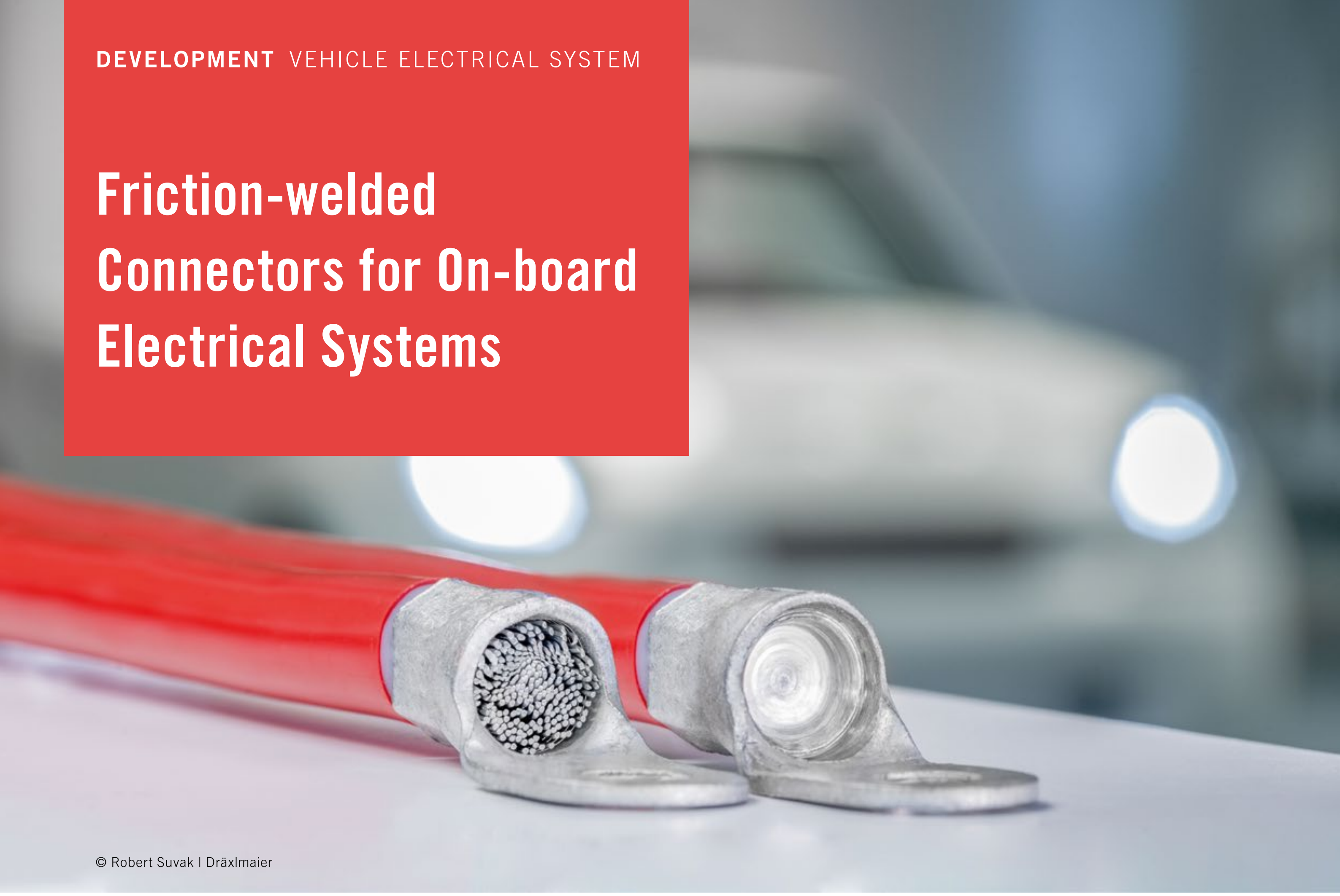
Friction-welded Connectors for On-board Electrical Systems



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The trend towards electric mobility means that lightweight construction strategies remain important in the automotive sector. This also affects the construction of on-board electrical systems, where aluminium conductors are increasingly being used. With an innovative process approach in the field of aluminium wire contacting, Dräxlmaier offers an interesting alternative to conventional joining methods. Friction welding is used to ensure a substance-to-substance bond.

LIGHTWEIGHT CONSTRUCTION AS A MOTIVATION

The use of aluminium in automobiles to optimise weight is being given a particularly high priority, especially when it comes to improving the possible range of electric vehicles. The effects of this lightweight construction trend are also reflected in vehicle wiring systems: while connection elements are often still made of copper or tinned copper due to the electrical, mechanical and chemical requirements on the material, aluminium wires are gaining importance as a substitute for copper wires.

This material change is, however, not easy to achieve due to the different characteristics of the material. In addition to the different creep behaviour of aluminium, there are also significant differences in the mechanical strength of both metals. Aluminium can be shaped easily due to its high ductility, but at the same time it has a lower strength than copper. This must be considered in terms of processing, from single wires to complete wiring systems, as well as with regard to the loads on the material during the lifetime of a vehicle. In return, due to its lower density this lightweight metal promises significant weight savings.

TECHNICAL CHALLENGES FOR CONTACTING

A closer look at the characteristics of aluminium highlights the challenges associated with its use as a material: aluminium has a natural tendency to form oxide layers, which can affect the current flow, and has a high tendency to creep in the micro range, which can be seen over longer periods of time. The latter is a limiting factor especially for crimp connections: because the merely force-locked pressed material can loosen over time, a sufficiently high-quality permanent connection is only possible with

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a disproportionately high outlay of effort. Thermal joining processes promise a more durable connection for connectors and cables: however, due to the different materials this leads to a metallurgically mixed connection that is difficult to achieve. The long-term stable contacting of aluminium wires therefore represents a particular challenge.

Ultimately, only a few technologies currently allow the permanent substance-to-substance bonding of large cross-section aluminium stranded conductors to connecting elements made of copper. These include rotary friction welding and ultrasonic welding. Most of these processes, however, are complex and often require ancillary joining elements such as solder shims or support sleeves. At the same time, reliable process monitoring is often limited or feasible only with great effort.

OPTIMISATION OF A PROVEN PROCESS

The Dräxlmaier group now offers the automotive industry a new, patented friction-welded contact process, which has been developed together with the Forschungs- und Entwicklungsgesellschaft Fügetechnik GmbH (FEF), a spin-off of the Institute of Welding and Joining Technology at RWTH Aachen University. The method is particularly well-suited for the joining of copper connection components with aluminium cables. It can, however, also be used for joining elements made of the same materials. As the procedure can be used to process all cable cross-sections from 10 mm² upwards, it covers a wide range of applications (unlike many other techniques on the market) and, at the same time, enables a robust and simple process control without the need for any additional joint components.

Before the start of friction welding, the line is positioned together with a connecting element – for example, a conventional crimp – in a workpiece holder and simultaneously pressed, whereby the two joining elements are fixed to each other. Subsequently, the actual contacting process takes place. In contrast to conventional friction welding, the necessary friction energy is not created by the relative movement of the two joint partners, but by a wear-resistant, rotating tool. This is inserted into the open end of the sleeve-like connecting element together with the exposed strands of the aluminium cable located therein, **FIGURE 1**. Due to the friction heat, the materials in the contact area are heated to just below melting point and plasticised, which causes them to mix and form a new structure. This prevents problems caused by phase transitions, including porosity, hot cracking or the formation of pronounced intermetallic phases. At the same time, light oil and moisture residues have no significant effects on the joining process or the connection quality.

RELIABLE CONNECTION BY MEANS OF A MATERIAL BOND

Since the welding tool diameter is normally greater than the inner diameter of the connecting element, use of the patented friction welding technique causes strongly mixed microstructures to form in the contact region between the strands and connecting element. These contribute to the integral connection of the two components, without causing any significant formation of high-resistance, intermetallic brittle phase components. By means of metallographic examinations or by using a scanning electron microscope, the stabilising diffusion regions are clearly visible in the micron range, **FIGURE 2**.

The frictional heat and the necessary process forces also cause the existing oxide layers on the individual wires of the braid to break down, resulting in a defect-free, densely compacted structure which is characterised by metallic bonds. If additional tinned connection elements are used, this tin, which already melts at relatively low temperatures,

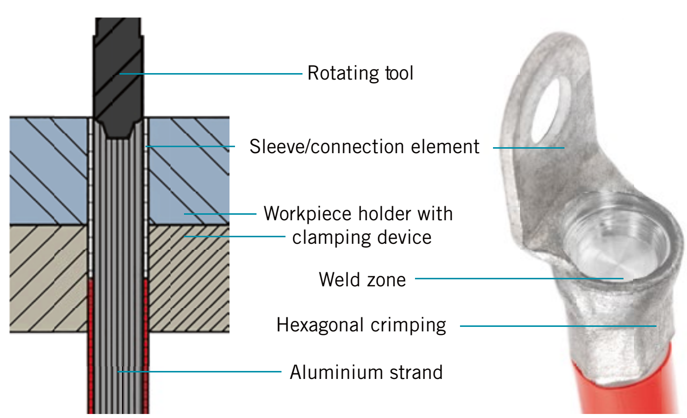

FIGURE 1 Representation of the patented friction-welding connection technology (© FEF | Dräxlmaier)

functions as an alloy component of locally arising mechanically resistant aluminium bronze, and also as a soldering material.

During the development process of the friction-welded connector, the link quality between flex and connecting member was also investigated using a push-out test. In this case, the connection component is severed behind the pressing zone and the resulting welding pill is mechanically driven out. In this test, the aluminium shows clearly recognisable, cohesively characterised fracture zones, which are a key indicator of a high quality connection in the edge region.

The integral contact with the friction-welded connector has decisive advantages compared with purely frictional and form-fitting methods such as crimp connections: In addition to a usually significantly higher thermal and electrical resistance to ageing, the new method also demonstrates particularly long-term mechanical stability.

HIGH ELECTRIC CONDUCIVITY

In the automotive field especially, contacts can be exposed to elevated temperatures which occur, for example, in the engine compartment of a vehicle. In order to check the durability of contacts under these conditions, temperature change tests are usually carried out, accompanied by measurements of the electrical resistance. Here, if materials with different thermal expansion coefficient, such as aluminium and copper are used ($\alpha_{Al} \approx 24.5*10^{-6}\ K^{-1}$, $\alpha_{Cu} \approx 17.7*10^{-6}\ K^{-1}$ [1]) mechanical stresses occur. This can reduce the cohesion of the conductor and connecting element and thus lead to increased electrical resistance.

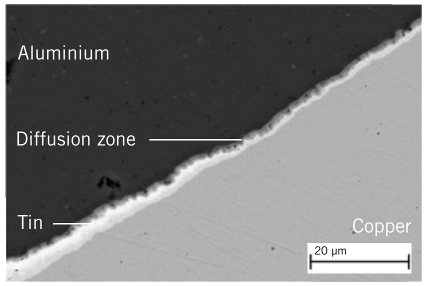

FIGURE 2 Microstructure of the joining region of a friction-welded connector sample under the scanning electron microscope (© FEF | Dräxlmaier)

This effect has a particularly strong impact only in form-fitting or force-locked components, as is the case with press connectors. However, as friction welding creates a material connection between the aluminium stranded conductor and the connecting element, the electrical conductivity of the friction-welded connector did not change in tests based on DIN EN 60068-2-14 [2], even after more than 100 temperature cycles. In addition, it provides a high electric conductivity across the board due to the metallic connection of all the individual strands of the conductor, which exceeded even the already known good properties of ultrasonically welded contacts in comparative tests, **FIGURE 3**.

OPTICAL QUALITY CONTROL

The exposed joint zone created by the Dräxlmaier technology provides the possibility of a simple optical inspection for quality assurance (unlike other friction welding methods on the market). Thus, a visually well-proportioned joining zone indicates a proper process flow. In conventional friction welding this is, however, covered by the joint partners.

In addition, a visual check can also draw conclusions about the state of the tool used: If this has the ideal size and is also properly positioned, the burr in the edge region of the joining zone is minimal.

LIGHTWEIGHT AND RELIABLE

The use of aluminium instead of copper in wiring systems is, as mentioned above, an important element in the further optimisation of vehicle weight. Since lightweight construction has particularly positive effects on the range of electric vehicles, significantly more aluminium cables will be used in the future particularly for these kinds of vehicles.

Compared to existing contacting methods, the procedure facilitates the use of aluminium cables in electrical systems, as it provides simple process control without auxiliary joining parts and the possibility of easily realisable optical quality inspection. What's more: at the same time it ensures high reliability due to the constant contact, as is increasingly required in the course of automated driving functions.

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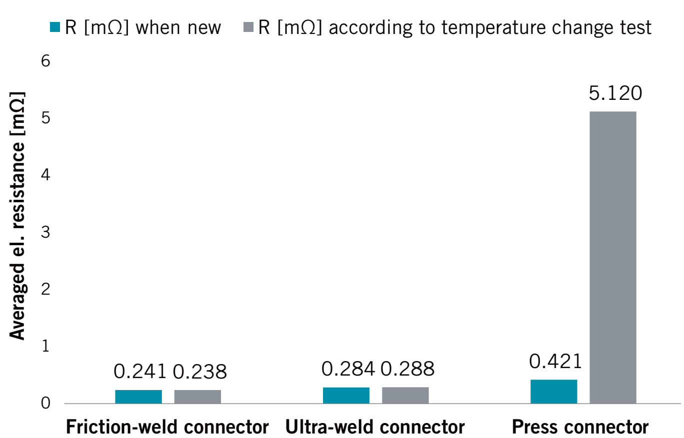

FIGURE 3 Electrical resistance of various connection methods (© FEF | Dräxlmaier)

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