2.7
12-5-78
240 NTS

MASTER

BDX-613-1868 (Rev.)

QUANTITATIVE COMPARISON OF ELECTRONIC
COMPONENT-SOLDER JOINT STRESS RELIEF
IN ENCAPSULATED ASSEMBLIES

By D. A. Cummings

Published November 1978

Topical Report

078 7000

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche \$3.00
 Paper Copy \$4.50

QUANTITATIVE COMPARISON OF ELECTRONIC
COMPONENT-SOLDER JOINT STRESS RELIEF
IN ENCAPSULATED ASSEMBLIES

By D. A. Cummings

Published November 1978

Topical Report
D. A. Cummings, Project Leader

Project Team:
D. C. Dyer
D. E. Walters
G. L. Woodburn

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Communications Services

**Kansas City
Division**

QUANTITATIVE COMPARISON OF ELECTRONIC COMPONENT-SOLDER JOINT
STRESS RELIEF IN ENCAPSULATED ASSEMBLIES

BDX-613-1868 (Rev.), Topical Report, Published November 1978.

Prepared by D. A. Cummings

Component lead sleeving is the most effective method for stress relieving both component bodies and solder joints in encapsulated electronic assemblies. Silicone has been the most effective sleeving found for reducing loads; however, it compares closely to heat shrinkable polyolifin sleeving in quantitative load tests run at ambient temperatures.

WPC-dkvh

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The Bendix Corporation
Kansas City Division
P. O. Box 1159
Kansas City, Missouri 64141

A prime contractor with the United States
Department of Energy under Contract Number
DE-AC04-76-DP00613

CONTENTS

Section	Page
SUMMARY.	5
DISCUSSION	6
SCOPE AND PURPOSE.	6
PRIOR WORK	6
ACTIVITY	7
<u>Approach</u>	7
<u>Test Data</u>	11
<u>Test Results</u>	11
ACCOMPLISHMENTS.	13
FUTURE WORK.	15
REFERENCES	16
APPENDIX. TEST RESULT PLOTS	17
DISTRIBUTION	24

ILLUSTRATIONS

Figure		Page
1	Stress Relief Sample Scheme.	7
2	Load Application and Measurement Device (P-98633)	8
3	Test Sample Configuration.	9
4	Instrumentation Used to Obtain Data.	9
5	Stress Relief Test Samples (P-98634)	10
6	Compressive Load Fixturing (P-98635)	10
7	Tensile Load Fixturing (P-98637)	12
8	Component Lead Movement Instrumentation (Extensiometer) (P-98636)	12
9	Sample of Test Data Obtained From X-Y Plot of Load on Component Side	13
10	Example of Raw Test Data From Loads Resulting at the Solder Joint Side	14

SUMMARY

Solder joint cracking and electronic component breakage in encapsulated high voltage electronic assemblies that are exposed to thermal cycling prompted the use of component lead bends and sleeving to protect against stresses caused by mismatches in thermal coefficients of expansion. The component lead bends, or stress relief loops, are preformed configurations including loops, humps, and right angle bends.

Quantitative comparisons were made of the effectiveness of each stress relief configuration without sleeving and with two different sleeving materials. Three encapsulants were used. Tensile and compressive loads were applied to test samples while instrumentation measured the resultant loads at positions representing both the component side and the solder joint side of the encapsulated stress relief loop. The tensile and compressive loads were applied to the component side of the test samples and were intended to simulate thermal cycling stress-strain action on the component body. Other tests on encapsulated solder joints with lead stress relief have been made. However, these tests have been qualitative--such as viewing and inspecting solder joints for cracks after they had been exposed to thermal cycling.

The results of the quantitative comparison include the following.

- Sleeving significantly reduces stress on encapsulated components and solder joints. Silicone sleeving is slightly more effective than heat shrinkable polyolifin.
- The full loop component lead is the most effective stress reducing configuration. The hump is a close second.
- Larger component lead wire more readily induces stress.
- The epoxy and 20-pound foam encapsulants introduce the most load on a component-solder joint system--especially with larger component leads.
- The use of stress relief bends in component leads--as opposed to the standard right angle bend--is of secondary significance when sleeving is used. Little difference is seen in component-solder joint lead protection with special lead bends once sleeving is used.

DISCUSSION

SCOPE AND PURPOSE

Present requirements for some encapsulated high voltage electronic assemblies include a stockpile life of as much as 20 years. During production, testing, and stockpile storage, units receive numerous temperature cycles ranging from -55°C to $+74^{\circ}\text{C}$. Because of the difference in thermal coefficients of expansion between encapsulants and various other materials in an electronic assembly, stresses are set up as adjacent and adhering materials expand and contract at different rates. These forces can cause solder joint or component damage as component leads are pushed or pulled between the component body and solder joint. Stress relief bends and sleeving are applied to electronic component lead wires in an effort to protect against these forces.

A quantitative comparison was made of various stress relief bends with and without sleeving in three commonly used encapsulants. Silicone rubber and heat shrinkable polyolifin sleeving were used on right angle, full loop, and hump style lead bends. Small (from $254\text{ }\mu\text{m}$ to $762\text{ }\mu\text{m}$ diameter) and large ($762\text{ }\mu\text{m}$ to 1.27 mm diameter) wires were used to simulate small and large component leads. The component leads were encapsulated in micro-balloon-filled epoxy, 128 kg/m^3 urethane foam, and 320 kg/m^3 urethane foam. Ten test samples were fabricated in each configuration: five were used for tensile loading and five were used for compressive loading. Figure 1 shows the possible combinations of test samples.

PRIOR WORK

Previous efforts¹⁻⁵ have described studies of thermally cycled test samples constructed with actual printed circuit boards and encapsulated stress relief techniques similar to the ones described in this report. Viewing ports were attached to these samples so visual inspection could be made of the solder joints after specified numbers of thermal cycles. The conclusions reached are consistent with the conclusions reached during the current effort. However, the current study provides a quantitative comparison and does not rely on human interpretation of the degradation of solder joints. In addition, the current study includes more possible parameters and takes into consideration the forces present on a component body as well as those potentially present on solder joints.

LEAD CONFIGURATIONS	WIRE DIAMETER	SLEEVING	ENCAPSULATION	LOADING DIRECTION
90° BEND	SMALL (0.508 mm)	POLYOLIFIN	128 kg/m ³ FOAM	TENSILE
FULL LOOP	LARGE (1.106 mm)	SILICONE	320 kg/m ³ FOAM	COMPRESSION
HUMP		NONE	EPOXY
45° HUMP				
4 TOTAL	2 TOTAL	3 TOTAL	3 TOTAL	2 TOTAL
<p>MULTIPLYING PARAMETERS RESULTS IN TOTAL OF 144 DIFFERENT SCHEMES</p> <p>144 DIFFERENT SCHEMES MULTIPLIED BY 5 TEST SAMPLES PER SCHEME EQUALS 720 TEST SAMPLES</p> <p>45° HUMP WAS NOT USED ON LARGE WIRE (SUBTRACT 90 SAMPLES) TO LEAVE TOTAL OF 630 SAMPLES</p>				

Figure 1. Stress Relief Sample Scheme

ACTIVITY

Approach

During the study it was assumed that the greatest forces introduced into an encapsulated component lead-solder joint system were the result of movement of the component body relative to the printed circuit board. The test samples were designed to have a force applied by a loading and measuring device (Figure 2) on the component side (Figure 3) and to measure the resultant loads at both the solder joint and component sides of the test sample. A diagram of the instrumentation used is shown in Figure 4.

The test samples were molded 10 at a time in specially designed molds that produced an encapsulated bar 254 by 25.4 by 25.4 mm. Ten 25.4 mm³ samples could then be cut from the bar. By eliminating

Figure 2. Load Application and Measurement Device

molding runs, this technique produced five tensile test samples and five compressive test samples of a given stress relief configuration with as much consistency as possible. Figure 5 shows a typical sample.

The rate of application of the load on the stress relief system was as slow as possible with the given equipment ($0.8 \mu\text{m/s}$). Loads were applied until the component lead traveled $254 \mu\text{m}$ or 88 N force occurred on the solder joint side of the test sample.

Figure 6 shows a test sample with compressive loading being applied. The sample is sitting on a load cell as force is applied from the component side. Other instrumentation measures the travel of the lead wire into the sample and the load at the solder joint side.

Figure 3. Test Sample Configuration

Figure 4. Instrumentation Used to Obtain Data

Figure 5. Stress Relief Test Samples

Figure 6. Compressive Load Fixturing

Figure 7 shows a test sample in tensile load fixturing. The instrumentation is the same as the compressive load with the addition of a brace to hold the sample to the load cell as the jaws pull the lead upward.

Figure 8 is a closeup view of the extensiometer used to measure the movement of the component lead as it is being loaded.

Test Data

Figure 9 is an example of the raw data obtained from an X-Y plot of the load on the component versus the movement of the component lead. The family of curves shown represents tensile data for right angle leads 1.02 mm in diameter, sleeved with silicon rubber, and encapsulated in 128 kg/m³ urethane foam.

Similarly, Figure 10 is raw data obtained from a force gage at the solder joint side of each test sample. This family of curves represents the load at the solder joint versus the movement of the component lead at the component side on the horizontal axis. Samples shown in Figure 10 are tensile tests of 1.02 mm diameter right angle bent leads with polyolifin sleeving and 320 kg/m³ urethane foam encapsulant.

Test Results

Results obtained from the 630 samples tested are given in the appendix. As can be seen from the previous test data examples, a curve was generated for each sample tested. The amplitude of each curve at 127 μ m was measured and plotted. This point was chosen because it represents a lead displacement well beyond that which might be obtained from a combination of the highest coefficient of expansion over the widest temperature range in an encapsulated stress relief loop. In other words, a stress relief system would not have to absorb more displacement than 127 μ m over the worst temperature range in a high voltage electronic assembly. In addition, the 127 μ m displacement represents a mid-point for the curves taken.

Each plot shows the range and $\bar{X}$ for the five data points taken for each configuration. A 45-degree hump configuration was included in the tests for small wires. This configuration was made with a Sandia Laboratories (Albuquerque) forming tool. The tool was limited to small size lead wire.

Plots marked with a T indicate that the load applied at the solder joint was in an opposite direction to that expected; that is, tensile loading at the component side resulted in compressive loading at the solder joint side. This phenomenon can be explained by noting, for example, that a hump loop in silicone sleeving with a compressive load is likely to compress the sleeving and actually pull on the lead leaving the solder joint side.

Figure 7. Tensile Load Fixturing

Figure 8. Component Lead Movement
Instrumentation (Extensimeter)

Figure 9. Sample of Test Data Obtained From X-Y Plot of Load on Component Side

It can be seen that an easy comparison of stress relief loops and sleeving can be made for a given encapsulant and wire size, and that an easy determination can be made of the best stress relief systems for a given application.

ACCOMPLISHMENTS

The results of this study can be used to select the optimum stress relief loop style and sleeving for an encapsulated electronic assembly. Although silicone sleeving may have the lowest resultant stress levels, polyolifin may be close enough and a wiser choice because of the ease of processing. In addition, component lead-to-body qualification load tests can be set to guarantee that the component can survive the next assembly encapsulated environment. Similarly, having the predicted load data for an encapsulated stress-relief-protected solder joint can permit the calculation of thermal fatigue in the solder and thus establish a basis for a long life solder joint system.

Figure 10. Example of Raw Test Data From Loads Resulting at the Solder Joint Side (Movement Is in the X Direction and Is Taken From the Lead on the Component Side.)

Without exception, test samples with sleeving were well below the load levels of those without sleeving at the component side. Although the loads on the solder joint side were low on many of the unsleeved examples, it can be concluded that the component lead wire was being seized by the encapsulant and preventing the component body from being cushioned from the resultant loads.

Comparison of the various loop configurations showed that the full loop component lead (Figure 1) was the most effective. However, the load levels received in the hump style were closely comparable. In addition, load levels in the vast majority of the sleeved right angle bend styles were only slightly higher than the other two styles. In general, it can also be concluded that the large wire system as well as epoxy and 320 kg/m^3 (20 lb) foam

encapsulants induced the most loads on components and solder joints. Higher modulus potting materials and wire involved in these particular stress relief test samples contributed to this conclusion.

FUTURE WORK

All of the test samples were exposed to forces at ambient temperature. Since the modulus of materials changes with temperature and at different rates, temperature testing of stress relief configurations would be appropriate in future efforts. Glass transition effects of materials would tend to load stress relief systems more at cold temperatures and less at hot temperatures.

REFERENCES

¹D. M. Jarboe, *Stress Relief Techniques for Reducing Thermal Fatigue in Solder Joints* (Final Report). Bendix Kansas City: BDX-613-1655 (Rev.), February 1978 (Available From NTIS).

²H. R. MacDougall, *Analysis of Stresses in Electronic Component Leads*. Sandia Laboratories Albuquerque: Physical Design and Materials Division Report #107, June 1975.

³H. R. MacDougall, *Analysis of Stress in Electronic Component and Solder Joint Due to Encapsulation*. Sandia Laboratories Albuquerque: Physical Design and Materials Division Report #111, December 1975.

⁴J. W. Munford, *The Influence of Several Design and Material Specifications on the Propensity for Solder Joint Cracking*. Sandia Laboratories Albuquerque: Report #SLA74-0114, March 1975.

⁵H. M. Weil, "Manufacturing Ideas--Process Changes Eliminate Most Cracked Joints," *Circuits Manufacturing*. Volume 11, No. 8, August 1971.

Appendix

TEST RESULT PLOTS

8 POUND FOAM (128 kg/m³) - SMALL WIRE 0.127 mm MOVEMENT LOAD ON COMPONENTS

8 POUND FOAM (128 kg/m³) - SMALL WIRE 0.127 mm MOVEMENT LOAD ON SOLDER JOINTS

Figure 1 is a line graph showing the load (N) versus time (s) for the pull and push tests. The Y-axis represents Load (N) with major ticks at 4.448, 8.896, 13.34, 17.79, 22.24, 26.69, 31.14, 35.59, 40.03, 44.48, 48.93, 53.38, and 57.83. The X-axis represents Time (s) with major ticks at 0, 2, 4, 6, 8, and 10. Two data series are plotted: Pull (open circles) and Push (filled circles). The Pull series starts at approximately 10 N at 0 s and increases steadily to about 57.83 N at 10 s. The Push series starts at approximately 10 N at 0 s and increases steadily to about 53.38 N at 10 s. A legend in the top right corner identifies the symbols: an open circle for 'PULL' and a filled circle for 'PUSH'.

Time (s)	Pull Load (N)	Push Load (N)
0	10.0	10.0
2	15.0	15.0
4	20.0	20.0
6	25.0	25.0
8	30.0	30.0
10	57.83	53.38

Material	Direction	Load (N)
POLYOLIFIN	PULL	~0.6
POLYOLIFIN	PUSH	~1.9
SILICONE	PULL	~0.5
SILICONE	PUSH	~0.5
NONE	PULL	~0.4
NONE	PUSH	~0.4
POLYOLIFIN	PULL	~0.8
POLYOLIFIN	PUSH	~0.8
SILICONE	PULL	~0.4
SILICONE	PUSH	~0.4
NONE	PULL	~2.5
NONE	PUSH	~2.8
POLYOLIFIN	PULL	~1.7
POLYOLIFIN	PUSH	~1.7
SILICONE	PULL	~0.4
SILICONE	PUSH	~0.4
NONE	PULL	~2.1
NONE	PUSH	~2.1
POLYOLIFIN	PULL	~1.2
POLYOLIFIN	PUSH	~1.2
SILICONE	PULL	~0.4
SILICONE	PUSH	~0.4
NONE	PULL	~4.2
NONE	PUSH	~4.2

8 POUND (128 kg/m³) FOAM - LARGE WIRE 0.127 mm MOVEMENT LOAD ON COMPONENTS

8 POUND (128 kg/m³) FOAM - LARGE WIRE 0.127 mm MOVEMENT LOAD ON SOLDER JOINTS

20 POUND (320 kg/m³) FOAM - LARGE WIRE 0.127 mm MOVEMENT LOAD ON COMPONENT

20 POUND (320 kg/m³) FOAM - LARGE WIRE 0.127 mm MOVEMENT LOAD ON SOLDER JOINT

DISTRIBUTION

	Copy
R. Bulcock, ERDA-KCAO	1
H. Barnett, SLA	2
R. L. Brown, SLA	3
J. Monford, SLA	4
P. Royer, SLA	5
T. J. Williams, SLA	6
J. E. Long, D/531, 1A46	7
H. T. Barnes, D/554, BD50	8-9
L. Stratton, D/554, 2C44	10-12
R. P. Frohmberg, D/800, 2A39	13
D. M. Jarboe, D/814, 2C43	14
R. L. Sadler, D/814, 2C43	15
G. L. Woodburn, D/814, XD43	16
D. C. Dyer, D/816, SG-3	17
A. G. Bennett, D/845, MF39	18
R. C. Douglass, D/845, MF39	19
R. G. Morgan, D/845, MF39	20
R. J. Powell, D/845, MF39	21
W. R. Sprague, D/846, MF39	22
D. A. Cummings, D/864, MF39	23
R. L. Morgan, D/864, MF39	24
R. E. Kessler, D/865, 2C40	25

BDX-613-1868 (Rev.)

QUANTITATIVE COMPARISON OF ELECTRONIC COMPONENT-SOLDER JOINT STRESS RELIEF IN ENCAPSULATED ASSEMBLIES, D. A. Cummings, Topical, November 1978.

Component lead sleeving is the most effective method for stress relieving both component bodies and solder joints in encapsulated electronic assemblies. Silicone has been the most effective sleeving found for reducing loads; however, it compares closely to heat shrinkable polyolifin sleeving in quantitative load tests run at ambient temperatures.

ELECTRICAL: Stress Relief

QUANTITATIVE COMPARISON OF ELECTRONIC COMPONENT-SOLDER JOINT STRESS RELIEF IN ENCAPSULATED ASSEMBLIES, D. A. Cummings, Topical, BDX-613-1868 (Rev.), November 1978.

Component lead sleeving is the most effective method for stress relieving both component bodies and solder joints in encapsulated electronic assemblies. Silicone has been the most effective sleeving found for reducing loads; however, it compares closely to heat shrinkable polyolifin sleeving in quantitative load tests run at ambient temperatures.

QUANTITATIVE COMPARISON OF ELECTRONIC COMPONENT-SOLDER JOINT STRESS RELIEF IN ENCAPSULATED ASSEMBLIES, D. A. Cummings, Topical, BDX-613-1868 (Rev.), November 1978.

Component lead sleeving is the most effective method for stress relieving both component bodies and solder joints in encapsulated electronic assemblies. Silicone has been the most effective sleeving found for reducing loads; however, it compares closely to heat shrinkable polyolifin sleeving in quantitative load tests run at ambient temperatures.