ALUMINIUM HYDROGEN TUBE PROTOTYPE MANUFACTURING

Çetin Karakaya[1], Ahmet Oğur[2], M. Oktay Alnıak[3]

[1] Sakarya University, Karasu Vocational School, Karasu, Sakarya.
[2] Sakarya University, Faculty of Engineering, Sakarya.
[3] Bahçeşehir University, Vocational School, Şişli, İstanbul.
e-mail: ckarakaya@sakarya.edu.tr

Abstract: This study includes production of high pressure resistant composite hydrogen tubes supported by R&D General Management of Ministry of Industry within the context of San-tez 123 Project.
In the context of San-tez 123 Project, for the first time in Turkish Industry, R & D activities were conducted and prototypes were produced for high pressure resistant storage tanks for hydrogen. In this study, behaviors of 6061, 6063 and 6082 alloys of the 6000 Al series have been investigated under high pressures which are used for manufacturing of tanks. Observations have been made for the quality criteria that tubes should provide.
Key Words: Al Mg Si alloys, high-pressure hydrogen storage tanks, high-pressure tank, finite element method analysis

INTRODUCTION

Within the scope of San-tez 123 supported by the Ministry of Industry, R & D work for high-pressure hydrogen storage tanks had been done and the prototypes were produced for the first time in our country. In this study, behavior of 6000 series of Al Mg Si alloys which are being used in the manufacture of tanks 6061, 6063 and 6082 are examined with computer-aided finite element method (ANSYS) under high pressure. Hydrostatic pressure tests are done for each alloy which are produced for prototypes and the test results are compared with ANSYS results. In this study primarily nine different protype tubes are produced in order to investigate cases of three different heat treatments for three different alloys. These tubes were subjected to analysis by computer modeling. These produced samples are blown after hydrostatic pressure tests. The results were compared. For the ANSYS test done by computer tensile test samples are removed from the tanks, yield curves are obtained from the cross section of shaped tube and from these data is entered and the program. The aim of the study is to determine the ideal statu of alloy type and heat treatment. (Alnıak *et al.*, 2008; Alnıak *et al.*, 2009).

High Pressure Resistant Composite Hydrogen Storage Tanks

In general, the structure of high-pressure hydrogen tanks is metal material inside and flat or helical type usually consisting of carbon fiber layers reinforcement. The general appearance of tanks storing hydrogen in the form of gas under high pressure as the general application of manufacturing is shown in Figure 1.
High-pressure tanks are divided into four categories;
Type 1 : Fully metallic tanks,
Type 2 : Glass wool-wound metallic tanks in general,
Type 3 : The tanks having initially glass fiber and than composite metallic material composed of carbon fiber in its interior part,
Type 4 : Basically, carbon-fiber composite tanks (inner part mostly consists of thermoplastic polymers) (Clefs cea, 2004)
Inner part which is called "liner" is obtained form tanks with many different methods. In the production of this interior part basicly deep drawing, extrusion, pressing, flow-forming methods are used. Method selection depends on the size of the investment and the form of the tank. After achieving a tank reinforcing wound layer is obtained from mechanisms which can be seen in Figure 1.

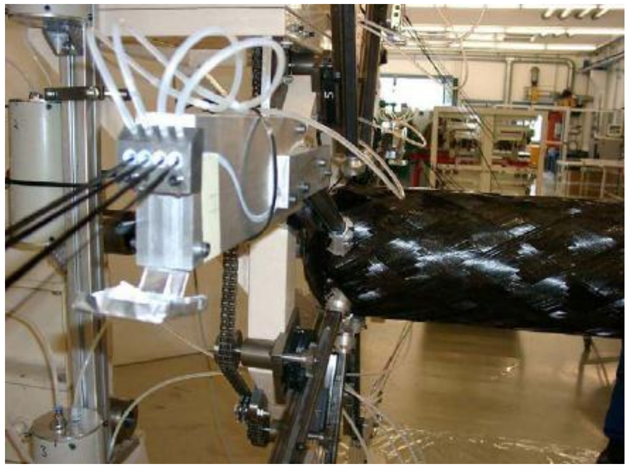


Figure 1. Wrapping of Carbon Fiber Supplementation on the Aluminum Tank (Rau and Colom, 2006)

Since the beginning of 2000, works have been done on the usage of hydrogen in vehicles. In this context, many prototypes are produced and after completion of tests vehicles brought in use. In many countries, there are hydrogen refueling stations.

PROTOTYPE TUBE MANUFACTURING AT ELEVATED TEMPERATURES

High-pressure hydrogen tanks are manufactured with flow-forming method in serial production. But in this study since the high investment cost for machine is high, spinning, extrusion and end closing with press techniques are used in the manufacturing. In the first stage, cylinder shaped material should be waited in the furnace until it reaches the forming temperature. Than as shown in Figure 2, first shape will be given between molds for a hollow cylinder shape. In this stage, scotch is placed into female mold and male mold begins to move towards down along stroke.

Figure 2. Getting a hollow cylinder shaped as a container from a filled cylinder by the help of a press

With the pressure of male mold, the material in the female mold is plastered on the male mold. In the first stage with the help of press a draft hollow cylinder is obtained from full material. In the next stage the length of the tank will be extended by reducing the wall thickness with height extension process as shown in Figure 3.

Figure 3. View of extension process

At this stage, the tank is forced to move a little lower matrix than the outer section's scale. With the effect of force the material starts to flow backward (indirect flow-forming). Thus, despite a decrease in cross-section of material extends throughout the tank. As can be seen in figure 4, after first forming process (press) and the second forming process (indirect flow-forming), thickness of the material is decreasing, but the length is increasing approximately two times. In addition, the material has become directed and more homogeneous in internal structure.

Figure 4. The comparison between first forming process and second forming process

Finally, the head of the extended tank is shrinked with the help of press in the molds. As seen in the Figure 5, material accumulation is occured during the shrinking process.

Figure 5. Shrinking process for end part of the Aluminum-hydrogen tank

In this study, first as a liner for the sample tanks were produced for 3 different 6000 series aluminum material. These samples are obtained in 9 ways without heat treatment, with T4 and T6 heat treatment and 3 different samples are taken from each sample. All the mechanical properties obtained from 27 tensile tests are used in the finite element analysis in computer. Liner tanks are subjected to hydrostatic pressure test and the results were compared to results obtained from ANSYS. For the last test, carbon-fiber wrapped on the liner and subjected to hydrostatic pressure test and the results are discussed. Linear dimensions of the tanks used in the experiments are as shown in Figure 6;

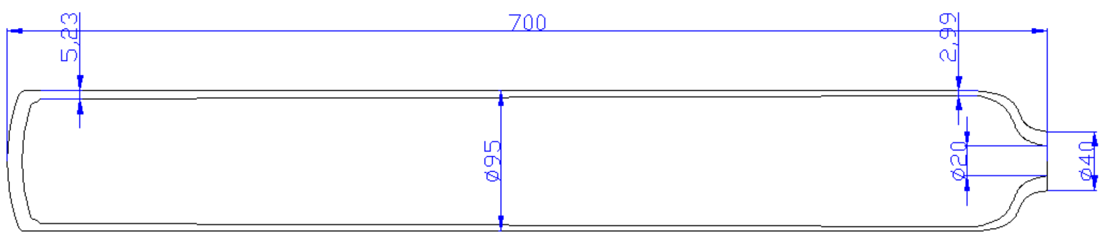


Figure 6. Tank Dimensions

Features of Tanks Used in The Experiments

Three different heat treatments is subject to availability for samples which are used in experiments;

F: The version after fabrications (manufactured) This condition; without any further action in order to change the strength or stiffness, refers to the physical structure after being manufactured.
T4: Solution heat treatment is applied and brought to steady state with natural aging. (500-525 ° C - 5 hours - rapid cooling in water)
T6: Solution heat treatment is applied and hardened with artificial aging (thermal heat treatment) (170-175 ° C - 12 hours of rapid cooling in water.
Metallurgical properties after primer production of 6XXX series aluminum alloys which is prepared for using in the experiments are shown in Table 1(Anonymous, 2009).
Chemical composition limits of EN-AW 6060 and EN-AW 6063 alloys which are typical 6XXX alloys are shown in Table 1. (EN 573-3 , Taken from Table 6)

Between 6XXX series alloys most commonly used alloys are 6060, 6063 (according to EN and new TS) and AlMgSi0.5 (according to DIN and old TS). These are generally the same as the chemical composition but some nuances may be seen.

Table 1: Chemical composition of Aluminum alloys 6060 and 6063 (Anonymous, 2009).

Element	EN AW 6060	EN AW 6063
Si :	0,30 - 0,6	0,20 - 0,60
Mg :	0,35 - 0,6	0,45 - 0,90
Fe :	0,10 - 0,30	0,35 (max.)
Cr :	0,05	0,10 (max.)
Cu :	0,10	0,10 (max.)
Zn :	0,15	0,10 (max.)
Mn :	0,10	0,10 (max.)
Ti :	0,10	0,10 / (max.)
Other :	0.05 % max. each total 0.15 % max.	0.05 % max. each total 0.15 % max.

Tensile Test

Pulling curves were obtained from tanks by preparing tensile test samples for tank modeling in ANSYS and linear static analysis. The samples were prepared in wire erosion machines. 3 samples are taken from the surface of the tank in longitudinal direction and their avarage is taken. Specimens for the tensile tests are prepared according to TS 138 EN 10002-1 (Test piece type of: 1). The sample sizes are shown in Figure 7.

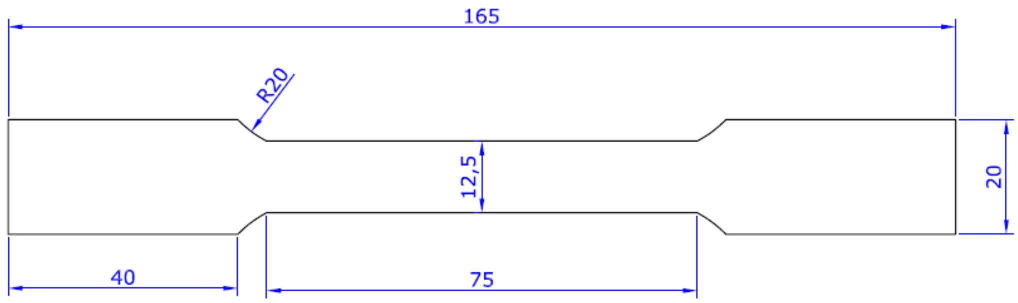


Figure 7. Dimensions of the tensile test samples coming out from the pipe according to TS 138 EN 10002-1

Graphs generated according to tensile test results are shown in Figure 8.

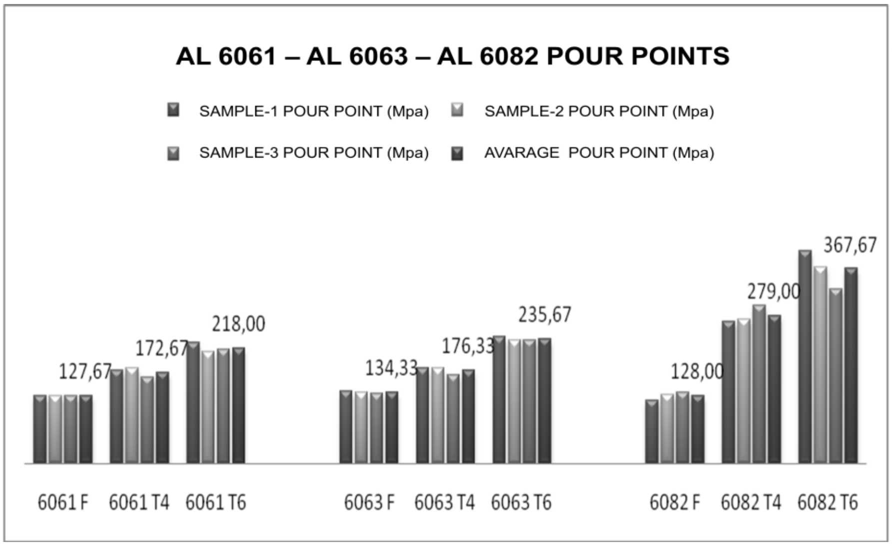


Figure 8. Pour Point Results Of Al 6061-Al 6063-Al 6082 Alloys Obtained By Tensile Tests

2.3. Finite Element (Ansys) Analysis

Finite element analysis was carried out with ANSYS software.

As an example bar pressure stress distribution of the tank which had AL 6082 T6 heat treatment is shown Figure 9.

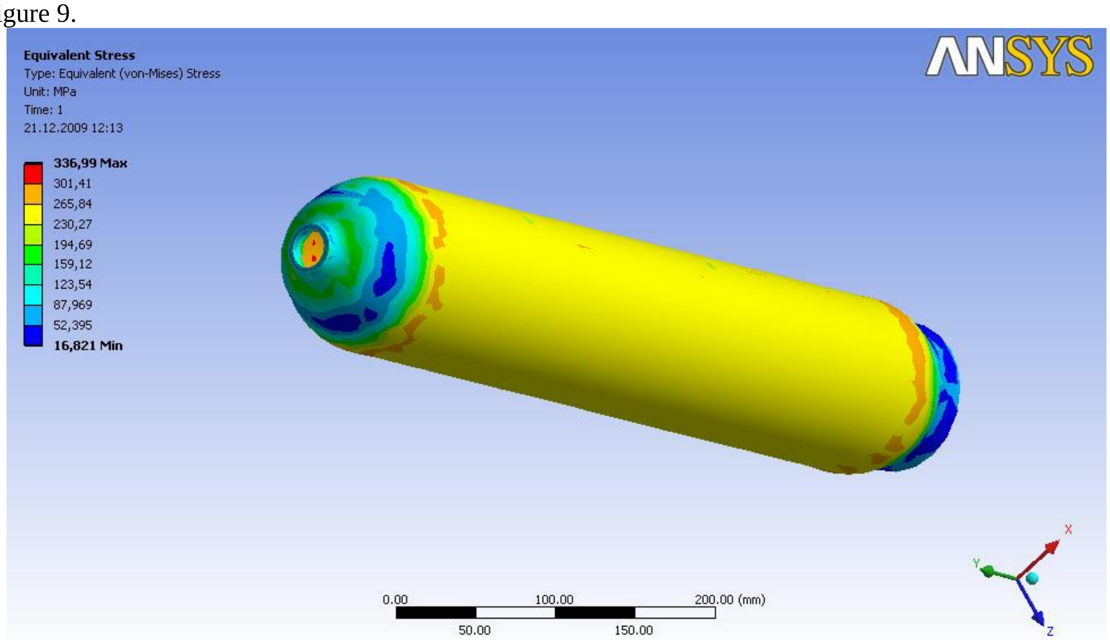


Figure 9. 6082 T6 201 Bar ANSYS Equivalent Stress Results

2.4. Hydrostatic Pressure Tests

Hydrostatic pressure tests for samples were carried out in Aygaz facilities in Gebze. A sample application after ruture tests is shown in Figure 10. Explosion pressure values of all samples are shown in Figure 11.

Figure 10. View of 6061 T6/1 Sample After Hydrostatic Pressure Test

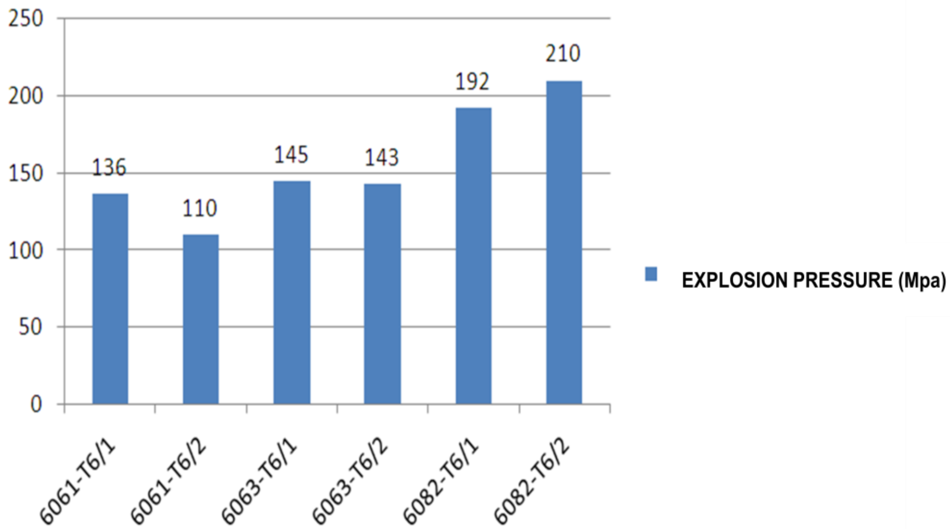
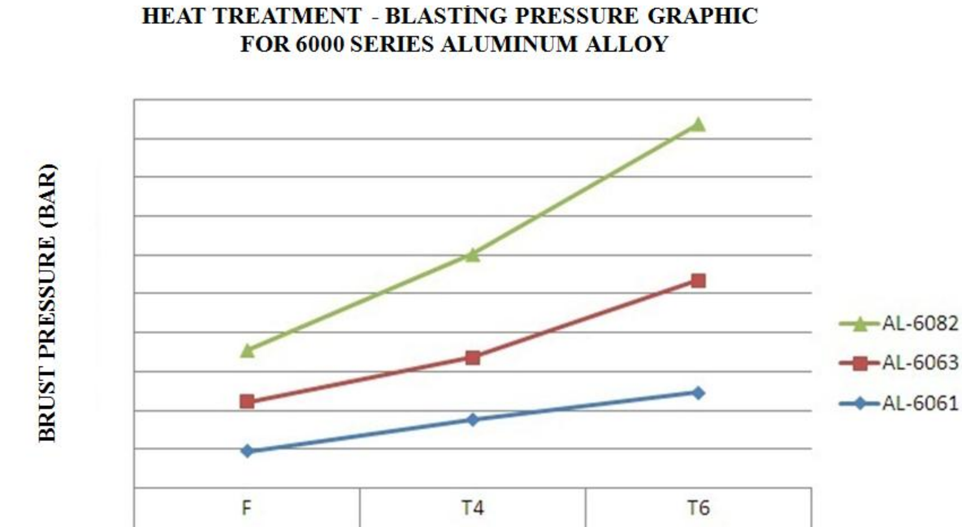


Figure 11. Hydrostatic Pressure Test Results

Heat Treatment State Chart and Explosion Pressure Graph of the hydrogen tube liner prototypes produced from 6000 Series aluminum alloy are shown in Figure 12;



	F	T4	T6
AL-6082	66 Bar	132 Bar	201 Bar
AL-6063	64 Bar	80 Bar	144 Bar
AL-6061	47 Bar	88 Bar	123 Bar

Figure12. Heat Treatment - Blasting Pressure Graphic for 6000 Series Aluminum Alloy

Explanations:

F: Without heat treatment T4: T4 With heat treatment T6: T6 With heat treatment

RESULTS

Hydrostatic pressure test results are calculated by taking the avarages of the results performed for each sample for more than one time. Two pressure tests were carried out for each sample to get the right data. In both without heat treatment, T4 and T6 heat treatment 6082 aluminum alloy provided the best strength properties.

Even if the tubes which are manufactured under Santez can not find a chance to be used for hydrogen storage, will have the chance to be used for compressed natural gas (CNG) storage.

Composite tubes are safe. Can be mounted under the vehicle. Luggage storage volume will grow.

We should have a leading position in implementation of hydrogen technologies in many areas with using our country's manufacturing infrastructure and manpower advantages in the manufacturing and efficient use of tanks.

Testing standards in design of hybrid vehicles should be searched and approved by an authorized organization.

Majority of prototype hydrogen storage tanks are 350 bar pressure operating tanks. With recent studies, pressure values are doubled and more hydrogen can be stored in the same volume. The first time in our country, tubes with 700 bar working pressure are manufactured within the context of Santez-123 project, supported by the T.C. Ministry of Industry. Studies for the compliance with the standards and commercialization are currently being performed. When the other parallel studies are finished, costs of hydrogen energy equipment which is being imported will decrease and prototype manufacture will be accelerated in our country as well as in developed countries.

Since the costs of batteries and fuel tanks imported from abroad are expensive the initial investment where hydrogen technology will be used, is so high. Therefore we should start to produce regarding domestic equipment as soon as possible.

In this study it is found that the high-pressure resistant thin-walled aluminum alloy tubes' strength properties are limited to 20MPa.

All related tests and quality criteria of these tanks are given in TS EN 1975. (TS EN 1975).

ACKNOWLEDGEMENTS

This research was carried out under the San-Tez 123 Project supported by the Ministry of Industry and Trade. At every stage of this work the Ministry of Industry and Trade, General Directorate of Industrial R & D and Sakarya University Head of the Scientific Research Projects Commission showed significant supports. Elimsan Corp. was also appreciated because of succesfull application of the project. Authors present appreciation to all authorized posts for their continues encouragement and support during the realization phases of the project.

REFERENCES

Alnıak, M.O., Oğur, A., Ertürk, M., Karakaya, Ç., Güneş, İ. (2008). *Yüksek Basınca Dayanıklı Kompozit Hidrojen Tankı İmalatının İncelenmesi*. VII. Ulusal Temiz Enerji Sempozyumu, UTES'2008, İstanbul-Turkey.

Alnıak, M.O., Oğur, A., Ertürk, M., Karakaya, Ç. (2009). *Araçlarda Hidrojen Kullanımı*. Uluslararası Katılımlı Nükleer&Yenilenebilir Enerji Kaynakları Konferansı, Gazi Üniversitesi Gölbaşı Kültür ve Kongre Merkezi, Ankara

Alnıak, M.O., Oğur, A., Ertürk, M., Karakaya, Ç. (2009). *Hidrojen Enerjisi ile Çalışan Hibrit Araçların Tasarım ve İmalatındaki Gelişmeler*. Türkiye 11. Enerji Kongresi, Tepekule Kongre ve Sergi Merkezi, İzmir.

Alnıak, M.O., Oğur, A., Ertürk, M., Şenel, F., Karakaya, Ç. (2009). *Yüksek Basınca Dayanıklı Kompozit Hidrojen Tanlarının İmalatı*. Sanayi Bakanlığı Santez Proje Sergisi, WOW Otel, İstanbul-Turkey.

CLEFS CEA – No.50/51, The Hydrogen Pathway, Winter 2004-2005.

Rau, S., Colom, J.S. (2006). *Session 2.4: Pressure Storage Systems II*. Ingolstadt.

http://www.aluminyumsanayi.com/aluminyumprofilgenel.html. Accessed on May 20, 2009.

TS EN 1975. *Transportable gas cylinders - Specification for the design and construction of refillable transportable seamless aluminium and aluminium alloy gas cylinders of capacity from 0,5 litre up to 150 litre*.