Application Aid 31
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Designing for Flexibility and Reliability

The name "flexible circuit" pretty much sums up the function of flex circuitry. It is, by the nature of the materials used in its construction, flexible. Although flex circuitry is supposed to fill applications that require the circuit to bend, flex, and conform to fit the specific use, a large percentage of failures in the field are a result of these flexing or bending operations. Using flexible materials in the manufacturing of a printed circuit does not in itself guarantee that the circuit will function reliably when bent or flexed. There are many factors that contribute to the reliability of a printed flex circuit that is formed or repeatedly flexed. All of these factors must be taken into account during the design process to ensure that the finished circuit will function reliably.

When designing a flex circuit, the designer must factor in all of the parameters that will have an impact on the circuit's ability to bend or flex in the specific application. These include, but are not limited to; whether the application is static or dynamic, bend radii, dielectric thicknesses and type, foil weight, copper plating, overall circuit thickness, number of layers, and number of flexures. This paper will address mainly flex-to-install applications that are 2 or more layers and will see less than 100 cycles over the life of the circuit.

When a circuit is bent or flexed, the layers on the outside of the bend are stretched and the layers on the inside of the bend are compressed. The tighter a circuit is bent or flexed, the more concentrated these forces become. If the circuit construction is uniform, the centermost layer will form what is called the neutral bend axis in which the material is not appreciably stretched or compressed. Figure 1 illustrates how the outer conductors on the bend will elongate from stretching thus reducing the conductor thickness.

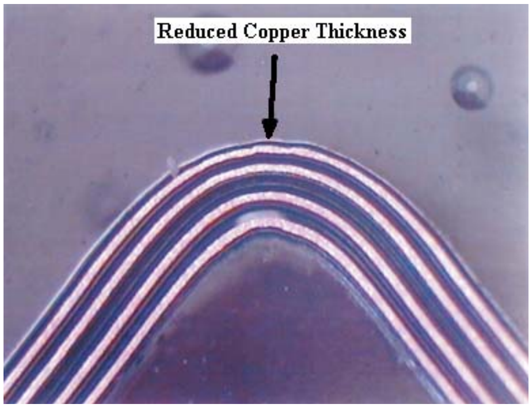

Figure 1

Several problems can arise when a circuit is bent sharply. Compression can cause wrinkles in the cover coat on the inside of the bend. Compression can also cause rippled conductors. Figure 2 shows how wrinkles can form in the cover coat on the inside of a bend.

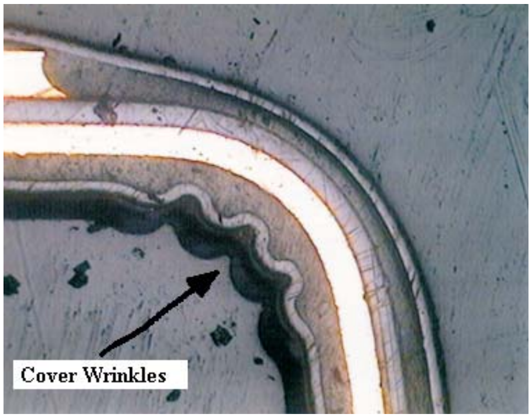

Figure 2

Cover wrinkles often result in delamination, and rippled conductors can lead to cracks. Stretching can result in tears in the cover material and/or broken conductors on the outside of the bend. Figure 3 shows how stretching on the outside of a bend can cause torn covers and fractured conductors.

Figure 3

Figure 4 illustrates an even worse scenario. The outer conductor has been stretched and a hairline crack has formed. This would be very difficult to detect during a visual inspection and would probably even pass a continuity test. The result would be a defective circuit that could very likely end up installed in the finished assembly where handling and/or vibration will almost surely cause the conductor to open.

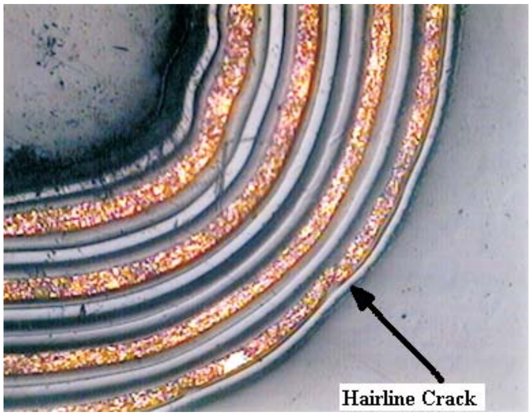

Figure 4

The circuit must be designed to withstand the stretching and compressing without exhibiting any of the aforementioned problems. These problems become more of a concern in applications that require the circuit to be bent beyond a 90-degree angle. As the bend angle increases beyond 90 degrees, the damaging effects of stretching and compressing increase dramatically. Anytime that a reduced radii bend beyond 90 degrees is incorporated into a circuit design, the circuit should be bent one time only. On bends over 90 degrees, it is also advisable to constrain the circuit in the formed condition to keep it from relaxing or being inadvertently reopened.

A good place to start the mechanical design is to define the requirements of the finished assembly. One of the most important features to establish is the bend radius. A general rule is that the tighter a bend radius becomes, the higher the probability of failure during flexing. Another important feature to define is the overall thickness of the flex circuit in the area that will be flexing. Using these two features, a ratio of bend radius to thickness can be calculated. This number is one indicator of whether the design is going to be reliable or if it will have a high probability of failure. If the bend radius is at least ten times the thickness of the material, there is a good chance that the circuit will function reliably. If the calculated bend radius falls below ten to one, the design may be questionable. Formulas for calculating the minimum allowable bend radius for several circuit types can be found in the IPC-2223 Sectional Design Standard for Flexible Printed Wiring. There are a number of features that can be incorporated into reduced bend ratio designs to ensure reliability. If at all possible, the circuit should be designed so that there will be no copper plating on the conductors in the flexing area. Electrolytically deposited copper has a much lower elongation potential than that of rolled annealed copper. The lower elongation of plated copper makes it more susceptible to fracturing when it is flexed. Utilizing selective (pads-only) plating or adding outer pads-only layers to the circuit can eliminate copper plating on the flexing conductors. Eliminating the copper plating will also reduce the overall thickness of the circuit (only in the flexing area for pads-layer alternative) by removing the thickness of the plating, which usually allows the manufacturer to also reduce the cover adhesive thickness. Either of these methods will have a cost impact, but the impact will be significantly less than the cost of a failure during service. Other types of additional plating such as gold and/or nickel should also be avoided in the flexing area for the same reasons.

Another option for making a low thickness to bend ratio more reliable is finding ways to reduce the overall thickness of the circuit in the flexing area. This can be done by reducing the base copper weight (and the corresponding adhesive thicknesses) or reducing the dielectric thickness. Another possibility is starting with adhesiveless base materials. Adhesiveless materials will usually reduce the starting thickness of each substrate by .001"-.002" when compared to adhesive based substrates. Reducing the thickness by a few mils may seem trivial, but if the net result pushes the bend ratio over 10:1, it is well worth the effort. Dielectric type will also be a contributing factor to the flexibility and ultimately the reliability of the circuit. Various dielectrics of the same thickness will have considerably different flexibility properties. Naturally, if stiffer materials are used in the construction, the result will be a stiffer finished product.

The conductor pattern should also be scrutinized to determine if any improvements could be made to make the circuit more robust. There are a number of questions that should be posed prior to releasing a design:

1. Is the construction balanced? It is important to balance the construction on each side of the neutral bend axis. Conductor weights and material thicknesses should be approximately the same on each side of the neutral axis. Since the inner and outer layers will be exposed to the most demanding stresses, heavier conductors should be placed on these layers. If possible, smaller, fragile conductors should be placed closer to the neutral bend axis to provide them more protection from bend related stresses. Conductors should be staggered from layer to layer and not stacked on top of each other (I beam effect) as shown in

figure 5. Stacking conductors will significantly increase the amount of stretching that the outer layers will have to withstand.

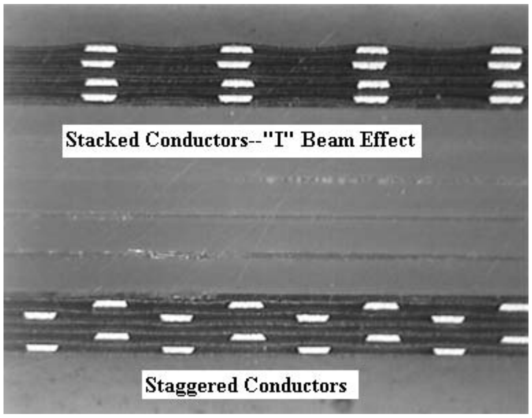

Figure 5

2. Do the conductors pass through bend areas perpendicular to the bend line? Conductors should always be routed through bend areas as close to perpendicular as possible.

3. Are there plated through holes in or near a bend area? Plated through holes should be kept out of the bend areas whenever possible. It is difficult to predict how stretching a conductor on one layer and compressing a conductor on another layer will affect the plated hole that interconnects the two layers. But, since the end result is unpredictable and since a defect would be very difficult to detect, it should be avoided.

4. Are termination pads near bend areas filleted? If the circuit will be bent within 1" of termination pads, fillets should be placed at each conductor/pad interface. Pad filleting is a good practice on all pads on flex circuitry, but is particularly important near a bend. An unfilleted pad represents a concentration point for stresses. This is especially true if the cover opening does not entirely capture the pad and exposes the conductor/pad interface. Stresses from a bend are not isolated to the immediate bend area and residual stresses can radiate out from the bend. These stresses can cause problems at stress concentrating points such as unfilleted pads (see figure 6).

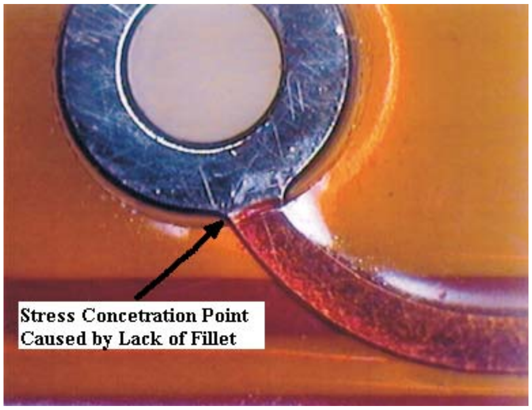

Figure 6

If shields and/or ground planes are required on the circuit, it is advisable to incorporate a crosshatched pattern rather than using solid copper. This will reduce the amount of copper on these layers and increase flexibility. The crosshatched pattern will vary from application to application depending upon the frequency of the noise the shield is to block. Typically, the openings in the shield pattern should be less than one-tenth the wavelength of the electrical noise. Another shielding option is replacing copper shields with a screened-on conductive coating such as silver epoxy. The conductive coating will be much more flexible than a copper shield would be.

The design should also be scrutinized for any other stress concentration points in the bend area. In static or mildly dynamic (<100 cycles) applications, the vast majority of failures are due to some type of stress concentration factor. Some stress concentration points such as an extremely tight bend are obvious. Other types can be subtle. There is no way to predict every attribute or combination of attributes that could cause bend stresses to be concentrated in a small area. There are several characteristics in particular that the designer should avoid.

1.There should not be any discontinuities in the cover coat or substrate near a bend.

2. Conductor thickness and width should remain constant in bend areas (i.e., no variations in plating or other coatings and preferably no conductor neckdowns).

3. The circuit outline should be designed so there are no twists in the finished assembly. Twisting can cause undue stress along the outer edges of the circuit. Any burr or irregularity from the blanking operation could potentially propagate into a tear.

4. There should not be any non-reinforced or unrelieved slits in the circuit. It is common to slit a flex circuit to allow different legs to flex in different directions. While this is a valuable tool to maximize efficiency, the end of the slit represents a vulnerable point for a tear to start and to propagate. To prevent this, it is important to place a drilled relief hole at the end of the slit (figure 7), and to reinforce these areas with hard board material or a patch of thick flex material or Teflon.

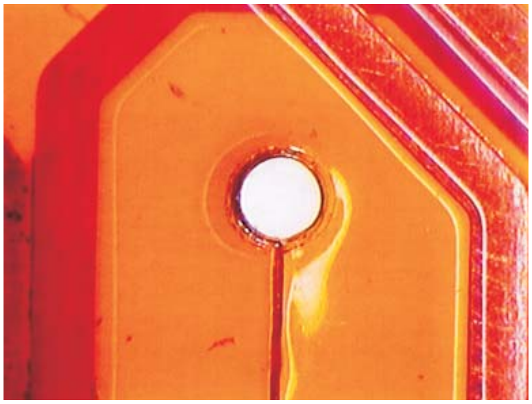

Figure 7

Another possibility is to make the slit as wide as possible and place a full radius at the end of the slit (figure 8).

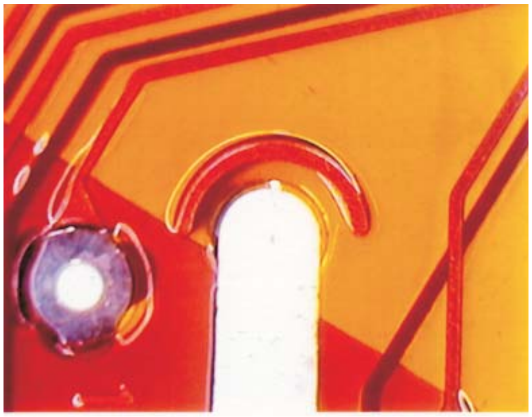

Figure 8

If reinforcement is not possible, the circuit should not be flexed within one half inch of the end of the slit (figure 9).

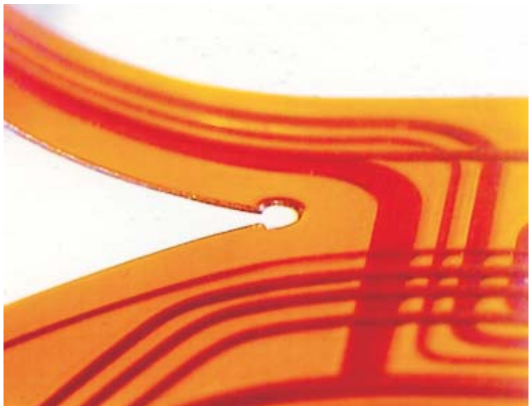

Figure 9

The circuit construction should be uniform and constant throughout the entire bend area. Any variation in construction in flexing areas has the potential to create a stress concentration point. Since it can be difficult to predict how specific stress concentration points will affect the circuit, they should be avoided if at all possible.

If bend reliability is still a concern, the construction (material stack up) of the flex area will require examination. The material selection and stack up should be reviewed carefully to determine if the circuit could be designed for greater flexibility. The most common method of making a multilayer circuit more flexible is "unbonding" the flexible substrates from each other. Since each of the substrates in the unbonded area has a much lower thickness than the total circuit, they are able to bend tighter than if they were fully bonded. Figure 10 shows the construction of a fully bonded and an unbonded 6-layer circuit.

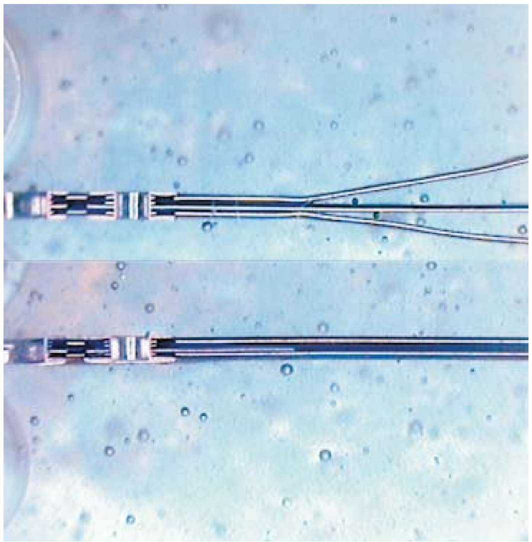

Figure 10

Figures 11 and 12 show how the internal layers of an unbonded construction are allowed to buckle when the circuit is flexed.

This buckling is the result of the compression being exerted on the substrates due to the bend. Using selective bonding techniques causes the neutral bend axis to move toward the outermost substrates of the assembly. The inner substrates will buckle rather than compress when they absorb the effect of the differential lengths experienced during a bend. This method does have some drawbacks, however. The buckling can cause clearance problems in some applications. Also, if the length of the unbonded area is short (less than .750"), there will not be sufficient area for the buckling to occur. The result will be a greatly exaggerated buckle that can cause a very tight bend radius at the bonded/unbonded interface. This situation can actually cause the problems that the unbonding was meant to eliminate. The buckling will become more pronounced, and perhaps excessive, as the length of the unbonded area decreases and the number of unbonded substrates increases. Also, the buckling effect will become even more pronounced and damaging when the circuit is bent past 90-degrees. Even though a circuit with more individual unbonded substrates is the most flexible, it is not always the most reliable. When the distance between bonded areas falls below 3/4 inch, the designer should consider combining substrates so that there are fewer unbonded layers. Figures 11-13 show 3 different constructions of the same 7 layer rigid flex circuit (5 flex layers). Figure 11 shows the circuit with 5 individual flex layers and excessive buckling. Figure 12 shows the same circuit with 1 single sided substrate sandwiched between 2 double-sided substrates. The buckling has been greatly reduced by simply changing the construction. Figure 13 shows the same circuit fully bonded.

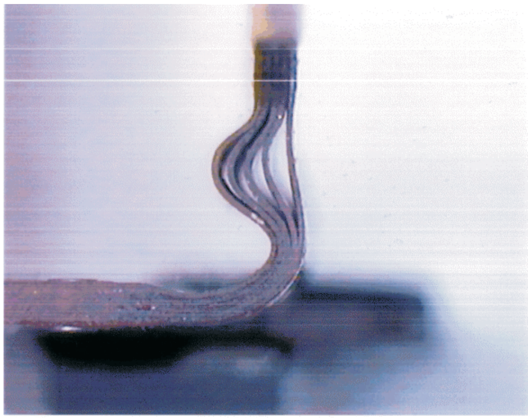

Figure 11

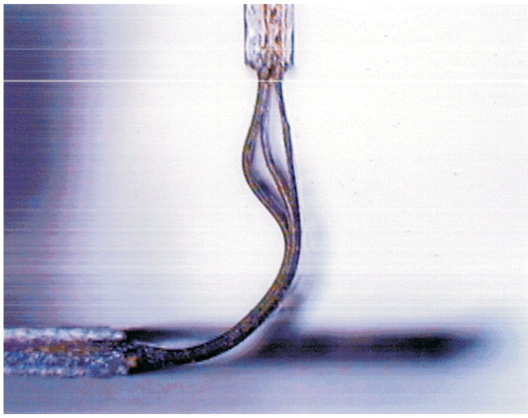

Figure 12

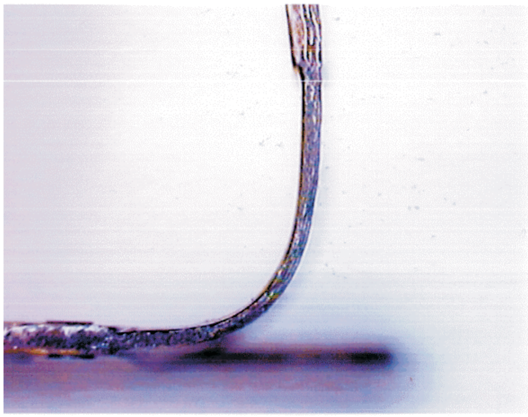

Figure 13

Naturally, there is no buckling using this construction and the liberal bend radius allowed this type of construction to be a reliable alternative.

Reliable bend radii that are tighter than 10:1 are possible if the circuit is formed using specialized tooling and will only be flexed one time. When a circuit is formed to a very tight bend radius, the copper on the layer on the outside of the bend will stretch. If the bend in the circuit is flattened, the ductile copper will not shrink back. The result will be distorted conductors that will fracture if the circuit is formed again.

In flex-to-install applications where a bend in the flex circuit may be cycled several times for servicing or repair of the device, the design should incorporate features to allow for this to happen. There are several design options that can be used to offset the damaging effects of multiple flexures. If clearance in the device is a concern, film or hardboard stiffeners can be strategically placed to force the flex circuit to bend in the same place each time it is cycled. If hardboard stiffeners are incorporated in a design and the bend area is immediately adjacent to the stiffener, it is advisable to place a bead of flexible epoxy or other material along the edge of the stiffener to act as a strain relief. Also, closed cell foam can be adhered close to the bend area to keep the circuit from creasing as shown in figure 14.

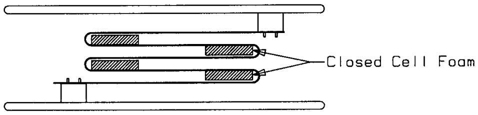

Figure 14

When considering the requirements that will be imposed on the flex circuit in the finished application, it is important to keep sight of the limitations of flex circuit materials. The design should allow for these limitations with a margin for error. End users of flex circuits will always be pushing manufacturers to make circuits that are smaller, denser, and more flexible. The challenge to the flex circuit industry will be to continue to push the limitations of flex circuitry without compromising reliability. It is also important for those designing flex circuits into their products to utilize one of the most powerful design tools available to them. That tool is the knowledge and experience of the flex circuit manufacturers. By working with flex circuit materials and designs everyday, the manufacturer gains an understanding of how the many variables come together to affect the performance of the finished product. When the designer enlists the assistance of the manufacturer during the design stage, he greatly increases the chances that his design will perform reliably. In the final analysis, all of the parties involved in creating a flex circuit, designers, manufacturers, and end users, are striving for the same goal. That goal is to have a reliable, trouble-free flex circuit installed in a finished assembly. When all of the parties work together, this goal will be easy to achieve.

About the Author

This Application Aid is adapted from a paper by Mark Finstad that was originally presented as a technical paper at the IPC National Flex Circuit Conference. Mr. Finstad is Principal Applications Engineer for the Flex Circuit Division of Minco Products. He has over 15 years experience in design, process development, and production of flexible printed circuits.