 possible failure mechanisms occur: loss of copper adhesion, loss of adhesion between dielectrics (such as clad and coverlay) or increase brittleness of the dielectrics (especially of the coverlay). The number of bends that the test circuit can survive will decrease with any of the failure modes.

The data in Table 3 shows bend performance after aging at 180C. The copper clad laminate used for this test was an all polyimide clad. Listed in the table are the coverlays tested. The percentages are based on the ratio of bends after 1000 hours of temperature aging to the number of bends with no aging. For this evaluation, the coverlays passed if the bend performance after thermal aging was at least 50% of bend performance with no aging.

Table 3. Percentage of Bends after Thermal Aging, 1000 hours

Coverlay	Starting Bends AR	Starting Bends AS	180C
X	477	468	73%
L	425	295	134%
J	234	210	61%
Bend Ratio 4.5			

The results show that some coverlays actually show good Service Temperature performance. The L coverlay has been known to survive in the temperature range of 150 to 180C depending on the circuit design and environment. The bend version of the Service Temperature gives a much more realistic value for L than the official IPC Service Temperature test method for coverlays.

The J coverlay appeared to fail mainly because of brittleness, and this reduced bend performance. This confirms that brittleness is one of the possible failure modes with high temperature aging, and this new method was able to capture the performance loss with this failure mode. This is probably also the case for the L, however, it is difficult to tell because of acrylic adhesive is covered with a polyimide film.

The all polyimide coverlay based on experimental film X shows very good performance. Part of this is that there is an all polyimide flexible circuit containing a polyimide clad and a polyimide coverlay. As long as good adhesion can be achieved between the polyimide and the copper foil, an all polyimide flexible circuit should have the best high temperature performance.

We have developed an all polyimide coverlay and bondply to use with the all polyimide copper clad laminates based on the X film. The new polyimide coverlay will require lamination temperatures of around 290 to 300C (554 – 572F), which will limit the use to only certain fabricators. So far it is clear that this is the best approach to achieve flexible circuits that can survive high temperatures.

We will continue to refine this new Coverlay Service Temperature test method. If it continues to show results more consistent with field experience, we will recommend that it be considered as an IPC test method.

Summary

To meet the increasing needs for flexible circuit materials for high temperature applications, new test methods will need to be developed. These new methods will assign new ratings, and we believe ratings that are consistent with actual performance. The present IPC Service Temperature test seems to work well for testing copper clad laminates. It does not work well for bondplies and especially coverlays. We have demonstrated a new coverlay test based on bend testing. The overall results clearly show that all polyimide clads, bondplies and coverlays will provide the highest Service Temperature performance.