An Experimental Investigation of the Effect of Temperature on Failure Behaviour of PVC Pipe

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Abstract: An experimental investigation of the effect of temperature on the internal pressure sustaining capacity of polyvinyl chloride (PVC) pipes, is presented. It is observed from the experimental results that there is remarkable effect of temperature on the mean failure pressure characteristics of the PVC pipes. With the increase of temperature, the mean failure pressure decreases remarkably.

Keywords : *PVC pipe, failure pressure, Temperature Effect.*

INTRODUCTION

Now-a-days one of the most important PVC product is the pipe. The moderate strength, moderate modulus of elasticity, moderate impact strength, excellent chemical resistance and light weight etc. have made PVC pipe attractive for wide range of application. It has replaced many products made of asbestos cement, concrete, aluminum and steel etc. because of its suitable mechanical and chemical properties and reasonable cost.

In regard to wide application of PVC pipes in various parts of the world, it is felt necessary to perform an investigation concerning their mechanical properties. A number of parameters has significant effect on its mechanical properties. However, in the present investigation, only the effect of temperature on the failure pressure of PVC pipe is taken into consideration.

J. W. Summers and E. B. Rabinovitch [6] investigated the effect of temperature on the modulus of elasticity and toughness of PVC materials. B. Terselius and J. F. Jansson [7] studied the effect of temperature on tensile properties of PVC materials. J. L. O' Toole [3] investigated the effect of temperature on the hoop stress of high density polyethylene (HDPE). R. W. Hertzberg [1] studied the perspective of fracture mechanics on the failure of plastic pipe. A. R. Ragab and A. El. Zoghby [4] investigated the bursting, impact resistance, short-and longterm stiffness tests on plain and spirally stiffened PVC pipes. But none considered the effect of temperature on the failure pressure characteristics of PVC pipes.

A wide variation of atmospheric temperature prevails in many parts of the world. In Bangladesh this variation is in between 8^0C to 44^0C approximately over the whole year. It may be mentioned that according to the British Standard (BS3505) the PVC pipes are tested at temperature of 20 ± 2^0C. In the circumstances the effect of temperature on the failure pressure characteristics of PVC pipes is considered to be very important. In conformity with the range of temperature in the country, for a wide range of temperature variation from 10^0C to 50^0C, the experimental investigation on the failure pressure characteristics of PVC pipes has been carried out. At each temperature a reasonable number of samples is considered for the study and the mean failure pressure is calculated [5].

EXPERIMENTAL SET-UP

The experimental set-up mainly consists of a constant-temperature bath, a hydraulic pump fitted with a pressure gauge and a temperature control device equipped with temperature indicators. Figure 1 shows respectively the two views of the constant temperature-bath. The constant-temperature bath is a water bath of dimensions 1028 mm (length) x 405 mm (breadth) x 450 mm (height). The bath is made of galvanised iron sheet of thickness 1.60 mm. It consists of a big tank (water bath), a small tank (test platform), two agitators, three heaters, a temperature controller, a temperature indicator and a thermometer. The test platform is also made of galvanised sheet of thickness 1.6 mm with dimensions 700 mm x 305 mm x 127 mm. It is immersed in the middle of the water bath and supported at a distance of 152 mm from the bottom with the help of four steel bolts. The bottom of the test platform is perforated to facilitate the flow of water. The two agitators are driven by DC electric motor. They are used with a view to maintaining uniform temperature throughout the bath.

Two 250 V, 3kW heaters as shown in the Figure 1, are used to heat the water in the tank to the desired test temperature primarily and afterwards a 250 V, 1kW heater is used to maintain the constant temperature. The 1kW heater is connected to the A.C. power source through a temperature controller and a magnetic contactor. The function of the controller is to operate the heater as per requirement to maintain the constant temperature in the water bath. The temperature indicator and the thermometer are used to measure the test temperature. The temperature controller also records the temperature for cross-checking.

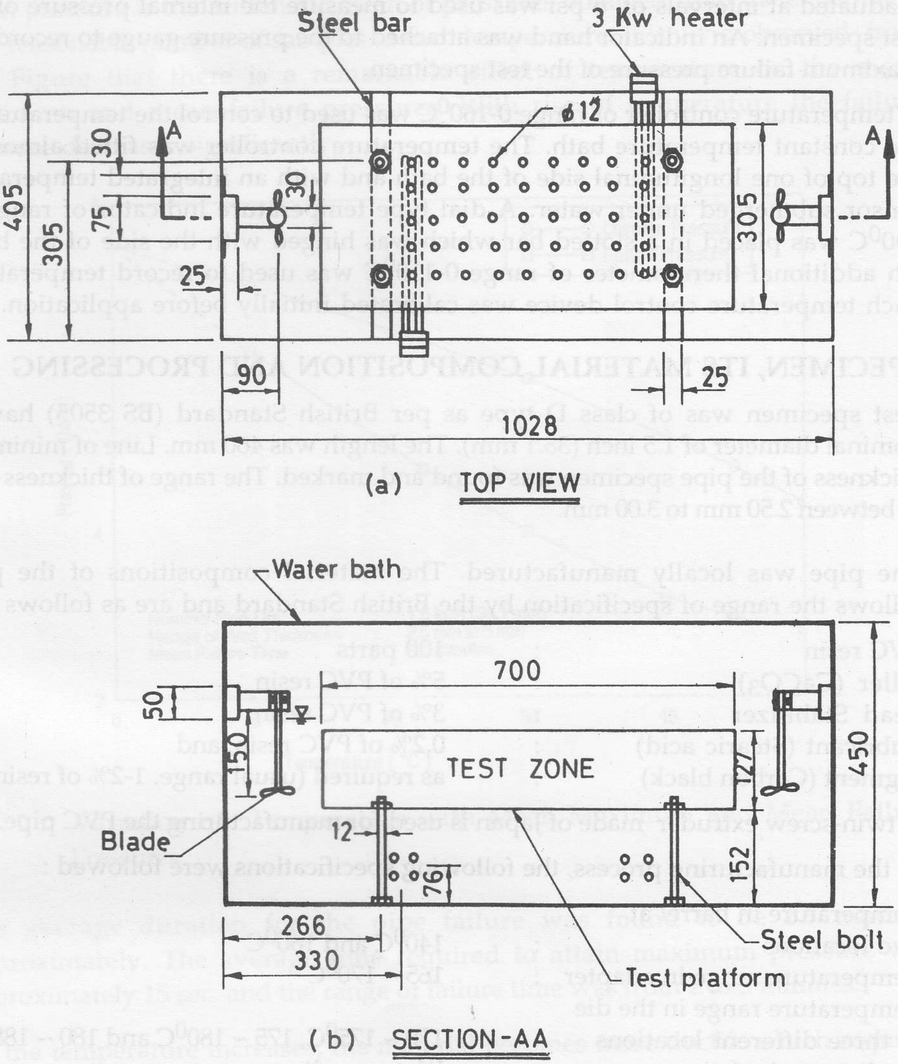

Fig. 1 : Two Views of the Constant Temperature-bath.

A hydraulic jack of capacity 20 ton was used with appropriate modification as a pump to develop the required internal pressure of the test specimen. Compressor oil was used as the pump fluid. The test specimen was connected to the pump by the help of 6 mm copper tube. A pressure gauge of range zero to 1000 psi (6.9 MPa) graduated at intervals of 5 psi was used to measure the internal pressure of the test specimen. An indicator hand was attached to the pressure gauge to record the maximum failure pressure of the test specimen.

A temperature controller of range 0-160^{0}C was used to control the temperature of the constant temperature bath. The temperature controller was fitted almost at the top of one longitudinal side of the bath and with an integrated temperature sensor submerged under water. A dial type temperature indicator of range 0-100^{0}C was placed in a slotted bar which was hinged with the side of the bath. An additional thermometer of range 0-110^{0}C was used to record temperature. Each temperature control device was calibrated initially before application.

SPECIMEN, ITS MATERIAL COMPOSITION AND PROCESSING :

Test specimen was of class D type as per British Standard (BS 3505) having nominal diameter of 1.5 inch (38.1 mm). The length was 460 mm. Line of minimum thickness of the pipe specimen was found and marked. The range of thickness was in between 2.50 mm to 3.00 mm.

The pipe was locally manufactured. The material compositions of the pipe follows the range of specification by the British Standard and are as follows :

PVC resin	:	100 parts
Filler ($CaCO_3$)	:	5% of PVC resin
Lead Stabilizer	:	3% of PVC resin
Lubricant (Stearic acid)	:	0.2% of PVC resin, and
Pigment (Carbon black)	:	as required (usual range, 1-2% of resin)

A twin-screw extruder made of Japan is used for manufacturing the PVC pipe.

In the manufacturing process, the following specifications were followed :

Temperature in barrel at two locations	:	140^{0}C and 160^{0}C
Temperature range in adapter	:	165 ~ 170^{0}C
Temperature range in the die at three different locations	:	170 ~ 175^{0}C, 175 ~ 180^{0}C and 180 ~ 188^{0}C.
Cooling method	:	Water cooling.
Screw speed	:	10 ~ 12 rpm.
Back pressure	:	0.8 ~ 0.9 MPa.
Take-up speed	:	0.01524 ~ .02032 m/s.

RESULT AND DISCUSSION

The variation of temperature with mean maximum and mean failure pressures of the pipe over the range of temperature from 10^0 to 50^0C is shown in Figure 2. Mean pressure is the arithmetic mean of pressures obtained from the experiment on a reasonable number of samples at each temperature. It is vivid observed from this Figure that there is a remarkable effect of temperature on the mean maximum and mean failure pressures. With rise of temperature the failure pressure decreases significantly.

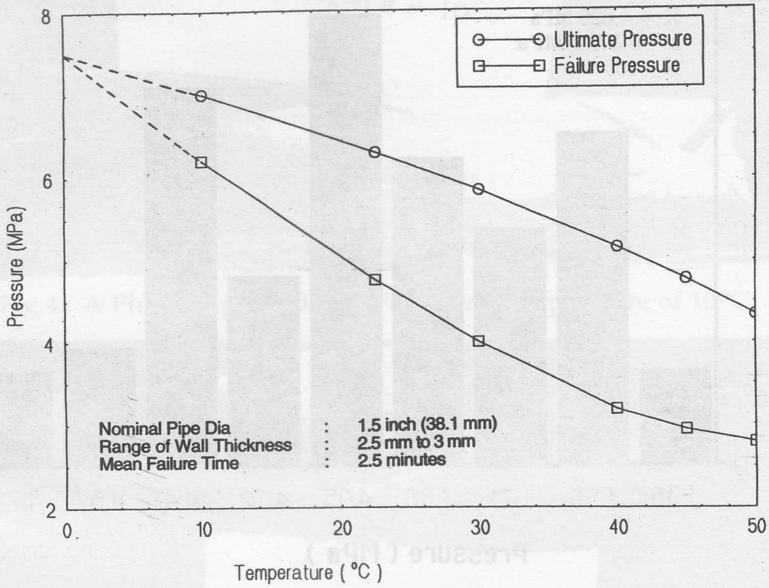

Fig. 2 : Variation of Temperature with Mean Maximum and Mean Failure Pressures.

The average duration for the pipe failure was found to be 2.5 minutes approximately. The average time required to attain maximum pressure was approximately 15 sec. and the range of failure time was from 2 to 3 minutes.

As the temperature increases, the material becomes more ductile which requires higher amount of liquid flow inside the pipe and the pipe swells at higher rate before failure. Thus at the higher temperature the time required for the failure is higher whis is observed from the experiment. This behaviour is the reason for larger difference between mean maximum pressure and mean failure pressure at the higher temperature in comparison to that at the lower temperature. It can be further observed that the two extrapolated curves of the mean maximum and minimum pressures coincide at abut 0^0C.

The Figure 3 shows frequency distribution of failure pressure at temperature of 30^0C. At this temperature, the arithmetic mean of the failure pressure, $\bar{x}$ = 4.028 MPa, standard deviation = .3724 MPa and the sample size, N = 100.

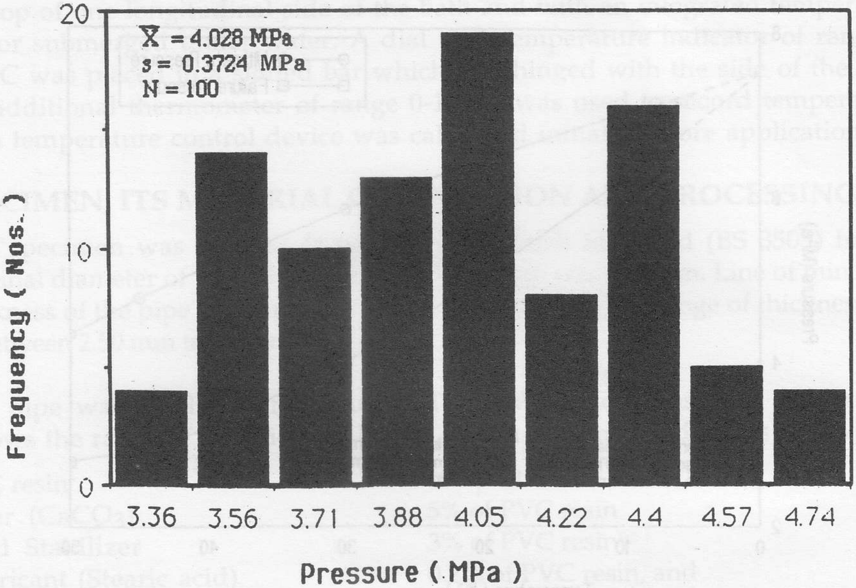

Fig. 3: Frequemcy Distribution of Failure Pressure at Temperature of 30°C.

Two types of failures such as brittle and ductile were observed in the investigation. At the lower temperature failure occurs with little deformation known as brittle failure while at higher temperature failure occurs with considerable deformation known as ductile failure. A specimen of the brittle nature of failure is shown in the Figure 4 at the temperature of 10°C while a specimen of ductile nature of failure is shown in the Figure 5. It can be further observed from the Figure 4 that the failure occurs with propogation of cracking while it can be seen from the Figure 5 that there has been appreciable deformation but failure occurs with local leakage. With the rise of the

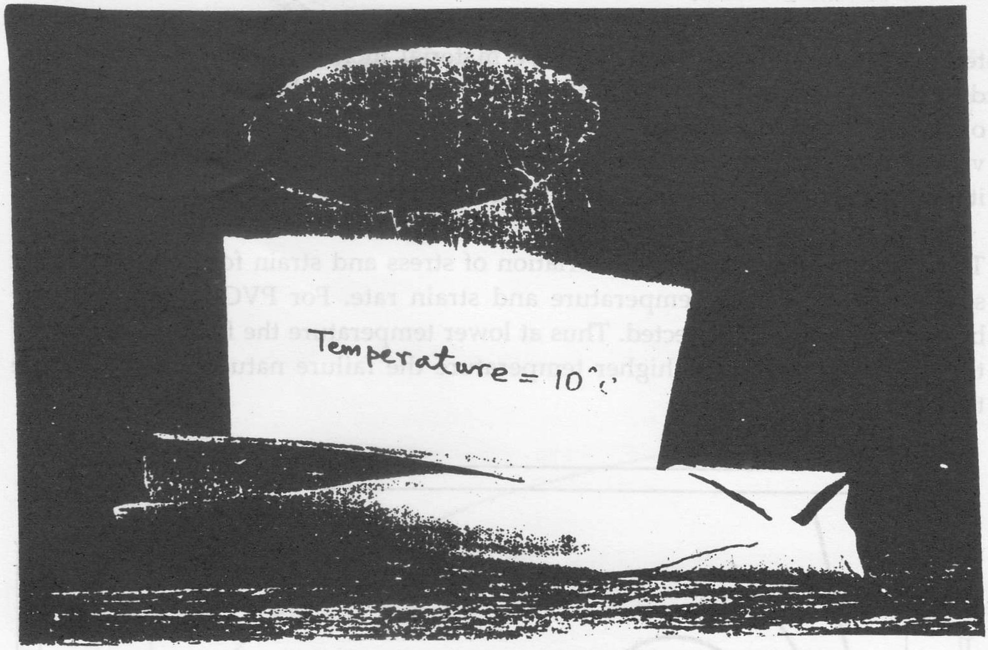

Fig.4: A Photograph of Brittle Failure at Temperature of 10^{o}C.

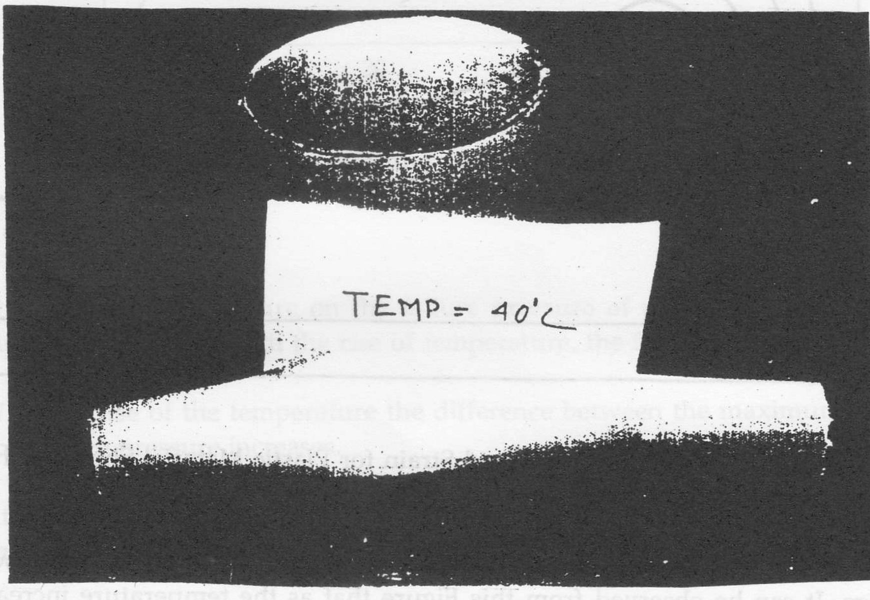

Fig. 5: A Photograph of Ductile Failure at Temperature of 40^{o}C.

temperature, the ductility of the pipe material increases, as a result the pipe deforms remarkably which can be seen from its swelling effect. It has been observed from the experiemnt that the specimen with relatively higher variation of thickness undergoes relatively higher amount of swelling effect and it occurs in the region of minimum thickness.

The Figure 6 shows as typical variation of stress and strain for plastic material showing the effect of temperature and strain rate. For PVC material similar behaviour is usually expected. Thus at lower temperature the failure nature is of the brittle type while at higher temperature the failure nature follows ductile type.

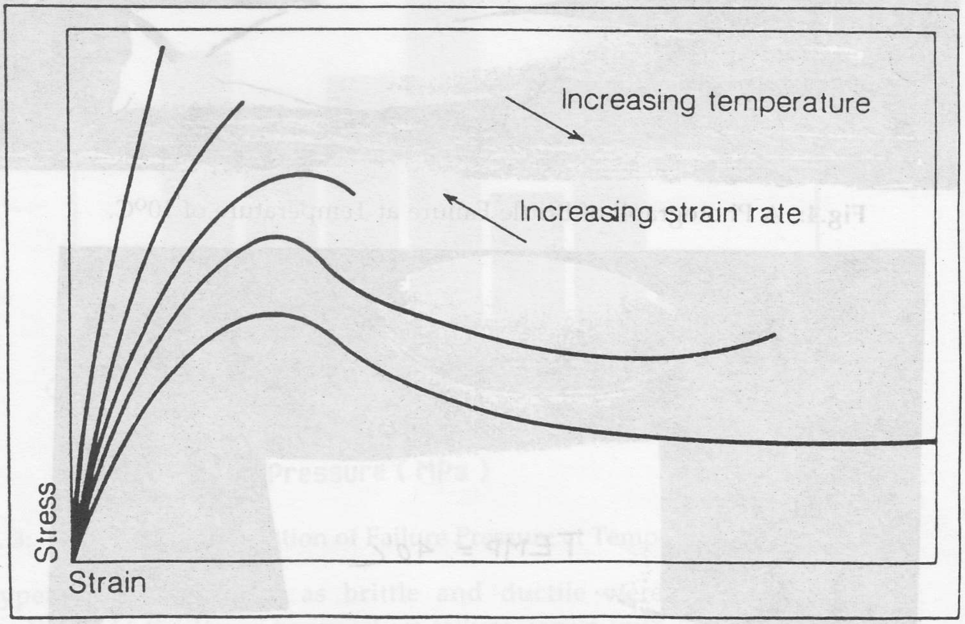

Fig. 6: Typical Variation of Stress and Strain for Plastic Material Showing the Effect of Temperature and Strain Rate.

The Figure 7 shows the effect of temperature on the percentage failure with leakage. It can be observed from this Figure that as the temperature increases the percentage of failure with leakage increases.

The uncertainties in the measurement of pressure and temperature are done by the method proposed by S. J. Kline and F. A. McClintock [2] and they are found within 2% which are considered to be insignificant.

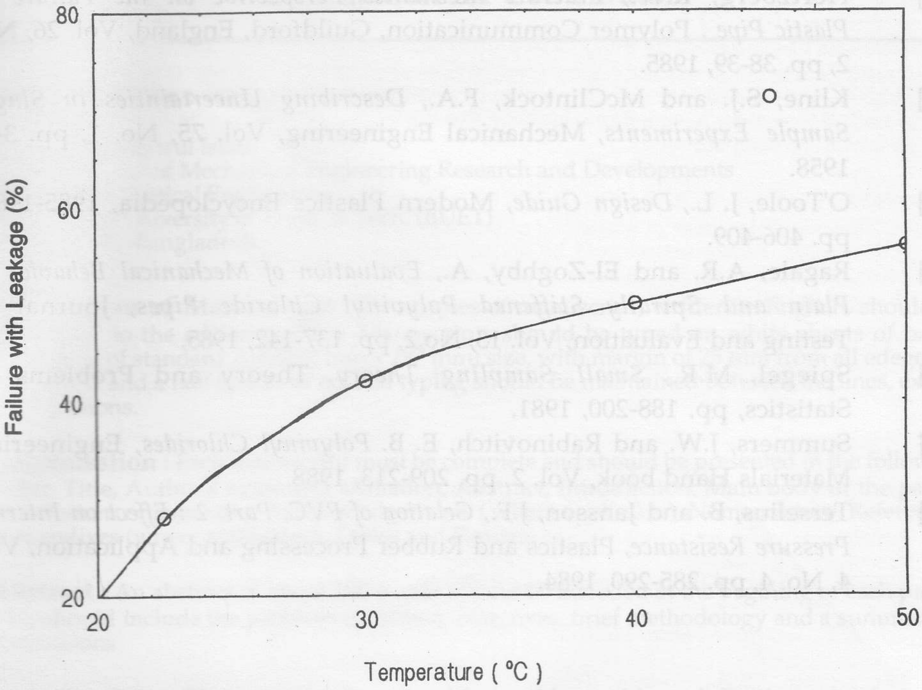

Fig. 7: Percentage Failure with Leakage vs. Temperature.

CONCLUSION

The effect of temperature on the failure pressure of polyvinyl chloride (PVC) pipe is appreciable. With the rise of temperature, the failure pressure drops.

With the rise of the temperature the difference between the maximum pressure and failure pressure increases.

At the lower temperature brittle nature of failure occurs which at higher temperature ductile nature of failure occurs.

With the increase of temperature, the percentage of failure with leakage increases.

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