Effect of Connection Process on Corrosion Resistance of Exhaust Hood of Gas-fired Heating and Hot Water Combi-boiler

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Abstract. In order to solve the obvious corrosion at the resistance spot welding connection position of galvanized sheet smoke hood of gas-fired heating and hot water combi-boiler, and eliminate the potential safety hazard of smoke hood seal performance degradation and smoke leakage, the design and This paper analyzes the advantages and disadvantages of exhaust hood from the aspects of This paper analyzes the advantages and disadvantages of exhaust hood from the aspects of structure design, material selection and process optimization, and draws up the optimization scheme. Acid salt spray test was used to study the corrosion resistance of aluminum alloy core pulling rivet, TOX riveting and resistance spot welding. The test results show that the corrosion resistance of galvanized exhaust hood with aluminum alloy core pulling rivet, TOX riveting and resistance spot welding. In view of the influence of manufacturing accuracy and production efficiency, TOX riveting process can be used for assembly and connection of galvanized sheet exhaust hood of gas-fired heating and hot water combi-boiler.

1. Introduction
In the life cycle tracking of gas-fired heating and hot water combi-boiler product, it was found that there was obvious corrosion at the location of the welded connection in the exhaust hood. The structure of the smoke exhaust hood is shown in Figure 1, and its local corrosion condition is shown in Figure 2, which is the corrosion condition of the product after long time use. The exhaust hood can be separated from the connection by a slight force, and subsequent disconnection will create a safety hazard such as smoke leakage. After analysis, the material used for the fume hood is 0.8 mm thick galvanized plate, the left side plate, bottom plate, cover plate and right-side plate make up the fume hood, each part is completed by shearing machine to open the material in the early stage, die drop punching, folding and forming stamping, and subsequently assembled and connected by resistance spot welding. In order to further understand the cause to solve the problem, a random sampling inspection was conducted on the models that had been in stock for three months. Figure 3 shows the
condition of the product when it was waiting for the factory, and slight oxidation traces were found. In order to solve the problem of obvious corrosion at the resistance spot welds of the gas-fired heating and hot water combi-boiler exhaust hood after a long period of use, a functional analysis was conducted according to the environment and conditions of use of the exhaust hood, with a view to further optimization and elimination of hidden safety hazards.

![Real object](image1.png)  
1-Left side plate 2-Bottom plate  
2-3-Cover plate 4-Right side plate  
(a) Real object  
(b) Two-dimensional schematic diagram  
Figure 1 Exhaust hood  

![Figure 2 Local corrosion after long use](image2.png)  
![Figure 3 The condition of the fume hood spot welds when it is to be manufactured](image3.png)  

2. Exhaust hood function and anti-corrosion requirements  
The gas-fired heating and hot water combi-boiler needs to work with a reasonable ratio of gas and air for ignition and combustion, and the heat exchanger will exchange heat between the high temperature flue gas after combustion and the cold water in the pipeline in order to raise the temperature of the water in the pipeline. The high-temperature flue gas from the gas combustion passes through the burner, heat exchanger, condenser and exhaust hood in turn, and then is discharged to the outdoors through the flue pipe. In order to improve the efficiency of the heat exchanger and to guide the discharge of high temperature flue gas, fans are usually installed to discharge the flue gas from multiple rewinds along the established piping.

After the combustion of high-temperature flue gas through the heat exchanger and condenser, the flue gas temperature drops significantly to below 100 °C near the exhaust hood, when the surface temperature of the flue gas contact material produced by combustion is lower than the dew point of the flue gas, then condensate is produced. Ideally, the flue gas condensate should be pure water [3]. The actual gas combustion flue gas and condensate composition are both quite complex. Gao Ying of Zhejiang University [2] et al. used Raman spectroscopy to analyze the natural gas composition and derive the components of natural gas more precisely. Natural gas is composed of methane, ethane, propane, carbon dioxide, nitrogen, hydrogen, carbon monoxide, and unknown alkane components.
above C4, which are treated with desulfurization and dehydration, in a proportion of more than 90%. As the national standard for natural gas allows the mass concentration of H2S contained in natural gas to be ≤20 mg/m³. H2S is generated during the combustion process with different air ratios to produce SO2 and SO3 or a mixture of the two. H2S combustion products react with water vapor to form H2SO4. When the flue gas temperature drops, it condenses into a liquid sulfuric acid mist, which adheres to the surface of the flue gas channel and produces strong corrosion, generating corrosion products sulfate. Natural gas also produces NO and NO2 during the combustion process. About 5-10% of NO2 is dissolved in water to form nitric acid. Natural gas and air also contain trace amounts of chlorides and fluorides, which decompose during the combustion process to produce hydrochloric acid and hydrofluoric acid, which will produce a highly corrosive mixed corrosive solution when fused with water vapor. The acidic gases CO2, NO, NO2, SO2 and chloride and fluorine ions in the combustion flue gas are not corrosive in the gaseous state, but dissolve in the condensate to produce a dilute acidic mixture of carbonic acid, nitric acid, sulfuric acid, hydrochloric acid and hydrofluoric acid, which causes corrosion of the heat exchange surface. According to the above analysis, the condensate in the condensate mainly consists of sulfate, nitrite, nitrate, bicarbonate and acid. The products of natural gas combustion are partially dissolved in the condensate, and the emission of hazardous substances to atmospheric pressure is reduced by one resulting in more complex condensate characteristics. When the condensate dries, its acid concentration increases and it becomes more corrosive [2]. Due to the presence of nitric acid and sulfuric acid, condensate corrodes the surfaces contacted by the flue gas passages, thus reducing the service life of the material, reducing its strength and ultimately affecting the safety performance of the product.

The corrosion that occurs in areas where condensate is present is mainly electrochemical corrosion [3]. The electrochemical corrosion circuit consists of parts that form the anode, cathode, electrolyte solution and external circuit. The electrolyte solution is acidic or neutral aqueous solution, electrons flow from the anode metal through the external circuit to the cathode metal, hydrogen ions absorb electrons at the cathode to form hydrogen gas, and the anode metal loses electrons to generate metal ions, directly causing metal destruction. Therefore, the appropriate surface treatment of the material can effectively extend the service life of the material by extending its corrosion resistance. The exhaust hood of gas-fired heating and hot water combi-boiler is made of 0.8mm thick galvanized sheet. Galvanized sheet is added to a hot-rolled or cold-rolled substrate with a galvanized layer that covers the substrate to insulate it from air, and zinc reacts with oxygen to form a dense oxide film that insulates it from air and moisture and prevents oxidation. A. K. Singh[4,5] of Tata Steel Research Centre, India, et al. conducted a detailed microstructural analysis of galvanized sheets with the help of scanning electron microscopy, energy dispersive X-ray analysis technique and conducted atmospheric oxidation test, salt spray test and sulfur dioxide test to study the root cause of its darkening to study the corrosion resistance of galvanized samples with different microstructures, their study showed that Galvanized sheet surface integrity its good corrosion resistance performance. The zinc on the surface of the galvanized sheet is more active than the iron in the substrate and acts as the cathode first, converting it into zinc ions to protect the bare steel from corrosion and delaying the overall corrosion of the material. In the acidic solution of condensate, the acidic gases such as nitrogen oxides and oxides in the flue gas and water vapor generate hydrogen ions needed for electrochemical corrosion, which will significantly increase the corrosion rate of the substrate. According to the analysis and the actual corrosion situation, the galvanized sheet can withstand condensation and no significant corrosion is seen on its unbroken surface.

3. Functional analysis and optimization solutions

According to the functional analysis and corrosion resistance requirements of the exhaust hood of the gas-fired heating and hot water combi-boiler [6], the galvanized sheet with an intact and unbroken surface can resist the corrosion of condensate for a longer period of time. When the components of the hood are assembled and connected by resistance spot welding, the nucleus formed damages the integrity of the galvanized surface to a certain extent, resulting in corrosion by condensation during the
long working hours of the hood. After generating severe corrosion or causing a partial reduction in the strength of the connection. Combined with the analysis of the above principles, the exhaust hood optimization program was initially determined based on the principle that it can withstand the corrosion of condensate for a long time. If the structural design of the exhaust hood is changed and an integrated design is used, the connections can be reduced. If the original sheet is first deep-drawn and shaped, followed by cutting the edges, but due to the large depth, there is still a risk that the galvanized coating will be thinned or even destroyed; if the connection between the parts of the exhaust hood is not changed without destroying the integrity of the galvanized coating, pull riveting and TOX riveting processes can be used. The optimization options and their advantages and disadvantages are shown in Table 1. After analysis and comparison, the process optimization using pull riveting and TOX riveting is more advantageous to improve the quality and efficiency of the fume hood, and is identified as the alternative optimization solution.

Table 1 Optimization schemes and their advantages and disadvantages

| Optimization schemes | Advantages                                                                 | Disadvantages                                                                 |
|----------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| One-piece structural design | No connection required, high productivity                                    | High difficulty in deep drawing and forming, thinning or breaking of plating. Requires new design and manufacturing of molds, which is more costly |
| Replacing exhaust hood material | No need to change the structure of stamping dies                             | Increase material costs                                                         |
| Connection process optimization | Rivet holes must be punched in the connection position of the fume hood parts | Increase the time to install rivets One by one riveted connection, increasing the time spent |
| TOX riveting process | No need to change the structure of stamping dies                             | Need to improve riveting equipment for effective positioning                   |

4. Optimized schemes and manufacturing processes

The original process scheme for the exhaust hood was assembled via resistance spot welding connections. The welding process starts with the left side plate positioned with the left edge of the exhaust hood cover and then spot welded to connect, then the right-side plate positioned with the right edge of the exhaust hood cover and then spot welded, and finally the bottom plate of the fume hood is installed into the bottom of the exhaust hood cover and spot welded. The whole assembly and connection process is constantly changing positions and accurate positioning before spot welding, with a total of 20 welding joints, and it takes at least 40-60s to complete the spot-welding connection of a single exhaust hood.

In order to achieve an effective connection without destroying the integrity of the galvanized plate plating, taking into account the efficiency of the connection, while not using materials with better corrosion resistance and increasing the cost of the product, a comparative test was conducted using the pull rivet connection process of aluminum alloy open end flat round head blind rivets and the TOX riveting process. The TOX riveting process it facilitates the flow of the sheet with the help of the mechanical extrusion principle, which forms rivet points and thus reliably connects the sheet [7]. The structure of the pull riveting and TOX riveting process is shown in Figure 4. Parts using the pull riveting process must have mounting holes for rivets that have been prefabricated, so prefabricated rivet holes can be used for positioning. After installing the rivets, the rivet gun can be used to start the operation. The main consideration for the assembly and connection sequence is the efficiency of the connection and the convenience of continuous operation, with no other special requirements. The
TOX riveting process is more complex in terms of equipment requirements. Given the structural composition of the exhaust hood, the exhaust hood cover is assembled with three parts, including the left and right-side panels, to wrap the entire riveted table, making it impossible to position the riveted connection effectively. At the same time, the bottom plate of the exhaust hood itself has an inverted structure, and there must be enough internal space to give rejection, so the exhaust hood cover and the left and right-side plates cannot be riveted at the same time. For this reason, the riveting process was improved in advance by making four special riveting machines, which were used to realize the riveting of the exhaust hood cover plate and the left and right-side plates in two directions, and the exhaust hood bottom plate and the left and right-side plates. Riveting equipment application control system and equipped with a cylinder for pressing, solenoid valve positioning device. When the device is powered on table reset, the solenoid valve is positioned with magnetic waiting ready.

![Fig. 4 Schematic diagram of riveting process structure](image)

(a) Pull rivet  
(b) TOX rivet

The assembly and riveting order of the exhaust hood is to rivet the right side of the exhaust hood cover to the right-side plate, then flip the left side of the exhaust hood cover to rivet the left side plate, and then rivet the left and right-side plates to the bottom plate of the exhaust hood respectively. The assembly process of the pull riveting process using aluminum open end flat round head blind rivets uses prefabricated rivet holes for positioning. TOX riveting process assembly and connection production process using the edge of the part positioning, are more accurate, and of quality control. The overall riveting of the exhaust evacuation hood is shown in Figure 5, and the appearance of the riveting points is shown in Figure 6. In terms of production efficiency, the riveting process has similar working hours as resistance spot welding, while the TOX riveting process can reduce the working hours of a single piece of exhaust hood from 40s to 8s, which improves the production efficiency of exhaust hoods and significantly reduces the environmental ventilation requirements because no obvious pollutants are generated.

![Figure 5 Overall appearance of exhaust hood](image)

(a) Pull rivet  
(b) TOX rivet
5. Corrosion test and analysis of results

In order to verify the corrosion resistance of the exhaust hood of the gas-fired heating and hot water boiler using the pull riveting process and TOX riveting process to the condensate generated by its working process, the acceleration test of the salt spray for exhaust hoods was designed referring to the national standard GB/T 24195-2009 “Corrosion of metals and alloys - accelerated testing involving cyclic exposure to salt mist, “dry” and “wet” condition [8]. The adjustment salt spray test chamber temperature is set to 35 ℃, and 12 ml of analytical pure nitric acid solution and 17.3 ml of analytical pure sulfuric acid solution are added into 5% mass fraction of neutral sodium chloride solution. A mass fraction of 10% of sodium hydroxide solution is used for pH adjustment to 3.5 ± 0.1. Test of other major process parameters is as shown in Table 3, to continuously spray acid salt solution for 2h, followed by drying conditions for 4h, after wetting conditions for 2h, and after 6 cycles have been completed, that is, 48h acid salt spray test. After the test, the exhaust hood was dried naturally in a room temperature environment for 1h, and then clean water was used to slowly rinse the residual salt solution on the surface of the hood, and after cleaning, compressed air was used to blow dry at a distance of about 400 mm to observe the corrosion condition of the hood, especially at the connection.

| Test chamber temperature | Drying conditions | Humid conditions | Nozzle pressure | Spray volume per hour |
|--------------------------|-------------------|-----------------|----------------|----------------------|
| 35℃±1℃                  | 60℃±1℃<30%RH     | 50℃±1℃>95%RH   | 1.0 kgf/cm²   | 2.0 ml/80cm²        |

After the acid salt spray test of the three different connection processes, it can be found that the exhaust hood connected by resistance spot welding has the most serious corrosion, as shown in Figure 7(a), and the fusion nucleus produces obvious oxidation rust stains, while the aluminum alloy open type flat round head blind rivet and TOX riveting process have no obvious corrosion phenomenon, as shown in Figure 7(b).

Figure 6 Appearance of the riveted joints of the exhaust hood
(a) Pull rivet  (b) TOX rivet

Figure 7 Appearance of exhaust hood after acid salt spray test
(a) Resistance spot welding process  (b) Pull riveting process  (c) TOX riveting process
After comparing the preliminary results of the test, it is clear that the corrosion resistance near the fusion nucleus of the resistance spot welding connection process is much lower than that of the pull riveting process and the TOX riveting process. The pull riveting process and TOX riveting process can pass a short acid salt spray test. To further verify the anti-corrosion performance of the exhaust hood using the pull riveting process and TOX riveting process connection, and close to the working reality of the gas-fired heating and hot water combi-boiler, the exhaust hood has been installed with the same model of the gas-fired heating and hot water combi-boiler for 1000h accelerated life test. According to the test results and the product production efficiency and cost, and in view of the high precision requirements of the prefabricated holes for the installation of the extractor rivets and the long working hours, it is recommended to use the TOX riveting process for the connection between the parts of the exhaust hood, which can be further optimized according to the accelerated life test results.

6. Conclusions
(1) The gas-fired heating and hot water combi-boiler galvanized plate exhaust hood parts using aluminum alloy open type flat round head extractor rivets for pull riveting process connection and TOX riveting process connection corrosion resistance are better than resistance spot welding connection process.

(2) Using TOX riveting process galvanized plate surface coating is not significantly damaged, still has a good corrosion resistance, and can be used for gas heating and hot water stove exhaust hood manufacturing process.

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