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Development of an actuation system to apply hydrogen storage alloy for the rehabilitative system

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Abstract.
BACKGROUND: Hydrogen has advantages that can be used as energy, but research on safe use is needed.
OBJECTIVE: In this study, an actuation system for rehabilitation is developed to drive the actuator using hydrogen storage alloy and to analyze the hydrogen release characteristics of the alloy.
METHODS: The system is automatically control and report the pressure, temperature and hydrogen flow using LabVIEW-based modules and LabVIEW software. $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ alloy was selected as hydrogen storage alloy. 5 MPa of hydrogen pressure was applied at 8.56 g of alloy powder for activation process and the temperature outside was maintained at 19°C to 21°C. The amount of hydrogen absorption was measured about 1.47 wt%. The actuation test was conducted at the temperature from 25°C to 80°C, increased by every 5°C. The actuation height was measured at each load of 5, 10, 15, and 20 kg. The voltage and current which is applied to peltier elements were set to 5.0 V and 2.5 A. The pressure changing in the system was checked for 5 min for each temperature, however, if the temperature at which the pressure inside the system changed, the time to heat the module was increased to 20 min. Hydrogen was first released at 70°C.
RESULTS: The loads of 5 and 10 kg were raised by 87 and 19 mm at 70°C, respectively. At 75°C, loads of 5, 10 and 15 kg were raised by 131, 70, and 15 mm, respectively. At 80°C, 5, 10, 15, and 20 kg were raised by 150, the end of the actuator, 83, 55, and 28 mm, respectively.
CONCLUSIONS: The actuation system in this paper can be applied to assistive device and rehabilitation system for assisting the movement of daily life of the elderly or people with disability.

Keywords: Hydrogen storage alloy, actuation system, rehabilitative system, $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$

1. Introduction

Hydrogen has much advantages as future energy. However, since hydrogen is a highly flammable

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material, continuous research on various technologies to safely storage and utilize hydrogen is needed. Using the hydrogen storage alloy has the advantage that the hydrogen storage alloy can compress 1000 times the initial volume safely and stored it at a very high density compared to the liquid or gaseous hydrogen storage methods. It can also be used by releasing the stored hydrogen adjusting the temperature and pressure. Using hydrogen storage alloys with these characteristics has attracted attention as this technology can be used in mobile distributed power sources due to the low operating pressure compared to other storage methods and has high consumer acceptance when used indoors [1–3]. The studies using hydrogen storage alloy as a driving source are outlined below.

Madaria used $La_{0.8}Ce_{0.2}Ni_5$ alloy for comparative analysis of hydrogenation and heat transfer efficiency of hydrogen storage alloy according to its charging method and types, such as hydrogen storage alloy powder and pellet inside a hydrogen compressor [4]. Obara used LaCeNiCoMn alloy in the development of a solar tracking system that can control the angle of solar panels with two metal hydride (MH) actuators [5]. Some researches on the development and utilization of hydrogen storage alloys as actuators are outlined below.

Ino used carbon fiber, aramid pulp, and $LaNi_5$ powder to develop a MH paper for use in soft actuator systems and analyzed its material and dynamic characteristics [6]. Sato used $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ alloy to develop a portable rescue tool that can be used to rescue survivors during disasters by temporarily raising collapsed building debris [7]. Jeon developed an SMH actuator using a peltier element and studied its temperature-pressure characteristics using $Zr_{0.95}Ti_{0.05}Fe_{1.4}Cr_{0.6}$ alloy [8]. Yan performed heat transfer analysis of hydrogen storage alloy modules for actuation system [9].

The actuation system using hydrogen storage alloy has been applied to the development of rehabilitation system for the daily life of the elderly because of the high power of the compact device. Hosono et al. measured lower-extremity blood flow during passive motion of the toe to design new rehabilitation equipment which is applying the soft MH actuator to toe joints for the purpose of preventing disuse syndrome, contractures, edema and bedsores [10,11]. Ino developed CPM machine for a finger joint using metal hydride actuator that includes a small metal bellows [12]. Ino and Sato designed an elbow CPM machine using a pair of metal or laminate film bellows [13]. Existing rehabilitation systems using hydrogen storage alloys use only mechanical movements due to the movement of hydrogen gas, but studies on measuring the exact flow rate of hydrogen are insufficient. Accurate flow measurement of hydrogen is necessary to assist the daily life of the elderly and the disabled. In this study, an actuation system for rehabilitative system was developed to drive the actuator using hydrogen storage alloy and to analyze the hydrogen release characteristics of the alloy.

2. System configuration

2.1. Actuation system

In this study, hydrogen was desorbed and absorbed by heating and cooling by two of peltier elements in the hydrogen storage alloy module with hydrogen storage alloy, whose performance was evaluated by the actuator. Figure 1 shows the block diagram of the hydrogen storage alloy actuation system. V1-8 and S1-4 are the valves to regulate the flow of hydrogen, and S1-4 is a pneumatic solenoid valve that can be automatically opened and closed using nitrogen. As the flow direction of hydrogen changes, pneumatic valves are used to accurately check and integrate the flow rates for each heating and cooling state. Figure 1a is Control panel, which contains several modules and control PCBs, and system controlled by LabVIEW program. Figure 1b is actuator, and the diameter of actuator (TPC Mechtronics Corp., Korea)

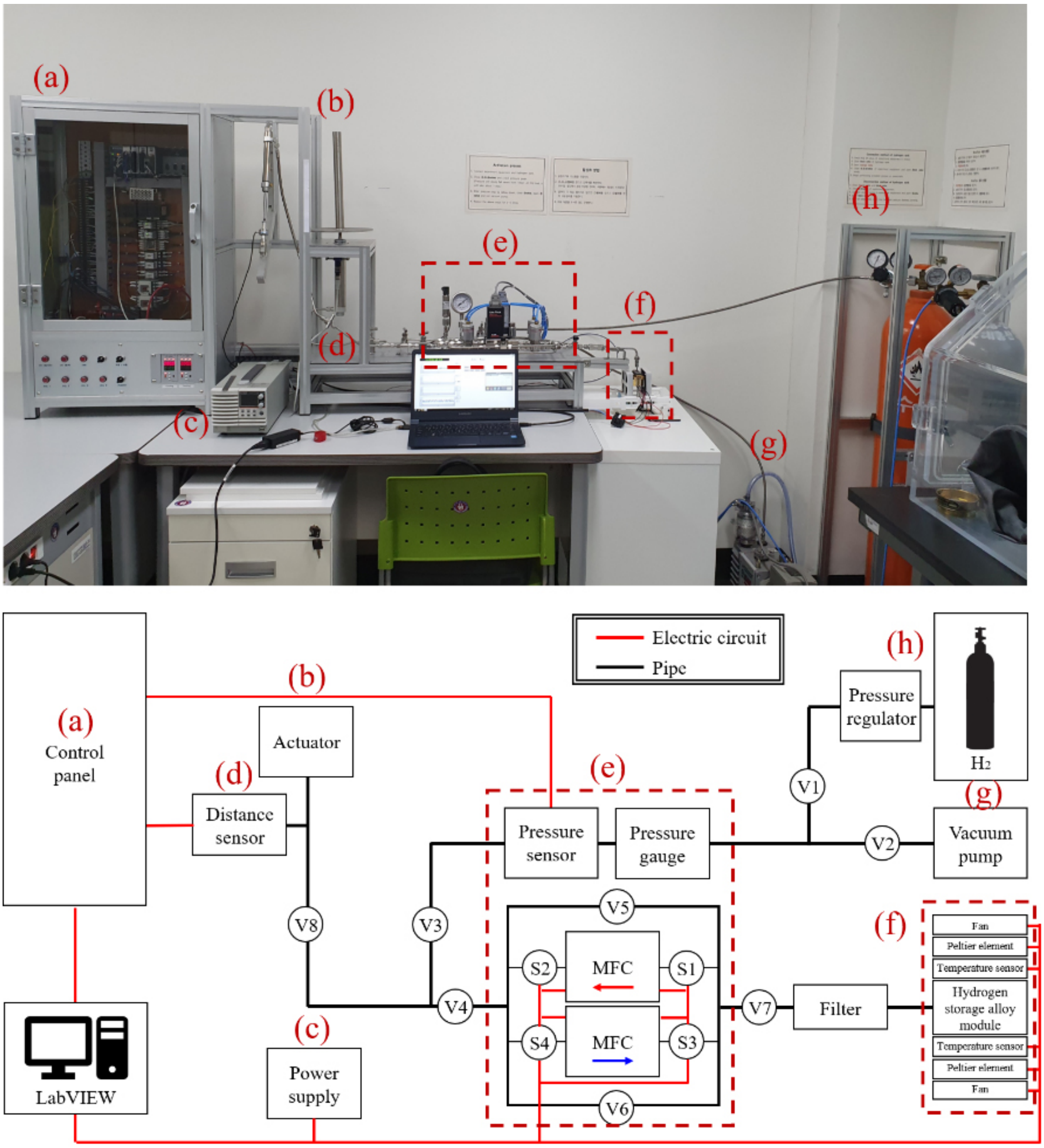

Fig. 1. Hydrogen storage alloy actuation system and block diagram of whole system; (a) Control panel, (b) Actuator, (c) Power supply, (d) Distance sensor, (e) Pressure and flow control part, (f) Hydrogen storage alloy module, (g) Vacuum pump, (h) Pressure regulator and hydrogen bomb.

is 32 mm, and strokes is 150 mm. Power supply was used PSW 80-27 (GW Instek, Taiwan) (Fig. 1c). Distance sensor was used US18-PA-5-NO3-VH (Datalogic, Italy) (Fig. 1d). Figure 1e is “Pressure and flow control part,” and Fig. 1f is “Hydrogen storage alloy module”. Vacuum pump was installed with

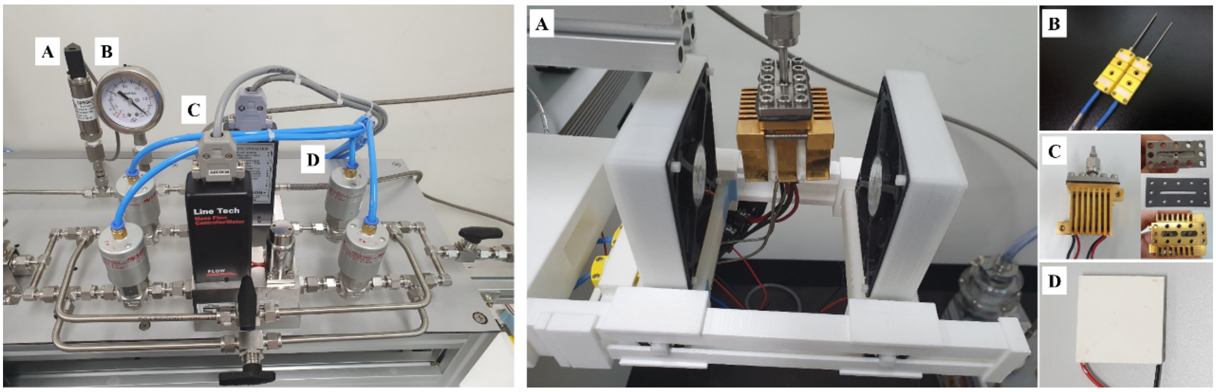

Fig. 2. (a) Pressure and flow control part; A-Pressure sensor, B-Pressure gauge, C-Mass flow controller (MFC), D-Pneumatic solenoid valves; (b) Hydrogen storage alloy module; A-Hydrogen storage alloy module part, B-Temperature sensor, C-Hydrogen storage module, D-Peltier elements.

GHP-150K (Kodivac, Korea) and pressure regulator was used YR-5061 (Yamato Sangyo Co. Ltd., Japan) (Fig. 1g and h).

2.2. Pressure and flow control

Figure 2a is ‘Pressure and flow control part’. Two different mass flow controllers can be used to control the amount of hydrogen entering the hydrogen storage alloy and the amount of hydrogen flowing out of the hydrogen storage alloy. A pressure sensor (OMEGA, USA) and a pressure gauge (SIGMA Tech, Korea) were used to continuously check the pressure inside the system. Two different MFCs (Linetech, Korea) and four pneumatic solenoid valves (Hy-Lok, Korea) were used to control the amount of hydrogen entering and flowing out of the hydrogen storage alloy.

2.3. Hydrogen storage alloy module

Figure 2b shows the hydrogen storage alloy module part. In hydrogen storage alloy module part, two temperature sensors (OMEGA, USA) check and control the temperature of the module and peltier elements (Wellen, China) change temperature of the module. The module consisted of module cover, sealing pad, peltier elements and power charging unit which is made of copper. The module cover distributes hydrogen gas in the two holes of hydrogen storage alloy power charging part. Sealing pad was made of 1 mm thick of teflon to prevent gas leakage. Besides, a hydrogen channel was inserted in order to shorten the activation time and increase the efficiency of hydrogen storage alloy. When the peltier element heats the module, hydrogen is released from the alloy in the module. Subsequently, when the peltier element and Fan cools the module, hydrogen is absorbed back into the alloy.

2.4. System control program using LabVIEW

Figure 3a is a block diagram of the VIs placed to control the system by selecting either control mode or auto mode. In control mode, power, heating/cooling mode, fans, solenoid valves can be turned on/off by the button on the front panel. In auto mode, it is designed to automatically control the entire system according to each condition by selecting either time mode or temperature mode. When the heating/cooling mode is changed, the direction of the DC voltage is reversed and it reverse a heating/cooling function

Table 1
Automatic change of device setting by changing mode (heating/cooling)

Mode		Power	Voltage	Fans	Solenoid valves			
					Sol 1	Sol 2	Sol 3	Sol 4
Auto mode	Heating	On	Forward	Off	On	On	Off	Off
	Cooling		Reverse	On	Off	Off	On	On

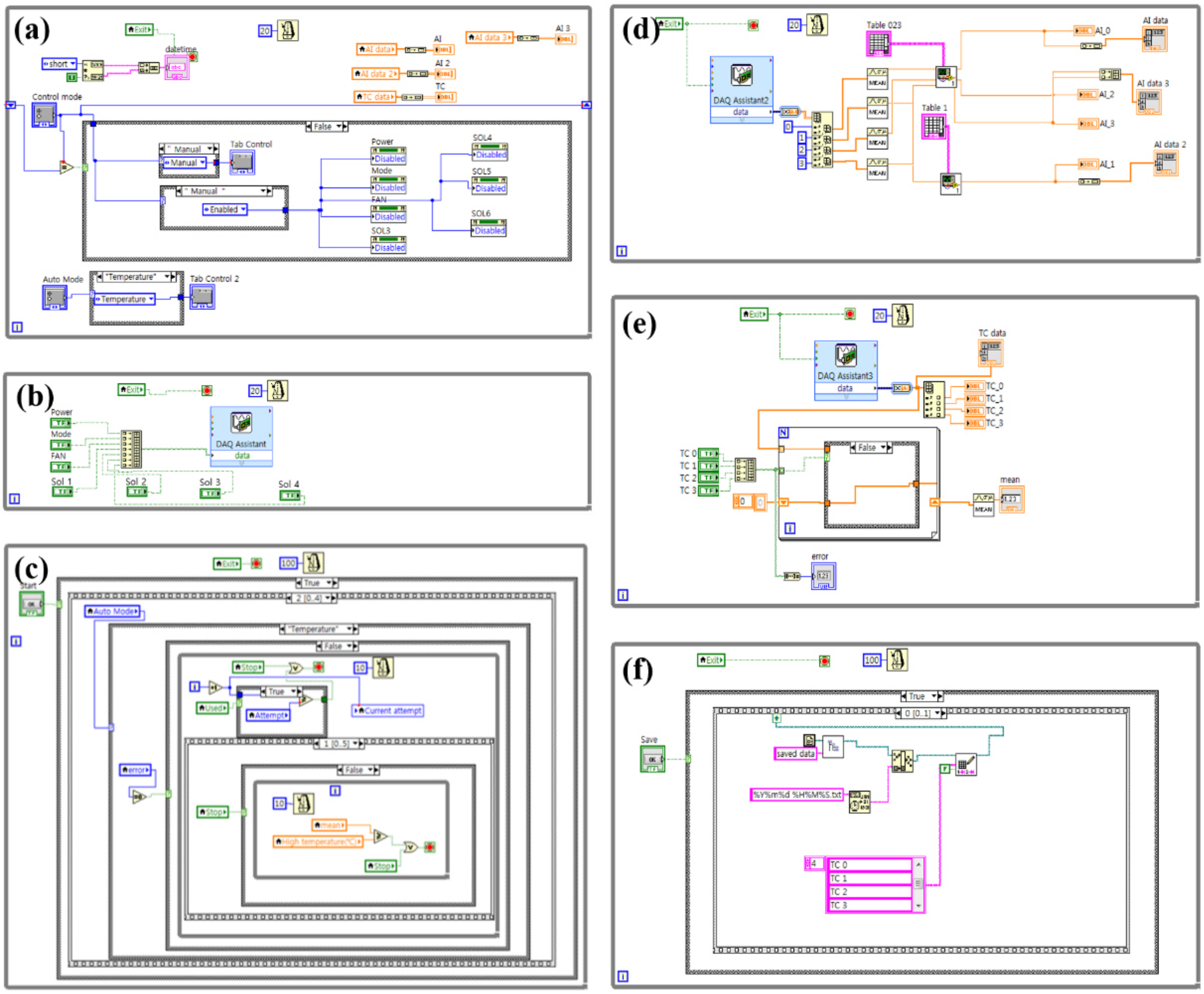

Fig. 3. (a) Block diagram for auto controlling all the functions, (b) Controlling power and fans on/off, heating/cooling mode change and solenoid valves open/close, (c) Block diagram of saving sensor values automatically, (d) Sensing values of pressure, load, and flow change, (e) Sensing value of the temperature change, (f) Block diagram of saving sensor values automatically.

of the peltier element in the hydrogen storage alloy module as shown in Table 1. Figure 3b is a block diagram created using the DAQ of digital output module (NI 9472), which controls on/off power and fans, heating/cooling mode switching, and opening/closing of the solenoid valves when in control mode. In this study, NI 9427 was used to turn on/off or change the applied mode of the connected device.

Figure 3c shows a block diagram that can control the system according to time/temperature mode when in auto mode. In time mode, heating and cooling times can be set, and in temperature mode, high and low

(a) (b) (c) (d)

Fig. 4. Powdering stage of the hydrogen storage alloy; (a) Hydrogen storage alloy, (b) Grinding, (c) 75 and 180 sieves, (d) Hydrogen storage alloy powder.

temperatures can be set. The heating/cooling mode is automatically changed if the average temperature, reaches high or low temperatures. Figure 3d shows a block diagram created using the DAQ of an analog input module (NI 9221). Through this block diagram, graphs of the values detected from the pressure sensor, load cell, and MFC are displayed on the front panel. Figure 3e shows a block diagram created using the DAQ of a temperature input module (NI 9211). The values sensed from a temperature sensor is sent by NI 9211. The average of the selected values from the measured temperature is displayed on the front panel. Figure 3f is a block diagram of the VIs placed to automatically save the measured sensor values in the Notepad program.

3. Material characterization

3.1. Preparation of the hydrogen storage alloy

$Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$, a Zr based alloy, was selected for the test run of this system. The alloy is easily activated at room temperature without a separate heat treatment process. It would be easy to use it in real life because of the not much high operating temperature. In addition, it was considered as it takes low cost compared to hydrogen storage alloys using other rare earths, such as La-based. Japan Metals & Chemicals Co. Ltd. (Japan) manufactured the hydrogen storage alloy which is used in this research using the arc melting technique. 41.83 Wt% of $Zr_{0.9}$, 2.44% of $Ti_{0.1}$, 15.90% of $Cr_{0.6}$, 39.83% of $Fe_{1.4}$ were requested for producing hydrogen storage alloy. Initially, the alloy without any action, was ground inside the glove box using grinders as shown in Fig. 4. Next, the sieving of the powdered alloy was performed using sieves with openings of 75 and 180. In the case of too small powdered alloy, the hydrogen storage alloy capacity was reduced. Thus, the experiment was performed by inserting into a module for hydrogen storage alloy a powder of $75 > x > 180$.

3.2. Characteristics analysis

3.2.1. HRXRD (high-resolution X-ray diffraction)

In this study, HRXRD (Empyrean, Malvern Panalytical, England) analysis was performed to determine if $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ was formed as a single phase and the type of crystal. As a result of the measurement, it was confirmed that a and b correspond to 5.0060 Å and c does not match 8.1930 Å, as shown in Table 2.

Table 2
Crystallographic parameters of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$

	a (Å)	b (Å)	c (Å)	α (°)	β (°)	γ (°)
$Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$	5.0060	5.0060	8.1930	90.0	90.0	120.0

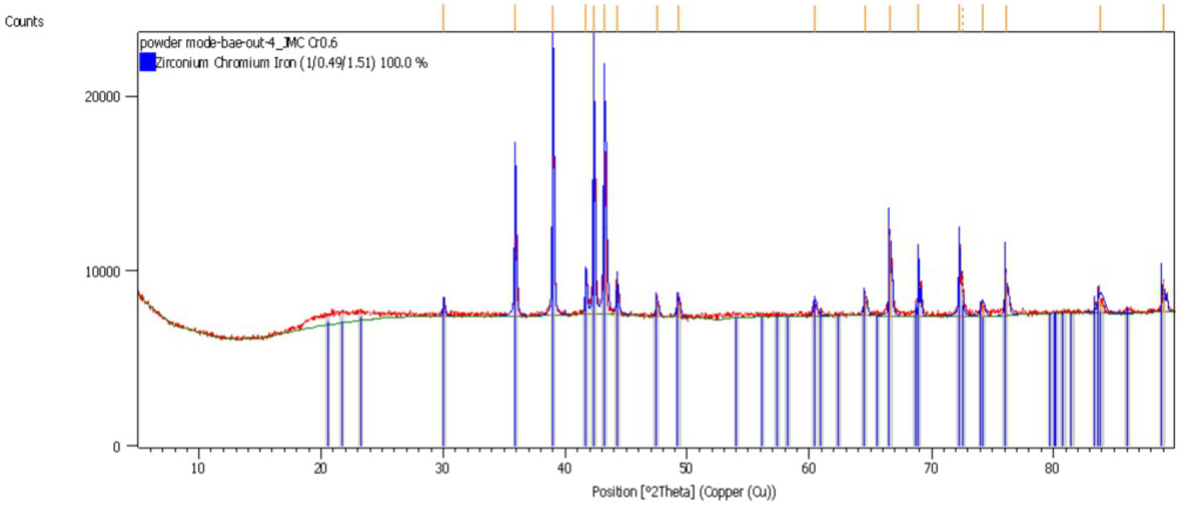

Fig. 5. HRXRD result of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$.

The α and β values were 90.0° and γ value was 120°, indicating that the alloy had hexagonal structures. In addition, it was confirmed that the Zirconium Chromium Iron ($Cr_{0.5}Fe_{1.5}Zr_1$) and the HRXRD measurement value match. It is considered that the wt% of Ti contained in the production was extremely fine and was not measured by the present measurement equipment, and the wt% of Cr and Fe also showed a slight difference. The HRXRD measurement of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ is shown in Fig. 5.

3.2.2. FE-SEM (field-emission scanning electron microscope)

In this study, FE-SEM and EDS mapping were measured to confirm the surface composition of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$. The alloy was measured four times, respectively, and the average value, with exception of the highest and the lowest, was obtained. The original wt% of Zr, Ti, Cr, Fe was 41.83%, 2.44%, 15.90%, and 39.83%, respectively, and the average wt% of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ for Zr, Ti, Cr, Fe were 40.73%, 2.40%, 16.37%, and 40.62%, respectively (Table 3). The composition ratio of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ was found to be slightly different from the previously planned values (Table 4). Figure 6 shows the EDS mapping result of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ alloy. It was confirmed that Zr, Ti, Cr, and Fe are uniformly distributed in the alloy.

3.2.3. ICP-OES (inductively coupled plasma optical emission spectrometry)

In this study, ICP-OES was performed to analyze the quantitative determination of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ for each constituent metal. The results are shown in Table 5. A total of three analyzes were performed, and the average values were calculated and compared with the wt% of each metal used when the alloy was manufactured. Since wt% of each metal showed similar values, it could be confirmed that the samples were uniformly distributed without aggregation. In the 1st trial, the Zr value was about 1% different from

Table 3
FE-SEM/EDS mapping result of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$

Element		Zr	Ti	Cr	Fe
1st trial	Wt%	41.01	2.43	15.95	40.61
2nd trial	Wt%	40.45	2.36	16.56	40.62
3rd trial	Wt%	41.13	2.18	16.18	40.51
4th trial	Wt%	38.64	2.44	16.82	42.09
Average	Wt%	40.73	2.40	16.37	40.62

Table 4
Difference between average measurement value (wt%) with original value (wt%)

	Element	Average (%)	Difference (%)
$Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$	Zr	40.73	1.10
	Ti	2.40	0.04
	Cr	16.37	−0.47
	Fe	40.62	−0.79

Table 5
ICP-OES analysis result of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$

	Zr	Ti	Cr	Fe	Sum
Average	41.28%	2.73%	17.34%	43.53%	104.88%
1st trial	40.50%	2.72%	17.37%	43.78%	104.37%
2nd trial	41.83%	2.72%	17.32%	43.36%	105.23%
3rd trial	41.52%	2.74%	17.32%	43.45%	105.03%

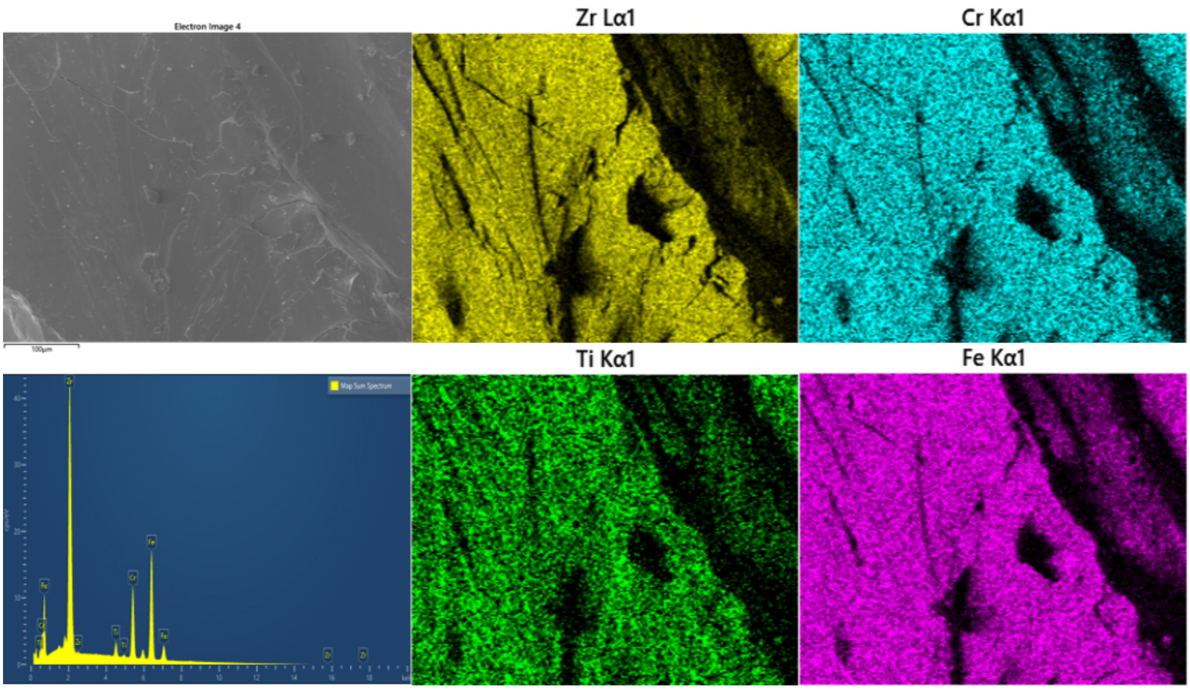

Fig. 6. FE-SEM and EDS mapping of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$.

the 2nd and 3rd values, and the Cr and Fe values were 1.44% and 3.7% different from the original values, respectively. However, as the total sum exceeds 4.88%, the difference is not large considering the error value.

3.2.4. Hydrogen absorption kinetics

Hydrogen absorption kinetics is a measure of the amount of hydrogen adsorbed by a hydrogen storage alloy at a certain pressure. The process of removing vacuum gas for 3 min at room temperature, introducing hydrogen gas of 1 MPa and maintaining for 1 min was repeated five times. This is a process for replacing the alloy with hydrogen gas. After that, the activation process was started. After vacuum degassing at room temperature for about 30 to 60 min, high pressure hydrogen was added to the sample and left until there was no pressure drop in the system. The vacuum gas removal treatment herein refers to a process for decomposing the metal hydride phase and returning it to the metal phase (hydrogen solid solution phase) by maintaining the pressure of the sample container at 1 kPa or less for several minutes. Thereafter, the reaction rate was repeatedly absorbed and desorbed at a temperature to measure the amount of hydrogen storage to speed up the reaction rate and stabilize the absorption and desorption properties. As a method for measuring the amount of hydrogen storage, vacuum origin was used. This is a method of absorbing hydrogen at the pressure to be measured to the activated sample and leaving it until the pressure inside the system shows an equilibrium value. The amount of hydrogen storage is obtained by calculating the percentage change in the weight percentage of the alloy (wt%) or the atomic ratio and the amount of change between the hydrogen and the alloy. In this study, the hydrogen storage in 4 MPa was measured using activated $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ alloy. The amount of hydrogen storage of this alloy was assisted by the Korean Institute of Energy Research. The measurement results are described in Section 5.

4. Actuation test

The activation treatment involved removal of oxides formed inside the powdered hydrogen storage alloy and solid-state storage of hydrogen on the hydrogen storage alloy loaded inside the module, so that hydrogen could be desorbed from the hydrogen storage alloy when heat was applied [14]. The hydrogen storage alloy was activated under 5 MPa pressure of hydrogen gas (room temperature was 19–21°C) and the activation process was repeated for 4 times. A movement of hydrogen in this system is shown as Fig. 7a. The actuation test is performed by controlling the temperature of hydrogen storage alloy module loaded with activated hydrogen storage alloy. Hydrogen in system is releasing from alloy and absorbing to alloy according to temperature of module which is shown as Fig. 7b. Before starting actuation test, all the hydrogen and other gases remaining inside the system besides the module is discharged to outside of system using vacuum pump. After that, opened the V3, V4, V7, V8 and closed the V1, V2, V5, V6, V9. The voltage and current of the power supply were set to 5.0 V and 2.5 A, respectively, and a 5 kg weight was placed on the actuator. Then, the LabVIEW control was changed to auto mode and set to temperature mode. The module was heated by applying electrical stimulation to the peltier device at 25°C to 80°C at 5°C intervals for 5 min. Next, the time to heat the module was increased to 20 min from the temperature at which the pressure inside the system changes to confirm the hydrogen release reaction. Finally, the actuation stroke was measured by increasing the load every 5 kg from 5 kg to 20 kg for each temperature at which hydrogen was released.

5. Results and discussion

The activation of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ alloy for this study was performed once, and the presence of

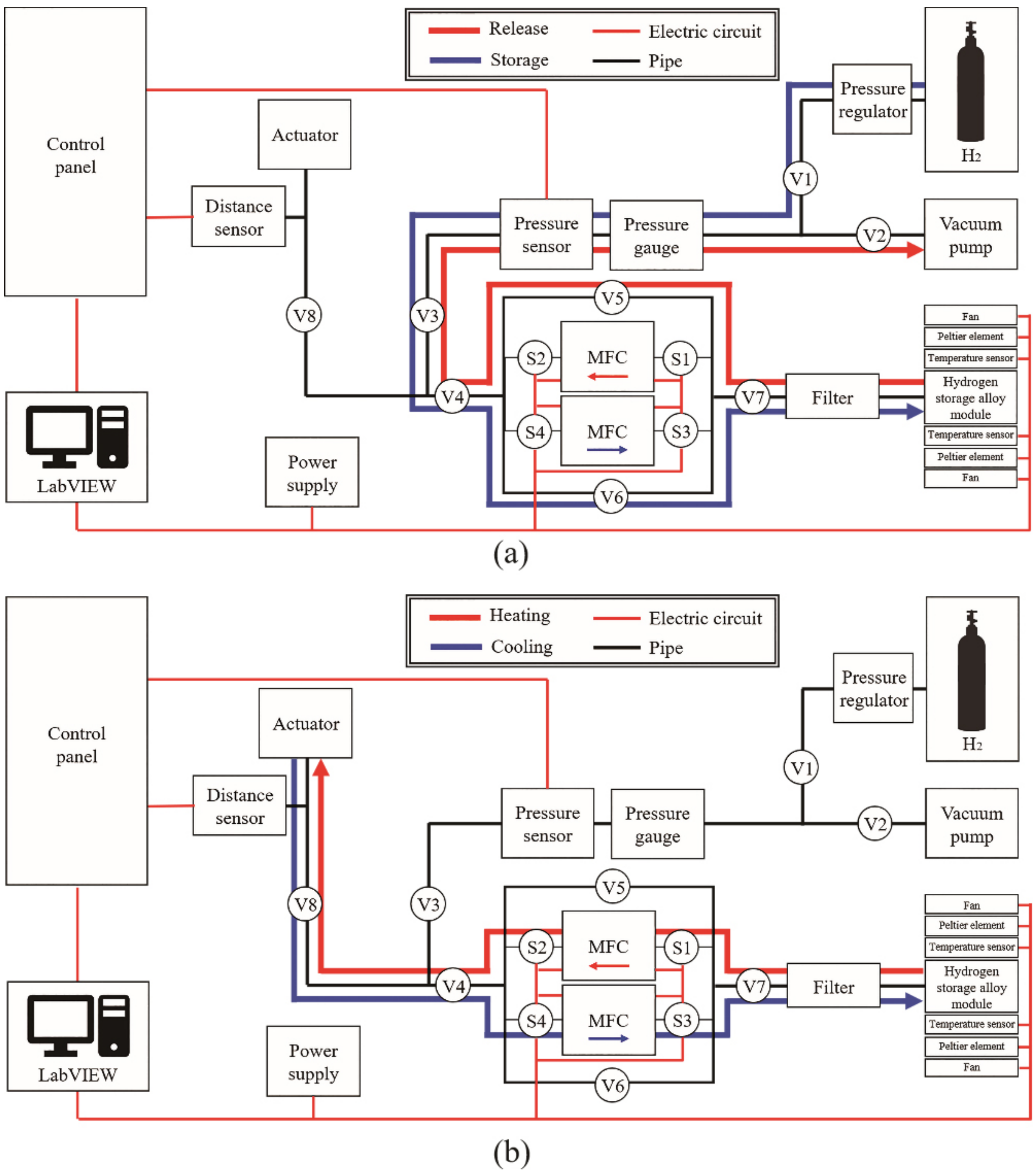

Fig. 7. Movement of hydrogen in hydrogen storage alloy system: (a) Activation process, (b) Actuation test.

vacuum was applied by applying hydrogen pressure of 5 MPa inside the system for 6 hours before starting the activation. The alloy used had a mass of 8.56 g. In this study, the amount of hydrogen adsorption was analyzed using the activated samples. Park measured an occlusion amount of the $Zr_{1-x}Ti_xCr_{1-y}Fe_{1+y}$

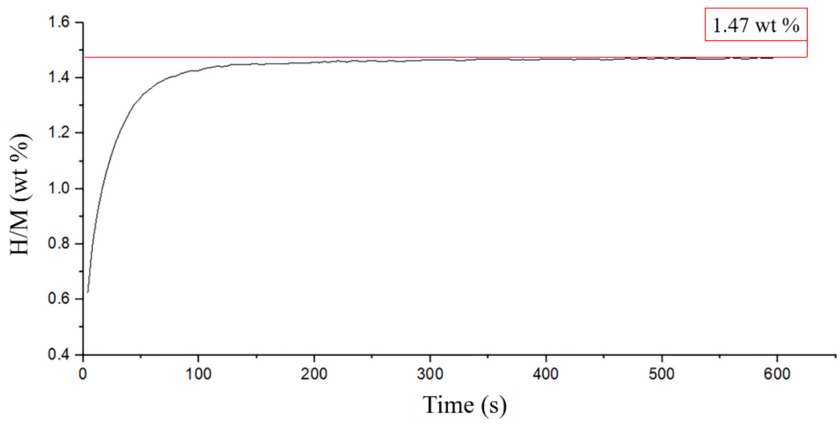

Fig. 8. Curve of hydrogen absorption kinetics of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ (20°C, 5 MPa of H_2).

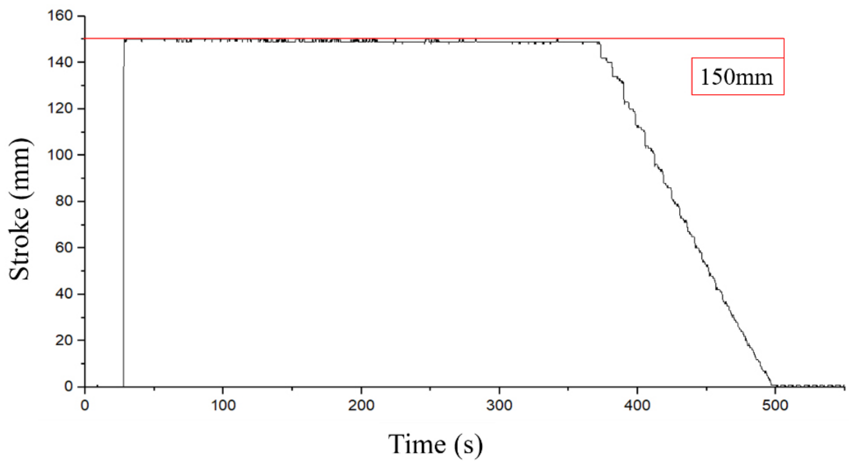

Fig. 9. Hydrogen releasing and absorbing.

alloy of 1.36 to 3.15 wt% [15]. In this study, the hydrogen storage of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ alloy, expected to be similar, was 2.84 wt%. With the help of the Korea Institute of Energy Research, the amount of hydrogen absorption was measured about 1.47 wt%, and the analysis result is shown in Fig. 8. The amount of hydrogen absorption of this alloy was measured differently from Park's results for two reasons. First is the difference of measurement conditions. If the activation of all samples is completely uniform, the measurement conditions do not considerably influence in the hydrogen adsorption amount. However, if all the samples are not uniformly activated, the amount of adsorption may vary depending on the measurement conditions. In addition, the alloy used in this study has exposed in the air a lot then the alloy which is used in Park's research. Exposed in the air may occur the formation of the ZrO_2 on the alloy surface. Since ZrO_2 has a monoclinic structure through which hydrogen does not pass, hydrogen adsorption performance can be notably reduced. Due to the small volume of inside the system, overall flow rate changes were not significant. When hydrogen was stored, it was 0 to 0.023 l/m, and the flow rate changed up to 3,287 l/m when the emission test was performed.

Before start actuation test, hydrogen releasing and absorbing test was conducted. The hydrogen storage

Table 6
Pressure and Lifting force change by load

	5 kg	10 kg	15 kg	20 kg
Pressure (MPa)	0.125	0.175	0.235	0.315
Lifting force (kgf)	100.531	140.743	188.998	253.338

Table 7
Results of the actuation test

Temperature (°C)	Load (kg)	Stroke (mm)	Lifting time (s)
70	5	87	1,200
	10	19	1,436
	15	–	–
	20	–	–
75	5	131	130
	10	70	200
	15	15	348
	20	–	–
80	5	150 (Max.)	373
	10	83	397
	15	55	635
	20	28	755

alloy module was heated by 80°C with 0kg of load. Actuator stroke was reached 150 mm at 28 s. After 280 s passed, hydrogen storage alloy module was cooled down. Actuator stroke was reduced to 0 mm for 192 s as shown in Fig. 9. The release of hydrogen was made at the same time as the release temperature was reached, but absorption could be confirmed to be complete after 192 seconds of cooling. The actuation test was conducted to increase the temperature of the hydrogen storage alloy module by 5°C from 25°C to 80°C to confirm the performance of hydrogen release. The pressure changing in the system was checked for 5 min for each temperature. As a result, hydrogen was first released at 70°C. After waiting for 20 min to sufficiently release hydrogen, the actuation stroke of each load of 5, 10, 15, and 20 kg was measured. When raising 5 kg, the system internal pressure was 0.125 MPa and the lifting force was 100.531 kgf, for 10 kg the system internal pressure was 0.175 MPa and the lifting force was 140.743 kgf. When raising 15 kg, the system internal pressure was 0.235 MPa and the lifting force was 188.998 kgf, and for 20 kg the system internal pressure was 0.315 MPa and the lifting force was 253.338 kgf (Table 6).

Result of the stroke changing was measured after piston stopped completely. The results are shown in Table 7. As the results, the loads of 5 and 10 kg were raised by 87 and 19 mm at 70°C, respectively. It took each 1,200 and 1,436 s until the piston completely stopped. At 75°C, loads of 5, 10 and 15 kg were raised by 131, 70, and 15 mm, respectively. It took each 130, 200 and 348 s until the piston completely stopped. At 80°C, loads of 5, 10, 15, and 20 kg were raised by 150, the end of the stroke, 83, 55, and 28 mm, respectively. It took each 373, 397, 635 and 755 s until the piston stopped.

However, this result is inconsistent with the PCT analysis in advanced research, which was referred to when selecting the alloy. In advanced research, $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ alloy emitted about 0.5 MPa of hydrogen at 30°C and released about 1.0 MPa at 60°C. The reason for this difference was became from composition and homogeneity of $Zr_{0.9}Ti_{0.1}Cr_{0.6}Fe_{1.4}$ alloy made and used in this study may be inconsistent with the alloy used in advanced research [15]. The inconsistent of alloy is the limitation of this research. Because of the alloy, the temperature at which hydrogen is released is 70°C, which is a higher temperature than the data referenced before alloy selection. Furthermore, the system is bulky, which makes it somewhat difficult to apply to rehabilitative equipment in the present state. More studies need to be carried out on this part, but slowly lift the large loads using less energy source is one of the characteristics suitable for rehabilitation device. Therefore, it is expected that those result of actuation test can be applied at development of joint rehabilitative devices or standing aids.

6. Conclusion

In this study, a new actuation system of automatic type that can be driven by hydrogen storage alloy were developed and release experiments were also conducted. Performance of system using hydrogen storage alloy was upgraded than existing system to automatically control and measure the hydrogen flow. This is a very important issue in the development of rehabilitation devices where user safety is important. It is also expected that this system will be applied to the development of devices that use hydrogen storage alloys as hydrogen storage sources in the future. Through the experiment, the actual driving performance of the new actuation system was confirmed. In addition, it was confirmed that the hydrogen pressure that the hydrogen storage alloy can release increases with increased applied temperature. In future studies, it is necessary to conduct research for improving the quality of the alloy and miniaturizing the system. The actuation system in this paper can be applied to assistive device and rehabilitation system for assisting the movement of daily life of the elderly or people with disability. It is expected to be used as a rehabilitation device for joints such as fingers, hands and knees of stroke patients or as a driving force for standing aids for disabled people.

Acknowledgments

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Conflict of interest

None to report.

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