

# Joining High Strength Steel and Aluminum-Friction Element Welding

by Laurence Claus

Perhaps one of the most difficult things to join together are thin metal sheets. The thickness is the problem because it just doesn't allow successful joining using many traditional techniques. Industries such as automotive and aerospace which heavily rely on thin metal sheets for structure and support have traditionally been the first to adopt new joining methods that work. For example, automotive has perfected spot welding and aerospace the use of solid rivets and other special fasteners. As time has gone by, however, new, lightweight materials have been added to the mix, and traditional joining methods are quickly becoming unfeasible or obsolete.

Automotive OEMs are rapidly evolving their body-in-white designs to include a hybrid make-up of lightweight aluminum castings, sheets, or extrusions, mild steel, and high and ultra-high strength steel components. These hybrid structures magnify an already challenging joining scenario into one of much greater magnitude. In particular, the joining of dissimilar materials like aluminum and steel make most traditional fastening methods, like spot welding, unfeasible.

When you throw high strength and ultra-high strength steel into the mix it additionally negates many newer technologies. The process of fastening ultra-high strength steels (those above 1000 MPa) poses a special challenge because most of the fastening technologies, which depend on piercing or deforming, cannot stand up to material of such high strength. Therefore, the options for joining aluminum to high strength steels above 1000MPa are extremely limited, as clinch joints and self-piercing rivets likely will not perform well.

Perhaps the only consistently successful and commercially proven method of joining these ultra-high strength steel combinations is a recently released technology from EJOT GmbH of Germany. The process is called EJOWELD® because its core technology is friction welding. Like self-piercing rivets and clinch technologies, it is packaged as a system with both the element, the delivery system, and the installation head designed to work harmoniously together. The actual fastening element is small and resembles a solid rivet.

Although relatively new, this method is already production proven and was launched on the 2015 model year of the Audi Q7. It continues to garner a great deal of interest worldwide with automotive OEMs because it provides joining options in areas of high demand for practical solutions, such as connections to pillars, door and roof beams, and tunnels.

**Figure 1** shows an example of the Composite Friction Fastener, CFF. This rather simple looking fastener is really a very sophisticated engineering innovation. The fastener (referred to as the "element") is designed to pierce the upper light metal layer (normally aluminum) and friction weld itself to the lower high strength or ultra-high strength steel layer (**Figure 2**). The finished joint is capable of fastening to ultra-high-strength steel sheet up to at least 1800 MPa in ultimate strength and is equivalent or stronger than a similar spot weld.

Like a spot weld, the process requires access by the installation equipment to both sides of the stack and leaves no protrusion from the lower sheet, unlike a self-piercing rivet or clinch joint. Although the head is low profile, it does protrude from the top of the joint unlike spot welds, self-piercing rivets, or clinch joints. Therefore, the designer must accommodate for the head protrusion.



Figure 1 »

Figure 2 ≈



**Figure 3** illustrates the process employed by EJOWELD® to obtain a successful joint. The process can be broken down to four distinct steps. In step one the fastening element is turned by the installation tool at up to 8000 rpms while an axial load is applied. The special point design, high speed, and axial load effectively push into the aluminum (or other "soft" material upper sheet) displacing it upwards, resulting in the penetration of the light metal top layer and upward flow of the displaced material to "mound" around the top of the penetration. This is obvious in **Figure 2** where the aluminum is clearly seen to have moved up and slightly out. The CFF element is specially designed with a head undercut to accommodate this material displacement.

Once the tip of the fastening element touches the high strength steel plate below, step two begins. This consists of rotating the element at high speed to generate enough heat to clean and prepare the surface for welding. This step is very important for a quality joint, as it eliminates any adhesive or surface coating that may be present at this interface.

### Joining Process - Steps

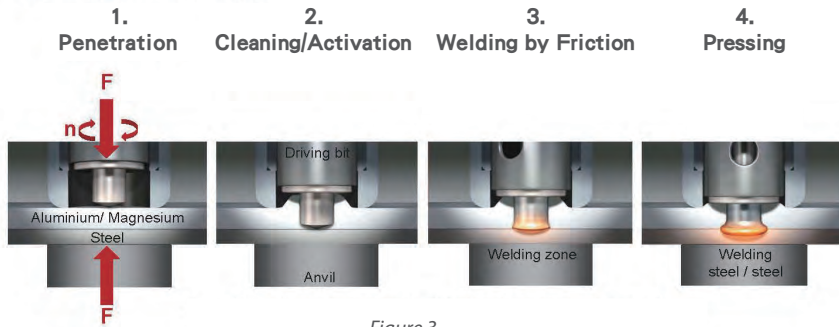


Figure 3



Figure 5

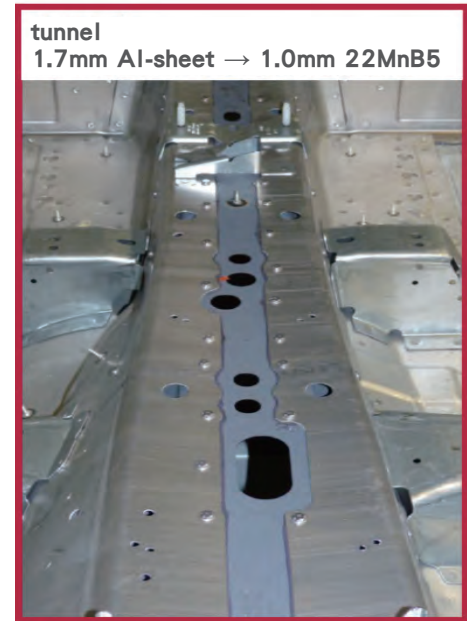


Figure 4

In step three additional axial load is applied, resulting in greater localized friction and a softening of the high strength steel in the area to be fastened and the tip of the CFF element. It is important to realize that the friction generates only enough heat to produce plasticity in the element and the sheet rather than a liquid pool. This is key because unlike a welding process that depends on fusing materials with the reconstitution of the liquid pool, there is little or no associated “heat effected zone”. In fact, the temperature produced in this process is much lower than the temperature required to melt steel so that there is no significant and possibly deleterious effects of a “heat effected zone.”

In the final step, number four, the system maintains the axial load, deforming the heated tip of the element and bonding the two components together at their interface. Although the actual values vary from application to application, the welded joint requires significantly higher force to pull apart than the light metal top layer can usually withstand in a lap shear or peel test. Therefore, the joint integrity is normally a function of the light metal sheet strength and not that of the fastened joint itself.

Although there is a lot of flexibility in the process, it still does have limitations. Unless the upper sheet has a pilot hole, it must be comprised of a light metal such as aluminum that can be pierced without damaging the substrate. Although it may be possible to pierce a mild steel upper sheet, this is normally not feasible as the CFF element would be prone to weld itself to this sheet and not the lower one. In a similar vein, the lower sheet must be steel to enable the friction welding process. In addition to materials, design limitations exist regarding the sheet thickness. For example, the upper light metal layer must be a minimum of 1.0 mm and no more than 5.0 mm and the bottom, high or ultra-high strength steel layer must be at least 1.0mm thick. The element requires two sided access and enough space to allow a robot C-frame to maneuver into position and clear the driver spindle and lower anvil of the installation unit. Although originally developed exclusively for ultra-high strength steel (up to 1800 MPa), subsequent testing has shown that the CFF elements will work on materials all the way down to approximately 300 MPa.

**Figures 4 and 5** illustrate examples of actual applications where aluminum and high strength steel have been joined together. Figure 4 illustrates the center “tunnel” feature of a floor pan structure. In this case 1.7mm aluminum is joined to 1.0mm 22MnB5 high strength Boron steel. Figure 5 illustrates another EJOWELD® connection. In this case, a 2.2mm aluminum casting is joined with 2.0mm 22MnB5 high strength Boron steel.

Like a spot weld or self-piercing rivet the control of the process and thus the resulting quality of the joint are extremely important. In the case of EJOWELD®, an entire integrated system must work in unison to achieve the desired results. By developing upfront the proper parameters the system will take care of proper installation during production. This is accomplished with a sophisticated controller capable of monitoring multiple feedback in each stage of the installation cycle. These include parameters such as time, load, and spindle speed. Although quality will primarily be a function of process control, like traditional spot welds the quality can also be monitored periodically with destructive testing like

a chisel test or cutting and viewing a cross section or by non-destructive methods like ultrasonic testing and comparing to visual boundary samples.

Once again, like spot welding or self-piercing rivets, the installation head will likely be mounted on an assembly robot. This provides the greatest degree of flexibility for the assembler. In addition, different size C-frames and anvil designs can be chosen to optimize reach or access by the robot. However, should an off-line or single use station be desired, the equipment can be mounted on a stationary post or mobile cart.

Although today's OEMs are always looking for new and innovative technologies to provide solutions to their challenges, one can never forget that practical manufacturing needs cannot be overlooked. Therefore, regardless of the joining process, it must possess good efficiencies and not be prone to unplanned downtime. It must also be cost effective, fast, and have efficient service. Failing to deliver in these areas can prevent even the best technology from getting adopted.

EJOWELD® friction welding is a sophisticated and elegant solution for joining lightweight materials to high and ultra-high strength steel in the automotive body architecture. As more automobiles follow the light weighting trends these types of mixed material joints will become more prevalent and engineers and designers will need to utilize this and other state-of-the-art technologies to fill the need. Although friction element welding is currently pretty much only an interest of the automotive industry, there is potential for this technology wherever someone might want to bring together aluminum and high or ultra-high strength steel.

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