Structural Design of Atypical Metal hydride Tank and Investigation of Generated Temperature Fields: Part I

Filip Duda[1*], Natália Jasminská[2]

Department of Energy Engineering, Faculty of Mechanical Engineering, Technical University of Košice, 042 00 Košice, Slovak Republic

*Corresponding Author

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***Abstract*—** *The article describes the structural design of an atypical metal hydride storage tank for hydrogen storage for mobile operations such as cars, buses, etc. The structural design of the tank consists of three main parts, namely an atypical bottom of an elliptical shape with a flange on which there is a 1/4NPT" thread, three seamless pipes and a second atypical bottom as a cap. Hydrogen storage works under low pressure of up to 30 bars and is based on TiFe alloys. In the next part, the article deals with the investigation of the temperature fields created in an atypical metal hydride tank, and then it is devoted to an effective method of cooling the metal hydride tank during the process of hydrogen absorption into the structure of the metal alloy.*

***Keywords*— Metal hydride, pressure tank, heat transfer.**

I. INTRODUCTION

Storage of hydrogen in high-pressure composite tanks with compressed gas (CGH2) at pressures from 350 to 700 bar is the most common method of supplying hydrogen to fuel cells. This solution has the advantages of relatively high hydrogen storage capacity, short refueling time (3-5 min) and virtually unlimited flow of hydrogen into the fuel cell. However, the volume capacity of hydrogen storage by the CGH2 system is too low. These systems also suffer from problems, namely: low safety and extremely expensive refueling infrastructure - both problems are associated with the high pressure of the stored hydrogen.

Metal hydrides (MHs) formed by the reversible reaction of gaseous H2 with a parent metal, alloy, or intermetallic compound to form a hydride are particularly promising for hydrogen storage. The use of MH can provide very high hydrogen storage capacity per unit volume (sometimes higher than liquid hydrogen), safety, reliability and high purity of supplied H2. Despite the conventional view of the low weight hydrogen storage capacity of "low temperature" intermetallic hydrides (≤ 2 wt.% H) as their main drawback in on-board hydrogen storage systems, in some special applications in vehicles the use of these materials appears to be very promising. Primarily this applies to material handling units, underground mining vehicles and water applications where the low gravimetric hydrogen storage capacity/high mass of metal hydrides can provide advantages in vehicle/vessel stabilization.

For this method of hydrogen storage to be used as effectively as possible, it is necessary to design the tank in such a way that it meets all operational parameters in terms of strength. It is also necessary to design an efficient cooling system of the tank during the process of hydrogen absorption into the structure of the metal alloy. This article discusses the solution to the structural design of an atypical metal hydride tank, as well as the design of effective cooling.

II. STRUCTURAL DESIGN OF AN ATYPICAL METAL HYDRIDE STORAGE TANK

The tank consists of three main parts, namely an atypical bottom of a rectangular shape, on which there are two holes with 1/4 NPT" thread, which serve for the supply of hydrogen to the MH tank, three seamless pipes and a second atypical bottom serving as a cap of the tank. In all pipes there is a heat transfer intensifier, which serves to effectively remove the heat generated during the process of hydrogen absorption into the structure of the metal alloy. The heat that is released during the process of hydrogen absorption into MH is approximately 1 MJ per 1 m^3 of stored hydrogen. The material from which the intensifier is made is aluminum, because it has good thermal conductivity (λ=237 $W \cdot m^{-1} \cdot K^{-1}$).

All main parts of the atypical metal hydride tank are made of stainless steel 316L-1.4404. It is a type of steel, that is compatible for hydrogen applications and chosen based on the STN EN 13322-2 standard. The mechanical properties of the steel used are listed in Table 1, the operating parameters of the designed tank are shown in Table 2. The structural design of the tank can be seen in Fig. 1.

TABLE 1
MECHANICAL PROPERTIES OF STAINLESS STEEL 316L-1.4404

0.2% Re (MPa)	Rm (MPa)	ρ ($kg \cdot m^{-3}$)	μ	E (MPa)
205	515	7950	0.3	$2.1 \cdot 10^5$

Where: Re-yield strength, Rm-strength strength, ρ-density, μ-Poisson's number and E-Young's modulus of elasticity.

TABLE 2
PARAMETERS OF THE DESIGNED VESSEL

The weight of the empty vessel	5.71 kg
Weight of metal hydride	8.5 kg
Total weight of the vessel with MH	14.2 kg
Metal hydride volume	$3 \cdot 10^{-3}$ m^3
Mass of stored hydrogen	0.116 kg
Volume of hydrogen	1.38 m^3
Generated heat	13867.8 kJ

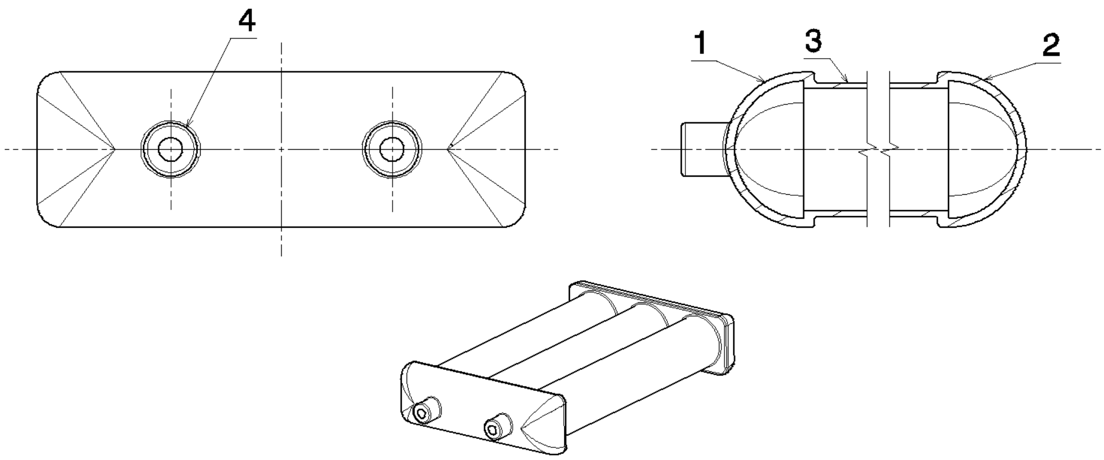

FIGURE 1: Structural design of an atypical metal hydride storage tank

Where 1- an atypical bottom of a rectangular shape with a hole for a flange, 2- an atypical bottom as a tank cap, 3- a cylindrical seamless pipe.

The control strength calculation of the designed tank solved in the Ansys Static Structural program showed that the maximum stress according to the Von Mises theory did not exceed the values higher than the yield strength Re according to Table 1 and the resulting stress on the tank was approximately 120 MPa at an operating pressure of 3 MPa, which means that the tank it is designed well enough for the given operating parameters.

III. SIMULATION OF HEAT TRANSFER OF THE DESIGNED ATYPICAL TANK

The simulation is solved using the FEM method, where the problem of heat transfer from the tank core is solved. In this simulation, a 3D model of the designed tank, in which the metal hydride alloy is located, is considered. The simulations were divided into three, where in the first simulation the tank was not cooled, in the second simulation the cylindrical parts of the metal hydride tank are immersed in water, which represents active cooling, and in the third simulation passive cooling in the form of heat transfer intensifiers, which are located in cylindrical seamless pipes, is considered and active cooling, where the tank, as in the second simulation, is immersed in the cooling liquid.

3.1 Setting up the First Simulation:

In the first simulation, the maximum temperature that arises in the tank during the process of hydrogen absorption into the structure of the metal alloy is investigated. The entire process of hydrogen absorption takes 20 min, which also represents the total time of the simulation. The simulation was performed in the ANSYS CFX program, where at the beginning it was necessary to set all the boundary conditions as well as to generate the mesh of finite elements. The finite element mesh of the simulation model consists of approximately 1,200,000 volume finite elements with quadratic approximation and 6,000,000 nodes. The mesh of finite elements of the simulation model is shown in Fig. 2. The initialization temperatures of the environment in which the tank is located, the tank itself and the metal hydride alloy were set to 20 °C. The power of the generated heat in the metal hydride alloy during the hydrogen absorption process is set to $107 \cdot 10^3$ $W \cdot m^{-3}$. Before starting the simulation, it is necessary to identify the individual domains of the tank and assign the selected material properties to them. These include a steel tank and a metal hydride alloy, and it is necessary to define the connection between the defined domains.

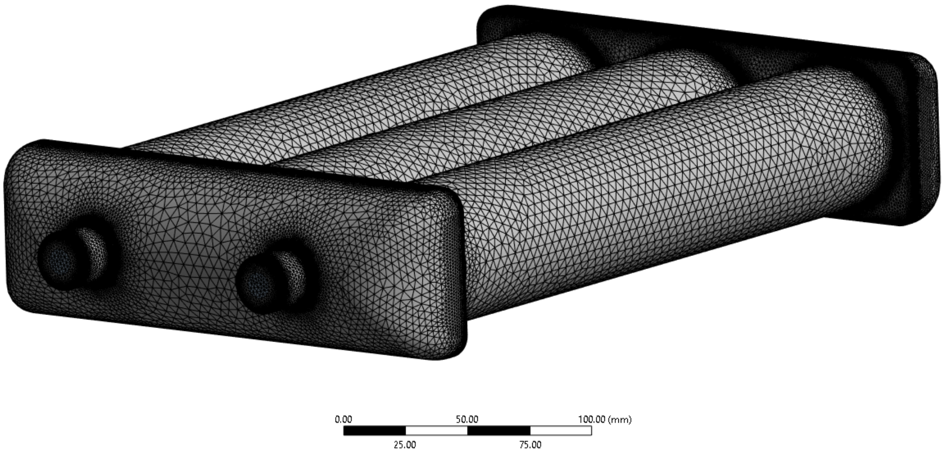

FIGURE 2: Finite element mesh of the first simulation

3.2 Results of the First Simulation:

The simulation showed that the maximum temperature in the tank during the process of hydrogen absorption into the metal alloy structure, which lasted 20 min, is approximately 49.5 °C. The result of the simulation is shown in Fig. 3.

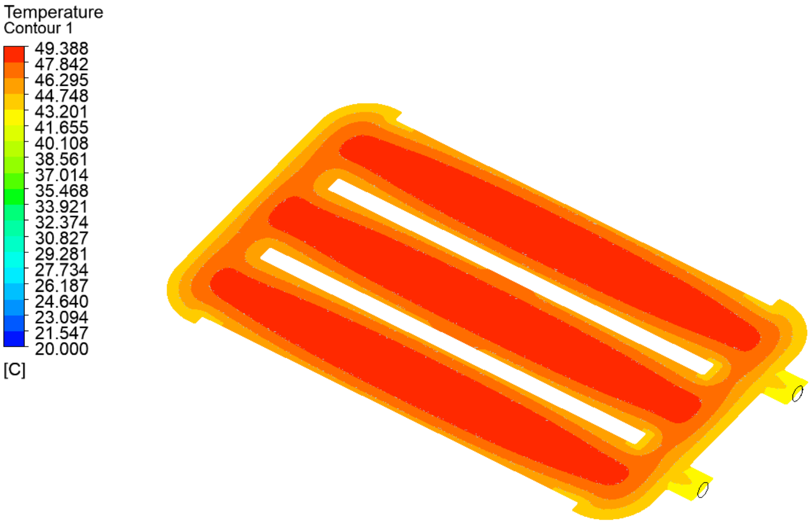

FIGURE 3: Maximum temperatures on the tank during the process of hydrogen absorption into the metal alloy structure without the use of a cooling system

For the kinetics of hydrogen absorption to be higher, it is necessary to cool the metal hydride tank and therefore it is necessary to design an effective cooling system so that the generated heat is removed from the tank as efficiently as possible.

3.3 Setting up the Second Simulation:

In the second simulation, the maximum temperature that arises in the tank during the process of hydrogen absorption into the metal alloy structure is investigated, while the cylindrical tubes are immersed in water at a temperature of 20 °C, which represents active cooling. The simulation time is set as in the first simulation to 20 min. The finite element mesh of the simulation model consists of approximately 1,400,000 volume finite elements with quadratic approximation and 6,500,000 nodes. The mesh of finite elements of the simulation model is shown in Fig. 4. The boundary conditions of this simulation have the same settings as in the previous simulation. Before the simulation, it is necessary to define the domains of the simulation model, assign the material used to them as in the previous simulation and set the connection between the individual domains. In this simulation, there are three domains: steel tank, metal hydride alloy and water.

FIGURE 4: Finite element mesh of the second simulation

3.4 Results of the Second Simulation:

The simulation showed that the maximum temperature in the tank during the absorption process was reduced to about 42 °C. The result of the simulation is shown in Fig. 5.

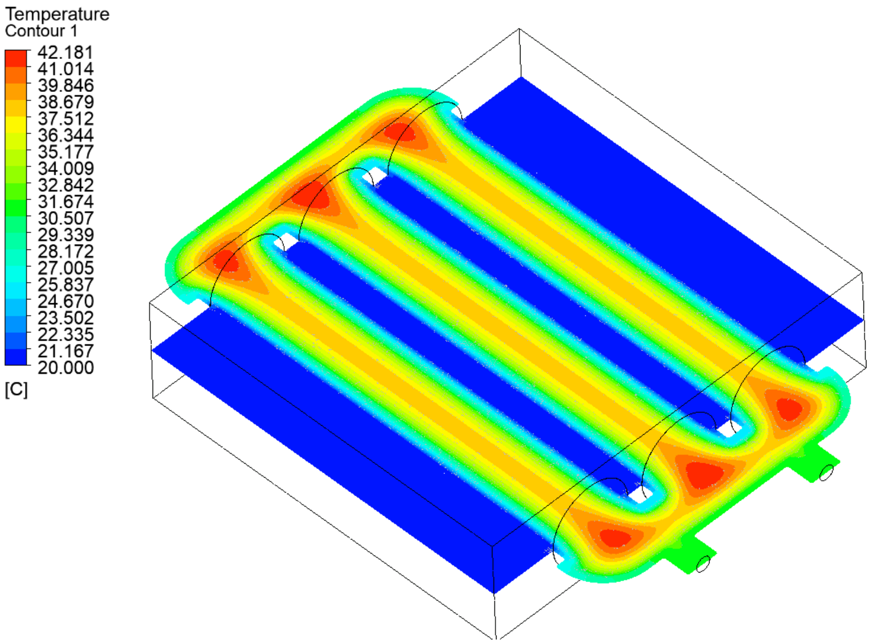

FIGURE 5: Maximum temperatures during the process of hydrogen absorption into the metal alloy structure using active cooling on cylindrical pipes.

For the heat to be dissipated even more efficiently and thus the kinetics of hydrogen absorption to be higher, it is necessary, for example, to insert a heat transfer intensifier into the cylindrical pipes.

IV. CONCLUSION

The task of this work was to design a metal hydride tank for storing hydrogen of an atypical shape for mobile applications. Another task of the work was the investigation of the occurrence of maximum temperatures in the tank during hydrogen refueling and subsequently the proposal of effective cooling for the designed tank.

In the first simulation, where no cooling was used, the maximum temperature in the tank was around 49.5 °C. Subsequently, after applying active cooling to the seamless pipes of the designed metal hydride reservoir, the temperature was reduced to approximately 42 °C, thanks to which the kinetics of hydrogen absorption into the metal hydride alloy increases.

Another task of this work will be to design a suitable shape of the internal heat transfer intensifier, for the most effective heat transfer to the inner wall of the steel tank, where this heat will be cooled by active cooling, which would further reduce the maximum temperature of the metal hydride alloy and which would significantly increase the kinetics of absorption hydrogen.

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