Sudan University of science and Technology
College of Graduate Studies
Department of Plastic Engineering

Practical Tests in Quality Control for HDPE Pipes

The effect Of Thickness an Temperature on The burst Pressure of HDPE Pipes

تأثير السمك ودرجة الحرارة على الضغط الانفجاري لانابيب البولى ايثلين عالى الكثافة

A Thesis Submitted in Partial Fulfillment of the Degree of M.Sc. in Plastic Engineering

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الآيـة

قَالَ تَعَالَىٰ:

﴿بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ ١ ٱلۡحَمۡدُ لِلَّهِ رَبِّ ٱلۡعَٰلَمِينَ ٢ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ ٣
مَٰلِكِ يَوۡمِ ٱلدِّينِ ٤ إِيَّاكَ نَعۡبُدُ وَإِيَّاكَ نَسۡتَعِينُ ٥ ٱهۡدِنَا ٱلصِّرَٰطَ ٱلۡمُسۡتَقِيمَ
٦ صِرَٰطَ ٱلَّذِينَ أَنۡعَمۡتَ عَلَيۡهِمۡ غَيۡرِ ٱلۡمَغۡضُوبِ عَلَيۡهِمۡ وَلَا ٱلضَّآلِّينَ ٧﴾

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Abstract

The hydrostatic pressure test was used for the high density polyethylene HDPE-100 Pipes to determine the pressure and time for failure and the relation between the two parameters. The study concluded the failure take place at the portion of lowest thickness. The low thickness of the pipe wall is a result of the fault in the setting of the gap in the angular die which is a processing mistake. The research studied the relation between the stress in the material and the working temperature. The least square method was used to determine this relation.

المستخلص

استخدم إختبار الضغط لمواسير البولي إيثلين عالي الكثافة لتحديد ضغط وزمن الفشل وارتباطهما مع بعض .

ووجد ان السبب الاساسي لفشل الماسورة هو إنخفاض سمك الماسورة عند منطقة ما.

وإنخفاض السمك هو نتيجه لخطأ في ضبط القالب الحلقي للماسورة.

كذلك تم دراسة العلاقه بين الإجهاد في مادة الماسورة ودرجه الحرارة . ومن ثم تم تحديد المعادله التي تربطهما بطريقة المربعات الصغر

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List of abbreviation

Symbol	**Description**	**Units**
HDS	Hydrostatic design stress	N/m^2
σ	Stress	N/m^2
P	Pressure	N/m^2
T	Temperature	K°
s	Thickness	Mm
t	Time	Sec
SCG	slow crack growth	-
n	Number of sample	-
a	Constant	-
b	Constant	-
c	Constant	-
x`	Arithmetic mean	-
y`	Arithmetic mean	-

Chapter One:

Introduction

Chapter One: Introduction

1.1 Preface:

-History of HDPE:

High Density Polyethylene (HDPE) is a versatile plastic that has many practical uses, not the least of which is for the fabrication of pipe. English chemists Reginald Gibson and Eric Fawcett created a solid form of polyethylene in 1935. This discovery was first used commercially was an insulating material for radar cables during World War II. In 1953, Karl Ziegler of the Kaiser Wilhelm institute invented high density polyethylene. In 1955 HDPE was first used as a pipe. For his invention of HDPE, Ziegler won the Nobel Prize for Chemistry in 1963. Since its discovery in 1933, PE has grown to become one of the world's most widely used and recognized thermoplastic materials.(1) The versatility of this unique plastic material is demonstrated by the diversity of its use and applications. The original application for PE was as a substitute for rubber in electrical insulation during World War II. PE has since become one of the world's most widely utilized thermoplastics. Today's modern PE resins are highly engineered for much more rigorous applications such as pressure-rated gas and water pipe, landfill membranes, automotive fuel tanks and other demanding applications. PE's use as a piping material first occurred in the mid 1950's. In North America, its original use was in industrial applications, followed by rural water and then oil field production where a flexible, tough and lightweight piping product was needed to fulfill the needs of a rapidly developing oil and gas production industry. The success of PE's pipe in these installations quickly led to its use in natural gas distribution where a coil able, corrosion-free piping material could be used in the field to assure a "leak-free" method of transporting natural gas to homes and businesses. PE's success in this critical application has not gone without notice and today it is the material of choice for the natural gas distribution industry. Sources now estimate that nearly 95% of all new gas distribution pipe installations in North America that are 12" in diameter or smaller are PE piping.

The performance benefits of polyethylene pipe in these original oil and gas related applications have led to its use in equally demanding piping installations such as potable water distribution, industrial and mining pipe, force mains and other critical applications where a tough, ductile material is needed to assure long-term performance. It is these applications, representative of the expanding use of polyethylene pipe that are the principle subject of this handbook. In the chapters that follow, we shall examine all aspects of design and use of polyethylene pipe in a broad array of applications. From engineering properties and material science to fluid flow and burial design; from material handling and safety considerations to modern installation practices such as horizontal directional drilling and/or pipe bursting; from potable water lines to industrial slurries we will examine those qualities, properties and design considerations which have led to the growing use of polyethylene pipe in North America.

1.2Backgrounds:

• Features and Benefits of PE Pipe

When selecting pipe materials, designers, owners and contractors specify materials that provide reliable, long-term service durability, and cost-effectiveness. Solid wall PE pipes provide a cost-effective solution for a wide range of piping applications including natural gas distribution, municipal water and sewer, industrial, marine, mining, landfill, and electrical and communications duct applications. PE pipe is also effective for above ground, buried, trenchless, floating and marine installations. According to David A. Willoughby, P.O.E., "… one major reason for the growth in the use of the plastic pipe is the cost savings in installation, labor and equipment as compared to traditional piping materials. Add to this the potential for lower maintenance costs and increased service life and plastic pipe is a very competitive product."(4) Natural gas distribution was among the first applications for medium-density PE (MDPE) pipe. In fact, many of the systems currently in use have been in continuous service since 1960 with great success. Today, PE pipe represents over 95% of the pipe installed for natural gas distribution in diameters up to 12" in the U.S. and Canada. PE is the material of choice not only in North America, but also worldwide. PE pipe has been used in potable water applications for almost 50 years, and has been continuously gaining approval and growth in municipalities. PE pipe is specified and/or approved in accordance with AWWA, NSF, and ASTM standards.

Some of the specific benefits of PE pipe are discussed in the paragraphs which follow:

- **Life Cycle Cost Savings** – For municipal applications, the life cycle cost of PE pipe can be significantly less than other pipe materials. The extremely smooth inside surface of PE pipe maintains its exceptional flow characteristics, and heat fusion joining eliminates leakage. This has proven to be a successful combination for reducing total system operating costs.
- **Leak Free**, Fully Restrained Joints – PE heat fusion joining forms leak-free joints that are as strong as, or stronger than, the pipe itself. For municipal applications, fused joints eliminate the potential leak points that exist every 10 to 20 feet when using the bell and spigot type joints associated with other piping products such as PVC or ductile iron. All these bell and spigot type joints employ elastomeric gasket materials that age over time and thus have the potential for leaks. As a result of this, the “allowable water leakage” for PE pipe is zero as compared to the water leakage rates of 10% or greater typically associated with these other piping products. PE pipe’s fused joints are also self-restraining, eliminating the need for costly thrust restraints or thrust blocks while still insuring the integrity of the joint. Notwithstanding the advantages of the butt fusion method of joining, the engineer also has other available means for joining PE pipe and fittings such as electro fusion and mechanical fittings. Electro fusion fittings join the pipe and/or fittings together using embedded electric heating elements. In some situations, mechanical fittings may be required to facilitate joining to other piping products, valves or other system appurtenances. Specialized fittings for these purposes have been developed and are readily available to meet the needs of most demanding applications.
- **Corrosion & Chemical Resistance** – PE pipe will not rust, rot, pit, corrode, tuberculation or support biological growth. It has superb chemical resistance and is the material of choice for many harsh chemical environments. Although unaffected by chemically aggressive native soil, installation of PE pipe (as with any piping material) through areas where soils are contaminated with organic solvents (oil, gasoline) may require installation methods that protect the PE pipe against contact with organic solvents. It should be recognized that even in the case of metallic and other pipe materials, which are joined by means of gaskets, protection against permeation is also required. Protective installation measures that assure the quality of the fluid being transported are typically required for all piping systems that are installed in contaminated soils.

- **Fatigue Resistance and Flexibility** – PE pipe can be field bent to a radius of about 30 times the nominal pipe diameter or less depending on wall thickness (12” PE pipe, for example, can be cold formed in the field to a 32-foot radius). This eliminates many of the fittings otherwise required for directional changes in piping systems and it also facilitates installation. The long-term durability of PE pipe has been extremely well researched. PE has exceptional fatigue resistance and when, operating at maximum operating pressure, it can withstand multiple surge pressure events up to 100% above its maximum operating pressure without any negative effect to its long-term performance capability.
- **Seismic Resistance** – The toughness, ductility and flexibility of PE pipe combined with its other special properties, such as its leak-free fully restrained heat fused joints, make it well suited for installation in dynamic soil environments and in areas prone to earthquakes.
- **Construction Advantages** – PE pipe’s combination of light weight, flexibility and leak -free, fully restrained joints permits unique and cost-effective installation methods that are not practical with alternate materials. Installation methods such as horizontal directional drilling, pipe bursting, slip lining, plow and plant, and submerged or floating pipe, can greatly simplify construction and save considerable time and money on many installations. At approximately one-eighth the weight of comparable sized steel pipe, and with integral and dependable leak free joining methods, installation is simpler, and it does not need heavy lifting equipment. PE pipe is produced in standard straight lengths to 50 feet or longer and coiled in diameters up through 6”. Coiled lengths over 1000 feet are available in certain diameters. PE pipe can withstand impact much better than PVC pipe, especially in cold weather installations where other pipes are more prone to cracks and breaks. Because heat fused PE joints are as strong as the pipe itself, it can be joined into long runs conveniently above ground and later, installed directly into a trench or pulled in via directional drilling or using the re-liner process. Of course, the conditions at the construction site have a big impact on the preferred method of installation.

- **Durability** – PE pipe installations are cost-effective and have long-term cost advantages due to the pipe’s physical properties, leak-free joints and reduced maintenance costs. The PE pipe industry estimates a service life for PE pipe to be, conservatively, 50-100 years provided that the system has been properly designed, installed and operated in accordance with industry established practice and the manufacturer's recommendations. This longevity confers savings in replacement costs for generations to come. Properly designed and installed PE piping systems require little on-going maintenance. PE pipe is resistant to most ordinary chemicals and is not susceptible to galvanic corrosion or electrolysis.

- **Hydraulically Efficient** – The internal surface of PE pipe is devoid of any roughness which places it in the "smooth pipe" category, a category that results in the lowest resistance to fluid flow. For water applications, PE pipe's Hazen Williams C factor is 150 and does not change over time. The C factor for other typical pipe materials declines dramatically over time due to corrosion and tuberculation or biological build-up. Without corrosion, tuberculation, or biological growth PE pipe maintains its smooth interior wall and its flow capabilities indefinitely to insure hydraulic efficiency over the intended design life.
- **Temperature Resistance** – PE pipe's typical operating temperature range is from 0°F to 140°F for pressure service. However, for non-pressure and special applications the material can easily handle much lower temperatures (e.g., to –40°F and lower) and there are specially formulated materials that can service somewhat higher temperatures. Extensive testing and very many applications at very low ambient temperatures indicate that these conditions do not have an adverse effect on pipe strength or performance characteristics. Many of the PE resins used in PE pipe are stress rated not only at the standard temperature, 73° F, but also at an elevated temperature, such as 140°F. Typically, PE materials retain greater strength at elevated temperatures compared to other thermoplastic materials such as PVC. At 140° F, PE materials retain about 50% of their 73°F strength, compared to PVC which loses nearly 80% of its 73° F strength when placed in service at 140°F.(5) As a result, PE pipe materials can be used for a variety of piping applications across a very broad temperature range. The features and benefits of PE are quite extensive, and some of the more notable qualities have been delineated in the preceding paragraphs. The remaining chapters of this Handbook provide more specific information regarding these qualities and the research on which these performance attributes are based. Many of the performance properties of PE piping are the direct result of two important physical

properties associated with PE pressure rated piping products. These are ductility and viscous-elasticity. The reader is encouraged to keep these two properties in mind when reviewing the subsequent chapters of this handbook.

• Ductility

Ductility is the ability of a material to deform in response to stress without fracture or, ultimately, failure. It is also sometimes referred to as increased strain capacity and it is an important performance feature of PE piping, both for above and below ground service. For example, in response to earth loading, the vertical diameter of buried PE pipe is slightly reduced. This reduction causes a slight increase in horizontal diameter, which activates lateral soil forces that tend to stabilize the pipe against further deformation. This yields a process that produces a soil-pipe Introduction 11 structure that is capable of safely supporting vertical earth and other loads that can fracture pipes of greater strength but lower strain capacity. Ductile materials, including PE, used for water, natural gas and industrial pipe applications have the capacity to safely handle localized stress intensifications that are caused by poor quality installation where rocks, boulders or tree stumps may be in position to impinge on the outside surface of the pipe. There are many other construction conditions that may cause similar effects, e.g. bending the pipe beyond a safe strain limit, inadequate support for the pipe, misalignment in connections to rigid structures and so on. Non- ductile piping materials do not perform as well when it comes to handling these types of localized high stress conditions. Materials with low ductility or strain capacity respond differently. Strain sensitive materials are designed on the basis of a complex analysis of stresses and the potential for stress intensification in certain regions within the material. When any of these stresses exceed the design limit of the material, crack development occurs which can lead to ultimate failure of the part or product. However, with materials like PE pipe that operate in the ductile state, a larger localized deformation can take place without causing irreversible material damage such as the development of small cracks. Instead, the resultant localized deformation results in redistribution and a significant lessening of localized stresses, with no adverse effect on the piping material. As a result, the structural design with materials that perform in the ductile state can generally be based on average stresses, a fact that greatly simplifies design protocol. To ensure the availability of sufficient ductility (strain capacity) special requirements are developed and included into specifications for structural materials intended to operate in the ductile state; for example, the requirements that have been established for “ductile iron” and mild steel pipes. On the other hand, ductility has always been a featured and inherent property of PE pipe materials. And it is one of the primary reasons why this product has been, by far, the predominant material of choice for natural gas distribution in North America over the past 30 plus years. The new or modern generation of PE pipe materials, also known as high performance materials have significantly improved ductility performance compared to the traditional versions which have themselves, performed so successfully, not only in gas but also in a variety of other applications including, water, sewer, industrial, marine and mining since they were first introduced about 50 years ago.

For a more detailed discussion of this unique property of PE material, especially the modern high performance versions of the material, and the unique design benefits it brings to piping applications.

Material Properties, Viscous-Elasticity PE pipe is a viscous-elastic construction material, Due to its molecular nature, PE is a complex combination of elastic-like and fluid-like elements. As a result, this material displays properties that are intermediate to crystalline metals and very high viscosity fluids. This concept is discussed in more detail in the chapter on Engineering Properties within this handbook. The viscous-elastic nature of PE results in two unique engineering characteristics that are employed in the design of PE water piping systems, creep and stress relaxation.

- **Creep is the time** dependent viscous flow component of deformation. It refers to the response of PE, over time, to a constant static load. When PE is subjected to a constant static load, it deforms immediately to a strain predicted by the stress strain modulus determined from the tensile stress-strain curve. At high loads, the material continues to deform at an ever decreasing rate, and if the load is high enough, the material may finally yield or rupture. PE piping materials are designed in accordance with rigid industry standards to assure that, when used in accordance with industry recommended practice, the resultant deformation due to sustained loading, or creep, is too small to be of engineering concern.
- **Stress relaxation** is another unique property arising from the viscous-elastic nature of PE. When subjected to a constant strain (deformation of a specific

degree) that is maintained over time, the load or stress generated by the deformation slowly decreases over time, but it never relaxes completely. This stress relaxation response to loading is of considerable importance to the design of PE piping systems. It is a response that decreases the stress in pipe sections which are subject to constant strain. As a viscous-elastic material, the response of PE piping systems to loading is time dependent. The apparent modulus of elasticity is significantly reduced by the duration of the loading because of the creep and stress relaxation characteristics of PE. An instantaneous modulus for sudden events such as water hammer is around 150,000 psi at 73°F. For slightly longer duration, but short-term events such as soil settlement and live loadings, the short-term modulus for PE is roughly 110,000 to 130,000 psi at 73° F, and as a long-term property, the apparent modulus is reduced to something on the order of 20,000-30,000 psi. As will be seen in the chapters that follow, this modulus is a key criterion for the long-term design of pepping systems.

This same time-dependent response to loading also gives PE its unique resiliency and resistance to sudden, comparatively short-term loading phenomena. Such is the case with PE's resistance to water hammer phenomenon which will be discussed in more detail in subsequent sections of this handbook.

As can been seen from our brief discussions here, PE piping is a tough, durable piping material with unique performance properties that allow for its use in a broad range of applications utilizing a variety of different construction techniques based upon project needs. The chapters that follow offer detailed information regarding the engineering properties of PE, guidance on design of PE piping systems, installation techniques as well as background information on how PE pipe and fittings are produced, and appropriate material handling guidelines. Information such as this is intended to provide the basis for sound design and the successful installation and operation of PE piping systems. It is to this end, that members of the Plastics Pipe Institute have prepared the information in this handbook.

1.3 Objectives of the research:

The objectives of this study can be summarized in the following points:

1. The relation of the pipe wall thickness with the hydrostatic pressure.

Chapter Two:

Literature review

Chapter Two: Literature review

2.1 Introduction:

HDPE Pipes have been used for piping system in various industries primarily because of its excellent resistance to cursive chemicals, its inherent toughness and ease of installation. HDPE pipe is definitely not substitute for conventional pipes but it is actually superior type product for many applications. The superiority of HDPE pipes are especially proven in the following properties.

2.1.1 HDPE Background and Benefits: For the past 80 years, since its discovery, Polyethylene has established itself as one of the most reliable and versatile thermoplastics on the market. Recently, after the continued success and development of bi-modal HDPE resins throughout Europe, North America has followed suit in its implementation of PE4710 resins (preceded by PE3408 and PE3608 resins). The introduction of these bi-modal resins has demonstrated remarkable benefits, namely in the form of higher pressure ratings, less raw material needed, increased resistance to environmental stress cracks, and longer lifetimes.

2.1.2 Key Benefits of HDPE:

- Smooth interior surface of HDPE allows for high flow characteristics.-Long service life – up to 100 years expected lifetime.

-Versatile – HDPE is used in geothermal, gas, potable water, sewage and manufacturing.
- When HDPE fittings are correctly fused to HDPE pipe it creates a leak-free joint that is just as strong, if not stronger, than the pipe itself.
- Corrosion and chemical resistant
-Toughness and durability of HDPE prevents the propagation of an initial small failure into a large crack, particularly in areas with high seismic activity.
-HDPE has the ability to operate in extreme weather conditions, ranging from 0°F to 140°F in typical pressure service installations. Many PE resins are stress rated to an elevated temperature of 140°F, along with a standard measurement at 73°F. According to the Plastic Pipe Institute, Typically, PE materials retain greater strength at elevated temperatures compared to other thermo plastic materials such as PVC. At 140° F, PE materials retain about 50% of their 73°F strength,

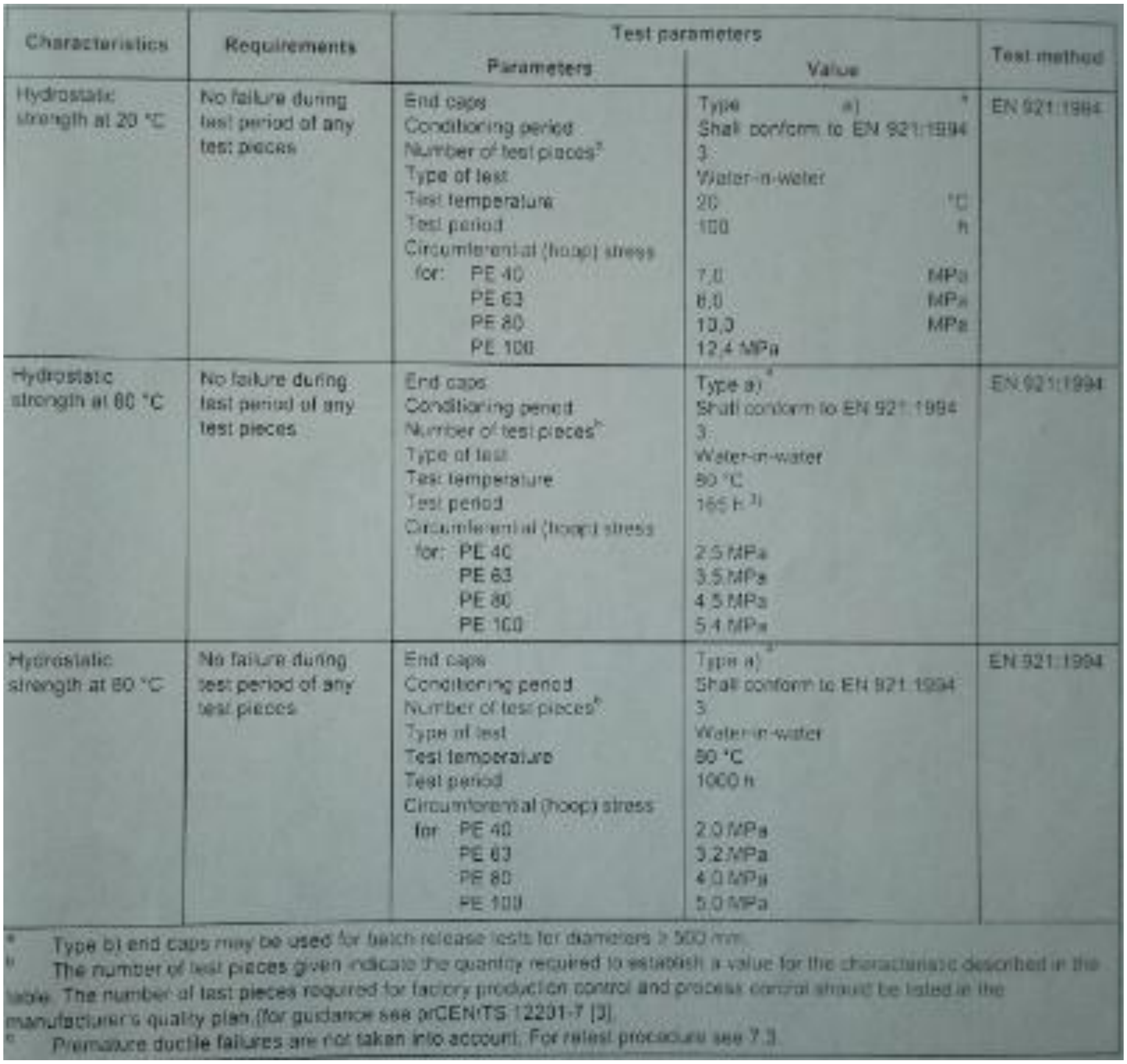
compared to PVC which loses nearly 80% of its 73°F strength when placed in service at 140°F. As a result, PE pipe materials can be used for a variety of piping application ns across a very broad temperature range.

2.2 Manufacturing Process

HDPE granules are fed into the hopper of the extruder which goes into the heated cylinder of the extruder, where the granules melt and are Conveyed (pumped) to the die exist. Now the melt passes through the Die and takes the shape of the die i.e. circular shape and emerges from the exit of the die. It then passes through the calibrator and is forced to take the shape of the inside of the calibrator which is round in diameter by the inside air pressure. This melt solidifies and taken round shape in the calibrator, which is cooled by passing chilled water through it continuously. Now the solid pipe is taken out from the water and is drawn continuously from the die. The speed is adjusted according to the thickness of the pipe required and extruder output. The pipes is either cut into 5 meters length or wound on the winder unit. Generally pipes up to 110 mm diameter can be made on this extruder.

2.3 Characteristics:

The number one characteristic that sets HDPE apart from other pipe types is that it can be made to be flexible. This quality opens HDPE pipe up to a different world of applications than rigid pipe. Another quality of HDPE is that it can melt and re-solidified a limitless number of times without losing any of its favorable qualities. For this reason, most HDPE pressure pipe is made to be 'butt welded'. This is where the ends of two sections of pipe are melted and then pushed and held together, forming a single pipe. These two characteristics make HDPE pipe the perfect candidate to be installed via directional drill. Long lengths of HDPE are welded together and then installed under roads, creeks, rivers, etc by a Horizontal Directional Drill (HDD) rig.



Characteristics	Requirements	Test parameters		Test method
		Parameters	Value	
Hydrostatic strength at 20 °C	No failure during test period of any test pieces	End caps Conditioning period Number of test pieces[b] Type of test Test temperature Test period Circumferential (hoop) stress for: PE 40 PE 63 PE 80 PE 100	Type a) [a] Shall conform to EN 921:1994 3 Water-in-water 20 °C 100 h 7,0 MPa 8,0 MPa 10,0 MPa 12,4 MPa	EN 921:1994
Hydrostatic strength at 80 °C	No failure during test period of any test pieces	End caps Conditioning period Number of test pieces[b] Type of test Test temperature Test period Circumferential (hoop) stress for: PE 40 PE 63 PE 80 PE 100	Type a) [a] Shall conform to EN 921:1994 3 Water-in-water 80 °C 165 h 3) 2,5 MPa 3,5 MPa 4,5 MPa 5,4 MPa	EN 921:1994
Hydrostatic strength at 80 °C	No failure during test period of any test pieces	End caps Conditioning period Number of test pieces[b] Type of test Test temperature Test period Circumferential (hoop) stress for: PE 40 PE 63 PE 80 PE 100	Type a) [a] Shall conform to EN 921:1994 3 Water-in-water 80 °C 1000 h 2,0 MPa 3,2 MPa 4,0 MPa 5,0 MPa	EN 921:1994

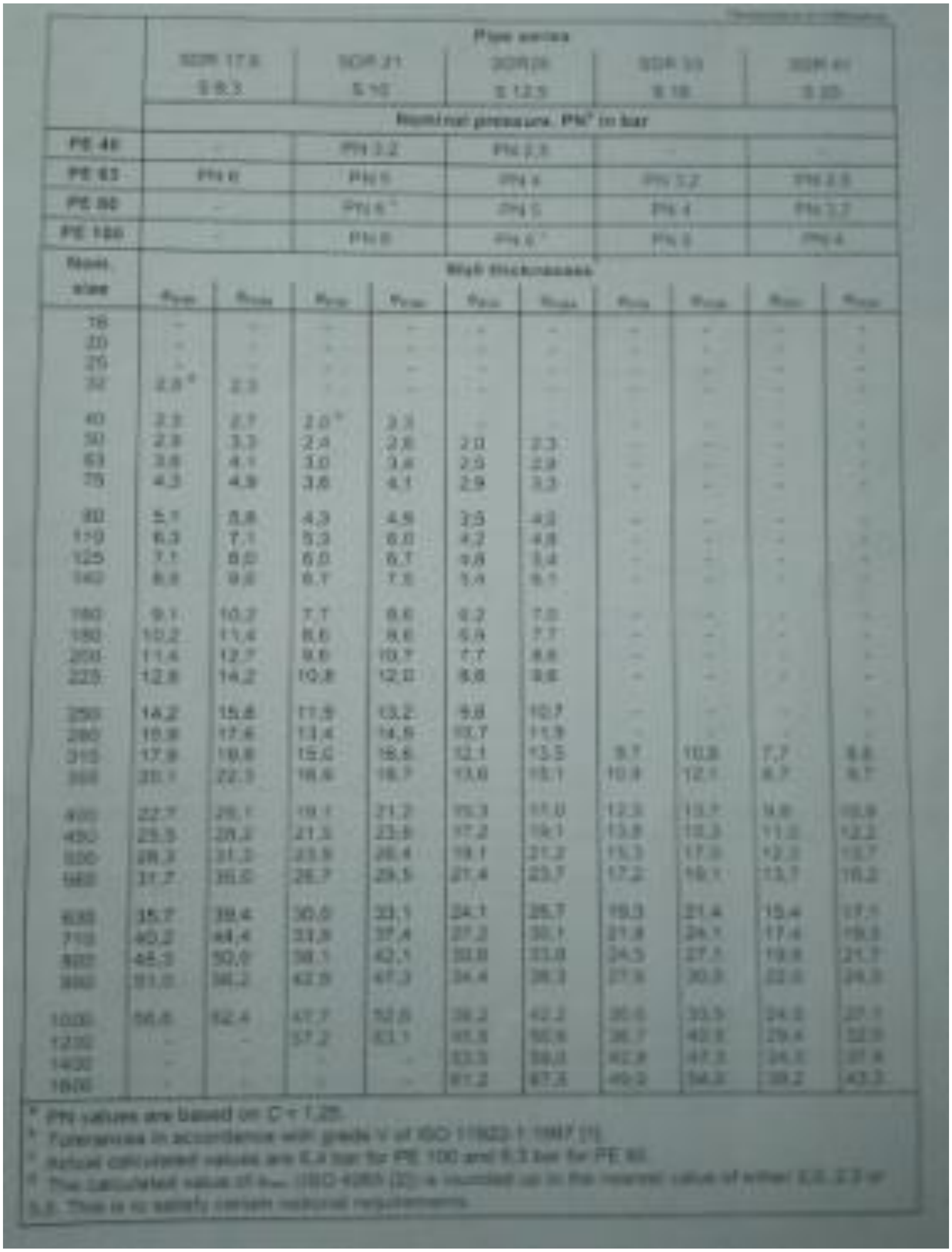
[a] Type b) end caps may be used for batch release tests for diameters ≥ 500 mm.

[b] The number of test pieces given indicate the quantity required to establish a value for the characteristic described in the table. The number of test pieces required for factory production control and process control should be listed in the manufacturer's quality plan (for guidance see prCEN/TS 12201-7 [3]).

[c] Premature ductile failures are not taken into account. For retest procedure see 7.3.

Table (2.1): Mechanical properties

Table (2.2): Wall Thickness



	Pipe series									
	SDR 17.6 S 8.3		SDR 21 S 10		SDR 26 S 12.5		SDR 33 S 16		SDR 41 S 20	
	Nominal pressure, PN[a] in bar									
PE 40	–		PN 3.2		PN 2.5		–		–	
PE 63	PN 6		PN 5		PN 4		PN 3.2		PN 2.5	
PE 80	–		PN 6[c]		PN 5		PN 4		PN 3.2	
PE 100	–		PN 8		PN 6[c]		PN 5		PN 4	
Nom. size	Wall thicknesses[b]									
	e_{min}	e_{max}	e_{min}	e_{max}	e_{min}	e_{max}	e_{min}	e_{max}	e_{min}	e_{max}
16	–	–	–	–	–	–	–	–	–	–
20	–	–	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–	–	–
32	2.0[d]	2.3	–	–	–	–	–	–	–	–
40	2.3	2.7	2.0[d]	2.3	–	–	–	–	–	–
50	2.9	3.3	2.4	2.8	2.0	2.3	–	–	–	–
63	3.6	4.1	3.0	3.4	2.5	2.9	–	–	–	–
75	4.3	4.9	3.6	4.1	2.9	3.3	–	–	–	–
90	5.1	5.8	4.3	4.9	3.5	4.0	–	–	–	–
110	6.3	7.1	5.3	6.0	4.2	4.8	–	–	–	–
125	7.1	8.0	6.0	6.7	4.8	5.4	–	–	–	–
140	8.0	9.0	6.7	7.5	5.4	6.1	–	–	–	–
160	9.1	10.2	7.7	8.6	6.2	7.0	–	–	–	–
180	10.2	11.4	8.6	9.6	6.9	7.7	–	–	–	–
200	11.4	12.7	9.6	10.7	7.7	8.6	–	–	–	–
225	12.8	14.2	10.8	12.0	8.6	9.6	–	–	–	–
250	14.2	15.8	11.9	13.2	9.6	10.7	–	–	–	–
280	15.9	17.6	13.4	14.9	10.7	11.9	–	–	–	–
315	17.9	19.8	15.0	16.6	12.1	13.5	9.7	10.8	7.7	8.6
355	20.1	22.3	16.9	18.7	13.6	15.1	10.9	12.1	8.7	9.7
400	22.7	25.1	19.1	21.2	15.3	17.0	12.3	13.7	9.8	10.9
450	25.5	28.2	21.5	23.8	17.2	19.1	13.8	15.3	11.0	12.2
500	28.3	31.3	23.9	26.4	19.1	21.2	15.3	17.0	12.3	13.7
560	31.7	35.0	26.7	29.5	21.4	23.7	17.2	19.1	13.7	15.2
630	35.7	39.4	30.0	33.1	24.1	26.7	19.3	21.4	15.4	17.1
710	40.2	44.4	33.9	37.4	27.2	30.1	21.8	24.1	17.4	19.3
800	45.3	50.0	38.1	42.1	30.6	33.8	24.5	27.1	19.6	21.7
900	51.0	56.2	42.9	47.3	34.4	38.3	27.6	30.5	22.0	24.3
1000	56.6	62.4	47.7	52.6	38.2	42.2	30.6	33.5	24.5	27.1
1200	–	–	57.2	63.1	45.9	50.6	36.7	40.6	29.4	32.5
1400	–	–	–	–	53.5	59.0	42.9	47.3	34.3	37.9
1600	–	–	–	–	61.2	67.5	49.0	54.0	39.2	43.3

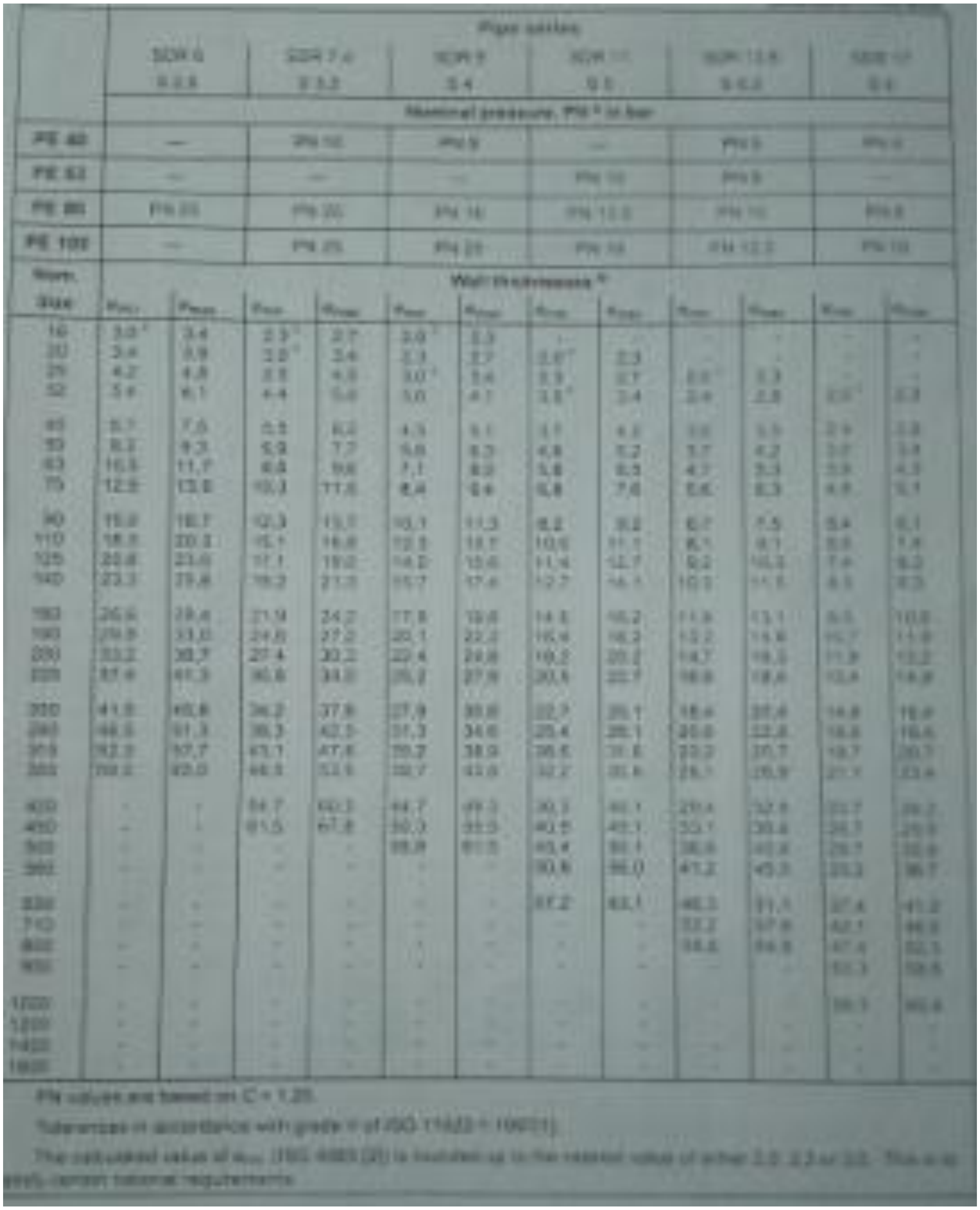
[a] PN values are based on C = 1.25.

[b] Tolerances in accordance with grade V of ISO 11922-1:1997 [1].

[c] Actual calculated values are 6.4 bar for PE 100 and 6.3 bar for PE 80.

[d] The calculated value of e_{min} (ISO 4065 [2]) is rounded up to the nearest value of either 2.0, 2.3 or 3.0. This is to satisfy certain national requirements.

Table (2.3): Wall Thickness



2.4 Background:

2.4.1 HDPE Classification System:

The classification of HDPE materials is presented such that the first 2 letters (PE) specify the resin (Polyethylene); followed by a 4-digit number system, where the first digit denotes the resin's density; the second digit denotes its resistance to stress crack; and the last two digits signify its HDS at 73°F in units of 100.

- Thus, according to ASTM Standard D3350, resin identified as **PE3608**, with a cell class of 345674C, specifically calls out:
  - Density falling between 0.940 and 0.947 g/cm3,
  - A PENT value of 100 hours.
  - And an HDS of 800psi (with a design factor of 0.50).
- Whereas resin identified as **PE4710**, with a cell class of 445474C, specifically calls out:
  - Density falling between 0.947 and 0.955 g/cm3.
  - A PENT value of 500 hours (for slow crack growth resistance).
  - And an HDS of 1000psi (with a design factor of 0.63).

2.4.2 Key Benefits of PE4710 Resin: Higher Density, which directly relates to an increase in tensile strength and chemical resistance.

Higher density also allows PE4710 materials to use fewer raw materials than PE3408/3608, while still accomplishing identical pressure ratings (more on this below). This allows for a decreased wall thickness (increased ID) in PE4710 pipe, which naturally increases water flow and improves thermal conductivity of the system. As it relates to pipes, substituting PE4710 pipe for pipes of a lower cell classification decreases system head loss, since the pipe's ID will increase.

2.4.3 Significant increase in SCG resistance: SCG is the most likely cause of failure in HDPE piping systems. This can be attributed to several reasons, such as poor backfill technique and rock impingements. According to the PPI, “The PENT (Pennsylvania Notch Test - ASTM F 1473) measures relative resistance to slow crack growth using a laboratory test method.

A specimen is cut from a compression molded plaque. It is precisely notched and then exposed to a constant tensile stress at a temperature of 176°F (80°C). The time to failure is recorded and this failure time is related to actual service life in the field. The PENT test has proven to be a very good indicator of SCG in PE pipes.

A published paper in Plastic Pipe VIII conference provided data, which correlated laboratory PENT values to field pipe performance. Based upon this data, a laboratory PENT value of 10 to 20 hours, should correlate to a field life of at least 100 years with very few failures. PPI determined that a requirement of at least 500 hours PENT slow crack growth resistance would provide assurance that high performance PE pipes will be highly unlikely to fail in the field in the slow crack growth mode." The requirement for PE3408 PENT is maintained at 10 hours, PE3608 at 100 hours, and PE4710 at 500 hours.

2.5 Plastics Extrusion processes

Plastics extrusion is a continuous process in which thermoplastic feedstock is converted to a molten, viscous fluid and then extruded into various shapes such as bar, rod, tube, and pipe. Plastic extrusion is also used to produce various profiles such as angles and channel shapes as well as mono-filaments and wiring insulation. The most commonly extruded thermoplastics include nylon, polycarbonate, polyethylene, and polyvinylchloride. Plastic extrusions are performed in a screw extrusion machine, with the machine's main components including a hopper, externally heated feed barrel, helically fluted extruder screw, and dieassembly.As the feedstock enters the feed barrel it is moved forward by the rotating screw. The feedstock is heated by its frictional movement as it is dragged forward. External heating bands help to bring the material to its final temperature.

Fig (2.1): Extrusion Line

2.6 Typical extruder moves the thermoplastic material through four zones:

2.6.1 Feed zone– in which trapped air is forced from the stock. The feed zone has a constant flight depth. The flight depth is the distance between the major diameter at the top of the flight, and minor diameter of the screw at the base of the flight.

2.6.2 Transition zone– in this zone the flight depth decreases, compressing and plasticized the thermoplastic material.

2.6.3 Mixing zone– here the flight depth is constant and there may be a special mixing element to ensure the feedstock is completely plasticized and mixed into a homogenous blend.

2.6.4 Metering zone – the flight depth here is also constant but much smaller than in the mixing zone. This section acts as a pump forcing the material through the extruder die assembly.

2.7 The three principal plastic extrusion processes are:

1. Pipes extrusion.
2. Blown film extrusion.
3. Profile extrusion.

Profile extrusion is a horizontal process producing long continuous shapes which are cooled in long cooling tanks filled with water after exiting the die assembly. A final cutting operation reduces the extrusion to stock lengths for later use.

Blown film extrusion is a vertical process where molten plastic passes through a die having a 360 degree annular opening. The tubular film produced is then filled with air. As a result, the tube expands out into a bubble having a diameter larger than the diameter of the annular opening of the die. As the tube cools, it is pulled up and flattened as it passes through a series of rolls. These rolls maintain tension on the plastic film as it is eventually wound into a coil for later use.

Chapter Three:

Materials and Methods

Chapter Three: Materials and methods

3.1 Introduction

3.1.1 Mechanical Properties of HDPE:

High-density polyethylene (HDPE) (0.941 < density < 0.965) is a thermo plastic material composed of carbon and hydrogen atoms joined together forming high molecular weight products ,then with the application of heat and pressure, The polymer chain may be 500,000 to 1,000,000 carbon units long. Short and/or long side chain molecules exist with the polymer’s long main chain molecules. The longer the main chain, the greater the number of atoms, and consequently, the greater the molecular weight. The molecular weight, the molecular weight distribution and the amount of branching determine many of the mechanical and chemical properties of the end product. Other common polyethylene (PE) materials are medium-density polyethylene (MDPE)(0.926 < density < 0.940) used for low-pressure gas pipelines; low-density polyethylene(LDPE) (0.910 <density < 0.925), typical for small-diameter water-distribution pipes: Linear low-density polyethylene (LLDPE), which retains much of the strength of HDPE and the flexibility of LDPE, has application for drainage pipes. Less common PE materials are ultra-high molecular weight polyethylene (UHMWPE) (density > 0.965) and very low density polyethylene (VLDPE) (density < 0.910).

3.1.2 The most important applications are as follows:

- Drinking water supply line.

- Water lines in hilly areas. Here the property of flexibility of HDPE

is exploited to the fullest extent.

- Irrigation lines.

- Industrial effluent disposal lines.

- Sewage and gas lines.

- Fuel gas line.

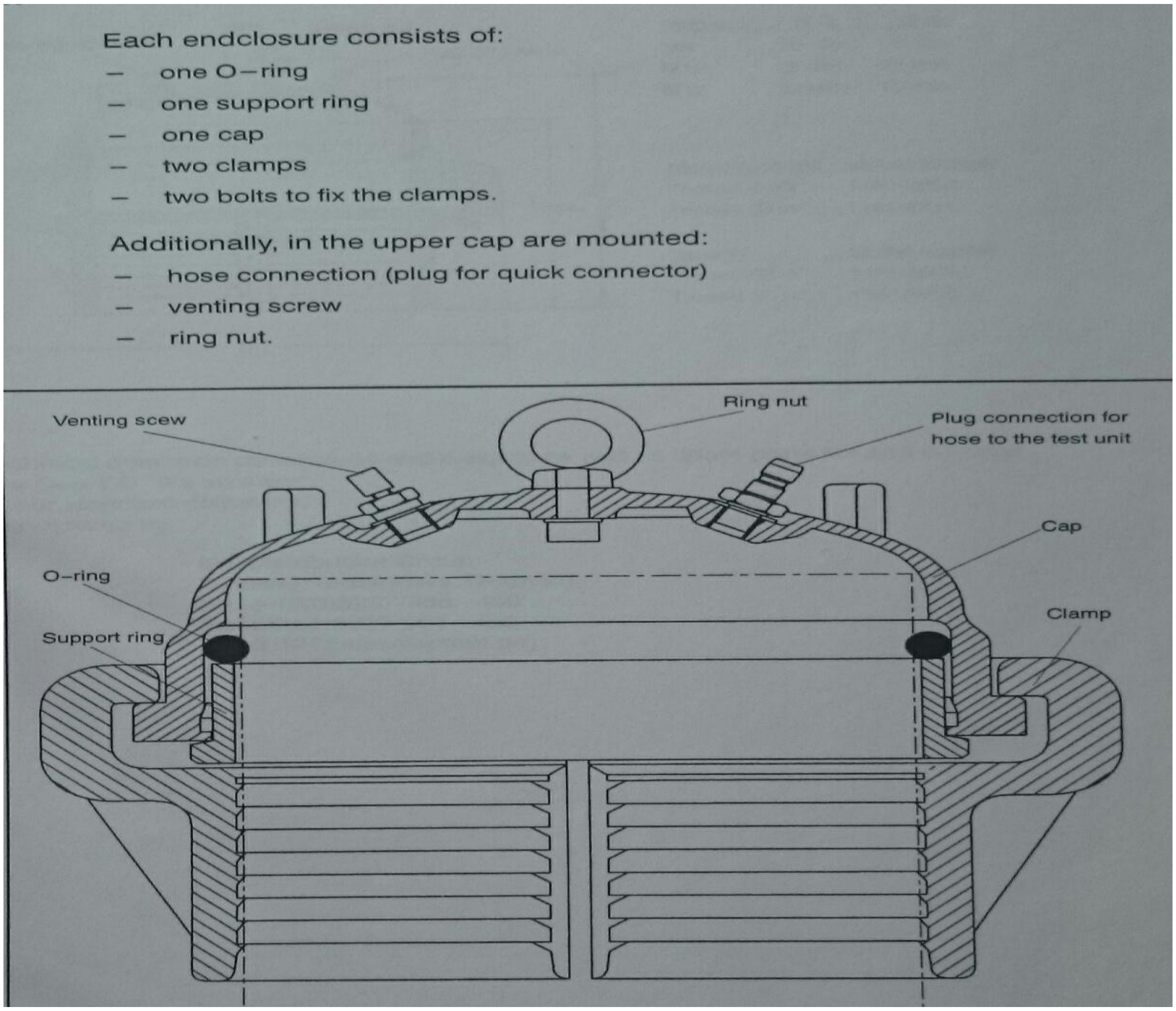
- Mining Industry.

3.2 Materials:

High Density Polyethylene (HDPE) Pipes are manufactured all over the world by extrusion technique. Sizing methods still vary but the trend is the pressure sizing i.e. introducing air at the pressure of about 0.8kg/cm2 to 1 kg/cm2 through one of the spider legs of the dies. HDPE Pipes are generally manufactured on single screw extruder. HDPE Pipes find application in a variety of fields in India and abroad.

3.3 Equipment:

Fig (3.1): shape of the caps for pressure test.



Each endclosure consists of:

- one O–ring
- one support ring
- one cap
- two clamps
- two bolts to fix the clamps.

Additionally, in the upper cap are mounted:

- hose connection (plug for quick connector)
- venting screw
- ring nut.

Fig (3.2): shape of the caps for pressure test.

Fig (3.3): pressure Test Specimen

Fig (3.4): tank for hydrostatic pressure test

3.4 Method:

3.4.1Test Specimens:

The material high density polyethylene (HDPE-100), Pipe Specimen, Length is 1000mm; the nominal outside diameter of the pipe is(OD) 110mm, internal diameter is (ID)101.6mm, thickness (4.2 to 4.8), pressure applied 6 bar.

3.4.2Hydrostatic Pressure Tester

- **Pipe Tester Airless:**
  -Type 1575
  With 1 to 50 pressurized terminals
  -Type 1568
  With 1 to 30 pressurized terminals
  For the pressure testing of pipes and pipe components.
  -Pressure range from 2 to 100 bars.
  -The test parameters can be set by screen touch.

  -Technical parameters input:
  The limit values should be defined in accordance with the allowed margins of error as specified in the respective test method applied.

  - International standards:
  EN standards, for instance, require: -1% to +2% and time values between 30 and 60 sec.

  -Temperature settings:
  The system accepts water temperature values for the test tank between (+19 C and +96 C with 1 decimal digit).
  -Operational temperature of the test container (Oven or tank) +1%.

Chapter Four:

Results and Discussion

Chapter Four: Results and Discussion

4.1ntroduction

Table (4.1): Relation between pressure and time.

x(T)	283	296	323	333	343	358
y (ln σ)	21.3	17.5	11	8.8	7.5	6

4.2 Calculation

4.2.1 Collected data:

Table (4.2): Collected data.

x (T)	283	296	323	333	343	358
y (ln σ)	21.3	17.5	11	8.8	7.5	6
$y\ x$	4775.34	4936.69	5236.80	5324.67	5429.69	5587.31
x^2	8008	87616	104329	110889	117649	128164

$$y = ax + b \longrightarrow 4.1$$

$$a = \frac{\sum x_i y_i - n y` x`}{\sum x_i{}^2 - n(x`)^2} \longrightarrow 4.2$$

$$b = y` - ax` \longrightarrow 4.3$$

$$\ln \sigma = -n \ln \mathrm{T} + \ln C \longrightarrow 4.4$$

$$x` = \frac{283 + 296 + 323 + 333 + 343 + 358}{6}$$

$\boldsymbol{x` = 322.67}$

$$y` = \frac{21.3 + 17.5 + 11 + 8.8 + 7.5 + 6}{6}$$

$\boldsymbol{y` = 16.19}$

$$a = \frac{\sum x_i y_i - ny`x`}{\sum {x_i}^2 - n(x`)^2}$$

$$\frac{\sum -ny`x`}{\sum {x_i}^2 - n(x`)^2}$$

$$\boldsymbol{a = -0.0174}$$

$$b = y` - ax`$$

b= 16.199- (-0.0174) *(322.667) = 21.81

b **=21.81**

$$\ln \sigma = -n \ln \mathrm{T} + \ln C$$

$$y = ax + b$$

C = e^{b}

C = $e^{21.81}$

C = 2974.69 * $\boldsymbol{10^{6}}$

$$\sigma = Ce^{-nT} \longrightarrow \quad 4.5$$

$$\boldsymbol{\sigma = 2974.69 * e^{-0.0174T}} \textbf{ Map}$$

4.3 Discussion:

4.1.2 Results of samples failure independent to different thickness

Table (4.3): test Results of pressure test failure.

NO	**PRESSURE (Bar)**	**Time (sec)**	Minimum Thickness OF Sample(mm)
1	18.54	88	4.30
2	17.66	81	4.26
3	18.81	91	4.34
4	16.89	75	4.21
5	19.12	95	4.39

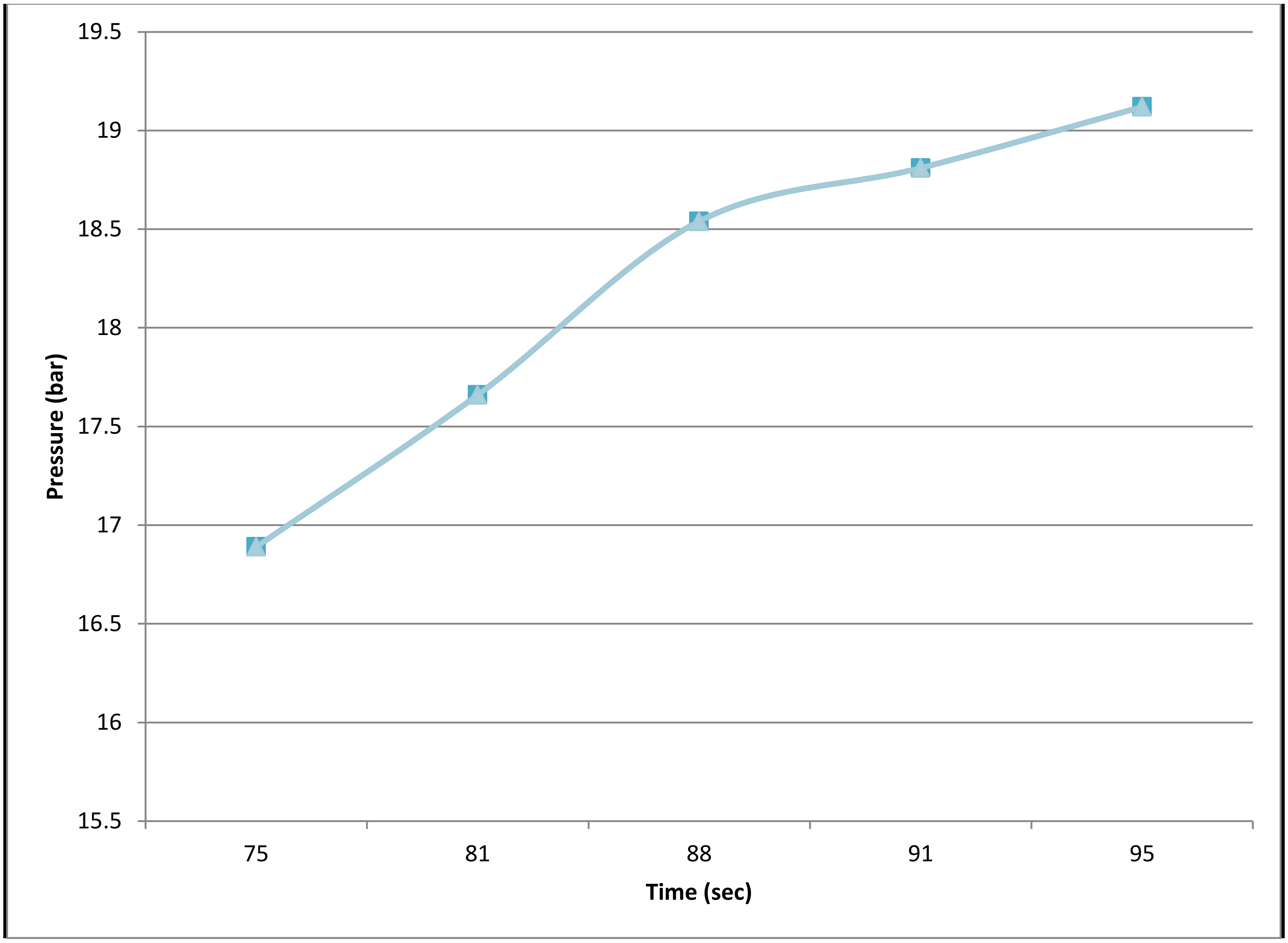


Fig (4.1): Relation between pressure and time.

These data is more logical use Log – Log paper to plot.

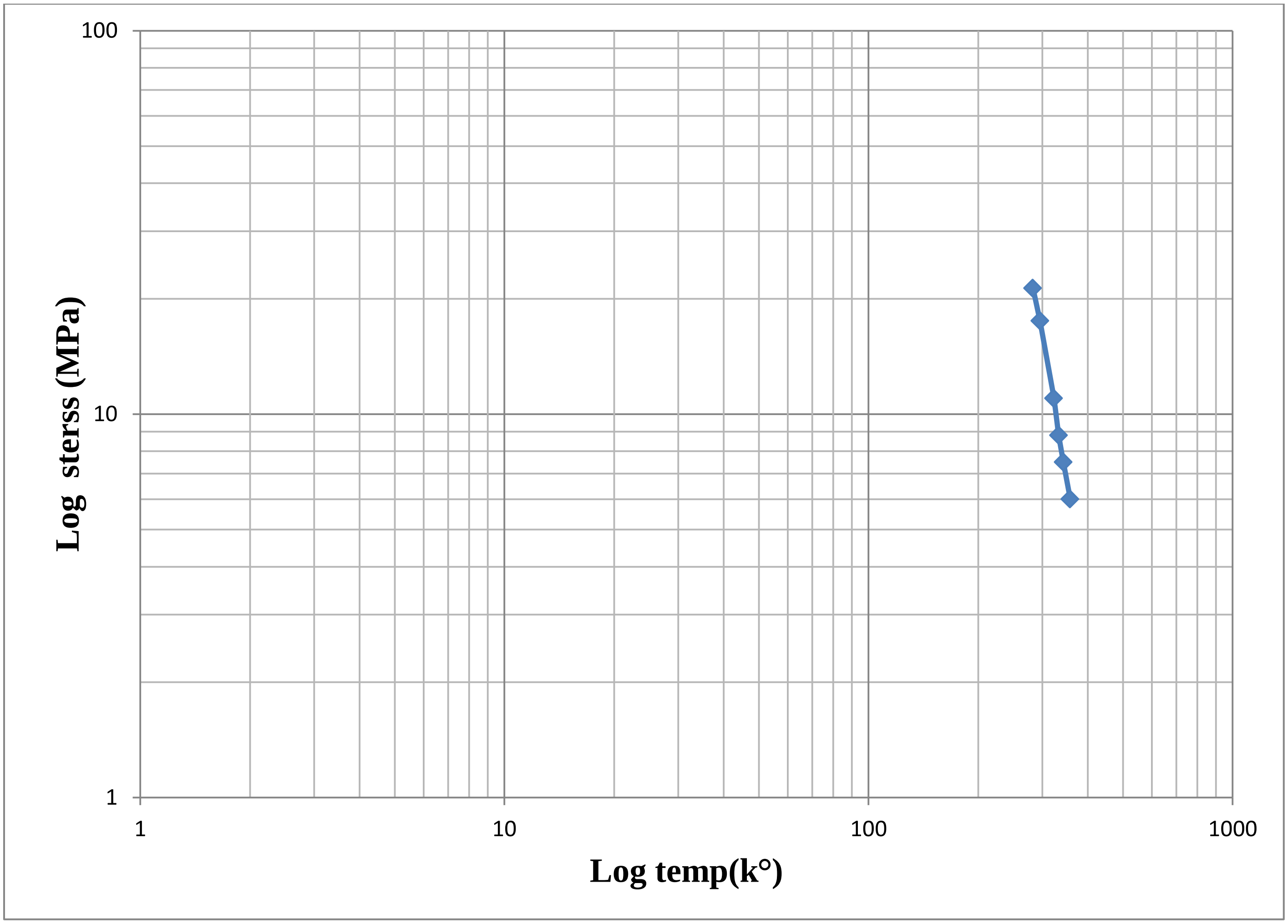


Fig (4.2): Relation between stress and temperatures

Fig (4.3): shape of specimen after failure.

Chapter Five:

Conclusions and Recommendations

Chapter Five: Conclusions & Recommendations

5.1 Conclusions

i. All Results of pressure test are not equals values and the reasons of this case the variation in thickness of samples.

ii. The higher value of pressure tester (19.12 Bar, at 95 Sec), and the lower value is (16.89 Bar, at 75 Sec), and another values of Samples its (18.81 Bar, at 91 Sec), (17.66 Bar, at 81Sec), (18.54 Bar, at 88Sec).

iii. The change in this results is due to different type in thickness for the Samples, When the sample of tester higher thickness its required long time and pressure like the sample NO (5), and at a lower thickness it's not required long time and pressure like the sample NO (4), the optimum results as: (19.12 Bar, at 95 Sec).

iiii. Finally, the result of this type of tester is dependent on many factors (the thickness of sample , time of cooling rate for product , and grade of material; like :(PE100 , PE80 , PE60 , PE40).

5.2 Recommendations

1. Would like to recommend to study such cases for another different size of sample according to parameters of machine.
2. Experience of the operator is a must to properly adjust the gap in the angular die. The uneven pipe wall thickness is the main reason for pipe failure.
3. The recycled material should not be used in the pipes 6 bar and diameter less than or equal to 110 mm for higher pressures the recycled material can be used since the pipe wall thickness is high greater than 4.5 mm.
4. The analysis of the failures.
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