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AlCunnect - A new Bimetal Combination of Aluminium and Copper

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Summary

AlCunnect is a new bimetal combination of aluminium and copper for various electrical and thermal applications.

AlCunnect especially is suitable as interface material between aluminium- and copper-based electrical conductors. By the substitution of copper through aluminium within the cable harness the overall weight is reduced by 50 % and comparable electrical conductivity. The aluminium alloy has a level of purity of 99.5 %. The copper alloy has an electrical conductivity of min. 58 MS/m. With the currently available combinations…

- Overlap-single
- Overlap-multiple
- Inlay
- Overlay

several applications are possible.

As production process the combination of roll cladding and additional heat treatment to create a mechanically stable intermetallic compound will be described.

An optional corrosion protection and its structure will be described. The results of its qualification where shown.

Keywords: battery, BMS (Battery Management System), cost, cooling, lithium battery

1 Introduction

Current trends in the market, such as light weight construction in automotive applications or the rising cooling requirements in power electronics are requesting the use of Aluminium in combination with Copper. DODUCO produces Copper clad bands with bondable Al-strips as an inlay for more than twenty years in a volume of about 250 metric tons per year. In the following text the material properties, the new manufacturing process, the test procedures and the final corrosion protection of the new material combination AlCunnect will be described.

2 AlCunnect – Types

Based on the know-how of the above mentioned cladding process the manufacturing of the four materials referred to as “overlap-single”, overlap-multiple, “overlay” and “inlay” type has been recently developed. The products and the typical achievable dimensions are listed in Tab. 1-3.

The overlap-single and overlap-multiple type is a combination of the two materials, Al and Cu, in a side-by-side configuration, as shown in Tab. 1. The maximum strip width, which can be manufactured, is 120 mm with a thickness up to 2 mm. The width of the overlapping area between Al and Cu is about 5 mm. The proportion of the Al to Cu band size can be adjusted to product needs and the final band can be delivered as a coil, e.g. for further stamping or coating processes. The material selection leads to Al 99.5 (EN AW 1050A) because of its availability on the market, electrical and mechanical properties, and the capability of electroplating this material. The pure Cu-PHC (CW020A) was selected because of its electrical and mechanical properties.

The Inlay type is an aluminium clad band with a copper inlay for several applications with the advantage to apply copper only on places where it is needed.

In the case of the overlay configuration, Al and Cu are connected across the total contact surface as shown in Tab. 3. The resulting matched material combination can have dimensions up to 200 mm on each side and 10 mm in thickness. The proportion of the Al to Cu thickness can be adjusted to product needs to a large extent.

Table 1: Typical dimensions of AlCunnect

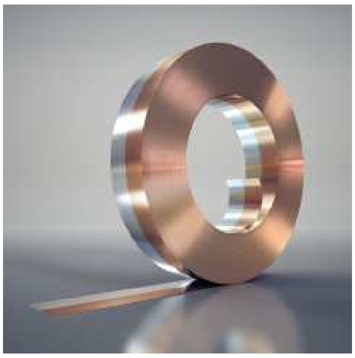
Type	Overlap-single	Overlap-multiple
Picture		
Total width	Up to 120 mm	Up to 120 mm
Thickness	Up to 2 mm	Up to 2 mm
Width of overlap	Approx. 5 mm	Approx. 5 mm
Width ratio Al/Cu	Different combinations possible	Different combinations possible

Table 2: Typical dimensions of AlCunnect

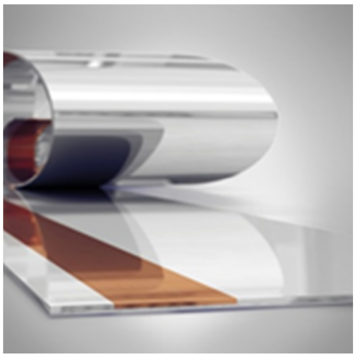
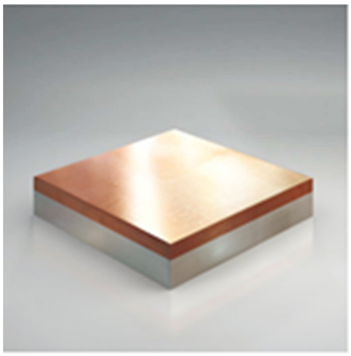
Type	Inlay
Picture	
Total width	Up to 120 mm
Total thickness	Up to 2 mm
Width of inlay	Min. 5 mm
Thickness of copper inlay	Min. 20 µm, max. approx. 25 % of total thickness

Table 3: Typical dimensions of AlCunnect

Type	Overlay
Picture	
Total width	Up to 200 mm
Total thickness	Up to approx. 12 mm
Thickness ration Al/Cu	Different combinations possible

3 Material Properties

Copper is well known for its very high conductivity. But its price has been increasing throughout the years. Aluminium on the other hand is lightweight and cheap compared to Cu. Finally Al has the fourth highest electrical and thermal conductivity. The comparison of the materials properties are summarized in Tab. 4.

Table 4: Data of the Materials

	Data of the Materials	
	Aluminum (Al)	***Copper (Cu)***
Price (USD/t) on March 8th 2019 [7]	1.848	6.398,50
Electrical conductivity	37.7 MS/m	58 MS/m ≙ 100 % IACS[a]
Density (g/cm³)	2.7	8.92
Thermal conductivity (W/mK)	237	401
Melting Point (°C)	660	1084
Modulus of Elasticity (GPa)	65	115
Linear Expansion Coeff. (10-6/K)	23.6	16.5
Standard	EN AW-1050A (Al99.5)	Cu-PHC (CW020A)
Chemical Composition	Acc. DIN EN 573-3	Acc. DIN EN 13599
Mechanical Properties	Acc. DIN EN 485-2	Acc. DIN EN 13599

[a] IACS: International Annealed Copper Standard

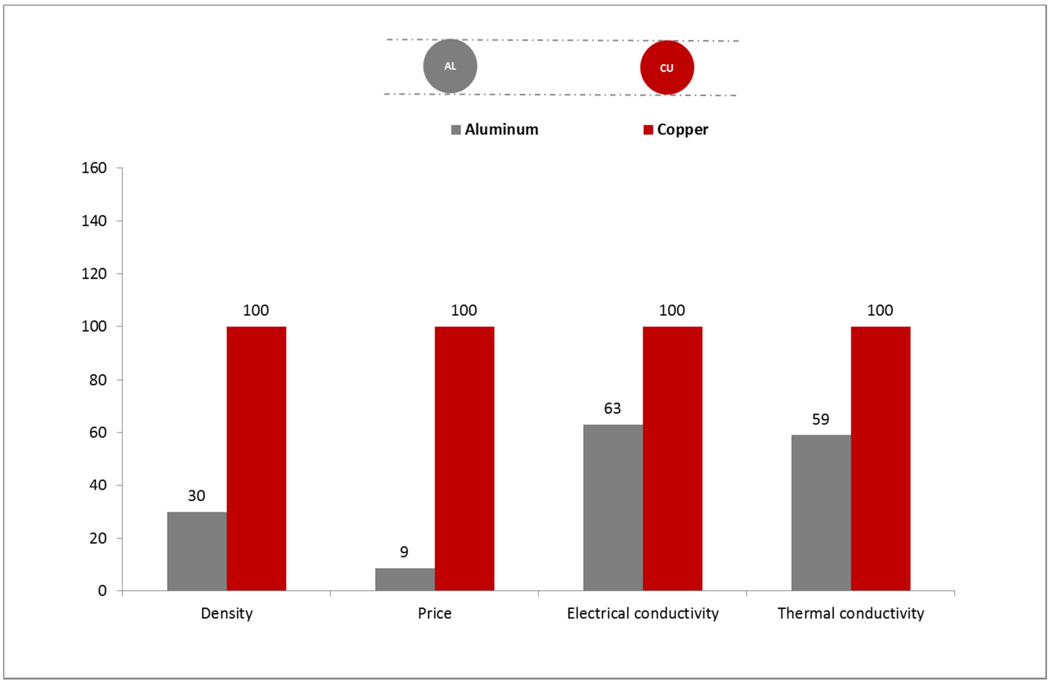


Figure 1: Comparison for same cross section

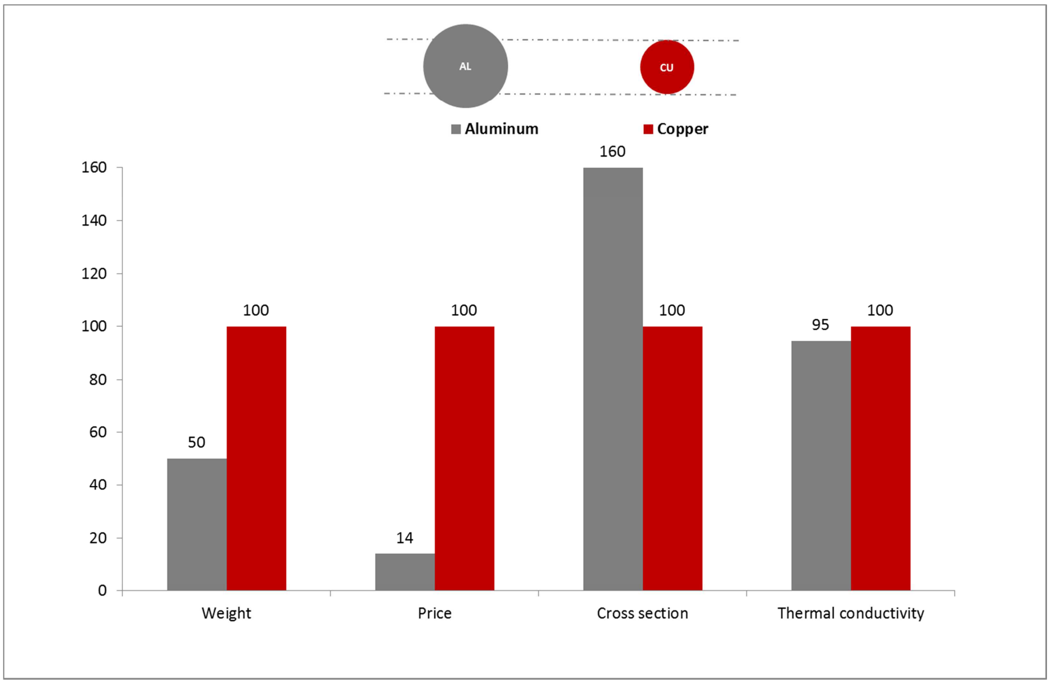


Figure 2: Comparison for same electrical conductivity

In Fig. 1 the parameters density, price and electrical and thermal conductivity for Cu and Al are compared under the precondition of equal cross sections of the conductor. Fig. 2 shows the same for the parameters weight, price, cross section and thermal conductivity under the precondition of equal electrical conductivity.

4 Technical Challenges

The technical challenges, which had to be solved during the development of the manufacturing process, are caused by the different properties of five potential equilibrium phases in the Copper-Aluminium system [1 - 5], which can arise during annealing. They exhibit varying brittleness, strength and electrical resistance. In the cross section of a laser welded Cu/Al join in Fig. 3 the formation of the IMCs are visible [6]. As a result, direct welding causes reliability problems because of micro-cracking at the seam. Therefore AlCunnect uses an ultra-thin IMC layer, as shown in Fig. 4, to connect Copper and Aluminium without these negative properties.

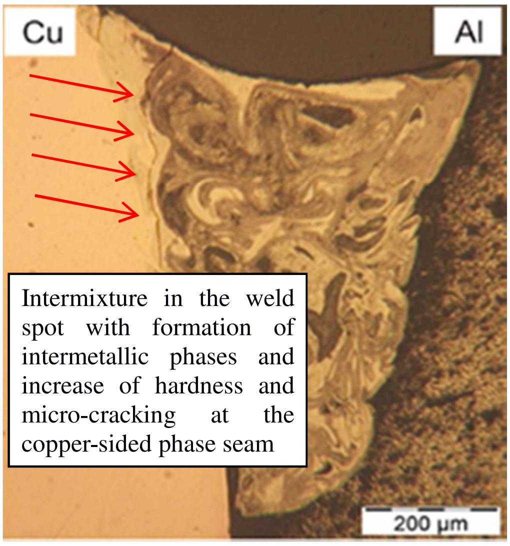


Figure 3: Cross section of laser welded Cu-Al

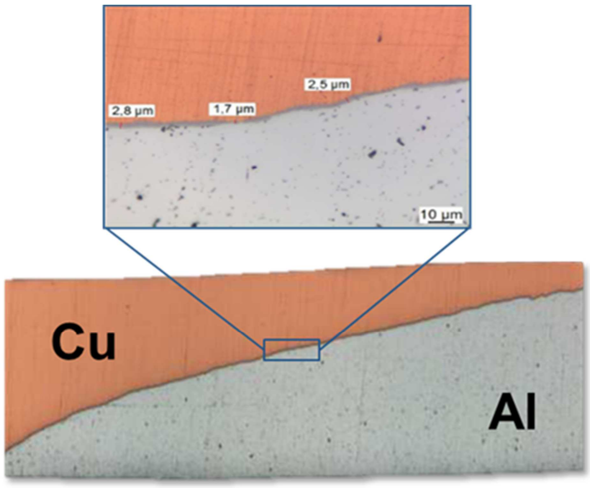


Figure 4: Cross section of AlCunnect interconnection zone

The used cladding process is shown schematically in Fig. 5. Two bands of preconditioned material are cladded mechanically by thickness reduction of more than 50 % during one pass through the rolling mill. To achieve a long time stability of this cold welded adhesive connection after cladding a heat treatment in a continuous furnace is applied afterwards. The temperature (400 - 500 °C), the time (15 - 25 min) and the atmosphere (reducing) in the furnace have to be adjusted to create the favoured IMC in the desired thickness. A typical result is shown in the cross section in Fig. 4

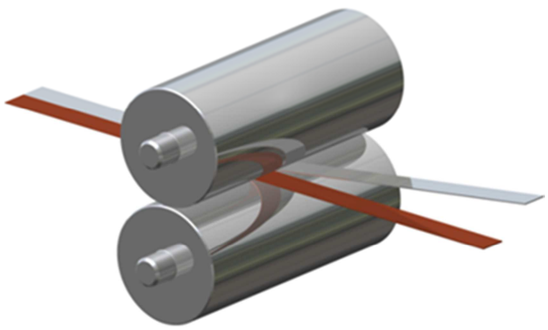


Figure 5: Cladding process (schematic)

5 AlCunnect – Properties and Material Testing

The material combination AlCunnect is a very mechanically stable composite with high electrical conductivity and can be used in temperatures up to 200°C. It is able to connect the two contact worlds of Copper and Aluminium together. This opens new potentials of cost and weight reduction, especially in automotive applications.

To check the stability of the interconnection zone tensile and bending tests have been performed. During the tensile test a specimen is stretched up to breakage and the applied tensile stress is measured in relation to the elongation (Fig. 6). The visual result of the tensile test is shown in Fig. 7, which always shows cracking in the Al, due to it´s lower modulus of elasticity in comparison to Cu.

During a bending test the specimen will be stressed to the maximum compressive value at the inside of the bend and to its maximum tensile value at the outside. In Fig. 8 the result of the bending test at an angle of 90° with a radius of 1mm is shown. No cracks can be observed in the bending area, which indicates a very good connection at the Al-Cu interface.

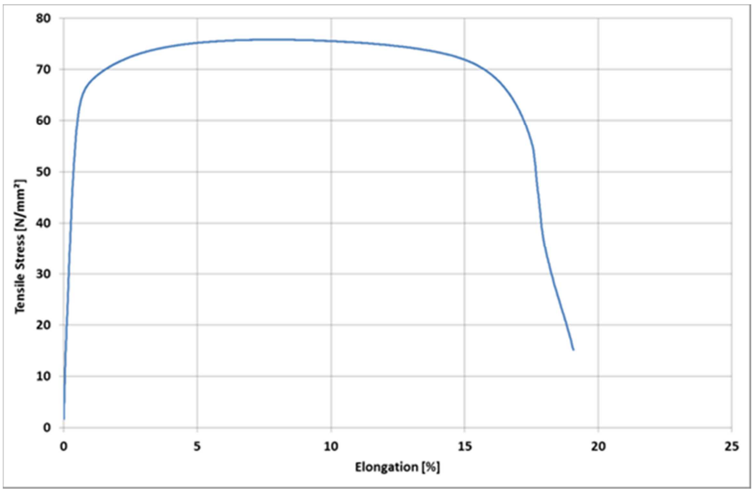


Figure 6: Diagram of tensile stress versus elongation of the specimen

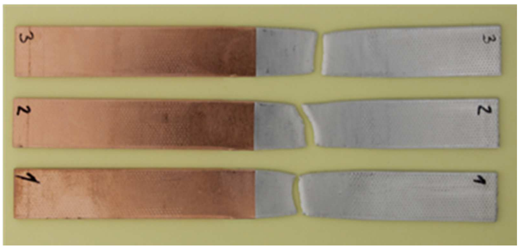


Figure 7: Specimens after tensile test (dimensions of specimen: 114 mm x 12,9 x 1,9 mm)

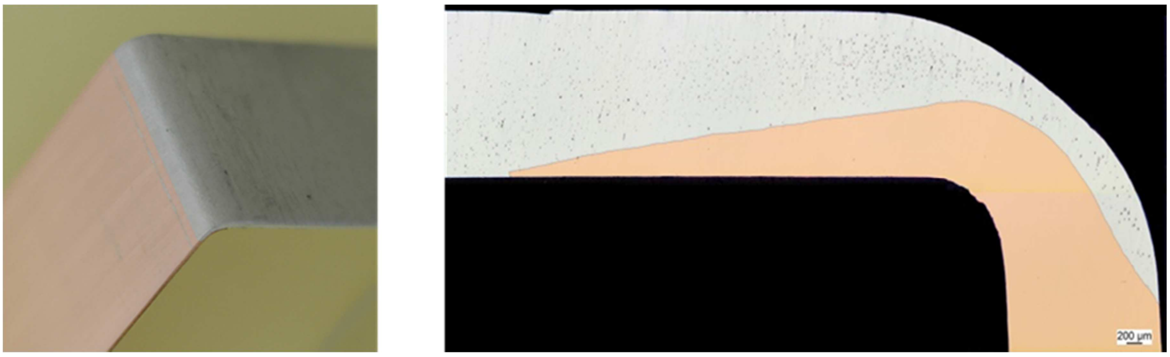


Figure 8: Specimen after 90°-bending test (R = 1 mm)

6 AlCunnect – Corrosion Protection

The electrochemical potential of Cu/Cu^{2+} is +0.34V and for Al/Al^{3+} is -1.66V. Therefore, the combination of the two materials will end up with an electrical potential difference of 2.0V. Thus, a blocking layer is needed to protect against mass transport to the phase boundary interface in the case of humidity exposure. To assure this corrosion protection for the AlCunnect composite, DODUCO developed special coating processes. The protection against environmental influences can be accomplished with an organic as well as an inorganic sealing (Fig. 9).

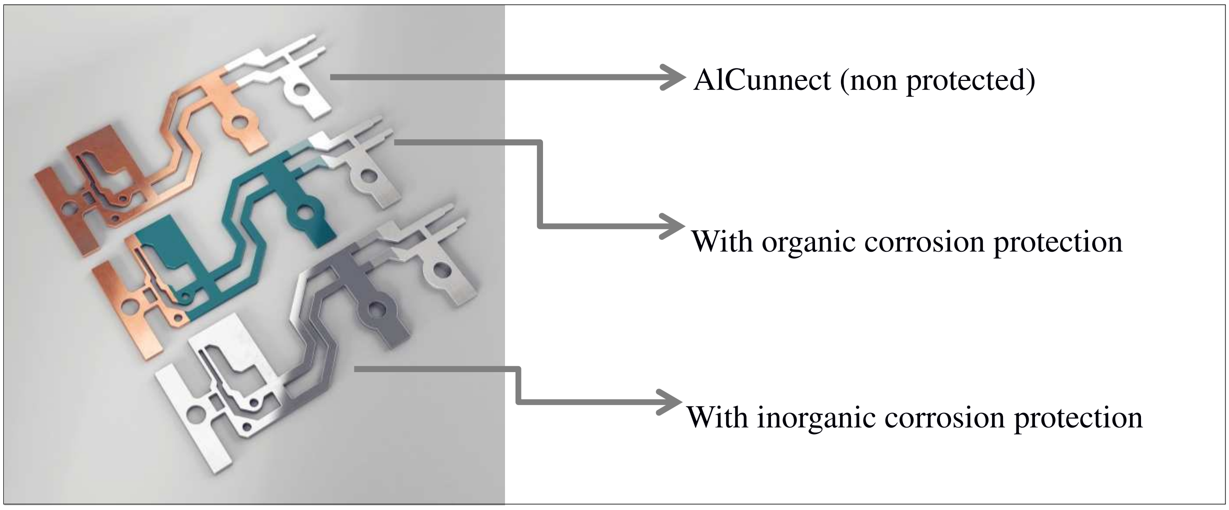
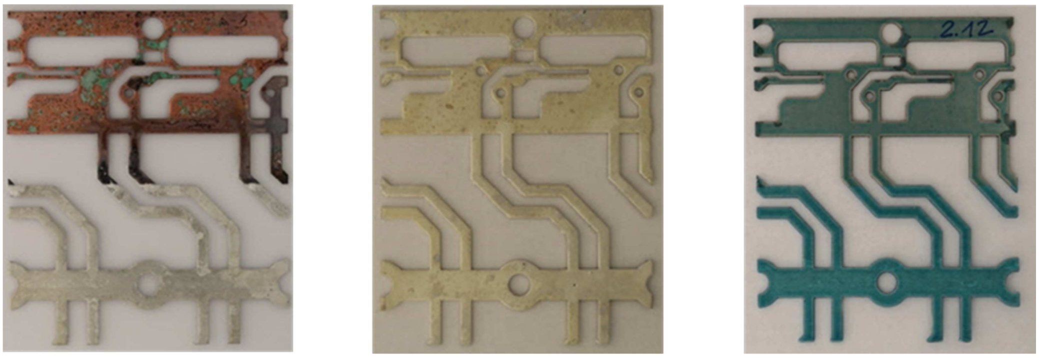


Figure 9: AlCunnect samples after stamping and application of organic and inorganic coating

For the organic coating with an insulating lacquer, a special spray coating process was developed, which can be applied full faced or selective in a reel-to-reel setup. The very short curing time after application and the wide range temperature options in use are both outstanding special features of this process.

Another option to avoid corrosion of the AlCunnect composite is an inorganic coating by electroplating. The coating can also be applied full faced or selective in reel-to-reel electroplating equipment.

The salt spray test procedures according to DIN EN 60068-2-11 (severity level 3) have been used to proof the corrosion resistance of the protective coatings. As shown in Fig. 10 the tin surface coating as well as the organic coating show constructive and reliable protection after the corrosion test, when compared to the non-protected specimen.



non protected | electroplated Ni + Sn | organic coating

Figure 10: Specimens after salt spray testing

7 Summary of Test Results

Fig. 11 shows a survey of all test procedures performed and the results achieved.

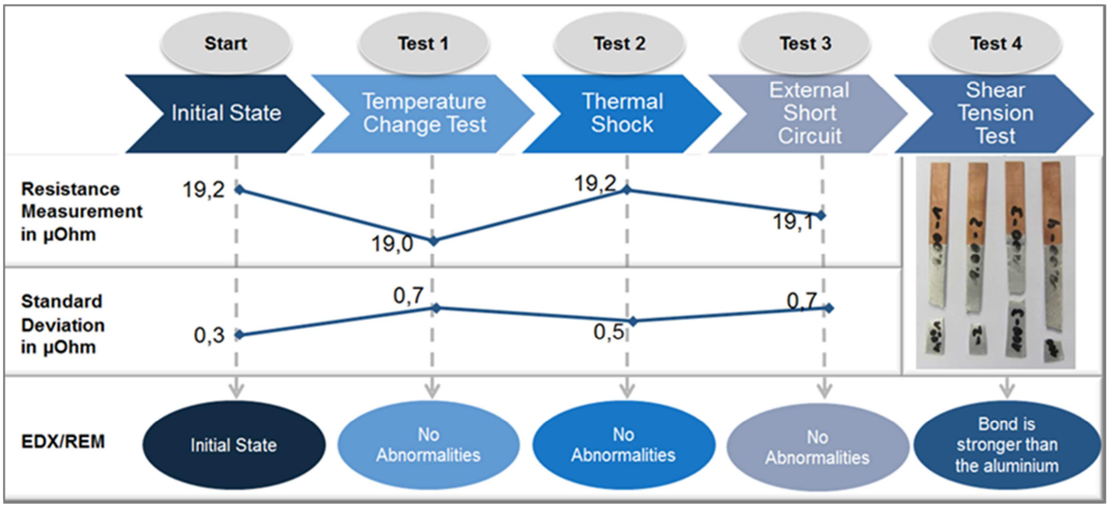


Figure 11: Overview of applied tests and summary of test results

8 Examples of Application

The three following examples show the variety of applications, which can be utilized with the new AlCunnect material. Using the overlay configuration (copper with overlay plated aluminium) heat sinks for power electronics can be manufactured using an impact extrusion process to form the pin fin structure at the aluminium side (Fig. 12).

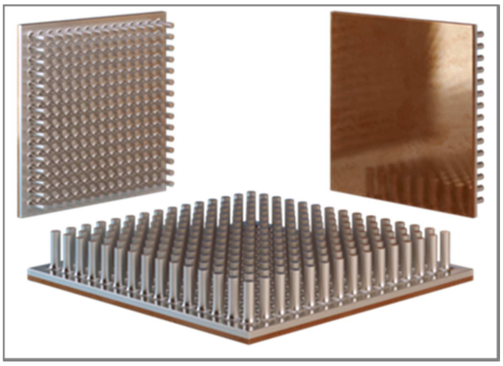


Figure 12: Al/Cu heat sink with pin fin structure

The overlapping clad metal can be used as plug connectors or cable lugs to join aluminium with copper for different applications, especially for the automotive industry (Fig. 13).

Figure 13: Al/Cu cable lugs

Additionally, the overlap and also the inlay clad material can be used in realizing individual connecting solutions for lithium-ion cells systems and BMS-Systems (Battery Management Systems). The overlap type is the ideal cell connector due to the combination of materials. Since in lithium-ion cells the anode is made out of copper, the cathode is made out of aluminium. See Fig.14. The inlay type can be used as connector for BMS-Systems. See Fig. 14.

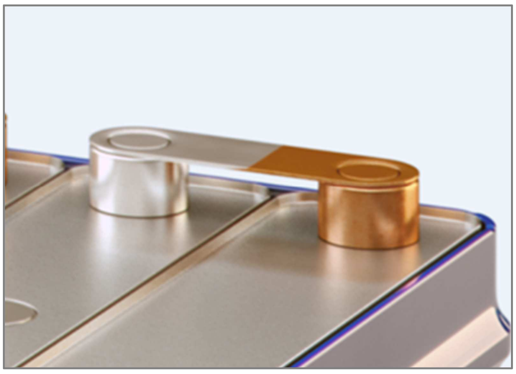
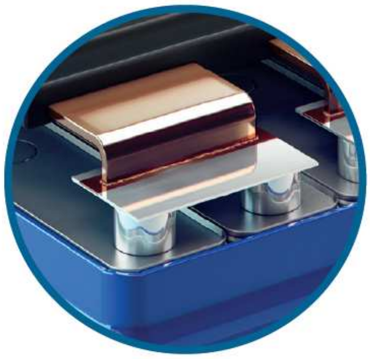


Figure 14: Cell connector



BMS-System

9 Conclusions

The present investigation shows a new method to generate roll cladded Cu-Al bands in overlap as well as in overlay and inlay configuration. The growth of the intermetallic phase has been analysed, and the mechanical and electrical parameters of the AlCunnect material investigated. To assure the corrosion protection of the material combination of Al and Cu two different coating processes have been developed. An organic lacquer or a Ni/Sn electroplated coating is proofed as a reliable corrosion protection in the salt spray test procedure. A few examples for the application of the AlCunnect material are described illustrating the new options opened by this innovative new material combination.

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Author

Daniel Schindler is working for the DODUCO Solutions GmbH in the department of process development since 2012. He is responsible for process development of all roll cladding and heat treatment procedures for the AlCunnect material family.

He received his degree Dipl-Ing (FH) in Mechanical Engineering at the University of Applied Siences in Karlsruhe in 2005.