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Redefining the Cost/Performance Curve for Rigid Flex Circuits

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Abstract

Rigid flex circuits have historically been used in military or commercial aerospace applications where performance was primarily dictated by specification rather than function. Rigid flex has proved to be useful in other marketplaces, such as consumer electronic goods, in consideration of the inherent higher reliability and smaller available form factor. Unfortunately rigid flex manufacturers have had limited material choices. This has led to higher cost materials and processes being used for less stringent applications, such as personal computing devices or automotive products, where cost drivers are significantly more important. Additionally, there is a constant drive in these commercial markets to reduce overall system size while increasing, or maintaining, high reliability.

This paper will focus on work done to define circuit board performance around application rather than specification controlled criteria. Several circuit board materials have been evaluated which will allow for lower cost rigid flex circuits to be produced and address specific functional performance requirements. Criteria such as flex bend life cycling and minimum bend radii will be presented for a number of material options.

INTRODUCTION

The benefits of using rigid flex circuitry as a packaging option have been well documented over the years. Data to support this view has been presented at industry conferences and published in many trade journals and periodicals. Flex and rigid flex circuitry has proven itself in high reliability applications ranging from fighter aircraft to implantable heart devices. The commercial electronics industry is starting to realize that rigid flex can offer unique, sophisticated solutions to the ever increasing demand on real estate within an electronic package. Evidence of this can be found in recent consumer products, such as Sony’s Digital Handycam™ camera, which uses four separate rigid flex assemblies to achieve a dense three dimensional package. As engineers look more to this technology to solve their complex packaging issues, the number of applications will increase significantly. One key element that has slowed the expansion of rigid flex into the commercial marketplace is cost. The rigid flex industry is making adjustments to address the competitiveness of this marketplace and is preparing for the anticipated demand and market growth.

Cost vs. Performance

Cost and performance of rigid flex circuitry have for years been based on the needs of high end users such as military and high reliability commercial applications. The needs of these customers were well known. Circuits had to withstand harsh environments and perform flawlessly or the results could be devastating. Consequently the performance and inspection criteria developed reflected the needs of a few customers. This ultimately was to the detriment of customers with less stringent needs. The testing requirements for military products are generally more specification oriented than application oriented. This leads to qualifying factors being imposed on a design that may not otherwise be required. For example, the flexibility requirement of a rigid flex designed and fabricated to MIL-P-50884C is 25 bend cycles around a mandrel that is equal to 12 X the thickness of the flexible section of the circuit board. To fulfill this requirement many suppliers use polyimide film as the base material core either in the form of an adhesiveless film or the more traditional polyimide film and acrylic adhesive combination. This material has proven itself to be a suitable base material for flexible circuits and can withstand thousands of flex cycles as witnessed by the abundant use of polyimide film for disk drive head applications. Having been designed for applications where the circuit will be bent or folded thousands of times it has a slightly higher cost than more traditional circuit board materials. Rigid flex circuits normally are folded once during installation and possibly several times during service or assembly. *One alternative, then, is to address the cost issue by re-evaluating the materials that are* *used to fabricate the circuit itself.* An alternative material that has been successfully used for the fabrication of rigid flex circuits is a thin core (normally less than 0.004”/ 100µm) epoxy glass material. As one would expect, this material is somewhat less flexible than a polyimide core material but at a fraction of the cost. This demonstrates how cost and performance are related for materials used in fabricating rigid flex circuits.

Application requirements

Choice of materials for use in fabricating rigid flex is based on a number of factors. The designer needs to be aware of the environmental conditions that the circuit will be exposed to during both assembly and use and a clear understanding of the electrical requirements. Other factors similar to standard PCB design must be documented and accounted for. More importantly, for rigid flex designs, the designer and fabricator must have a clear understanding of the mechanical stresses that the circuit will undergo during assembly and use. This last factor is where the requirements for a rigid flex circuit depart from those of traditional rigid printed wiring boards. Rigid flex circuits, by design, are meant to bend and form and so must the materials used to manufacture them. The number of cycles and bend radius is dependent on the intended use and is potentially different for each application. Designers must clearly describe how the circuit will bend or form both during installation and use. Specific information such as distance between the rigid sections, height between the rigid sections when formed, allowable bend radius, maximum number of folds or flexes, and a picture showing the formed configuration all will assist the fabricator in choosing the best material to use for a particular application.

Circuit material choices

Polyimide film core and covercoat

As stated earlier, the predominant material used in rigid flex has been polyimide film. This material has been used quite successfully as both the base and the coverfilm providing protection to the traces in the flex section. A cross section of a typical rigid flex circuit showing these materials is shown in Figure 1. Circuits using this construction are capable of passing hundreds and perhaps even thousands of flex cycles. Such a construction does, however, carry a premium price. Polyimide film is more expensive than more traditional circuit board materials. Manufacturers that use polyimide film need to become specialists in handling thin core materials that have little if no structural integrity. Processing equipment tends to be more sophisticated, designed specifically for handling these thin, flexible cores. Flex circuit manufacturers have spent years optimizing their processes to get acceptable yields as these materials have a tendency to show dimensional instability during processing. Rigid flex circuits are different than traditional PWB’s in the fact that the traces in the flex section must also be covered with a material that is capable of being bend and formed. The most popular method of protecting the flexible area of a rigid flex is to laminate a polyimide covercoat in this area. This material provides both mechanical support and electrical insulation to the traces. There are several reasons why a fabricator would not want to use this method in their process, including the cost of polyimide film, added process steps (material preparation and lamination), and process flow issues.

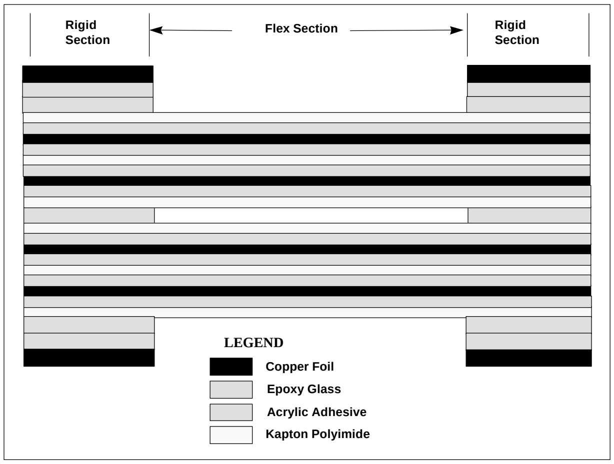

Figure 1
Typical polyimide film based rigid flex

Thin epoxy glass core with polyimide covercoat

An alternate material that has been used quite successfully for rigid flex processing is a thin epoxy glass material. By using a thin glass cloth base material circuit board, producers have been able to demonstrate acceptable flexibility for “flex-to-install” applications including military and high end commercial electronics. One such construction is Teledyne’s REGAL® Flex. This construction uses 1080 glass style prepreg as the base core material. Copper foil is laminated to this core material to create an innerlayer that is approximately 0.004” (100µm) thick. This material by itself is not flexible enough to allow for bending without damaging the glass fibers. When encapsulated with a suitable material, such as polyimide film, the result is a lower cost innerlayer that is less susceptible to handling damage during processing and will allow for many bending cycles. Teledyne has manufactured multi-layer rigid flex circuits using this type of construction that have withstood over 350 flex cycles[1]. Polyimide film is still used in the formed section but the amount used is relatively low.

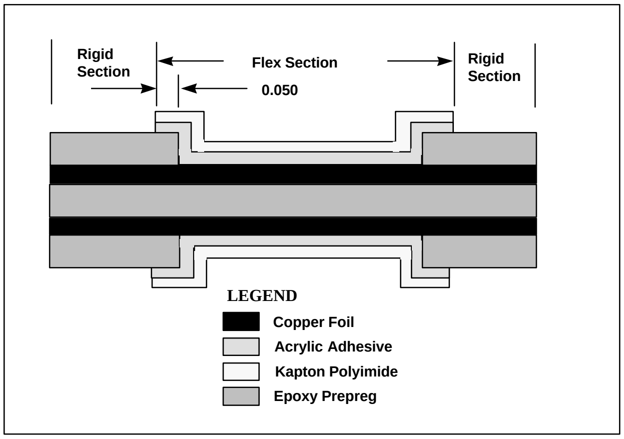

Figure 2
Cross section of REGAL® Flex innerlayer

Flexible liquid covermasks
Another simpler solution to covering the traces in the flex section of a rigid flex is to apply a liquid covermask. Traditional soldermasks or conformal coatings used on PCB's are not suited for this type of use. The covermask must be capable of being bent, twisted, and contorted during processing, testing and use. To address this need several suppliers have developed specific cover masks for use in these applications. These materials have shown to provide excellent environmental protection and mechanical support to the flex section of a rigid flex circuit. The major benefit to this type of processing is that the material itself is less expensive when compared to a polyimide film covercoat. The processing of this material is similar to a standard soldermask, and fabricators can use any one of several ways to apply the mask such as screen printing or spraying. This removes the need for a laminating press and the inherent extra expenses required for that type of operation. Performance requirements of the material differ somewhat from supplier to supplier, but most, if not all, will pass the 'flex-to-install' requirement outlined earlier. Acceptance of this material for flex applications has been reported by at least one major supplier of flexible liquid photoimageable covercoat. This manufacturer reported that a flexible covermask had been accepted by a major automotive manufacturer for under-the-hood applications and by a major manufacturer of hard disk drives [2]. Another supplier of flexible covermask has reported that a mask not only passed IPC-SM-840 flexing criteria over a 0.150" diameter (3.8mm) mandrel, but was capable of bending around a 0.040" (1.0mm) mandrel with no flaking, lift, or adhesion failure [3]. Liquid flexible covermasks can be applied either over a flexible base material such as polyimide, or over a thin core epoxy core material.

Modified fiber prepreg
There are other materials that can be used as a base material or coverlay material for rigid flex circuits. One of these materials under development at Teledyne involves modifying an epoxy prepreg material to enhance the flexibility to permit tighter radius bending. Modifying the epoxy glass material to enhance the flexibility has shown to offer significant increases in the number of bending cycles that can be achieved when compared to standard fiber glass material. This also offers the advantage of smaller form factor packaging by permitting smaller bend radii without damage to the core material. This product, identified in the accompanying charts as REGAL® X, is now available for prototype testing for rigid flex. Development work is continuing for several high volume consumer applications requiring low cost tight form factor packaging.

Copper Foils
During testing of different material combinations it was discovered that the copper conductors themselves played a significant role in the flexibility of a circuit. There are several choices of copper grade that can be used and all have different life expectancies for endurance and forming capability. Flex manufacturers normally use rolled annealed (RA) copper foil to provide the best performance for continuous flexing applications. Testing has shown that other copper grades such as High Temperature Elongated (HTE) or Electro-Deposited (ED) foil can also be used for flex-to-install applications. The benefit of these grades is the lower cost of raw material. The choices for copper grades are shown below:

GRADE	Relative Flexibility	Relative $
RA Foil	High	High
HTE Foil	Medium	Medium
ED Foil	Low	Low

The performance of the copper foil during flexing is also determined somewhat by the width of the traces. Wider conductors tended to be more robust during bending evaluations than narrower traces. This was true for most of the samples evaluated.

Testing and Results
Testing was done in accordance with MIL-P-50884C for both folding flexibility (*flex-to-install*) and flexibility endurance (*continuous flexing*). All tests

were performed per the guidelines of IPC-TM-650, TM 2.4.3.1. The test vehicle chosen was a section of the IPC-A-28/29 Flex Endurance Artwork. This artwork has three different conductor widths, 0.025" (635 µm), 0.010" (250 µm), and 0.005" (125 µm) which form the conductive pattern. The samples were all long enough to accommodate testing on a Universal Manufacturing "Flex Tester" machine which permitted better process control of the test. Various copper weights (thickness) and styles such as rolled annealed (RA), electro-deposited (ED), and high temperature elongated (HTE) were evaluated to determine the effect of copper ductility on flexibility and forming. Liquid covermask samples were evaluated to the requirements of IPC-SM-840 Para. 3.5.2.2 and tested to IPC-TM-650, TM 2.4.29. For tight bend form factor testing the samples were bent around various mandrel sizes less than 0.125" (3.175mm) and flexed to failure. The number of completed cycles was recorded.

Test procedure

Each test vehicle was prepared for evaluation by soldering a probe to each end of the conductive copper trace. Probes were then attached to the input and output end of the tester so that a complete electrical path was formed. Each sample was formed around a mandrel before the test sequence was run. For the "flex-to-install" test the sample was taken through a full 180° range of motion around the mandrel. For the "continuous flexing" test samples were subjected to approximately 135° of movement around a mandrel. Further definition of the test procedure can be found in the referenced documents and Test Procedures. Each specimen was visually inspected for evidence of separation or physical damage after each bend cycle up to a maximum of 25 cycles or to failure as determined by either a break in the copper trace or complete failure of the dielectric material. Samples that survived the test for more than 25 cycles were cycled to failure as defined by a break in the trace.

Results

The results for the tests are shown in the accompanying charts. Charts 1 through 4 show the results of "flex to install" and "flex endurance" for different double sided test specimens. Chart 1 shows data on REGAL ® 1 basestock, a thin epoxy core, with polyimide film covercoat. Chart 2 shows the same basestock with a flexible soldermask. All flexible covermask samples were spray coated with Taiyo PSR 9000. The data shows a decrease in the total number of bend cycles when using the flexible covermask over epoxy glass cores, but all but one sample surpassed the military requirement of 25 cycles. The data in Chart 3 represents the performance of the flexible covermask over polyimide film for flex to install and flex endurance applications. This chart also compares the various copper styles available for use in printed circuit fabrication. The rolled annealed copper exceeded the requirement of 25 cycles and the other copper foil types performed well enough to be considered for applications which require a low number of cycles such as formed for installation and service. Chart 4 shows the performance of a modified epoxy glass core, REGAL® X, with a polyimide covercoat. There is an increase in the durability of the flex section as indicated by the higher number of cycles achieved when compared to standard thin core epoxy glass. This material has shown to perform better than a standard thin core epoxy glass, but not as well as polyimide film basestock. Charts 5 and 6 compare performance of a single sided (one copper plane) layer for a polyimide film base to a thin core epoxy glass base. Both samples for this evaluation used a flexible mask provided by Taiyo. The data shows that this mask is capable of thousands of cycles when applied to a flexible base material and rolled annealed copper. Other copper styles performed well enough to be considered for flex to install applications. When this same material is applied to a thin core epoxy glass the overall number of flex cycles decreases, but still shows that the material performs well enough to be considered for circuits that need to bend or form. The last two charts illustrate the ability of thin core epoxy glass to be bent into a tight form factor. A standard weave 1080 prepreg core was compared to a REGAL® X core. The modified epoxy glass material showed a considerable increase in the number of flexes attained around a much smaller mandrel.

Summary

Rigid flex circuits have demonstrated superior reliability for military and high reliability commercial applications. Recent advancements in both materials technology and processing equipment now make it possible to lower the cost of producing these unique circuits. The data, although preliminary, shows that these newer materials will work for certain applications in which the performance from a flexing or forming standpoint is known. The inherent lower cost to procure raw materials and to process circuits using these materials will transfer to lower circuit prices. Designers now can use this information to make educated decisions as to which material combination would be best for their particular design. For the future, more work will be done to expand the data and add to the matrix.

Acknowledgments
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DATA CHARTS
Flex Cycling
Double Sided Flex Specimen

Sample	Flex to Install		Flex Endurance	
	.125 Diameter Mandrel		.125 Diameter Mandrel	
	Cond. Width	# Cycles	Cond. Width	# Cycles
1080 Prepreg with 1 Oz. RA copper and Polyimide Covercoat	.025	78	.025	229
	.010	71	.010	248
	.005	N/A	.005	194
106 Prepreg with 1 Oz. RA copper Polyimide Covercoat	025	281	025	443
	.010	285	.010	499
	.005	278	.005	403

Chart 1-Double sided REGAL® 1 epoxy core Testing Baseline

Sample	Flex to Install		Flex Endurance	
	.125 Diameter Mandrel		.125 Diameter Mandrel	
	Cond. Width	# Cycles	Cond. Width	# Cycles
1080 Prepreg with 1 Oz. RA copper Flexible Covermask	.025	36	.025	83
	.010	34	.010	86
	.005	20	.005	65
106 Prepreg with 1 Oz. RA copper Flexible Covermask	025	108	025	321
	.010	104	.010	215
	.005	92	.005	270

Chart 2-Double sided REGAL® 1epoxy core with flexible soldermask covermask

Sample	Flex-to-Install		Flex Endurance	
	.125 Diameter Mandrel		.125 Diameter Mandrel	
	Cond. Width	# Cycles	Cond. Width	# Cycles
Polyimide film base with 1 Oz. RA copper and flexible mask cover	.025	77	.025	101
	.010	68	.010	95
	.005	34	.005	61
Polyimide film base with 1 Oz. HTE copper and flexible mask cover	.025	57	.025	59
	.010	58	.010	53
	.005	19	.005	22
Polyimide film base with 1 Oz. ED copper and flexible mask cover	.025	44	.025	43
	.010	36	.010	25
	.005	17	.005	20

Chart 3-Double sided polyimide base with flexible mask cover

Sample	Flex to Install		Flex Endurance	
	.125 Diameter Mandrel		.125 Diameter Mandrel	
	Cond. Width	# Cycles	Cond. Width	# Cycles
1080 Prepreg with 1 Oz. RA copper and Polyimide Covercoat	.025	179	.025	337
	.010	158	.010	280
	.005	165	.005	263
106 Prepreg with 1 Oz. RA copper and Polyimide Covercoat	.025	330	.025	576
	.010	358	.010	459
	.005	N/A	.005	N/A

Chart 4-Double sided REGAL® X epoxy core and Polyimide Film Coverfilm

DATA CHARTS
Flex Cycling
Single Sided Flex Specimen

Sample	**Flex Endurance**		**Flex Endurance**	
	.125 Diameter Mandrel		.250 Diameter Mandrel	
	Cond. Width	# Cycles	Cond. Width	# Cycles
Polyimide film base with 1 Oz. RA copper and flexible mask cover	.025	2292	.025	30,486
	.010	2482	.010	15,130
	.005	2181	.005	8934
Polyimide film base with 1 Oz. HTE copper and flexible mask cover	025	2827	025	13,113
	.010	1101	.010	8618
	.005	792	.005	2659
Polyimide film base with 1 Oz. ED copper and flexible mask cover	025	2039	025	17,937
	.010	1913	.010	10,968
	.005	611	.005	5519

Chart 5 - Single sided polyimide film base sample with various copper styles and flexible covermask

Sample	**Flex Endurance**		**Flex Endurance**	
	.125 Diameter Mandrel		.250 Diameter Mandrel	
	Cond. Width	# Cycles	Cond. Width	# Cycles
1080 prepreg base with 2 Oz. RA copper and flexible mask cover	.025	73	.025	428
	.010	92	.010	384
	.005	n/a	.005	n/a
1080 prepreg base with 1 Oz. HTE copper and flexible mask cover	025	64	025	96
	.010	197	.010	168
	.005	185	.005	145
1080 prepreg base with 1 Oz. ED copper and flexible mask cover	025	14	025	371
	.010	89	.010	511
	.005	111	.005	393

Chart 6 - Single sided REGAL 1 with various copper choices and flexible covermask

The preceding charts (Charts 1 - 6) show the results of testing performed on various material combinations as evaluated for “flex-to-install” and “flex endurance” applications.

DATA CHARTS

Bending (Form Factor)

Sample	Bend Radius (Flex to install)		
	Copper & Wt.	.031 ∅ Mandrel	.062 ∅ Mandrel
1080 Prepreg (0.003” thick) base stock with polyimide coverfilm	½ Oz. RA	8	10
	½ Oz. HTE	3	8
	½ Oz. ED	3	7
106 Prepreg (0 .002” thick) base stock with polyimide coverfilm	½ Oz. RA	17	200 (+)
	½ Oz. HTE	9	46
	½ Oz. ED	8	31

Chart 7 - Double sided REGAL® 1 Testing Baseline

Sample	Bend Radius (Flex to install)		
	Copper & Wt.	.031 ∅ Mandrel	.062 ∅ Mandrel
1080 Prepreg (0.003” thick) base stock with polyimide coverfilm	½ Oz. RA	32	88
	½ Oz. HTE	5	10
	½ Oz. ED	6	13
106 Prepreg (0 .002” thick) base stock with polyimide coverfilm	½ Oz. RA	74	200 (+)
	½ Oz. HTE	21	57
	½ Oz. ED	19	47

Chart 8
Double sided REGAL® X epoxy core and Polyimide Film Coverfilm

The results above show a significant increase in the form factor that is attainable without damage to the core material by modifying the glass fiber reinforcement

References

[1] J. Keating & R. Larmouth, “High Volume Applications of Commercial Rigid-Flex”, Proceedings IPC Expo 1996

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[3] W.J. Thatcher & P.M. Banks, “A Flexible Alternative”, PC Fabrication, Vol. 18, No. 12, December 1995 pp28-30.