International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 17 (2018) pp. 13321-13334

Charpy Impact and Tension Tests of Two Pipeline Materials at Room and Cryogenic Temperatures

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Abstract

There are a number of material alternatives for pipelines used to transport oil, natural gas and water for long distances. For instance, the majority of pipelines in Libya are made of API 5L X60 steel. The water is transported across the Mediterranean Sea from Turkey to Cyprus island by means of a 80 km long HDPE (High Density Polythylene) pipeline. In the present study, the tensile, Rockwell hardness and Charpy impact tests of the oil pipeline steel API 5L X60 were carried out both at RT (Room Temperature) and also at NT (Liquid Nitrogen Temperature) following either ASTM or EN ISO standards. The same procedure was also followed to characterize the same properties of the HDPE samples. It was found that the Charpy impact properties of the notched API 5L X60 steel samples were reduced drastically from 210J to 5J once cooled down to liquid nitrogen temperature. Nevertheless, the tensile strength at room and liquid Nitrogen temperatures were on average 498MPa and 580 MPa, respectively. The Rockwell Hardness B Scale was found as 65 at room temperature and 88 when cooled in liquid nitrogen. Both the tensile strength and also fracture elongation of the HDPE were reduced when tested at liquid nitrogen temperature. Its tensile strength was found as 470 kPa at RT whereas it dropped to 130kPa at liquid nitrogen temperature. Its fracture elongation was also reduced from 368 % to 65 % when cooled down to liquid nitrogen temperature. The Charpy impact energy of the HDPE was dropped from122 to 44 kJ/m^2 when cooled down to liquid nitrogen temperature. The examination of fractured samples showed that the un-notched API 5L X60 steel samples did not lose their ductile fracture behavior when cooled down to liquid nitrogen temperature. However, this was not observed in the HDPE samples. Thus, HDPE did not appear to be suitable material for sub-zero temperature use.

Keyword: API 5L X60; HDPE; Charpy impact test; tensile test; Rockwell hardness

INTRODUCTION

In recent years, the demand for petroleum and natural gas is gradually on the increase, and the capacity of oil– gas pipeline transportation has been developing greatly. Transmission pipelines have a good safety record due to a combination of good design, materials and operating practices (Macdonald & Cosham, 2005). However, like any engineering structure, the best-designed and maintained pipeline may become defective as it progresses through its design life.

The old pipes laying in the ground are made from the full spectrum of materials, such as cast and ductile irons, asbestos cement, steel, PVC and PE. Steel is arguably the world's most "advanced" material. It is a very versatile material with a wide range of attractive properties which can be produced at a very competitive production cost (Sinha, 1989; Bello, 2007). The complexity of steel arises with the introduction of further alloying elements into the iron-carbon alloy system (Keehan, 2004). The optimization of alloying content in the iron carbon alloy system, combined with different mechanical and heat treatments lead to immense opportunities for parameter variations and these are continuously being developed. Pipeline steels have for many decades been in demand but are becoming vital because there is an expansion in the need to transport liquid as gas fossil fuels over large distances and in dire environments. There are many essential properties for pipeline steels.

High density polyethylene (HDPE) is also used as a drainage pipe material because it is lightweight, corrosion resistant, easy to install, and has a low maintenance cost (Hsuan, 1999). The design of HDPE corrugated drainage pipe is based on the assumption that the pipe will deform and thus relieve stress (Hsuan, 1999). HDPE has become the leading polymeric material for gas and water pipelines due to its many advantageous properties over metal such as lower weight, higher chemical and corrosion resistance, ease of bonding and low delivery, construction and maintenance costs.

Two basic types of impact testing have evolved: (1) Bending which includes Charpy and Izod tests, and (2) tension impact tests (Singh, 2009). Bending tests are most common and they use notched specimens that are supported as beams. In the Charpy impact test, the specimen is supported as a simple beam with the load applied at the center (Mechanical Engineering, 2016). In the Izod test, the specimen is supported as a cantilever beam (Mechanical Engineering, 2016). Using notched specimens the specimen is fractured at the notch (Mechanical Engineering, 2016). Stress is concentrated and even soft materials fail as brittle fractures. Bending tests allow the ranking of various materials and their resistance to impact loading. Additionally, temperature may be varied to evaluate impact fracture resistance as a function of temperature. Both Charpy and Izod impact testing utilize a swinging pendulum to apply the load (Murray et al., 2008). On the other side, the tensile impact test avoids many of the pitfalls of the notched Charpy and Izod bending tests. The behavior of ductile materials can be studied without the use of notched specimens. Pendulum, drop-weights and flywheels can be used to apply the tensile impact load. The notched bar tests are extensively used of all types of impact tests Therefore, the impact measures the energy necessary to fracture a standard notched bar (i.e. notch toughness) applying an impulse load or sudden load (Singh, 2009). The notch provided on the tension side in the specimen locates the point of fracture (i.e. acts as stress concentration point). All forms of the impact test depend upon the swinging pendulum (Singh, 2009). The height from which it drops is a measure of its inertia at the lowest point. There it collides with the specimen, breaking latter and continuing onward in its swing. The height to which the Pendulum rises is dependent upon the inertia left in the pendulum after breaking the specimen (Singh, 2009). The difference between height and the height to which it would have risen, had no specimen been present is a measure, the energy required to break the specimen. This, expressed in Joules (i.e. N-m), is the impact value of the specimen. A high impact value indicates better ability to withstand shock than an impact value (Singh, 2009).

Engineers use metallic materials in designing structures and machine elements which are almost always subject to external loadings and environmental conditions. Metallic materials fail in different modes depending on the type of loading (tensile, compressive, bending, shearing, or torsion) and on the service conditions (temperature and corrosivity of the environment) (Matsagar, 2015). Strength is of little use without toughness and there is usually a trade-off between the two. Toughness is generally expressed as impact toughness since in the majority of circumstances it is measured using a Charpy or Izod impact notch test (Lucon, 2015). Ductility is a measure of the degree of plastic deformation that the metal can sustain before fracture (Keehan, 2004). It is important for a designer to know how much plastic deformation will be experienced before fracture in order to avoid disastrous consequences in certain applications (Keehan, 2004). It may be measured by percentage elongation or area reduction of tensile specimens (Keehan, 2004).

In this work, there are several objectives on studying mechanical testing on API 5L X60 and High Density Polyethylene (HDPE) pipeline. The API 5L X60 is a commonly used in pipeline steel in Libya. The HDPE polyenes are used in the pipeline that transports water across Mediterranean Sea from Anamur (Turkey) to Gecitkale (TRNC). Two main objectives that were needed to be achieved at the end of this study are; (1) to understand the changes in mechanical behavior of API 5L X60 steel and HDPE polymer as a result of impact test and tensile tests and (2) to understand the effect of liquid Nitrogen temperature treatment on the mechanical behaviors with composition variations in the API 5L X60 steel and HDPE samples.

MATERIAL AND METHOD

Material used

All pipe materials used in this experiment were donated and subject to availability from the pipe manufacturers. The equipment used for machining all the samples was a high pressure waterjet machine; this type of machine is widely used in industries for cleaning, surface preparation, and cutting of soft materials. During the mechanical tests, API 5L X60 and HDPE pipe samples were first tested at temperature 25℃ (Room Temperature, RT), then they were cooled in liquid nitrogen temperature, NT, (-196℃) before tested. In this study, spectrometer analyzer was used to obtain the material compositions of steel at both temperatures, RT (without liquid nitrogen treatment) and NT (with liquid nitrogen treatment). The nominal compositions of API 5L X60 are listed in Table 1, which shows the major elements of the API 5LX60 pipeline. It is concluded that testing temperature is effect the chemical composition of API 5L X60. Moreover, the material compositions of HDPE material are tabulated in Table 2. The liquid nitrogen was obtained from Libyan Iron and steel company at Misurata. It was possible to cool the samples down to -196℃ in the liquid Nitrogen.

Table 1. Major elements in the API 5L X60 pipeline steel found in the analysis

No. of test	**Element**			
	Fe	**C**	**Mn**	**Si**
	RT			
1	98.64216	0.15357	0.89711	0.18281
2	98.66088	0.15285	0.88419	0.17987
3	98.66805	0.1503	0.88184	0.17822
Average	98.65703	0.15224	0.887713	0.1803
SD	0.013366	0.001816	0.008219	0.002329
SD%	0.01	1.19	0.93	1.29
	NT			
1	98.7439	0.14326	0.84746	0.16841
2	98.727	0.13341	0.85412	0.16753
3	98.727	0.13266	0.85223	0.16005
Average	98.7228	0.136443	0.85127	0.16533
SD	0.007017	0.005912	0.003433	0.000968
SD%	0.01	4033	0.4	0.58

Table 2. Material properties of HDPE

RT		NT	
Density	≥930 kg/m^3	Density	≥930 kg/m^3
Melt Flow index	0.3 g/10 min	Melt Flow index	0.3 g/10 min
% black carbon	2 -2.5%	% black carbon	2 -2.5%
Young's Modulus	0.55 -1 GPa	Young's Modulus	0.55 -1 GPa
Yield Stress	20 – 30 MPa	Yield Stress	20 – 30 MPa
Stain at failure	≥ 350%	Stain at failure	≥ 350%
Shore hardness	39-40 N	Shore hardness	35-36 N
Toughness	2 – 5MPa.m$^{0.5}$	Toughness	2 – 5MPa.m$^{0.5}$

Table 3. Standard used in this work

Tests	**Pipeline material**	**Standards**
Tensile stress testing	Low carbon steel	ASTM E 8M – 04
Tensile stress testing	HDPE	ISO 6259
Impact test	API 5L X60and HDPE	ASTM E 23 – 00
	HDPE	BS EN ISO 179:1997

All standardized specimen samples were machined according to the standard given in Table 3. These standards specify the necessary measurements, ratios and tolerances the test specimens must obtain in order to yield reliable results. Care was taken during machining to obtain as close to optimal measurements as possible.

Charpy impact testing

Test specimens for Charpy impact test are machined with small API 5L X60 and HDPE pieces according to ASTM E23 – 00 and BS EN ISO 179: 1997, respectively. According to the standards, the dimensions of V-notch specimen of API 5L X60 and HDPE are shown in Figures 1 and 2, respectively.

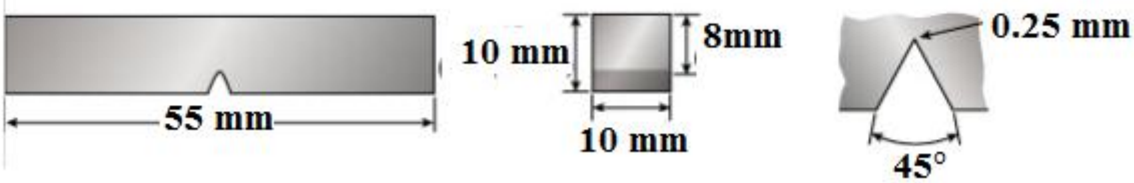
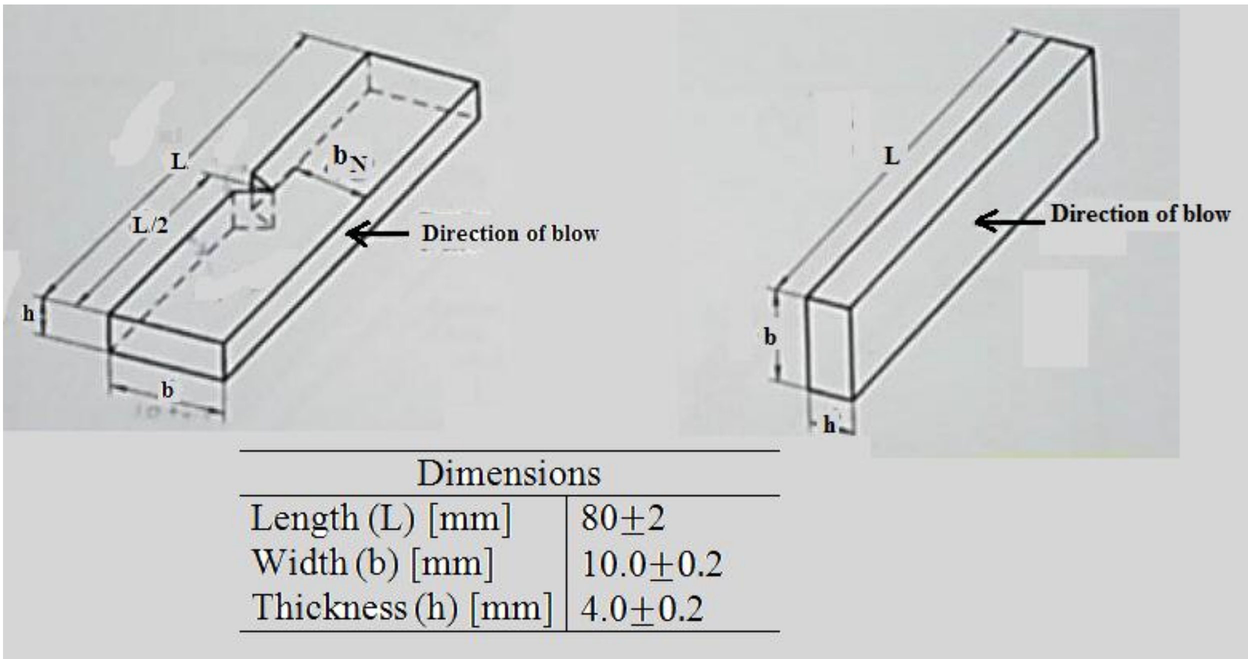


Figure 1. The standard Charpy specimen of API 5L X60 steel



Dimensions	
Length (L) [mm]	80±2
Width (b) [mm]	10.0±0.2
Thickness (h) [mm]	4.0±0.2

Figure 2. The standard Charpy specimen of HDPE

Charpy test procedure

In the present, tests specimens of API 5L X60 and HDPE were examined in Libyan Iron and Steel Company's laboratory and Mechanical Engineering laboratory at Near East University, respectively. Generally, three tests were performed for API 5L X60 and HDPE at various temperatures. The measurements for Charpy impact was done three times for each specimen at different temperature and the results were averaged.

API 5L X60

In this part, the CI-No 30 pendulum (hammer) type with capacity of 30 kg-m was used for testing the impact of API 5L X60 according ASTM E23-00.

The specimens can be divided into two groups before testing in the Charpy impact test as follows

1. Three specimens of API 5L X60 was tested at room temperature (25°C).
2. Three specimens of API 5L X60 was immersed in nitrogen liquid before testing them.

The three tests specimens of API 5L X60 were cooled down in a bath containing nitrogen liquid for tests performed at temperatures -196°C. The specimens cooled down in the Nitrogen bath were immersed in the liquid for 30, 90 and 180 minutes. After sufficient cooling, the specimens were inserted directly into the test machine and tested. For the test, a hammer strokes the notched specimens then the absorbed energy by each specimen was recorded. The tests were performed and energy was recorded using standard Charpy impact machine. Three specimens were tested in each step and the average values were considered.

The measured total energy, E, the energy given by the instrumented Charpy instrument, and the measuring angle, β, of each test were recorded. The measured E values of API 5L X60 can be calculated using equations 3.1 and 3.2, respectively.

$$E = Energy\ (kg.f.m) \times 9.80665 \quad (1)$$

$$E = Pd(cos\beta - cos\alpha) \quad (2)$$

where *Pd* is torque of the hammer, α is starting angle of the hammer before impact (α = 143°) and β is angle after impacting the specimen.

HDPE at NEU

Charpy impact tester XJJ-50 in the mechanical Laboratory of Near East University was used to test the HDPE material according BS EN ISO 179-1:2001. Three specimen samples were tested at 20°C and relative humidity of 65%. For the test, a hammer strokes the notched specimens then the absorbed energy by each specimen was recorded. The tests were performed and energy was recorded using standard Charpy impact machine. Three specimens were tested in each step and the average values were considered.

The measured total energy, E, the energy given by the instrumented Charpy instrument, and the measuring angle, β, of each test were recorded. The measured E values of HDPE can be calculated using Equation 3.3.

$$E = Pd(cos\beta - cos\alpha) \quad (3)$$

where *Pd* is torque of the hammer (8.03878 N.m), α is starting angle of the hammer before impact (α = 150°) and β is angle after impacting the specimen.

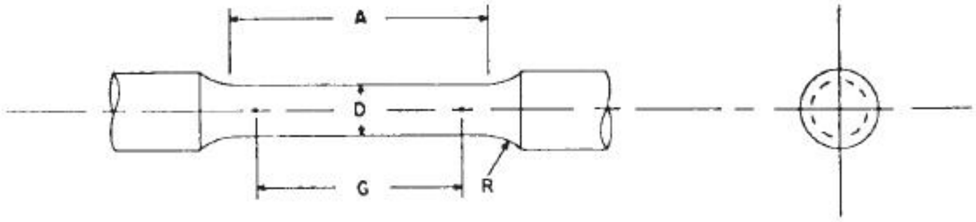
Tensile testing

The tension test is one of the most commonly used tests for evaluating materials. In its simplest form, the tension test is accomplished by gripping opposite ends of a test specimen within the load frame of a test machine; A tensile force is applied by the machine, resulting in the gradual elongation and eventual fracture of the test specimen. During this process, force extension data, a quantitative measure of how the test specimens test provides force extension data that can quantify several important mechanical properties of a material. These mechanical properties determined from tensile tests include the following:

- Young's modulus
- Yield strength
- Ultimate tensile strength
- Elongation

Specimen Preparation of API 5L X60 Pipeline Steel

Tests were conducted in accordance with ASTM E 8M – 04 standard. Test specimens were cut-out of the steel pipe samples and prepared with the dimensions shown in Figure 3. The diameter of the specimen used in this work was 9 mm. The tensile tests were conducted firstly at room temperature (25°C). Then, the test specimens were cooled down in a bath containing nitrogen liquid for tests performed at temperatures -196°C. The specimens cooled down in the nitrogen bath were immersed in the liquid for 30, 90 and 180 minutes. Then the specimens were inserted directly into the test machine and tested.



	Dimensions , mm	
	Standard specimen	Size specimen proportional to standard
	12.5	9
G-Gage length	62.5±0.1	45.0±0.1
D-Diameter (Note 1)	12.5±0.2	9.0±0.1
R-Radius of fillet, mm	10	8
A-Length of reduced section, mm (Note 2)	75	54

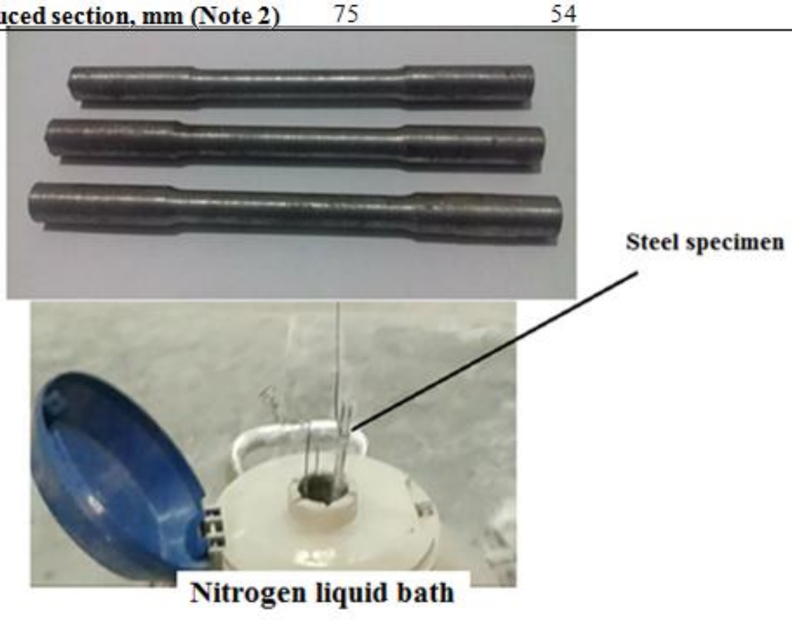


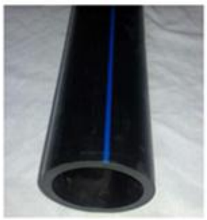
Figure 3. Measurements and tolerances of tensile stress test specimens, machined according to standard

Tensile Testing Procedure of API 5L X60 Pipeline Steel

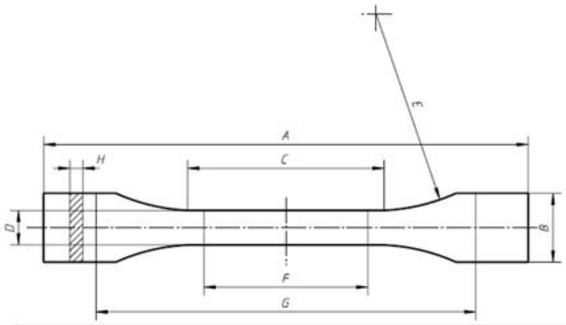
Tensile tests apply forces directly the material sample, usually by using clamps to securely grip two opposite ends of the sample and then pulling the ends away from each other. As the force is slowly increased the stress on the material slowly increases and the sample elongates until it reaches its maximum strain and the material breaks. Ultimate load [kg], Ultimate tensile stress [kPa], and elongation at yield, El, (%) were recorded. Three specimens were tested in each step and the average values were considered.

Preparation of HDPE Specimens

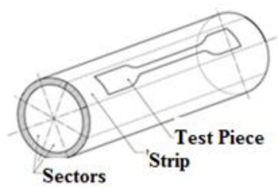
The cutting method for HDPE specimens is described in ISO 6259-1. Cut strips from the pipe as supplied, i.e. which has not been heated or flattened, so that their axis is parallel to the axis of the pipe and the positions from which the strips are taken conform to pipes of nominal outside diameter greater than 63. Cut strips from the length in such a way that they are equally distributed around the circumference of the pipe as shown in Figure 4. The procedure of cutting method for HDPE specimens was occurred at room temperature. Test specimens were cut-out of the HDPE pipe samples and prepared with the dimensions shown in Figure 4 in accordance with ISO 6259-3. The tensile tests were conducted firstly at room temperature (25°C). Then, the test specimens were cooled down in a bath containing nitrogen liquid for tests performed at temperatures -196°C. The specimens cooled down in the Nitrogen bath were immersed in the liquid for 30, 90 and 180 minutes. Then the specimens were inserted directly into the test machine and tested.



(a) HDPE pipeline



(c) Stamp



(b) Procedure described in ISO 6259

Symbol	Description	Dimensions mm
A	Overall length (min.)	150
B	Width of ends	20 ± 0,2
C	Length of narrow, parallel-sided portion	60 ± 0,5
D	Width of narrow, parallel-sided portion	10 ± 0,2
E	Radius	60
F	Gauge length	50 ± 0,5
G	Initial distance between grips	115 ± 0,5
H	Thickness	That of the pipe

(e) Tensile test dimensions

(d) Stamp sample and hydrulic press pipeline

Figure 4. Preparation of test sample from HDPE pipeline material

Tensile Testing Procedure of HDPE

Tensile tests were conducted at various temperatures using Universal tensile tester at Misurata Factory, Libya. Ultimate load [kg], Ultimate tensile stress [kPa], and elongation at yield, El, (%) were also recorded. Three specimens were tested in each step then the average values were considered at each temperature.

Rockwell Hardness Testing

The hardness of steel specimens was tested according to ASTM E 18-00, using the Rockwell Hardness testing machine for API 5L X60 and Shore hardness tester for HDPE at the Libyan of Iron and Steel company workshop.

This test machine is the widely accepted due to its speed, freedom from personal errors, ability to distinguish small hardness difference, and a small size of indentation. The hardness is measured according to the depth of indentation, under a constant load. In order to do the Rockwell Test the following procedures must be followed:

- Position the specimen to be tested close to the indenter.
- Apply the minor load to establish a zero reference position.
- Apply the major load for a specified time period called a dwell time, in this case 60seconds.
- Release the major load leaving the minor load applied.

The Rockwell number represents the difference in depth from the zero reference position as a result of the applied major load. Three specimens were tested in each step and the average values were considered.

The Hardness specimens were conducted firstly at room temperature (25℃). Then, the test specimens were cooled down in a bath containing Nitrogen liquid for tests performed at temperatures -196℃. The specimens cooled down in the Nitrogen bath were immersed in the liquid for various times (30, 90 and 180 minutes). Then the specimens were inserted directly into the test machine and tested.

RESULTS AND DISCUSSIONS

Charpy impact test behaviors

API 5L X60 steel

The results are seen in the last two columns of Table 4. It can be noted that the Charpy absorbed energy values for the un-notched API 5L X60 samples did not change much at room and liquid nitrogen temperatures, Tables 4 and 5. On the other side, for the V-notched samples the Charpy absorbed energy values dropped from approximately 210J to 5J once cooled down from RT to NT. Gotefroid et al. (2014) reported the Charpy absorbed energy was 169 J at RT for V-notched API 5L X60 steel.

The photographs of the test specimens can be seen in Figure 5 and 6. It can be seen that the un-notched samples did not fracture neither at RT or NT. However, notched samples fractured both at RT and NT. Hence the steel was sensitive to notches at both temperatures. As seen n Figure 4.2, the notched samples broke in a ductile manner at room temperature. However, they broke in a brittle manner when they were cooled in liquid Nitrogen. On the other side, it is seen in Figure 5 that the un-notched samples kept their ductility not only at RT but also at liquid nitrogen temperature. Hence, the notch and crack free API 5L X60 steel pipelines can remain safe at sub-zero temperatures.

Table 4. Data from the Charpy impact tests of API 5LX60 steel samples at RT (25℃)

No. of test	V-Notch	Without Notch	V-Notch	Without Notch	V-Notch	Without Notch
	β[°]		**Energy [kgf.m]**		**Absorbed Energy [J]**	
specimen 1	58.50	2.00	21.865	30.00	214.422	294.20
specimen 2	62.00	2.50	20.970	30.02	205.645	296.16
specimen 3	60.00	2.50	21.490	30.02	210.745	296.16
Average	60.16	2.33	21.442	30.13	210.271	295.51

Table 5: Data from the Charpy impact tests of API 5LX60 steel cooled in Liquid Nitrogen

Time	**30 min**					
No. of test	**V-Notch**	**Without Notch**	**V-Notch**	**Without Notch**	**V-Notch**	**Without Notch**
	β [°]		**Energy [kgf.m]**		**Absorbed Energy [J]**	
specimen 1	130.000	6.00	2.680	29.920	26.282	293.415
specimen 2	130.500	6.50	2.570	29.900	25.203	293.219
specimen 3	130.000	5.50	2.680	29.950	26.282	293.709
Average	130.167	6.00	2.625	29.925	25.922	293.448
Time	**90 min**					
No. of test	**V-Notch**	**Without Notch**	**V-Notch**	**Without Notch**	**V-Notch**	**Without Notch**
	β [°]		**Energy [kgf.m]**		**Absorbed Energy [J]**	
specimen 1	140.500	9.50	0.555	29.765	5.443	291.895
specimen 2	140.500	10.00	0.555	29.740	5.443	291.650
specimen 3	141.000	11.50	0.460	29.650	4.511	290.767
Average	140.667	10.33	0.523	29.718	5.132	291.437

Time	**180 min**					
No. of test	**V-Notch**	**Without Notch**	**V-Notch**	**Without Notch**	**V-Notch**	**Without Notch**
	β [°]		**Energy [kgf.m]**		**Absorbed Energy [J]**	
specimen 1	141.000	29.00	0.440	28.820	4.315	282.628
specimen 2	141.500	30.00	0.535	27.680	5.247	271.448
specimen 3	141.500	32.00	0.535	27.370	5.247	268.408
Average	141.333	30.33	0.535	27.525	4.936	274.161

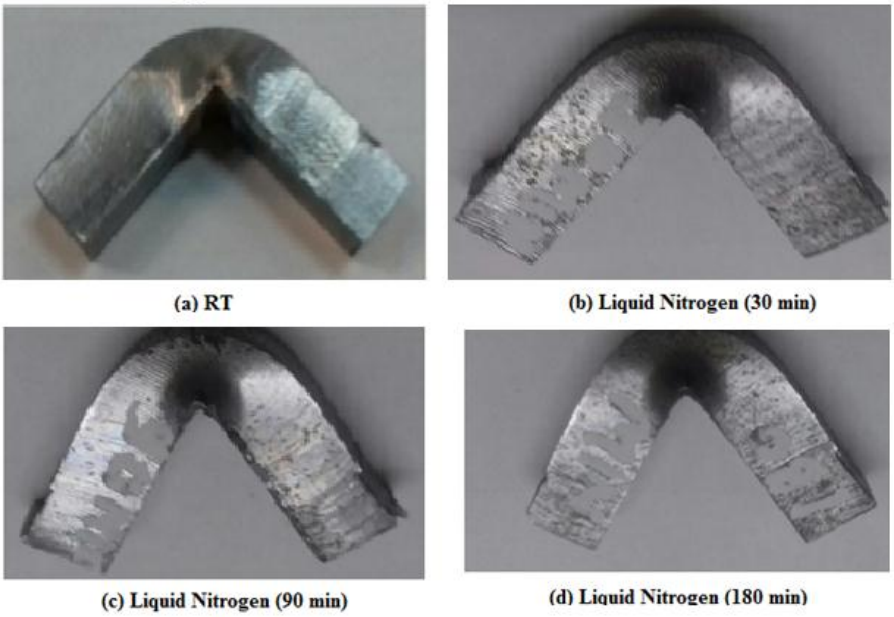


Figure 5. Testing specimens of API 5L X60 (without Notch) after impact test at various temperature (10mm (width)× 10mm (thickness)× 55mm(length))

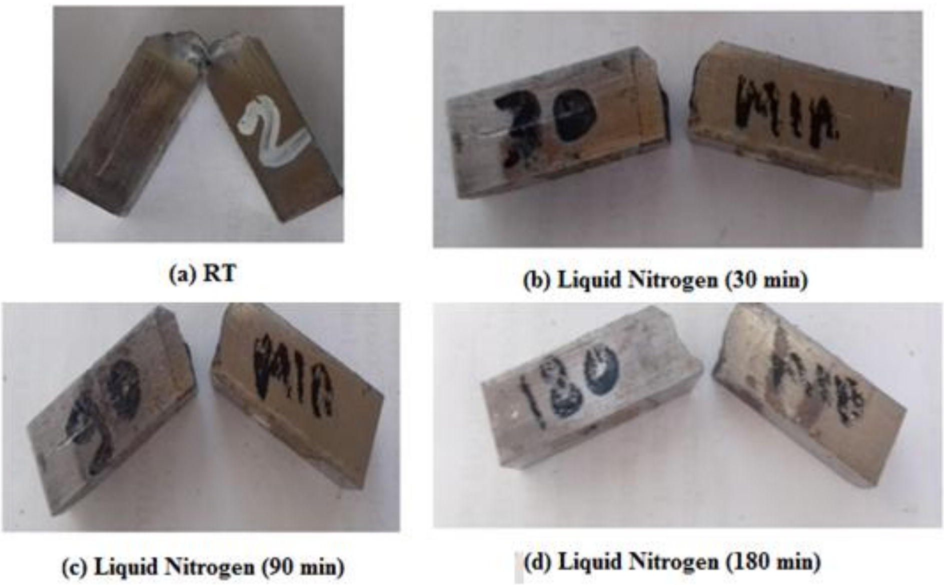


Figure 6. Testing specimens of API 5L X60 (with Notch) after impact test at various temperature (10mm (width)× 10mm (thickness)× 55mm(length)) with 2mm depth (V)

HDPE

Notched and un-notched HDPE samples were tested at 20℃ and 65% relative humidity in the mechanical Engineering Laboratory of Near East University (NEU).

The un-notched samples did not fracture (Figure 7) whereas notched sample fractured (Figure 8). The test data and the Charpy absorbed energies were found 122 kJ/m^2 and 44 kJ/m^2 for the un-notched and notched samples, respectively (Table 6). HDPE specimens were not tested at liquid Nitrogen temperature similar data can be found in the literature (ISO Industries, 2000). Therefore, the room temperature behavior of the HDPE samples were similar to that of API 5L X60 steel samples. HDPE was sensitive to notches.

Table 6. Data from Charpy impact tests of HDPE samples with and without notches

	No. of test	**β[°]**	**Absorbed Energy [J]**	**a [kJ/m^2]**
With notch	1	135	1.28	40.0
	2	136	1.18	35.9
	3	130	1.89	56.1
	Average			44.0
Without notch	1	113	3.82	95.5
	2	93	6.74	163.5
	3	109	4.35	106.0
	Average			121.7

Figure 7. HDPE samples without notch after impact testing at RT carried out in Mechanical Engineering Laboratory, NEU (10mm (width)× 4mm (thickness)× 80mm(length))

Figure 8. HDPE samples with notch after impact testing at RT carried out in Mechanical Engineering Laboratory, NEU) (10mm (width)× 4mm (thickness)× 80mm(length)) with 2mm depth (V)

Tensile Test Behaviors

The photographs of the tension test samples of API 5L X60 steel and HDPE samples are given in Figures 9 and 10, respectively. The tension test data for the two materials are given in Table 7 and 8.

It's seen that in all samples the fracture occurred within the gauge length. In the case of API 5L X60 steel varied a little whither the sample was tested at room temperature or liquid Nitrogen temperature. The sample soaked for 180 minutes in the liquid Nitrogen elongation about 10% more than its counterpart tested at room temperature.

An increase of 17% in ultimate tensile strength was noted. It appeared that cryogenic heat treatment had a positive effect both on tensile strength and fracture elongation of API 5L X60 steel samples.

No specification is given for stress at yield for the HDPE pipe material in the ISO 6259-3:1997 standard. However, it is recommended that the mean elongation at yield must be greater that 350%. The elongation in this study was measured as 369% at room temperature.

The tensile strength at yield and break were 470 kPa and 440 kPa, respectively as seen in Table 8. Sharp decreases were observed both in elongation and also in strength when the HDPE samples were cooled in Liquid nitrogen before tests. For instance, the tensile strength at yield was 150kPa and elongation was 33% when the sample was cooked for 180min in the elongation curves of HDPE samples can be seen in Figure 11.

As in the case of un-notched Charpy impact test samples, the tensile behavior of API 5L X60 steel samples were unchanged when cooled in liquid Nitrogen, Figure 9. The tension test samples were machined following the ASTM E8 standard and were free at any notches and other surface defects. Unlikely, the tension test samples of HDPE lost their ductility when cooled in liquid Nitrogen, Figure 10. The HDPE may not be a suitable material for pipelines that would operate at sub-zero temperatures.

(a) RT (b) Liquid Nitrogen (30 min) (c) Liquid Nitrogen (90 min) (d) Liquid Nitrogen (180 min)

Figure 9. Tensile test specimens of API 5L X60 steel fractured at different temperature at Libyan iron and Steel Company, Misurata Libya (size specimens of 9mm and A-length of reduced section of 54mm)

(a) RT (b) Liquid Nitrogen (30 min) (c) Liquid Nitrogen (90 min) (d) Liquid Nitrogen (180 min)

Figure 10. Tensile test specimens of HDPE fractured at different temperatures at Libyan iron and Steel Company, Misurata Libya (overall length is 150mm and length of narrow parallel -sided portion is 60$\pm$0.5mm)

Table 7. Data from tension test samples of API 5L X60 steel fractured at various temperatures

No. of test	**Area [mm^2]**	**Diameter [mm]**	**Gauge length [mm]**	**Ultimate load [kN]**	**Ultimate tensile stress [MPa]**	**New length [mm]**	**tensile strain [mm/mm]**	**El [%]**
RT								
specimen 1	63.60	9.00	45.00	3.08	484.3	54.00	0.20	20.00
specimen 2	63.60	9.00	45.00	3.13	492.1	54.00	0.20	20.00
specimen 3	63.60	9.00	45.00	3.30	518.9	54.00	0.20	20.00
NT								
Time [min]	**30 min**							
specimen 1	63.60	9.00	45.00	3.50	550.3	54.30	0.21	20.67
specimen 2	63.60	9.00	45.00	3.51	551.9	54.50	0.21	21.11
specimen 3	63.60	9.00	45.00	3.53	555.0	54.20	0.20	20.44
Time [min]	**90 min**							
specimen 1	63.60	9.00	45.00	3.36	528.3	54.77	0.22	21.71
specimen 2	63.60	9.00	45.00	3.79	595.9	54.77	0.22	21.71
specimen 3	63.60	9.00	45.00	3.70	581.8	54.76	0.22	21.69
Time [min]	**180 min**							
specimen 1	63.60	9.00	45.00	3.90	613.2	55.10	0.22	22.44
specimen 2	63.60	9.00	45.00	3.88	610.1	55.00	0.22	22.22
specimen 3	63.60	9.00	45.00	3.87	608.5	54.90	0.22	22.00

Table 8. Data from tension test samples of HDPE fractured at various temperatures

	Area [mm^2]	**Yield Force [N]**	**Yield Elongation [mm]**	**Break Force [kN]**	**Break Elongation [mm]**	**Tensile Strength at Yield [kPa]**	**Tensile Strength at Break [kPa]**	**Elongation [%]**
RT								
specimen 1	100	46.5	11.62	26.7	400.06	470	440	368.97
NT								
Time [min]	**30 min**							
specimen 1	100	46.43	7.58	28.63	31.4	270	250	65.6
Time [min]	**90 min**							
specimen 1	100	52.7	15.12	28.22	29.3	170	140	41.53
Time [min]	**180 min**							
specimen 1	100	55.13	17.52	28.33	21.9	150	130	32.75

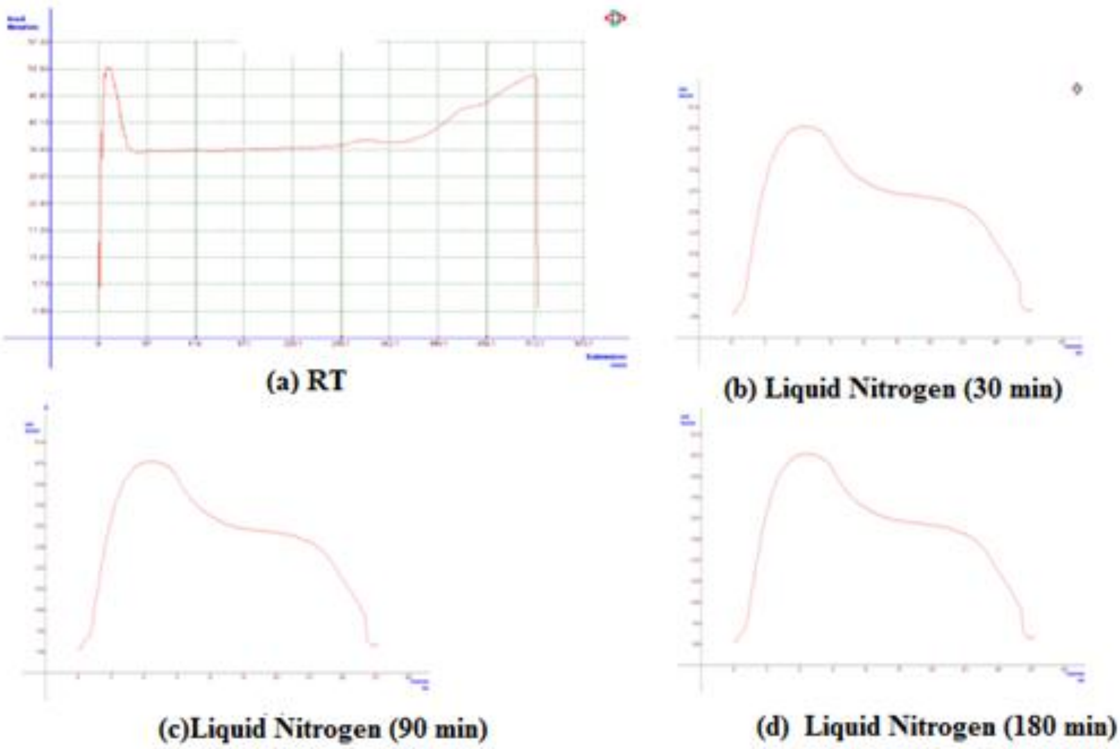


Figure 11. Load vs elongation curves of HDPE samples fractured at various temperatures

Hardness Test

The hardness test data for the API 5L X60 steel and HDPE are given in Table 9. Increases in HRC values are found for API 5L X60 steel samples when cooled in liquid Nitrogen. On the contrary, small decreases in the shore hardness values of the HDPE samples were noted. The results of this study for API 5L X60 steel were compared with those of Godefriod et al., (2014. It can been seen that the mechanical properties of API 5L X60 steel found in this work are in agreement with that of Godefriod et al., (2014).

Table 9. Hardness Testing for API 5L X60 and HDPE samples

Temperature	API 5L X60 (HRB)	HDPE (shore Hardness)
RT	65	45
Liquid Nitrogen (30 min)	81	39
Liquid Nitrogen (90 min)	82.66	40
Liquid Nitrogen (180 min)	87.3	41

CONCLUSIONS

The tensile and Charpy impact tests of the oil pipeline API 5L X60 were carried out both at RT (Room Temperature) and also at liquid NT (Liquid Nitrogen Temperature) following either ASTM or EN ISO standards. Moreover, the effect of RT and NT on the properties of steel API 5L X60 were investigated. The same procedure was also followed to characterize the same properties of a different pipeline material HDPE (High Density Polyethylene) particularly, used to transport water and natural gas.

The results showed that the Charpy impact energy of the un-notched API 5L X60 steel samples did not change much when cooled from room temperature to liquid Nitrogen temperature. On the contrary, the Charpy impact energy of notched specimen was reduced sharply from 210J to 5J once cooled from room temperature to liquid temperature. The tensile strength fracture elongation and hardness were all increased when steel sample was cooled in liquid Nitrogen.

The Charpy impact energies were found as 122 kJ/m^2 to 44 kJ/m^2 for the un-notched and notched HDPE samples tested at room temperature. The samples were not tested at liquid nitrogen temperature. Unlike the API 5L X60 steel, the tensile strength and fracture elongation reduced significantly when cooled down to liquid nitrogen temperature. A small decrease was also noted in its hardness.

It is understood that the un-notched API 5L X60 steel sample did not suffer a ductile to brittle transition when cooled down to liquid Nitrogen temperature. However, this was not the case for the HDPE samples, Hence, pipelines made of API 5L X60 can be used at sub-zero temperatures, but the HDPE is not a suitable material for sub-zero temperature use.

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