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An Investigation into Plastic Pipes as Hot Water Transporters in Domestic and Industrial Applications

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Abstract

This work discusses convenience of thermo-pipes as compared to traditional steel and copper pipes when used for transporting hot water in domestic and industrial applications. Comparison is made here between thermo pipes and steel pipes regarding strength, material properties, corrosion resistance, aging effect, energy saving, electrical properties, and workability. Tensile tests were conducted in this research for two types of thermo pipes: Cross-Linked Polyethylene (Thermopex) and Polypropylene Random Copolymer (PPRC). The tests were conducted by computer labs of Royal Scientific Society. A lot of material properties (E, σ_y, σ_f, u_r, u_t, B, e%, a%) were gained from these tests, which are in good agreement with the values given by the manufacturer. The results show, that both types of thermo-pipes (polyethylene and polypropylene) are more convenient for heating purposes, corrosion resistance, and easier workability than traditional materials like steel and copper. Thermo-pipes materials behave satisfactorily when subjected to thermal stresses for long periods of time (aging effect). Also, they possess low thermal and electrical conductivities with lower melting points than steel. Therefore, they exhibit higher energy conservation and safety than steel pipes do.

Keywords: Thermo-pipes, plastics, water heating transportation, thermal stresses, aging effect, thermal and electrical conductivities.

Nomenclature

σ_y	: Yield stress, MPa
σ_f	: Fracture stress, MPa
u_r	: Modulus of resilience, MPa
u_t	: Modulus of toughness, MPa
e%	: Percent elongation,
a%	: Percent reduction in area
PPRC	: Thermopipe Polyproylene Random Copolymer
CLPE	: Cross Linked Polyethylene = Thermopex = Pex
DSC	: Differential Scanning Calorimetry
σ_{avg}	: Average tensile stress
B	: Bulk modulus
u_r	: Modulus of resilience
u_t	: Modulus of toughness
e%	: Percent elongation
a%	: Percent area reduction

1. Introduction

The development of efficient thermo pipes since the mid of 1980s resulted in a worldwide rapid increasing use of these pipes for domestic and industrial applications. This requires studying their properties and behavior when subjected to high temperature and pressure, trying to improve their quality for future applications.

Two types of thermo pipes are investigated in this work:

1.1. Polypropylene Random Copolymer (PPRC) Thermo-pipes have proved to be deal for plumbing, heating, air conditioning, and for a wide range of industrial and medical uses. PPRC system has been improved with the additional of a full range of PPRC fittings that can be poly-welded to thermo-pipe system creating fully watertight systems even under most severe conditions of use, [1].

1.2. Cross-linked Polyethylene (Thermopex) thermo pipes are capable of handling a wide variety of materials in industrial and domestic applications including water, fluid waste, gas, and chemicals. Furthermore, piping systems can be manufactured for electrical installations, [2].

Thermo pipes are made of high quality raw materials using some of the most advanced production techniques in the world. Also, engineers are required to develop piping systems for special needs.

The workability of these pipes, due to lightness (low density ρ = 898 kg/m, ρ = 7850 kg/m) and flexibility (1/E, E = 2.1-3.4, GPa = 200GPa) is fast and easy. Together with its wide range of fitting, lightness and flexibility of thermo pipes permit an easy, stable, and fast construction of hydro thermo sanitary installations compared to conventional pipes of steel or copper. The fitting used for the pipes are brass fittings. There are some installation

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instructions that must be taken into consideration when installing pipes, [1] and [2]. Pipes and fittings should not be directly exposed UV radiation. Ultimately, this will lead to crystallization of its material, [1].

When using thermo pipes in space heating, hot water of changeable temperature flows within pipes; and hence raises their temperature. The temperature variations occur in longitudinal and radial directions with destroying effect on the pipes. Because such a distribution leads to local deformations and stress concentrations, cracks will initiate at such locations. In other words, local temperature gradients will result in generating thermal stresses in the pipe. Pipe aging and pipe failure can be considered as a direct result of thermal stresses.

The effect of this phenomenon on pipe properties and materials will be studied in this research - focusing on material properties taken from tensile and fatigue tests, temperature effect, variation of melting point, and thermal and electrical conductivities.

Heating systems are one of the most important applications at homes, companies, school, universities, and other facilities. Best materials for space-heating pipes are Polypropylene Random Copolymer (PPRC) and Cross-Linked Polyethylene (PEX). These two types of thermo pipes are widely used in heating systems due to convenient properties.

Thermo pipes reach their operating temperature much faster than metal pipes, because of dissipated energy of thermo pipes. Since low thermal conductivity is less than thermal conductivity of metal pipes. This indicates that less energy is wasted by heating pipes and less insulation is needed, too. Table 1 includes some of the mechanical and thermal properties of thermo pipes. Also, high level of thermal insulation (low thermal conductivity k), ensures minimal drop in temperature of the fluid transported between the hot water source and the delivery points.

Thermo Pipes Possess Some Important Characteristics, Like:

- Low Heat Dissipation and Energy Saving:
  Due to low thermal conductivity, thermo pipe systems reach their operating temperature much faster than metal piping systems do. Thus, less energy is wasted in heating the pipes and less insulation is needed, figure 1,

- Low Friction Loss:
  The smoothness of internal surface of pipe with no porosities leads to low friction coefficient which results in low friction loss with high velocities.

- No Corrosion Resistance:
  Thermo pipes don't rust given that their chemical resistance for most chemicals and all water types,.

- Thermal Memory :
  In practice, any incorrect bend or twist can be easily rectified. If thermo pipe (CLPE) is heated to its softening temperature (135°C), it retains its original shape.

Table 1: Mechanical and thermal properties of thermo pipes [1-2].

Thermo pipe Property	Polypropylene Random Cpolymer (PPRC)	Cross-linked Polyethylene CLPE (Thermopex)
Density, ρ	895 kg/m^3	930 kg/m^3
Melting range, M_p	140-150 °C	
Yield stress, σ_y	21 MPa	
Fracture stress, σ_f	40 MPa	
Percent elongation, $e\%$	800	
Brinell Hardness, HB	40 MPa	
Mod. of elasticity, E	0.8 GPa	
Shear modulus, G, at:		
0°C	1100 MPa	
10°C	770 MPa	
50°C	180 MPa	
60°C	140 MPa	
80°C		
100°C		
Impact stress, σ_{imp}	No break at -10°C	No break at -20°C No break at +20°C
Thermal coefficient, α	1.5 x 10^4	1.4 x 10^4
Thermal conductive., k	0.24 W/mK	0.41 W/mK
Specific heat, c	2 kJ / kgK	

- Quit Water Flow And Less Noise:
  The high insulation value of CLPE reduces noise level significantly and damps water hammer. The elasticity of PPCR is 257 times higher than that of steel.

A thermo pipe system will absorb water hammers, which cause annoying vibration noise inside the building

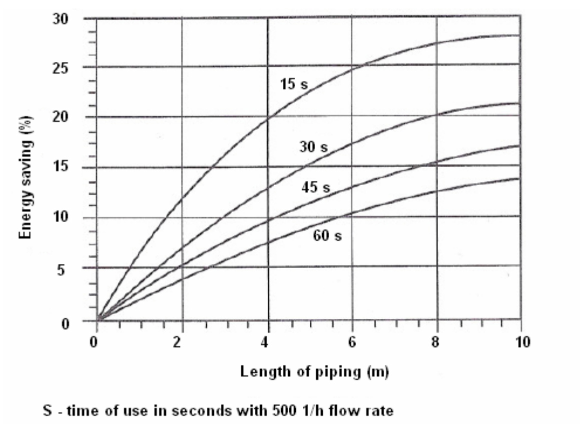


Figure 1: Percentage energy saving under transient conditions

Table 2: Operating temperature, pressure and service life for PPRC and CLPE

Operating temperature (°C)		Servicelife (year)	
PPRC	CLPE	PPRC	CLPE
20	20	50	50
40	40	50	50
60	60	50	50
-	70	-	50
80	80	50	25
-	90	-	10
95	95	50	10
Operating pressure (bar)			
PPRC	CLPE		
20	12.5		
20	10.4		
12.6	8		
-	7		
7.8	6		
-	5.5		
5.2	5		

- *Hygienic And Nontoxic*
  Thermo pipe systems are not toxic in line with current international standards, and they meet international standards for drinking water systems.
- *Frost Resistance*
  Thermo pipe will not burst in cold weather. The elasticity of thermo-pipe material allows the pipe to increase in cross-sectional diameter according to volume of the frozen material. For example the operating- temperature range is +95°C to -100 °C for CLPE
- *Long Life*
  The molecule structure of thermo-pipes material and special additives ensure a high mechanical resistance and a long life depending on operating temperature and pressure. A thermo pipe system can be expected endure for 50 years.
- *Abrasion Resistance*
  Abrasion resistance of thermo piping is four times equal to that of metal piping, allowing higher water velocities up to 7 m/s without corrosion problems.

2. Theoretical Background

2.1. Properties Of Thermo-Pipe Materials

2.1.1. Thermal conductivity k

Thermal conductivities of thermo-pipe materials are $k = 0.24$ W/mk(for PPCP) and $k = 0.41$ W/mk (for CLPE), as shown in table 1.

These values are too small compared to $k = 45$ to 60 W/mk for steel and $k = 300$ to 400 W/mk for copper.

This means that the thermo-pipe materials are of high level of thermal insulation, which guarantees low heat loss on the part of the fluid transported. This lead to minimal drop in temperature between the hot water source and the delivery points with energy saving [1].

The low thermal conductivity value of thermo-pipe materials causes strong reduction in the formation of condensation on the outside of the pipe; a phenomenon that happens frequently on metal pipes in some temperature and humidity conditions.

Due to low thermal conductivity, thermo-piping systems reach their operating temperature much faster than metal piping systems do, consequently less energy is dissipated and less Isolation is needed. The percentage of energy saving under transient conditions is shown in figure 1, where energy saving percentage (%) is drawn versus length of piping (m) for different time periods of use and with 500 l/h flow rate, [1].The thermo pipes are also very poor electrical conductor. In addition, no punctures will occur because of any stray current.

2.1.2. Hoop Stress and Internal Pressure

The relationship between the maximum operating pressure and the hoop stress of the thermo pipe is given by the following equation, [2]

$$p = 20\, t\, \sigma / (d-t) \qquad (1)$$

p = internal pressure (bar),
σ = hoop stress (MPa),
d = outside diameter of the pipe
t = wall thickness (mm)

2.1.3. Operating Temperature and Pressure

Thermopex in general can withstand on operation pressures up to 12.5 bar for 50 years of service life, also a temperature range between 95°C to (-100°).

2.1.4. Dimensions of The Thermo Pipes

Thermo pipes PPRC and CLPE are manufactured in the following dimensions according to DIN 8077 / 78 and DIN16893 standards, respectively. They are available in the following diameters as shown in tables 3.a and 3-b.

1. For fluids and gases, the required inside diameter can be calculated from the following equation [1];

$$d_i = 35.7 \sqrt{(Q/v)} \qquad (2)$$

Q = flow rate, (l/s),
v = fluid flow speed, (m/s).
Reference values for v are: 1 to 3 m/s for liquids, and, 10 to 30 m/s for gases.

2. For heating systems:

$$d_i = 0.6 \sqrt{H/(v\, \Delta T)} \qquad (3)$$

2.1.5. Total Loss of Pressure

The total system head loss in pressure is obtained by adding together continuous and localized loss of pressure [1].

$$\Delta p = L \times R + 10Z \qquad (4)$$

Δp = total pressure loss, (mm c.a.)
L = Pipe length (m),
R = continuous loss of pressure, (mm c.a./m)

Table 3-a: Thermo pipe PPRC dimensions with nominal working pressure of 20 bar (*: PN20) and of 10 bar (**: PN10)

d_o mm (in)	t mm	d_i mm
16 (3/8)	2.7 *	10.6
20 (1/2)	3.4 *	13.2
25 (3/4)	4.2 *	16.6
32 (1)	5.4 *	21.2
40 (1.25)	6.7 *	26.6
50 (1.55)	8.4 *	33.2
63 (2)	10.5 *	50
75 (2.5)	12.5 *	73.6
90 (3)	8.2 **	90
110 (4)	10 **	102.2
125 (5)	11.4 **	114.6
140 (5.5)	12.7 **	130.8
160 (6)	14.6 **	
d_o = outer diameter d_i = inner diameter t = wall thickness		

Table 3-b: Thermo pipe CLPE standards dimensions

d_o(mm)	T(mm)	di (mm)	L (m)
16	2	12	50, 100
20	2	16	50, 100
25	2.3	20	50
32	3	26	50

Z = localized pressure (mbar)

$Z = \Sigma r \times v \times \gamma / 2g \cong$ (5)

γ = 999,7 kg/ m = specific weight of water,

g = 9.81 m/s = gravity acceleration,

v = speed of water (m/s) in the pipe'

r = coefficients,

Figure 2 shows pressure loss Z versus flow speeds v in relation to r-1 and water temperature of 10 °C.

2.1.6. Temperature effect on thermo pipe materials

2.1.6.1. Thermal expansion (elongation) of thermo pipes

The pipe expansion ΔL can be calculated from the basic formula [1]

$\Delta L = \alpha \times L \times \Delta T$ (6)

ΔL = pipe expansion, (mm)

α = thermal expansion coefficient of Thermo pipe, $\alpha_{avg} = 0.15\ °C^{-1}$,

L = pipe length (m),

Δt = temperature difference between warm water and ambient temperature (°C).

Figure 3 shows temperature difference versus pipe expansion. Since thermo pipes can be laid in walls or under floors in direct contact with lime, gypsum or cement.

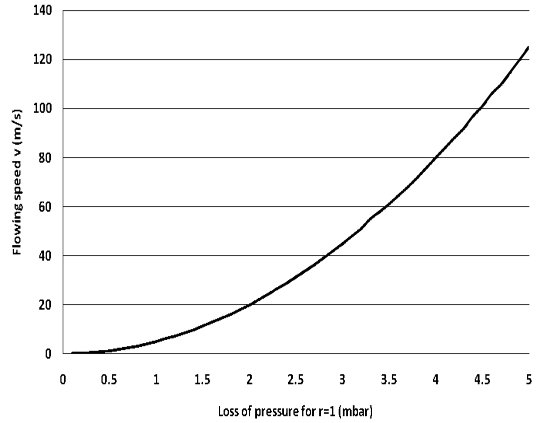


Figure 2: Loss of pressure z in relation to r=1 with water at 10 °C for various speeds v.

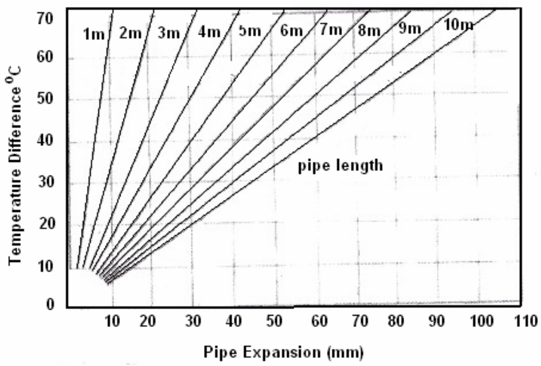


Figure 3: Pipe expansion dependence on temperature difference.

then the Previously mentioned values of ΔL and ΔT are only valid for surface mounted systems. Values are lower for pipes installed in the wall or under the floor.

2.1.6.2. Thermal Transition of Polymer

When polymer is exposed to temperature, thermal transition will occur. In other words, thermal transitions are changes that take place in polymer when it is heated. The melting of a crystallized polymer is one example on these changes. Determining the melting point of thermo pipe plastic materials is very important for this work. Differential Scanning Calorimetry (DSC) is a technique that is used to study the behavior of polymer when it is heated.

During heating, the polymer shows different characteristics:

1. *Constant Heat Flow Q/T and Heat Capacity Cp ,[1] It is:*

$(q/t)/(\Delta T /t) = q/\Delta T = C_p$, figure 4, And $q/t = f$ = heat flow (7)

2. *Glass transition temperature Tg*

Heating polymer after reaching a certain temperature will rise suddenly upward through $\Delta(q/t)$. This shifting in the heat flow means getting more heat flow and thus increasing the heat capacity of the polymer.This happens because the polymer has just gone through glass transition. Polymers have higher heat capacities than glass transition.

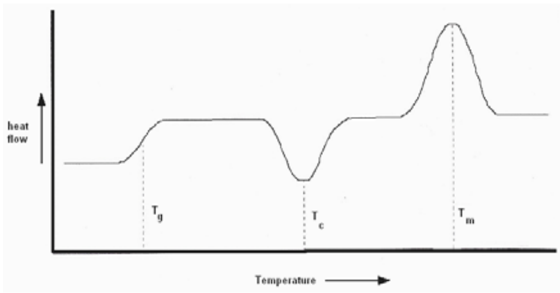


Figure 4: The whole DSC test operation.

Because of this change in heat capacity of polymers at glass transition temperature, DSC can be used to measure the polymer's glass transition temperature. Since the change in the heat flow does not occur suddenly, but over a temperature range ΔT_g, it makes picking one discrete T_g value complicated. Therefore, the middle of the incline is picked as Tg.

3. Crystallization Temperature Tc

Beyond glass transition, a polymer has a lot of mobility. It never stays in one position for a long time. When it reaches the right temperature, it will move into ordered arrangement (crystal arrangement). In a crystal arrangement, polymers emit heat. Drop in polymer heat can be seen as a full-size dip in the plot of heat flow q/t versus temperature T as shown in figure 4. The temperature at the lowest point of the dip is usually considered to be the polymer's crystallization T_c.

4. Melting and Melting Point (Temperature) Tm

Heating polymer beyond T_c will result in positive jump in the heat flow (melting transition) with melting point T_m. When the polymer reaches the melting temperature T_m, crystals start to fall apart and melt. The chains depart their ordered arrangement and start to move freely. For melting the polymer crystals, they must absorb energy (heat). Melting is a first order transition, i.e., when polymer reaches the melting temperature, the polymer's temperature will not rise until all the crystals have melted. Accordingly, the little heater under the sample pan has to supply the polymer with a lot of more heat in order to melt crystals and to keep temperature rising at the same rate as that of the reference pan. This extra-heat flow during melting displays as a peak on the DSC plot in figure 4.

3. Materials, Equipments and Experiments

3.1. Materials and Material Selection

Thermo pipes PPRC and thermopex CLPE investigated in this work are made of row materials according to international standards. Themopipes are made of polypropylene material that is randomly polymerized (PPRC) - applying European raw materials according to German DIN 8077 and DIN 8078 .Thermopex pipes are made of Poly Ethylene material that is created from European raw materials according to German DIN16892 and DIN16893.

The final product as pipes is investigated and tested. However, the chemical composition and analysis of these raw materials are beyond the scope of this research.

3.2. Tests and Equipments

The equipments include measurement tools, devices, and machines. Equipments used in this work will be discussed in sequence with the stages of their use throughout the experimental work.

Experimental work done on thermo pipes in this work includes the following:

1. tensile tests
2. differential Scanning Calorimetry (DSC) tests to determine the thermo pipe's melting point T_m and oxidation temperature T_o
3. Burst pressure tests

These tests are conducted at the RSS labs.

3.2.1. Tensile tests:

3.2.1.1. Samples Preparation:

Five almost flat samples from each thermo pipe types (PPRC and CLPE) were prepared. Each sample has the dimensions shown in figure 5. Not to forget that these samples are taken from pipes with dimensions shown in Table 3-a, therefore the samples are not perfect flat but with some curvature. Flat sheets of these materials were not available.

3.2.1.2. Calculations

The tension test is conducted by increasing changeable load at a constant strain rate to the specimen shown in figure 5, using the tensile machine AG-IS MS shown in figure 6. The purpose of this test is to obtain the stress-strain diagrams for PPRC and CLPE materials and to read mechanical properties belonging to these thermoplastic materials, such as: Young modulus E, yield stress σ_y, ultimate stress σ_u, elongation percent, area reduction percent, Poisson's ratio, fracture stress, and etc, The main relations used by tensile test to determine the mechanical properties can be summarized as follows [4]:

$$\sigma_{avg} = P/A_o \quad (8)$$

$$\varepsilon_{eng} = \delta/ L_o = (L_f - L_o)/ L_o \quad (9)$$

$$E = \sigma_y / \varepsilon_y \quad (10)$$

$$u_r = \int_0^{\varepsilon_y} \sigma \, d\varepsilon = \int_0^{\varepsilon_y} E\varepsilon \, d\varepsilon = ½ E \varepsilon^2 = ½ \sigma_y^2/ E \quad (11)$$

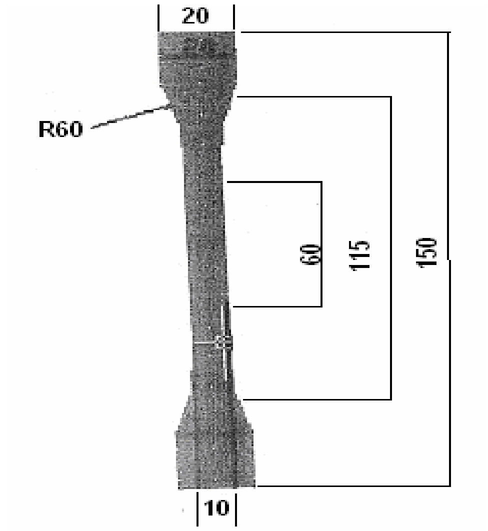
$$u_t = \int_0^{\varepsilon_f} \sigma \, d\varepsilon = 2/3 \, \sigma_m \varepsilon_m \quad (12)$$

= area under the σ-ε curve up to fracture

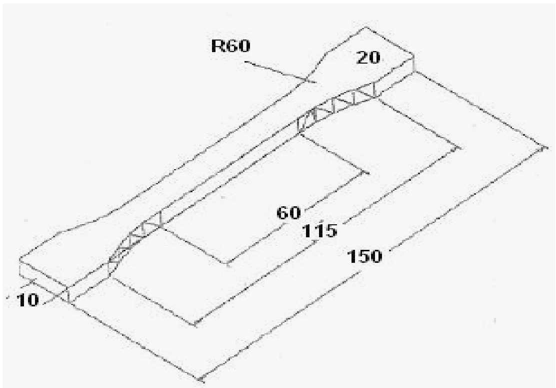
$$B = 1/3 \, E \, (1-2\nu) \quad (13)$$

$$e\% = (L_f - L_o)/ L_o * 100 \quad (14)$$

$$a\% = (A_o - A_f)/ A_o * 100 \quad (15)$$



(a)



(b)

Figure 5: Polyethylene Specimen's dimension, (a), (b).

3.2.1.3. Equipments

a) Tensile Machine:

The tensile machine AG-IS MS series (table type) shown in figure 6 was used in this work.

b) Tensile Machine Camera:

Figure 7 shows the tensile machine camera used in this Work a single camera mode which uses only one camera is shown in figure 7-a. This mode was used to measure the peak-to-peak distance. The gauge length was measured as the distance between the gauge marks as shown in figures 7-b and 7-c.

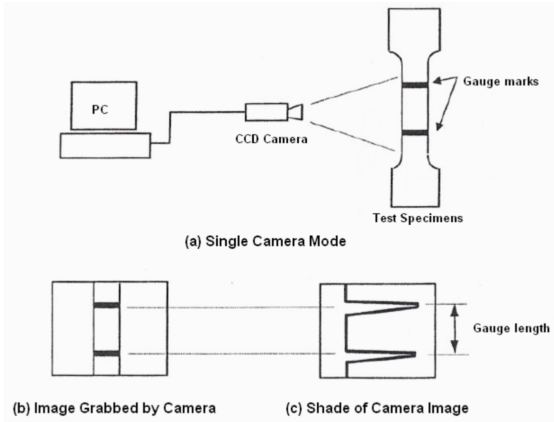


Figure 7: Tensile machine camera.

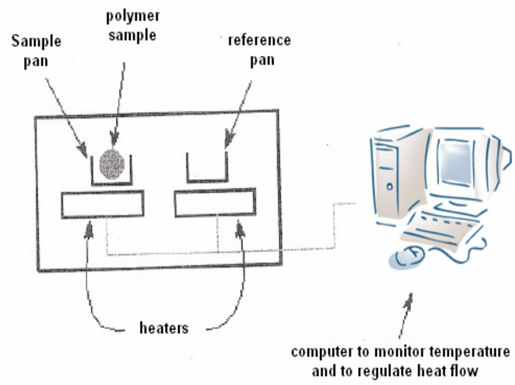


Figure 8: The DSC apparatus.

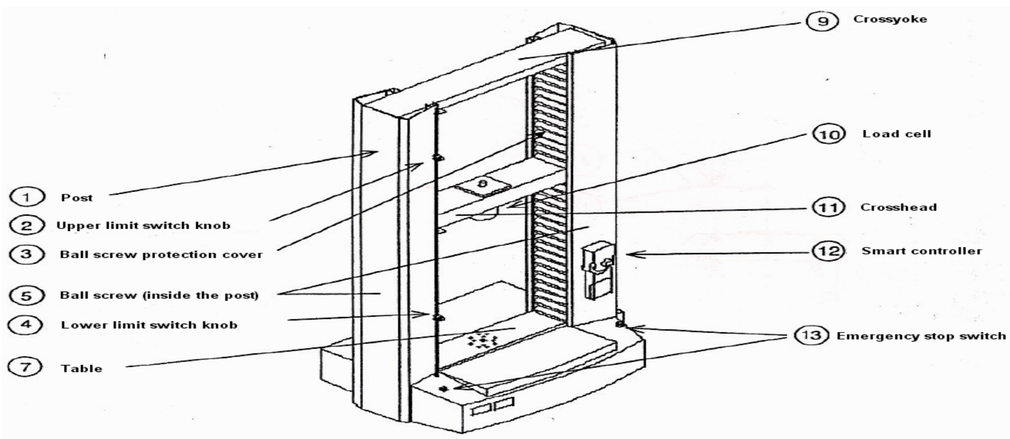


Figure 6: Main parts of the AG-IS MS series (Table-type) Mainframe [10].

3.2.2. Differential Scanning Calorimetry Test

3.2.2.1. Equipment :

DSC apparatus

Figure 8 shows the differential scanning calorimetry apparatus used in this work to measure the temperature of thermo pipes when exposed to temperature. The calorimetry is a known technique, and it is discussed in literature [4]

3.2.3. Pressure Burst Tests

3.2.3.1. Equipments:

Pressure Tester:The apparatus is a pressure tester machine with maximum pressure of 100 bars.

3.2.3.2. Samples

a) Sample a For PPRC Tests

Test conditions:

- Ambient Water Temperature = 20 °C
- Test Duration = 1 hour
- Sample Dimensions: L x d0 x t = 550 mm x 32 mm x 5.4 mm (three samples).

Table 4: Sample dimensions for the pipes PPRE and CLPE

Sample	Thickness (mm)		Width (mm)	
	PPRC	CLPE	PPRC	CLPE
1	5.66	2.07	10.073	10
2	5.76	2.01	10.20	10
3	5.63	2.02	10.167	10
4	5.77	2.10	10.20	10
5	5.60	2.13	10.18	10
Sample	Gauge length (mm)			
	PPRC	CLPE		
1	50	50		
2	50	50		
3	50	50		
4	50	50		
5	50	50		

b) For CLPE Tests

Test conditions:

- Ambient Water Temperature = 20 °C.
- Test Duration = 1 hour.
- Sample Dimensions: L x d0 x t = 500 mm x 20 mm x 2 mm (three samples).

4. Experimental Data and Results

4.1. Tensile Tests Results:

Tensile test were executed for the five specimens made of each pipe material PPRC and CLPE. The data of each sample is given in table 4.

Five stress-strain diagrams belonging to the five samples of material were obtained. Two representative diagrams for PPRC and CLPE are shown in figures 9 and 10, respectively.

Material properties obtained from these diagrams are tabulated in tables 5.

4.2. DSC Results

Melting points and oxidation temperatures were obtained from differential scanning calorimetry tests. Table 6 shows these values PPRC and CLPE pipes.

Table 7 shows some important material properties of pipes made of plastics (PPRC and CPLE), steel and copper for sake of comparison when used as hot water transporters in domestic and industrial applications.

5. Results and Discussion

- By considering the conditions when the tests were conducted at the RSS, unlike conditions followed by the *"World Plastics"*, results are in good agreement with those of the world plastics, [1-3].
- Results and materials properties given in table 6, *E*, u_t, ductility, costs, σ_y, thermal conductivity, melting point, oxidation temperature, and density show plastic pipes

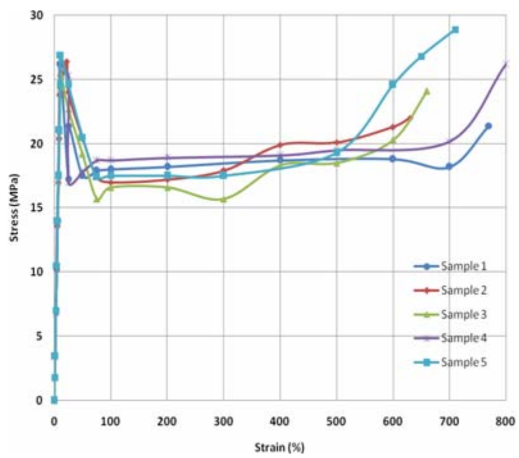


Figure 9: Stress-strain diagram for Thermo pipe (Copolymer polypropylene, PPRC).

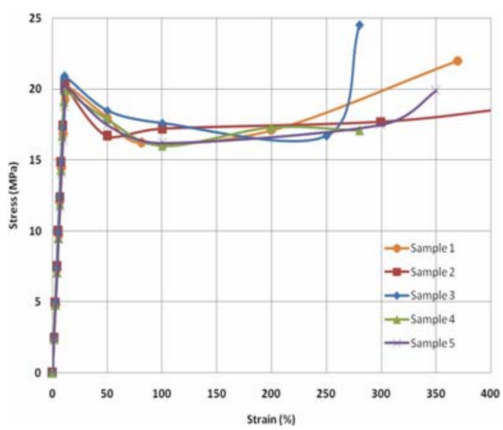


Figure 10: Stress-strain diagram for Thermopex (Cross-linked polyethylene, CLPE).

Table 5: Material properties of PPRC and CLPE pipe

Property	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Average
σ_y (MPa)						
PPRC:	26.2	26.4	25.5	26.1	26.9	26.22
CLPE:	20.3	20.3	20.9	19.9	20.2	20.32
σ_f (MPa)						
PPRC:	21.4	22.0	24.1	26.2	28.9	24.52
CLPE:	22	18.7	24.5	17.1	19.9	20.44
E (MPa)						
PPRC:	238	240	231	261	245	243
CLPE:	169	185	190	181	168	178.6
u_r (MPa)						
PPRC:	1.44	1.45	1.40	1.31	1.48	1.42
CLPE:	1.22	1.12	1.15	1.09	1.21	1.16
u_t (Nmm/mm^3)						
PPRC:	109.85	92.4	106.1	139.73	136.79	116.97
CLPE :	54.27	52.36	45.73	31.92	46.43	46.14
B (N/mm^2)						
PPRC:	248.11	250	241.48	271.88	254.74	253.24
CLPE:	-375.93	-410.10	-422.22	-402.02	-374.07	-396.87
e%						
PPRC:	770	630	660	800	710	714
CLPE:	370	420	280	280	350	340
a% PPRC:	88.51	86.3	86.84	88.89	87.65	87.64
CLPE:	78.72	80.77	73.68	73.68	77.78	76.93
ε_y (mm/mm)						
PPRC:	11	11	11	10	11	10.8
CLPE:						
ε_f (mm/mm)						
PPRC:	770	630	660	800	710	714
CLPE:	370	420	280	280	350	340

Table 6: Melting-point temperature T_m and oxidation temperature T_{ox}

	Melting point Tm (°C)		Oxidation temperature T_{ox} (°C)	
	Trial 1	Trial 2	Trial 1	Trial 2
Thermo pipe PPRC	143.7	145.7	274.1	275.1
Thermo-pex CLPE	128.1	128.4	257.3	258.2

5.1. pressure burst results

Table 8: pressure burst results

Sample	Pressure (bar)		Notes
	PPRC	CLPE	
1	100	58	No burst
2	100	57.5	No burst
3	100	58.5	No burst

Table 7: Some important properties of plastic pipes (PPRC and CLPE) and metal pipes (steel and copper)

No.	Property	PPRC	CLPE	Steel	Copper
1	Service life (y)	up to 50	up to 50	up to 15	up to 20
2	Density (kg/m^3)	895	930	7850	8900
3	Workability	Easy	easy	difficult	Difficult
4	Maintenance	Easy	easy	Difficult	Difficult
5	Corrosion resistance	no corrosion	no corrosion	high corrosion	
6	Melting point (°C)	144.7	128.3		
7	Abrasion resistance	4*A_{met}	4*A_{met}	A_{met}	A_{met}
8	Fluid speed Profile	low friction loss	low friction loss	high friction loss	high friction loss
9	Frost resistance (bursting probability)	No burst	no burst	burst	burst
10	Linear thermal Coefficient at 20°C (10^{-4}/°C)	1.5	1.4- 2	0.10- 0.18	0.166-0.176
11	Specific heat at 20°C (kJ/kg.°C)	2	2.3	O.44	0.385
12	Thermal conductivity at 20°C (W/m.°C)	0.24	0.41	45- 60	300- 400
13	Costs	cheaper than CLPE	more expensive than PPRC	Expensive	Very expensive
14	Electrical Conductivity	very low	very low	high	high

- PPRC are more suitable as thermo pipes than plastic pipes CRPE.
- As a general result, plastic pipes are more suitable than steel pipe and copper pipes as thermo pipes (pipes for transporting hot water). PPRC pipes are more convenient than CRPE pipes for thermo pipes.
- The melting points of both PPRC and CRPE are so high that no fear of melting if these pipes are used for transporting hot water even when boiling point is 100°C.
- PPRC and CRPE pipes are hygienic because no possibility of oxidation of these pipes due to their high oxidation temperatures.
- Thermal conductivity of PPRC is lower than that of CRPE. This means that heat transfer rate of PPRC pipes is lower than that of CRPE pipes. PPRC can preserve the water temperature better than CRPE pipes and PPRC can achieve a longer life than CRPE, [5].

- PPRC has greater linear thermal expansion coefficient α than that of CRPE. For the same ΔT and the same length, the final length of PPRC pipe will be greater than that of CRPE pipe. [$\Delta L = L_2 - L_1 = \alpha\ \Delta T\ L_1 \Rightarrow L_2 = L_1 (1+\ \alpha\ \Delta T) \Rightarrow L_2 > L_1$]
  CRPE is better than PPRC regarding this property since it resists thermal deformation more than PPRC does. Plastic pipes are worse concerning this property than metal pipes.
- The heat energy amount that can be stored by CRPE is higher that of PPRC. This is because of the fact that specific heat of CRPE is greater than that of PPRC, which means that CRPE possesses a greater specific heat capacity than PPRC. Again, CRPE is better in relation to this property than PPRC.
- In this research, the basic important tests such as tensile tests, differential scanning calorimetry tests, and pressure bursting tests, were conducted. As a future work, It is recommend to run the following test: bending, fatigue, torsion and shear tests.

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