NATIONAL PHYSICAL LABORATORY

Teddington Middlesex UK TW11 0LW Telephone +44 20 8977 3222

Test Report

BINDING STRENGTH OF COPPER CLADDING ON ALUMINIUM BUSBARS USING THE ELCOMETER PULL-OFF TEST

Restricted – In Confidence

By
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NPL Materials Division

Summary

Elcometer pull-off tests were conducted to assess the binding strength of copper cladding on aluminium busbars. Tests were conducted using standard 12.7 mm diameter stubs attached to the copper cladding with FM1000 adhesive from Cytec Engineering. Three sets of copper clad specimens were examined which had been exposed to -40 °C to + 110 °C for 0, 50 and 100 cycles. None of the claddings were found to delaminate in the pull-off tests indicating that their binding strengths were all greater than that of the adhesive used to attach the stubs (>61 MPa).

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Date of issue: 14/10/14

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NPLT01-06/07

CONTRACT

The contract between NPL and Applied Composite Materials Ltd was as follows:

Initial and final binding force tests on copper clad aluminium busbars to be conducted.

Start: 7 October 2014

Completion: 14 October 2014

Customers artefacts:

Table 1 ***Copper clad aluminium busbars with different environment exposure cycles have been given the following NPL codes.***

NPL code	Environmental exposure
AAKJZ232A	0 cycles
AAKJZ232B	50 cycles (-40 °C to + 110 °C)
AAKJZ232C	100 cycles (-40 °C to + 110 °C)

1. INTRODUCTION

NPL was instructed by Applied Composite Materials to conduct a series of pull-off tests using the Elcometer pull-off tester to determine the binding strength of copper clad aluminium busbars exposed to -40 °C to + 110 °C for 0, 50 and 100 cycles. This report describes the tests and the results obtained.

2. TEST PROCEDURE

Adhesion tests were conducted by attaching aluminium stubs (12.7 mm diameter) to the copper cladding using FM1000 adhesive. The tests were conducted using a commercially available Elcometer Patti 100 test rig with a F12 piston (Figure 1). The tests involved screwing a pull-off stub into the top platen of the rig which could be moved freely relative to the lower platen. The stub was then pulled from the copper cladding by inflating a pneumatic bladder that pushes the two platens apart. The peak pneumatic pressure at failure was recorded and converted to a value of tensile stress (binding strength) through look-up tables supplied with the equipment.

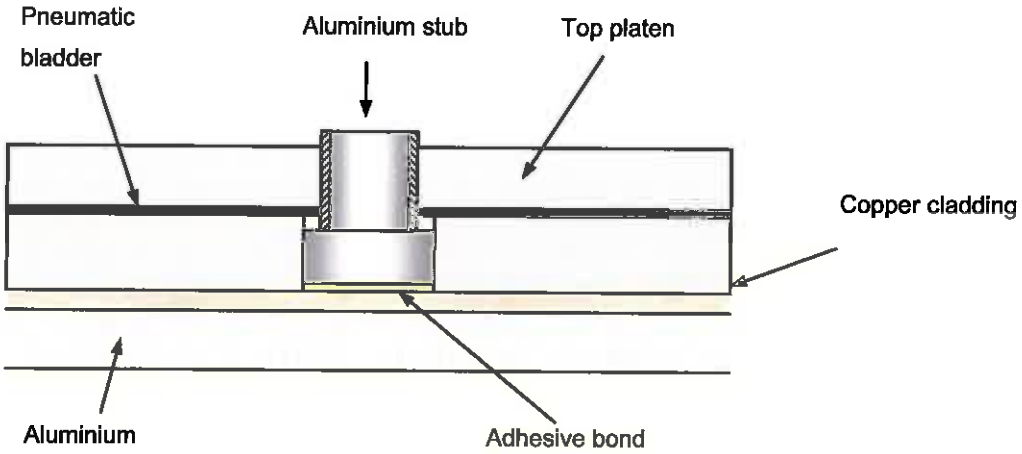

Figure 1 Schematic Representation of Pull-Off Test Equipment

3. RESULTS AND DISCUSSION

The binding strengths obtained from the pull-off tests are shown in Table 2 with three repeat tests conducted on each bar.

After a stub had been pulled from the surface, the fracture surface was visually examined. In each case it was found that the FM1000 adhesive had failed with no sign of any of the claddings delaminating (Table 2). This indicates that the binding strength of the cladding is greater than the adhesive used to attach the stubs for each of the specimens examined. The variability in the results is due to variability in the adhesive rather than the cladding and it would appear valid to assume that the binding strength of the cladding is greater than the maximum value obtained using the pull-off test of 61 MPa. Increasing the number of exposure cycles the busbars were subjected appears to have no effect on the binding strength of the copper cladding (Table 2).

4. CONCLUSIONS

None of the claddings were found to delaminate in the pull-off tests indicating that their binding strengths were all greater than that of the adhesive used to attach the stubs (>61 MPa). Increasing the number of cycles the specimens were exposed to had no significant effect on the binding strength of the specimens up to 61 MPa.

Table 2 Pull-off tests results for copper clad aluminium busbars

Disc Number	NPL Material Code	Exposure cycles	Tensile strength (MPa)
1	AAKJZ232A	0	55.60
1	AAKJZ232A	0	60.90
1	AAKJZ232A	0	59.10
2	AAKJZ232B	50	58.10
2	AAKJZ232B	50	59.20
2	AAKJZ232B	50	61.00
3	AAKJZ232C	100	59.10
3	AAKJZ232C	100	60.10
3	AAKJZ232C	100	58.10

Appendix 1 Interfacial strength test

An additional test was conducted for the customer, which was outside the main measurement service contract. This involved conducting an interfacial strength test on a busbar prepared by the customer. The specimen was rectangular shaped with a width of 20mm and precisely drilled with a 4mm long channel cut from the upper copper layer through the sample leaving just the bottom copper layer. A second channel was then cut parallel to the first through the bottom copper layer leaving a bimetallic connecting area (Figure 2). The bars were tested using an Instron 5500 K8026 tensile machine fitted with a calibrated load cell (load cell no. UK034, E11809111310). The specimens were placed in the grips, taking care to align the longitudinal axis of the test specimen with the axis of the testing machine. Tests were conducted at a rate of 1 mm/min and the tests continued until the specimens fractured. Load-cell force measurements were automatically recorded throughout the experiments. The load-displacement results for this test are shown in Figure 3, with the maximum load at fracture recorded as 2.945 kN.

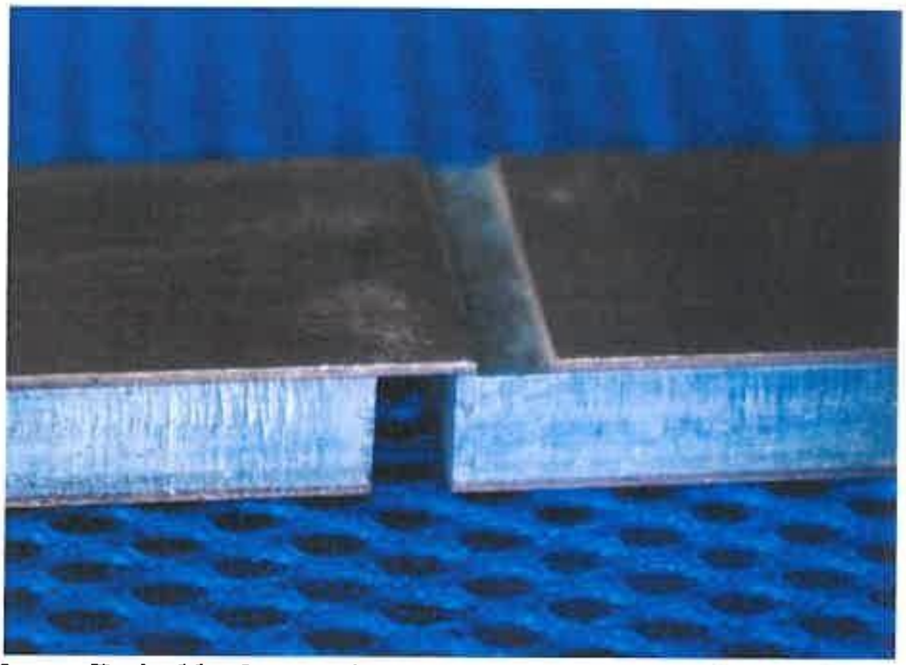

Figure 2 ***Typical busbar specimen used for the interfacial strength test***

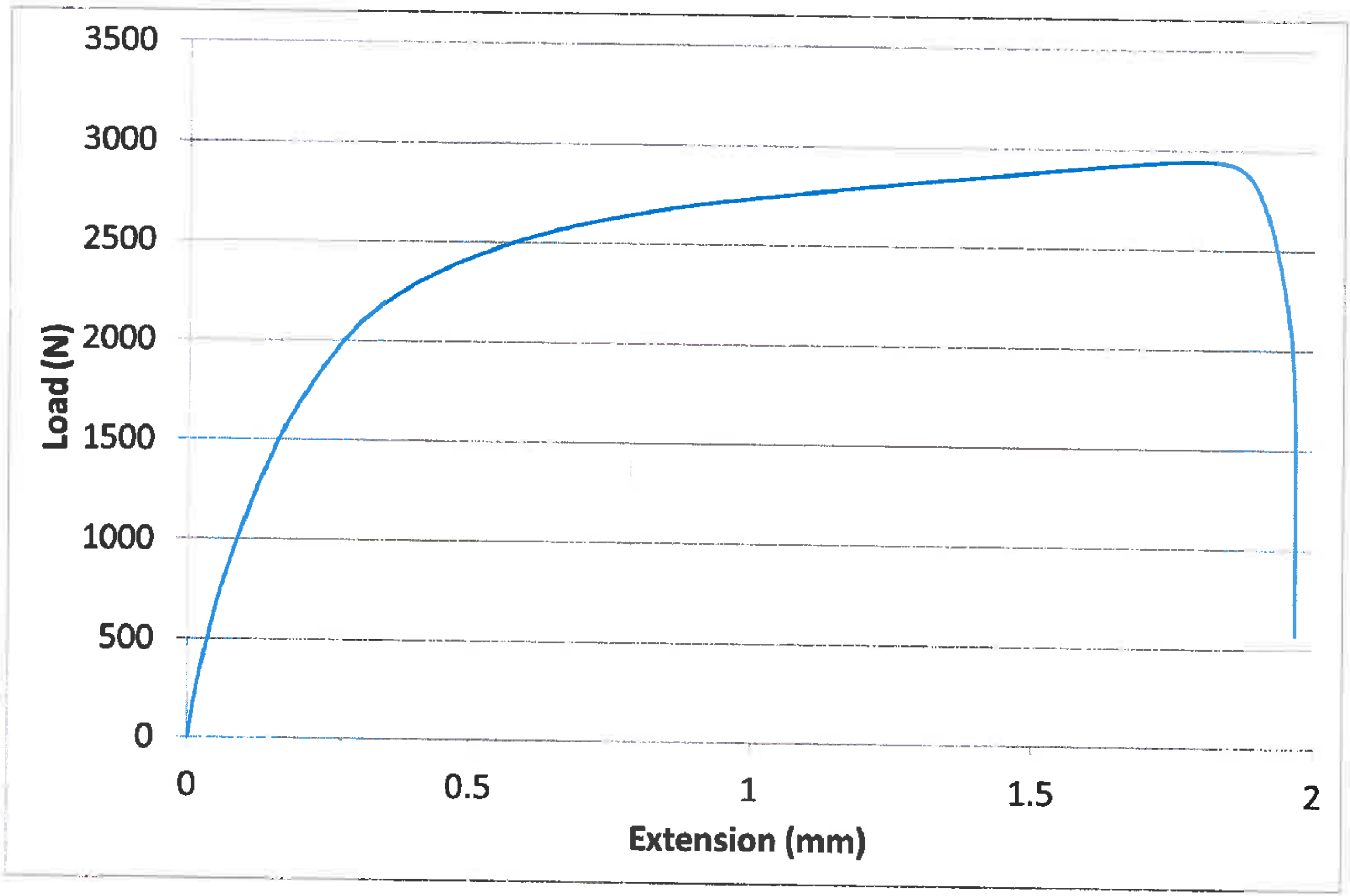

Figure 3 ***Load-displacement results obtained from interfacial strength test.***

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Test Report

英国国家物理实验室　检测报告

使用ELCO 测试仪及拉拔法测试

铜包覆铝母线排结合强度

严格保密

A. S. Maxwell
英国国家物理实验室 - 材料部

结论：

使用 ELCO 测试仪做拉拔试验以检测铜铝复合母线排结合强度。测试中使用 12.7 毫米直径的标准基座将其由 Cytec Engineering 公司提供的 FM1000 胶粘剂附着在铜包覆层上。三组铜铝复合样品分别暴露在-40°C 到+110°C 的交变温度环境中经历 0 次，50 次及 100 次循环，随后进行拉拔试验。所有样品均未发生分层脱离现象，表示复合界面的结合强度大于用以测试的基座粘合强度极限（即大于 61 MPa）。

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合同：

英国国家物理实验室与应用复合材料公司签署合同内容为：
测试铜铝复合母线在初始与终端状况下的结合力

实验开始于： 2014 年 10 月 7 日

实验完成于： 2014 年 10 月 14 日

客户提供实验样品材料：

表格一、 经历不同温度极限循环次数的铜铝复合母线 NPL 编码

国家物理实验室 NPL 编码	实验条件
AAKJZ232A	0 次循环
AAKJZ232B	50 次循环（-40ºC 与+110ºC 之间）
AAKJZ232C	100 次循环（-40ºC 与+110ºC 之间）

1、介绍

应用复合材料公司要求英国国家物理实验室使用 ELCO 测试仪进行一系列拉拔测试，以测定铜铝复合母线在经历 0 次、50 次、100 次由-40ºC 到+110ºC 的温度变更循环后的铜铝界面结合强度。本报告阐述了实验流程与实验结果。

2、测试程序

本实验是通过将铝基基座材料（直径为 12.7 毫米）通过 FM1000 胶粘剂附着在铜包覆层上。测试过程是将 F12 活塞（图 1 所示）放置在 ELCO PATTI-100 测试仪试验台上。本测试流程为将基座旋入实验台的相对于下部压盘而言可以自由运动的上部压盘上。此后，通过在上下两个压盘间的充气囊推动两压盘分离，进而使得附着在铜包覆层上基座形成向上拉拔力。

记录拉拔使基座分离时的峰值气压值并通过该测试仪附带的表格将其转换为结合力值（结合强度）。

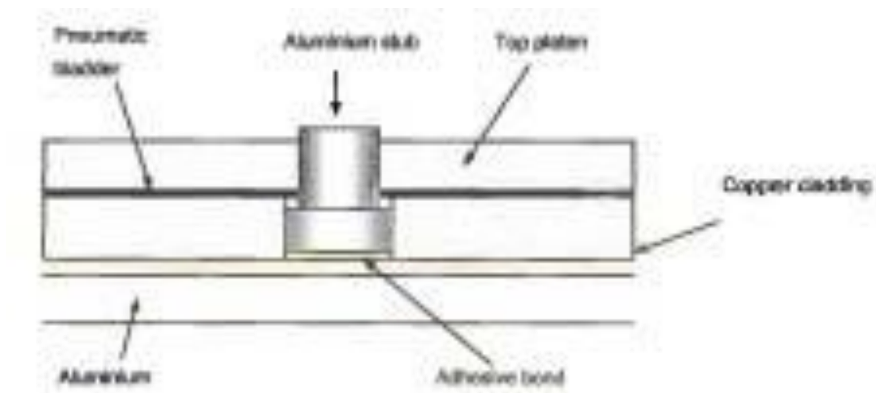

图 1、 拉拔试验设备示意图

3、结果与讨论

拉拔试验测得的结合强度列于表 2，每个样品均重复三次试验。

当基座从表面拉开后，对断裂面进行检查。各种状况均为 FM1000 粘合剂脱开，而铜铝复合界面没有丝毫分层迹象（表 2 所示）。表明铜铝复合界面结合强度大于将基座附着在每个检测样品上的胶粘剂极限粘合强度。测试结果差异是由粘合剂的差异而造成，并非复合界面造成，由此可得出铜铝复合界面结合强度远大于本实验所能测试的极限拉断值 61 MPa。增加铜铝复合母线经历温度变更的循环次数对铜铝复合界面的结合强度没有影响（表 2 所示）。

4、结论

在拉拔试验中没有发现铜铝复合层有分层脱离迹象的结果表明，其结合强度大于用来将基座附着的粘合强度极限（大于 61 MPa）。在 61 MPa 的限度内，增加温度变更的循环次数对样品复合界面结合强度没有显著的影响。

表格二、铜铝复合母线拉拔测试结果

编号	样品编码	循环次数	分离强度（MPa）
1	**AAKJZ232A**	0	55.60
1	**AAKJZ232A**	0	60.90
1	**AAKJZ232A**	0	59.10
2	**AAKJZ232B**	50	58.10
2	**AAKJZ232B**	50	59.20
2	**AAKJZ232B**	50	61.00
3	**AAKJZ232C**	100	59.10
3	**AAKJZ232C**	100	60.10
3	**AAKJZ232C**	100	58.10

附录 1、界面剪切强度测试

本测试服务之外为客户进行了附加测试，对由客户提供的母线排样品进行界面剪切强度测试。该样品为 20mm 宽的矩形长条。从上面铜层精准铣出一条 4 mm 长的通道仅留下底面铜层。再从底部铜层沿平行于第一通道方向铣出第二通道仅留下一个双金属连接区域（如图 2 所示）。使用 Instron 5500 K8026 强度拉伸机并配备校准负载单元进行测试（负载单元编号：UK034，E11809111310）。将样品放置在把手中，测试样品的纵向轴线沿测试机的轴向对准。以 1 mm/min 的试验速率连续测试样品直至（铜层部分）拉断。整个测试过程自动记录负载单元的载荷力数据。本试验载荷与位移的测试结果如图 3 所示，（铜层部分）断裂时的最大载荷值记录为 2.945 kN。

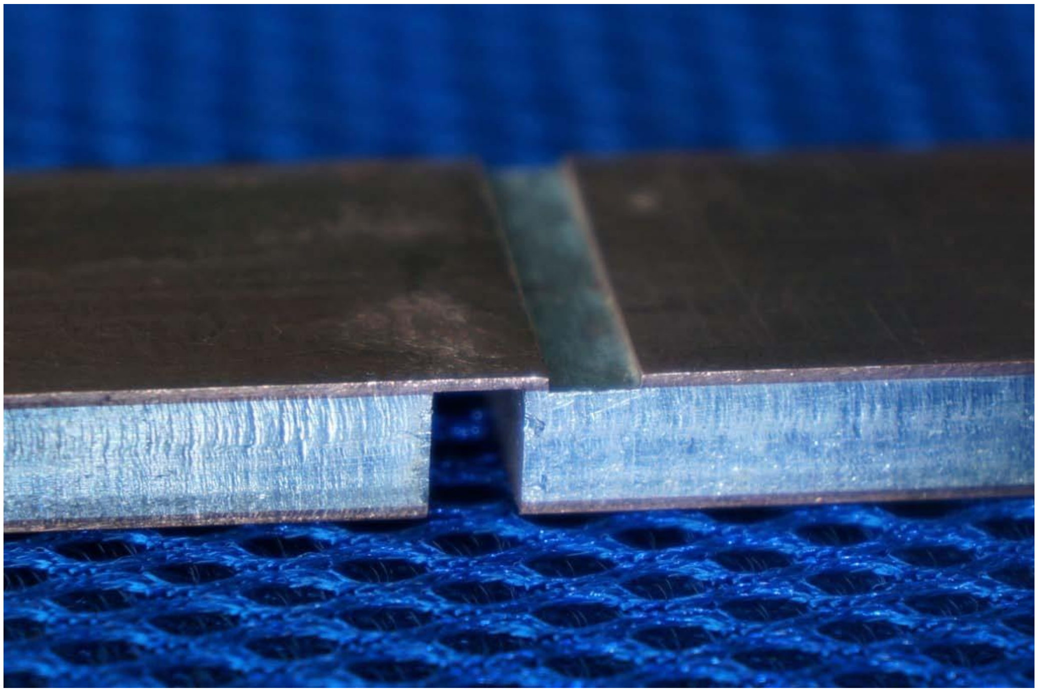

图 2、本用于界面剪切强度试验的典型母线样品。

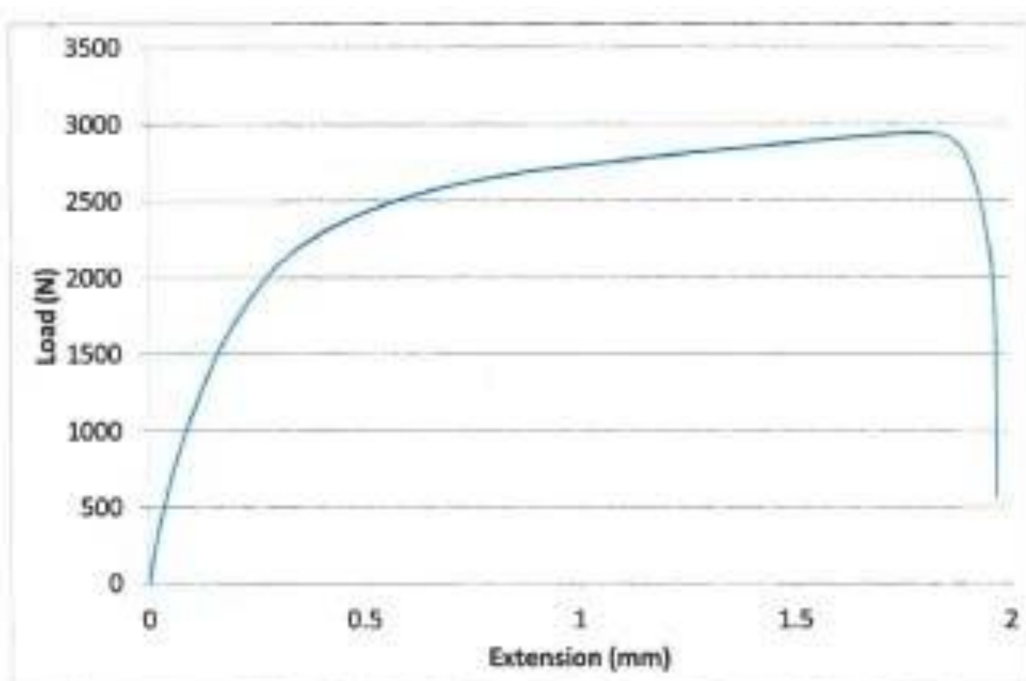

图 3、界面剪切强度试验获得的荷载与位移测试结果。