Journal Homepage: http://ijcpe.uobaghdad.edu.iq
Iraqi Journal of Chemical and Petroleum Engineering
Vol. 25 No. 1 (March 2024) 37 – 47
EISSN: 2618-0707, PISSN: 1997-4884

Evaluation and Performance Analysis of Liquefied Petroleum Gas Cylinders

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Abstract

This paper presents the experimental results of the tensile, bending, hardness, hydrostatic testing, and microstructural properties of liquefied petroleum gas cylinders from local sources. The burst pressure and fracture sites were also investigated. In addition, know how LPG cylinders are compliant with ISO 4706 requirements as per standard to get approval and acceptance. The tests were performed on three samples (C1, C2, and C3), and all the tests were according to the specification. Tensile testing was carried out at room temperature (23C°) as per ISO 6892-2016. Tensile test specimens with a gauge length of 50 mm were prepared from the sidewall of cylinders. The equipment used is built up around a 250 KN maximum capacity of (Instron Servo-Hydraulic Testing Machine Model 1332). At the same time, micro-hardness testing was carried out as per ASTM A384. Diamond indenter (pyramid) with a face angle of 136° was used. During testing (1kg) load was applied on the sample with a dwell time of 15 seconds. As for bending tests were carried out in accordance with ISO 7438 for all cylinders to evaluate their welding qualities. The results of microstructural characterization show that the carbon content for all samples averaged ~ 0.067 wt.% and manganese ~ 0.46 wt.% and the microstructure was largely ferritic. The tensile strength of the parent metal showed that LPG gas cylinders recorded high tensile strength of ~ 418 MPa on average, yield strength of ~ 291 MPa on average, a % elongation 26.6 (for parent metal), the tensile strength of ~ 449 MPa as average, yield strength of ~ 314 MPa as average, % elongation 32 (for weld metal) and hardness of ~ 143 (kg/mm^2) as average by Vickers scale. Moreover, in the hydrostatic pressure test, the computer controlled electro-hydraulic servo pressure test machine was used. The results of the hydrostatic pressure test were as follows, pressure burst (BP) 103 bar, nominal hoop stress 528 MPa, volumetric expansion 25%, hydrostatic extend ratio 3.9%, sites of failure exist out of welding, and finally no fragmentation observed regarding to fracture types. All samples tested exhibited high resilience to crack propagation which showed ductile fracture after burst and tensile tests.

Keywords: Liquefied petroleum gas cylinders; ISO4706 Requirements; Tensile, bending; Hardness tests; Hydrostatic Testing.

Received on 17/09/2023, Received in Revised Form on 31/12/2023, Accepted on 03/01/2024, Published on 30/03/2024

https://doi.org/10.31699/IJCPE.2024.1.4

1- Introduction

In the beginning, the ISO 4706 standard is a comprehensive specification for all the details about the raw material, manufacturing methods, subsequent heat treatment, use, transportation, and safety precautions, and therefore it was necessary to cover all of that, in addition conducting tests according to the aforementioned specification requires extensive study of several other sub-specifications. In this context, household gas cylinders are usually made of welded low-carbon steel and are filled with a gas consisting mainly of butane (C_4H_{10}) or propane(C_3H_8) or a mixture between them in proportions up to (70–30 %), While less frequently the cylinders are filled with butane. Moreover, we find that both are colorless and odorless at room temperature [1, 2]. On the other hand, to help detect leaks and reduce the risk of explosion a stench agent is added. In this case, ethyl mercaptan is used. This is of benefit because it has a distinctive and bad smell and also because it is non-corrosive, has low Sulphur content, and possesses a boiling point very near that of LPG [3]. On the other hand, it was found that the specific calorific value depends on the chemical composition of the gas, and it was found that the value is equal to 12.78 kWh / kg compared to wood, which is equal to 3.89-5 kWh / kg and for charcoal in the range of (7.5-8.34 kWh/kg). As a fuel, it is used in several important uses or applications, on top of which are vehicles of all kinds, heating homes, hospitals, and government headquarters. Also, it is now increasingly used as an aerosol propellant and a refrigerant, replacing chlorofluorocarbons to reduce damage to the ozone layer.

LPG is nontoxic but highly flammable. Because it is non-toxic, but it has high flammability and therefore it has to be dealt with very carefully in this case all equipment and devices used to store gas or transport must comply with international safety standards to avoid accidents. Therefore, all systems that deal with gas must be subject

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to maintenance and periodic inspection. In this context, gas handling facilities in all its forms must be subject to strict monitoring by government authorities, with an emphasis on preventing the enforcement of fire and explosion incidents. The increasing LPG use increased the likelihood of risk i.e. enhanced the risk of what is known as a boiling liquid expanding vapor explosion (BLEVE). According to several references [4-7] several explosions were observed in public and private properties such as workshops, cafes, houses, cars, trains, etc. repeatedly and resulted in the ignition of several fires and caused side effects, on top of it comes the problems of the environment and what our world suffers today.

As an example of the previously explained serious incidents where standards are not applied, as pointed by D. T. Chondrou et al. [2]. reported that a serious accident occurred on February 4, 2015, at Loutron village, close to the city of Amfilochia, in western Greece, the explosion of an LPG pressure cylinder stored inside a local restaurant. Five fatalities were reported at the time of the incident, 11 were severely injured, and some of them were pronounced dead months later. Accidents involving LPG cylinders for household use may cause fire, explosion, loss of lives, adverse acute or chronic health effects, a threat to public health, and environmental damage. In regards to the process of producing cylinders, we find that they contain stages for processing sheet metal for successive industrial processes, which include blanking, deep drawing and piercing, trimming, and joggling. It is followed as a subsequent step by the welding process for the valve boss, valve guard ring, foot ring, and the two halves. All that follows, as noted by the reference [8] heat treated, tested, shot blasted, painted, and then the valve is attached and tested finally. Whereas, concerning accidents and quality assurance, as noted by R. Akula et. al and C. Kiran et. al [9 - 11] the cylinder material must have a tensile and compressive strength capable of resisting the internal pressures caused by gases. Since the function of the cylinders is to transport the dangerous and flammable gas which is a liquid from the filling unit up to reach the consumer, which is under high pressure and which turns into a gas when released from the cylinder, burnt as gas. Considering that the expansion ratio of gas-liquid is 270:1 at atmospheric pressure. The benefit of it is to make LP-gas more economical to transport and store with large quantities of gaseous fuel in a small container. The containers are normally filled with 80-85% liquid, leaving 15-20% ullage or vapor space for expansion temperature increase.

As noted in scientific articles [4, 12, 13], it was found that high temperatures have a direct impact on increasing pressure, which leads to the explosion of the cylinder, and here is the reason for the presence of a pressure relief valve. Concerning the manufacturing route, we find that the number of two cylinders of each batch (203 cylinders and below) is manufactured subject to acceptance test by methods called destructive tests according to the specification accordance to ISO 4136 for verification of cylinder material properties (yield strength, tensile strength, percentage elongation of parent metal, weld tensile strength, weld joint strength, etc.) as a part of certification process. Whereas, as noted by the references [14, 15] one cylinder is tested for every manufactured lot (403 cylinders and below) for different hydrostatic pressure tests, which is briefly called (hydro-test). This test is considered one of the most important tests that must be conducted on each system under pressure, including the subject of this paper, in which several important characteristics are identified such as (rupture pressure, sites of failure, total volume expansion determination, etc.), as will be discussed in detail during this current paper. Before delving deeper into the pressures in which burst occurs (BP) and as a conclusion, BP is the maximum pressure cylinders can withstand without bursting.

Recently as indicated by Y. Kisioglu et al, Y. Borse et al [16, 17] burst pressure and sites of failure can also be estimated by using FEA approaches. In addition to all that he mentioned previously, the following conditions must be met in the material chosen for manufacturing, and these conditions (1) suitable for formability (2) it has good weldability, (3) no deterioration over time (4) steel used has mechanical properties that able to reaches to desired properties for cylinders after normalizing, stress relieving or stabilizing. To achieve these conditions, this means LPG cylinders must be subjected to inspection and testing which means ensuring that the LPG cylinders are in conformance with ISO 4706. These tests should only be done by qualified personnel. Moreover, the other purpose of the standard (ISO 4706) was also to facilitate agreement on the design and manufacture in all countries. And since the temperatures are different from one country to another and from one season to another. That means the cylinders are subject to a large difference in temperature differences, starting from +65 to -50°C. That makes the pressure inside the cylinders will vary, too. In Europe as an example, the pressure in the propane bottle in the winter amounts up to 0.45 MPa and in summer up to 1.00 MPa. The pressure for the butane-propane mixture becomes 0.20 MPa in winter and 0.65 MPa in summer. Furthermore, when the cylinders work at elevated temperatures (40–50ºC), resulting in a pressure rise up to 1.7–2.0 MPa depending on the liquid mixture contained [4]. As explained previously, it is clear that liquefied petroleum gas cylinders are considered pressure vessels and therefore the utmost caution must be taken into account when dealing with them. To avoid many human, economic, and environmental accidents as previously discussed. Which requires determining the mechanical properties and studying the microstructure, and that was the first objective of the study. Secondly, based on the available information. Data related to the experimental determination of burst pressures (BP) and its failure location in LPG cylinders by the hydrostatic test seems to be limited. That was the most important goal of the current paper. Finally, and after getting all the results. The other goal was to know how LPG cylinders are in compliance to requirements as per ISO 4706 standards (Make sure it fit ISO 4706 requirements) to get approval and acceptance and ensure safety.

2- Experimental Work

Before we enter into the details of the practical part of this study, as is clear from its title, it evaluates the performance of the cylinders according to their specifications, and therefore it was necessary to conduct these tests according to their conditions and compare them according to their requirements, and therefore most of these tests and their evaluation was under this context.

2.1. Cylinders Material

The material used in the manufacture of cylinders is an unformed plate and classified as low alloy carbon steel AISI 1020 (DIN C22) with 3mm thickness as designed according to ISO 4706. And by reviewing most of the references, it was found that they are made by three-piece or two-piece construction. The interest of this current paper will focus on the second type, which is two-piece construction containing only circumferential welds was investigated as shown in Fig. 1. In summary, a manufacturing method that is done by welding the upper domed shape and the lower domed shape, which produced by a pressing machine (deep drawing process) on an unformed plate with 3 mm thickness designated for this purpose. Noting that domed ends can be tori-spherical, Semi-ellipsoidal, or Hemi-spherical in shape. After completing all manufacturing and welding processes, these cylinders have been subjected to a heat treatment process before service. In this study, three liquefied petroleum gas (LPG) cylinders of two pieces were tested and given the following numbers (C_1, C_2, and C_3). Two of them (C_1 and C_2) were for the purpose of the hydrostatic test and the third gas cylinder (C_3) was used to prepare the samples for mechanical properties determination which includes tensile testing, bend testing, and hardness testing. The hydrostatic test includes revealing volumetric expansion (VE), rupture pressure (BP), nominal hoop tresses (NHS), and sites of failure. Moreover, to be sure these household gas cylinders conform to the ISO 4706 requirements. The length of the cylinder (without upper protection collar & bottom height) and outer diameter were measured at 515 mm and 324 mm respectively. The cylinder's bottom height was measured at 50 mm. For more information on cylinder specifications see Table 1. Though, in this study, the effects of hydrostatic pressure testing and manufacturing process on the mechanical properties of gas cylinders were not investigated, I add my voice to the research that says hydrostatic pressure testing alters the properties of the material to a significant degree. And this for me was confirmed by experiments for unpublished private research. There are two main reasons: The first is no samples were available from the raw materials (the sheet metal used to produce the gas cylinders) to compare and assess the extent of changes that occurred. Secondly, this is another major work that requires independent study, hopefully in the future.

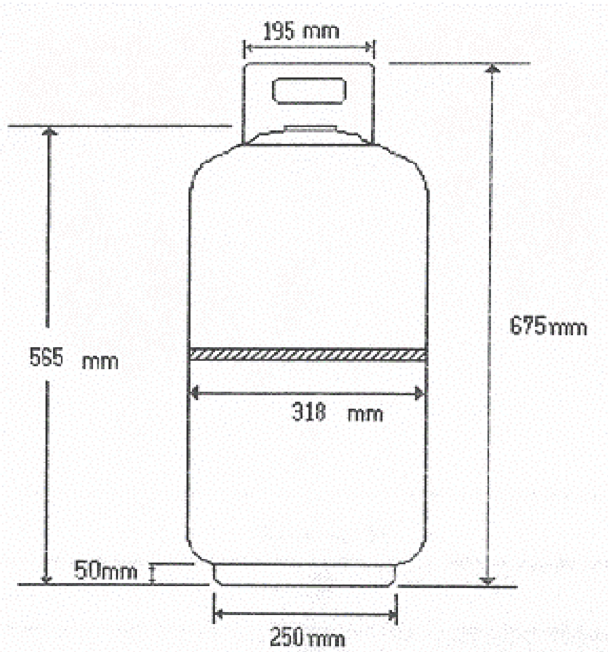

Fig. 1. Design Parameters of LPG Gas Cylinder

Table 1. Specifications of the Gas Cylinders Being Studied

Empty Weight (kg)	Over all Height (mm)	Inner Dia. (mm)	Min. Wall Thickness (mm)	Min Test Pressure (bar)	Water Capacity (L)
18.5	675	318	3.10	30	36
INTERNATIONAL STANDARD REQUIREMENTS					
18±1	668±5	318±1	3.0	25	35±1

2.2. Virtual Examination

In the science of non-destructive detection, which includes a set of techniques, visual detection comes first for several reasons, the most important of which are cost reduction and time-saving, which are the basis for the success of any work. Virtual examination methodology conducted, one of its basics is cleaning the cylinder externally from dirt, grease, etc., followed by removing the external paint by a method called (shot-blasting process) as shown in Fig. 2. to examine the external surface of the cylinder for, 1) superficial defects like dents, cuts, gouges, bulges, cracks, laminations or excessive base wear; 2) heat damage (torch or electric arc burns), 3) other defects (incorrect or unauthorized stamp markings, or unauthorized additions or modifications). Results of the virtual examination showed that the cylinders are in regular form shape and free from previous defects. The virtual examination results also showed that the maximum deviation of the cylindrical part for tested cylinders is equal to 0.1%. Moreover, the difference between the maximum and the minimum outside diameter in the same cross-section is equal to 0.5% of the mean of these diameters (excellent vertical stability). The results obtained values conform with ISO 22991 and ISO 6406 requirements [31, 34 - 37]. In addition, the cylinders are manufactured in a way that ensures comfort at transport, stable at the horizontal level, and contain the following data: owner's name or cylinder manufacturer's name; cylinder mass (empty weight), cylinder capacity, pressure test, year-made, gas-packed weight, gas-packed type, production sequence number. The design parameters of LPG gas cylinders are given in Fig. 1.

Fig. 2. LPG Cylinder after the Shot Blasting Process

2.3. Chemical Composition Analysis

Metallurgical analysis using spectroscopy device was used to determine the chemical composition of cylinders. Table 2 shows the result of the analysis obtained. Annex with Table 2 the requirements as per ISO 4706. This result fits with the values mentioned in reference [18,19]. Therefore, it is classified as low carbon which is used in these applications and also widely used in a variety of industrial and consumer products that are fabricated by forming or welding, or both. Many of the properties of these steels including formability and suitability are related to microstructure. As illustrated in Table 2 and as shown in Fig. 3 (pearlite oriented along the rolling direction) with low carbon content (0.0937, 0.0963, 0.0113) is suitable for pressing or drawing and welding. From the above presented it is clear that the results of the chemical analysis composition of LPG gas cylinders conform with ISO 4706 requirements.

3- Results and Discussion

3.1. Microstructural Characterization

First, we should mention that the goal to link microstructure examination in the current study was for the purpose of ensuring the results obtained by chemical analysis are fits with obtained microstructures examination. And this point has been confirmed. Furthermore, general characteristics of the microstructure were observed under the optical microscope from cylinder samples in the longitudinal direction (the rolling direction). The specimen was ground, polished following standard procedure, and then etched by 2% Nital solution. Examination under the optical microscope was carried out at various magnifications. Microstructure showed that the structure consists of ferrite and pearlite with equiaxed grains as shown in Fig. 3 (R – side) and indicated by the arrow, the ferrite phases are the light patches, whereas the pearlite phases are the black to grey patches comprising of alternating layers of ferrites and cementite (consists of fine lamellar structure).

Table 2. Chemical Composition by wt. % of LPG Cylinders Annex with ISO 4706 Requirements

Cylinder Number	Carbon	Manganese	Silicon	Sulphur	Phosphorus
C1	0.0937	0.4694	0.0122	0.0074	0.0122
C2	0.0963	0.4601	0.0115	0.0068	0.0101
C3	0.0113	0.4520	0.0125	0.0069	0.0123
ISO 4706	0.250 Max.	1.60 Max.	0.45 Max.	0.04 Max.	0.040 Max.

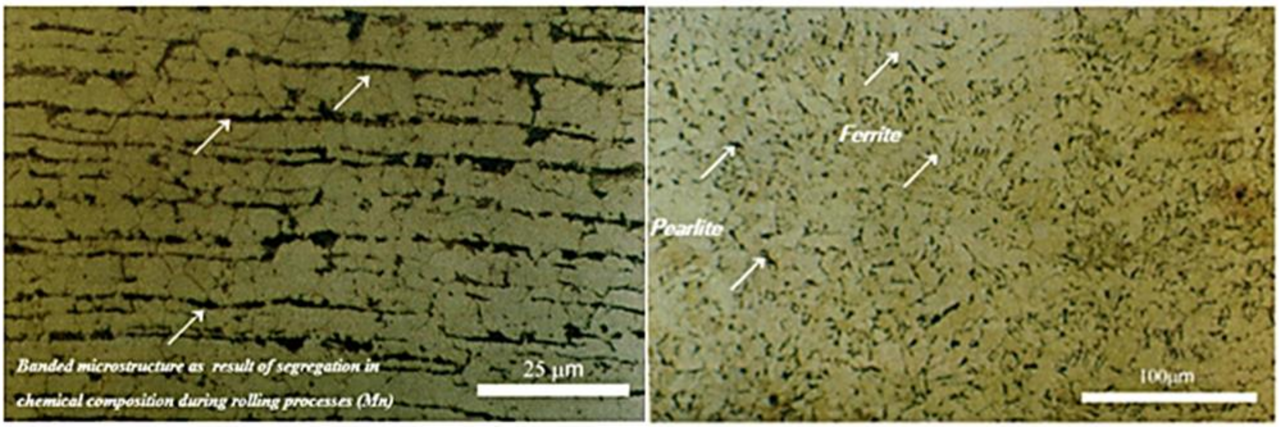

Fig. 3. O.M. image of LPG Cylinder. The Right Shows a Ferrite and Pearlite Structure. Left Shows a Longitudinal Banded Structure Extending in the Rolling Direction

The presence of the uniform and equiaxed shape grains indicates that the cylinders have undergone a subsequent heat treatment process (treatment after the completion of all manufacturing processes) for the purpose of freeing them from residue stresses and also an indication that the recrystallization process was successfully completed, which leads to improving compatibility between strength and ductility. This means expecting the cylinders to pass the tensile test (as a measure of strength) and bending test (as a measure of ductility) with success. Moreover, it will give us: to improve their resistance to the formation of cracks. Non-fragmentation of cylinders when collapse or failure occurs. Also, this is enhanced by the presence of a sufficient amount of manganese ~ 0.45% ~ 0.47% as shown in the sections following. In addition, is one of the requirements of ISO 4706. While at the mid-thickness of the cylinder structure, a banded structure will exist. The reason it exists is due to the segregation of the alloying elements during solidification. Subsequent hot-working operations result in segregation aligned in the direction of working processes, which results in the banded appearance delineated in the microstructure as shown in Fig. 3 (L – side). Its presence was limited to a few bands only, which means that it does not affect the results.

3.2. Tensile Test

As shown in Fig. 4, all mechanical tests were performed on gas cylinders in their final position, i.e. (finished cylinders) and specifically for the parent metal and welds. Knowing that these tests were carried out at room temperature on three rectangular shapes. One test specimen was taken from places (1), (2), for tensile testing and (3), (4) for bending test. The tensile equipment used in the present study is built up around a 250 KN maximum capacity of (Instron Servo-Hydraulic Testing Machine. Model 1332). Tensile test specimens with original gauge length (Lo = 50 mm) for wall thickness for cylinder shell (a > 3 mm) were prepared. A group of specimens was taken from the base metal, while another one was taken across the cylinders and had the weld zone transversely in the middle according to ASME section IX 2013[20]. To reduce the uncertainty of the measurements results i.e. (for accuracy) the samples were tested by the method of the test at room temperature according to ISO 6892-2016 [20] on a universal testing machine calibrated following ISO 7500-1 standard (Testing Machine has class 1 or better class) with a strain rate equal to 2.5×10^{-4} S^{-1} for the purpose to determine, yield strength (ReH), percentage elongation (%) and ultimate tensile strength (Rm) of the parent metal and weld area. In order to minimize bending and to ensure the force is applied axially the tested pieces are gripped by 15 MPa as a preliminary force in accordance of ASTM E1012 [21]. To obtain the mechanical properties, the tensile test of these samples is carried out until fracture occurs. In the steel under study, there are two elements that influence the microstructure, namely carbon, and manganese, which affect the performance of these cylinders. In this context, it was found that as is clear from section 2.3 and section 3.1, which related to chemical composition analysis and microstructural characterization respectively. The results show that the carbon content for all samples averaged ~0.093 - 0.011 wt.% and manganese ~0.45 - 0.47 wt.% and the microstructure was largely ferritic with a small fraction of pearlite as shown in Fig. 3 (R – side). As we know carbon greatly influences the mechanical properties of steel, including its mechanical strength, hardness, and ductility. Increasing the carbon content increases the tensile strength and hardness but decreases the ductility and weldability. As in medium carbon steels. In this case, and to overcome the problem, the appropriate micro-alloying with elements such as niobium, titanium, vanadium, and boron was added and coupled with isothermal treatment processing can provide an excellent combination of high strength and ductility [21-28,38,39]. In this context, steel with low carbon content (typically < 0.3%) is known for its exceptional ductility and malleability. They are easy to weld and form making them suitable for construction, as in the current study, LPG gas cylinder manufacturing. But that will inevitably affect the strength because it will result in the formation almost completely ferrite phase (responsible for ductility). That's why manganese (~ 0.45% - 0.47%) was added to this steel. In order to enhance the formation of pearlite in proportion to which the goal is to obtain compatibility between them. Manganese increases the tensile strength and hardenability of steel. Moreover, wt.% for manganese must not exceed a certain limit. In this context and as reported by B. Ardayfio et al., [40] the optimum to keep manganese content between ~ 0.30% and ~ 0.76% to avoid embrittlement. As we mentioned earlier the existence of banded structure was limited to a few bands only, which means that it does not affect the mechanical properties results. Based on the above analysis, it is expected that the cylinders will pass the mechanical tests successfully, and this is confirmed by the results obtained as in Table 3 therefore all gas cylinders are within the range of ISO 4706 requirements.

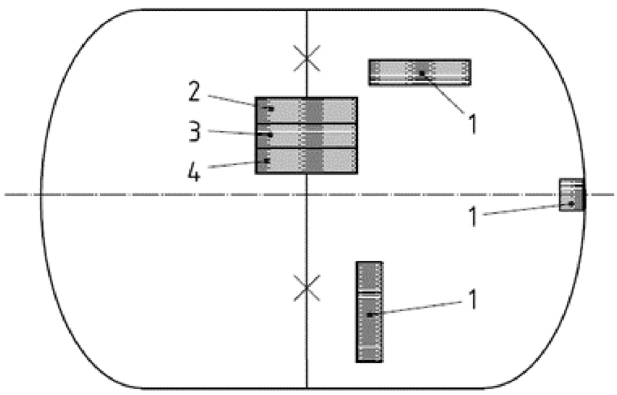

Fig. 4. Sampling Location for Tensile and Bending Testing

Table 3. Tensile Test Results of Parent Metal, Weld Metal and Requirements as per ISO 4706

Types of Tests	ISO 4706 Requirements
Rm (MPa).	360 – 430
ReH (MPa).	Min. 240
Elongation (%).	Min. 25 %
Parent Metal Test Results	
Rm (MPa).	415,422,417
ReH (MPa).	297,293,283
Elongation (%).	26.3, 27.5, 25.9 %
Weld Metal Test Results	
Rm (MPa).	447,448,452
ReH (MPa).	307,310,324
Elongation (%).	31,31,35

3.3. Hardness Test

First, to prevent the samples from burning and distortion due to the effect of the samples on heat, a cutting milling tool machine with a cooling liquid system was used to prepare hardness test samples. After this process (cutting), the samples were prepared to remove all dirt and scratches from their surface by a process called grinding and polishing because their presence affects the accuracy of the results. All samples were tested on the Vickers microhardness device with different surface positions of each sample. To check the consistency and uniformity the micro-hardness testing was carried out as per ASTM A384 [29] with the following specifications: one kilogram load, fifteen seconds dwell time, and 500 X microscopic magnification. The results of the hardness tests are shown in the Table 4. Note that all the readings in the table are an average of five readings.

Table 4. Results of the Average Hardness Test

Sample	Average Vickers hardness (kg/mm^2)
(C_3) – 1	143.6
(C_3) – 2	142.5
(C_3) – 3	141.9

3.4. Bending Test

It is considered that bending test was done for the purpose of identifying ductility of materials and it is a simple and easy way to evaluate the quality of the cylinders from this point of view. In summary, the test is expressed as the extent to which the material is able to resist the appearance of cracks on the outer surface. The, bending test were carried out in accordance to ISO 7438 [30]. As shown in Fig. 4, one specimen from the topside of the circumferential weld, place (3) and one on the underside of the the table are an average of five readings.

circumferential weld, place (4). In this test the samples were prepared based on the thickness of the cylinder, where test piece with round edges were used with a radius not exceeding 1.5 mm ($a \leq 1.5$ mm). The test was done by the way the load perpendicular to the weld zone which has been bent through angle 180°. When evaluating the test, if there are cracks visible on the surface and they were seen with the naked eye without the use of magnifying aids is considered as evidence that test piece withstood the bend test. In this context, we would like to note that the test was performed on the same machine that we used to determine the tensile properties. As a result, all the samples targeted in this study showed that there were no visible cracks or breaking on the surface of the samples when bent at 180 degrees. This means that they conform to the requirements approved in the specifications.

3.5. Calculation of Compressibility of Water

The LPG cylinders, which are completely empty, were placed horizontally and were filled with water calculated accurately by a meter, so they recorded 36 liters (36.0097 kg), and this value is in fact in the range of the values allowed in the specification, which are 35 ± 5 liters. Moreover, the formula used for the calculation of the compressibility of water, C_w is as follows [36]:

$$Cw = m \, x \, P \, x \left(K - \frac{0.68\,P}{10^5}\right) \quad (1)$$

Where (C_w = C in Eq. 1) is the compressibility in square meters per newton (Pa^{-1}); m is the mass of water in kilograms; P is the test pressure (30 bar); K is the factor for individual temperature is equal 0.04604 at 25 °C [36]. In this study, the mass of water (m) in the cylinder at zero gauges pressure = 36.0097 kg, water forced into cylinder to raise pressure to 30 bar = 1440.388 cm^3 (1.440 kg), and the total mass of water in the cylinder at 30 bar = 37.4497 kg, therefore the value of C_w = 51.4963 cm^3

3.6. Burst Tests

In this test, computer controlled electro-hydraulic servo pressure test machine was used. For the safety aspect, the cylinder is placed vertically (Fig. 1) in a special room attached to the machine and equipped with special windows against shock and explosion, so that the engineer operating the machine can monitor the progress of the test through the control panel and live viewing. The test sequence begins by placing the sample in the test chamber and filling it with water and giving a simple experimental pressure not exceeding 5 bar to ensure that there is no leakage before the actual start of the test. The test details are summarized in the specifications attached to Table 1. On the other hand, the requirements of ISO 4706 and here specifically the part related to hydrostatic pressure testing are summarized in numbers in Table 5. The test begins with the gradual increase of the pressure of the cylinder placed in the test chamber by means of a single-acting hydraulic pump (The machine is equipped with two acting hydraulic pump) each of them has its own function, knowing that they can be operated together. As scenes from the thickness homogeneity test (Fig. 5). The wall thickness of the cylinder is variable and is at the highest value near the middle welding of the cylinders (3.4 - 3.5 mm) and gradually decreases to reach (3.1 – 3.2 mm) at the top and bottom, both of which conform to the specifications. Whereas as shown in (Fig. 6), the rupture pressure was 102 bar as the minimum value and 104 bar as the maximum value and therefore the average is 103 bar. The cracking pattern of the cylinders (see Fig. 6). As depicted in figure, fracture of length 170mm by 30 mm wide opening (cylinder C_1) and 170 mm with 20 mm wide opening (C_2).

3.7. Thickness Calculation and Thickness Homogeneity

The actual wall thickness (a) of the cylindrical shell shall be not less than that calculated using Eq. 2. Also, the wall thickness of the ends of gas cylinders (b) shall be not less than that calculated using Eq. 3 [30, 31].

$$a = \frac{P_C \times D}{\frac{20 \times R_0 \times J}{4/3} + P_C} \tag{2}$$

$$b = \frac{P_C \times D \times C}{\frac{20 \times R_0}{4/3} + P_C} \tag{3}$$

(J = 1.0) because our cylinders without a longitudinal weld, (J = 0.9) in case of cylinders with a longitudinal weld, R_0 = minimum value of yield stress = 283 MPa (Table 3), D is the outside diameter of the cylinder as given in the design drawing (see Fig. 1) = (D_i + 2t) = 324 *mm*. In this study D > 150 *mm* i.e. actual thickness must be not less than a_{min} = $(D/250)$ + 0,7 = 2.0 *mm* (a_{min} must be ≥ 2.0 *mm*), a_{min} is the minimum wall thickness of the cylindrical shell. The actual wall thickness was calculated using (Eq. 2) = 2.3 *mm* i.e. (a) > a_{min}. That means it is conform with ISO 22991 requirements [31]. In this study shape factor C = 0.885, the value of which depends on the ratio of height of the semi-ellipsoidal portion in the cylinder (H) to outer diameter of cylinder (D) i.e *H/D* as given in (Table 6). While the wall thickness of the ends of gas cylinders (b) is calculated using (Eq. 3) = 2.0 *mm* i.e. (b_{min} must be ≥ 2.0 *mm*). This value is identical to the results obtained (Fig. 5) and conforms with ISO 22991 requirements. Returning to the thickness examination was done by qualified personnel have Level l (as operator), supervised by Level II and personnel qualified by Level III to oversee the entire ultrasonic examination program as defined in [37]. The wall thickness was checked point-by-point by ultrasound device tester (DM3) with (± 5%) as accuracy. As shown in Fig. 5, we find that the wall thickness of the cylinder is not fixed but changes, although this change is identical to the requirements of the specification, where it was found that the maximum value of this difference is 17% at the ring welding area at the middle of the cylinder, while the lowest value for that difference is 6% at the top and bottom of the cylinder respectively.

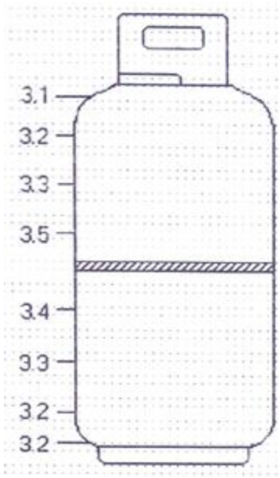

Fig. 5. Homogeneity Thickness Results by mm

Table 5. Hydrostatic Test Results and Requirements

Test Type	Requirements as per ISO 4706
Pressure at burst (BP).	50 bar minimum
Hoop Stress as nominal	Min. 323.5 MPa
Volumetric Expansion	≥ 15% (for TS > 410 MPa)
Hydrostatic extend as ratio	Maximum 9%
Crack Initiation	Not initiate in a welding region
Fracture Type	Not cause any fragmentation
Results of Hydrostatic Test	
Rupture Pressure (BP).	104 and 102bar
Hoop Stress as nominal	533 and 523 MPa
Volumetric Expansion	both 25%
Hydrostatic extend as ratio	3.9 - 4.0 %
Crack Initiation	Fracture did not initiate in the weld
Fracture Types	No any fragmentation observed

Table 6. Relationship between H/D and shape factor C

H/D	C	H/D	C	H/D	C	H/D	C
0.25	1.000	0.31	0.734	0.37	0.621	0.43	0.576
0.26	0.931	0.32	0.731	0.38	0.612	0.44	0.572
0.27	0.884	0.33	0.687	0.39	0.604	0.45	0.570
0.28	0.854	0.34	0.667	0.40	0.596	0.46	0.568
0.29	0.809	0.35	0.649	0.41	0.588	0.47	0.566
0.30	0.775	0.36	0.633	0.42	0.581	0.48	0.565

3.8. Burst failure analysis

In the test to determine the pressure at which the cylinder burst (BP), we can use this test to obtain other important information such as the volumetric expansion coefficient, the nominal hoop stress (NHS), and the magnitude of the volumetric expansion (VE). These hydro-tests reveal Volumetric Expansion (VE), Burst Pressure (BP) and Nominal Hoop Stresses (NHS). These values are considered as critical parameters in hydro-testing of LPG Cylinders [16,31-33]. This information as noted by Y. Kisioglu et al [32] it can help us to identify other important engineering properties. In the experiment of determining the rupture pressure (BP) as in Fig. 6, it was found that the beginning of crack initiates at the top of the cylinder exactly at its middle but above the ring welding area and then it continues to expand longitudinally as shown in Fig. 6.

Fig. 6. Showing the Crack Shape, Length and Position Relative to Welded Region

3.9. Hydrostatic Test

As noted earlier in clause 3.6, the test must be carried out using a device that meets the conditions of the specification. Two of the samples numbering (C_1 and C_2) were subjected to a hydrostatic pressure test. of 30 bar (minimum permissible test pressure Pt min = calculation pressure Pc = 30 bar), while retaining this pressure for a period of time of 30 seconds. Only cylinders for commercial butane service (Pc = Ptmin = 15 bar). Knowing that during this period which is thirty seconds we do not seen any evidence of pressure drop or leakage. This is acceptable and consistent with the references [33-35] which state that the presence of any pressure drops or any leakage outside the cylinder body or on the welding joints is a confirmed indication of the failure of the cylinder for use. In addition to what was mentioned. In addition to the above, the rate of pumping water inside the body of the cylinder should not exceed five times the capacity of the water inside the cylinder per hour, meaning that the pressure is not allowed to increase suddenly, but must increase gradually until the test pressure is reached.

3.10. Total Volume Expansion Determination

The total volume expansion determination sometimes called hydrostatic stretch test. In this test, the cylinder is filled with water and this quantity is calculated or measured and found equal to V1 (36009.7 cm^3). This is what expresses the original volume of the cylinder (before any pressure is applied). Now the volume cylinder V1 is gradually pressed with water until we reach 30 bars for a minimum period of 60 seconds and at this moment, the amount of water that has entered the cylinder is accurately monitored by the machine tools. And it was found that the amount of water that entered is equal to V2 (37450.088 cm^3). And the water capacity in the cylinder was calculated again after removing the pressure and by the process of re-pumping the pressure it was found that the amount of water entering and recorded on the machine numbers is equal to V3 (36065.26 cm^3). Based on these results, it is now possible to calculate the total volumetric expansion, which is equal to (1440.388 cm^3), which is the difference between V1 and V2. While the difference between V1 and V3 gives or represents the amount of permanent expansion (PE = 55.56 cm^3). Therefore, as indicated in some references [34-36] the ratio of hydrostatic extend or percent total volume of expansion (%TE) must be less than 9% or 1/5000 of the original cylinder volume (which less), to say that the cylinder passed the test. In this case, the total volume of expansion, TE = the amount of water pumped to the cylinder in order to increase the pressure to 30 bar (1440.388 cm^3) minus compressibility of water (C_w) which equal (1388.89 cm^3). As result, % TE = (PE / TE) * 100 = 3.9 – 4.0 %, for both cylinders C_1 and C_2 respectively. The results obtained are fully in accordance with ISO 4706.

3.11. Determination of Total Permanent Volume Expansions

As indicated in Fig. 6, the shape of the balloon (circumferential and longitudinal expansions) is an indication of a permanent deformation that has occurred, but in all cases, it is important to calculate it because there is a limit to the deformation allowed in the ISO 4706 standard, which requires that these values do not exceed the number ≥ 15% of the initial volume of the cylinder. The magnitudes of expansions measured manually from the LPG cylinders after burst experiments. Based on these measurements, the permanent volume expansions were about 24% ±1 of the initial volume of the cylinders. In other terms, the amount of permanent volume expansions can be calculated by dividing the volume at which the cylinder burst (9002.425 cm^3) / original volume (36009.7 cm^3) × 100 = 25%, where (9002.425 cm3) is the amount of cylinder volume increase and is registrar on the hydrostatic test machine at the same second of cylinder burst. This obtained result conform with ISO 4706 requirements.

3.12. Hoop Stresses Calculation

Initially the cylinder used previously in the volumetric stretch test can be used for this purpose. In this test, the cylinder subjected to an increasingly and continuous hydrostatic internal pressure until it bursts. Internal pressure of cylinder at which its burst is noted and recorded as burst pressure. Based on that burst pressure nominal hoop stresses can be calculated using Eq. 4 [34, 41].

$$Hoop\ Stress = \frac{\mathrm{Pi\ Di}}{2t} \quad (4)$$

Where Di = internal diameter by mm, Pi = internal hydrostatic pressure at bursts, t = minimum thickness of the cylinder by mm. Using the previous Eq. 4, it is possible to calculate the hoop stress. Where it was found that the values of this stress are equal to 533 and 523 MPa for C_1 and C_2 cylinders respectively, which conform with ISO 4706 requirements.

4- Conclusions

Most advantageous in the present study, is to ensure safe pressurization and to analyse found indications after the tests in more detail. This research studies the evaluation and performance analysis of LPG cylinders by practice methods. The experiments were carried out on three LPG cylinders C_1, C_2, and C_3. Three samples are extracted from each of LPG cylinders for each of tensile test, bending test and Hardness test according to ISO 6892-2016**,** ISO 7438 and ASTM 384 standards from each of LPG cylinders to examine the mechanical properties. In addition, metallographic inspection and chemical analysis was also carried out, for the purpose of ensuring that the results of the chemical analysis are fits with microstructures images obtained by optical microscopy. While the purpose of the current paper also was to determine experimentally the total volume expansion, rupture pressure, hoop stress and sites of failure. Results values obtained are compared with ISO 4706 requirements (Refillable welded steel gas cylinders). As a summary, evaluation and performance analysis of LPG cylinders in this study is conform with ISO 4706 requirements. Therefore, the LPG cylinders is expected to be in safe side and they can be used without any accidents.

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تقييم وتحليل أداء اسطوانات غاز البترول المسال

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الخلاصة

أسطوانات غاز البترول المسال هي نوع من أوعية الضغط التي تتطلب أعلى درجات الاحتياط والحذر لتخزين الغازات المضغوطة وبسبب ان ضغوط الانفجار ومواقع الفشل لأسطوانات غاز البترول المسال يبدو أنها غير متاحة بالقدر الكافي في المراجع العلمية لهذا كان تركيز هذة الورقة الحالية على تلك النقطة بالاضافة لمعرفة سلوك تلك ألاسطوانات للمتطلبات الدولية وفقا للمواصفات المعتمدة وذلك لغرض الحصول على الموافقة والقبول. وفي هذة الدراسة تم إجراء العديد من الاختبارات على أسطوانات غاز البترول المسال قبل الحصول على شهادة الجودة ووضعها في الخدمة. التجارب أجريث على ثلاث عينات من أسطوانات غاز البترول المسال (C3,C2,C1) حيث خضعت جميع الاختبارات للمواصفات القياسية الدولية (ISO 4706). فيما يتعلق بالخواص الميكانيكية تم إجراء ثلاثة اختبارات (الشد، الانحناء، الصلابة) وفقا لمعايير (ISO 6892-2016 ,ISO 7438، ASTM 384)على التوالي. علاوة على ذلك الاختبارات المائية هي اختبارات رئيسية يتم إجراؤها على أسطوانات غاز البترول المسال للحصول على الموافقة والقبول وفي هذا السياق كشفت النتائج عن مقدار التمدد الحجمي الدائم للأسطوانة، وضغط الطوق الاسمي والضغط الداخلي الذي تنفجر عنده الأسطوانة (ضغوط الانفجار BP) وزمن ومواقع الفشل. في هذة الورقة البحثية ايضا تمت دراسة البنية الداخلية باستخدام الميكروسكوب البصري للتاكد من ان النتائج التي تم الحصول عليها عن طريق التحليل الكيميائي تتناسب و الصور المجهرية للبنية الداخلية لجسم الاسطوانات حيث ان هذه المعلومات مهمة لضمان أن تصميم وبناء الأسطوانات آمن ويتم وفقا للمعايير.

الكلمات الدالة: اسطوانات غاز البترول المسال، متطلبات ISO4706، الشد، الانحناء، اختبارات الصلابة، الاختبار الهيدروستاتيكي.