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Aachen, November 18-19, 2024

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Influence of contact resistance on Cu- and Al-Elements after Plasma-electrolytic Processing

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Abstract

The study examines the influence of plasma electrolytic processing of Cu and Al elements on the size of the contact resistance. The size of the contact resistance is of great importance for the optimization of the operating point of non-conventional processing methods, such as PeP, ECM and their hybrid processes. Comparisons are made with roughened surfaces and normal delivery conditions. The classification of the contact resistances is carried out according to the specifications in [1].

1 Introduction

The magnitude of the contact resistances in an equivalent circuit diagram of EC machining or machining with hybrid EC processes or plasma electrolytic polishing (PeP) essentially determines whether work can be carried out at the optimal operating point or whether the machining process can be used at all. In [1] it was shown that contacts with Au-coated or Zn-coated contacts meet these requirements very well. However, in a large number of applications, cable lugs made of copper or aluminum are necessary. Since it was demonstrated in [2] that copper's corrosion resistance is improved by PEP processing, the question arises whether this can also minimize contact resistance. Another question is to what extent the roughness must be reduced in order to achieve a relevant reduction in contact resistance.

2 Experimental Setup

For the new study, the experimental setup was changed to ensure a smaller scatter of the measured values and to make the measurement results more stable.

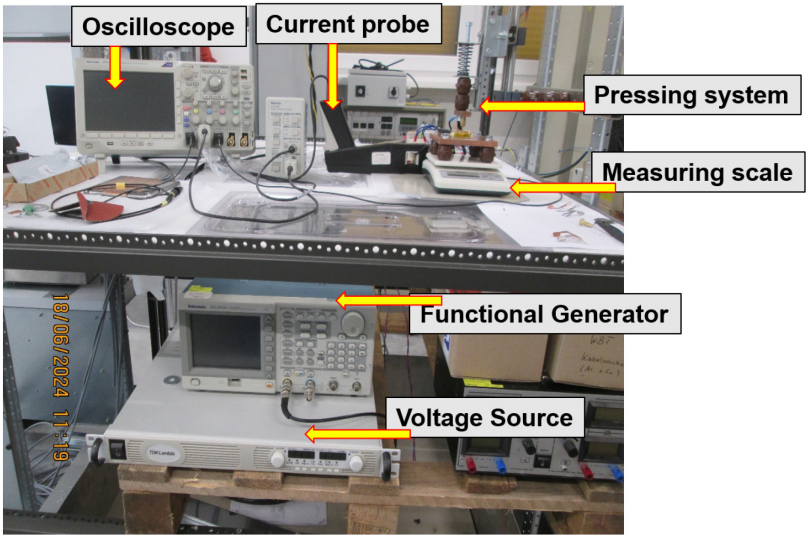


Figure 1: *Experimental Setup for measurement of contact resistance.*

In Fig. 1, you can see the contact pressure system, the voltage source and the function generator that supplies the measuring voltage across the contact. On the table is the oscilloscope for current and voltage measurement and the measuring scale for force measurement. In Fig. 2, the force system can be seen more clearly. On the scale is a positioning and cooling plate and the holder for the contacting material. The holder consists of a table that is larger than the sample and a cylindrical stamp with a diameter of 2 mm. Both are made of brass. Cu contact grease is used to further reduce the contact resistance to the table. This way, only the contact between stamp and sample is evaluated. The plate weight plus holder (1664 g) can be compensated using the scale.

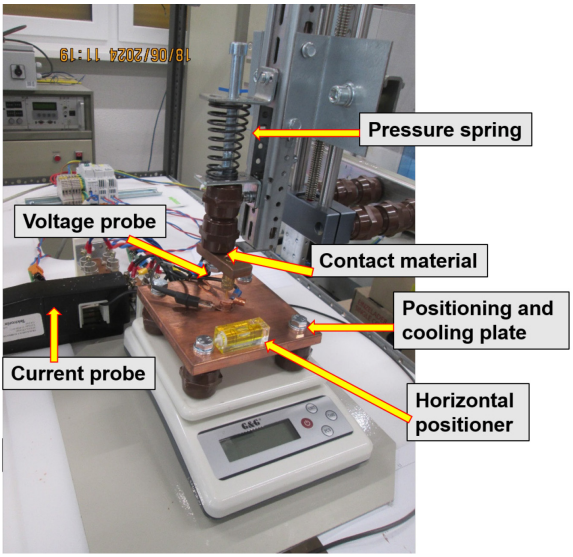


Figure 2: *Experimental Setup for pressing force*

In addition to the Cu cooling (380 W/ (m² K), air cooling (33 W/(m² K) was also used. In addition, the measurement was carried out with 1 ms pulses to reduce the Joule heat input at the contact point. This measure makes it possible to use measuring currents of up to 100 A. (Fig. 3).

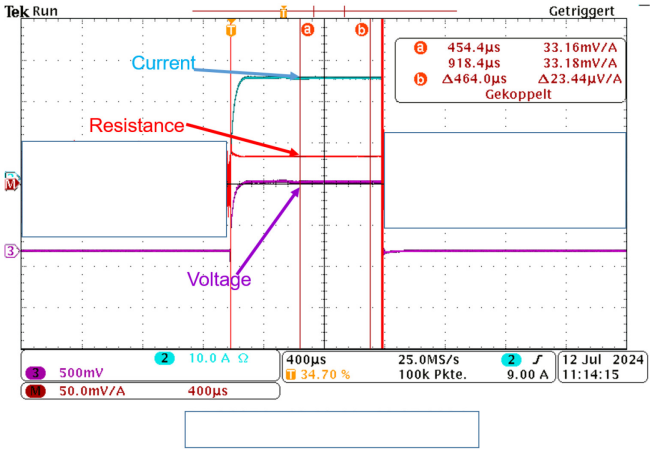


Figure 3: *Measuring contact resistance*

3 Results and Discussion

3.1 Parameter conditions

Three surface conditions were investigated for the two materials copper (Cu) and aluminum (Al). The first version was the delivery condition, which was only cleaned on the surface with acetone. In the second version, the surface was roughened with 320 grit sandpaper and in the third version it was plasma electrolytic polished (PeP). The Ra values determined are summarized in Tab. 1.

Table 1: *Ra value for the different contact surfaces*

Material	Condition	Ra in µm
Al	untreated	0.454
Cu	untreated	0.213
Al	320 sand paper	0.764
Cu	320 sand paper	0.704
Al	PeP1 (30 s) [1)]	0.405
Al	PeP2 (30 s) [1)]	0.339
Al	PeP3 (30 s) [1)]	0.332
Al	PeP4 (30 s) [1)]	0.394
Cu	PeP1 (30 s) [1)]	0.166
Cu	PeP2 (30 s) [1)]	0.144
Cu	PeP3 (30 s) [1)]	0.209
Cu	PeP4 (30 s) [1)]	0.147
Cu	PeP5 (30 s) [1)]	0.139
Brass	Counter contact surface	0.148
	[1)] Beckmann Institute	

3.2 Measurement of the contact resistance

The untreated materials (Fig. 4) were measured first and the Z values were far above the desired maximum value of 5 mΩ. From 10 N onwards, the static final value is reached, which is explained functionally in [3]. However, the resistance values achieved are not acceptable for many applications. The surface images and roughness's in Tab. 1 show clear differences between the Al and Cu contact shoes. Even after the same PEP, differences in the roughness of the Cu and Al samples are apparent. The only reason for this can be the different formation of the passive layers on the surface of the two materials.

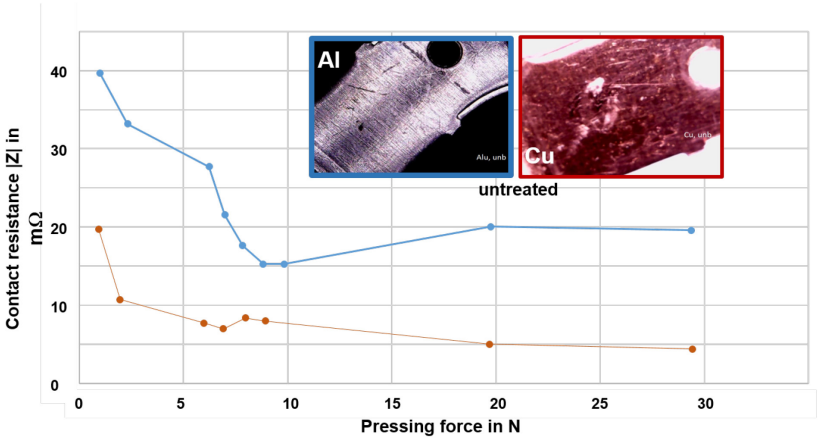


Figure 4: *Contact resistance vs. pressing force for untreated material*

During sand paper processing, the average roughness was more than tripled, whereby the existing grooves were eliminated in the Al. New grooves were created in the Cu, as can be seen in Fig.5.

Cu shows a high level of consistency at values between 2 mΩ and 7.5 mΩ, which is achieved by smoothing even at low contact forces. Al only shows this behavior from 10 N and at a much higher level at 40 mΩ. Al cable lugs with this processing are therefore fundamentally unusable.

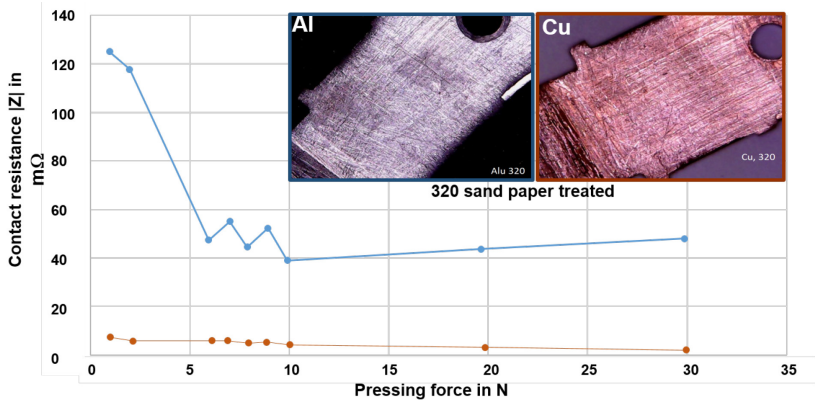


Figure 5: *Contact resistance vs. pressing force for roughened material*

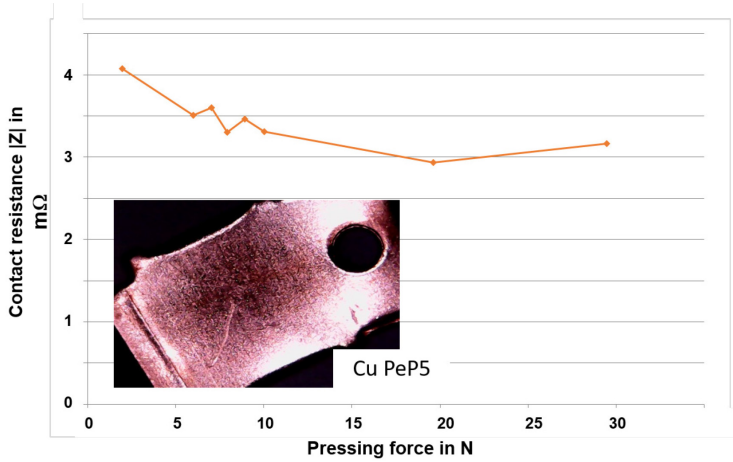


Figure 6: *Contact resistance vs. pressing force for PeP processed Cu*

The Cu cable lugs with PeP processing show a reduction in the contact resistance to 60% of the initial value, corresponding to the reduction in roughness. Fig. 6 shows a selected series of tests with the lower roughness Ra.

The primary influencing factor is that the 30-second PeP was not sufficient to remove the larger surface grooves. The contact pressure was not sufficient to crush the roughness. Fig. 7 shows an example of the Al-PeP cable lugs. Only at 20 N does the 10 mΩ limit of the contact resistance fall below, whereby this sample has the smallest roughness value with Ra = 0.332 µm. The Al-PeP

cable lugs show significantly poorer contact resistance and also greater fluctuations in the range of lower contact pressures (Fig. 8).

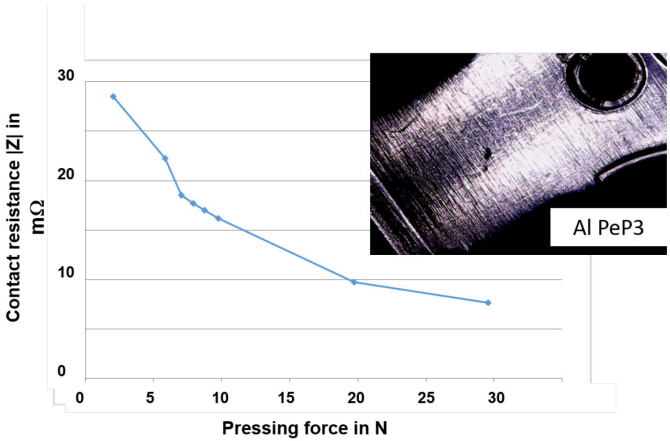


Figure 7: *Contact resistance vs. pressing force for PeP processed Al*

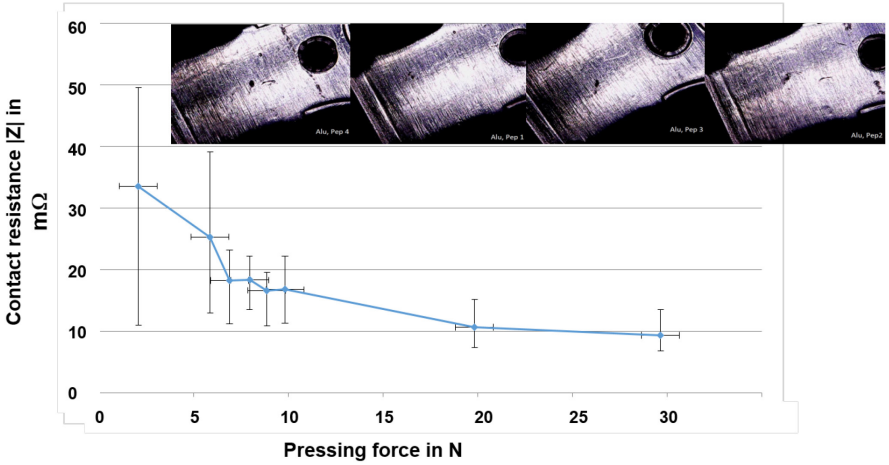


Figure 8: *Contact resistance vs. pressing force for PeP processed Al with error limit*

However, the roughness of the contact surface does not necessarily guarantee a lower contact resistance. In the Al-PeP series, an Al-PeP sample with a Ra

value of 0.405 µm has a maximum contact resistance |Z| of 13 mΩ and an optimal |Z| value of 7 mΩ.

4 Conclusion

The study shows that the Cu cable lugs have significantly lower contact resistances than Al cable lugs. PeP processing can achieve contact resistances of less than 5 mΩ, which is good enough for most applications. The surface hardness plays a decisive role here. It was found that the Cu samples showed that squeezing the roughness peaks leads to very low contact resistances starting at forces of 10 N.

When considering the results, it must still be taken into account that the determined Z values include the real and imaginary resistance components. It can therefore be assumed that the ohmic component for the 100 kHz of the test arrangement is less than 50% of the determined Z values. The assumed 5 mΩ limit would therefore correspond to an ohmic component of approx. 2 mΩ.

PeP processing is efficient when the roughness of the contact surface can be reduced to Ra less than 0.2 µm and no insulating intermediate layers are created. In the case of Al cable lugs, this involves longer processing and it is still unclear what influence larger Al_2O_3 areas have.

For applications such as µECM, the capacitive and inductive components must be determined more precisely.

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