

# Efficiency and Precision of Welding Process for the Automotive Parts

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**Abstract.** In this article it is detailed the welding techniques applied in the automotive industry, highlighting how these methods contribute to improved efficiency and precision in manufacturing processes. By utilizing advanced technologies and high-performance materials, hot element welding ensures durable and high-quality connections essential for the production of modern vehicles. However, the specific innovation of this study lies in the detailed analysis of process parameters and their optimization for automotive applications, particularly airbag component manufacturing, providing quantified improvements in joint strength and quality. This approach ensures both efficiency and precision are maximized in high-stress automotive environments. By the statistically point of view, the aim of the study is to analyze the results of compression test. Specific results of compression tests show that the welding process described delivers significant improvements in mechanical properties. The results test for specific hot element welding highlight the processing automotive products and providing superior solutions to industry challenges. The test results also demonstrate enhanced durability and reliability when compared to conventional welding techniques. In conclusion, hot element welding is revolutionizing alternative of the automotive industry, offering efficient and precise methods for modern components of vehicle production. By adopting these advanced techniques, it was achieved new standards of quality and durability.

## 1 Introduction

In the field of automotive manufacturing, the industries are focusing on replace conventional materials with lightweight materials, such as advanced high strength steel. Recently, it was developed a novel welding technology called resistance element welding (REW) as a fusion joins technology by combining the mechanical (riveting) and thermal (welding) joining principles [1, 2]. Additionally, the most of the automotive manufacturers have committed to use friendly ad eco-environmentally technologies in order to produce the safety and performant products. Despite the advancements in welding techniques, current research still lacks detailed exploration of process optimization for critical safety

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components like airbags. This study addresses that gap. Also, the gas emission standards required by many countries stimulate the active researches on joining of dissimilar material in the automotive industries [3, 4]. This paper presents a detailed analysis of the REW process for automotive airbag components, exploring critical parameters such as heating temperature, bonding force, and material characteristics. The objective is to optimize these parameters to improve joint integrity and meet stringent automotive safety standards.

The resistance element welding for production of airbag components, it provides the necessary joint strength and durability for these critical safety systems. This process involves the use of electrically heated element to melt thermoplastic surfaces, allowing them to bond under controlled pressure.

The REW process, a further development of the conventional RSW process, can be defined as a novel joining technology to join multi-material-compounds in the production lines with the same joining technology as with conventional steel parts [5]. In principle, the REW process uses an auxiliary joining element which is integrated into the aluminum carrier sheet in different ways and it could be understood as a thermal-mechanical joining technology which combines the advantages of mechanical (form-fit) and thermal (metallic bond) joining principles and enables a boundary stretch of joining dissimilar material combinations [6].

The fundamental principles suppose that the resistance element welding process relies on an electrically heated device, known as a heating element, which transfers heat to the thermoplastic surfaces intended for welding. Upon reaching their melting point, the thermoplastics become viscous, enabling them to bond under controlled pressure. This results in a homogeneous and robust joint upon cooling and in particular for airbag components, precise control of this process is essential to ensure reliability and safety. In this regard, the purpose of this paper is to describe and analyses the welding process for the automotive parts. In particular, there are detailed the technical and scientific aspects of this process, highlighting its importance in ensuring the safety and functionality of airbag components.

## **2 Process steps description**

### **2.1 Surface preparation**

Proper surface preparation plays a critical role in ensuring the structural integrity of welds, as any contaminants such as oils, dust, or residues present on the surfaces can significantly compromise joint strength, making them susceptible to failure under operational stresses. In line with ISO 26262 standards, ensuring contamination-free surfaces is paramount for critical safety components such as airbags. This preparatory process encompasses multiple essential steps: initially cleaning the surfaces using appropriate solvents like isopropyl alcohol or acetone to effectively eliminate oils and residues, followed by conducting a meticulous visual inspection to confirm the surfaces' cleanliness. Additionally, it is imperative to ensure thorough drying of the surfaces to prevent any moisture from being trapped during the welding process, which could otherwise lead to defects or weakened bonds.

### **2.2 Heating**

The heating phase plays a pivotal role in thermoplastic welding, essential for achieving optimal material fusion without compromising its integrity. The temperature of 600°C was determined based on a combination of experimental data and industry standards, including

reference to specific welding standards in the automotive sector. This phase involves several critical steps to ensure effective joining of plastic components used, for instance, in airbag assemblies.

Firstly, setting the heating element temperature is crucial, typically calibrated to 600°C, which proves ideal for the efficient melting of commonly employed thermoplastics. This temperature setting is meticulously chosen to balance rapid heat transfer and material integrity during the welding process.

Secondly, precise positioning of the heating element is paramount. It is strategically placed between the plastic parts slated for fusion, ensuring full and uniform contact with both surfaces. This positioning maximizes heat transfer efficiency across the joint interface.

Thirdly, controlling the heating duration is pivotal. The duration of heating is determined by various factors such as material composition and thickness of the components. Monitoring the process until the surfaces reach a tacky state is imperative, signifying the optimal moment for initiating the joining process.

Technical nuances further underscore the importance of material properties and heating element design. Variations in melting points among different thermoplastics necessitate the 600°C temperature setting for achieving uniform and rapid heating. Heating elements are typically crafted from materials like aluminum or brass, chosen for their high thermal conductivity, ensuring consistent heat distribution. Additionally, elements may feature coatings such as PTFE to prevent undesired adhesion of molten plastic, thus maintaining the integrity of the weld.

### **2.3 Removal of the heating element**

The careful and precise removal of the heating element is of paramount importance in ensuring the structural integrity and functionality of welded plastic components. Automation of this process, combined with real-time feedback mechanisms, has shown to significantly reduce human error and improve weld quality. This phase is critical as it directly influences the final quality and reliability of the joint. Timing is crucial; the heating element must be removed promptly upon achieving the optimal tackiness of the molten surfaces. Careful handling techniques are imperative to prevent any disturbance to the softened edges of the plastics. Post-removal, a meticulous inspection is conducted to verify the uniformity of the melted surfaces, ensuring consistent quality across the weld. In industrial settings, automation systems are frequently employed to execute this step with precision and repeatability, minimizing human error and optimizing production efficiency. Operators, equipped with specialized training, play a pivotal role in manual adjustments, where their expertise in discerning the exact level of surface tackiness prevents premature or delayed removal actions. This meticulous approach not only maintains the integrity of the welded joint but also enhances the overall reliability and performance of the assembled plastic components in diverse applications ranging from automotive airbag modules to medical devices.

### **2.4 Joining**

The joining phase is of utmost importance as it marks the culmination of the welding process, where the actual fusion of plastic components occurs. The choice of bonding force at 35% of the material's tensile strength was based on empirical testing and aligns with standards for thermoplastic welding in automotive applications. Achieving a strong and uniform weld hinges critically on precise alignment and the application of optimal pressure. Prior to bonding, meticulous alignment of plastic surfaces ensures perfect mating, essential for structural integrity. Applying a specific bonding force, typically set at 35%, is crucial to

facilitate material fusion without causing undue deformation or excess molten plastic expulsion. Maintaining this pressure throughout the cooling phase, which varies from seconds to minutes based on material composition and part dimensions, consolidates the weld. Technical intricacies include employing hydraulic or pneumatic presses for uniform force application, crucial in avoiding weak points. Furthermore, controlling the cooling rate post-welding is imperative to mitigate thermal stress-induced defects; methods such as forced air or specialized cooling jigs effectively manage this process.

### **3 Importance of specific parameters in plastic welding**

Proper management of specific parameters is paramount in plastic welding to ensure robust joint integrity and overall product reliability. The analysis of these parameters reveals that a fine balance must be maintained between heating and cooling rates to avoid defects such as warping or internal stress. These findings are critical for applications in airbag component manufacturing, where even minor defects can compromise safety. The heating element temperature plays a pivotal role, set precisely at 600°C to facilitate rapid and uniform plastic surface heating. This elevated temperature is crucial for swiftly reaching the melting points of various thermoplastics, thereby reducing cycle times and optimizing production efficiency. Technical considerations include maintaining uniform heating across the entire surface to prevent weak spots in the weld and meticulously controlling heat to avoid material degradation, despite surpassing typical thermoplastic melting points.

The bonding force applied during welding is equally critical, set at 35% of the material's maximum with stainable force. Furthermore, the study introduces a novel approach to monitoring these parameters using integrated sensors, ensuring real-time quality control during the welding process. This innovation significantly enhances the precision of the welds and reduces variability in joint quality. This precise force distribution across the joint area is essential to achieve a strong weld without inducing excessive material flow or deformation, ensuring structural integrity. Moreover, meticulous pressure settings are calibrated to optimize bonding strength while preventing joint irregularities.

Achieving uniform melting depths of approximately 2mm from both upper and lower ribbed components ensures deep and homogeneous joints. This specific depth control is pivotal in maintaining consistent joint quality, balancing between inadequate melting that could result in weak bonds and excessive material flow that may compromise structural integrity.

Detailed technical analysis and optimization encompass material considerations, focusing on thermoplastic properties such as polypropylene (PP), polyethylene (PE), and polycarbonate (PC), each characterized by distinct melting points and properties influencing viscosity and thermal conductivity. The choice of high thermal conductivity materials like aluminum or brass for heating elements, coupled with non-stick coatings such as PTFE, prevents undesired adhesion during the welding process.

Control systems incorporating precision temperature and pressure sensors ensure adherence to the 600°C set point and consistent application of the 35% bonding force, respectively. Process optimization further involves determining optimal heating durations and uniform heat distribution, crucial for achieving simultaneous melting across the entire weld surface. Calibration of pressure application systems and automated alignment mechanisms guarantee precise joint positioning before welding, contributing to operational efficiency.

Post-welding controlled cooling rates and specialized cooling jigs mitigate thermal stresses and preserve joint integrity, underscoring the meticulousness in maintaining weld quality. Quality control procedures encompass non-destructive testing (NDT) methodologies such as ultrasonic inspection and X-ray imaging, crucial for detecting internal defects and ensuring surface quality through visual inspections. Destructive testing methods like tensile

and impact tests validate weld strength under real-world conditions, reinforcing compliance with stringent safety standards like ISO 26262 and FMVSS 208.

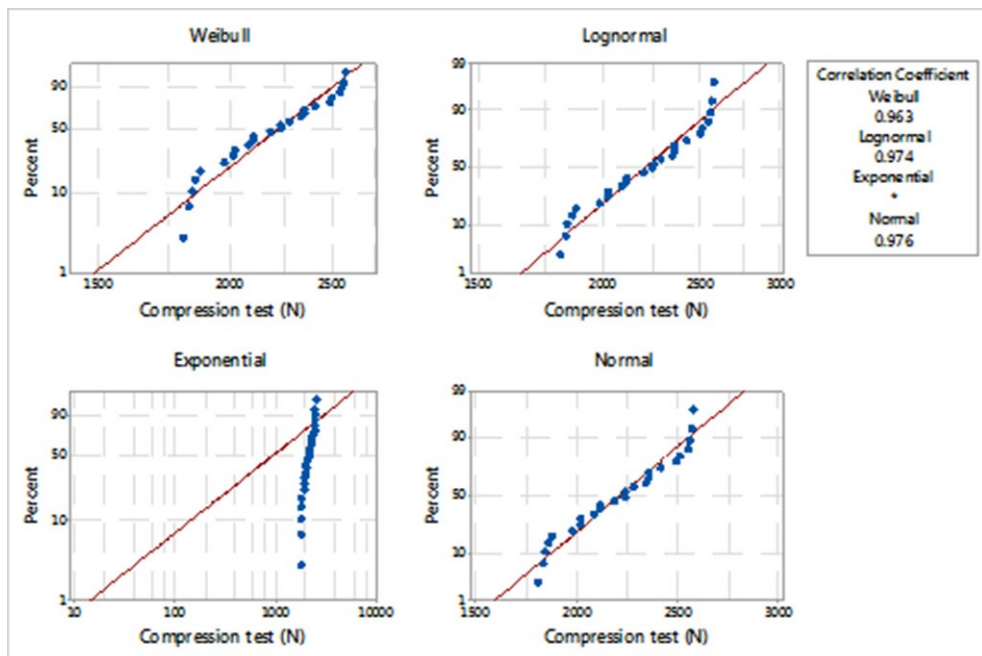
## 4 Case study

Case studies involving airbag gas generator housings, gas distribution tubes, inflator caps and modules, and mounting elements illustrate diverse welding challenges and stringent requirements in automotive applications. The choice of airbag components for this study was driven by their critical role in vehicle safety and the need for highly reliable joints. The case study results underscore the improvements in weld strength and durability achieved through the optimized REW process. These case-specific challenges underscore the necessity for precise welding parameter control to ensure product reliability under varying operational conditions.

The data analyses consist in validation of statistical model. Considering the most used distribution of lifetime date, the goodness-of-fit was applied. The results of estimated Anderson-Darling statistics are synthetically presented in Table 1. The graphical representations of probability plots for compression test (N) are shown in Figure 1. It can be concluded that the data follow very well the considered distribution, less exponential repartition. With 95% confidence interval (CI), the normal distribution was adopted for the estimation of the main statistical parameters.

**Table 1.** Estimated Anderson-Darling statistics.

Distribution	Anderson-Darling (adj)	Correlation Coefficient
Weibull	1.139	0.963
Lognormal	0.916	0.974
Exponential	18.183	-
Normal	0.883	0.976



**Fig. 1.** Probability plot for compression test.

Compare to imposed limits of maximum acceptable compression test value, in Figure 2 it can be observed the estimated likelihood. Additionally, in Table 2 are presented the estimated descriptive statistics. For analyzed test, the mean is 2208 N with a standard deviation of 254.95 N and a median of 2208 N. The results highlight that the tested parts has recorded better value at compression test which it means superior quality and mechanical properties.

**Table 2.** Estimation of mean for compression test.

Distribution	Mean	Standard Error	95 % Normal CI	
			Lower	Upper
Weibull	2203.47	52.399	2103.13	2308.60
Lognormal	2209.49	54.071	2106.01	2318.05
Exponential	1366.23	214.936	1003.72	1859.67
Normal	2208.07	53.200	2103.80	2312.34

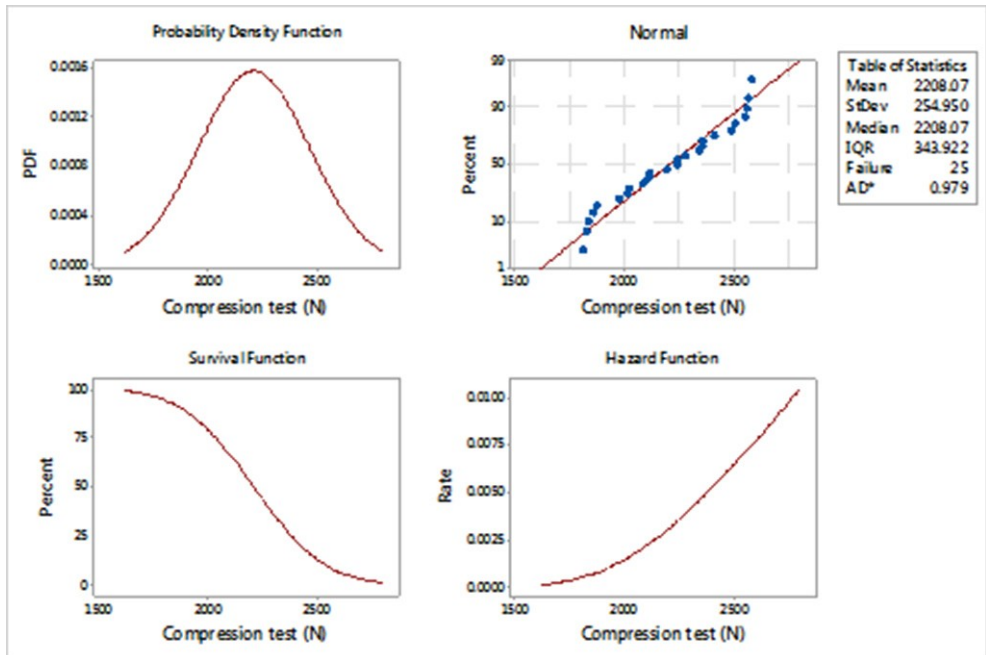


Fig. 2. Distribution plot for compression test.

## 5 Conclusions

Heated element welding is an essential process in the manufacturing of automotive airbag components. This study has demonstrated that by optimizing the process parameters—such as heating element temperature (600°C), bonding force (35% of tensile strength), and melt depth (2 mm) - substantial improvements in joint integrity and durability can be achieved. Future work will focus on refining the process further, particularly in terms of automation and real-time monitoring, to enhance production efficiency and weld quality. By continually improving these processes, the automotive industry can ensure even higher safety standards for critical components like airbags. By meticulously controlling the heating element temperature, bonding force, and material melting, manufacturers can ensure the production of high-quality, reliable components. The parameters of 600°C for the heating element, a bonding force of 35%, and melting 2 mm from both the upper and lower ribs are crucial for achieving optimal joint strength and integrity. Understanding and optimizing these aspects are key to maintaining safety standards and ensuring the effective performance of airbag systems.

The detailed analysis of compression test and optimization of the heated element welding process, combined with rigorous quality control and compliance with safety standards, ensure that airbag components perform reliably under extreme conditions. Continued advancements in this technology will further enhance automotive safety, contributing to the protection of vehicle occupants in the event of a collision.

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