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报告编号：FISEND-20131107001

Comparison Test Report Between
对比测试报告

The Copper Clad Aluminum (CCA) Busbars Produced in Horizontal continuous casting and in Cu tube filled with Al Liquid

铜包铝排水平连铸法 VS.套管法

Test Date: 2012.11.5-2013.11.7
测试日期：2013.11.5-2013.11.7

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Proprietary Information

Purpose 目的

To conclude the differences of CCA busbar in Continuous casting and in Cu tube filled with Al liquid by comparing their test performance and analyzing the test data, The data can be customer's reference。
本测试旨在通过对水平连铸法生产的铜包铝排与套管法生产的铜包铝排的各项特征性能进行对比测试分析，得出两种工艺生产的铜包铝排的优缺点，为客户选择提供参考依据。

Summary 摘要

1. Sampling and number
   测试样品选取及编号

Technology Method 工艺方法	Type 规格	No 编号	Heating 状态	Length 长度
Horizontal continuous casting 水平连铸法	60X10	1、2、3、4、5	Anneal 退火态	2m
Cu tube filled with Al liquid 套管法	60X10	①、②、③、④、⑤	Anneal 退火态	2m

2. Comparisons of test items and performances:
   对比特征性能测试项目

   2.1. Bonding and reliability Test
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   几何尺寸

   2.3.2. Density
   密度

   2.3.3. Copper Volume Ratio
   铜层体积比

Test Items and Comparison Data 测试项目及数据对比

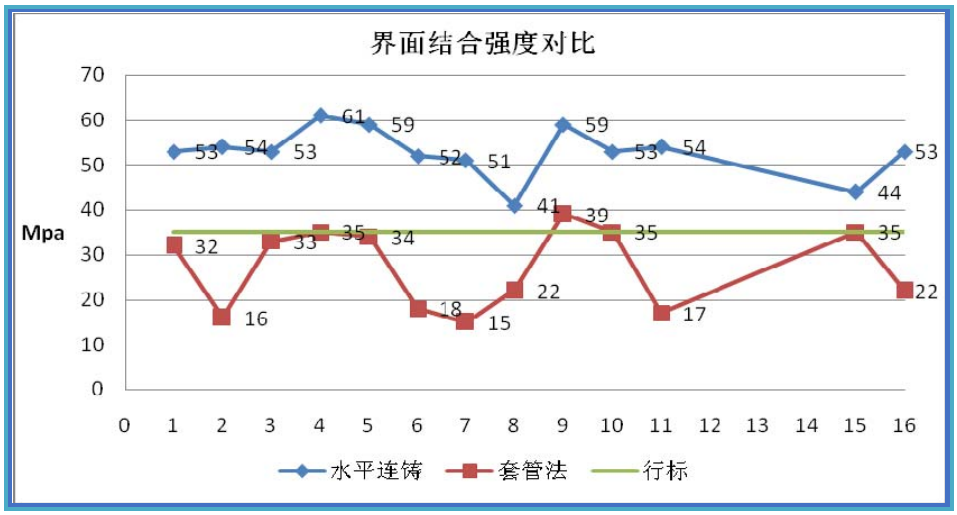
1. **Bonding performance and reliability Test** 结合及可靠性的对比测试

1.1. Bonding Strength 界面结合强度

1.1.1. Test Describe: Select No. 3 and ③ in five samples, Cut into16 pieces continuously and number them from 1-16, Then test bonding performance. Odd number shows bonding performance on one side and even number shows bonding performance on the other side.
试验描述：在准备好的 5 只料中抽取 3 及③，连续锯切 16 块界面结合式 样，并编号 1-16 号，单双号分别为上表面和下表面的界面结合强度以表明上下面结合力的连续性。

1.1.2. Test data and curve
测试数据及曲线

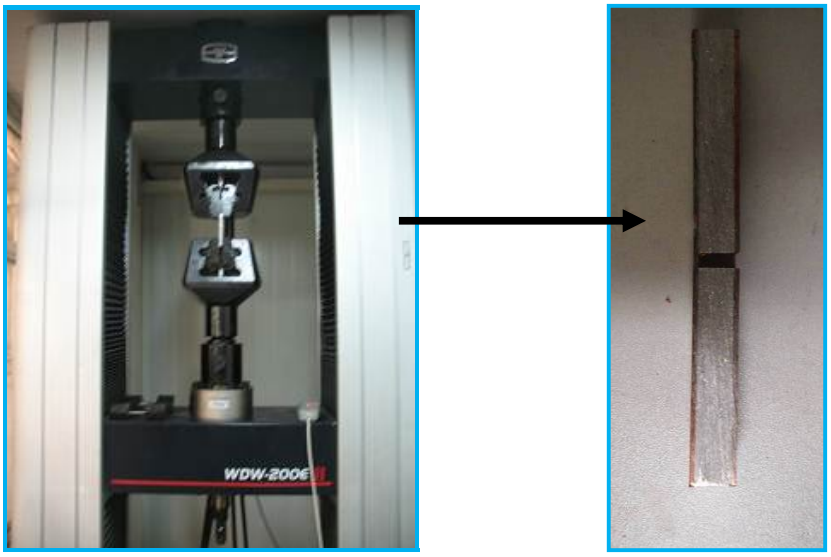
Comparison of Bonding Strength



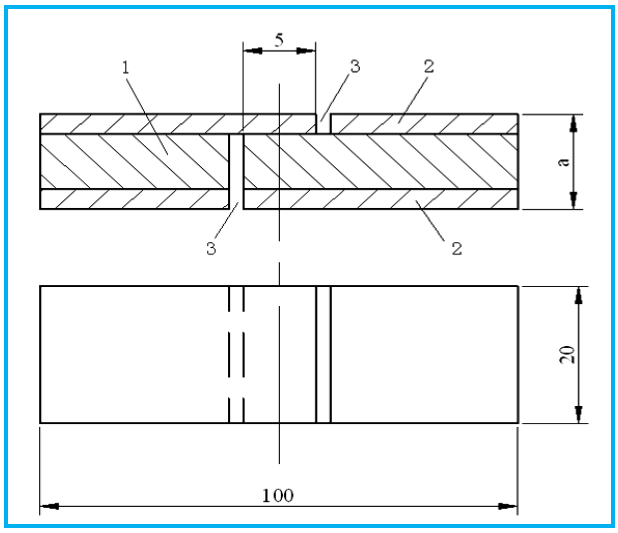
Continuous Casting Cu tube filled with Al liquid

1.1.3. The test data showed that average bonding strength of CCA busbar in continuous casting is 52.6MPa and 27.7Mpa in Cu tube filled Al Liquid, it can be concluded that CCA busbar produced in continuous casting have stronger bonding strength than that in Cu tube filled with Al liquid
由测试数据及曲线显示水平连铸生产的铜包铝排界面结合强度均值为 52.6Mpa，套管法铜包铝排的 27.6Mpa, 水平连铸工艺生产的铜包铝排的界面结合强度优于套管法,更可靠

1.1.4. Test Equipment： 200KN Tensile Tester
测试设备：200KN 拉力试验机



1.1.5. Drawing of Test sample:
测试试样图纸及说明



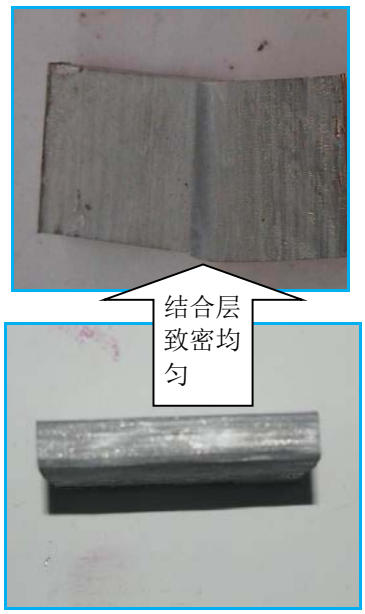
Note 备注:
1——Aluminum core 铝芯;
2——Copper coating 铜层;
3——Groove 槽。

1.2. Bonding Layer Characteristic after Peeling
剥离及结合层状态

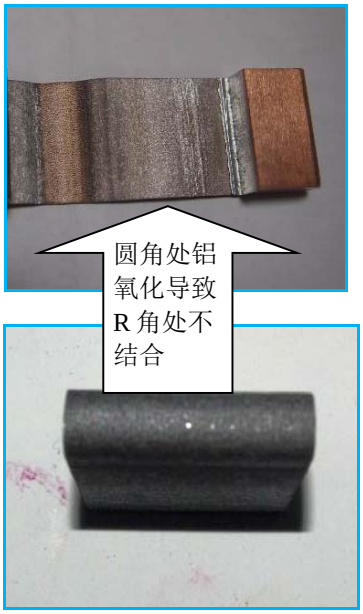
1.2.1. Test Description : select samples（3& ③in continuous casting and Cu tube filled with Al Liquid , Each is 30mm in length .Cut the layers of copper and Al off at 10mm from the edge in transversal direction by CNC mill, then peel the copper layer in transverse to check the bonding layer

试验描述：水平连铸法和套管法分别取样块 30mm 长（3 及③），在距侧边约 10mm 处使用数控铣床将铜层及中间铝层洗掉，将铜层延剥离，查看复合层状态。

1.2.2. Sample Picture 样品照片



Horizontal Continuous Casting

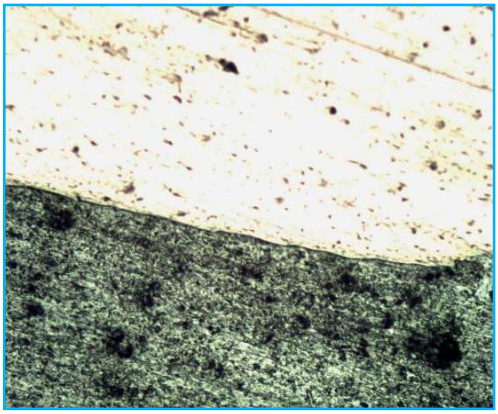


Cu tube filled with molten Al

1.2.3. Bonding Layer Characteristic: The CCA busbar in Horizontal Continuous Casting bonded well and is very difficult to peel; The CCA busbar in Cu tube filled with Al liquid is easy to peel and delaminated on the R corner showing Oxide AL
剥离后界面状态：水平连铸工艺生产的铜包铝排剥离后观察界面均匀致密，剥离困难；套管法工艺生产的铜包铝排用手轻易剥离，剥离后，R 角处的铝表面有氧化现象存在。

1.3. metallographic photo of bonding layer
结合层处金相照片

1.3.1. The CCA busbar in continuous casting: it shows even and compact layer
水平连铸法结合层处金相显示铜铝结合层均匀致密
The CCA busbar in Cu tube with Al Liquid: it shows obvious crevice in the bonding layer
套管法生产的铜包铝排结合层处有明显缝隙


Horizontal Continuous Casting
水平连铸法 200 倍


Cu tube filled with Al Liquid (200 times)
套管法 200 倍

1.4. Bending Performance

折弯

1.4.1. Test Describe:

试验描述：

a) Sampling Method: Sampling1、5（①、⑤） and cut in 400mm/piece

取样方法：分别在 1、5（①、⑤）两只料取样，长度 400mm.

b) Test Description: .all samples are bent by R10 tooling in 3 times

试验描述：每块分别使用 R10 凸模进行连续折弯 3 次

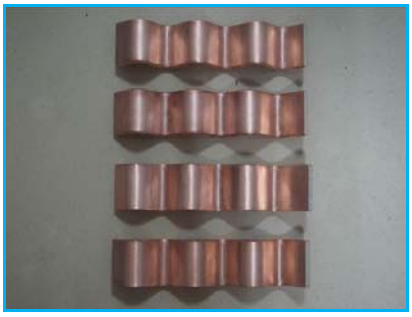
1. Check if have longitudinal crack on bending part of both parts, then make penetrant test to confirm.观察正反面折弯处是否存在纵裂存在，并进行渗透判定
2. Cut the sample respectively in transversal and longitudinal direction, then make Penetrant test to check if have delamination on bending part in both directions.
折弯后样块进行横向和纵向剖切，用渗透探伤方法检验结合层是否存在分层现象。

1.4.2. Check 1: conclusion and Pictures

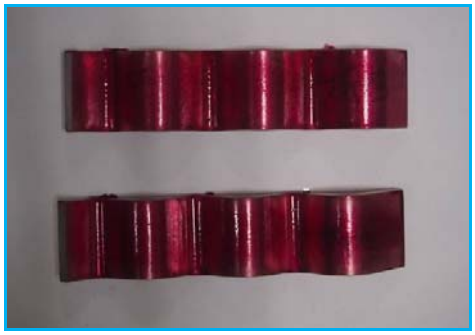
检验 1：判定及图片

Technology Method 工艺方法	No.编号	1	2	3	4	5	6
Horizontal continuous casting 水平连铸	1	PASS	PASS	PASS	PASS	PASS	PASS
Horizontal continuous casting 水平连铸	5	PASS	PASS	PASS	PASS	PASS	PASS
Cu tube filled with Al Liquid 套管法	①	PASS	PASS	PASS	PASS	PASS	PASS
Cu tube filled with Al Liquid 套管法	⑤	PASS	PASS	PASS	PASS	PASS	PASS

The Front Side 正面

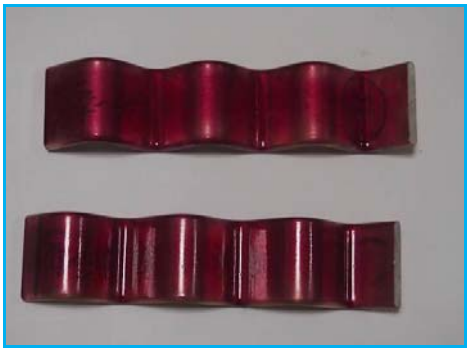


The back side 反面


Keep15 Minutes with Penetrant 渗透


Keep15 Minutes with Developer 显像

Horizontal Continuous Casting 水平连铸法


Keep 15 Minutes with Penetrant 渗透


Keep15 Minutes with Developer 显像

Cu tube filled with Al Liquid 套管法

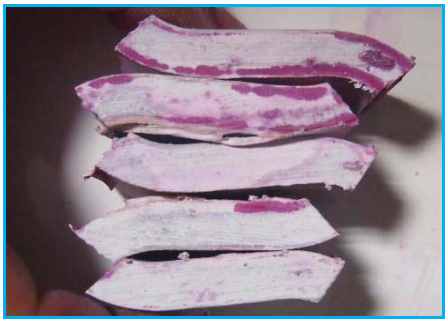
1.4.3. Bend and then cut in both transverse and longitudinal direction ,check if delaminated in bending part by penetrant test 检验 2：折弯后样块横向和纵向同时剖切，用渗透探伤方法查看折弯后铜铝是否分层

Technology Method 工艺方法	NO 编号	1	2	3	4	5	6
Horizontal continuous casting 水平连铸法	1	PASS	PASS	PASS	PASS	PASS	PASS
Horizontal continuous casting 水平连铸法	5	PASS	PASS	PASS	PASS	PASS	PASS
Cu tube filled with Al Liquid 套管法	①	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL
Cu tube filled with Al liquid 套管法	⑤	FAIL	FAIL	FAIL	FAIL	FAIL	FAIL

Bonded well After Cutting（1、5）
水平连铸法锯切后试样照片

Delaminated after cutting （①、⑤）
套管法锯切后开裂照片

①、⑤Transverse 套管法横向



①、⑤Longitudinal 套管法纵向

1、5Transverse 水平连铸法横向

1、5 Longitudinal 水平连铸法纵向

1.5. Punching
冲孔

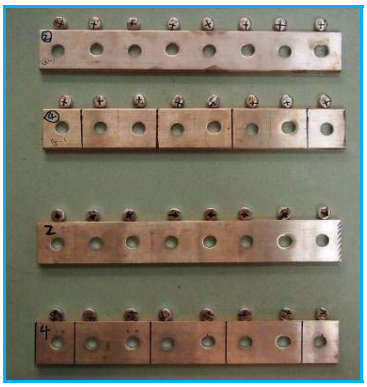
1.5.1. Test Description：Select samples of 400 mm in length from 2、4(②、④）and punching 16 holes(8 holes each on front and back side) by diameter 17mm tooling with 0.3mm die spacing. Check if delaminated and confirm by liquid penetrant Examination
试验描述：分别在 2、4（②、④）取 400mm 长度试样，使用单边模间隙 0.3mm 的 Φ17mm 直径的冲模进行冲孔检验，正反各 8 个孔，查看是否分层，并渗透法进行确认。

1.5.2. Punching Test Result
冲孔测试结果

Technology Method 工艺方法	No. 编号	1	2	3	4	5	6	7	8
Horizontal continuous casting 水平连铸法	2	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Horizontal continuous casting 水平连铸法	4	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Cu tube filled with Al Liquid 套管法	②	PASS	PASS	PASS	PASS	PASS	FAIL	PASS	PASS
Cu tube filled with Al Liquid 套管法	④	PASS	PASS	PASS	FAIL	PASS	PASS	PASS	PASS

1.5.3. Test Picture
检测图片

Marking 标示



After Punching 冲孔后

Liquid Penetrant Examination 着色渗透探伤检验

Horizontal Continuous Casting 水平连铸法 Failed for Cu tube filled with Al Liquid 套管法

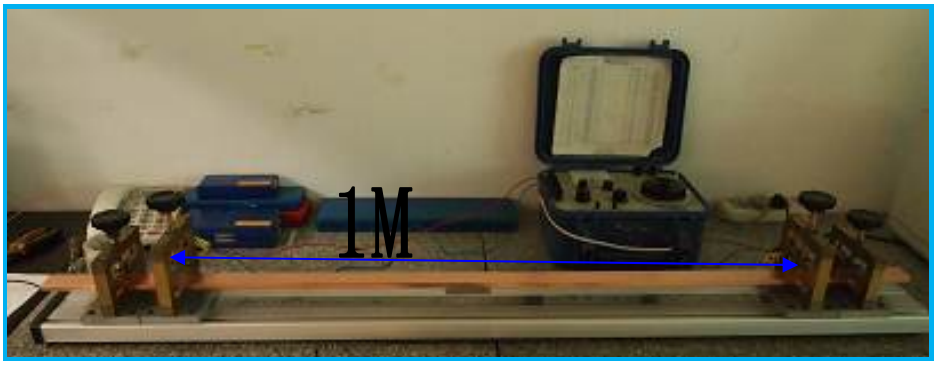
2. Electric Performance 电学性能

2.1. Electrical Resistivity 电阻率

Technology Method 工艺方法	Electrical Resistivity 电阻率 Ω·mm²/m(20℃)					
	1	2	3	4	5	Average 平均
Horizontal Continuous Casting 水平连铸法	0.023649	0.022626	0.023705	0.023654	0.023	0.023327
Cu tube filled with Al Liquid 套管法	0.024325	0.024611	0.024363	0.024322	0.024458	0.024416

2.2. Test Equipment: DC Resistance Tester
测试设备：直流电阻电桥

2.3. Test Picture
测试照片



3. Physics Performance 物理性能

3.1. Dimension 几何尺寸

3.1.1. Test Data 测试数据

Technology Method 工艺方法	Size 尺寸 mm					
	1	2	3	4	5	平均
Horizontal Continuous Casting 水平连铸	59.9	59.6	59.8	59.7	59.6	59.7
Cu tube filled with Al Liquid 套管法	59.3	59.0	59.0	59.5	59.9	59.3
Horizontal Continuous Casting 水平连铸	9.93	10.07	9.96	9.85	10.1	10.0
Cu tube filled with Al Liquid 套管法	9.95	9.96	9.98	10	10	9.98

3.1.2. Test Equipment: Callipers
测试设备：数显卡尺

3.1.3. Test Picture
测试图片

Horizontal Continuous Casting 水平连铸法

Cu tube filled with Al Liquid 套管法

3.2. Density and Copper Volume Ratio
密度和铜层体积比

3.2.1. Test Description: Drainage test method , sample length 30mm, average value of 5 pieces
Formula Density= $Weight_{air}$/ ($Weight_{air}$-$Weight_{water}$)

试验描述：采用排水法进行测试，测试方法： 取样块长度 30mm，五块取平均值。
排水法公式 $\rho = m空 \div (m空 - m水)$

3.2.2. Test Data 测试数据

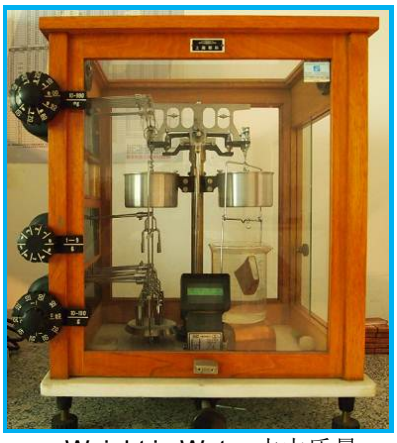
Technology Method 工艺方法	Density 密度 g/cm³					
	1	2	3	4	5	Average 平均
Horizontal Continuous Casting 水平连铸法	4.22	4.21	4.23	4.23	4.29	4.236
Cu tube filled with Al Liquid 套管法	3.96	3.96	3.94	3.97	3.95	3.956

Technology Method 工艺方法	Copper Volume Ratio 铜层体积比					
	1	2	3	4	5	平均
Horizontal Continuous Casting 水平连铸法	24.5%	24.4%	24.7%	24.7%	25.6%	24.8%
Cu tube filled with Al Liquid 套管法	20.3%	20.3%	20.0%	20.5%	20.2%	20.3%

3.2.3. Test Equipment: Analysis Balance
测试设备：分析天平(精确度 0.1mg)

3.2.4. Test Picture 测试图片

Weight in Air 空气中质量



Weight in Water 水中质量

Conclusion 结论

The compared test data for busbar produced in Continuous casting and in Cu tube filled with Al Liquid:
水平连铸工艺生产的铜包铝排与套管法工艺生产的铜包铝排对比结果如下：

1. The comprehensive performance and reliability of busbar produced in Continuous casting is better than that in Cu tube filled with Al Liquid 水平连铸工艺结合性能及可靠性优于套管法工艺

2. The conducting property of busbar produced in Continuous casting is better than that in Cu tube filled with Al Liquid 水平连租工艺导电性能优于套管法工艺

3. Physics Property: the dimension busbar produced in Continuous casting is more stabilized than that in Cu tube filled with Al Liquid ,but Cu Volume ratio and Density is larger than that in Cu tube filled with Al Liquid. 物理性能 ： 水平连铸工艺尺寸稳定性优于套管法工艺，体积比及密度水平连铸工艺大于套管法工艺。

测试设备清单 Test Apparatus

Digital Caliper 数显卡尺

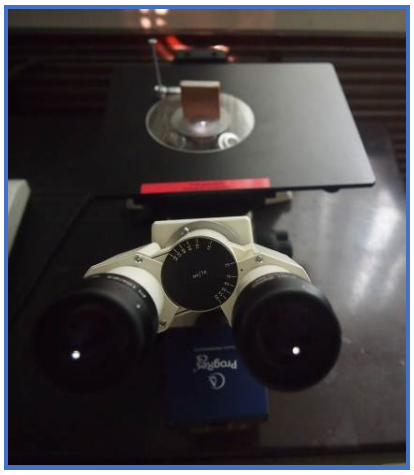
200KN Tensile Tester 拉力试验机

Physical Balance 物理天平

DC Electric Resistance Bridge 直流电阻电桥

Spectro Meter 斯派克光谱仪

250kgf Brinell hardness Tester 布氏硬度计



Axiovert 40 MAT Microscope
卡尔蔡司显微镜

Brinell Hardness tester 62.5kgf
布氏硬度计