Report No. PPCD(SSP)/0708

Report

On

Evaluation of “SHK” brand PPR pipes & fittings for hot and cod water supply in buildings

Sponsored by

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Project No.	-	SSP 0708
Title	-	Evaluation of 'SHK' brand PPR pipes & fittings for hot and cold water supply in buildings
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CONTENTS

Evaluation of ‘SHK’ brand PPR pipes & fittings for hot and cold water supply in buildings

1.0 Introduction

Today, plastics are listed among building materials in India with their applications occupying prime position in construction industry. About 20 % of total production of plastics goes into building applications as an alternative to wood, steel, concrete and other conventional materials. As moulded products, plastics have provided altogether new concepts in design and performance unmatched by any conventional materials. Over the last 30 years, the construction industry has successfully evaluated and adopted various plastics products in actual usages. In piping systems, the use of plastics (PVC, PE, GRP etc.) has brought about a fair amount of economy in water supply schemes, cable ducts etc. as against conventional GI/CI/RCC pipes in certain sizes. This has resulted in the large scale adoption of plastics in piping systems in the country. It is no surprise to know that the growth rate of Indian plastics industry is one of the highest in the world with plastics consumption growing at 16% per annum (compared to 10% in China and 2.5% per annum in U.K.). The per capita consumption of plastics in India is ~16 Kg. With increasing consumption in the global market and the constant drive to improve our living standards, the scope for use of plastics is bound to increase many fold and make the production double in the coming years.

Plastic piping has been successfully utilized in a variety of uses for over 50 years because of its strength, durability, joint integrity and long term cost-effectiveness. The market for plastic pipes and fittings in India is in its growth stage growing at double digit CARG (~10%) during FY 2013- FY 2018. The market can be segmented into HDPE, PPR, UPVC, CPVC and others. Among plastic pipes, the PPR is the most popular in plumbing across the world. Global demand for plastic pipe systems is projected to rise 8.5% annually over the next three years. The main driver for this growth is the increased investment of Government in irrigation, housing and sanitation sectors through schemes such as Housing for All, AMRUT and PMKSY. The increased focus of Govt. on rural water management also supports the demand of plastic pipes in India. Plastic piping systems are a sustainable and environmentally responsible choice that will serve generations to come. They are energy efficient during manufacturing and provide protection from contamination during service. Strong, durable, light weight and flexible, these piping systems require significantly less energy to fabricate, transport and install than metal or concrete alternative.

Polypropylene random copolymers (PPR) are thermoplastic resins produced through the polymerization of propylene with ethylene or butane bonds introduced in the polymer chain. PPR is a bit of softer but have better impact strength, is tougher and more durable than homo PP. Due to high impact resistance combined with good stiffness and high chemical resistance makes the PPR material suitable for use with potable water, foodstuffs as well as pharmaceutical and chemical industries. The PPR pipe was developed in Europe in the early 1990's. Improvement in the performance of PPR pipes in terms of deformation and displacement could be further achieved by constructing it in composite layered walls. A pipe may consist of an outer layer and inner layer of extrudable polymer sandwiching a middle plastic for added strength. In order to address compatibility issue, attempts have been made to produce a multilayered pipes using same extrudable polymer as outer, middle and inner layers. Glass / carbon fibres have been used as reinforcement in the middle layer of pipes composition to improve their mechanical properties.

M/S SHK Polymer industries, Ahmedabad, approached this Institute to assess the suitability of 'SHK' brand PPR pipes & fittings for hot and cold water supply in building services. The party is manufacturing PPR pipes and fittings of different dimensions.

2.0 Scope of work

2.1 Physical and Mechanical Tests

Dimension (outside diameter, wall thickness, ovality etc), surface finish, density, water absorption, pigment dispersion, melt flow index, impact strength at 0^0C and 27^0C and hydrostatic pressure test at low & ambient temperatures.

2.2 Thermal properties

Softening point, co-efficient of linear thermal expansion and thermal stability.

2.3 Potability Tests

- Potability tests of water drawn from filled pipes such as pH, total dissolved solids, total living mortality, taste, odour, colour and turbidity at different conditions of storage.

- Overall migration of leachable additives at different temperatures and storage durations according to IS 9845.

- Estimation of metal traces in water drawn from filled pipes at RT and 70 ^{0}C. and conformity assessment as per IS: 10500-1991.

- Microbiological test- extract preparation, inoculation, assessment in the form of coliform organisms (MPN) by tube method.

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2.4 To assess the suitability of 'SHK' brand PPR pipes & fittings as per existing Standards (DIN 8077/8078/16962 and IS 15801) for hot and cold water supply in buildings.

3.0 Experimental

3.1 Materials

M/s SHK Polymer industries, Ahmedabad, supplied three layered PPR pipe samples (outer green layer - UV stabilized; Middle black PPR layer; Inner white layer - antibacterial) containing 20, 25 and 32 mm dia in a desired length (>500 mm). These pipes belong to PN 16 pressure ratings. The party also supplied socket, elbow, tee and end cap. Pipes of 160 mm dia with PN10 were also supplied for potability tests.

3.2 Methods

3.2.1 Physical Tests

The PPR pipes were examined for their appearance, finish and workmanship. The dimensions of the PPR pipes were measured as per DIN 8077. The outside diameter of pipes at five different points was measured and its mean value was reported. Their ovality was measured by taking difference between the maximum and the minimum outside diameter at the same cross-section. The wall thickness of the pipes was measured with the help of micrometer. Five readings at different points were considered for an average value.

3.2.2 Scanning electron microscopy

The dispersion of ingredients and internal morphology of PPR samples were studied under Scanning electron microscope (Quanta 200F). A small piece of PPR pipe was cut and mounted on a stub. Prior to examination, a thin film of Au/Pd coating was applied on the mounted sample to render them conductive.

3.2.3 Thermal Tests

3.2.3.1 Thermal expansion

Dynamic Mechanical Analyzer (DMA 2980 TA Instruments USA) was used to determine thermal expansion of pipe samples under expansion mode. A probe of tip diameter of ~ 2.5 mm was placed on the sample with the pre-determined load of 1 N. The sample was first conditioned by heating upto its softening temperature and cooling with loaded probe to the starting temperature to relieve the internal stress. The change in length of samples was recorded with respect to temperature in the range of 37 -104^{O}C at 5^{O}C/min. The co-efficient of thermal expansion was calculated by the following equation:

$$\alpha = \frac{\Delta l}{L \times \Delta t}$$

Where,

α	=	Co-efficient of thermal expansion (/ ^{O}C)
Δ l	=	Change in length in mm
L	=	Original length in mm
Δ t	=	Temperature difference in ^{O}C

3.2.3.2 Softening point

DMA was run under penetration mode to determine softening point of samples. The penetration probe was placed on the sample at 1 N load. The tangent of peak in dimensional change versus temperature was recorded as a softening point of pipe material.

3.2.3.3 Thermogravimetric Analysis

Thermal stability of PPR piping material was studied by a Simultaneous Thermal Analyzer (Perkin-Diamond TG/ DTA). The sample of 10.54 mg was kept in the thermo-balance. Thereafter, a thermal run was carried out between 35^{0} C and 700^{O} C at a heating rate of 10^{O} C /min under nitrogen atmosphere. A continuous change in the weight loss with respect to temperature was recorded to assess the weight loss profile, char residue and rate of thermal degradation.

3.2.3.4 Melt flow index

The melt flow index of PPR pipe samples was measured according to ASTM D 1238-86. The sample was run under nominal load of 2.16 kg at 230^{O} C. The fine cut pieces of pipe were introduced into the bore of the cylinder of a melt flow indexer and placed it in the magazine. Prior to measurement, the sample was pre-heated for 3 minutes. The length of measurement section was fixed for 10 mm. Melt flow index and density of the pipe melt was recorded.

3.2.3.5 Reversion

The reversion test of PPR pipes was carried out as per DIN 8078/IS 15801. Three 200 mm long PPR pipe samples were cut from the pipe length and marked on the external surface approximately 50 mm from each end of the test pieces around the whole circumference. The distance between the two marks, l_O (reference length), was approximately 100 mm. The samples were then placed on a glass plate in an oven at 135^O C for 2 hrs and then extended the temperature to 150^O C for 2 hrs. The precaution has been made to avoid the contact between the samples. Test pieces were removed from the oven and allowed to cool in air without being moved at the ambient temperature. The distance between the two scribed marks was measured along the surface of the pipe.

The relative change in length, T as a percentage was calculated by the following formula.

$$T = \frac{l_O - l_1}{l_0} \times 100$$

Where

l_0 and l_1 are the distances (reference lengths) in mm before and after the test.

3.2.4 Mechanical Tests

3.2.4.1 Impact strength

The PPR pipes were tested for impact at 27^{O}C and 0 ^{O}C using impact testing machine. The specimens were conditioned in a water bath at a test temperature for at least 1 h prior to the test. 200 mm long PPR pipe of dia 20 mm was placed on the vee block. The temperature was maintained at 0^{O}C by the mixture of ice and salt. A hemispherical striker of 250 g was allowed to fall freely from a height of 500 mm for 20 mm dia and 1000 mm for 32 mm dia on the marked line on the pipe. The failure of pipes, if any, was recorded.

3.2.4.2 Hydrostatic pressure/Creep strength

The PPR pipes were tested for hydrostatic pressure at 20 ^{0}C and 95^{O}C as per DIN 8078/IS 15801. A 360 mm long PPR pipe of 20 mm dia was taken for pressure testing. Both the ends of PPR pipe were fitted with the locking plugs in such a way that the axial forces coming from the internal pressure are transmitted to the pipe. The pipe was remained free to move in a longitudinal direction. The pipe was then kept in water bath for 1 h to adjust the temperature. The pipe was filled with the water and tested for burst pressure and also for the sustained pressure at a test pressure of 16 MPa for 1 h at 20^O C, 4.2 MPa for 22 hrs and 3.5 MPa for 1000 hrs respectively at 95^O C through a closable opening in one of the locking plugs. The test pressure (p) was calculated as follows -

$$p = \frac{2 \sigma s}{d - s}$$

Where,

σ	=	induced stress (MPa)
s	=	minimum wall thickness (mm)
d	=	outside mean diameter (mm)

3.2.5 Potability Tests

3.2.5.1 Overall migration

Leaching of chemical additives from the pipe wall was assessed as per IS: 9845 - 86 using water as simulating solvent under different temperatures (30 - 90^{O}C) and storage durations (1, 5 and 10 days). The samples were washed with distilled water and then immersed into water in the ratio of 1cm^2 pipe material / 2 ml extractant. Simultaneously, water extractant was kept in the glass beaker in an identical manner, which served as a control. The water extract was evaporated in a pre-weighed platinum crucible in an oven maintained at constant temperature (100 ± 5^{O}C). The difference between the residues of pipe extract and the corresponding control was taken as the measure of global migration in mg/l.

3.2.5.2 Potability tests of water stored in the pipes

The potability tests of water withdrawn from the filled PPR pipes were carried out as per standard specifications given in Table 1.

3.2.5.2.1 pH and dissolved solids

The water was stored in the pipes for 1, 5 and 10 days. The pH of withdrawn water from the filled pipe was measured with a calibrated pH meter. The dissolved solids of water withdrawn from the pipes were measured as per IS: 10500-91. The stored water was filtered through Whatman filter paper No 42. The water was evaporated to dryness at 105^{O} C. The beaker was cooled up to a constant weight.

The change in weight was calculated as follows-

$$\text{Dissolved solids (mg/l)} = \frac{\text{(wt. of beaker with residue - wt. of empty beaker) mgx1000}}{\text{ml of sample}}$$

3.2.5.2.2 Turbidity

The water withdrawn from the filled pipes was subjected for turbidity test with the help of a calibrated Turbidimeter (AQUALYTIC, Germany). The water samples were poured in the glass tube and placed before the light path in the sample cell. The change in light path was recorded in terms of NTU.

3.2.5.2.3 Total living mortality

Kanghi fishes were used for total living mortality test. The fishes were collected from the local market and placed in the tap water of 48 hrs for acclimatization. Subsequently, the fishes were transferred into the water filled pipes for 96 hrs. The mortality of fishes was observed after every 24 hrs intervals. The sample was also kept for 10 days to know mortality of fishes

3.2.5.2.4 Micro-biological test

The water samples were kept in pipes for 4, 5 and 6 weeks. Tube method was adopted for microbiological test according to IS: 10500-91. In a tube method, the inoculation of sample was carried out in the 3 tubes containing MacConkey's broth. The sample was then incubated for 24 hrs at 37^{O}C. The positivity in tube was determined by the change in colour from purple to yellow and accumulation of gas in the fermentation tube. The most probable number (MPN) of the coliform was calculated after 48 hrs.

3.2.5.2.5 Toxic metals

An extract of PPR samples in water was prepared at 27 and 70^{O}C for 24 hrs extraction duration. The surface area of 150 cm^2 sample was taken as per IS: 14399 (Part 1) -96. The extract was examined for various traces of metals such as cadmium, lead, iron, zinc, copper and mercury. Inductive Coupled Plasma spectrophotometer was used for estimation of heavy metals in the extract. The reference metal was used for making a calibration curve.

4.0 Result and Discussions

4.1 Physical properties

"SHK" brand PPR pipes belong to PN 16 classes. They are smooth, uniform in colour and free from visible cracks, inclusions, and other heterogeneities. The dimensional details of pipes and fittings are given in Table 2 & 3. The average outside diameter, wall thickness and ovality of these pipes satisfy the requirements of IS-15801 and DIN 8077 Standards. Fittings such as Tee, elbow and socket meet the requirements mentioned in DIN 16692.

As given in Table 4 for the physico-mechanical properties of PPR piping materials, the density of PPR was ~909 Kg/m^3 as compared with the specified limit of 925 Kg/m^3 mentioned in IS-15801 / DIN 8078. The PPR piping materials absorbed negligible water (0.01%) when immersed in cold water for 24 hrs. The melt flow index of PPR piping material was 0.47 g/10min when tested at 230º C and 2.16 kg pressure which is below the permissible limit of 30% of MFI of base resin. The melt flow density was 0.64 g/cc at 230º C for 166 seconds. This indicates that PPR material has an adequate flow and also recyclable. The softening point as observed under DMA in penetration mode was ~138^{0}C. This indicates that PPR has adequate temperature resistance for hot water distribution systems. In addition to this, the thermal stability of PPR was assessed by thermo-gravimetric analysis (Fig. 1). The weight loss in the PPR sample was negligible upto 100º C. At 200^0 C and 300^0 C, the weight loss in the PPR sample was 0.45% and 2.64% only. The char residue of PPR at 700^0 C was negligible showing that PPR has no filler materials. Under DTG curve, the thermogram exhibited a peak at~ 393^0 C indicating decomposition temperature of PPR. The rate of maximum decomposition of PPR was ~11%/min. DTA thermogram shows an exothermic peak at ~396^{0}C showing crystallization and decomposition of PPR. The endothermic peaks were substle. These results indicate that PPR has adequate thermal stability. The coefficient of thermal expansion of PPR was1.47x10^{-4} /ºC as observed under DMA. This value is comparable to the value mentioned in DIN 8078. The result is very useful during finalization of installation details of pipes.

Fig. 2 shows SEM images of PPR piping materials. The entire morphology has been divided into three distinct layers because of compositional variations. No agglomeration of constituents was observed in the microstructures. The outer layer seems to be plastic and smooth. Contrary to this, middle layer exhibited hard microstructure. The inner layer was featureless. No foreign inclusions or discontinuity was observed in the PPR. This indicates that the piping material has insignificant reworking material.

4.2 Portability studies

The quality of water stored in the PPR pipes was assessed in terms of overall migration of leachable additives from the piping material and also their toxicity characteristics. The extraction test as per IS - 9845 was carried out at different temperatures for 1, 5 and 10 days storage duration (Table 5). It was observed that increasing temperature increased overall migration of the leachable additives. At 40ºC, the total leachable additives were ~ 6.45 mg/l only after 24 hrs. When the temperature was raised upto 80º

C, the leachable additives increased to ~12.31 mg/l only which is well below the permissible limit of 60 mg/l mentioned in IS 10910. The total leachable additives also increased with increasing storage duration. At 10 days, the total leachable additives increased to ~16.20mg/l only from ~6.45mg/l at 40^0 C. The maximum total leachable additives from the pipe wall were ~33.75 mg/l at 80^0C for 10 days. This value is also well below the permissible limit of Standard. Fig.3 shows the overall migration of leachable additives as a function of temperature and storage duration. It was found that overall migration of leachable additives increased with the increase of temperature and extraction duration. Above 60^0C, the difference in the leachable additives was more pronounced. The results indicate that water flowing through the PPR pipes is safe from the potability point of view.

The quality of water filed in the PPR pipes was also examined according to IS 10500 (Table 6). No change in the odour, colour and taste of water withdrawn from the filled pipes was observed when compared with the tap water. The turbidity of water was almost similar as tap water (0.71-0.84 NTU) and found under permissible limit (10 NTU). The pH of pipe water (7.32-7.7) was comparable to tap water and found below the permissible limit (6.5-8.5). The total dissolved solids (159-195mg/l) were below 500mg/l as prescribed in the Standard. These values were found under permissible limit of Standard even after 10 days storage duration. It was observed that pipe has no contribution to the mortality when kanghi fishes were placed in the pipe stored water for 96 hrs.. The fishes were as active as it was in pond water even after 10 days. The water stored in the pipes was subjected for micro-biological test. Table 7 gives results on water stored in the pipes for 4 weeks, 5 weeks and 6 weeks. The coliform growth in the water was negligible under multiple tube method. The control sample has also negligible MPN. The photoview of bacterial test is given in Fig.4 (a-c). This suggests that PPR pipe does not support any kind of biological growth. The possibility of toxic metals in the leached water from pipes was also explored as per IS-10500 (Table 8). The experiments were performed taking the water extract carried out at RT and 70^0 C. No toxic metals were detected in the pipe water. Therefore, it is considered safe from toxic metal point of view. A comparison between the specified values of Standards and obtained values was made (Table 9). The quality of water flowing through the PPR pipes meets the requirements of IS 10500-91-Indian standard specifications for drinking water.

4.3 Properties of PPR pipes

The mechanical properties of pipes are given in Table 10. It was observed that the pipes had retained their original shape (roundness) under reversion test. The change in length of pipe was insignificant (0.4%) when samples are subjected at 135º C in an air circulating oven. The pipes were intact during impact at 0ºC and room temperature. No splitting or cracking was observed in the pipes. The hydrostatic test of pipes was conducted as per IS-15801 DIN 8078. It was found that pipes were intact and sustained for specified period at given pressure. The fittings were also tested for heat reversion and creep strength. During creep test, there was no leakage/fracture during test. No cracks or blisters in the fittings are visible when tested under reversion at 150º C.

A comparison in the properties of PPR pipes and fittings were also made with the requirements mentioned in DIN 8078/16962 and IS 15801 (Table 11 - 13). It was found PPR pipes and fittings meet the requirements of Standard spec
ifications.

5.0 Conclusion and Recommendations

- On the basis of experimental results, 'SHK' brand PPR pipes & fittings have been found suitable for portable hot and cold water in building services.

- 'SHK' brand PPR pipes & fittings satisfy the requirements of DIN 8077/8078/16962 and IS15801 for dimensions and physico-mechanical properties, IS 10500 for drinking water and IS 10910 for leachable additives as its safe use for drinking water.

- The work has been carried out on the samples supplied by the party and the results reported are based on these samples.

Table 1.Toxicity tests and standards followed

Sl. No.	Name of test	Maximum acceptable limit/ concentration	Standard followed
1.	PH	6.5 to 8.5	IS: 10500-91 Indian Standard Specification for drinking water
2.	Total dissolved solids (mg/l)	500	Do
3.	Odour	Unobjectionable	Do
4.	Taste	Agreeable	Do
5.	Turbidity (NTU)	10	Do
6.	TLM Test (maximum tolerance limit of mortality)	No mortality	Standard methods for the examination of water sewage and Industrial Wastes, 15^{th} edition 1980, APHA-AWWA-WPCT
7.	Microbiological test Multiple tube/ 100 ml (37°C/48h)	10/ 100 ml	IS: 10500- 91 Indian Standard Specification for drinking water
8.	Overall migration of constituents from plastics (mg/l)	60	IS: 10146-87 Polyethylene for its safe use in contact with food stuff, pharmaceuticals and drinking water

Table 2. Dimensions & visual details of 'SHK' brand PPR pipes as per DIN 8077/IS: 15801- 2008

Dimension & Appearance	PPR pipe (DIN 8077/IS 15801)

	20 mm pipe		25 mm pipe		32 mm pipe	
	Required value	**Obtained value**	**Required value**	**Obtained value**	**Required value**	**Obtained value**
Outside Diameter (mm)	DIN : 20+0.3 IS : 20+0.3	20.28	DIN: 25+0.3 IS : 25+0.3	25.05	DIN: 32+0.3 IS : 32+0.3	32.06
Ovality (mm)	DIN : < 1.2 IS : < 1.2	0.18	DIN: < 1.2 IS : < 1.2	0.21	DIN: < 1.3 IS : < 1.3	0.22
Wall thickness (mm)	DIN : 2.8min IS : 2.8min 3.3max	3.08	DIN: 3.5min IS : 3.5min 4.1max	3.56	DIN: 4.4min IS : 4.4min 5.1max	4.89
Colour	Green					
Visual Appearance	Smooth, clear and free from grooves					

Table 3.Dimensional details of 'SHK' brand PPR fittings as per DIN 16962 (Part 6-8)

Parameter	Dimension	Dimension
	20 mm	**25 mm**

	Required Value (DIN 16962)	Obtained Value	Required Value (DIN 16962)	Obtained Value
A. Tee (DIN 16962, Part 7)				
Dia at mid point (d_1)	$19.3^{0}_{-0.3}$	19.07	$24.3^{0}_{-0.4}$	23.94
Dia at mouth (d_2)	$19.5^{0}_{-0.3}$	19.38	$24.5^{0}_{-0.3}$	24.27
(min.) Radius (k_1)	11	11.00	13.5	13.68
(min.) Tee laying length (t_1)	14.5	15.41	16	17.65
(max.) Out of roundness	0.4	0.08	0.4	0.12
B. Elbow (DIN 16962, Part 6)				
Dia at mid point (d_1)	$19.3^{0}_{-0.3}$	19.25	$24.3^{0}_{-0.4}$	24.23
Dia at mouth (d_2)	$19.5^{0}_{-0.3}$	19.30	$24.5^{0}_{-0.3}$	24.34
(min.) Radius (k_1)	11	11.10	13.5	13.67
(min.) Elbow laying length (t_1)	14.5	15.87	16	17.91
(max.) Out of roundness	0.4	0.18	0.4	0.19
C. Socket (DIN 16962, Part 8)				
Dia at mid point (d_1)	$19.3^{0}_{-0.3}$	19.01	$24.3^{0}_{-0.4}$	24.02
Dia at mouth (d_2)	$19.5^{0}_{-0.3}$	19.24	$24.5^{0}_{-0.3}$	24.25
(min) Radius (k_1)	3	3.91	3	3.18
(min) Socket laying length (t_1)	14.5	14.98	16	17.57
(max.) Out of roundness	0.4	0.09	0.4	0.13

Table 4. Physico-thermal properties of ‘SHK’ brand PPR Pipes

Property	Value

Density (Kg/m^3)	909
Water absorption (%, 24 hrs)	0.01
Melt Flow Rate of pipe (g/10min) (230°C / 2.16 kg) as per IS: 15801- 2008	0.47
Melt Flow Density (g/cc) at 230°C for 166 sec	0.621
Overall migration (mg/l) 24 h at 40°C as per IS: 9845 - 1998	6.45
Softening point (°C) - DMA method	138.32
Co-efficient of thermal expansion (/°C) - DMA method (30-100°C)	1.47×10^{-4}

Table 5.Overall migration of leachable additives from 'SHK' brand PPR pipes after various extraction durations

Temperature (°C)	**Overall migration (mg/l)**		
	1 day	**5 days**	**10 days**
40	6.45	13.40	16.20
60	9.51	17.14	26.50
80	12.31	28.58	33.75

Table 6. Potability characteristics of water samples drawn from 'SHK' brand PPR pipes

Name of Test	Control Tap Water (days)			PPR Pipe (days)		
	1	5	10	1	5	10
pH	7.32	7.40	7.61	7.45	7.56	7.70
Total dissolved solids (mg/l)	159	167	178	164	180	195
Turbidity (NTU)	0.71	0.72	0.73	0.75	0.79	0.84
Taste	None	None	None	None	None	None
Odour	Odour less	Odour less	Odour less	Odour less	Odour less	Odour less
Colour	No change	No change	No change	No change	No change	No change
Total living mortality (96hr in tank water)	No mortality	No mortality	No mortality	No mortality	No mortality	No mortality

Table 7. Toxic metals estimation in the PPR pipe extract ('SHK' brand) by ICP Method

Property	**Value (mg/l)**		
	Control	**PPR sample**	
		RT	**70°C**
Iron (Fe)	ND	ND	ND
Cadmium (Cd)	ND	ND	ND
Lead (Pb)	ND	ND	ND
Zinc (Zn)	ND	ND	ND
Copper (Cu)	ND	ND	ND
Mercury (Hg)	ND	ND	ND

* Non-detectable

Table 8. Microbiological test of 'SHK' PPR pipe extract

Storage time	**Multiple tube method (per 100 ml)**	
	Control	**PPR Pipe**
4 weeks	NIL	NIL
5 weeks	NIL	NIL
6 weeks	NIL	NIL

Table 9. Potability evaluation of water extractant of 'SHK' brand PPR pipes as per IS: 10500 - 91 (Indian Standard Specification for Drinking Water)

Property	**Required value (IS: 10500 - 91)**	**PPR pipe Obtained value**
Colour	No change	Pass
Odour	Unobjectionable	Pass
Taste	Agreeable	Pass
Turbidity	10	0.75
Dissolved solids (mg/ l max)	500	194
pH	6.5 - 8.5	7.45
Microbiological test (6 weeks)		
Multiple tube MPN/100 ml (37°C/48 h)	10	NIL
Toxic metals (ICP method)		
Cadmium (mg/l) max.	0.01	ND*
Lead (mg/l) max.	0.05	ND
Zinc (mg/l) max.	5.0	ND
Copper (mg/l) max.	0.05	ND
Mercury (mg/l) max.	0.001	ND

* Non-detectable

Table 10. Mechanical properties of 'SHK' brand PPR Pipes/fittings as per IS: 15801- 2008

Property	**Value**
Reversion Test (%)	No crack/bister 0.41
Hydraulic Characteristics (Internal Creep Rupture)	No bursting/leakage/localized swelling
Burst Pressure (Bar)	90-100
Impact Strength 0°C 27°C	Neither splitting nor crack

Table 11. Assessment of 'SHK' brand PPR pipes as per IS: 15801- 2008

Property	**Clause No.**	**Required Value (IS 15801)**	**PPR Pipe Obtained Value**
Colour	5	Agreed between buyer and seller	Green
Dimension	7		
Nominal diameter (mm)	7.1	20 + 0.3	20.03
Outside diameter (mm)	7.1	20 + 0.3	20.28
Ovality (mm)	7.1	1.2	0.18
Wall thickness (mm)	7.2	2.8 - 3.3	3.08
Visual appearance	8	Smooth, clean & free from grooves	Smooth, clean & free from grooves
Performance Tests			
Overall migration test (mg/l)	6.6	60	6.45
Hydrostatic characteristics 20°C& 95°C (1 & 22 hrs)	9.1	No sign of localized swelling, leakage & no bursting	No failure
Reversion test (%, max)	9.3	< 2.0	0.41
Impact strength	9.4	Failure should not exceed 10% of the specimens tested	Pass
Density (kg/m^3)	9.5	900 - 925	909
Melt flow rate (g/ 10 min)	9.6	0.63 (≤ 0.5 + 30% of base material)	0.47

Table 12. Properties of 'SHK' brand PPR pipes (25mm dia) as per DIN 8077/8078-96

Property	Clause No.	Required Value (DIN 8077/8078)	Obtained Value
Condition of sample	4.1	Free from blisters, shrink holes and in homogeneity	Free from defects
Surface finish	4.2	Smooth	Smooth
Average outside diameter (mm)	4.3	25 + 0.3	25.05
Ovality (mm)	4.3	1.2	0.21
Min wall thickness (mm)	4.3	3.5 + 0.6	3.56
Creep strength	4.4	No burst/ leak during stressing	No bursting/ leaking
Impact strength	4.5	Failure not exceed 10% of the specimen	No failure at 0ºC and 25ºC
Heat reversion (%)	4.6	< 2	0.41

Table 13. Properties of 'SHK' brand PPR fittings as per DIN 16962 (Part 5)

Property	Clause No.	Required Value (DIN 16962)	PPR Fittings Obtained Value
Condition of sample	3.1	Free from voids, blisters, in homogeneity and fresh	Free from defects
Creep strength	3.2	No leakage/ fracture during stressing (pipe coupling, T-joints and socket joints)	No failure
Heat reversion (%)	3.3	No cracks/ blistering/ delamination at 150 $\pm$ 2^{O}C	No visual defects
Surface finish	3.4	No zone burnt/ overheating, free from sink marks	Free from defects

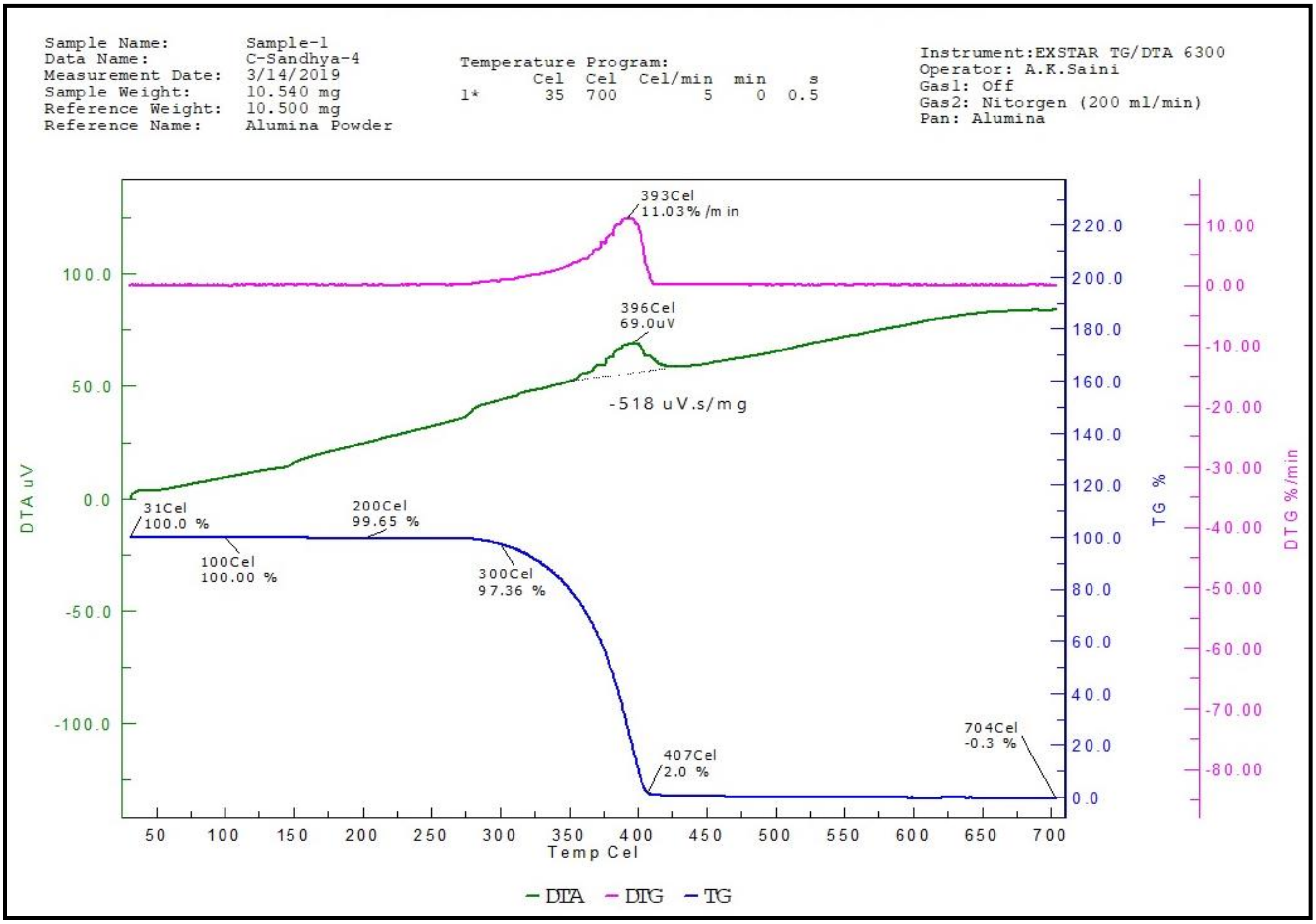
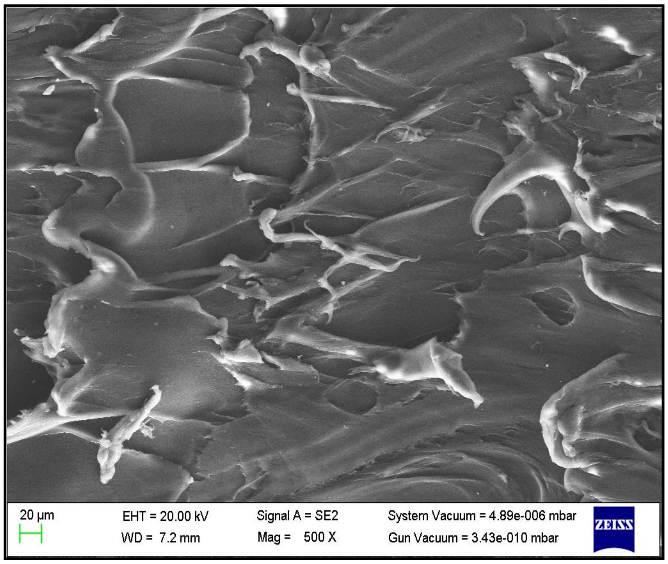
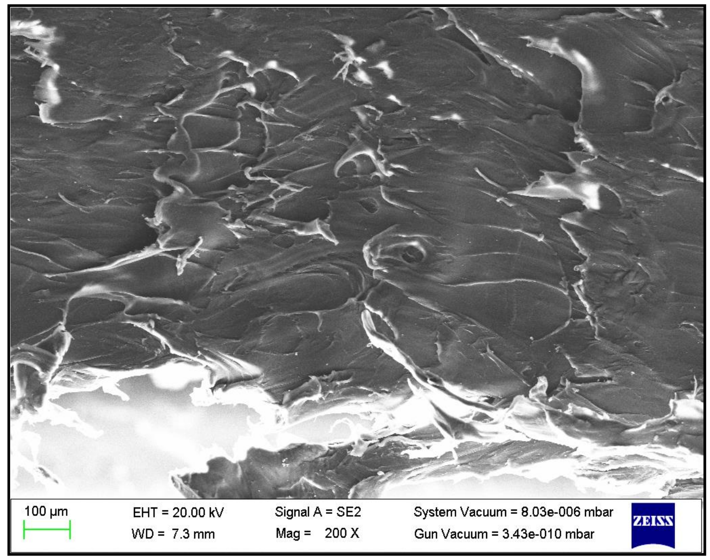


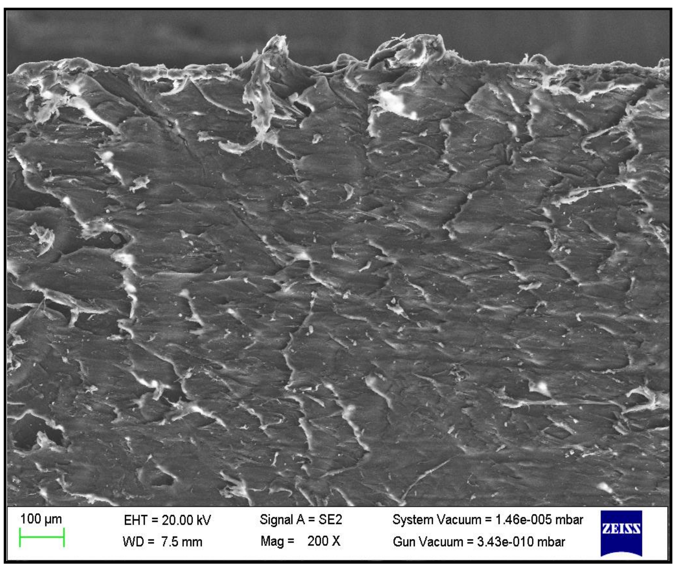
Fig. 1 Simultaneous thermal analysis of PPR pipe material showing its thermal stability



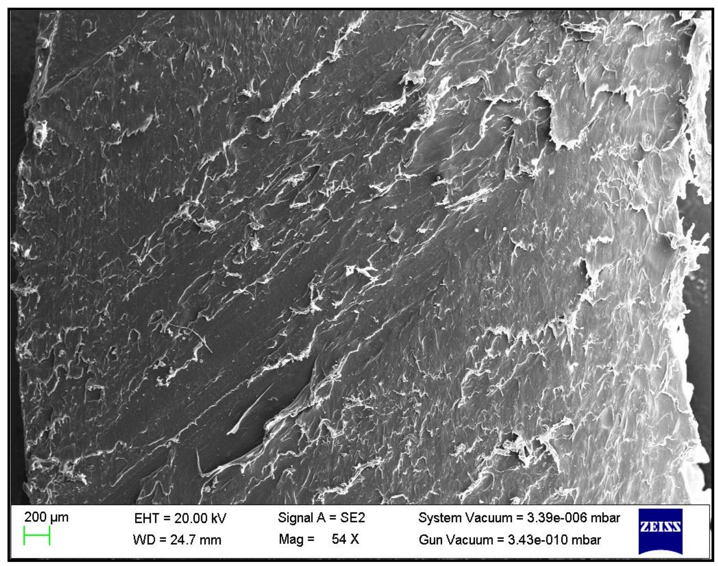
Outer layer



Middle layer

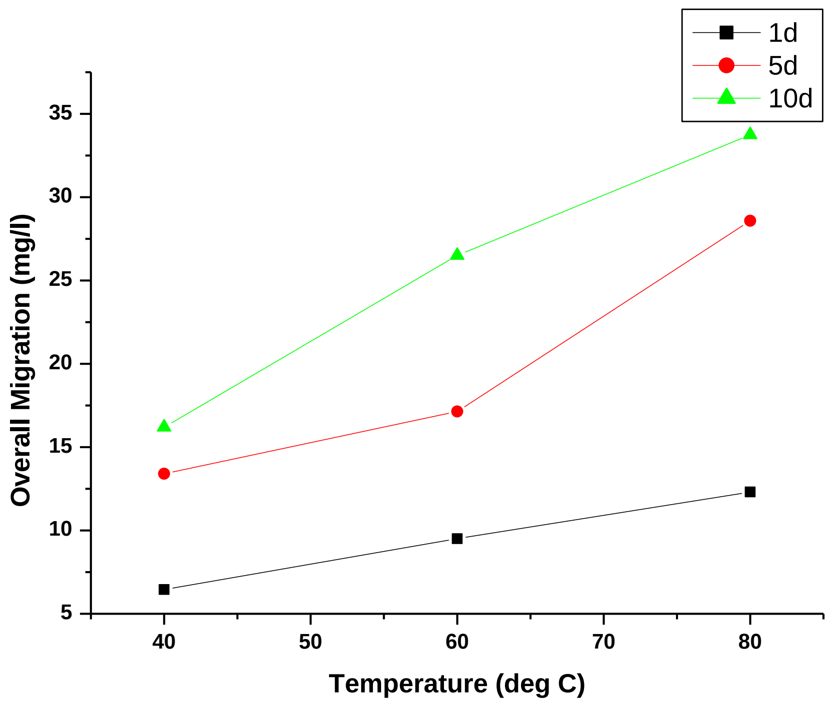


Inner layer



Complete view of three layer

Fig. 2 Scanning Electron micrographs of SHK pipes showing internal morphology of different layers



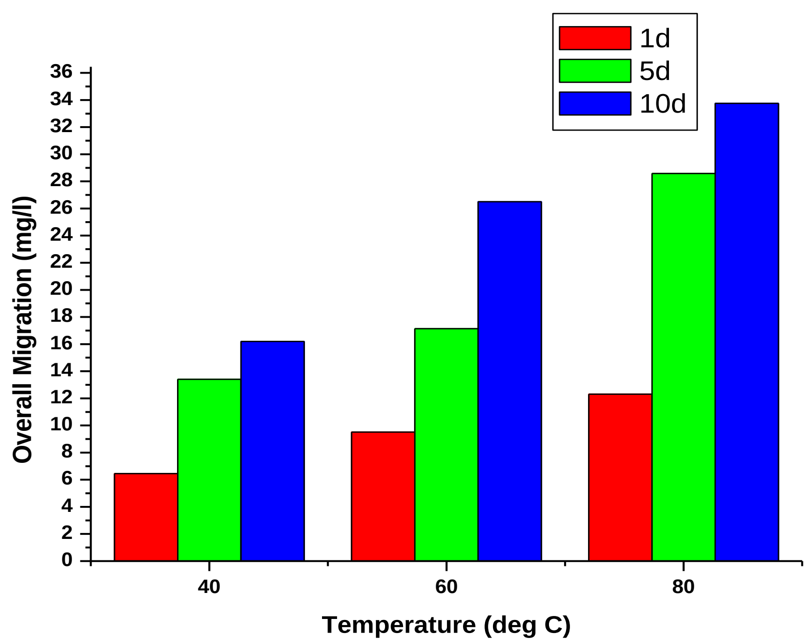
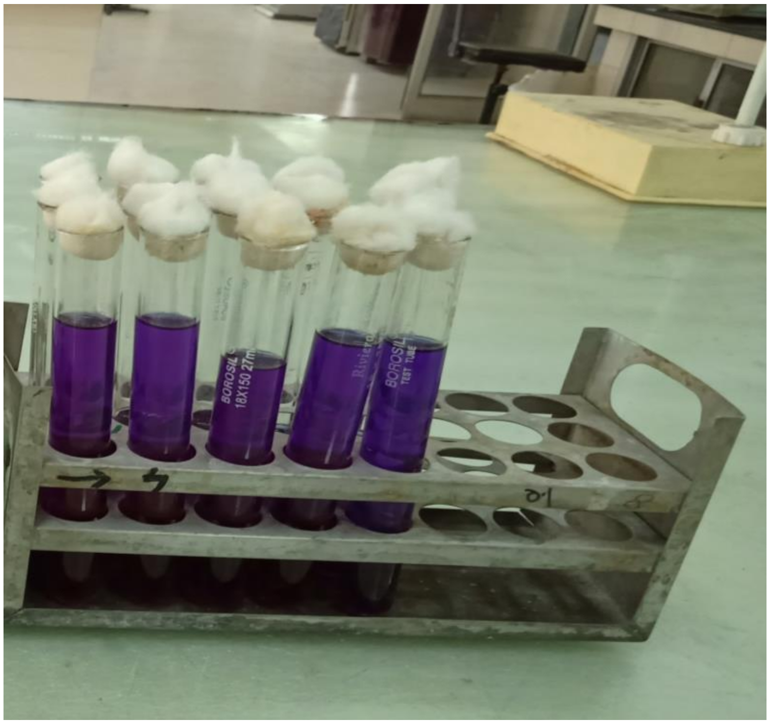


Fig. 3 Overall migration of leachable additives as a function of temperatures and storage time of SHK PPR piping materials

Control Water



Pipe Water

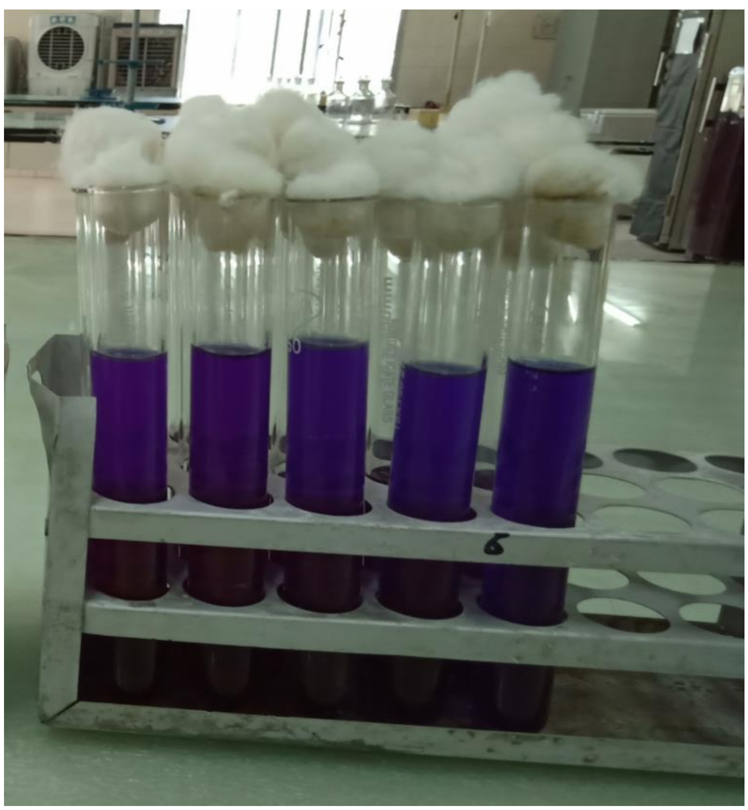
Fig. 4a. Microbiological test of pipe extract showing inoculums after 4 weeks

Control Water

Pipe Water

Fig 4b. Microbiological test of pipe extract showing inoculums after 5 weeks

Control Water



Pipe Water

Fig 4c. Microbiological test of pipe extract showing inoculums after 6 weeks