The Impact Analysis of Automobile Weight Reduction Policies on Automotive Fastener Development in Advanced Countries

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I. Introduction

Globally speaking, as industries advance, serious impacts have been inflicted on the environment. Energy resources and environmental protection become issues in the industrial countries, while relevant regulations and agreements have been made. The automotive industry has been an important industry in the manufacturing sector and plays an important role in environmental protection. Automobile weight reduction and energy conservation have become the development trends of the automotive industry in the world. If the weight of an automobile reduces by 10%, fuel efficiency will increase by 6-8%; therefore, weight reduction means energy saving and reduction of carbon footprint. Because safety has to be taken into consideration, design must be more meticulous and intricate than the designs of former automobiles. In such new design, fasteners play an important part and must have the following five characteristics in comparison to the fasteners of former automobiles, including higher strength, lighter weight, longer durability, easier installation, and better appearance.

Each main auto manufacturing country or region has its own automobile weight reduction policy. In Japan, the classification is based on types of vehicles; in the US and Europe, it is classified by fuel efficiency. In this article, the automobile weight reduction policy of the US will be used as the first example to explore the origin of such policy and its development. Then, how advanced countries implement their automotive fastener development to react to the automobile weight reduction policy.

II. The History of U.S. Automobile Weight Reduction Policies

As of now, the U.S. is on the top rank in terms of car manufacturing and it has also been the first country that adopts the policy of carbon emission reduction through automobile weight reduction. Of the carbon emission classification in the U.S., automobile transportation represents 36% in the 2nd place, which is only second to power generation. According to **Fig. 1**, the category of small vehicles contributes 60% of the emission; mid-size and large vehicles at 23%; and other types of vehicles at less than 20%. Therefore, in order to reduce carbon emission, it is a good idea to start with motor vehicles.

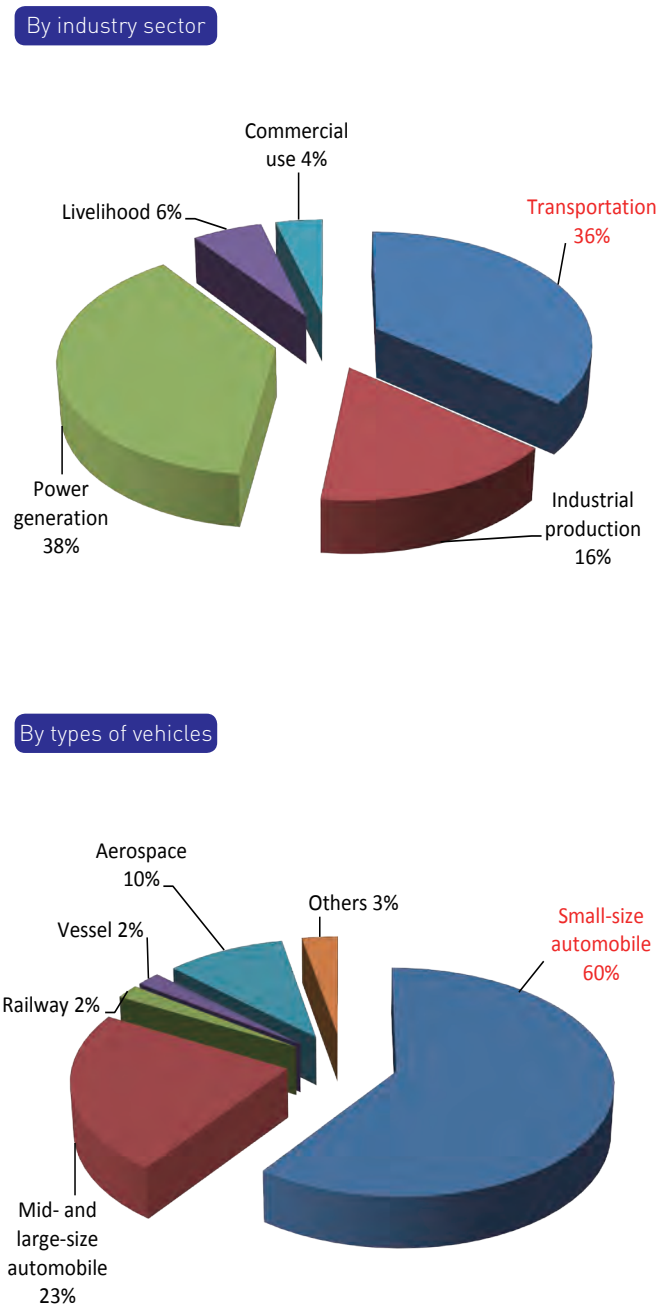

Fig. 1 Classification of U.S. Carbon Emission Contributors
Data source: Center for Climate and Energy Solutions; arranged by MII of MIRDC (Aug. 2015)

Introduction of U.S. Automobile Weight Reduction Policies

(1) CAFE and PNGV

In 1975 when certain Arabian countries stopped exporting oil to the U.S., the CAFE (Corporate Average Fuel Economy) was enacted in the U.S. CAFE requires all models of vehicles to reach the fuel efficiency of 18 miles per gallon (or 7.65 km per liter). In 2011, the CAFE raised the requirement to 27.5 miles per gallon (or 11.7 km per liter). After 2011, President Obama authorized the EPA and NHTSA (National Highway Traffic Safety Administration) to jointly formulate new regulations: requiring the fuel efficiency of 54.5 miles per gallon for motor vehicles produced after 2025. President Obama explicitly expressed that such new requirement would allow the U.S. to rely less on imported oil.

In April 2010, the EPA and Department of Transportation (DOT) jointly announced their new gasoline efficiency requirement for vehicles produced from 2012 to 2016, which aims to increase the fuel efficiency to 34.1 miles per gallon for vehicles by 2016. In 2011, the requirement was further raised to 43 to 56 miles per gallon for vehicles made from 2017 to 2025.

The CAFE has strict stipulations on air bags, ABS and side-impact body; however, these stipulations work unfavorably against fuel economy and weight reduction. Therefore, U.S. Department of Energy devised a joint development project, PNGV (Partnership for a New Generation of Vehicles), inviting USCAR (United States Council for Automotive Research) and the three big automakers (Daimler, Chrysler, Ford and General Motors) to join the project. Starting from 1993, the US government invested US$ 200 million per year in R&D for weight reduction of automobile bodies and power systems. Aluminum bodies and reduction of the number of fasteners in the suspension system were methods to reach fuel efficiency of 80 miles per gallon. Later in 2001, former President George W. Bush's administration cancelled the project and then part of the contents were transferred to the FVTP (Freedom and Vehicle Technologies Program), which aimed at the development of large lithium batteries and electric vehicle battery applications. Though PNGV was cancelled, the global trend of the reduction of carbon footprint remains unchanged. Big automakers

continued to work on automobile weight reduction and released models such as Chevrolet Bolt EV developed by GM, F-150 Raptor pick-up and carbon fiber GT sports model developed by Ford. All of these models will be the focus in the Frankfurt Motor Show held in the second half of 2015.

(2) Highly Populous States Also Have Their Automobile Weight Reduction Policies

The Californian government enacted the first state law (AB1493) requiring GHG (greenhouse gas) emission limits for motor vehicles, making it the first state government in the U.S. to do so. In the future, the federal government of the U.S. will continue to implement motor vehicle weight reduction measures, while highly populous states such as California and New York will pass and enforce additional regulations pertinent to vehicle weight reduction.

III. Development of Fasteners to Facilitate Automobile Weight Reduction

Generally speaking, the total weight of fasteners (typically, 2,500 to 3,000 pieces) comprises less than 6% of the weight of a vehicle. Therefore, fasteners do not play an important role in vehicle weight reduction; instead, the body and components are more important in terms of vehicle weight reduction. Fasteners connect components together and they also link components with the body. Hence, fasteners play an important role in safety and performance of a vehicle. For example, the body of a vehicle may be made of aluminum and its suspension system may be light but of high strength; fasteners linking the suspension system to the body should be of new material and have improved connective performance.

We Have Found 4 Global Development Trends of Lighter Automotive Fasteners:

(A) Configuration Change in Fastener Heads and Increase in Its Strength:

U.S. leading automotive fastener company Phillips Screw suggested car manufacturers reduce the depth of predrilled holes on the body. By doing so, the head height and size of a fastener as well as the thickness of sheet metal could be effectively reduced. Secondly, high-strength fasteners are used in order to reduce the number of fasteners needed and the total weight of fasteners. **Fig. 2** illustrates a comparison between Phillips Screw Company's conventional fastener and its optimized fastener.

Star Screw (a screw with a head characterized by a 6-point star-shaped pattern) was developed long after automobile fasteners were first developed. Its patented trademarks include Torx and Torx Plus and these trademarks are under the possession of Acument Global Technologies, which is a leading fastener manufacturer in the U.S. The angle between the plane of contact between tool and fastener and the circumferentially directed force is much closer to 90 degrees in a Torx type of head than in a conventional hex head. Because the Torx screw has higher tolerance to wear and deformation, it has longer service life. In the past, the production of Torx screws was protected by the patent right and hence a premium had to be paid to Acument Global Technologies; but now, we only have to purchase TORX punch to produce and sell TORX screws.

Mazda continued to stress on the weight distribution in its CV for MX-5, which had shown the highest sales record in the small-size convertible market. The model specifically designed for Europe weighs 998 kg. The engineers of this model express that they adopt "Gram Strategy," which means that any excessive gram would have to be avoided. All fasteners used in MX-5 are TORX. Every piece of the screw weighs 8 grams less (Note: the left side of the head is smaller than the right side). With 2,500 TORX fasteners fitted in an MX-5, the weight of this vehicle is slashed by 20 kg, enabling the model to return to its former weight while maintaining its high performance.

(B) Aluminum Fasteners

The second trend is about fasteners made of aluminum. To decrease the weight of a vehicle, the body and components are mainly made of aluminum and magnesia. As the thermal expansion coefficient of carbon steel is different from those of aluminum and magnesium, galvanic corrosion may take place easily; therefore, deeper threaded holes are required to ensure serviceability, which also means that the thickness and length of a fastener will be increased. In contrast, fasteners made of pure aluminum don't have such drawback and hence they may be lighter and thinner. **Fig. 3** clearly illustrates the difference in threaded-in depth between using a carbon steel fastener and using an aluminum fastener to joint with an aluminum alloy or magnesium alloy component.

Forming fastener heads is the most difficult and important step in forging because the deformation rate reaches as high as 70%. Therefore, forming fastener heads is the most important step to increasing the yield rate. Aluminum fasteners must meet the requirements for high-strength, high thermal resistance, high tolerance to corrosion, and the ability to withstand extreme conditions. 6000 series

Fig. 2 Comparison Between Phillips Screw Company's Conventional Fastener and Its Optimized Fastener
Data source: "Optimizing Fasteners for Weight Reduction, Serviceability and High-Speed Assembly", Michael Mowins, Phillips Screw Company; arranged by MII of MIRDC (Aug. 2015)

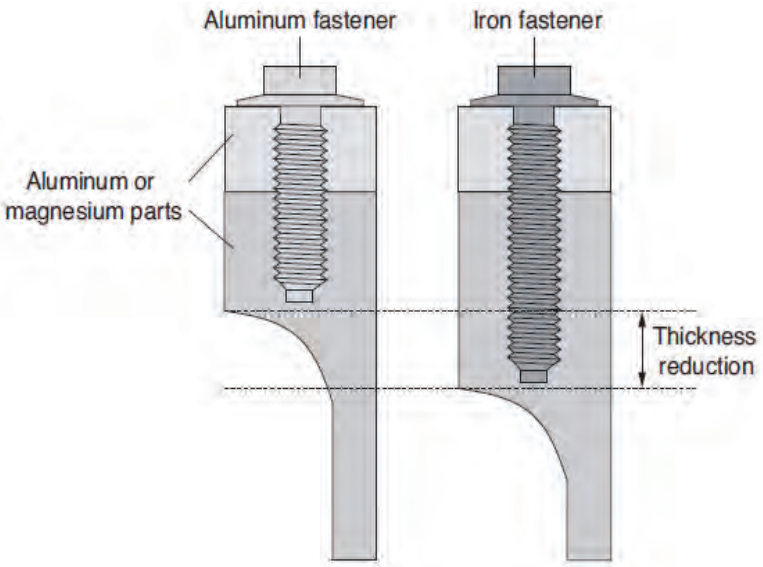

Fig. 3 The Difference in Threaded-in Depth Between Using a Carbon Steel Fastener and Using an Aluminum Fastener to Joint with an Aluminum Alloy or Magnesium Alloy Component
Data source: "6056 Aluminum Alloy Wire for Automotive Fasteners" (Oct. of 2013); arranged by the MII of the MIRDC, Aug. of 2015

Class		Strength	Workability	Heat Resistance	Corrosion Resistance
2000 (Al-Cu) series		○	△	△	×
5000 (Al-Mg) series		△	△	△	△
6000 (Al-Mg-Si) series	General-purpose	△	○	○	○
	High-strength	○	△	○	○
7000 (Al-Zn) series		◎	△	×	×

◎ very good, ○ good, △ not very good, × not good

Table 1 Properties of Four Different Series
Data source: arranged by MII of MIRDC

aluminum alloy wire coils should be the best option. **Table 1** illustrates the properties of four different series in terms of their strength, thermal resistance, tolerance to corrosion, and the ability to withstand extreme conditions.

Cold forging is suitable to be used for materials that are hard to be processed or are soft, such as aluminum. To reduce the weight of vehicles, Japanese Sumitomo Corp chooses 6056 aluminum alloy to make automotive fasteners because it shows high strength, high thermal resistance and high tolerance to corrosion. Please see **Table 2**.

Tensile Strength	**400 MPa**
0.2% Yield Strength	**360 MPa**
Ductility	**8%**

Table 2 Physical Properties of 6056 Aluminum Automotive Fasteners
Data source: Sumitomo Electric Toyama Co., Ltd.; arranged by MII of MIRDC

It is hard to forge a head for the fastener made of 6056 aluminum, because alloy heterogeneity may result in cracks and folds on the surface. One reason is the precipitation of coarse and uneven grains which are generated during hot rolling. Most alloys developed by European suppliers currently used to make automotive fasteners are heterogeneous, so heterogeneous segregation and precipitation of coarse grains often occur. This is why defective forged parts are produced. This problem can only be eliminated when there is any breakthrough in forging or other new types of alloys available in the market

(C) Optimization of Fasteners Used for Main Automotive Bodies Made of Carbon Fiber

The third trend is about the new carbon fiber compound material, whose properties have to be simultaneously optimized. The leading Dutch fastener manufacturer Nedschroef has not only improved the strength of carbon steel fasteners (for reducing the number of fasteners used in a vehicle), but also has boldly used a new material, CFRP (carbon fiber reinforced plastic), on vehicle bodies and components. BMW is the first automaker to use such a new material on its models (i3 and i8 series); therefore, fasteners must be also optimized to be used with CFRP.

For this purpose, Nedschroef established Techno Centre R&D Facility to carry out tests. The first test is the stress test on the surface, in which a cylinder made of super-strength NT16 steel presses against a CFRP board until the board is dented. Test results indicate that the bearing surface of a fastener must be increased to prevent CFRP from falling down when external force cause a dent on it.

The second test is about friction, in which a fastener is fastened until 75% of the required yield rate and average friction coefficient have been reached. The friction coefficient may be calculated from the average torque according to the EN ISO 16047. The test result of a CFRP board shows that its average friction coefficient is 0.07, which is 40% to 50% lower than that of a sheet metal.

The third test is about galvanic corrosion, which is caused by the heterogeneity difference between carbon fiber and fasteners made of certain metals. Nedschroef uses fasteners made of 304 & 316 stainless steel and aluminum alloys

including EN AW 5000, 6000 and 7000 series. The company continues to explore how other materials (including titanium, copper and different types of stainless steel) interact with CFRP, in order to find the optimal material for fasteners. Coatings on fasteners, which may be made of expensive materials, such as titanium alloy and stainless steel alloy, may increase the performance of fasteners fitted to CFRP. As a result, solutions with better price/performance ratios can be provided to fasteners manufacturers.

Nedschroef has successfully developed three types of automotive fasteners for compound carbon fiber automotive component assembly. They are:

1. Fasteners made of EN AW 6056 aluminum alloy.
2. Carbon steel fasteners with two coatings.
3. 316 stainless steel fasteners with special heat treatment.

German leading fastener manufacturer ARaymond also focuses its effort on tight engagement between fasteners and automotive components. ARaymond collaborates with Renault of France in the usage of tight engagement technology to reach the goal of automobile weight reduction. Till now, there are four types of materials that have been used to reach the goal of weight reduction: carbon fiber composite material, fiberglass, magnesium-aluminum alloy and high-strength lightweight steel. However, these materials are not easy to be welded and galvanic corrosion may occur. ARaymond and Renault successfully developed a new adhesion technology and used it in Renault's concept car, EOLAB, which was debuted in Paris Motor Show held in Jan. 2015. The new adhesion technology enables coatings on fasteners to stay clean and dry, thus making it easier to be assembled/removed and favorable for industrial automation. The technology can speed up the progress of automobile weight reduction.

(D) Automotive Plastic Fasteners

The fourth trend is about plastic fasteners. In 2013, British fastener manufacturer TR Fastenings supplied plastic fasteners to be used on Atom, a sports car model by Ariel Motors (also an automaker in the UK). These plastic fasteners supplied by TR Fastenings are light and resilient; more importantly, a two-piece plastic rivet can be used to replace the conventional three-piece combo – a bolt, a nut and a washer, substantially reducing the number of fasteners and the space and hence reaching the goal of weight reduction.

IV. Conclusion

As the aforesaid, we can see in the process of automobile weight reduction that new materials with high tolerance to corrosion and deformation are used to fabricate fasteners. Hence, the value and prices of fasteners can be increased. These new fasteners are superior to the old fasteners in terms of physical properties and performance.

As forging a star-shaped head for a fastener is comparatively difficult, Taiwanese brand King Tony has encountered difficulty in improving the precision of head forging. Such difficulty is quite common for small-size and mid-size fastener manufacturers in Taiwan. As of now, in Taiwan, only Yulon has created its own brands. Therefore, for fastener manufactures that want to develop fasteners for carbon fiber assembly or adhesion technology, it would be better to join a foreign firm's R&D projects. Otherwise, if these manufacturers carry out their own research and development, it is very likely that they may encounter bottlenecks; besides, such an approach is risky in terms of its investment and return. Among the aforesaid four global development trends about automotive fasteners, aluminum fasteners would be the better choice for Taiwanese fastener manufacturers, as aluminum alloy, forging, and die technology have been developed long ago and are quite mature. Only slight improvements in forging technology and galvanic corrosion would be needed for Taiwan to catch up with the industrial countries. Once the gap is bridged, it will be much easier for Taiwanese companies to secure their own presence in the market. ■