Electronics, Communications and Networks
A.J. Tallón-Ballesteros et al. (Eds.)

doi:10.3233/FAIA231198

Recent Advances in Battery Binders with an Insight of Predictive Commercial Development

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Abstract. Binders are a type of material used in batteries to hold the active materials together, forming a stable and functional battery electrode. Binders are typically made from polymeric materials and are used to obtain good mechanical adhesion, descent conductivity, and excellent overall performance. For their commercial development, this review shows the proportion of cathode/anode binders in different battery costs. In addition, aqueous binders have the tendency to gradually replace PVDF binders in the future by taking advantage of their low cost and create considerable output value. In application, as a new binder under the silicon-based anode, polyacrylic acid (PAA) has important advantages in enterprise product development.

Keywords. Binder, battery, commercialization

1. Introduction

With the development and popularization of machine learning, artificial intelligence, and renewable energy technologies, human life has become more convenient [1, 2]. Energy has been an essential pillar of human technological development, and with the development of technology, portable electronic devices have become indispensable tools for people [3]. The battery as the most common energy storage device has an important significance to the performance of electronic devices [4], and the main issue facing the development of energy storage devices is to enhance the energy density, lifetime and efficiency of the battery. Lithium-ion batteries (LIBs) are a widely used and well-developed energy storage device [5], but they have certain limitations in use: lithium ion has a negative impact on the environment and the process of recycling LIBs is complex; LIBs are expensive because lithium is a rare metal; the cycle life is not ideal and lithium batteries have poor electrical conductivity, slow diffusion of lithium ions, and low actual specific capacity when charged and discharged at high rates; the vibrational density of the positive electrode of LIBs is small, with densities generally around 0.8 to 1.3; a large impact on the performance of LIBs at low temperatures can be observed. The zinc ion

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battery (ZIB) is a recently developed energy storage device with high energy density, high efficiency and friendly to the environment [6]. Na-ion batteries (NIBs) are also a recent development, although the technology is not mature [7], and although the efficiency and energy density are not comparable to LIBs, the stability and safety, cost and environmental protection are better than LIBs [8].

The NIBs principle is similar to that of LIBs, relying on Na ions in the cathode and anode transport to maintain work. However, as Na ions are larger than lithium ions, they are heavier and less energy dense than LIBs. The main function of the binder is to physically bond all the electrode materials together and to maintain them in order to ensure efficient electron and ion transportation (see Figure 1). Most of the binders used in LIBs today are Polyvinylidene fluoride (PVDF), a highly non-reactive thermoplastic fluoropolymer made from the polymerisation of vinylidene fluoride. PVDF is a specialty plastic with a low density (1.78 g/cm3) [9], excellent thermal stability (chemical structure stability at 375°) [10] and good chemical inertness [11] and point-interpretation wettability.

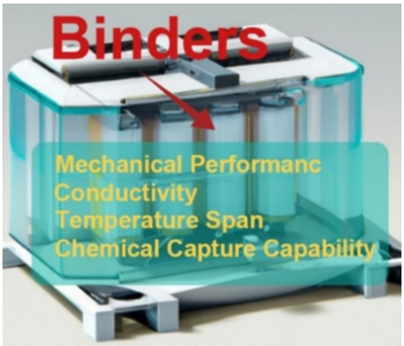

Figure 1. Binder Applied to Cells in Energy Storage Devices Schematic Diagram

2. Functions and Roles of the Binders on Batteries

2.1 Mechanical Performance

The primary objective of binders is to gather electrode materials based on adhesion, which is determined by the interface between the electrode material and the binder material. Silicon-based Li-ion batteries have poor cycling stability due to expansion and pulverization of the Si electrode, leading to a failure of electron conduction and reduction in battery capacity. Mechanical interlocking and interfacial forces can be used to simulate the role of the binder in bonding active material particles and conductive particles. The tensile property of the binder is one of the objectives of the new generation of binder designs [12]. The parameters of tensile strength, elongation at break, modulus of elasticity and elastic limit all describe the tensile properties of the binder. The tensile strength, which characterizes the resistance to maximum uniform plastic deformation of the material reflects the resistance to fracture. If the tensile properties are not excellent enough, it is susceptible to fracture when the electrode volume expands, leading to problems with electrode material cracking, electrolyte depletion, overall cell expansion or shattering of active material particles that seriously affect the life of the battery.

2.2 Conductivity

The ion transfer rate of Li^+ ions in LIBs is crucial [13], and the design of the binder material needs to consider how to improve the conductivity of the ions. Adding units with electrolyte swelling is a simple and effective way to improve ion transfer, but too much swelling can affect the electron mobility and therefore the electron conductivity. Other factors such as polar groups, ionization, the porous structure of the electrode, the high amorphous nature of the polymer, the ability of the electrolyte to absorb ions, and the wettability of the cathodically active material can also influence the diffusion of ions. The efficiency of the electron transfer in a battery is a major issue [14], and conductive agents are essential to enhance the electrochemical activity of the electrodes [15]. However, large volume electrodes undergo significant volume changes during redox reactions [16], and the combination of a conductive agent and binder can reduce the energy density of the battery. Binder materials can be modified by molecular modification, doping, or structural design at the nanoscale to achieve satisfactory electronic conductivity.

2.3 Temperature Span

A binder that is resistant to high temperatures will give the electrode material the ability to maintain a stable reaction even at high temperatures [17]. Low temperatures also influence the life of the battery [18]. At low temperatures, the viscosity of the electrolyte increases, which undoubtedly affects the migration and diffusion of ions, and electrode materials with poor conductivity can be polarized quite readily, reducing the capacity of the battery; for batteries with metal ions forming the cathode, if the battery is not operated for a long time, the metal ions can be prone to form dendrites, affecting the safety of the battery. For batteries with metal ions forming the cathode, if left unused for a long period of time, metal ions can readily form dendrites, affecting battery safety. Moreover, low temperatures can easily cause metal ions that should return to the cathode to precipitate out at the anode (LIBs, ZIBs, etc.), reducing battery capacity.

2.4 Chemical Capture Capability

The chemical structure of a binder is an important consideration for its trapping capacity [19, 20]. PVDF, the commonly used binder material today, is difficult to react with many electrode materials or metal ions without modification, forming covalent or hydrogen bonds for capture [21]. Binders with a certain trapping capacity can improve the cycle life and energy density of cells using electrolytes that readily dissolve active material particles. Chemical interaction, adsorption of cations, nucleophilic substitution, and electrochemical redox conversion are the most effective methods for the capture of polysulfides. The modification of binder materials to give them a variety of properties is the way in which chemical action is used to give the binder the ability to bind to the sulfur.

3. Commercialization of Battery Binder

3.1 Market Space

The market space for binders in different batteries is growing rapidly due to the increasing demand for high-performance and durable batteries in various applications such as electric vehicles, portable electronics, and grid storage [21]. The percentage of binder cost in different batteries is significant to consider with an insight of predictive commercial development from there perspectives [22]. Firstly, economic feasibility. The cost of the binder is a critical factor in determining the economic feasibility of a battery technology and would vary significantly depending on the type of binder used, so this can have an impact on the overall cost of the battery [23]. Scholars can gain insights into the economic feasibility of different battery technologies. Secondly, performance optimization. The binder plays a crucial role in determining the performance of the battery. It affects the adhesion of the active material to the current collector, which in turn affects the battery's capacity, cycle life, and rate capability. By understanding the percentage of binder cost in different batteries, researchers can optimize the binder composition and amount to achieve the desired performance. Thirdly, commercialization potential. Commercialization of battery technologies is highly dependent on their cost-effectiveness, performance, and reliability. This information would assist scholars to gain insights into the commercialization potential of these technologies and help investors and manufacturers make informed decisions about which battery technology to invest in. In particular, this paper analyzes the cost of binders as a percentage of the cost of different batteries, providing insights for stakeholders to gain an overview in this industry.

Specifically, cathode binder accounts for about 1.4%-1.65% of the cost of ternary Batteries. The cost of a single GWh ternary battery is 1.75-2.06 million dollars after using imported materials, with the current cost of cathode binder accounting for 1.4-1.65%. Binder cost in China is slightly lower but is still dominated by imported materials. Secondly, cathode binder accounts for about 2.2%-2.5% of the cost of lithium iron phosphate batteries. The current single GWh lithium iron phosphate battery consumes 2200-2500 tons of lithium iron phosphate cathode material and adds imported PVDF about 1%. The use of PVDF binder in China is 33-37 tons, with a cost of 2.26-2.58 million dollars. Lithium PVDF use is still dominated by imported materials. Thirdly, anode binder accounts for about 1.07%-1.37% of the battery cost. The current anode binder mainly uses a combination of CMC and SBR, and the current consumption of artificial graphite material used in single GWh battery is 950-1000 tons. The cost of imported materials is 9.12-9.6 million yuan, while the cost of using materials is significantly lower in China, with the possibility of substitution. Fourthly, binder accounts for 2.47%-2.78% of the cost of ternary batteries and 3.5%-3.87% of lithium-iron phosphate batteries. The current material cost measurement is based on imported materials, with existing imported binder accounting for 2.47%-2.78% of the ternary battery cost and 3.5%-3.87% of the cost of lithium iron phosphate batteries in China.

3.2 Aqueous Binder: Substitution in China and Technology Iteration

Aqueous binders have the potential to meet the increasing demand for sustainable and environmentally friendly energy storage solutions [24]. It indicates that aqueous binder is a suitable alternative to PVDF binder because PVDF has risk of reproductive toxicity, so material companies and battery companies are developing cheaper, more environmentally friendly, equally good performance aqueous binders. At the same time, aqueous binder has lower cost with a high possibility of substitution compared with PVDF binder. Specifically, poly tetra fluoroethylene (PTFE)/ polyacrylic acid (PAA) is lower than PVDF for single GWh battery cost, providing incentive for battery factories to adopt it. PTFE is only suitable for moderate-to-low voltage environment, and the use of PAA battery initial capacity is lower than PVDF. Therefore, the aqueous binder is more suitable for most LIBs and/or energy storage. For example, carboxymethyl cellulose (CMC) and styrene butadiene rubber (SBR) anode binder in China has been applied to EV lithium battery with higher substitution potential. According to Green Global International Inc (GGII) data, the localization rate of CMC/SBR was less than 5% in 2017, and the current localization rate is less than 10%, so there is much room for substitution in China.

The output value of aqueous cathode binder technology iteration can have a significant impact on the energy storage industry. Aqueous cathode binder technology iteration of the 2025 output value space may reach $50 million. The output value space of aqueous binder such as PTFE under the new binder technology is 1500-14,500 tons and 57.29-438 million dollars in 2023 and 2025. Furthermore, market demand for Chinese CMC and SBR material will be over $400 million. The output value of graphite anode binder pastes in 2023 and 2025 will be 114 and 406 million dollars respectively.

4. Conclusion and Outlook

In conclusion, recent advances in battery binders have shown promising results in enhancing the performance and durability of batteries, especially in the field of electric vehicles and grid-scale energy storage. Binder materials play a crucial role in maintaining electrode integrity, facilitating ion transport, and preventing undesired side reactions. The selection of the appropriate binder material is therefore critical in designing high-performance batteries for various applications.

However, the commercialization of advanced binder technologies still faces several challenges, including high production costs, scalability issues, and the need for further optimization and testing. To overcome these challenges, it is essential to establish closer collaborations between academia, industry, and government agencies to facilitate the development and commercialization of advanced binder technologies.

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