A Review of The Effect of Environmental Stress Crack Resistance (ESCR) on High-Density Polyethylene (HDPE) Material

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Abstract- *Estimating a material's stress behaviour from the point at which it is loaded, the objective of this research is to get an analysis of the development of mechanical stress on high-density polyethylene (HDPE) material, with a particular emphasis on crack initiation and propagation in environmental stress cracking. An increase in the crosslink density reduces molecules' mobility, increasing the brittleness of polymers. Changes in the ratio of copolymers and blends can lead to a shift in the characteristic balance, which might compromise their toughness. A decrease in plasticizer concentration can reduce flexibility, while the abrasive particle fibre employed to strengthen the polymer can lower the composition toughness and elongation at break. Previous research has shown that polymer crystallinity increases when environmental stress cracking occurs. Furthermore, the interphase region joining crystals and the surrounding amorphous region is where polymer chains are most prone to snap apart.*

Keywords- High density polyethylene, environmental stress cracking, propagation, ductility, brittleness

I. INTRODUCTION

Thermoplastic HDPE (high-density polyethylene) is commonly used in packaging engineering. Polyethylene is a semi-crystalline polymer made up of a long chain of carbon atoms with two hydrogen atoms linked to each carbon atom. These only happen when the number of chains branching off the sides of the major chains is modest. Inside crystalline regions, molecules have directionally dependent local properties (within each crystal). The subsequent irregular structure is amorphous when tangled molecular copolymer branching the molecular trunk chains interfere with or prevent the tight and layered packing of the trunks. A dense network of polymer chains produces a robust material with moderate rigidity.

The fraction of crystalline areas in high-density polyethylene resin is higher than in low-density polyethylene resin. The finished product's tensile strength and environmental stress fracture resistance are affected by the size and size distribution of crystalline areas. Since the molecular chains in HDPE and other thermoplastic polymers are not cross-linked, such plastics will melt when heated sufficiently. The use of heat allows thermoplastic polymers to be shaped, moulded, moulded, or extruded. Thermosetting resins are made of chemically cross-linked molecular chains that set when the plastic has initially created these, and resin will not melt but disintegrate when heated to a temperature lower than their melting point. During manufacturing, the high temperatures and energy required to form and shape the polyethylene induce random orientations of molecules within the molten material to align in the extruding aperture. The ordered arrangement of the multilayer crystalline polyethylene molecules is maintained at room temperature. Tie molecules are molecules that connect the crystalline and amorphous areas. When stress exceeds the capacity of the polymer chains, the polymer flows (alters its shape). Tensile forces (stresses) cause a brittle fracture, which is visible as cracking. This can happen at very high strain rates in HDPE. The material at the leading ends of the crack captures these released tensile forces (stresses), considerably increasing the severity of the stress field and the possibility of continuing cracking at that point and all sites ahead.

Stress riser and stress intensity factor are words used to detect and measure the increase in the stress field at the crack tips. If these regions contain and appropriately adapt to this additional burden, cracks will not propagate, otherwise, crack propagation will occur. This is how the mechanism of delayed fracture development is defined. Stress risers are proportional to the stress level, and cracks would not increase in a stress-free environment or when the degree of tension at the crack's tip is below a certain threshold. The energy connected with the stress field is largely absorbed when the twisted mass of molecules responds in time to the sustained stresses when the tip of a spreading crack leaves a crystal and enters the disordered, non-layered, more loosely packed, tangled molecules of the amorphous zone.

Moreover, tensile strength explains that the tensile strength at yield is the point at which a tension causes the material to bend beyond its elastic region (permanent deformation). Whenever a material is stressed below its yield point, it recovers all of the energy that went into its deformation. Recovery is feasible when polyethylene crystals are exposed to modest strain levels and preserve their integrity. Greater tensile strength and brittleness are associated with higher density formulations (higher proportion of crystals, lower molten index).

II. ENVIROMENTAL STRESS CRACKING RESISTANCE (ESCR)

The Environmental Stress Crack Resistance (ESCR) explains that Polyethylene may fracture more quickly when exposed to specific temperatures and stresses in certain compounds than when exposed to the same temperatures and stresses in the absence of those chemicals. Neutral materials such as alcohols, detergents (wetting agents), halogens, and aromatic compounds are commonly used as stress cracking agents for polyethylene. Environmental stress crack resistance, or simply ESCR, is a feature of a material that allows it to resist ESC. The process is unknown, although ESC failures are often caused by the formation of fractures in regions of tensile stress that progressively increase and propagate over time.

While the strain experienced by the material is proportional to the tension applied to it in this region, when the tension is lifted, the material returns to its original form, as it was before the stress was imposed. Once a given amount of stress, the material becomes permanently stretched and cannot return to its former shape after the tension is relieved. This is referred to as the yield point. As the stress on the material grows, the strain on the material increases to the point where a crack forms in the substance, which finally breaks. Necking and, as a result, fracture stress occurs at this position. The stress and strain graph of the polymer is depicted in the diagram below.

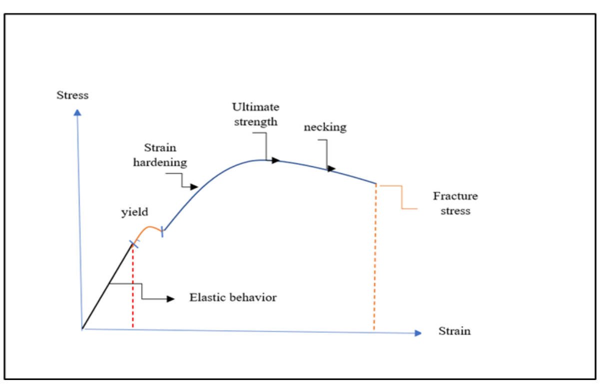

Figure 1-The stress and strain graph of polymer

There are some impacts of ESC on HDPE material at manufactured field which can cause a minor or significant on them, for example:

- HDPE bottle cap cracks have come in touch with colour pigment (chemical) during the process.
- HDPE bottle cap crack due to higher stress applied.
- Detergent bottle from HDPE cracked due to mechanical behaviour.

III. TYPE OF MATERIAL

The incidence of ESC is defined by the type of material utilized. It is known that polyethylene is a group of polymers that includes various components, such as LDPE and HDPE. Compared to the material properties of LDPE and HDPE in property of flexibility, HDPE is more crystallinity, and it becomes harder and more inflexible as a consequence of this. ESC resistance may be higher in materials with higher degrees of crystallinity.

It also reduces the ESC because the compounds can't be absorbed as quickly in the material, and the stress required causes the material to collapse higher. Furthermore, enhancing bonding improves the probability of materials breaking by reducing gaps or free space in increasing the difficulty of working with the materials and detangle the material, trying to make it stronger.

Colour compounding

- In polymer ESC, it's critical to consider the stability of the polymer's chemistry and the colorant's chemistry while constructing a colorant packaging for the polymer. Colorants can decompose the composition of a polymer's constitution, weakening its original qualities like impact resistance. The amount of colourant added to the polymer also affects its properties and durability. If you think of colourants as pollutants, the more you use them, the worse the effect on the plastic will be. Adding colorant above 1 percent can affect the properties of the polymer, which can change crystallinity and molecular weight.

Material deterioration

- The impact of deterioration according to material compression is comparable to that of annealed. It reduces free volume, which improves stress fracture toughness. deterioration occurs over time at a level that is dependent on the thickness of the material and rises with temperature. Temperature and physical deterioration are inextricably linked. Sub-Tg annealing strengthens the adhesion by melting below the glass transition temperature (Tg). The physical deterioration process can be accelerated by increasing the annealing temperature. When comparing between deteriorating at room temperature and after sub-Tg annealing, the testing period of sub-tg annealing is extended before fracture appears. However, sub-TG annealing causes certain improvements in morphology, for example, growth in the proportion of cross-linked, that could take time to occur at room temperature deterioration, while this connection can increase the ESCR.

- The stress cracking phenomenon is not generated by a component but rather by the synergistic action of numerous elements. Besides other considerations, periodic stress contributes to ESC and causes hastened fracture in polymeric materials. Further from that, when chemicals that are consistent with the material interacted with these same materials at particular stress and strain levels, as well as temperature, the material will be affected**.**

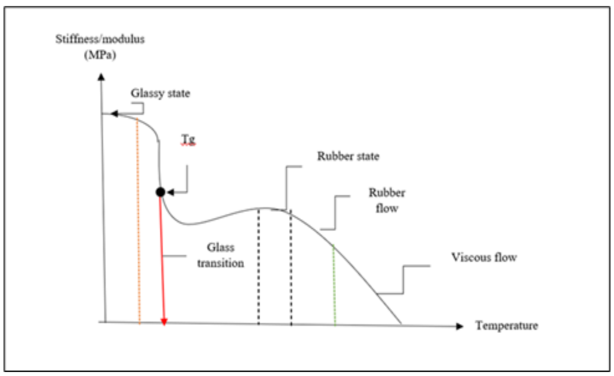

Figure 2- glass transition temperature on polymer

Stress applied

- When a ductile polymer is strained, it will eventually break due to static aging or creeping fracture. As the amount of stress applied decreases, the duration for fracture reduces, however at lower levels of stress, additional variables such as chemical assault, temperature, and so on can speed up the cracking process. When substantial stress is applied, a dense network of locally yielding sites emerges, which grows and multiplies before coalescing and cracking over time. Consequently, beneath high stress, the material will fail early ductile, regardless of other conditions, but under low stress, the material will fracture slowly or eventually brittle. Whenever the temperature is raised, the yield stress and yield strain of the material drop, until both are zero at Tg. Plasticization is inversely proportional to yield stress, while annealing is proportional to it. It also rises in tandem with strain rate, which is equivalent to polymerization time. There are two types of stress which play an important role that can be forming a fracture in the material. For example, during the tensile load is added to the material it tends to break. while applying compression stress there is no crack form in the material. This is because that tensile stress molecular disembarrass which can cause ESC failure. Compressive stress, on the other hand, can cause mechanical failure in a material, but such failure would not be classified as ESC.

Temperature

- The impact of temperature on ESC materials is complicated. If a material is annealed, it is subjected to thermal processing to minimize internal tensions. As a result, the material's charge density reduces, increasing its resistance to fatigue cracking. On the other hand, as the temperature rises, the stress and strain parameters that cause ESC reduce.

Environmental Stress Cracking Resistance (ESCR) on High density polyethylene (HDPE) material:

- The capacity of materials to fibre reinforced or broken due to environmental stress is known as environmental stress cracking resistance. This testing can help to reduce the cost of manufacturing and product maintenance that would otherwise be incurred owing to the failure of these materials.
  - ➢ Reducing percentage of chemical agent /colour pigment during process because it can decrease impact of ESCR which can affect the crosslink density and microstructure of HDPE material.
  - ➢ The lower stress applied on HDPE material can reduce the level of ESC
  - ➢ Low environmental temperature can diminish ESC rate. Compare to higher environmental temperature.

IV. LITERATURE REVIEW

Marco Contino et.al (2020)Environmental Stress Cracking of High-Density Polyethylene under planestress conditions

The important results of this paper are that under plane stress, tests on specimens with two different degrees of crystallinity, generated through two separate manufacturing techniques, revealed that a greater value of this characteristic enhances elongation at break in air. Instead, in the absence of an organic manner, the two specimens behaved similarly, and the collected data is shown on the same J vs. fracture start time curve. The examination of the individual ductile and brittle components of J reveals that in the presence of the organic manner, plastic deformations of polyethylene crystalline domains are reduced, with tie molecule separation probably being the major failure mechanism. This study demonstrates the intricate relationship that exists between ESC and the applied stress state. Despite the sheer number of situations where ESC restricts product lifespan, it's critical that future research doesn't overlook these considerations by focusing just on plane strain analysis. Simultaneously, a greater knowledge of the function of the manufacturing process in influencing environmental fracture resistance should offer material makers important information for developing effective options.

Fares D.Alsewailem et.al (2020)On the Environmental Stress Cracking Resistance of High Density Polyethylene (HDPE)

These investigations demonstrated the necessity of choosing the right type of PE for a tough evaluation because the surface is exposed to strains while interacting with chemicals or with regular water. Solvent transport over PE pipes and disposal sealing are two possible uses. Another element that might affect PE's ESCR is the quantity and kind of agents and reinforcement used in its production.

Anna Gobetti et.al (2020) Application of short-term methods to estimate the environmental stress cracking resistance of recycled HDPE

This paper explains the mechanical and thermal properties connected to ESCR to the abundance of bond monomers as a polymeric feature. Associated with data reasonableness, strain hardening modulus and natural draw ratio could be determined by a tensile test at room temperature instead of 80 °C to assess a simple experimental process precompiled as a quality management check to determine relatively the presumed ESCR of recycled HDPE from various manufacturing heaps. Moreover, the properties reviewed that the SIS ratio as a polymer component more exposed to form narrow crystals connected by various link substances, the proving fracture toughness as an intrinsic property that measures the cross-links' separation capacity, and the characteristic draw proportion as a biosensor characteristic to the polymeric connection toughness through the microstructural tie compounds are all measured. Their reciprocal connection substantiated this dependency of the found attributes on the examined macromolecular features. Therefore, enables the creation of a testing investigation that can be used in industrial research centers for quality management to check if the predicted ESCR of various manufacturing phases surpasses the needed goal specifically set by an ESCR test in a reciprocal manner.

Byoung-Ho choi et.al (2009) Modeling of the Fracture Mechanism of HDPE Subjected to Environmental Stress Crack Resistance Test

The ASTM D1693 Procedure B was used to assess the ESCR performance of six HDPE samples. The failure mechanism of failed specimens from the environmental stress crack test was investigated using microstructural methods. The size and number of remaining fibers on the crack surface of data with different ESCR values were larger and more numerous than those that failed at shorter time intervals. This suggests that low ESCR samples have a more fatigue crack mechanism than larger ESCR ones. This might be due to a change in propagation qualities and duration of treatment to IGEPAL1 solver amongst HDPE resins, including the HDPE resins' moderate fracture development resistance. The ESC begins near the root of the notch tip, which is not predicted as a crack starting position, according to freeze-fracture surface analysis. Due to bending stress, the ESC promulgates as a spherical region, and the cracking form eventually changes into a partial structure.

Marco contino et.al (2018) Time-temperature equivalence in environmental stress cracking of high-density polyethylene

Fracture data was successfully time-temperature equivalent. Bimodal HDPE started later than monomodal due to different molecular weight distributions. The two materials had shorter initiation times and faster crack propagation rates in two active environments (bleach solutions with and without sodium hypochlorite). High pH prevents chemical constituents from dissociating into active chlorine, as in commercial bleach solutions.These findings emphasize that, within the range under consideration, the temperature does not affect the competitiveness of the instructional context, instead acting merely to speed up or slow down the cracking processes depending on the material's fundamental deformations. Specifically, ESC takes place in the brittle fracture regime, and a region bounded is generally characterized by detachment of the tie bonds, a method that the ESC mediators support.Time-temperature similarity in the context of ESC is crucial because it means that data on fracture mechanics gained through temperature enhanced testing can be used to anticipate the long-term behaviour of polymeric goods even when exposed to harsh conditions.

V. CONCLUSION

This review helped establish the best appropriate ESC test method for the future. Testing of ESC of material used in HDPE. This study's findings could be beneficial to the industry.The ESC testing results indicated that the chemicals were too harsh for the materials being tested or the selected strain level was too high. First, the results of tests carried out with a chemical were compared to those carried out without chemicals. As illustrated in the literature, Because of its higher molecular weight value and a lower percentage of chain branching, high-density polyethene (HDPE) does not crack under normal conditions. In contrast to this, with low resistance when tested in a chemical solution. In part, the reduced crystalline phase composition often results in more excellent resistance to stress cracking because of the increased break elongation. Utilizing copolymers is a viable option for reducing high crystallinity. When comonomers are introduced to polymers, the proportion of the crystalline phase often drops.Crystallinity may change during resin processing. Reducing the processing temperature and time and quick cooling (or quenching) towards the end of the fabrication process minimizes crystalline content, increasing amorphous content Due to distinct molecular weight distributions, bimodal HDPE began as opposed to monomodal, as mentioned earlier. However, residual stress in the parts may lower ESC resistance if cooling occurs too quickly.In many cases, scientific, standardized tests are used to evaluate the susceptibility to ESC. One easy test includes submerging bent pieces of polymer in a specific media and then inspecting the strips for any indications of flaws after they have been exposed to the substance. The duration of time it takes for a significant cause to begin, including such microscopic cracks or cracking, is one of the characteristics that may be observed.

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