Fasteners Enable Lightweighting Efforts 扣件-輕量化的新選擇

by Laurence Claus

History is full of examples of technologies whose invention long predates their actual practical introduction into society. We could say of these ideas that they were simply "before their time". Although that would be accurate, it would probably be a fairer assessment to say that they required further maturing and the development of enabling technologies to make them work. Take, for example, one of the most iconic inventions of all-time, the electric light bulb. The earliest light bulbs were invented in the early 1800s. It would be eighty years later that Edison would discover the carbon fiber filament and create the first practical incandescent light bulbs. However, electric light wouldn't become truly a mainstay in society for another thirty or forty years as enabling technology, such as electrical power generation, transmission and distribution, matured and became a practical reality.

Technology development hasn't changed much over the centuries. An idea is created or a need identified. Often the idea cannot stand alone and requires other improvements and enabling factors to catch-up to it and, when combined, make the original idea a reality.

Today, one of society's highest priorities is the preservation and stewardship of natural resources. This means, not only using the limited resources we have better, but also making sure that we don't do things to damage and squander those same resources. In this vein, many of the world's countries have been making efforts to conserve resources by legislating protections into their society. In 2011, the United State's President, Barack Obama, initiated legislation that would require the new automotive fleet (cars sold into the market in any given year) to increase their average CAFE (Corporate Average Fuel Economy) rating from about 27 miles per gallon to 53.4 miles per gallon by 2025.

This is a significant increase in a relatively short span of time. However, the good news for auto makers is that many of the technologies needed to achieve this milestone are already available. The challenge, therefore, is to take these existing technologies and combine them with new, enabling technologies to make automobiles that can meet these new requirements.

The automobile OEMs will not solve this problem implementing only one change. In fact, they will require the combination of many new technologies if they wish to achieve their intended goal. To illustrate with a practical example, consider the changes in airport and airplane security over the last fifteen years. Many changes have occurred in the screening procedures, airport access, and on-board security. No single change, however, can be credited with fulfilling the entire goal of passenger and society safety or with preventing any new, major, airborne hijacking or terrorist attacks. These goals have been achieved only through the combined, incremental improvement that each of these changes has provided. In the same way, as automotive OEMs tackle the CAFE challenge they will need to employ many improvements to powertrain efficiency and lightweighting the vehicle.

It is with respect to the lightweighting activity that the fastener industry needs to be particularly attuned to. This is because many of the lightweighting activities will require new and innovative approaches to fastening. The remainder of this article will look at some of these challenges and the specific fastening technologies that have developed to address them.

First, one should understand how fasteners can impact lightweighting activities. They can do this in one of two ways, either directly or indirectly. A direct impact would be one where a lightweight material is substituted for a heavier one or a fastener design is utilized that specifically eliminates fasteners from the total number required. An indirect impact would be one where the fastener enables the use of a lightweight material or a lighter gauge or sized item constituting a lower net mass.

Direct Lightweighting Applications

Lightweight Materials

Figure 1: RIBE Aluform® All-Aluminum Fasteners

There is definitely a trend by automakers, especially in powertrain applications, to consider the use of aluminum fasteners. Aluminum is particularly attractive because a part made of aluminum is almost one-third the weight of the equivalent steel part. On just a single part, this strategy may not have a significant impact, but when combined with many fasteners in the same system, the impact can be substantial. For example, the German fastener company RIBE's innovative Aluform® bolts (**Figure 1**) account for approximately 200 M6 through M12 fasteners in one of BMW's six cylinder engines in production since 2004. This accounts for about 5 kilograms (~11 pounds) of weight savings. In a similar example, take German fastener manufacturer EJOT's Delta PT® ALU, an all-aluminum thread forming fastener for plastics. One thousand 6mm x 50mm steel pan head versions of this fastener would be approximately 11.25 kg while the equivalent version in aluminum would be about 3.86 kg, over a 60% weight savings. When utilized in systems that incorporate a high volume of similar fasteners such as door modules or instrument panels, the savings can quickly add up.

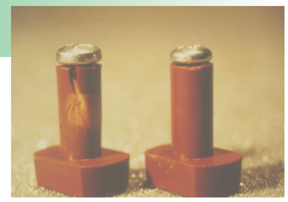
In addition to the weight savings there may be other advantages realized. Often times using like materials in a bolted joint can reduce or eliminate the consequences of pairing dissimilar materials together. Specifically the advantages gained in powertrain applications by eliminating differential rates of thermal expansion and contraction can be significant. Galvanic corrosion can also be a problem when pairing dissimilar metals, so that pairing like materials in a joint may reduce or eliminate risks associated with galvanic corrosion.

On the flip side, these changes are not immune to presenting some major challenges and disadvantages. Perhaps prime among them is the strength. Although aluminum has an excellent specific strength (or strength relative to density), when actual strength is compared head-to-head with a high strength steel bolt there is a wide gap. Therefore, if designers are seeking to use aluminum fasteners they must take into account the strength needs of their joints and systems and design accordingly. Additionally, materials like aluminum are much more prone to galling, a condition where frictional interaction of the mating threads causes localized bonding of the surfaces. In a minimal case, the bolts "stick" a little bit as they are tightened and in the worst case they seize completely and ruin the joint.

Designs Provide for Less Material

Perhaps of greater significance but often harder to understand and quantify is the ability of some innovative thread designs to reduce the amount of material in the screw or its mating surroundings. Take for example, the EJOT Altracs Plus®, a thread forming screw for light metals. Extensive testing has shown that the same clamp load can be achieved with less thread engagement than an equivalent traditional tapping screw. This need for less thread engagement for equal or better performance equates to shorter and, thus, lighter screws.

Figure 2: Screw/Boss on Left is Type AB and on Right is EJOT® Delta PT®



The other consideration is the impact that the thread design has on the mating nut member. If the nut member is a tapped hole in the wall of a large casting, there is likely little to be saved. However, if the nut member is an individual boss in a casting or injection molding, its size can have a significant weight impact. Take, for example, a plastic application. In former times a common screw to use in plastics was a Type AB. It was possible to use such fasteners, but at the expense of consuming large quantities of materials because of the boss wall thicknesses required to manage the internal stresses induced by the thread form. Many modern and innovative thread forms do not exert such high radial forces and, thus, can be designed to work with smaller boss walls. **Figure 2** illustrates this behavior, and shows the results of two identical diameter screws of different thread designs. The unaffected boss is with the EJOT® Delta PT® screw, designed specifically for optimum assembly in thermoplastics, while the other fastener is a Type AB. The Type AB could be made to work, but only with the addition of more wall thickness, which adds to both the cost and weight of the plastic component.

Indirect Methods

Trends in Automobile Body-in-White

Although lightweighting the fasteners is a current area of interest, the greatest efforts are being placed on lightweighting the automotive body structure. The rationale is quite simple, the weight savings gained by lightweighting the body structure and panels adds up much more quickly than any other form of weight savings. However, assuming that changing from steel to aluminum or some other light weight structure is simple, would be patently wrong. In fact, these changes are governed by many factors, including technical feasibility, safety, meeting regulations, and cost feasibility. These challenges make this one of the automotive OEM's greatest areas of interest and study today.

There are several directions that an automotive OEM might take. They could take the direction that Ford Motor Company took with the Ford F-150. This game-changing vehicle went to an almost all aluminum body and sub-structure. In doing so they took out almost 700 pounds (over 300 kg) from the previous model. Although very effective, this strategy has the disadvantage of being the costliest. For various specialized vehicles and profitable models this strategy will undoubtedly work. However, on those models where cost pressures are high or profit margins very narrow, this strategy will not work.

A second strategy, and one more likely to be more broadly used, is the combining of multiple mixed materials, such as aluminum, mild steel, and high strength steel. As technology develops, this direction will also factor in carbon fiber composite structures, engineered plastics, and aluminum and magnesium die castings. In fact, many models today already incorporate some mix of all of these materials.

A third strategy is to pair aluminum with high and ultra-high-strength steel. This is really a variant of the above second strategy and one that is currently garnering a great deal of interest. The interest level is high because high strength steel is relatively cheap and can meet demanding performance requirements at much thinner and, therefore, lighter gauges.

The challenges associated with these strategies are many, although there are a couple that stand-out. These are:

- Pairing of new materials or dissimilar materials do not lend themselves to traditional fastening methods. Because of aluminum's excellent heat transfer it is harder to weld than steel. When combined with steel it becomes almost impossible to weld. Therefore the traditional method of resistance spot welding is not an option.
- Connecting to extruded and tubular structures limit or outright prevent reverse side access. This limits all fastening technologies that require reverse side access or support.
- High strength steels reach a limit at about 1000 MPa where their strength starts to exceed the capabilities of most mechanical fastening methods. Therefore, actual, reliable methods for fastening materials to high and ultra-high-strength steels are limited.
- Adhesives may not be of sufficient strength on their own or require some traditional fastened joints during the set period.
- Potential for galvanic corrosion in dissimilar metal pairings
- Repair and replacement of the fastener element or joint.
- Threaded fasteners usually perform poorly in thin sheet joints
- Clearance holes and tolerance compensation

There are a number of traditional and new, fastening technologies that address these challenges or enable these joints to be possible. Many of the automotive OEMs are giving these technologies a hard look. Several of the enabling technologies being utilized to address these challenges are:

Clinch Technology

Clinching technology is used for joining aluminum to aluminum and aluminum to mild steel. Although there are a variety of different variants available, in essence these are cold forming methods that create a "button" where the two layers have been pressed together in an interlocking "dovetail" type of configuration resulting in a high static and dynamic strength joint. The advantages of these types of joints are that they do not require heat, provide excellent strength properties, and are formed in a pressing operation with simple tooling. They do have limitations, including feasibility of use with high-strength steels, access needed to both sides of the joint, and assembly speed.

Self-Piercing Rivets

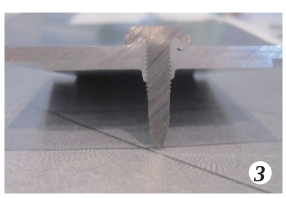
Self-piercing rivets are usually used to connect aluminum to mild steel. The process is such that a semi-tubular rivet is pressed into the top layer of material, piercing it. The rivet proceeds into the lower layer where it flares out interlocking the two sheets. SPRs have many of the same limitations as clinching methods including limitations of material strength, required access to both sides of the joint, and assembly speed.

Flow Drill Screwing

The flow drill process was developed many years ago as a way to form an extrusion in thin sheets or cross sections (such as tubes) that did not allow easy access to both sides. In flow drilling, a specially designed tool is rotated at very high speed generating localized heat and plasticity in the contact area. This contact area is then penetrated resulting in a nice extrusion that can be up to three times the thickness of the penetrated surface. This extrusion can then be tapped to form a strong, integral nut member. A number of years ago, this technology was combined into a threaded fastener to create a self-piercing, self-extruding, self-tapping screw. The German fastener company, EJOT® pioneered this technology with their FDS® screw. This fastener provides some advantages not available with clinching and self-piercing rivets. The most obvious advantage is that it only requires one-sided access. This makes it an ideal solution for connecting into tubular substructures or in locations that are too small or limit access for a tool on the back side. Some additional advantages include repairability (can be replaced with a standard metric fastener), ability to pierce the top sheet in addition to the lower sheet, ability to join more than two layer stacks (3 and 4 layer stacks are feasible) (**Figure 3**), ability to join aluminum and mild steel (**Figure 4**), and installation times as good or better than other commonly utilized methods. It does have limitations, the primary one being related to thickness and ultimate strength of materials to be pierced. This method continues to gain users with one of the most recent being on the all-new aluminum Ford F150 with more than 150 FDS® screws in each vehicle.

Friction Welding Elements

Perhaps one of the most vexing challenges today is joining aluminum to high-strength and ultra-high-strength steel, particularly when the ultimate strength of the steel exceeds 1000 MPa. An answer to this dilemma has recently been introduced by the German fastener company EJOT®, with the EJOWELD® product line. This is a friction welding process which utilizes special element


3

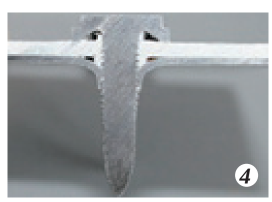

4

Figure 3: EJOT® FDS® in 3-Layer Stack
Figure 4: EJOT® FDS® Aluminum on Steel Stack

design, high rotation speed and axial force to pierce an aluminum top layer, clamp the joint, and weld to the high-strength steel bottom layer (**Figure 5**). There are two versions, the Composite Friction Fastener, CFF, and the Composite Friction Pin, CFP. The CFF has a more blunt point and does not pierce the bottom layer. It requires two-sided access but is capable of joining to ultra-high-strength steel, up to about 1800 MPa in ultimate strength. The CFP has a sharp point and is capable of piercing both the upper and lower layers. It is applied with one-sided access but is limited to high-strength steel layers exhibiting ultimate strength of 1000 MPa or less.

Although this article has only given examples of lightweighting activities in the automotive industry, these trends cross over to many other fastener using industries. Lightweighting has always been a challenge in the aerospace and defense fastener industry. However, it is increasingly finding interest in other places as well, such as white goods, personal electronics, medical, and agriculture. Any application where lighter weight or lower cost associated with downsized materials is important will garner interest with those challenged to find new technologies that enable them to succeed with their goals. Fastener manufacturers and suppliers should be encouraged to learn about these trends and new technologies so that they can educate their customers and users about solutions that make the best sense.

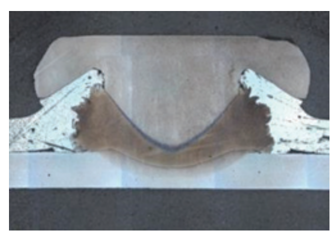


Figure 5:
Example of EJOT® EJOWELD® CFF Aluminum to High-Strength Steel Joint