

# Research Status of Steel - Aluminum Joining Technology for Automobile Parts

Kai Xu<sup>1</sup>, Qirui Cui<sup>2</sup>, Guoqiang Li<sup>1</sup> and Shuquan Zhang<sup>3</sup>

<sup>1</sup>Department of Mechanical Engineering, Anhui Technical College of Mechanical and Electrical Engineering, Wuhu 241000, China

<sup>2</sup>College of Science, Northwestern Polytechnical University, Xian 710072, China

<sup>3</sup>Changzhou Institute of Technology, Changzhou 213002, China

**Abstract**—Lightweight is an inevitable trend for the future development of automobile bodies. There are several suitable for steel-aluminum lap connection technology, with the application of steel-aluminum hybrid body. Mechanical connection technology, welding technology and adhesive riveting composite connection technology are introduced in the paper. The idea of a hybrid material body structure based on the concept of "suitable materials for the right part" is a good balance between the requirements for lightweighting, processability, safety and cost as a whole. It represents the future development of automotive body structure of the latest trends.

**Keywords**—automobile parts; steel-aluminum joining technology; research status

## I. INTRODUCTION

The lightweight vehicle is mainly reflected in the application of high specific strength, high specific stiffness of the new material manufacturing body structure, chassis and power system structure to achieve the purpose of weight loss. Currently four new materials used in automotive lightweight materials including high-strength steel, aluminum alloy, magnesium alloy and composite materials. The steel-aluminum composite structure has a good application prospect in automobile and aviation industry etc, with the advantages of both materials. But how to get the high quality joint of dissimilar metals is the most difficult technical bottleneck for the popularization and application of steel-Al composite structure in engineering.

The application of steel-aluminum hybrid car body will bring the dissimilar metal connection, joint matching, galvanic corrosion and thermally induced deformation and other outstanding problems. To this end, domestic and foreign experts and scholars and technical staff conducted some exploratory research, developed a number of new technologies and new technology.

## II. STEEL-ALUMINUM CONNECTION TECHNOLOGY RESEARCH STATUS

In recent years, with the application of steel-aluminum hybrid body, there are several suitable for steel-aluminum lap connection technology, mainly divided into mechanical connection technology, welding technology and adhesive riveting composite connection technology.

### A. Mechanical Connection of Steel-Aluminum Lap Joints

The main techniques used for mechanical connection of steel-aluminum bodies are self-piercing riveting (SPR) and clinch joint (CJ)<sup>[1]</sup>.

### 1) Self-piercing riveting

Self-piercing riveting is a low temperature forming process that uses a half-pipe type rivet to pierce the upper deck and then expands the rivet body into the lower deck, thereby creating a mechanical interlock between the two planks. The connection process is shown in Figure 1.

Self-piercing riveting is essentially a cold connection technology, its unique way to connect it can effectively overcome the aluminum alloy, magnesium alloy, titanium and other light metal materials difficult to use resistance spot welding welding shortcomings, not only for the same material between Double-layer and multi-layer connection of metal materials such as aluminum-magnesium, steel-aluminum, steel-magnesium, aluminum alloy / magnesium alloy / high-strength steel and high molecular materials / composite materials<sup>[2-4]</sup>. Half-pipe-type rivets are made of high-strength steel, and after anti-corrosion surface coating treatment.

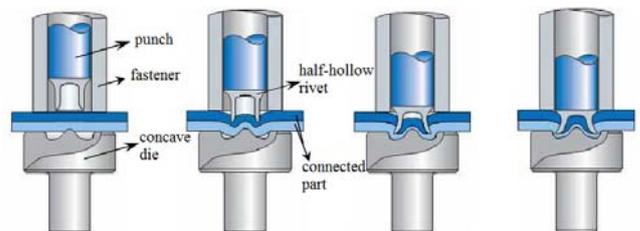


FIGURE I. CONNECTION PROCESS OF SELF-PIERCING RIVETING

### 2) Clinch joint

Clinch joint connection, also known as stamping connection or locking, is recently developed for the connection of thin-walled plate of the new connection technology, which in the punch, blank holder and die under the joint action of the connected material at the connection point through the local plastic deformation to form self-locking point to achieve the purpose of connection, the process shown in Figure 2<sup>[5]</sup>.

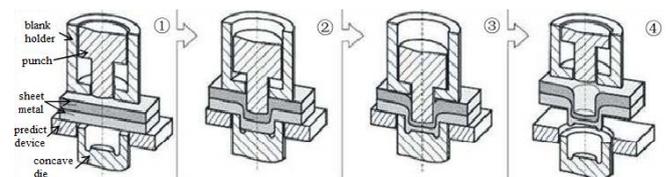


FIGURE II. CLINCH JOINT CONNECTION

Clinch joint is one of the most competitive sheet joining technologies after SPR connection technology. Compared with SPR, it does not require rivets, in the scale of

manufacturing, the total cost is significantly lower than the SPR connection; in the connection process, the plate of the rust-proof coating or paint layer along with plastic deformation flow without tear damage, will not damage the part surface, it will not affect the connection point strength and corrosion resistance. The clinch joint connection greatly increases the degree of freedom of the body structure selection, which has become one of the hot topics in engineering and academic research.

### B. Steel - Aluminum Lap Joint Welding Technology

Suitable for steel - aluminum body welding process are mainly friction stir spot welding and laser spot welding<sup>[6-7]</sup>. Friction stirring spot welding is from friction stir welding, divided into keyhole type and non-porous type. Laser spot welding is mainly segmented spot welding.

As early as 1993, the Japanese Mazda company has the key hole FSSW for RX-8 sports car aluminum body of the lap spot welding, the principle shown in Figure 3<sup>[8]</sup>. The stirring needle keyhole will be left in the solder joint position after completion of the welding. In the 2005 Mazda MX-5 sports car, the first use of FSSW will be aluminum alloy luggage cover connected to the steel locator.

Figure 4 shows the basic principle of backfill FSSW<sup>[9]</sup>. The mixing head consists of three parts - the mixing pin, the sleeve and the jacket. By controlling the relative movement of the three parts, the mixing head is filled with the keyhole formed in the retracting process. The specific spot welding process is: friction heating → stirring flow 1 → stirring flow 2 → welding forming, the spot welding joint is flat and without key hole. The mechanical properties of FSSW are better than those of other FSSW joints, but the mixing tools are more complex and inefficient.

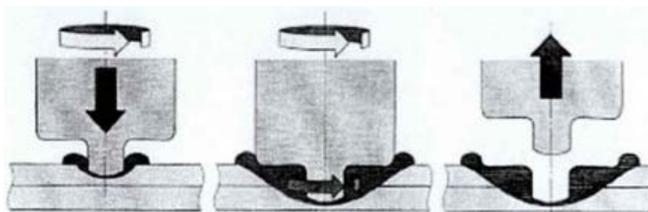


FIGURE III. THE KEY HOLE FSSW

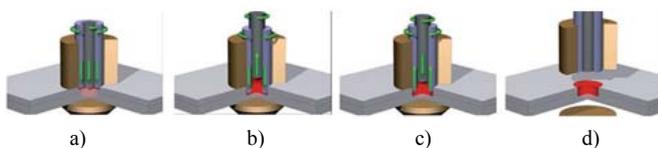


FIGURE IV. THE BACKFILL FSSW  
A) FRICTION HEATING B) STIRRING FLOW 1  
C) STIRRING FLOW 2 D) WELDING FORMING

FSSW has been widely used in light-alloy spot welding of aluminum and magnesium, etc. It has many good features, but its application on steel-aluminum lap joints is very limited. For example, steel-aluminum interface produces brittleness phase, the connection strength is low, the mixing tools is easy to wear and other shortcomings. FSSW needs to break through the principle of innovation process limitations, improves process adaptability and joint connection quality.

Japanese scholars Hitoshi Ozaki, etc with the power of 2KW fiber laser on the SPCC low carbon steel and A5052 aluminum alloy laser rolling test, the analysis of the two parameters of the weldability of the material, compound

layer formation and mechanical properties of the joint influences<sup>[10]</sup>. The results show that aluminum alloy can be quickly and fully wetted and adhered to the steel plate by the efficient heating method, and a good steel-aluminum lap joint (steel on aluminum) is obtained, and different intermetallic compound FeAl, FeAl<sub>2</sub>, Fe<sub>2</sub>Al<sub>5</sub> and FeAl<sub>3</sub> are formed at the interface of connection.

Hunan University, Peng Li, Zhou Dian-wu, etc have carried out laser lap welding comparative test on steel / aluminum interlayer metal added or not with galvanized steel and 6016 aluminum alloy as the object of study<sup>[11]</sup>. The mechanical properties and microstructure of the intermetallic compounds were studied.

Beijing University of Technology Zhang Dong-yun, Gao Shuang-xin, etc have carried out DC06 steel and 6061 aluminum alloy lap brazing welding process research, by using CO<sub>2</sub> laser welding<sup>[12]</sup>. The microstructures and phases of the joint were analyzed, and the mechanical properties of the joint were tested. Studies have shown that a lower energy density can obtain a thinner intermetallic compound layer and a higher joint shear strength with respect to higher energy density.

### C. Steel-Aluminum Lap Joint Adhesive Riveting / Bonding Bonding Composite Connection Technology

Compared with other connection methods, adhesive connection has its unique advantages: adhesive connection using surface contact is not easy to produce stress concentration, connection strength, stiffness and fatigue strength is relatively high, and a wide range of connections, can be used in a variety of light metals, steel and the connection of different materials, compared with spot welding and riveting.

The new structural adhesive has the characteristics of high strength and high rigidity and toughness and flexibility at the time of impact load. It can meet the needs of body structure and expand the application range of adhesive connection<sup>[13-14]</sup>. Adhesive connection has its inherent shortcomings: a, glue the connection effect is susceptible to heat and humidity; b, gel solidification need to heat and take a long time before the solidification of sheet metal to be fixed to prevent mutual Sliding; c, bonding failure mode is a sudden cracking, failure to bear the load instantly reduced to zero, the body structure in the application of the existence of security risks. In view of this, bonding and riveting / welding together in general to form a riveting / bonding welding composite connection process for the body structure.

F. Moroni et al have studied the influence of the factors such as plate spot, thickness, joint distance, aging treatment and temperature on resistance spot welding, punch riveting, traditional riveting, SPR connection<sup>[15]</sup>. The results show that the overall performance of the composite joint is much higher than that of the mechanical joint alone. Compared with the adhesive joint, the adhesion of the adhesive joint in the composite joint is better than that of the adhesive joint. And the temperature and aging treatment have the same effect on the performance of the adhesive and riveting composite joints.

A. Pirondi et al have simulated the failure process of bonding-riveting, adhesive-riveting and joint shear tests using ABAQUS, and obtained the peak value of the

shear-tensile displacement curve<sup>[16]</sup>. Stiffness, energy absorption and other parameters were good agreement with the experiment, which laid the foundation for the optimization and performance prediction of viscous-riveting composite joints based on CAE analysis.

### III. THE DEVELOPMENT TREND OF STEEL-ALUMINUM CONNECTION TECHNOLOGY

The idea of a hybrid material body structure based on the concept of "suitable materials for the right part" is a good balance between the requirements for lightweighting, processability, safety and cost as a whole. It represents the future development of automotive body structure of the latest trends.

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#### REFERENCES

- [1] T.A. Barnes, I. R. Pashby. Joining techniques for aluminum space frames used in automobiles(Part II -adhesive bonding and mechanical fasteners)[J]. *Journal of Materials Processing Technology*, 2000, 99(s1-3):72-79
- [2] Jacek Mucha. A Study of Quality Parameters and Behavior of Self-Piercing Riveted Aluminum Sheets with Different Joining Conditions[J]. *Journal of Mechanical Engineering*, 2011, 57(4): 323-333
- [3] Alan Luo, Theresa Lee, Jon Carter. Self-Pierce Riveting of Magnesium to Aluminum Alloys[R].SAE paper 2011-01-0074
- [4] Huang Shu-yan. Process and Quality Evaluation Research of Self-piercing Riveting for Dissimilar Metal Aluminum/steel[D].Shanghai : Shanghai Jiao Tong University, 2011
- [5] Y.A be, M. Kishimoto, T. Kato, et al. JOINING OF HOT-DIP COATED STEEL SHEETS BY MECHANICAL CLINCHING[J]. *International Journal of Material Forming*, 2009, 2(1):291-294
- [6] Gerhard Liedl, Robert Bielak, Julia Ivanova, et al. Joining of Aluminum and Steel In Car Body Manufacturing [J]. *Physics Procedia*, 2011, 12(Part 1):150-156
- [7] T. DebRoy, H.K.D.H. Bhadeshia. Friction stir welding of dissimilar alloys-a perspective[J]. *Science and Technology of Welding and Joining*, 2010, 15(4):266-270
- [8] Pan, T (2007), 'Friction Stir Spot Welding (FSSW)–A Literature Review', 2007 SAE World Congress, Paper No.2007-01-1702, Warrendale, PA, Soc. of Automotive Engineers.
- [9] Dong Tao, Wang Lang, Lu Cang-jin, et al.Research progress of friction stir spot welding at home and abroad[J], *Modern welding*, 2012, 02:1-4
- [10] H. Ozaki, M. Kutsuna. Laser-roll welding of a dissimilar metal joint of low carbon steel to aluminum alloy using 2 kW fiber laser[J]. *Welding International*, 2009, 23(5), 345-352
- [11] PENG Li, ZHOU Dian-wu,XU Shao-hua, et al.Laser lap welding structural properties and first-principle computation of zinc-coated steel and 6016 aluminum alloy[J].*The Chinese Journal of Nonferrous Metals* 2012, Vol.22. No.1, 230-238
- [12] Zhang Dong-yun, Gao Shuang-xin, Gao Hai-yun, et al.Study on the technology of laser welding of Aluminum/steel dissimilar metal[J].*Laser & Optoelectronics Progress*,2011, 48(6):87-94
- [13] ZHOU Dian-wu, LIU Yuan-li, LI Ning-ning, et al. Effect of Sn-5%Zr Powder Addition on Microstructure and Mechanical Property of Steel/Al Laser Welding[J]. *Chinese Journal of Lasers*, 2015, 42(5):95-103
- [14] ZHOU Dian-wu, DAI Ting, XU Shao-hua, et al. Microstructure and properties of galvanized steel/aluminum alloy laser-adhesive hybrid bonding[J]. *The Chinese Journal of Nonferrous Metals*, 2014, 24(7):1736-1743
- [15] F. Moroni, A. Pironi, F. Kleiner. Experimental analysis and comparison of the strength of simple and hybrid structural joints[J]. *International Journal of Adhesives*, 2010, 30:367-379
- [16] A. Pironi, F. Moroni. Clinch-Bonded and Rivet-Bonded Hybrid Joints: Application of Damage Models for Simulation of Forming and Failure[J]. *Journal of Adhesion Science and Technology*, 2009, 23:1547-1547