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Development of A New Portable Rescue Tool Using Metal Hydride Alloys

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ABSTRACT:- This paper addresses the development of a new rescue tool for saving survivors buried in the debris of a collapsed building caused by a large-scale natural disaster. Because access to the public energy supplies as well as the seriously stricken area are frequently cut off just after the occurrence of a large natural disaster, a new rescue tool powered by metal hydride (MH) is being proposed. The tool achieves a large lifting force solely utilizing thermal energy; in addition, it is effective for confined space entry and rescues without the need for electricity or fuel. The lifting tool that was designed and experimentally produced was comprised a robust telescopic cylinder having 50 mm of lifting stroke and 6500 N of lifting output force per 0.1 MPa of internal pressure, an airtight MH container, and a portable heat source employing calcium oxide. The composition of MH as the pressure source was $LaNi_{4.3}Co_{0.5}Mn_{0.2}$, which slightly desorbed hydrogen at 40°C and possessed 0.2–0.3 MPa of equilibrium pressure at 80°C. The MH source was enclosed within a solidly constructed airtight container that heated the MH via a heat source in contact with the bottom surface of the container. When the MH was heated using 200 and 300 g of calcium oxide; the MH temperatures in both the cases reached in excess of 70°C after 48 seconds. This reaction created a lifting force of 10000 N in the telescopic cylinder for hydrogen pressures of 0.17 MPa. The 300 g of calcium oxide reaction created MH temperatures in excess of 75°C and allowed for constant hydrogen desorption for over five minutes from the start of heating. It is estimated that the lifting tool utilizing this mechanism, MH compositions, and a higher equilibrium pressure at 75°C will provide a higher output force. In addition, a lifting tool where the initiation of hydrogen desorption occurs at lower temperatures will provide a faster response time for the lifting operation.

Keywords:- Rescue tool, Metal hydride, Calcium oxide, Natural disaster, Initial rescue work

I. INTRODUCTION

The extrication time of person buried in debris of a collapsed building due to a natural disaster such as a large-scale earthquake or a landslide has a significant effect on the individual's survival rate. The three-day period after the occurrence of the natural disaster is called the "golden seventy-two hours" when rescuing victims buried in a confined space. In the disaster of the great Hanshin–Awaji earthquake, which occurred in Japan on January 17, 1995, 96% of the survivors rescued by fire department workers were rescued within the first three days of the earthquake's occurrence [1]. Rescue teams require prompt and flexible responses just after the occurrence of a large natural disaster; however, the access to the stricken area is frequently cut off. In such cases, the transportation of equipment for rescue operations, including special-purpose vehicles and heavy machinery, is significantly delayed. This requires the dispatch of rescue teams by marching into the disaster on foot. Hence, rescue teams relying on their own power play an almost exclusive role in assisting the victims. Powered tools used for rescue operations that are driven without electricity or fuel, especially those used confined space entry, are extremely useful in an isolated, stricken area that is blocked off from traffic and energy supply while increasing the efficiency of any required manual work.

Hydrogen is now recognized as a sustainable energy carrier that will help create a cleaner environment for future generations. There are several hydrogen storage methods including compressed hydrogen gas storage, liquid hydrogen storage, and material-based hydrogen storage [2-5]. Metal hydrides are also material-based hydrogen storages that can store over 100 mL/g of hydrogen gas [6, 7]. The metal hydride (MH) alloy can release absorbed hydrogen via thermal energy conduction. A force device applying the hydrogen pressure within an enclosed space of a cylinder is called a MH actuator. The hydrogen pressure used to apply the force originates from the reversible reaction of the MH alloy as it absorbs and desorbs hydrogen gas [8, 9]. The advantages of the MH actuator include high force output compared to the small size of the overall assembly, silent operation, negligible vibrations, and mechanical buffer action. The MH actuator is also suitable as a power source of rehabilitation equipment or assistive devices for the people with disabilities [8, 10-12]. It will qualify as the powered tool available for confined space entry and rescue since it is the motive force does not require an external source of electricity or fuel.

This study describes the development of the new tool using a MH actuator and a portable simplified heat source to assist the initial rescue work in a disaster-stricken, isolated and impoverished area due to a natural disaster. In particular, we evaluate that fundamental performance of the mechanical structure and discuss how the functions mentioned in this study can fulfill the demands of professional rescue workers.

II. DESIGN OF THE NEW LIFTING RESCUE TOOL

A. Current Status Of The Existing Rescue Tools

Currently, the primary tools employed by professional rescue workers for lifting heavy loads while working in confined spaces comprise lifting bags driven by high-pressure air. Most of the lifting bags are made of a hard rubber reinforced by aramid fibers. For example, a lifting bag with a 250-mm square shape and a rated air pressure of 0.8 MPa is inflated through the introduction of regulated high-pressure air. This bag can lift a 3-ton load approximately 50mm. Consequently, the lifting operation of loads using lifting bags require air pressure sources that require external power sources such as a mobile tank filled with high pressure gas. However, a mobile air tank is difficult to station at more than one emergency site because it is extremely heavy for the rescue personnel to carry to an affected area while on foot.

Regarding other lifting tools that work without an external supply of electricity or fuel, a hydraulic jack typically used for car maintenance and based on manual operation of the cylinder, can be utilized. This type of manual jack, however, cannot assist the lifting operation in an affected site with sufficient stability because the working mechanism, which requires a base to be placed on flat ground, will not slide. Hence, it is not suitable for rescue missions in an affected spot where uneven ground is present. Therefore, a considerable demand is expected for the proposed lifting tool because there is no need for a high-pressure air tank or a flat surface to achieve vertical lifts.

B. Request specifications from rescue workers

A technical briefing with professional rescue workers was conducted to discuss the required specifications expected of the lifting tool prior to the initiation of the design process of the lifting tool. First, the workers suggested that a lifting height of several inches would be suitable rather than a large lifting height of several feet. In actual rescue work, once a lifting tool such as an air bag is sufficiently inflated, cribbing is used to maintain the lifted height. Once the cribbing is safely in place, the lifting operations are then repeated. They indicated that a lifting tool with a large lifting height is a danger during unstable load conditions and the complication of the mechanism combined with the increase in the size of the tool to obtain a large lifting height generally makes the usability inconvenient. Second, the workers suggested that a solid, stout lifting tool is required to avoid damage due to rough handling during severe working conditions. Though the lifting bags utilized by rescue workers are thin and light, the main body made of hard rubber presents a bursting hazard. Therefore, a simple shaped tool with a rigid metal frame would be suitable as a rescue device. Third, they suggested that the lifting tool should be easy to operate and handle. The lifting bags require a connection to a gas pressure source, including hoses and an air regulator, for proper operation. Thus, specialized knowledge and techniques for that tool are required.

It is notable that the requests from the workers can improve the usability of the new rescue tool for rescue experts as well as for the general population. In a major disaster, rescue teams will take time to arrive at the affected area. Additionally, there will be a serious shortage of professional rescuers during the early stage of any large disaster because there will be a large number of sites requiring assistance. During the great Hanshin-Awaji earthquake, over 90% of people who escaped from their broken houses did not receive help from the professional rescue workers; 34.9% were self-aided, 31.9% were helped by families, and 30.7% were helped by friends, neighbors, or passersby [13]. Thus, a new rescue tool that can be handled with relatively ease by the general public will contribute toward saving a number of people buried in confined spaces. Assuming such use, it is required that the new rescue tool is designed to be suitable for stockpiling in the community.

C. Specification details of the lifting tool prototype

According to above-mentioned requests and requirements, the prototype specifications of the new lifting tool applying the MH actuator were determined. The working mechanism of the lifting tool is shown in Fig. 1. A hydrogenated MH alloy in a sealed main frame can immediately release hydrogen molecules via an endothermic reaction during heating. This reaction causes the necessary increase in hydrogen pressure in the main frame to produce a telescopic motion of the lifting tool. Afterwards, the dehydrogenated MH absorbs the hydrogen molecules within the sealed space via an exothermic reaction during cooling of the MH; thereby results in a retraction of the telescopic cylinder of the lifting tool.

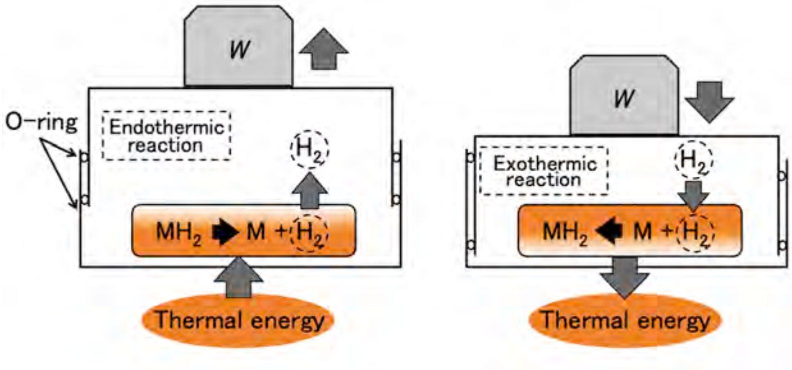

Fig.1: Working mechanism of the new lifting tool using a MH actuator, where M is the MH alloy and *W* is a load.

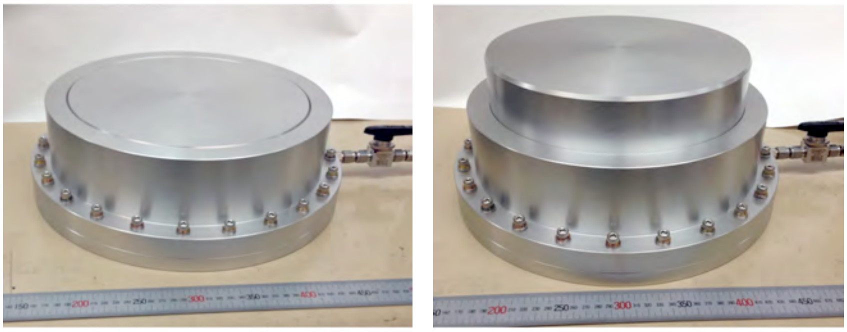

Fig.2: External appearance of the new lifting tool prototype; (left) pre-operation and (right) at lifting.

A single-acting pneumatic telescopic cylinder made of duralumin, as shown in Fig. 2, was employed for the lifting mechanism to obtain several inches of lift of heavy rigid objects. The sliding portion of the telescopic cylinder was sealed by double dynamic radial O-rings with impermeability to hydrogen molecules. The base frame and lifting frame of the telescopic cylinder measured 304 mm and 260 mm in diameter, respectively, and was 105 mm in height. The lifting frame had an expansion and contraction stroke of 50 mm with a 658 cm^2 internal area of the upper surface. The lifting frame provided an estimate 6450 N of lifting force per 0.1 MPa of internal hydrogen pressure increase. O-rings made of vinylidene fluoride rubber were employed because of the significant airtightness in a hydrogen environment and good heatproof properties. The selected O-rings were sufficiently thick to achieve a maximum squeeze rate to provide maximum hydrogen sealing and were arranged in the flanges of both the base frame and lifting frame of the telescopic cylinder. The telescopic cylinder with the double dynamic radial O-rings arrangement did not allow any hydrogen leakage during fifty consecutive tests of the telescopic motion.

The most important factor affecting the working performance of the new lifting tool was the characteristic features of the hydrogen absorption/desorption cycle of the MH. There are many MH compositions including $LaNi_5$, $CaNi_5$, TiFe, $TiMn_{1.5}$, $ZnMn_2$, Mg_2Ni, and $MmNi_5$ (Mm is mishmetal). In addition, the composition of any MH alloy suitable for the lifting tool power source must meet three requirements for the characteristic hydrogen absorption/desorption cycle. The first requirement is that the hydrogen absorption/desorption reactions must occur at an ambient temperature. More specifically, no hydrogen absorbing reaction of the MH alloy can occur in atmospheric temperatures such as 40°C and the bulk amount of the absorbing reaction must occur above atmospheric temperatures. The second requirement is that the hydrogen absorption capacity per weight must be a large quantity of to over 1.0 wt% of hydrogen. The third requirement is that the hydrogen absorption/desorption reaction above ambient temperatures is large; hence, to desorb additional hydrogen requires an increase of a few degrees. $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ is one of the MH compositions that meets these requirements and subsequently selected for the lifting tool prototype.

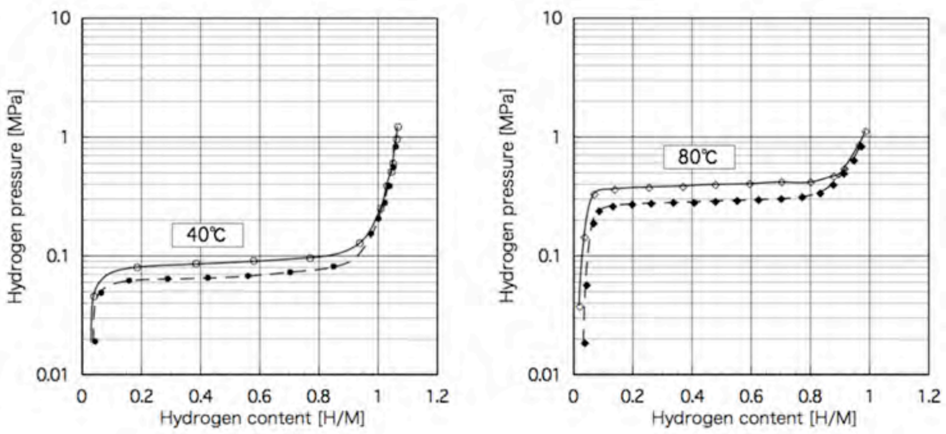

Fig.3: PCT diagrams of LaNi4.3Co0.5Mn0.2 MH alloy at 40°C and 80°C.

A basic characteristic for each MH alloy composition is shown in the relationship of the hydrogen pressure and hydrogen content curve under constant temperature (PCT diagram shown in Fig. 3). The diagram demonstrates absorption and desorption reactions at fixed temperature frequently occur at a certain hydrogen pressure. Fig. 3 shows the PCT diagrams for $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ MH alloys that were adopted for the lifting tool. The level line of the PCT diagram is called an equilibrium hydrogen pressure. As can be seen, the higher the fixed temperature of the MH, the higher the equilibrium pressure that is obtained. This composition of the MH alloy has an equilibrium pressure less than 0.1 MPa at 40°C and 0.3–0.4 MPa at 80°C. It means that the $LaNi_{4.3}Co_{0.5}Mn_{0.2}$

cannot absorb hydrogen at room temperature and begins to release hydrogen at higher temperature than room temperature. Therefore, $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ fully satisfies the first requirement. $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ has 140mL per gram of the MH of the hydrogen absorption capacity corresponding to 1.25 wt% in hydrogen weight percent. Therefore, the composition also satisfies the second requirement. Furthermore, the low inclination of the equilibrium hydrogen pressure is an important advantage exhibited by the $LaNi_5$ type MH. The inclination of the equilibrium pressure of the $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ composition demonstrated by the level line of Fig. 3 is significantly flat, which is a fairly good feature compared to other MH compositions. Because the flat equilibrium hydrogen pressure will generally provide a large quantity of desorbing reaction with a little temperature increase, that feature is consistent with the third requirement. For these reasons, it was determined that the specified composition is suitable for a prototype of the lifting tool in this study.

III. EXPERIMENTAL METHODS

To confirm that the lifting tool can provide adequate performance, an experiment to lift a load using a prototype tool was executed. The main body of the lifting tool using the single-acting pneumatic telescopic cylinder shown in Fig. 2 was fixed in a tensile/compression testing machine at the most reduced height, namely, the lifting frame of the cylinder was stored in the base frame. An airtight MH container was designed as an outside attachment and connected to the telescopic cylinder with an airtight flexible tube. The MH container made of duralumin measured 130 mm in diameter and 34 mm in height. The MH was heated by bringing the bottom surface of the container into contact with a flat exothermic body.

Three hundred grams of 100 mesh powdered $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ MH was enclosed in the MH container and was made to absorb 30000 cm^3 of hydrogen with 99.99999 % purity. Calcium oxide, used as a heat-generating element with a weight of 200 g or 300 g, was brought into contact with the bottom of the MH container immediately after being reacted with addition of water at a weight of 70% of the calcium oxide. As the MH temperature increased, the desorbed hydrogen was transferred through sealed space and resulted in an increased in the internal hydrogen pressure within the telescopic cylinder that initiated the required lifting work.

To simulate a vertical lifting operation against an approximate 1000 kg load, the moving head of the compression testing machine was programed to maintain the initial height of the cylinder until 10000 N of lifting output force was achieved; subsequently, the cylinder began to rise. The lifting height in this experiment was set to 40 mm instead of 50 mm because a suitable safety margin was required for testing purposes. The MH temperature, the amount of hydrogen desorption, the internal pressure of the telescopic cylinder, and the displacement of the moving head of the testing machine were measured during the experimental process. The lifting displacement and lifting force were obtained from the tensile/compression testing machine (Type 8801, Instron Inc. UK, with force capacity up to ±100 kN and 150 mm of usable stroke). The MH temperature was

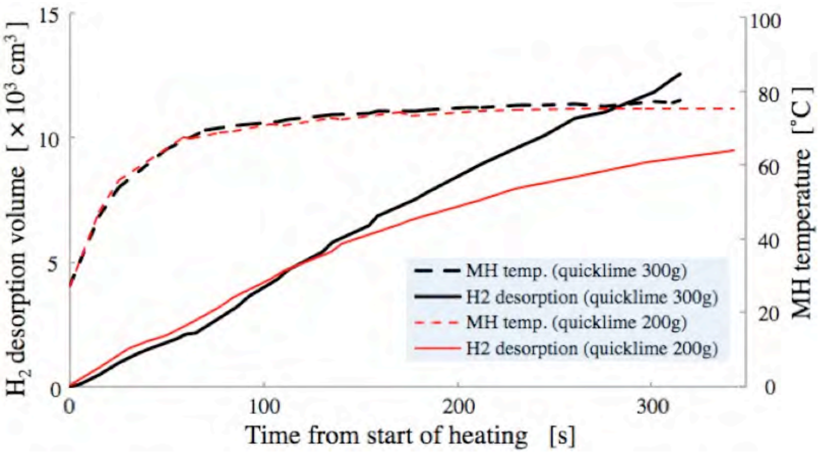

Fig.4: MH temperatures and H_2 desorption volumes from the start of MH heating in case of 200 and 300 g of calcium oxide.

measured by a sheathed thermocouple (HTK0220, Hakko Electric Co., Ltd. Japan) through the airtight container using a sealed coupling joint. The internal pressure of the cylinder was measured using a voltage-output pressure transducer (PVL-20KB, Kyowa Electronic Instruments Co., Ltd. Japan), and the amount of hydrogen desorption was calculated based on the capacity in the cylinder and the internal pressure.

IV. RESULTS AND DISCUSSION

Fig. 4 shows the transition of the MH temperature in the airtight container and the amount of desorbed hydrogen from the MH after the start of the MH heating for the cases of 200 and 300 g of calcium oxide. Though both the 200 g calcium oxide (200Ca) and 300 g calcium oxide (300Ca) provided 70°C for the MH temperature at 48 seconds after starting the heat exposure, the rate of the temperature rise of the 200Ca while reaching 70°C was slightly faster than that of the 300Ca. This was caused by the lower amount of calcium oxide because it is easier to spread water over the whole amount of the calcium oxide; thereby allowing for more efficient heat generation during the early part of the reaction. However, the final temperature of the 300Ca was approximately 77°C, which was approximately 2°C higher than that of the 200Ca. Because the internal energy of the MH decreases due to hydrogen desorption, maintaining a high MH temperature requires a larger supply of thermal energy to compensate for the decrease of the MH temperature during the hydrogen release. Because the 200Ca showed a tendency of slightly lower temperature than the 300Ca from around two minutes after the start heating, it was suggested that the 200Ca had achieved most of the exothermic reaction by that time.

The hydrogen desorption volume of the 200Ca was slightly more than that of the 300Ca in the early period due to the similarities tendencies involved with the MH temperature transition; however, the desorption volume for the 200Ca case was less than that of the 300Ca from approximately two minutes after the heating starts. Because the hydrogen desorption volume of the 300Ca continued increased nearly linearly for over five minutes, it was suggested that 300Ca, which was the same weight of the MH, was the adequate amount to use for the prototype of the lifting tool.

Fig. 5 shows the transition of the internal hydrogen pressure in the telescopic cylinder and the lifting displacement against the 10 000 N load for both the 200Ca and 300Ca cases. The 200Ca exhibited a slightly faster increase in the hydrogen pressure and a shorter time was required to reach the 10000 N output force than that of the 300Ca case. However, the lifting displacement in the 300Ca was faster than that for the 200Ca case two minutes after the heating starts. The lifting displacement of the 300Ca showed an almost linear increase similar to the tendency in the linear transition of the hydrogen desorption from the MH.

Based on this experiment, it is proved that the lifting tool prototype using hydrogen pressure from the MH can accomplish the intended purpose of lifting heavy loads during rescue work within confined spaces when calcium oxide is used as a heat source. However, since more 300 seconds are required to lift the 1000 kg of load to a height of 40 mm in this experiment, the performance was insufficient in both the practicable load value and the lifting rate to use in an actual rescue work. Various methods for compensating these deficiencies will be collectively described in the next section. Incidentally, this lifting tool can stop lifting halfway by closing a valve between the telescopic cylinder and the MH container. At that time, the MH ceases to desorb hydrogen in order not to exceed the equilibrium pressure even though it remains high temperature. Additionally, the MH in the airtight container will then respond to maintain the equilibrium hydrogen pressure according to the present temperature.

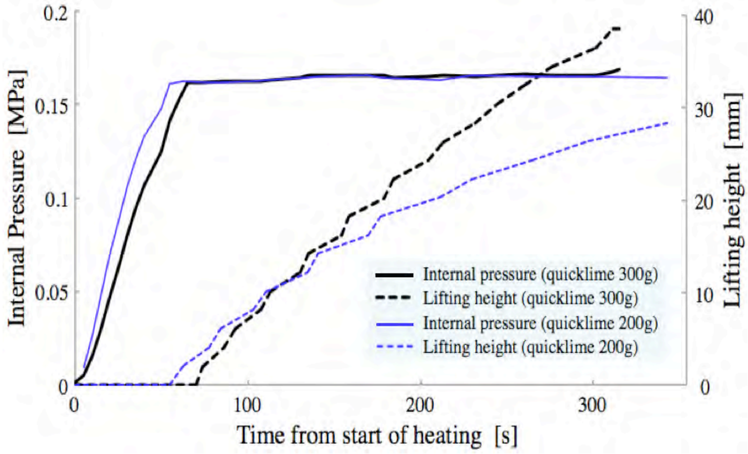

Fig.5: Internal pressure and lifting height of the lifting tool from the start of MH heating in case of 200 and 300 g of calcium oxide.

V. OPTIMIZATION OF THE LIFTING PERFPRMANCE

Modification of the MH-based apparatus can improve the lifting speed and output force for the rescue tool. The MH composition of $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ was selected because of the lower equilibrium hydrogen pressure than that at atmospheric pressure and temperature. This choice was intended ensure that hydrogen was desorbed from the MH and the output force was generated only when the MH was actively heated. The $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ showed approximately 0.04 MPa of the equilibrium pressure at 20°C, which is considerably lower than atmospheric pressure. As can be seen in Fig. 3, the equilibrium pressure for the pressure increasing direction (indicated by the broken line) at 40°C was quite lower than the atmospheric pressure. This was too low to avoid hydrogen desorption from the MH except during heating operations; hence, the equilibrium pressure between 0.09 and 0.1MPa would accomplish that goal. Even though equilibrium hydrogen pressure of the $LaNi_5$ composition at 40°C is approximately 0.3 MPa, a slight addition of cobalt and manganese to the $LaNi_5$ permits a reduction of the equilibrium pressure at the same temperature. For example, a reduction of the manganese addition from the $LaNi_{4.3}Co_{0.5}Mn_{0.2}$ will provide the equilibrium pressure at room temperature between 0.09 to 0.1MPa. The MH composition with a high equilibrium pressure at room temperature will similarly exhibit features of high equilibrium pressure at higher temperatures. Although a hydrogen pressure of 0.17 MPa is necessary to obtain 10000N output force for a MH temperature of 70°C, the manganese reduction of the MH composition will produce the same hydrogen pressure at a lower MH temperature. If it reaches 0.17 MPa for a MH temperature of 60°C, the output force of 10000N in the lifting tool will be achieved at an earlier time after the beginning of the heating operation. The maximum output is expected to increase after reaching the MH temperature of 75°C because the equilibrium pressure of this composition at 75°C will be significantly higher than 0.17 MPa. Thus, the performance of the lifting tool can regulate both the working rate and the maximum output force by modification of the MH composition.

Additionally, increasing the thermal energy generated by the heat source leads directly to an improvement of performance of the lifting tool. The calcium oxide temperature of the part in contact with the MH container at the exothermic reaction in this experiment measured approximately 100°C. The maximum attained temperature of a heat source will be raised by employing purer calcium oxide than what was used in this experiment or calcium oxide can be mixed with aluminum powder. These steps will also improve the lifting tool performance. Further methods for upgrading the lifting rate and force include rising the amount of MH used and enlarging the hydrogen pressure receiving area of the lifting frame of the telescopic cylinder. The larger the amount of the MH, the faster the lifting occurs at the same MH temperature; however, an increase in the calcium oxide volume is inevitable to supply sufficient thermal energy for the increased amount of the MH. Enlarging the hydrogen pressure receiving area of the cylinder will ensure a larger output force in proportion to the increment of area for an identical attained pressure resulting in the enlargement of the cylinder diameter and mounting of the required amount of the MH and calcium oxide. Therefore, it is suggested that the modification of the MH composition and the calcium oxide content are realistically more useful for the methods of improving the working performance of this lifting tool.

VI. CONCLUSIONS

The targets of this paper were a conceptual proposal and a performance confirmation of a new lifting tool utilized for an initial rescue work in an affected area due to natural disaster with loss of public energy supply. This tool was designed based on the specification requirements from the professional rescue workers and employed the operating principle of lifting using a portable heat source based on calcium oxide and including a robust telescopic cylinder operated by the hydrogen pressure. The hydrogen pressure varies according to hydrogen absorption/desorption from the heated MH.

Results of this experience demonstrated that the heating operation based on the calcium oxide heat source could increase the MH temperature up to 75°C for ten minutes or more. This was sufficient to desorb enough hydrogen from the MH and could vertically lift the 1000 kg of load. In addition, the results of this study showed that the new lifting tool, which has a simple structure, would contribute to the initial rescue work in an isolated and natural disaster-stricken area without infrastructure such as the electricity or fuel supply. The modifications of the MH composition and the increase in generated thermal energy of the calcium oxide provided improvement to the lifting tool relative to the lifting speed and output force. Finally, because calcium oxide has highly hygroscopic property, development of a simple breakaway heat source unit, which can avoid humidity absorption for a long period, will allow for long storage times of the lifting tool.

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REFERENCES

[1]. Y. Kawata, "The great Hanshin-Awaji earthquake disaster: damage, social response, and recovery", Journal of Natural Disaster Science, Vol. 17, No. 2, pp. 1-12, 1995.

[2]. M.A. DeLuchi, "Hydrogen vehicles: an evaluation of fuel storage, performance, safety, environmental impacts, and cost", International Journal of Hydrogen Energy, Vol. 14, No. 2, pp. 81–130, 1989.

[3]. F. Michel, H. Fieseler, G. Meyer, and F. Theißen, "On-board equipment for liquid hydrogen vehicles", International Journal of Hydrogen Energy, Vol. 23, No. 3, pp. 191–199, 1998.

[4]. N.L. Rosi, J. Eckert, M. Eddaoudi, D.T. Vodak, J. Kim, M. O'Keeffe, and O.M. Yaghi, "Hydrogen storage in microporous metal-organic frameworks", Science, Vol. 300, No. 5622, pp. 1127–1129, 2003.

[5]. A.C. Dillon, K.M. Jones, T.A. Bekkedahl, C.H. Kiang, D.S. Bethune, and M.J. Heben, "Storage of hydrogen in single-walled carbon nanotubes", Nature, Vol. 386, pp. 377–379, 1997.

[6]. H.H. Van Mal, K.H. Buschow, and A.R. Miedema, "Hydrogen absorption in LaNi5 and related compounds experimental observations and their explanation", Journal of Less-Common Metals, Vol. 35, No. 1, pp. 65–76, 1974.

[7]. J.J. Reilly, R.H. Wiswall, "Formation and properties of iron titanium hydride", Inorganic Chemistry, Vol. 13, No. 1, pp. 218–222, 1974.

[8]. Y. Wakisaka, M. Muro, T. Kabutomori, H. Takeda, T. Izumi, S. Ino, and T. Ifukube, "Application of hydrogen absorbing alloys to medical and rehabilitation equipment", IEEE Transactions on Rehabiliation Engineering, Vol. 5, No. 2, pp. 148–157, 1997.

[9]. K. Kurosaki, T. Maruyama, K. Takahashi, H. Muta, M. Uno, and S. Yamanaka, "Design and development of MH actuator system", Sensors and Actuators A: Physical, Vol. 113, No. 1, pp. 118–123, 2004.

[10]. T. Tsuruga, S. Ino, T. Ifukube, M. Sato, T. Tanaka, T. Izumi, and M. Muro, "A basic study for a robotic transfer aid system based on human motion analysis", Advanced Robotics, Vol. 14, No. 7, pp. 579–595, 2000.

[11]. M. Sato, S. Ino, N. Yoshida, T. Izumi, and T. Ifukube, "Portable pneumatic actuator system using MH alloys employed as assistive devices", Journal of Robotics and Mechatroncs, Vol. 19, No. 6, pp. 612–618, 2007.

[12]. M. Sato, M. Hosono, K. Yamashita, S. Nakajima, and S. Ino, "Solar or surplus heat-driven actuators using metal hydride alloys", Sensors and Actuators B: Chemical, Vol. 156, pp. 108–113, 2011.

[13]. Y. Marumo, "Disaster Management and Social Capital in Cases of Shinjuku-ku: Generational Differences Do Matter", The Senshu Social Capital Review, No. 3, pp. 71-90, 2012.