Service Life & Common Failures of Polyethylene Pipes

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These days' polyethylene pipes have become a suitable, cost effective alternative for iron and concrete pipes. These pipes, both High Density (HDPE) and Medium Density (MDPE) can carry potable water, wastewater, slurries, chemicals, hazardous wastes, cables and compressed gases as well as oils. However, when exposed to external environment or put into application of hot fluid transfer, sustained contact with such warm surrounding can impair with the thermo oxidative stability of these pipes. All polymers are susceptible to degradations in presence of heat and hence adequate importance should be given during their designing to ensure their long time stability.

Pipe Failures

Amongst the different types of pipe failures, the most important are Hydrostatic Pressure Failure, Slow Crack Growth and Rapid Crack Propagation. Pressure Failures are generally ductile in nature where the local axial stress exceeds yield stress of the resin material resulting in plastic deformation. In case of Slow Crack Growth, the failure pattern is brittle in nature and it starts slowly in axial direction even at a stress which is much lower than the yield stress of the material. Thermo Oxidative degradation of the material has a strong influence in determining the Slow Crack Growth resistance of the material.

Rapid Crack Propagation is a state when the pipe is almost at the end of its service life with most of its stabilizers having been consumed and the material becoming intrinsically so weak and degraded as to withstand any further load.

We will deal here with different types of pipe failures and about the parameters controlling such failures.

Hydrostatic Pressure Failure

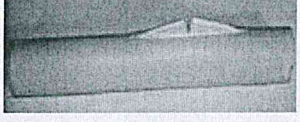

Fig 1. Ductile Failure in Pipe

Ductile Failures are accompanied by large deformation and a crack perpendicular to the pipe's axis. This leads to a formation of a typical "nose" (Fig. 1). It is clear that the time taken for failure in this type of rupture is very much dependent on the actual stress level in the pipe. The factor that determines ductile failure is the creep in the pipe wall. By creep we generally mean "deformation under constant stress." The higher is the density (crystallinity), the lower is the creep phenomenon and the higher is the pipe's resistance towards the ductile failure.

Rapid Crack Propagation

Rapid Crack Propagation (RCP) is a violent mode of failure happening over a few seconds of time. RCP are more common in thicker walled pipe sections and sections with high operating stress. It is more likely to happen at relatively lower temperature. Higher density pipes are more resistant to Rapid Crack Propagation than pipes of relatively lower density.

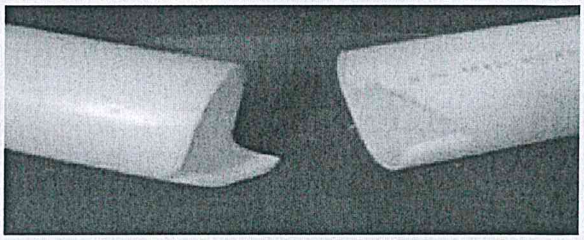

Fig 2: Brittle Failure in Pipe

RCP are commonly triggered by an impact event such as a rock impingement or hit on a line. The impact energy forms a crack that propagates rapidly along the pipe Line. RCP type of failure is generally brittle in nature.

Slow Crack Growth

Slow Crack Growth (SCG) occurs in pipes when molecular bonds creak (Fig: 3) and small cracks grow to a critical length resulting in a pipe wall failure. SCG failure happens over a relatively longer period

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of time. Unlike Hydrostatic Pressure Failure and Rapid Crack Propagation, Medium density pipes have more resistance towards SCG than higher density pipes. SCG are common in pipes of all sizes and wall thickness. SCG can be both brittle and ductile in nature.

Slow Crack Growth performance governs the estimate of pipe life expectancy. Thermo oxidative degradation has a strong effect in initiating crack in pipe surface at a stress much lower than yield stress.

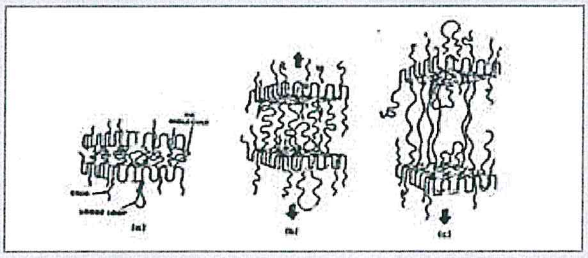

Fig 3: Separation of Lamellas

In most instances it has been observed that improvement of Slow Crack Growth resistance is achieved at the cost of sacrifice in Hydrostatic Design Stress and Rapid Crack Propagation. RCP and HDS resistance improve with increase in density (crystallinity), where SCG resistance is better in medium density material.

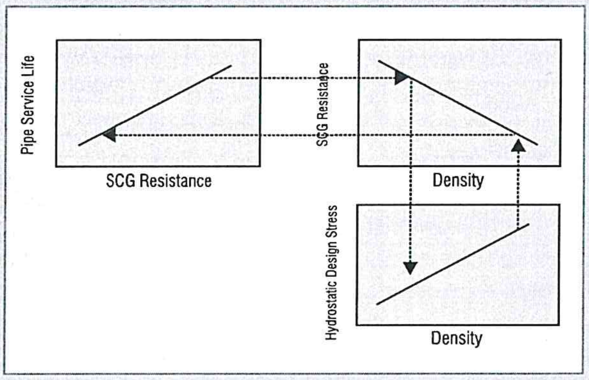

Fig 4: Density Dependency of SCG & HDS

Distribution of co-monomer is very much important to maintain proper density level in High Density Polyethylene. Balance between Slow Crack Growth and Hydrostatic Design Stress is best if the distribution of co-monomers favors the high molecular weight chains of a bi modal HDPE.

Again the length of the very co-monomer is very much important. Best results were observed if the co-monomers are of shorter length and their inclusion in the main backbone is uniform. Improved resistance in case of higher molecular weight is obvious.

It has been proved that inclusion of co-monomer in higher molecular weight fraction of bi-modal pipe provide equivalent SCG resistance at higher level of density and thus maintaining better balance between SCR and HDS.

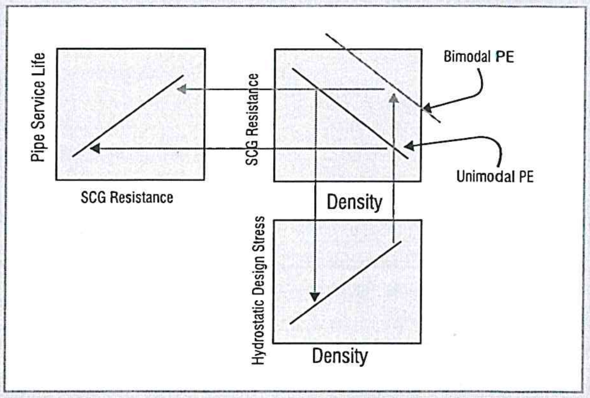

Fig 5: Insertion of Co-monomer in Higher Molecular Weight Fraction of Bi-modal Pipe gives good balance between HDS and resistance towards SCG

HDS = Hydrostatic Design Stress SCG = Slow Crack Growth

Plastic pipes used in outdoor application are susceptible to undergo degradation in presence of oxygen and sunlight depending upon atmospheric condition. Sustained conveyance of fluid / water at an elevated temperature may also lead to slow degradation of pipes. This type of degradation may even contribute to bond breakages leading towards catastrophic failure in pipe structure. Repeated Oxidative Induction Study (as per ASTM D 3895 or DOT Method) is generally carried out to determine the Oxidative Stability as well as efficiency of additive packages in pipe recipe by means of Differential Scanning Calorimeter.

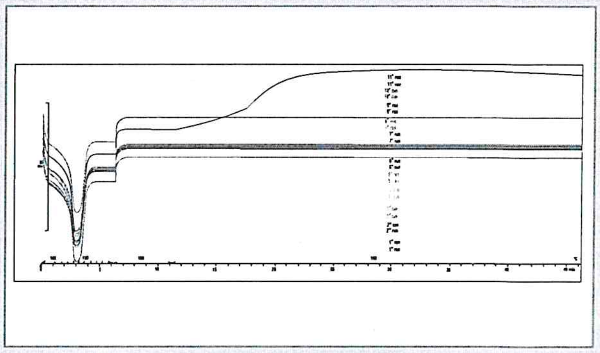

Fig 6: Differential Scanning Calorimeter Graphs of Repeated Oxidation Induction Test of Pipe Pellet Sample

General observations during Repeated Oxidative Induction Study are:

- Initially there is no exothermic peak in Differential Scanning Calorimeter graph, indicating no degradation. However, the sample starts yellowing, which gradually darkens on repeated test reruns.
- With increasing number of test reruns, respective curves (exothermic humps) generally appear to be broader first and then narrow down, indicating change in molecular weight distribution due to vis-breaking or similar type of thermal effect. Measurement of T1/2 can provide a good approximation for same.

Another simple test can be carried out to have an idea whether there is any carryover of additive from pipe backbone, if the pipe is subjected for water conveyance at elevated temperature. Pipe pellets can be taken in a wire-case and boiled in water at an elevated temperature (similar to its transportation temperature through pipe) for hours and then again test for oxygen induction temperature can be conducted with the dried pellets for an extended period of time to observe whether there is any change compared to earlier results and observations.

Service Life Approximation of Polyethylene Pipes

An experiment can be exercised for life time approximation of polyethylene pipes based on Accelerated Oxidation Test (similar to OIT test as mentioned in ASTM D 3895 or DOT Method) in the presence of oxygen flow, to determine the respective onset of failure in oxidized cupper pan.

Then Arrhenius Equation / plot can used to estimate the approximate life same of pipes in equivalent condition of temperature and oxygen. Onset temperature decreases with increase in test temperature. Temperature should be expressed in Kelvin scale.

The Arrhenius Plot

An Arrhenius plot displays the logarithm of kinetic constants (ln k) plotted against inverse of temperature (1 / T).

Arrhenius plots are often used to analyze the effect of temperature on the rates of chemical reactions.

The Equation is written as

$k = A e^{-E/RT}$ .... (1)
Where k = Rate Constant,
A = Exponential Factor,
E = Activation Energy, R = Universal gasconstant,
T = Temperature in Kelvin scale.

The equation (1) can be rewritten as
$\ln k = \ln A - (E/R)(1/T)$

Plotting ln k against (1/T) gives (-E/R) as slope and ln A as intercept.

Conclusion

Polyethylene pipes play a very important role in modern transportation, distribution and transmission systems. The use of polyethylene pipes made it possible to achieve significant advantage in construction times and installation costs. However, some catastrophic failures take place in PE pipes for various reasons. Amongst various types of failures, most significant are hydrostatic pressure failure, rapid crack propagation and slow crack growth. Slow crack growth is having a strong bearing in predicting the service life of pipes. Thermo oxidative degradation leads to crack formation in pipe surface, even at a stress much lower than its yield stress. Adequate importance should be given during designing a pipe component, both in molecular design as well as in its additive package, to ensure their long time service life stability. Oxidative Induction Study can provide a suitable means to have an apparent idea about service life of Polyethylene pipes.

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No one can make you feel inferior without your consent.

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~Eleanor Roosevelt

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