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The Effect of Battery Manufacturing under Different Conditions and Its Contribution to CO Emissions

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Abstract

Lithium-ion (Li-ion) batteries play a crucial role as energy sources for electric vehicles and portable electronic devices due to their high energy density. However, this high energy density leads to increased temperatures during operation, which negatively impacts the performance of nickel strips as the primary electrical connectors within the battery. Suboptimal welding of nickel strips results in safety issues, evidenced by gas leaks from the battery. This research aims to explore the impact of welding defects on battery performance, considering the role of gas sensors in enhancing safety. The test samples used are nickel strips with a thickness of 0.1 mm and a width of 5 mm, evaluated using varying currents of 10A, 20A, 40A, and 50A at room temperature. Observations were made regarding nickel degradation, followed by an analysis of carbon monoxide (CO) and carbon dioxide (CO_2) emissions. The results indicate a temperature increase of up to 78,8°C at the nickel tip, along with the identification of three welding points representing efficient values. Furthermore, the welding results on the battery produced microstructural defects that led to an increase in CO emissions by 18 ppm and CO_2 emissions by 500 ppm during the 1C charging process until reaching 100%.

1 Introduction

Lithium-ion (Li-ion) batteries have become a fundamental power source for electric vehicles and portable electronic devices due to their high energy density and ability to endure multiple charging cycles [1-3]. In the manufacturing process of battery packs, welding interconnections between cells is a key element. Resistance welding is widely favored in the battery industry due to its low cost and reliability in supporting optimal battery performance [4-6]. The quality of these connections directly impacts the energy efficiency and reliability of the battery pack as a whole, as the interconnections facilitate electrical power flow during both the charging and discharging processes, making them crucial for safety and performance [7]. The resistance welding process involves passing an electric current through the nickel strip, which accumulates at several welding points and generates heat. The accumulated heat causes the material at the contact points to melt and bond, creating a connection with very low resistivity and minimal thermal dispersion [8-10]. The welding parameters are influenced by various factors, such as current and welding duration [11]. Defects in welding can lead to excessive electrical resistance, safety concerns, and fire hazards [12]. Although many studies have been conducted on resistance welding in lithium-ion batteries,

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most have focused on macroscopic parameters such as joint strength and welding efficiency [13]. However, limited research explores the microstructural effects of welding defects, such as porosity and small gaps, on the emission of hazardous gases during charging and discharging cycles [14]. This gap highlights the need for further research to understand how micro defects can affect the overall safety and performance of batteries and to develop early detection methods using gas sensors [15]. Previous research, such as that conducted by, demonstrated that welding with three welding points resulted in reasonably strong joints; however, it did not consider the microstructural effects that may arise from increased current during the welding process [16]. Conversely, a study by Phichai et al. identified that three-point welding yielded superior results in terms of joint strength. However, it did not explore the impact of small gaps formed on the surface of the battery terminals, which could affect long-term stability. It indicates that while the three-point welding configuration can enhance joint strength, aspects remain that have not been thoroughly investigated, particularly microstructural changes and potential defects arising from variations in welding parameters [17-20]. The microstructure formed due to increased current may influence stress distribution and the long-term durability of the joint, ultimately contributing to an increase in contact resistance and electrical conduction efficiency.

Furthermore, the small gaps that appear on the surface of the battery terminals have the potential to serve as pathways for the gradual escape of gases, which can lead to electrolyte degradation as well as a decline in battery performance over time, especially under conditions of repeated charging and discharging. Although several studies have addressed the effects of welding parameters on the mechanical strength of the joints, there is a paucity of in-depth research regarding the relationship between microstructure, the formation of gaps, and the gas release mechanism [21]. Therefore, there is a pressing need for more comprehensive studies on the effects of microstructural defects in batteries that may impact both the safety and performance of these energy storage systems. This study aims to expand on previous findings by exploring the effects of higher welding currents and analyzing harmful gas emissions, as well as testing samples with more varied parameters to provide a more comprehensive understanding of the relationship between welding quality, material degradation, and battery safety. In this study, the impact of nickel strip welding was analyzed using nickel samples with a thickness of 0.1 mm and a width of 5 mm. Thermal analysis was performed by varying the welding current by 10A, 20A, 30A, 40A, and 50A at room temperature. The application was tested on a 12V 3Ah battery with a discharge rate of 1C to evaluate the microstructure changes further. Gas emission observations were made at a rate of 1C to full capacity during the charging process. The results of this study are expected to provide greater insight into the relationship between welding quality, material degradation, and battery safety and highlight the importance of using gas sensors in detecting potential system failures to improve the operational safety of Li-ion batteries.

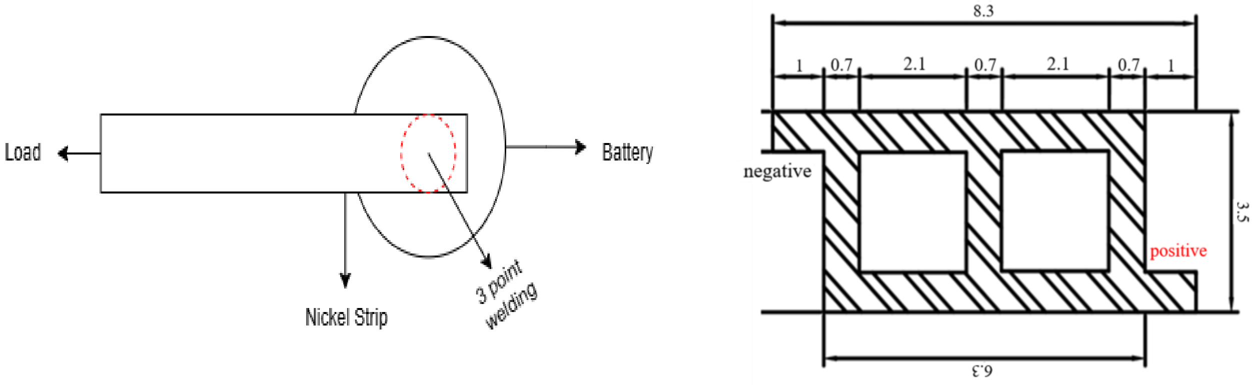
2 Experimental Methods

This study utilizes commercial nickel strips with a thickness of 0.1 mm and a width of 5 mm, selected based on their well-documented thermal and electrical properties in the battery industry. In battery assembly, nickel strips of this thickness provide sufficient flexibility to distribute current in parallel and series configurations between battery cells. The nickel strips are precisely cut to fit the holder of a 3000 mAh battery, ensuring optimal connection and minimizing electrical resistance. This research focuses on two main aspects: thermal monitoring and microstructural analysis of welding defects. Thermal monitoring measures temperature changes in the nickel strips during charge and discharge cycles to identify potential overheating. Meanwhile, the analysis of welding defects involves examining the microstructure of the welded joints to detect porosity or microscopic gaps that could lead to gas leakage, electrolyte degradation, and a decline in battery performance. Thermal monitoring is conducted by applying electrical current loads of 10A, 20A, 30A, 40A, and 50A to the nickel strips. These variations are designed to evaluate the thermal response of the nickel strips under different operational conditions. During testing, the temperature of the nickel strips is monitored in real-time using a thermal camera to identify heat distribution visually. The recorded temperature data is analyzed and compared with previous simulations to observe potential overheating points. Localized heat concentrations may weaken the material structure at the welding area, increasing the risk of microstructural defects and negatively affecting the overall battery performance. An applied test is conducted on a 12V 3Ah battery sample connected to nickel strips.

Table 1. Test parameters and equipment

Parameter	Specification
Nickel strip thickness	0.1 mm
Battery capacity	2600 mAh
Welding machine	Resistance spot welding machine, calibrated
Welding current	5 kA
Welding time	10 ms
Pressure	5 N/mm²
Test conditions	Temperature: 25°C, Humidity: 50%

This test is performed under a 1C current load to simulate real operational conditions. The welding method is resistance spot welding, with precisely adjusted electrical current settings to ensure optimal results. The number of welding points is set to three, as recommended for achieving maximum mechanical strength. The battery pack is housed in a casing designed to fit its dimensions and equipped with MQ-7 and MQ-135 gas sensors as shown in Figure 2. These sensors are used to monitor potential carbon monoxide (CO) and carbon dioxide (CO_2) emissions that may occur during the testing process. Experiment setup shown in Figure 1.



(a) (b)

Figure 1. (a) Experiment setup welding, and (b) Experiment setup nickel

After testing, the results are examined and observed microscopically to analyze structural changes in the welded joints. Gas sensor readings for CO and CO_2 are recorded throughout the charge-discharge cycles to evaluate the impact of welding on gas emissions. The overall results of this study are expected to provide valuable insights into the effects of welding methods on electrical connection quality, heat distribution, and the potential release of hazardous gases that could affect the long-term performance and safety of batteries. Furthermore, the findings from this research are anticipated to contribute to developing more optimized and safer welding techniques for future battery applications.

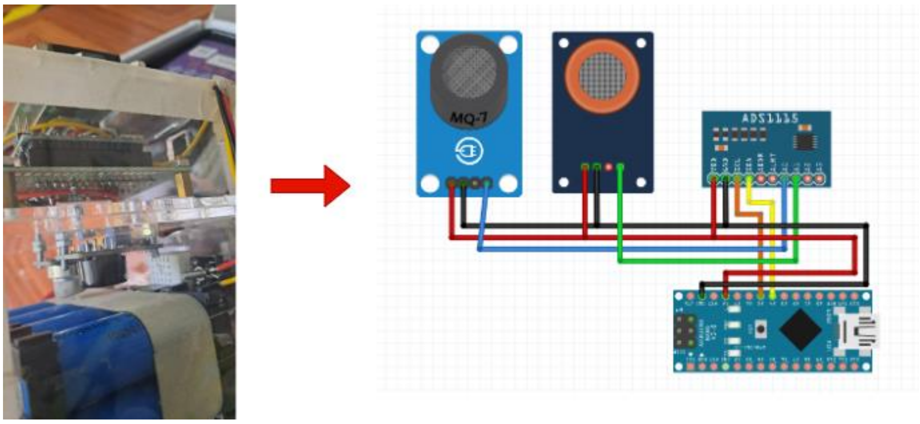


Figure 2. Wiring MQ -7 and MQ-135

3 Results and Discussion

3.1 Thermal Analysis of Nickel Strip

The test results indicate a relationship between current intensity and temperature increase in nickel strips. Initially, the rise in current leads to a nearly linear increase in temperature due to the electrical power being converted into heat. However, after reaching a certain point, the rate of temperature increase begins to slow down as more heat is dissipated into the environment through convection and radiation. Additionally, nickel's positive temperature coefficient resistance increases with rising temperature, which automatically reduces the effective current flowing through the strip, thereby inhibiting further temperature rise. This condition indicates that after surpassing a certain threshold, the increase in current no longer results in a significant temperature rise, signifying the achievement of thermal saturation. From a material perspective, the nickel strip has a specific thermal conductivity limit, meaning that heat distribution within the material is not always uniform, especially when high currents are applied. Furthermore, the interaction between nickel's electrical and thermal properties affects heating efficiency, where excessively high temperatures can lead to structural changes in the material, such as oxidation or decreased mechanical strength. In practical applications, this phenomenon of thermal saturation is crucial to consider in the design of nickel-based heating systems, such as industrial heating elements and electronic devices. Understanding the operational limits of current and temperature can aid in designing more efficient and durable systems, as well as preventing the risk of overheating that could damage the material or lead to overall system failure. In Figure 3, the temperature trends suggest that interactions between electrical and thermal properties impact heating efficiency.

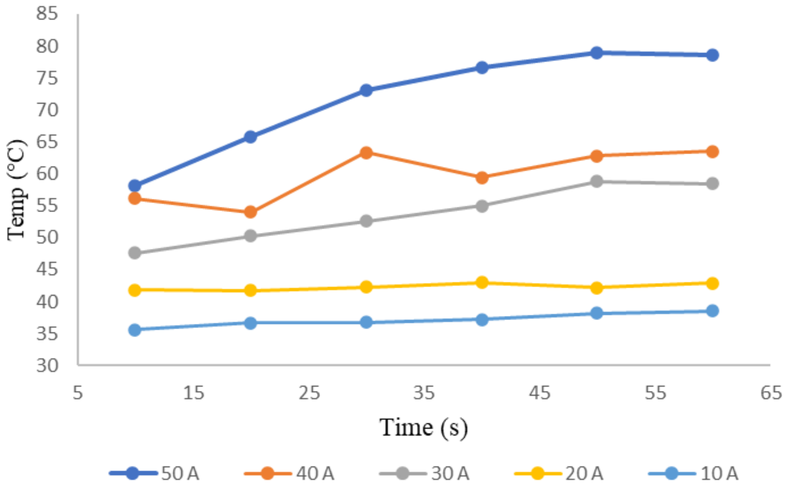
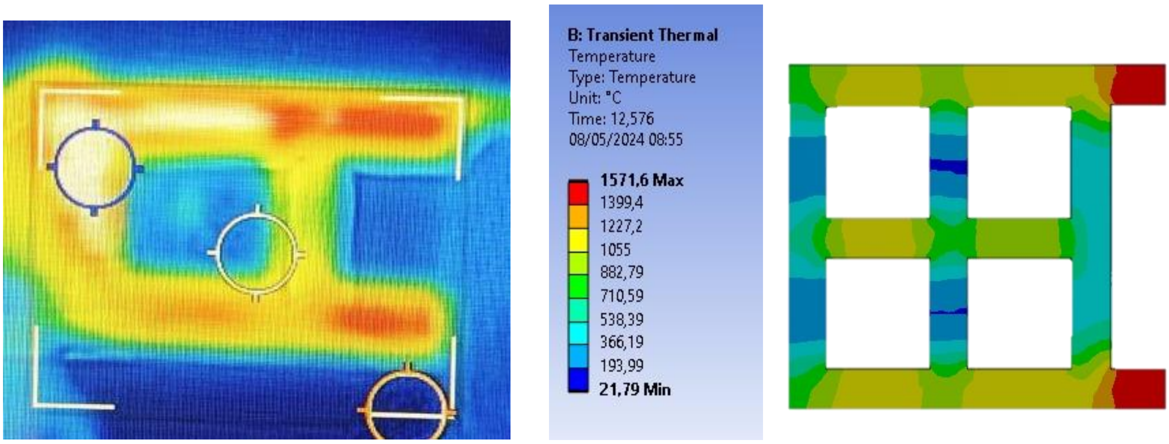


Figure 3. The effect of current on the heat of nickel strip

The thermal analysis in Figure 3 can be further correlated with the infrared images and simulations shown above, which depict the heat distribution in a nickel-based structure. The left-hand infrared image of Figure 4 highlights areas of concentrated heat, where higher temperatures are indicated by the red and yellow regions, which is in line with the concept of thermal saturation discussed earlier due to increased resistance at higher temperatures. The right-hand simulation image reinforces this observation by visualizing stress and heat accumulation in specific structure parts. As explained earlier, nickel’s positive temperature coefficient causes its resistance to increase with temperature, limiting further heat generation and creating a non-uniform temperature distribution, as seen in the localized heating zones in the image. In battery applications, such effects become critical when considering welded nickel connectors in battery packs, where excessive heat generation at the contact points can lead to structural weakness, oxidation, or even material failure. This emphasizes optimizing current flow and thermal dissipation in nickel-based electrical connections to improve battery reliability and safety.

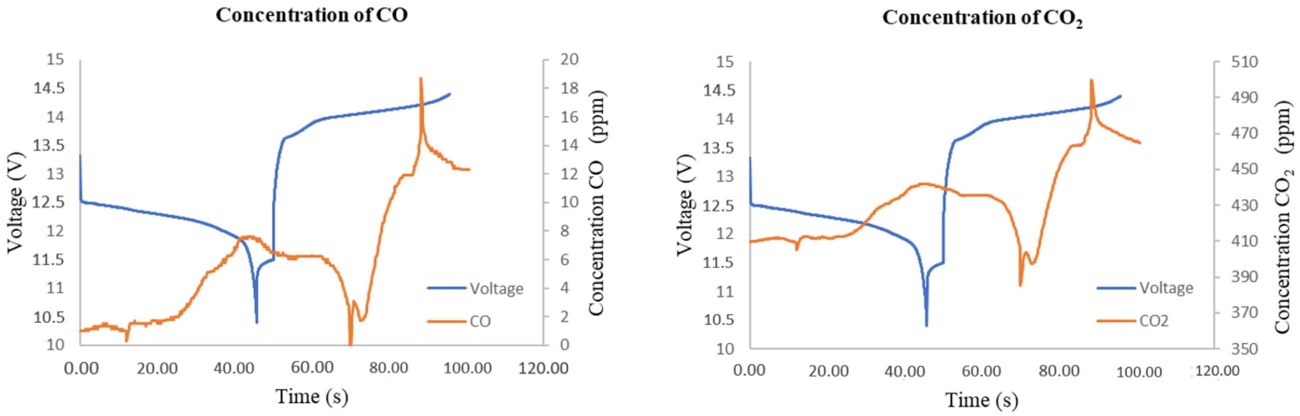


(a) (b)

Figure 4. Heat concentration that arises: (a) Thermal camera results, and (b) Modelling results

3.2 Load testing for welding with a pack battery 12V DC 3 Ah

Based on the previous analysis of the heating effect on the nickel strip due to electric current, the application test of a 12V 3Ah battery with a 1C C-rate gas sensor shows that temperature changes also affect the concentration of CO and CO_2 gases in the surrounding environment. The graph illustrates in Figure 5 that the spike in the electrical voltage (represented by the blue line) coincides with significant variations in the concentration of CO and CO_2 gases (depicted by the orange line). Specifically, the CO concentration increases from about 2 ppm to 18 ppm, while the CO_2 concentration increases from about 360 ppm to 500 ppm. Under ideal conditions, each battery component, both at the cell and pack levels, should be completely isolated from liquid, solid, or gas leakage. This phenomenon can be attributed to potential material decomposition or gas release resulting from local heating, which occurs at junction points or areas of high resistance. Furthermore, thermal interactions with the surrounding environment can affect gas dispersion, leading to fluctuations in the concentration detected by the sensor. The implications of these findings are particularly relevant in the context of battery and electrical system applications, where electric current heating of nickel junctions can trigger the release of potentially hazardous gases or indicate material degradation.



(a) (b)

Figure 5. Gas concentration that arises: (a) CO measurement result, and (b) CO_2 measurement result

In addition, microscopic observations were performed to assess structural defects, as shown in Figure 6. The area affected by the weld will likely experience microstructural changes due to exposure to high temperatures. Cracks in the weld result can be attributed to thermal stresses, which arise from uneven expansion and contraction of the material during the cooling process. Based on previous analysis of nickel strip heating due to electric current, this area also has the potential for increased electrical resistance and excessive heat release, which can further exacerbate degradation. In the context of batteries, such cracks are of significant concern, as they can lead to structural failure, high contact resistance, and potential gas release due to unwanted electrochemical reactions.

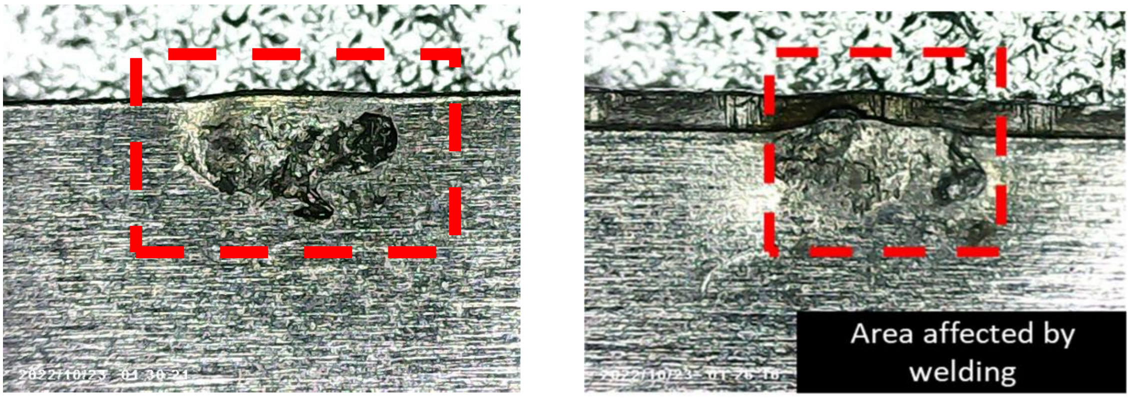


Figure 6. Area affected by 2-point welding

4 Conclusions

The analysis shows a strong correlation between heating due to electrical current, gas release, and structural defects in nickel strips used in battery systems. Localized heating caused by high electrical currents leads to uneven temperature increases, particularly in areas with higher resistance. This releases gases such as CO and CO_2, which have been observed to increase significantly from 2 ppm to 18 ppm for CO and from 360 ppm to 500 ppm for CO_2. This phenomenon indicates potential material degradation due to excessive heating, posing risks to system reliability and safety, especially in battery applications. Additionally, the thermal saturation effect in nickel strips limits further temperature rise after a certain point, yet it can still induce microstructural changes that contribute to material weakening.

Beyond the heating effects, microscopic analysis reveals that the areas affected by welding are prone to microstructural changes and cracks due to thermal stress during the cooling process. These cracks can increase contact resistance, hinder heat dissipation, and ultimately accelerate material degradation. In battery applications, cracks can lead to mechanical failure, oxidation, and gas release due to unwanted electrochemical reactions. Therefore, optimizing the design of nickel connections, both in terms of heat dissipation and welding techniques, is crucial in enhancing battery system performance and safety.

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