



Hydrogen storage properties of $\text{TiMn}_{1.5}\text{V}_{0.2}$ -based alloys for application to fuel cell system

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ABSTRACT

To meet the requirements of fuel cell power system for electric bike, the influence of partial substitution of Zr and Cr on hydrogen storage performance of $\text{TiMn}_{1.5}\text{V}_{0.2}$ -based alloys is investigated first, and a hydrogen storage tank is then built using the developed $\text{TiMn}_{1.5}\text{V}_{0.2}$ -based alloy as metal hydride bed and its hydrogen supply ability is further evaluated. It is found that for $\text{TiMn}_{1.5}\text{V}_{0.2}$ -based alloys, the Zr substitution for Ti effectively reduces the plateau pressure but increases the plateau slope, while the partial substitution of Mn by Cr decreases the absorption plateau pressure, leading to a smaller hysteresis factor. After the optimization of components, 6 kg of $\text{Ti}_{0.95}\text{Zr}_{0.05}\text{Mn}_{1.4}\text{Cr}_{0.1}\text{V}_{0.2}$ alloy powder with 5 wt.% aluminum foam is mixed uniformly to form a metal hydride bed inside the tank. The measurements show that the tank releases up to 82 g of hydrogen to produce a 200 W fuel cell output for 300 min and has a stable cyclic capacity, indicating that hydrogen storage system of $\text{TiMn}_{1.5}\text{V}_{0.2}$ -based alloys for fuel cell power system of electric bike is applicable.

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1. Introduction

In the last two decades, electric bikes and scooters (for short: E-bikes) have attracted intense attention, due to their low energy consumption and zero tail-pipe emissions [1,2]. More than 90% of E-bikes are driven by valve-regulated lead acid (VRLA) batteries. However, low energy density and environmental issues of VRLA batteries block its development as mobile power systems in the future [2]. This has in turn led to increasing interest in fuel cell powered E-bike, which is expected to offer higher energy density and meet the growing demand for environmentally clean fuels.

At present, on a fuel cell powered E-bike for sale, fuel cell power system mainly consists of high pressure tank and fuel cells. Compared with the high pressure hydrogen, hydrogen stored in metal hydride is regarded as having more potential for mobile applications owing to its advantages in safety and reliability [3–7] and become one of the most powerful technology barriers to the widespread acceptance of hydrogen as an energy vector for automotive applications [8–11]. Recently, metal hydride tanks filled with the conventional AB_5 -type intermetallics [12–14], alanates [15,16] or MgH_2 [17] were prepared and investigated for use as hydrogen sources for proton exchange membrane fuel cells

(PEMFC). Several numerical and experimental studies have been reported and focused on improving the structure inside metal hydride tanks to enhance heat and mass transfer properties. By contrast, direct experimental studies on the hydrogen storage performance of metal hydride beds are rarely reported. The metal hydride bed formed by AB_5 -type intermetallics provides low hydrogen yield (about 1 wt.%) and that formed by alanates or MgH_2 release hydrogen at a high temperature of 473–573 K, suggesting that a new materials should be developed to form metal hydride beds to meet the requirements of fuel cell power system at room temperature (RT).

Substoichiometric $\text{TiMn}_{1.5}$ -based Laves phase alloys are more promising metal hydrides to manufacture the metal hydride bed, due to their high hydrogen storage capacity at RT, easy activation and relatively low cost [18–24]. However, poor plateau characteristics are the stumbling blocks to their development as hydrogen sources for fuel cell systems [25,26]. To overcome these shortfalls, the partial substitution for Ti or Mn was attempted. For example, the hydrogen absorption capacity of $\text{Ti}_{1-x}\text{Zr}_x\text{Mn}_\alpha$ ($1.4 \leq \alpha \leq 1.9$, $0.05 \leq x \leq 0.4$) increased with enhancing Zr content, but the desorption capacity reached its maximum with $x = 0.1$ [18,27]. In the case of partial substitution for Mn, the plateau pressure of $\text{TiMn}_{\alpha-y}\text{M}_y$ alloys ($1.3 \leq \alpha \leq 1.5$, $0.1 \leq y \leq 0.5$, $\text{M} = \text{Cu, Co, Fe, Ni, V, Cr}$) increased when Mn was replaced by Cu, Co or Fe, but decreased when replaced by Ni, Cr or V [18,19]. Moreover, multicomponent alloys such as $\text{TiMn}_{1.25-x}\text{Cr}_{0.25}\text{V}_x$ ($x = 0, 0.2, 0.3, 0.4, 0.5$) [28], $\text{TiV}_{0.6}\text{Fe}_{0.15}\text{Mn}_{1.3}$

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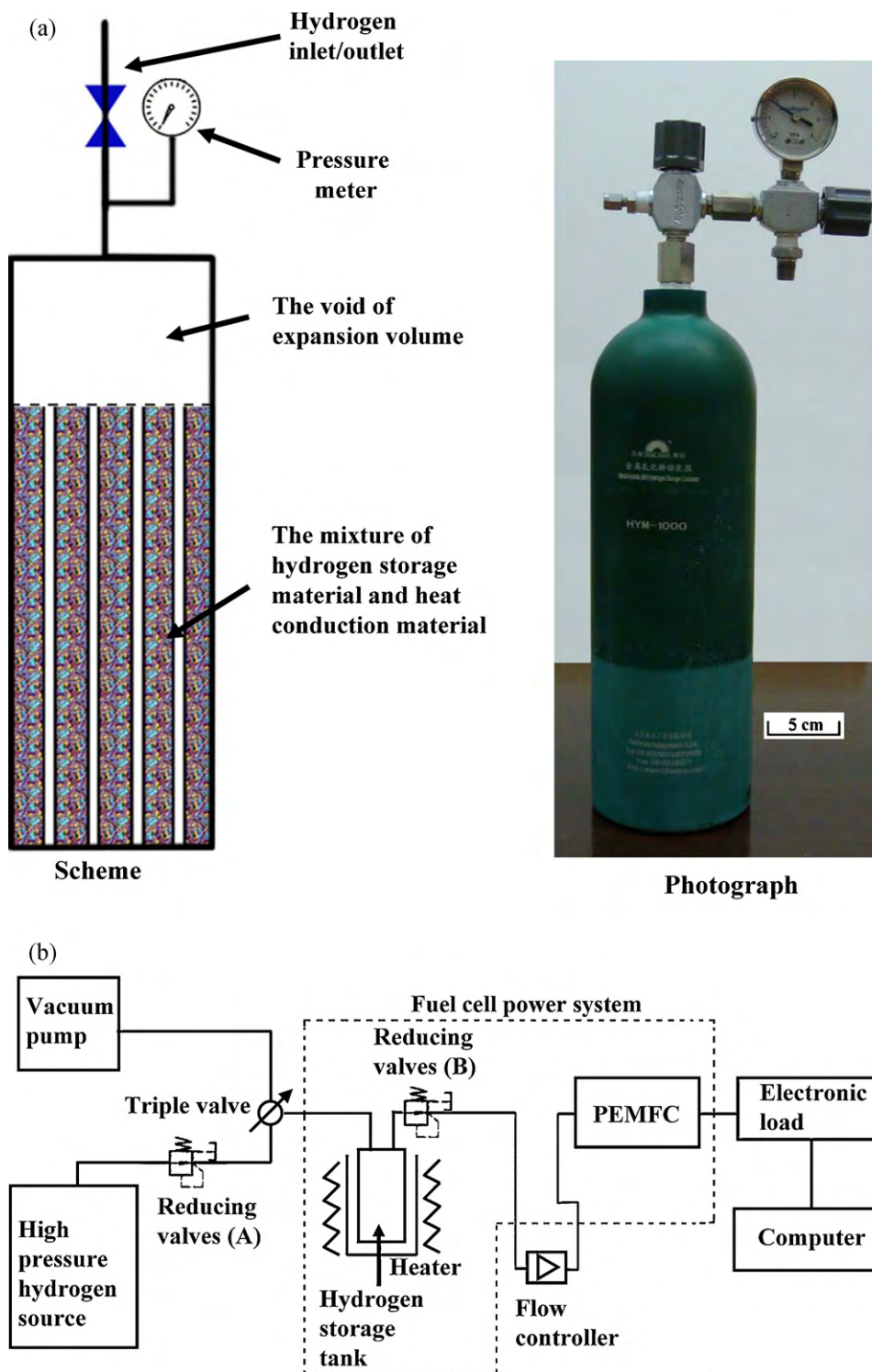


Fig. 1. The simplified scheme and photograph of the hydrogen storage tank (a) and the schematic diagram of the test bench associated with the fuel cell system (b).

[29] and $T_{0.95}Zr_{0.05}Mn_{1.45}M_{0.5}$ ($M = V, Cr, Mn, Co, Ni, Al$) [24] were also prepared to improve the hydrogen storage performance. Nevertheless, it is noticed that previous work on the $TiMn_{1.5}$ -based alloys was performed mainly in laboratory, but the reports about practical application, such as their use as hydride beds in hydrogen storage tanks for automotive applications, was rather limited [30]. It is significant to adjust hydrogen storage performance of $TiMn_{1.5}$ -based alloys, following the demands of fuel cell power systems.

Previous work on $TiMn_{1.5}V_x$ [31] showed that $TiMn_{1.5}V_{0.2}$ alloys presented a single C14 Laves phase and had a maximum hydrogen storage capacity of 1.54 wt.% at 313 K among $TiMn_{1.5}V_x$ ($x = 0-0.5$). Considering this fact, in the present work, the influence of partial substitution of Ti by Zr and Mn by Cr in $TiMn_{1.5}V_{0.2}$ alloy was investigated systematically to develop a suitable material for metal hydride beds. Based on the experimental results obtained, a hydrogen storage tank was prepared using the $Ti_{0.95}Zr_{0.05}Mn_{1.4}Cr_{0.1}V_{0.2}$ alloy as a metal hydride bed and its hydrogen supply ability as

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