

# EVALUATION METHODS FOR CROSSLINKED POLYETHYLENE PIPES FOR HOT WATER SUPPLY AND SPACE HEATING SYSTEMS

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## ABSTRACT

This paper describes test methods for crosslinked polyethylene (PEX) pipes to evaluate long-term performance such as the resistance to chemical degradation due to residual chlorine at high temperature by the formation of crosslinked molecular structure and the addition of suitable antioxidants. As the methods of manufacturing PEX, the silane crosslinking process and the peroxide crosslinking process are used to produce PEX pipes for hot water supply and space and bath heating at Osaka Gas.

The Oxidation Induction Test (OIT) and the gear oven test are accelerated tests and useful to evaluate relative thermal stability. However, these tests are not directly correlated to actual life.

The immersion test is also useful to clarify the relation between immersion time and time to oxidation in a high concentration of aqueous solution of residual chlorine is obtained.

The long-term performance of pipes can be generally evaluated by the stress rupture test. The stress rupture diagram is the most important data to indicate the actual creep strength of PEX pipes. The hoop stress corresponding to a operating pressure of 0.5 MPa even at 90 degrees C is 2 MPa, and the service life under continuous use is  $3 \times 10^4$  hr or more, which is almost equivalent to 30 years under intermittent use at the rate of 3 hours a day even when a safety factor of 2 is assumed as the regression line for the experimental data.

The stress rupture test by circulating a 3-ppm aqueous solution of chlorine at elevated temperature is a suitable test method to evaluate the actual life of PEX pipes.

## INTRODUCTION OF PEX PIPES

Plastic pipes are used for water and hot water supply for residential use in Japan. Figure 1(a) shows a material share of their pipes for residential use in Japan estimated from a research in 2002. Plastic pipes included PVC pipes occupy 67 % of the total use. PEX pipes and polybutene(PB) pipes are used as plastic pipes. PEX pipes are mainly used for hot water supply and space heating systems. A share of applications of plastics pipes in Japan estimated from a research in 2002 is also shown in Figure 1(b). The total annual usage is approximately 8,000 t and that of estimated present value is 10,500 t. The share is 39 % for water supply, 24 % for hot water supply, 20 % for floor heating, and 17 % for air conditioning and others.

A typical residential system using a water heater used for central heating and terminal appliances such as a bathroom heater and a dryer, a dish washer and a dryer, an air conditioner, a floor heating, and a full-automatic bath has been developed in Osaka Gas in Figure 2. PEX pipes are commonly used as hot water distribution pipes connecting a water heater and terminal appliances.

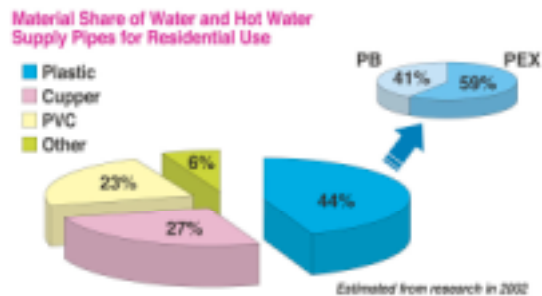


Figure 1(a). Share of plastic pipes for residential use in Japan

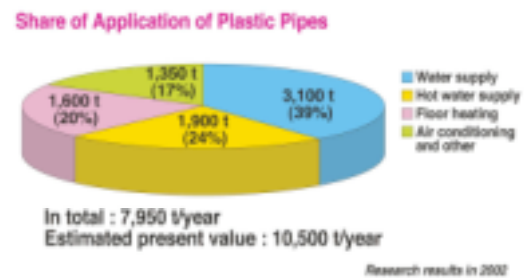


Figure.1(b). Share of applications of plastics pipes in Japan



Figure 2. A typical residential system using PEX pipes

The annual consumption of PEX pipes in our company is 3.3 million meters (approximately 300 ton/year) for hot water distribution pipes connecting a water heater and terminal appliances and 11.2 million meters for floor heating pipes (approximately 220 ton/year). The nominal diameters for hot water distribution pipes are mainly from 6 mm to 13 mm. A pair of PEX pipes with a signal line in a protect corrugated pipe is used as shown in Figure 3. The annual consumption of PEX pipes in our company is 11.2 million meters for floor heating pipes. The nominal diameter is now only 5 mm.

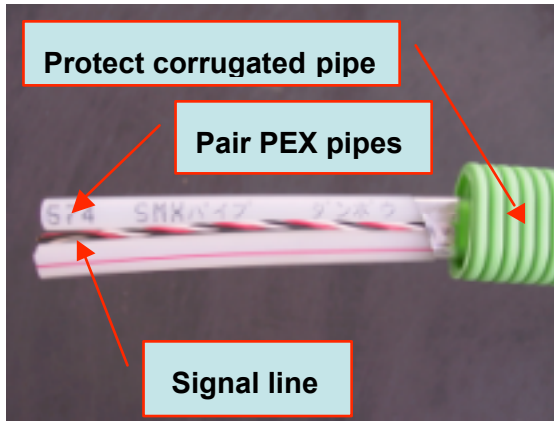


Figure 3. Typical distributing pipes system connecting water heater and terminal appliances used PEX pipes

For PEX pipes to have flexibility, the subway process, in which the protect corrugated pipes are installed in advance and PEX pipes are laid through these corrugated pipes at the time of interior finishing work, is employed. In addition, the PEX pipes can easily be replaced.

### REQUIRED PERFORMANCE OF PEX PIPES

Figure 4 shows schematic stress rupture curves of a conventional and high performance PEX pipes. There are three modes of failures which are ductile failure (I), brittle failure (II), and chemical degradation failure (III). To maintain long-term resistance to chemical degradation due to residual chlorine at the elevated temperature, suitable antioxidants were added. A polyethylene resin with a high molecular weight was also selected. A crosslinking of 80 % or more was made for a formation of network structure. As a result, a more stable three-dimensional molecular structure and a considerably greater stress-rupture strength than that of conventional PEX pipes were formed.

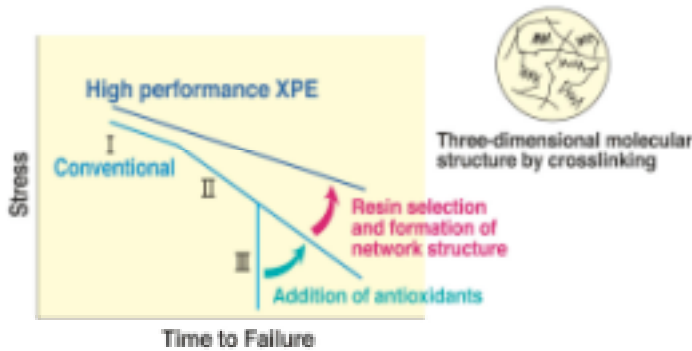


Figure 4. Schematic stress rupture curves

The maximum operating pressures are determined for water and hot water supply for each temperature range by the allowable hoop stress that results in the 50-year life considering safety factors as 2.0 for PB and 1.5 for PEX and Standard Dimension Ratio (SDR) as 12 for PB and 8 for PEX specified in JIS K6778<sup>1)</sup> and JIS K6769<sup>2)</sup> as shown in Table 1.

Table 1.

	Temp.(degreeC)	0-20	21-40	41-60	61-70	71-80	81-90	91-95
PB	Maximum Operating	1.0-0.9		0.8-0.7	0.6	0.5	0.4	-
PEX	Pressure(MPa)	1.50	1.25	0.95	0.85	0.75	0.70	0.65

The specifications of plastic pipes for water and hot water supply in our company are as follows.

(1) Water and hot water supply

- Maximum operating temperature is 60 degrees C.
- Maximum operating pressure is 0.5 MPa.
- Maximum residual chlorine concentration is 3ppm.
- Maximum copper iron concentration is 0.3 mg/l (trace amount).
- Water hammer resistance (1.5MPa) and static water pressure resistance are required.
- 30-year-or-more life of a system is required to be guaranteed.

Because of the improvement of water faucets, the water hammer is not a serious problem as it used to be. However, the water pressure is getting higher due to the deregulations on direct connection of a water heater and terminal appliances with plastic pipes without a water storage tank. The maximum copper iron concentration is 0.3 mg/l because the metal joints and heat exchange part in a water heater includes copper. Residual chlorine concentration is getting higher because of the action against Legionella bacterium. The elapsed operating time for water and hot water supply is as follows: 3 hr/day × 365 day/year × 30 year = 32,850 hr ≈ 3 × 10<sup>4</sup> hr.

The maximum operating pressures are also determined for heating and bath circuits for each temperature range by the allowable hoop stress that results in the 50-year life considering a safety factor as 2.0 and SDR as 12 for PEX specified in Japan X-linked polyethylene Pipe Association (JXPA)<sup>3)</sup> as shown in Table 2.

Table 2.

Temp.(degreeC)	0-40	41-60	61-80	81-90	91-
Maximum Operating Pressure(MPa)	0.5	0.4	0.3	0.25	*1

\*1: Determined by the agreement between a user and a supplier.

The specifications of plastic pipes for heating and bath circuits in our company are as follows.

(2) Heating and bath circuits

- Maximum operating temperature is 90 degrees C.
- Maximum operating pressure is 0.25 MPa.
- Maximum residual chlorine concentration is 3 ppm for bath circuits.
- 30-year-or-more life of a system is required to be guaranteed.

The 30-year-or more life of a system for the heating circuit should be guaranteed at 90 degrees C under the inner pressure of 0.25 MPa. No failure for 12,000 hr or more is required at 110 degrees C as an accelerated test. The elapsed operating time for heating is as follows:

- Floor heating and air conditioning 8 hr/day × 120 day/year × 30 year = 28,800 hr
- Bathroom heating and drier 2 hr/day × 365 day/year × 30 year = 21,900 hr
- Mist sauna 1.4 hr/day × 365 day/year × 30 year = 15,330 hr, in total 66,030 hr

The extrapolation limits are based on an experimentally determined life at 110 degrees C. The value of the extrapolation factor K which is the expected lifetime at a given temperature divided by the lifetime at 110 degrees C is shown in Table 3.<sup>3)</sup>

Table 3.

Temperature ( degrees C)	Extrapolation factor K
100	2.5
95	4
90	6
85	12
80	18
75	30
70	50

The extrapolated life of 12,000 hr × 6 = 72,000 hr satisfies the required life of 66,030 hr.

The 30-year-or-more life of a system for the bath circuit should be also guaranteed at 90 degrees C with the residual chlorine concentration of 3 ppm. No failure for 11,000 hr or more is required at 95 degrees C under the inner pressure of 0.2 MPa with the residual chlorine concentration of 3 ppm.

With respect to additional factors affecting a lifetime, contacts with a metal and the existence of metal ions in a hot water should be paid attention to reduce a lifetime of PEX pipes. 90 % metal joints was already converted to plastic joints. Chemical agents such as urethane foam spray, solvents for adhesives, surfactants, and cleaners used in installation, and glue and adhesive for aluminum sheet in heating mats affect a lifetime. Influence of anti-freezing fluid should be also considered.

## EVALUATION METHODS FOR LONG-TERM PERFORMANCE

Many test methods are investigated to evaluate the long-term performance such as thermal stability and the resistance to chemical degradation due to residual chlorine at high temperature by the formation of crosslinked molecular structure and the addition of suitable antioxidants. As the methods of manufacturing PEX, the silane crosslinking process and the peroxide crosslinking process are used to produce PEX pipes used as distributing pipes connecting a water heater and terminal appliances.

The Oxidation Induction Time (OIT) test and the gear oven test accelerated a time are useful tests to evaluate relative thermal stability. However, these tests are not directly correlated to an actual life. The immersion test is also useful as the relation between an immersion time and a time to oxidation in a high concentration of aqueous solution of residual chlorine is obtained. The long-term performance of pipes can be generally evaluated by the stress rupture test. The stress rupture diagram is the most important data to indicate the actual creep strength of PEX pipes.<sup>4)</sup>

Figure 5 shows failure curves as a parameter of temperature of PEX pipes. 30-year-or-more life of a system for water and hot water supply is required to be guaranteed at 60 degrees C under an internal pressure of 0.5 MPa for PEX pipes. As the accelerated test conditions, the stress rupture tests were conducted at 80 and 90 degrees C and at an internal pressure of 1.0 through 1.5 MPa for a PEX pipe of SDR 9. It was found that the regression line satisfies the 30-year-or-more life of  $3 \times 10^4$  hr for water and hot water supply considering safety factor 2 even at 90 degrees C.

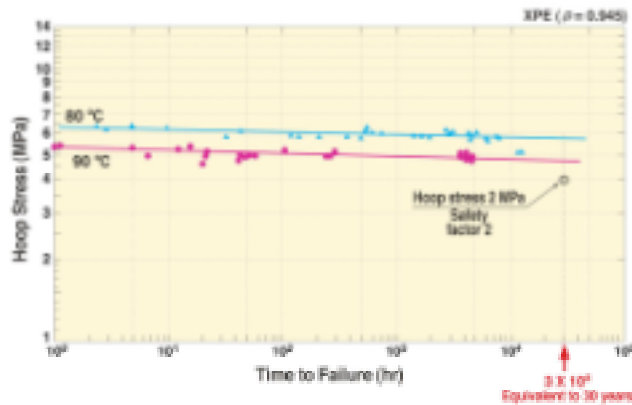


Figure 5. Stress rupture diagram of PEX pipes

Figure 6 shows evaluation results of PB pipes indicating a relation between a time and a reciprocal of temperature as a parameter of various tests. The OIT test is useful for evaluation of a function of antioxidant. A line of no addition of antioxidant is quite below. It is not precise to predict a lifetime because the temperature acceleration is too high. A line of 50 %-holding tensile elongation in a hot water in the immersion test was below that of 50 %-holding tensile elongation in air in the gear oven test because antioxidants moved in a hot water. Furthermore, a line indicating a failure time in tensile creep test in aqueous solution of residual chlorine was below that of 50 %-holding tensile elongation in a hot water in immersion test, resulting in close to the actual life time.

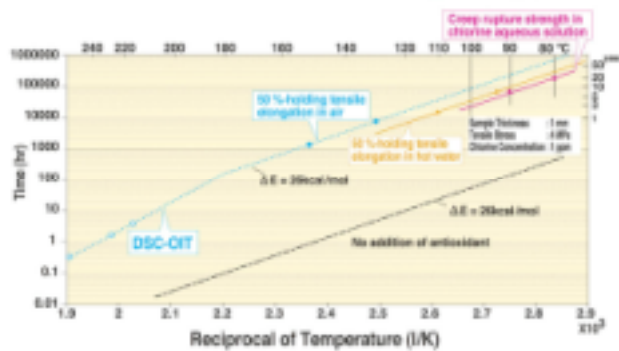


Figure 6. Evaluation results of PB pipes

The Essential Work of Fracture (EWF) test is recently introduced to determine fracture toughness of a thin-wall product standardized by ISO/CD18874.<sup>4)</sup> The relation between specific work of fracture  $W_f$  and ligament length  $L$  was plotted. As a least squares regression line was obtained, The intercept between the vertical axis and the regression line indicates the essential work of fracture  $W_e$ . The slope indicates the plastic work of fracture  $\beta W_p$  where  $\beta$  is the plastic zone shape factor. The EWF test was conducted to obtain fracture toughness for a new resin of non-crosslinked PolyEthylene Raised for Temperature (PERT) and conventional XPE. It was found that PERT has a high fracture toughness equivalent to that of XPE.

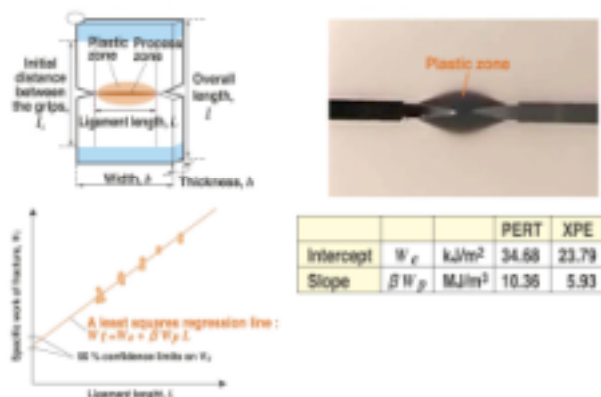


Figure 7. Test results of EWF

## CONCLUSIONS

PEX pipes are also widely spread for hot water supply and space heating in Osaka Gas. The hot water supply systems have been established. They can also enhance the work efficiency at housing construction sites and also reduce the working time by a benefit of light weight and flexibility of a material.

## REFERENCES

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