Introduction

Traditionally, metallic pipes have been used in hot and cold water distribution systems. These materials were found to corrode faster due to contact with chlorinated water where chlorine is used as a disinfectant, which is a strong oxidizer and can increase the rate of corrosion. Originally, free chlorine was the predominant disinfectant used because it was "effective, economical, and easily available." Now a days, polymeric materials have replaced traditional material, mostly because of its low cost, excellent chemical resistance, high strength with low weight, easy processing etc.

Chlorine resistance is the strength of a material to protect against chlorine attack or reaction. A material with low chlorine resistance generally results in a mass loss, increase in surface hardness and loss of mechanical strength. When testing a material for chlorine resistance, important factors include temperature, concentration, exposure duration, and mechanical stress. It has been reported that many polymers exposed to chlorinated water degrade at rates that can adversely influence the properties and, hence, the function of the polymer. Thus, polymer-based materials used in the handling of chlorinated water (e.g. purification membranes, pipes, and pump parts) often require frequent replacement due to degenerative effects initiated by exposure to chlorinated water.

Study and characterization of LDPE/Polyolefin elastomer and LDPE/EPDM blend: effect of chlorinated water on blend performance

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Abstract

The free chlorine present in water which is used as a disinfectant is reported to reduce the life of the polymeric material. The objective of this work is to study the influence of chlorine concentration on low-density polyethylene (LDPE) and blends of LDPE with ethylene butene copolymer (EBC) and ethylene propylene diene terpolymer (EPDM). The LDPE blend with EBC and EPDM were tested with water containing 50, 500, and 5000 ppm chlorine under static condition for 500 h at 25 and 80 °C. It has been seen that at 5000 ppm chlorine concentration, the mechanical properties of LDPE, LDPE/EBC blend, and LDPE/EPDM blend changed drastically and a significant reduction in the elongation at break was found for LDPE, LDPE/EBC, and LDPE/EPDM blend. LDPE/EPDM shows stable modulus value for 5000 ppm as 80 °C. Chemical changes in the aged sample were studied by Fourier transform infrared spectroscopy (FTIR) where an increase in the O–H and C=O peaks were observed. The thermal characteristics of LDPE, LDPE/EBC blend, and LDPE/EPDM blends were investigated using DSC and TGA which shows that the melting temperature and crystalline melt temperature remains unchanged while percent crystallinity increases slightly. Scanning electron microscope showed that there was the formation of microcracks and cavities on the fracture surface of LDPE, LDPE/EBC blend, and LDPE/EPDM blend after exposure to a higher concentration of chlorine indicative of degradation. Furthermore, the Chlorine resistance of LDPE/EPDM blend at 5000 ppm chlorine concentration is much higher than that of pristine LDPE.

Keywords

Chlorinated water, Disinfectant, Accelerated testing, thermoplastic elastomer, Thermal degradation

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several studies have reported the effect of chlorinated water on polymers, mostly polyethylene. By exposing the polyamide Nylon 66 to chlorinated water, Cl₂ was found to be the key reactive intermediate responsible for polyamide degradation. In addition to chlorine concentration, temperature and pH are important parameters but have not been adequately defined. Additionally, a wide variety of materials are available to the water industry, ranging from nitriles (NBR), noreprene, EPDMs, Polytetrafluoroethylene (PTFE), Polysulphone (PSU), Polypropylene (PP), and Polyvinyl chloride (PVC). Each material undergoes some unique reaction when exposed to free chlorine or chloramines. Some have been observed to resist degradation, while others degrade rapidly. Additional results are available from Solvay technical bulletin that compare the performance of Polysulfone polymers and polyacetal in chlorinated environments. The following materials have been evaluated: Polyvinylidene fluoride (PVDF), Polyethylene (PE), Polypropylene (PP), Polyphenylsulfone (PPSU), Polyetheretherketone (PEEK), Polyetherimide (PEI), Polyamid (PA12), Polyimide (PI), and Polyetherketone (PEK). Many antioxidants (AO) were also reported that increased the chlorine stability of Polyethylene. The effect of chlorinated water on high-density polyethylene pipes stabilized with a combination of phenolic and phosphite antioxidants like phenol and phosphite show that chlorinated water rapidly degraded the antioxidants. The loss of antioxidant activity could be the result of either extraction into the inner medium or chemical consumption by reaction with various active species formed in the aging medium and is found to be a prevalent step during aging. Subsequently, the polymer undergoes chain scission which then leads to a loss in mechanical strength and ultimately a reduction in the life of pipes as can be seen for PE pipes exposed to chlorinated water.

Hassinen et al. have observed that antioxidant is consumed rapidly even far into the pipe wall, due to diffusion of chlorine species into the solid plastic material. Colín et al. showed a rapid consumption of a phenolic antioxidant in a 1.2 mm thick layer near the inner pipe wall, after which there was no propagation of the antioxidant. These authors suggested that chlorine dioxide reacts not only with the antioxidant but also with polyethylene, at a considerable lower rate. However, Stevens and Seeger provided evidence that the reactivity of saturated hydrocarbons to chlorine dioxide is strictly zero. Dear and Mason found that chlorine can penetrate polyethylene in amorphous regions without reacting with the polymer chains. In 1957, Russell reported that autoxidation of aryl hydrocarbons and peryrex radicals was a cause of the failure of polymer materials. Hence, the deterioration of polyethylene may not be due to the disinfectant but to the by-products (radicals) of chlorine or chlorine dioxide dissolving in water.

Polymer blends play a significant role in preparing high-performance materials. Properties of blends are mainly determined by its structure. The study on binary polymer blends containing crystalline polymer has received more attention from both scientific and technological viewpoints. For blends, the miscibility, morphology, and crystallization behavior have been widely investigated. Blending of two or more different polymers makes it possible to achieve various property combinations of the resulting material—mostly in a more cost-effective way than by synthesis of new polymers. The blend offers the wide range of properties like excellent chemical resistant, good weatherability, high thermal resistant, good electrical insulation properties.

The Polyolefin Elastomer (POE)-ENGAGE is a premium impact modifier for a wide variety of plastics and Thermoplastic elastomer (TPE) applications. Blends using ENGAGE resins exhibit significant improvements in impact strength and a better balance of properties with addition levels ranging from 5 to 30%. Several new EPDM-based products were reported that have been formulated specifically for chloramine resistance in aggressive water utility applications. EPDM rubber is ideal for outdoor applications because of its excellent resistance to ozone, oxidants, and severe weather conditions. With the water industry, EPDM is widely used for O-rings, valve seats, flat gaskets, and pond liners. More recently, peroxide-cured EPDM is being used where chloramines resistance is important.

All over the world a lot of work has already focused on the performance of LDPE, HDPE, MDPE, Nylon, Poly (sulfone) and crosslinked-PE in a chlorinated environment. There is no open literature available on the performance of a blend of LDPE with an elastomeric material in chlorinated water. Recently, polyethylene molecular structure has been modified by the addition of co-monomer (octene) in order to enhance intrinsic thermomechanical properties without material cross-linking.

In the present work, the effect of concentration of chlorine at a different temperature on the properties of polymer (e.g. elasticity, weight change, hardness and tensile strength, crystallinity and surface morphology) of LDPE and its blends are studied.

Materials and methods

Material

LDPE (MF 4 gm/10 min, the density of 0.922 gm/cc) has been supplied by Reliance Petrochemicals, Mumbai. Ethylene propylene diene terpolymer (EPDM) (Mooney viscosity, ML1+4 at 125 °C 45, NORDEL IP 3745, ethylene content = 70% with 0.5% of ENB, and density of 0.88 g/cc) was supplied by Dow chemical, Mumbai. Ethylene-Butene copolymer (EBC) (Mooney viscosity, ML1+4 at 121 °C 13, Engage 7256, having Crystallinity 23% and density of 0.885 g/cc) was supplied by Dow chemical, Mumbai. Sodium Hypochlorite (NaOCl) procured from SD Fine Chemicals, Mumbai as a laboratory chemical grade were used. Sodium Hydroxide (NaOH) and Hydrochloric acid (HCl) from SD Fine Chemicals. Polyethylene diolefin terpolymer (POE)-ENGAGE is a premium material—mostly in a more cost-effective way than by synthesis of new polymers. The blend offers the wide range of properties like excellent chemical resistant, good weatherability, high thermal resistant, good electrical insulation properties.

Preparation of Blends of LDPE/EBC and LDPE/EPDM

A blend of LDPE/EBC and LDPE/EPDM were prepared in ratio 70:30. Firstly, the mix was melted blended in a twin screw co-rotating extruder (Lab Tech Engineering Co. Ltd., Germany) having L/D ratio of 32:1 and temperature profile from the hopper to the die as 160, 170, 180, 190, and 180 °C, respectively. Extruded strands were water cooled at 30 °C and pelletized. Pellets obtained were further used for injection molding after...
pre-drying at 80 °C for 8 – 10 h. Injection molding ( Boolani machinery India Ltd, Mumbai, India) was done maintaining temperature profile of 190, 200, and 210 °C from the hopper to the injection nozzle, respectively. Standard ASTM-based samples for tensile testing (Type IV) were obtained from injection molding. Formulation of LDPE/EBC and LDPE/EPDM has been given below. Batches having optimum properties were selected for further study. The initial properties have been provided in Table 1. In the sample code “LDPE” stands for Low-density polyethylene, EBC stands for ethylene butene copolymer (Engage), and “EPDM” stands for Ethylene propylene diene terpolymer. The summary Testing method and characterization performed are shown in Figure 1.

Accelerated aging methods
Aging solutions were prepared according to ASTM D6284a with reagent water to form a 4% sodium hypochlorite. Water pH was adjusted using NaOH and HCl. The first method (referred to as the 50 ppm method) involved adding 4% NaOCl directly to reagent water to achieve 50 ppm as Cl₂ free available chlorine concentration. The Same procedure was followed for the preparation 500 and 5000 ppm chlorinated solution. Several die-cut dumbell shaped LDPE, LDPE/EBC, and LDPE/EPDM samples were placed in separate 1 L glass bottles with polypropylene caps. Chlorine solution was added and sealed bottles were stored vertically at 25 and 80 °C oven in the dark. On Day 21 (500 h), the samples were removed from the chlorinated solution and placed in reagent water and stored in the dark at room temperature. After 24 h of soaking in reagent water, all remaining samples were removed and dried in an oven at 60 °C for 24 h. Tensile properties after aging were measured according to ASTM D638. Physical properties were also measured after a specific interval of time e.g. Hardness, melting point, percent crystallinity, surface structure, and percent mass change. Test specimens were routinely inspected for any visual change.

Table 1 Formulation of LDPE/EBC and LDPE/EPDM blend

| Sr. no | Sample name | LDPE (Wt %) | EBC/EPDM (Wt %) | Tensile strength (MPa) | Modulus (MPa) | Elongation at break (%) | Hardness (Shore A) |
|--------|-------------|-------------|-----------------|------------------------|--------------|-------------------------|------------------|
| 1      | LDPE        | 100         | 0               | 16                     | 597          | 135                     | 57               |
| 2      | LDPE/EBC    | 70          | 30              | 14                     | 343          | 455                     | 61               |
| 3      | LDPE/EPDM   | 70          | 30              | 14                     | 345          | 370                     | 68               |

Characterization techniques

Percent mass change
Aged sample was dried in an oven for 24 h at 80 °C before weight measurement. Mass variation was calculated by the equation: $\Delta M = \left(\frac{M_f - M_i}{M_i}\right) \times 100$, where $M_f$ is the final mass and $M_i$ is the initial mass.

Mechanical tests
Dumbell-shaped samples were subjected to a tensile test to determine tensile strength, % elongation as well as Young modulus using LLOYD UTM with 50 kN load. Cross head speed was set to 50 mm/min. Sample dimension was 50 mm × 5 mm × 2 mm. Numbers were derived from three replicas of the same samples producing close results.

Hardness
Polymer hardness was measured with a shore D hardness test according to ASTM D2240 using a Zwick 7206 Hardness Tester. Three measurements were taken for each sample and then averaged to ensure a uniform hardness value representative of the sample as a whole.

Differential scanning calorimetry (DSC)
To analyze the melting and crystallization behaviors of neat polymers and their blends, differential scanning calorimetry (DSC; TA Q100, USA) was used. The samples were heated from room temperature to 200 °C at 10 °C min⁻¹ and kept for 2 min at this temperature to erase thermal history. Then to study the crystallization process the blends were cooled to 0 °C at a controlled rate of 10 °C min⁻¹. After holding the samples at 0 °C for 2 min, the melting tests were run at a heating rate of 10 °C min⁻¹ from 0 to 200 °C. The second melting curve was recorded and used to calculate the crystallinity. The weight of each sample was 5 mg. Percent crystallinity was calculated as $W_c = \frac{\Delta H_m^{\text{Experimental}}}{\Delta H_m^{\text{100% Theoretical LDPE}}} \times 100$, where $\Delta H_m$ is the heat of fusion of sample and $\Delta H_m^{100\%}$ is the heat of fusion of 100% crystalline PE taken as 293 J/g.

Thermogravimetric analysis
Thermogravimetric analysis (TGA) was performed by using Perkin Elmer Pyris 1 at the heating rate of 20 °C/min from ambient temperature to 700 °C in the air atmosphere. In this technique, the mass of the substance and thermal decomposition of polymer blend were measured as a function of temperature.

Fourier transform infrared spectra analysis
The Fourier transform infrared spectra analysis (FTIR) spectra of both sample before and after exposed to chlorinated water...
At 25 °C weight gain in the sample was lower as compared to 80 °C. At 80 °C, the weight gain was more and this phenomenon matched with data reported by Marshall J. As the concentration of chlorine was increased from 50 to 5000 ppm, the weight gain also increased due to the oxidation of the material.

Weight Change within ±0.6% was statistically significant and in an acceptable range. Test results, which are summarized in Figure 2, confirmed that the LDPE, LDPE/EBC, and LDPE/EPDM have very good resistance to cold and hot chlorinated water. LDPE/EPDM showed a slight but statistically significant weight gain at 5000 ppm chlorine concentration due to sorption of water by EPDM and oxidation at a higher temperature.

Mechanical properties

Effect on tensile strength after exposure to chlorine

A summary of the tensile strength test results was shown in Figure 3(a) and (b) for 50, 500, and 5000 ppm chlorine concentration exposure at two different temperature conditions. As shown in Figure 2, the mass gain has been observed for exposure to 5000 ppm because of water absorption and this can change the macroscopic mechanical behavior of the blend.

When water is absorbed, there is increased mobility of the polymer chains, resulting in lower strength, modulus, and percent elongation. Tensile strength reduces from 16 to 12 MPa for unexposed and exposed specimen of LDPE and from 14 to 7 MPa for unexposed and exposed specimen of LDPE/EBC. While LDPE/EPDM show lower rate of reduction in tensile strength ranges from 14 to 12 MPa for exposed specimen (Figure 3(a) and (b). At higher temperature (80 °C) reduction in tensile strength is greater compared to normal temperature (25 °C). The tensile strength of the native LDPE is 16 MPa. After only 500 h of exposure at 80 °C, the strength is reduced near to half, approximately 9 MPa. Approximately 50% of the tensile strength reduction is also found in the case of LDPE/EBC and LDPE/EPDM at harshest condition (5000 ppm at 80 °C).

Effect on percent elongation after exposed to chlorine

Percent elongation at break is shown in Figure 4(a) and (b) for unexposed specimens and specimens exposed to chlorine.

Results and discussion

Percent mass changes

Figure 2 gives the variation in mass change with various concentration of chlorine of LDPE, LDPE/EBC, and LDPE/EPDM blend.
concentration and temperature conditions. There was, however, great variability in elongation at break results and a clear brittle failure mode for 5000 ppm as 80 °C LDPE and blends specimens in comparison to ductile fracture for unexposed samples of LDPE and its blends. The reduction in percent elongation was caused by chain scission and chlorinated water induced oxidation. As with the percent elongation data, there is significant reduction found for LDPE ranges from 150 % to 50% for unexposed and exposed specimens. Also in the case of LDPE/EBC and LDPE/EPDM blend, the percent elongation value reduce approximately to 50% at harshest conditions. At 50 ppm concentration of chlorine and temperature of 25 °C, the percent elongation value slightly reduce ranges from 450 to 250% for LDPE/EBC blend and for LDPE/EPDM ranges from 350 to 280%.

**Effect on modulus after exposure to chlorine**

Young’s Modulus data for unexposed and exposed LDPE, LDPE/EBC and LDPE/EPDM blends samples are shown in Figure 5(a) and (b). The plot shows a linear decrease in modulus with respect to the concentration of chlorine for both unexposed and exposed samples.

As shown in Figure 5(a) and (b), an LDPE is started with a modulus of 600 MPa, but over time this will predictably

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**Figure 4** Effect of various concentration of chlorine and temperature on percent elongation at break of LDPE, LDPE/EBC, and LDPE/EPDM (a) Represents the percent elongation variation at 25 °C and (b) Represents the percent elongation variation at 80 °C

**Figure 5** Effect of various concentration of chlorine and temperature on young’s modulus of LDPE, LDPE/EBC, and LDPE/EPDM (a) Represents the young’s modulus variation at 25 °C and (b) Represents the young’s modulus variation at 80 °C

**Table 2** Hardness value before and after exposure to chlorine at a temperature of 25 °C

| Sr. no | Sample name         | Before | 0 ppm | 50 ppm | 500 ppm | 5000 ppm |
|--------|---------------------|--------|-------|--------|---------|----------|
| 1      | LDPE                | 57     | 60    | 65     | 65      | 63       |
| 2      | LDPE/EBC 70/30      | 61     | 63    | 58     | 67      | 60       |
| 3      | LDPE/EPDM 70/30     | 68     | 62    | 61     | 60      | 61       |

Table 2 Hardness value before and after exposure to chlorine at a temperature of 25 °C
concentration of chlorine, while in the case of a blend of LDPE/EBC and LDPE/EPDM the hardness decreased. This result supports FTIR and Mass change, in which the mass gain was found +0.5% in the case of higher temperature and Hydroxyl peak intensity increased.

Thermal properties

The melting temperature, crystallization temperature, and percent crystallinity data of LDPE, LDPE/EBC, and LDPE/EPDM are shown in Table 4. Exposure for 5000 ppm at 80 °C in LDPE and LDPE/EPDM had a major influence on the crystallinity profile. There was no influence of chlorine on melting peak temperature of LDPE, LDPE/EBC, and LDPE/EPDM blends. Oxidation of polyolefins in the solid state led to an increase in crystallinity.16,30–32

DSC is typically used as a quick screening tool to check any structural changes in the material when heating up the sample. For semi-crystalline materials, this is used to measure the amount of energy needed to crystallize. No changes are seen for the unexposed material whereas a slight shift in crystallization temperature is seen after aging. This is an indication that the crystalline structure of the material has somewhat changed.

The shape of the melting peak has changed and an enlargement is observed essentially at a lower temperature after exposure to chlorine for a long time. The observed broadening of the melting peak on the 5000 ppm-aged sample at 80 °C is probably due to differences in the crystallite sizes. It is also interesting to note that the melting peak temperature was lower by (3 °C) after aging (500 and 5000 ppm aged samples). Hassinen et al. reported that the melting peak temperature of degraded HDPE was 3 °C lower than the un-degraded HDPE (after 438 h of aging at 3 ppm and 105 °C). These results suggest that the 5000 ppm aged sample had degraded.12

An increase in mass crystallinity had already been reported as an indicator of a polyethylene (HDPE, LLDPE, and PEX) degraded layer.12,33–36 Literature agrees that the crystalline component is preserved during aging, and therefore only the amorphous component is degraded leading to an increase in crystallinity.12,37

Table 3 Hardness value before and after exposure to chlorine at a temperature of 80 °C

| Sr. no | Sample name | Before 0 ppm | 50 ppm | 500 ppm | 5000 ppm |
|--------|-------------|--------------|--------|---------|----------|
| 1      | LDPE        | 57           | 61     | 60      | 62       | 64       |
| 2      | LDPE/EBC 70/30 | 61           | 63     | 62      | 63       | 63       |
| 3      | LDPE/EPDM 70/30 | 68           | 69     | 55      | 59       | 59       |

Table 4 Melting and crystallization properties of LDPE, LDPE/EBC, and LDPE/EPDM blends

| Sample name          | LDPE       | LDPE/EBC 70/30 | LDPE/EPDM 70/30 |
|----------------------|------------|----------------|-----------------|
|                      | Tm (°C)   | Tc (°C)   | Xc (%) | Tm (°C) | Tc (°C) | Xc (%) | Tm (°C) | Tc (°C) | Xc (%) |
| Before               | 115       | 97        | 22.7   | 113     | 94     | 17.6   | 112     | 95     | 14.3   |
| 50 ppm & 25 °C       | 113       | 97        | 24.3   | 114     | 94     | 19.3   | 112     | 95     | 18.9   |
| 500 ppm & 25 °C      | 114       | 98        | 26.8   | 114     | 95     | 23.2   | 113     | 94     | 17.8   |
| 5000 ppm & 25 °C     | 113       | 97        | 29.1   | 114     | 94     | 22.5   | 112     | 95     | 20.7   |
| 50 ppm & 80 °C       | 114       | 97        | 28.0   | 114     | 95     | 19.3   | 113     | 95     | 14.29  |
| 500 ppm & 80 °C      | 115       | 98        | 29.6   | 113     | 94     | 21.7   | 113     | 94     | 20.5   |
| 5000 ppm & 80 °C     | 112       | 98        | 31.3   | 113     | 95     | 17.3   | 113     | 95     | 21.5   |
Table 5  Degradation characteristics of LDPE and their blend

| Sample name | \( T_{10}^a \) | \( T_{50}^b \) | \( T_{90}^c \) | \( T_{10}^a \) | \( T_{50}^b \) | \( T_{90}^c \) | \( T_{10}^a \) | \( T_{50}^b \) | \( T_{90}^c \) |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Before 403  | 458 486     | 446 483     | 502 466     | 491 507     | Before 446  | 489 507     | 464 491     | 508          |
| 5000 ppm 80 °C | 457 490   | 516 459     |            |             | 466 491     | 407          |             |

\( a \) Temperature at which 10% weight loss  
\( b \) Temperature at which 50% weight loss  
\( c \) Temperature at which 90% weight loss.

Figure 7  Enlargement around the hydroxyl band (OH) region of FT-IR spectra after exposure of LDPE, LDPE/EBC, and LDPE/EPDM as a function of Chlorine concentration at 25 and 80 °C
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at 446 °C and after exposure at 459 °C. Also, in the case of LDPE/EPDM before exposure degradation took place at 466 °C and after exposure at 464 °C. Pure LDPE polymer decomposes more rapidly compared to LDPE/EBC and LDPE/EPDM blend with increasing temperature in both cases before and after exposure to chlorine. This showed that there is no effect of chlorine on the thermal properties of blends.

Fourier Transform Infrared Spectroscopy (FTIR)

Changes in the chemical structure of the polymer can be studied by infrared spectroscopy. Polymer oxidation is shown by

Figure 8  Enlargement around the carbonyl band (C=O) region of FT-IR spectra after exposure of LDPE, LDPE/EBC, and LDPE/EPDM as a function of Chlorine concentration at 25 and 80 °C

Thermogravimetric analysis

To examine the thermal stability of above-mentioned polymers and blend, TGA (Figure 6) data under nitrogen flow were obtained, and the results have been summarized in Table 5. The LDPE, LDPE/EBC, and LDPE/EPDM blend polymer showed a single step of decomposition. If initial decomposition temperature at which 10% weight loss were considered were assumed to be a measurement of thermal stability, LDPE, before exposure, decomposes at 403 °C, while, after exposed, decomposes at 457 °C. However, in the case of a blend of LDPE/EBC before exposure degradation took place at 446 °C and after exposure at 459 °C. Also, in the case of LDPE/EPDM before exposure degradation took place at 466 °C and after exposure at 464 °C. Pure LDPE polymer decomposes more rapidly compared to LDPE/EBC and LDPE/EPDM blend with increasing temperature in both cases before and after exposure to chlorine. This showed that there is no effect of chlorine on the thermal properties of blends.
corresponding to hydroxyl was found significant for aging at 500 and 5000 ppm and is shown in Figure 7(a–f).

The C=O bond was also analyzed (Figure 8(a–f)). The C=O bond has also been reported as an LDPE oxidation indicator.

For the C=O bond, the same consideration as for the OH bond can be taken into account.

the appearance of hydroxyl (~3400 cm⁻¹) shown in Figure 7 and carbonyl (~1700 cm⁻¹) peaks shown in Figure 8.29,32,38,39

In particular, Colin et al.,40 for the pipe sample exposed to chlorine dioxide containing water show an increase in hydroxyl absorption as well as an increase in carbonyl absorption which is in agreement with our data. The growth of peak corresponding to hydroxyl was found significant for aging at 500 and 5000 ppm and is shown in Figure 7(a–f).

The C=O bond was also analyzed (Figure 8(a–f)). The C=O bond has also been reported as an LDPE oxidation indicator. For the C=O bond, the same consideration as for the OH bond can be taken into account.
FT-IR has been used to evaluate potential chemical organic changes in a material. The right section of the graph is used as a fingerprint area from a material and can be used to identify a material. There are some major changes visible for LDPE, LDPE/EBC, and LDPE/EPDM at higher concentration and temperature around 1,700 cm⁻¹, which is an indication of oxidation.

The correlation shows it to be a carbonyl absorption peak, which should not be present at all. It may have been formed by oxidation, which may have occurred by several possible mechanisms, but especially by exposure to chlorine-induced oxidation and this has been in agreement with data reported by K. Karlsson et al. in 1993.

**Morphology**

SEM was used to evaluate the extent of degradation in the sample exposed to chlorine. SEM offers a hyper-magnification of the surface and can allow observation of the surface imperfections, such as micro-cracks. A superficial light layer is formed on the surfaces of the sample dipped in chlorine solution. SEM examination of nitrogen fractured surface of unexposed and exposed samples showed that the surface roughness increases due to chlorine pitting as observed from Figure 9(a–f). Figure 9(a) showed micrographs of LDPE before aging, in which no crack and smooth surface was observed. While the Plenty of cracks on the rough fractured surface were prominent in the case LDPE after exposure as shown in Figure 9(b). It also exhibited discontinuous path with cavities and some flow lines observed in LDPE after exposed to 5000 ppm at 80°C. Figure 9(c) showed micrographs of LDPE/EBC 70/30 blend, in which surface became relatively smoother and the number of cavities was less compared to LDPE samples before aging due to the compatibility of blend and softness in some part of EBC (Figure 9(a)). LDPE/EBC blend exposed to chlorine concentration of 5000 ppm and temperature of 80°C showed increases in number of cracks with an increase in surface roughness which indicate that at higher concentration of chlorine starts oxidative degradation of LDPE/EBC blend. In the case of LDPE/EPDM, micrographs (Figure 9(e–i)) show same morphology as in the case of LDPE and LDPE/EBC before aging. Figure 9(f) represents the fractured surface of LDPE/EPDM sample exposed at 5000 ppm at 80°C. After aging LDPE/EPDM blend of 5000 ppm at 80°C, showing that the size of the cavity was increased with surface roughness.

**Conclusion**

This paper includes weight loss, surface hardness, mechanical properties, FT-IR, DSC, and surface morphology data for LDPE, LDPE/EBC (70/30), and LDPE/EPDM (70/30) that immersed in hot chlorinated water. For exposure time up to 500 h in hot chlorinated water, LDPE/EBC and LDPE/EPDM showed drastic degradation in mechanical properties, as well as an increase in the surface roughness, was observed from SEM. The results show that at the highest concentration (5000 ppm), large reductions take place in performance due to temperature and chlorine exposure effect. While the temperature was amplified at high concentrations, LDPE exhibited the least degradation, particularly with respect to percent elongation and change in hardness. At 80°C and at 5000 ppm concentration, all performance parameters were greatly reduced, with bulk parameters changing by over 50 percent, and tensile strength and modulus dropping by approximately 10 percent. For example, LDPE/EBC and LDPE/EPDM at high concentration experienced relatively small changes in performance at a temperature of 25°C. From this it can be concluded that the blends of LDPE/EBC and LDPE/EPDM had excellent resistance to hot and cold chlorinated water. Most materials followed anticipated trends of increasing degradation with increasing temperature across all concentration levels, some anomalies were observed. However, exposure to chlorinated water at higher temperature and concentration of chlorine can result in formation of cracks observed from SEM images and also the loss of material from a LDPE, LDPE/EBC and LDPE/EPDM surface were found. For the LDPE/EPDM material, a constant modulus was measured after the 500 h exposure in high concentration at 80°C. In addition to the reduction in elongation, hardness increased (2–9%) as concentration increased. FT-IR data indicate that upon exposure to higher temperature and chlorine concentration, carbonyl- and hydroxyl-forming reaction products are formed. FT-IR analysis revealed that all transmittance indices showed the same general trend of increasing the chlorine concentration. The FT-IR and mechanical data for LDPE/EBC and LDPE/EPDM blend are in agreement, revealing the effectiveness of the both EBC and EPDM. TGA and DSC showed that there is no effect of chlorine on the thermal properties of blends.

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**Disclosure statement**

No potential conflict of interest was reported by the authors.

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