



Research Article

Analysis of Accelerated Weathering and Mechanical Properties of HDPE Polymer Composites with Carbon Black and Zinc Oxide Nanoparticles for Floating Solar Power Plants

Mohammed Wasim Khan^a, Rai Sujit Nath Shai^a^aDepartment of General Engineering, Institute of Chemical Technology, Mumbai.400019

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A B S T R A C T

The research aimed to create a composite material for the floaters used in floating solar power plants. High-density polyethylene (HDPE) was combined with 1, 1.5, 2, and 2.5% of carbon black (CB) and 1, 2, and 3% of zinc oxide (ZnO). Mechanical tests were carried out after accelerated weathering for 311, 634, 954, 1403, and 2878 hours in dry (out of water) and wet (sample floating in water) conditions. HDPE loses tensile strength, impact resistance, and elongation at break after 634 hours and 954 hours of weathering. The Shore D hardness did not show any significant change. The best performance was observed in batches D4 and W4, which contain 2% CB and 1% ZnO, in dry and wet conditions. The SEM (scanning electron microscope) shows the external morphology of D1 and W1 (pure HDPE) and D4 and W4 (composite) and revealed that pure HDPE was more degraded compared to the composite. Thermal properties and stability were analyzed using TGA (Thermogravimetric analysis). A further increase in CB and ZnO will reduce the strength of the composite. It was found that HDPE with 2% CB and 1% ZnO was a good composite material for developing the floaters used in floating solar power plants.

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As the consumption of fossil fuels increases, their availability keeps declining. With the rise in demand for energy, sustainable energy sources are being prioritized because they can be used indefinitely and are also environmentally favorable. Solar energy is a promising energy source due to its accessibility and sustainability (Kumar et al., 2021), but it requires extensive land for installation. Floating solar power systems can address the issue of territory (Akella et al., 2009; Painuly, 2001; Razeghi Jahromi et al., 2023; A. Sahu et al., 2016). Floating solar power plants are opening up new investment opportunities where various variables contribute to cost reduction and environmental improvement. Floating solar power Voltic (FSPV) plants are economically viable and have positive social effects (Bax et al., 2022; Fereshtehpour et al., 2021; Rauf et al., 2020).

The most popular material for floating photovoltaic systems in the polyolefin family is HDPE (Aghabarari, 2016). HDPE (High-Density Polyethylene) is a thermoplastic polymer used in a variety of applications due to its high density, chemical resistance, thermal stability, and tensile strength. HDPE material is light and is not greatly impacted when used in natural weathering conditions for an extended period, making it ideal for creating floats for floating solar panel structures (A. K. Sahu & Sudhakar, 2019). Alok K. Sahu et al. evaluated the mechanical properties of HDPE immersed in seawater at different intervals until 2160 hours. HDPE immersed in seawater shows no significant change in tensile strength, impact strength, or hardness. A maximum increase in tensile strength is observed when HDPE is exposed to seawater for 768 hours, making it suitable for structures in solar floats (A. K. Sahu et al., 2019). HDPE can deteriorate as a result of temperature changes, moisture, and ultraviolet radiation. When a substance is exposed to sunlight and weather for an extended period, its stability becomes extremely important. By absorbing the entire sun spectrum and preventing high-energy photon penetration, carbon black works as a stabilizer to prevent UV-induced degradation of polyethylene plastic (Carmona & Ravier, 2002; de Blécourt et al., 2013; Nayak et al., 2014; Reese et al., 2011). Two studies found that the mechanical characteristics like tensile and flexural strength of the polymer lattice are improved when carbon black is added, but the composite's impact strength was found to be reduced (Flandin et al., 2001). L.C. Mendes et al. discovered that non-stabilized HDPE experienced

*Corresponding Author's Email: mec21mw.khan@pg.ictmumbai.edu.inURL: https://www.jree.ir/article_194865.html

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impressive environmental oxidative degradation. At the same exposure time, the characteristics of the stabilized HDPE remained essentially unaltered, proving the effectiveness of the additives used in this sample (Mendes et al., 2003). Alok K. Sahu et al. investigated the effect of HDPE on the mechanical behavior of carbon black composites. These composite mechanical properties are best at a 2% loading in an HDPE matrix, with a decrease in mechanical properties after a 3% loading (A. K. Sahu et al., 2020). Parvin et al. examined the results of separately adding talc (T) and carbon black (C) at concentrations from 0 to 40 weight percent to HDPE. The enhancement of crystallinity and crystallite size occurs when carbon black and HDPE components are combined. HDPE works better with carbon black than talc, resulting in an 80% increase in hardness (Parvin et al., 2013). Jassim et al. evaluated the change in tensile strength of the pipe made from MDPE material mixed with and without carbon black to analyze and compare the effects of ultraviolet radiation. The results show that virgin MDPE pipe has a lower tensile strength at breakpoints than carbon black-infused MDPE pipe. Due to the function of carbon black as a UV stabilizer, the value of tensile strength at the break is unchanged by exposure to UV light (Jassim, and Mahdi 2017).

To improve the mechanical properties and photocatalytic activity of polymer composites, zinc oxide has been utilized. Recently, nano zinc oxide has been introduced to enhance the durability of polypropylene. These nanoparticles possess various potential applications due to their high exciton bonding energy and wide bandwidth, including anti-inflammatory, wound-healing, and antioxidant properties. Nano-sized ZnO particles have smaller dimensions and a larger specific area compared to micro-sized ZnO particles, resulting in stronger interfacial interactions when incorporated into other materials. Enhanced interactions between nanoparticles and the HDPE matrix were observed when ZnO was used separately and in powdered form, indicating improved energy dissipation characteristics (Bajwa et al. 2021; Grigoriadou et al. 2018; Hokkanen, Bhatnagar, and Sillanpää 2016; Lu and Hsieh 2010; Vahidi et al. 2022; Zhao and Li 2006). The study conducted by Douglas Naue Simoes et al explored the effects of thermally accelerated aging on the mechanical and chemical characteristics of thermoplastic elastomers with zinc oxide as an additive. They found that the mechanical properties of the TPE composites loaded with ZnO remained largely unchanged even after undergoing thermal aging (Simões et al., 2017) The inclusion of ZnO nanoparticles has enhanced both the tensile and impact strengths of HDPE. This addition significantly augments the potential of HDPE by improving its thermal stability, crystallization, and mechanical properties within the matrix (Gao et al. 2022, Rasouli et al. 2016). Karina Rojas et al. synthesized polymeric nanocomposites by combining zinc oxide nanoparticles and low-density polyethylene (LDPE) through melt compounding. These approximately 17 nm-sized nanoparticles, produced via sol-gel, were utilized in both their as-prepared state and after organic modification with oleic acid (Mod-ZnO). The Young's moduli of LDPE/ZnO and LDPE/Mod-ZnO increased by 15% and 18%, respectively, compared to neat LDPE (Rojas et al., 2019). After referencing numerous research papers, it was noted that numerous manufacturers produce floaters utilized in floating solar power plants employing pure HDPE polymer material. However, over its lifespan, it loses its mechanical properties owing to UV light exposure. Given that floating solar installations typically endure for extended periods due to their high installation costs, incorporating additives such as CB (carbon black) and ZnO (zinc oxide) could augment their mechanical properties.

1.1 Methodology

The flowchart below illustrates the research methodology pursued in the paper in accordance with the research objectives. A literature survey was conducted to select suitable materials for floater application, followed by exposure to sunlight and water for specified durations. Subsequently, mechanical analysis and characterization were performed. Based on this interpretation, the results were derived.

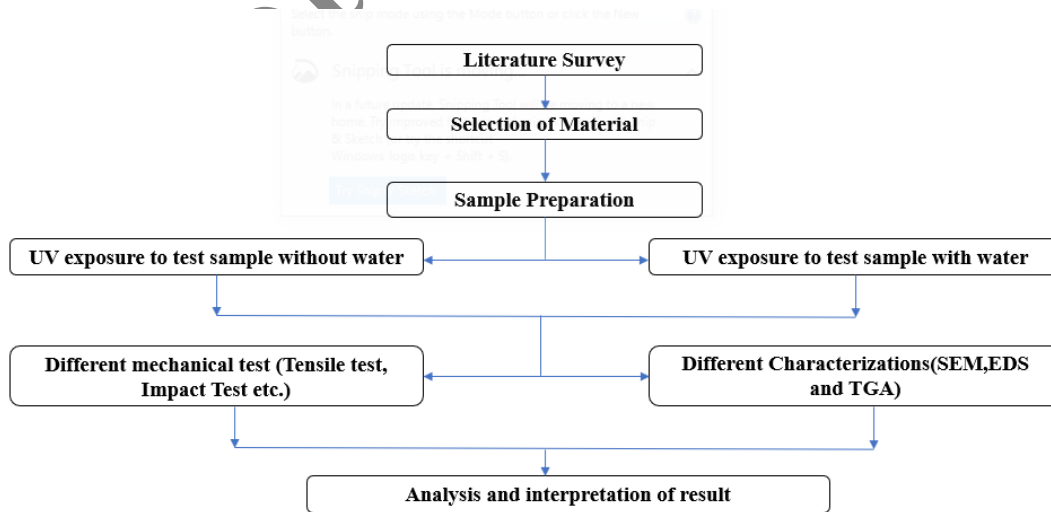


Figure 01 A flowchart of the research methodology

2.1 Sample Preparation:

The test specimen was made from commercial HDPE (high-density polyethylene) polymer (grade 156A200) supplied by GAIL India Pvt Ltd, with a polymer density of 956 kg/m³ without additives and a melt flow index of 20 (g/10 min). The virgin HDPE was compounded with carbon black (CB), grade N550 supplied by Hamdri Chemical Pvt Ltd, which has a density of 2500 kg/m³ and a size of 53 nm, with weight percentages of 1, 1.5, 2, and 2.5%, and zinc oxide (ZnO) supplied by Bharat Zinc Ltd, which has a density of 5600 kg/m³ and a size of 40 nm, with weight percentages of 1, 2, and 3% of HDPE polymer, in the lab mixture for 15 minutes with coupling agent Silane SI-69. Then, the powder was fed to the twin-screw extruder for processing into granules composite as shown in Fig. 3(A). The processing of composite material was carried out at temperatures of 190°C, 200°C, and 210°C, respectively. Different mechanical test specimens were prepared according to ASTM standards, such as the tensile test (ASTM D638), elongation at break (ASTM D638), notch Izod impact test (ASTM D256), and hardness (Shore D) test (ASTM D2240) (Shah, 2006), by injection molding using an Injkon Vibrant Gujarat machine with an 80 T capacity (Fig. 3(B)) at a temperature of 210°C and pressure of 60 bar (A. K. Sahu et al., 2020). A total of 13 batches were made from B1 to B13, where B1 consisted of pure HDPE, and the other 12 batches of composite were prepared with different percentages of CB and ZnO, respectively (see Table 01).

Table 01

Different additive concentrations in composite

Batches	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
HDPE	100	98	97.5	97	96.5	97	96.5	96	95.5	96	95.5	95	94.5
CB	-	1	1.5	2	2.5	1	1.5	2	2.5	1	1.5	2	2.5
ZnO	-	1	1	1	1	2	2	2	2	3	3	3	3

2.2 UV exposure to test sample:

The sample was exposed to UV radiation from sunlight in an open environment for varying durations to assess the mechanical degradation of the composite material caused by ultraviolet (UV) light (Ovali & Sancak, 2022). Three distinct weather conditions (summer, rainy, and winter) were observed from April 2nd to December 12th, spanning a total of 255 days. The sample remained positioned at zero degrees relative to the horizontal, as illustrated in Fig. 02. Two separate experiments were conducted: one with the sample submerged in water and another without water, both conducted in Boisar, India (Fig. 3(B)). Floaters were utilized to keep the sample afloat in water, and the influence of water on mechanical degradation was assessed (Fig. 3(C)).

2.2.1 UV exposure to test sample without water (DRY):

The sample was exposed to UV radiation in an open environment for UV exposure without the presence of water present (Fig. 02) for varying durations of time. Subsequently, the material's mechanical properties of the material were assessed.



Figure 02 The weathering of the sample out of water (left figure) and the weathering of the sample in water (right figure).

2.2.2 UV exposure to test sample with water (WET):

The sample was immersed in an open water tank filled with water (Fig. 02) for UV exposure for several hours. Subsequently, various mechanical tests were conducted to assess its different mechanical properties.

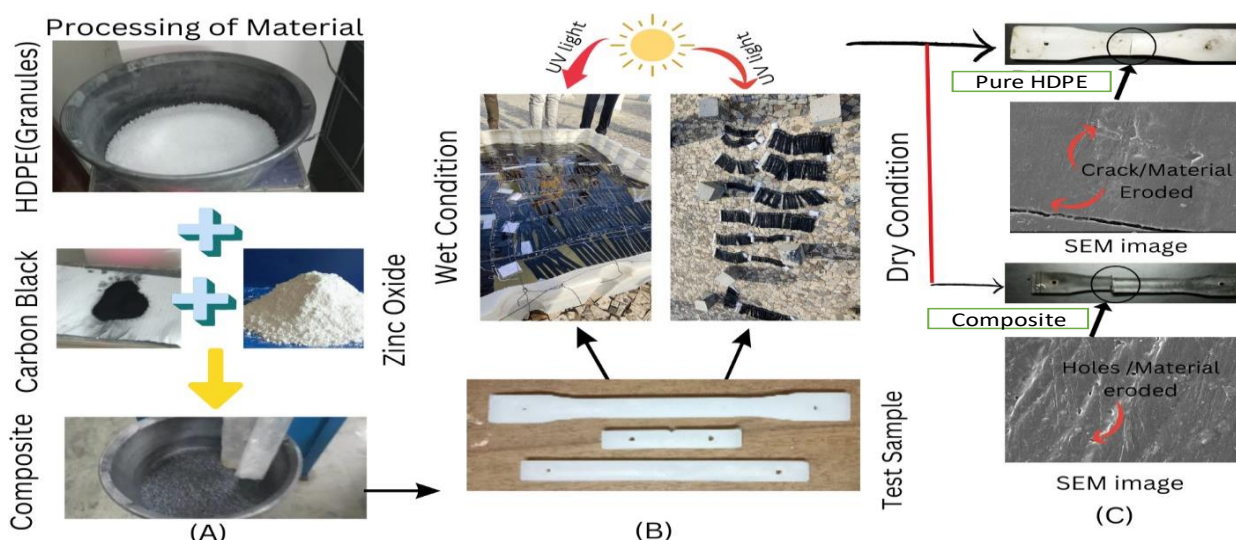


Figure 3 (A) the Processing of material to form composite; (B) the Test sample and weathering in dry and wet conditions; (C) Degradation of Pure HDPE and Composite with SEM.

3. Result and Discussion:

3.1 Analysis of Mechanical Properties:

Many researchers reported that Carbon black (CB) and Zinc Oxide (ZnO) worked as very good additives or fillers for anti-UV resistance (Parvin et al., 2013; Rasouli et al., 2016). Here, we have utilized carbon black (CB) and zinc oxide (ZnO) in an HDPE polymer composite, employing varying weight percentages to enhance the enhancement of mechanical properties of the floater material. Additionally, we aim to ascertain the advantages of water in reducing the mechanical degradation of the composite.

3.1.1 Tensile strength at break:

The tensile strength of the composite is enhanced by adding UV additives to the polymer matrix because the additives have a much higher strength value than polymer matrices (Rojas et al., 2019). The tensile strength at break of virgin HDPE with 1%, 1.5%, 2%, and 2.5% carbon black and 1%, 2%, and 3% ZnO composite of dumbbell-shaped samples was tested in the laboratory under weathering and non-weathering conditions. Fig. 4(1aD) shows the result of the composite that was kept in an open environment without water, and Fig. 4(1aW) shows the result of the sample that was immersed in water. D1 to D5 batches were tested in dry conditions, and W1 to W5 in wet conditions, all with 1% ZnO; however, it is observed that the virgin HDPE coded with D1 (dry) and W1 (wet) has a non-weathering condition tensile strength at break of 20.8 N/mm², but after 2787 hours of weathering, it decreases to 3.084 N/mm² (dry) and 10.565 N/mm² (wet), losing its property by 50% in wet conditions and 85% in dry conditions. Compared with other batches containing CB and ZnO, it shows better results (Parvin et al., 2013; Rasouli et al., 2016). Batches coded with D4 and W4 show the optimum and highest results. For non-weathering conditions, the tensile strength was 30.399 N/mm² for both dry and wet conditions, but after weathering for 2878 hours, it decreased to 24.059 N/mm² (dry) and 25.059 N/mm² (wet), indicating a reduction in tensile strength at break by approximately 20.778% in dry conditions and 17.57% in wet conditions due to increased brittleness and decreased ductility after weathering (Parvin et al., 2013). In batches D2, D3, and D5, the reduction in tensile strength was 32.69%, 32.41%, and 39%, respectively, while in batches W2, W3, and W5, the loss of tensile strength was 29%, 28%, and 30%, respectively. Therefore, the degradation of the composite in these batches is also higher compared to D4 and W4, which contained 2% CB and 1% ZnO (Flandin et al., 2001), indicating better dispersion of ZnO and CB with HDPE, reducing particle surface properties and minimizing erosion of material from the surface polymer and composite (Rojas et al., 2019).

If we consider Figs. 4(2bD) and 4(2bW) at 2% ZnO, batches D6 to D9 and W6 to W9 degrade with respect to D1 and W1, respectively. Batch D8 and W8, both containing 2% CB, exhibit better results after and before weathering, with a reduction in tensile strength of 27.7% and 20%, respectively. The reduction in tensile strengths of batches D6, D7, and D9 were 54.67%, 57.36%, and 30%, respectively, and for batches W6, W7, and W9, they were 48%, 41%, and 26.3%, respectively. So, when comparing the loss of property in D8 and W8, it is less compared to other batches at 2%. Nowhere else have we observed that when comparing Fig. 4(a), which represents 1% ZnO, as we increase the ZnO to 2%, the tensile strength decreases (Liang & Yang, 2009).

Upon observing Fig. 4(3cD) and Fig. 4(3cW) at 3% ZnO, we notice degradation in the composite batches D10 to D13 and W10 to W13 compared to D1 and W1. Batches D12 and W12 exhibit a 2% loss in tensile strength. The carbon black (CB) content was 35.6% and 34.4%, which is optimal compared to other batches under dry and wet conditions. These conditions experienced reductions of 43%, 40%, and 41% for D10, D11, and D13, and 38%, 39%, and 36% for W10, W11, and W13 respectively. Analysis of all figures in Fig. 3 across different ZnO percentages indicates strong interfacial interaction between additives and the HDPE matrix, which delays major shear yielding under tensile loading direction (Abou-Kandil et al., 2015; Parvin et al., 2013). This interaction prevents

the breaking of covalent bonds in polymers, which are responsible for erosion and surface roughening, leading to significant degradation after weathering (Ovali & Sancak, 2022; Rasouli et al., 2016). This phenomenon is also observable in SEM images from Fig. 8. Carbon black at 2% demonstrates superior results (A. K. Sahu et al., 2020). However, increasing CB above 2% or ZnO above 1% results in decreased tensile strength at break. Therefore, the optimal formulation for composite development appears to be D4 and W4.

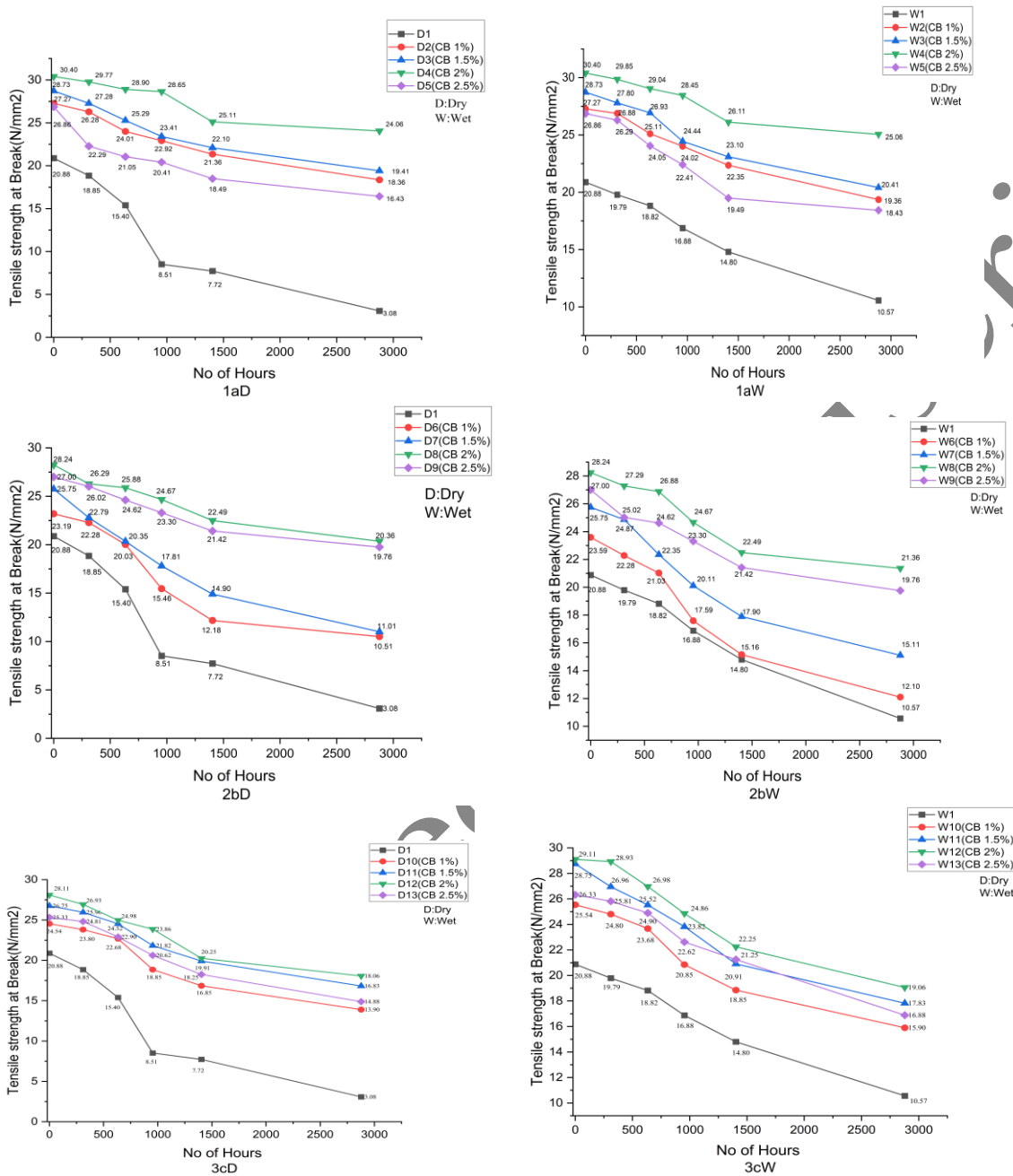


Figure 4 Tensile strength at break (a) at 1% of ZnO, UV Exposure with and without water; (b) at 2% of ZnO, UV Exposure with and without water; (c) at 3% ZnO, UV Exposure with and without water.

3.1.2 Elongation at break:

Several researchers have reported that elongation at break value can be a good measure to monitor the lifespan of a composite (Korciem et al., 2021). Figures 5 depict the percentage of elongation at break for all 13 composite batches before and after UV exposure under dry and wet conditions. Figs. 5(1aD) and 5(1aW) display the results of batches D1 to D5 and W1 to W5, each containing 1% ZnO with varying concentrations of carbon black. The virgin HDPE, labeled as batch D1 for dry conditions and W1 for wet conditions, exhibits a significant reduction in property following 954 hours of weathering. Its losses reach 95% of the original value after 2787 hours of weathering in dry conditions. This degradation is attributed to chain breaking within the material, leading to a decay in its mechanical properties (Korciem et al., 2021; Liang & Yang, 2009). Material that fractures before reaching the yield point indicates excessive brittleness compared to its original state. However, in wet conditions, this brittleness gradually decreases from 74.5% to

17.14% over 2787 hours. Batches D4 and W4 exhibit superior performance compared to both the all-composite and pure HDPE, which contains 2% CB and 1% ZnO. The non-weathered values for D4 and W4 were 86.2%, decreasing to 69.95% in wet conditions and 64.43% in dry conditions after 2787 hours of weathering. While composites D2, D3, and D5, and W2, W3, and W5 demonstrate favorable outcomes compared to D1 and W1, the most promising results are achieved by batches D4 and W4, containing 1% ZnO and 2% carbon black, as discussed previously.

Similarly, in Figs. 5(2bD) and 5(2bW), displaying the varying values of elongation at break for D6 to D9 and W6 to W9 concerning D1 and W1 before and after weathering at 2% ZnO, the 2% carbon black batches D8 and W8 exhibit superior results among all composites from D6 to D9 and W6 to W9. The percentage of degradation gradually decreases from 86.77% to 60.35% for D8 and from 86.77% to 62.35% for W8.

In Figs. 5(3cD) and 5(3cW), the results of batches D10 to D13 and W10 to W13 for wet and dry conditions are shown concerning D1 and W1 at 3% ZnO. Again, 2% carbon black with batches D12 and W12 shows the better results regarding pure HDPE in dry and wet conditions or regarding the other composites like D10, D11, and D13 and W10, W11, and W13, which are 86.27% to 30.77% for D12 and 86.27% to 27.24% for W12. One more thing noted here is that D13 batches show a huge reduction in elongation at break after 954 hours of weathering, that is, 55.05% to 19.15% at 2.5% carbon black. It shows that carbon black increases above 2% and 3% of ZnO, increasing the brittleness of the material, which causes the material to break too early due to higher stress concentration in cracks (Liang & Yang, 2009). Therefore, based on Fig. 5, D4 and W4 are the best formulations to form the composite that had 2% CB and 1% ZnO oxides in the virgin HDPE, which avoids breaking off the chain too early and enhances the properties (Parvin et al., 2013; Rasouli et al., 2016).

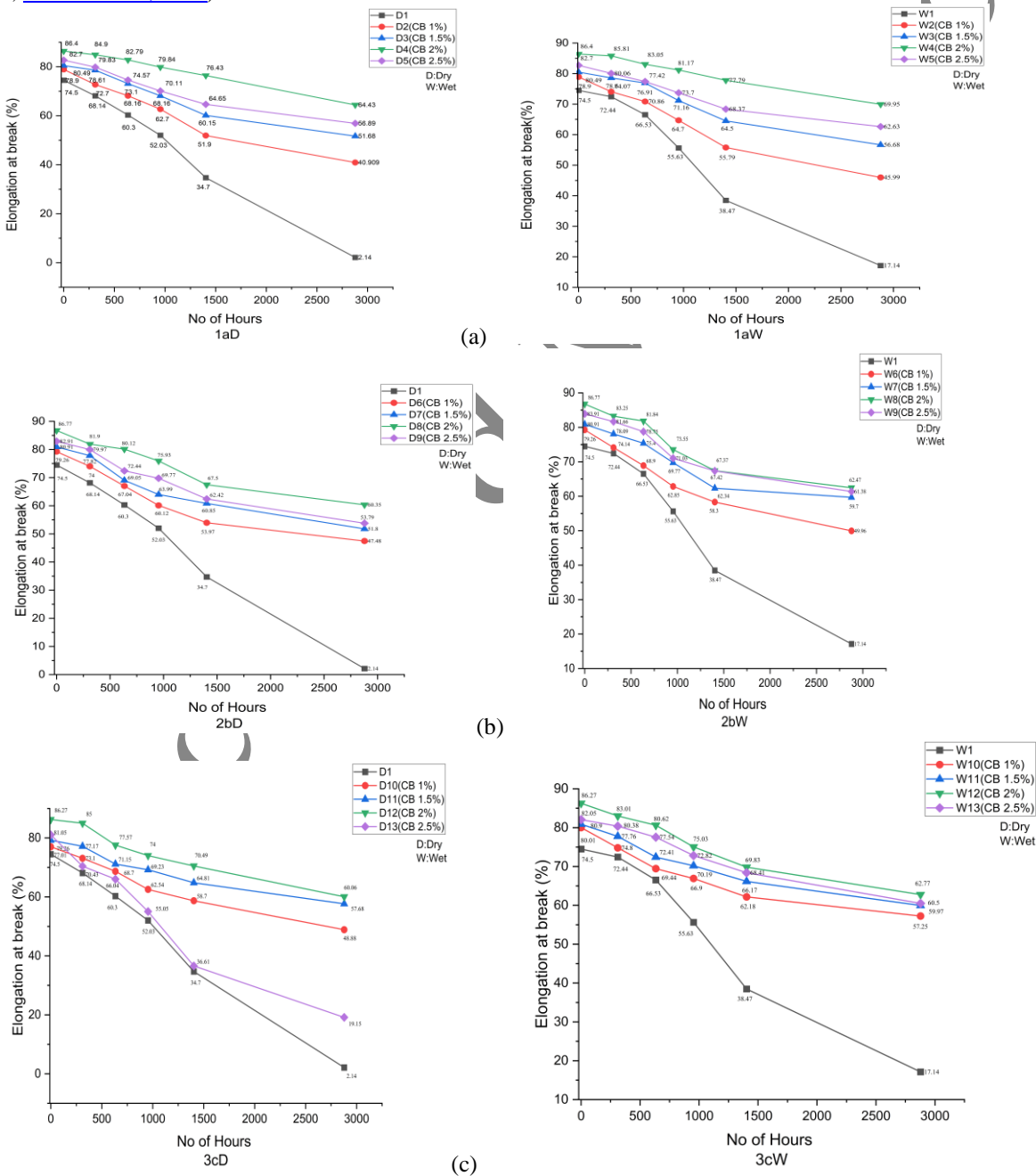
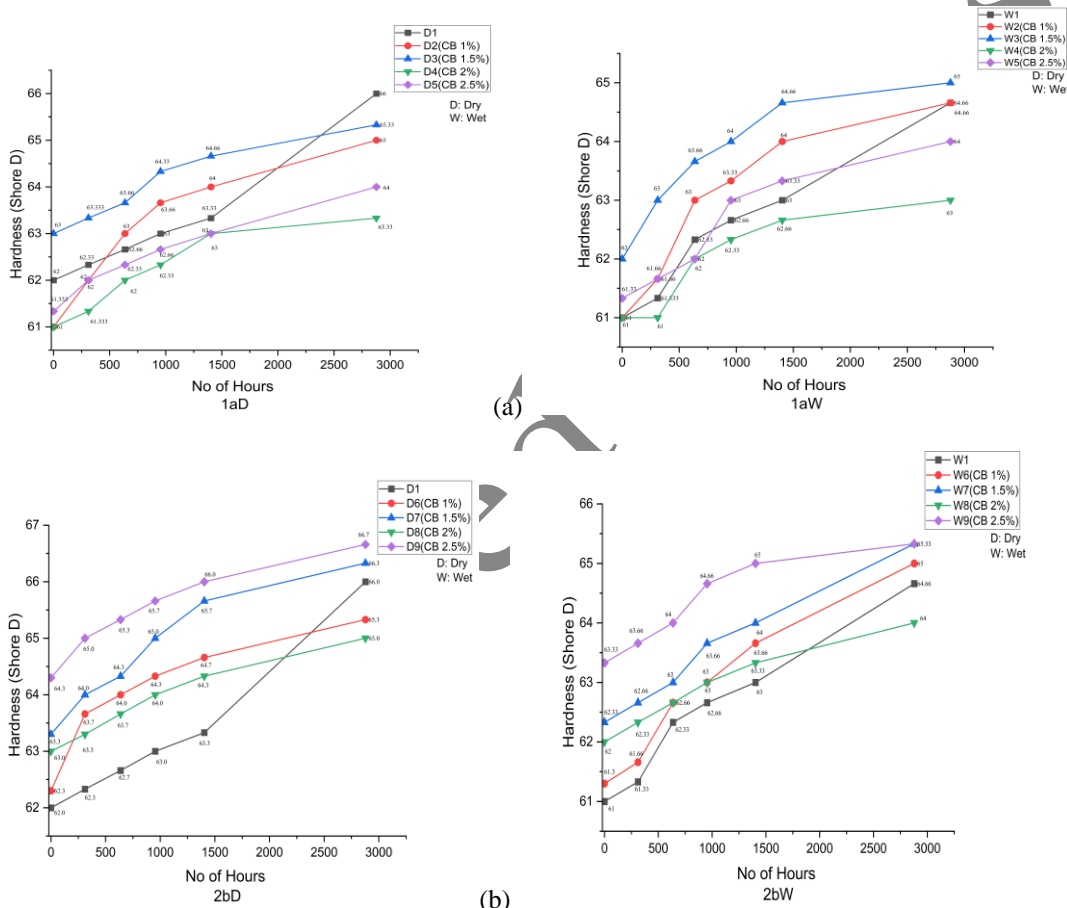


Figure. 5 Elongation at break (a) at 1% of ZnO, UV exposure with and without water; (b) at 2% of ZnO, UV exposure with and without water; (c) At 3% ZnO, UV exposure with and without water.

3.1.3 Hardness (Shore D):

The hardness is a mechanical property that is used to assess the surface resistance against indentation of the material, and it is influenced by the mobility and flexibility of the polymer chain structure (Sit et al., 2023). The shore D hardness test was carried out for all 13 batches of samples before and after weathering conditions, and degradation of material was recorded; the results are shown in Figs. 6 with the number of hours in dry (D) and wet (W) conditions. As UV (Ultra-Violet) light falls on materials, the hardness of the materials increases in the form of brittleness, as shown in both figures 6 (1aD) and 6 (1aW) at 1% ZnO, but it does not significantly increase. The maximum hardness that was obtained after weathering for 2787 hours for pure HDPE was 66 for D1 and 64.66 for W1. For composite, it was 66.67 for D9 at 2% ZnO and 2.5% carbon black; this is only an increase of 1% as shown in Fig. 6 (2bD) for dry conditions, and for wet conditions, the maximum hardness value for D13 at 3% ZnO and 2.5% carbon black was 66 from Fig. 6 (3cW) after weathering for 2787 hours. It is also approximately an increase of 1.5% in hardness. As such, other batches of dry and wet conditions like D2 to D13 and W2 to W13 do not show any significant change as the nature curve shows in Figure 6 at different concentrations of ZnO and carbon black, except D9 and W13, which are due to an increase of CB 2.5% and ZnO 2%, 3%, which show maximum hardness because carbon black and ZnO increase the brittleness or may increase hardness due to an increase in crystallinity of polymers (Sit et al., 2023), but W4 and D4 formulations show the lowest degradation compared to other batches that have 2% carbon black and 1% ZnO. It was observed that as carbon black increases by 2% and ZnO by 1%, the hardness of the material also increases in both dry and wet conditions (Parvin et al., 2013; Rasouli et al., 2016)



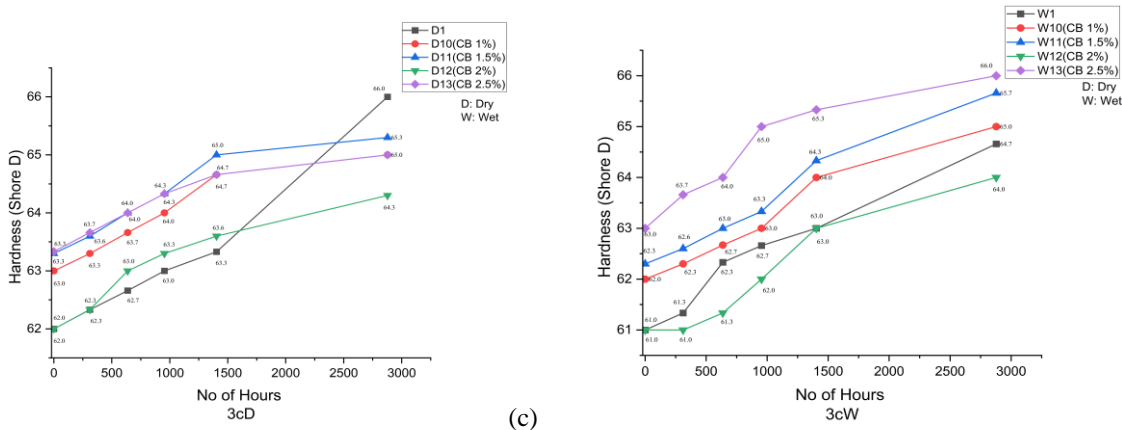


Figure. 6 Shore D hardness (a) at 1% of ZnO, UV exposure with and without water; (b) At 2% of ZnO, UV exposure with and without water; (c) At 3% ZnO, UV exposure with and without water.

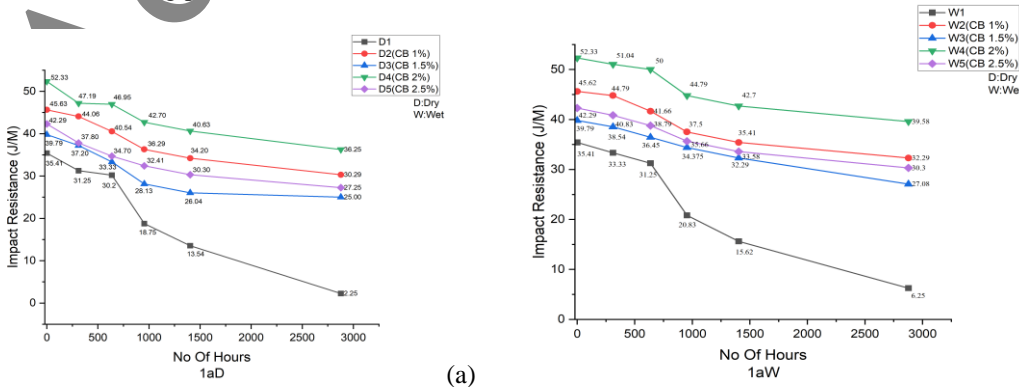
3.1.4 Impact Resistance:

Impact resistance is a mechanical property that is used to monitor the fracture toughness of a material when subjected to an impact load (Liang & Yang, 2009). The impact resistance of all 13 batches is depicted in Fig. 7 under both weathering and non-weathering conditions, along with the corresponding number of hours. Figures 7(1aD) and 7(1bW) illustrate the degradation of material from batch D1 to batch D5 and from W1 to W5 at 1% ZnO. Batches D1 and W1, consisting of pure HDPE material, exhibit a sudden loss of impact resistance after 634 hours in both dry and wet conditions. Specifically, batch D1 experiences a decrease in its property by 93.64% (dry) from its initial value and by 82.37% for wet conditions. This degradation is attributed to photodegradation upon exposure to UV light, leading to macro damage, which initiates with micro-cracks as demonstrated in the SEM images in Fig. 8. Macro damages, such as gloss loss and chalking, render the surface more irregular due to material erosion (Estrada-Núñez et al., 2006; White & Turnbull, 1994). However, composite batches like D2, D3, and D5 under dry conditions, and W2, W3, and W5 under wet conditions, exhibit improved performance at various hour intervals for pure HDPE, albeit gradually decreasing. Batches D4 and W4, containing 2% CB and 1% ZnO, demonstrate the best performance among all composites in both dry and wet conditions, with a reduction in impact resistance only from 52.33 J/m to 36.25 J/m, which is 30.72%, and from 52.33 J/m to 39.58 J/m in wet conditions, which is 24.36%.

In Figs. 7(2bD) and 7(2bW), the impact resistance of the material for batches D6 to D9 and W6 to W9 after and before weathering at 2% ZnO is shown. The nature of the curve is depicted in Figs. 6 (2bD) and 6 (2bW), where batch D7 and W7 exhibit the maximum value, but the loss of impact resistance is less in the D8 and W8 composite. Batch D7 and W7 experience a gradual loss of impact resistance, whereas batch D8 and W8 show a sharp drop in impact resistance after 634 hours. The other formulations of composite, D6, D9, W6, and W9, experience a higher loss of impact resistance compared to the other two batches, W7, W8, D7, and D8, which are 45%, 52%, 33%, and 27%, respectively.

Considering Figs. 7(3cD) and 7(3cW), which illustrate the degradation of composites with pure HDPE for batches D10 to D13 and W10 to W13 at 3% ZnO, the degradation in D10, D11, D12, and D13 was 41.3%, 42.4%, 43%, and 44.25%, respectively. In wet conditions (W10, W11, W12, and W13), the degradation of the composite was 37.33%, 41.12%, 39.36%, and 35.3%. It is observed that degradation was less in D10, which contains 1% CB, and W13, which contains 2.5% CB. We have observed that for all figures at 1% to 3% of ZnO and different variations of CB, increasing the CB by more than 2% and 1% of ZnO leads to increased material degradation, as reported by many researchers.

CB and zinc oxide increase the crystallinity of the material and slow down the transformation phase from ductility to brittleness, thus keeping the resistance energy for impact loads available. This prolongs material life and prevents it from easily cracking like pure HDPE (Parvin et al., 2013; Rasouli et al., 2016). However, this is true for D4 and W4 batches with 2% CB and 1% ZnO because this combination exhibits better interfacial interaction between the polymer and additives. The dispersion of the formulation is also better, avoiding agglomeration in the matrix, which would otherwise lead to voids in the matrix, as depicted in micrographs from Fig. 7. After the weathering period, this decreases the service life of the composite (Estrada-Núñez et al., 2006; Koriem et al., 2021).



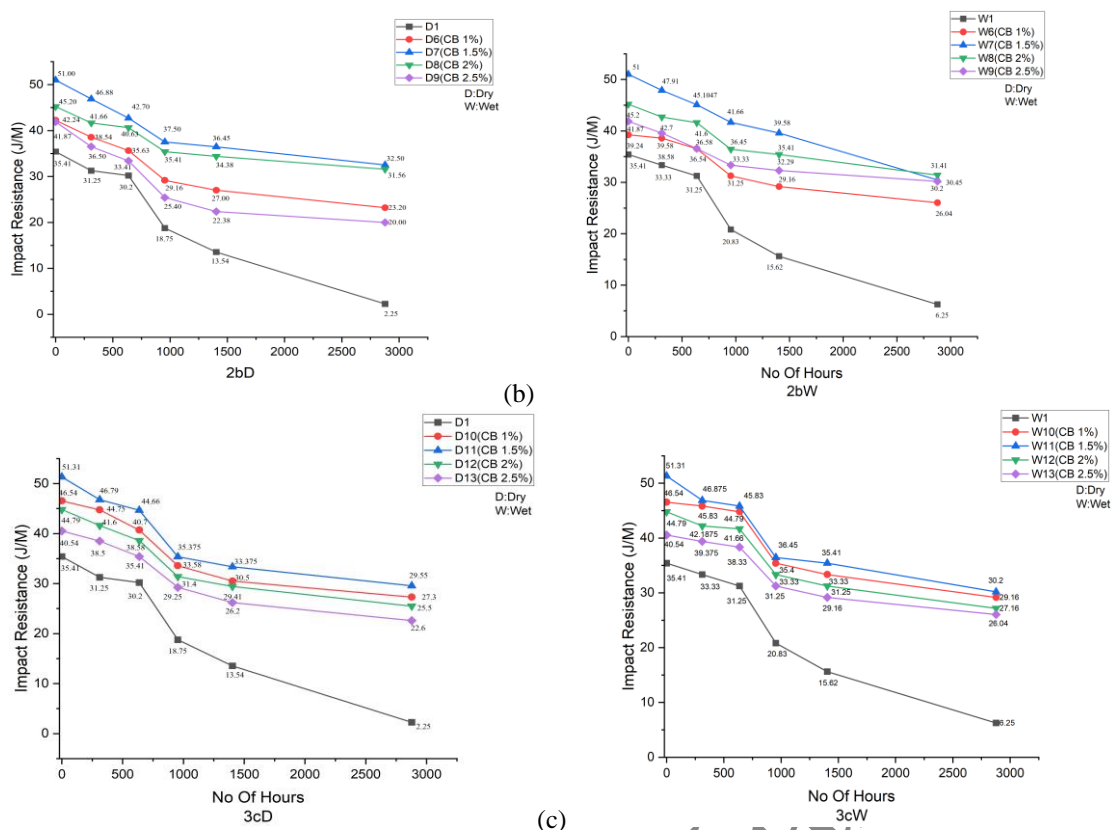


Figure. 7 Impact resistance (a) at 1% of ZnO, UV exposure with and without water; (b) at 2% of ZnO, UV exposure with and without water; (c) at 3% ZnO, UV exposure with and without water.

Table 2

Comparison of dry and wet conditions w.r.t degradation of sample:

Weathering Condition	Dry (Direct Expose to UV light without Water) % Degradation		Wet (Sample immersed in water and exposed to UV light)	
	Pure HDPE(D1)	Composite (D4)	Pure HDPE(W1)	Composite (W4)
Tensile strength at break(N/mm ²)	85%	20.778%	50%	17.57%
Elongation at break (%)	97.32%	25.25%	79.74%	18.85%
Hardness (Shore D)	9.38%	6.67%	4.69%	3.174%
Impact Resistance(J/m)	93.64%	30.72%	82.37%	24.36%

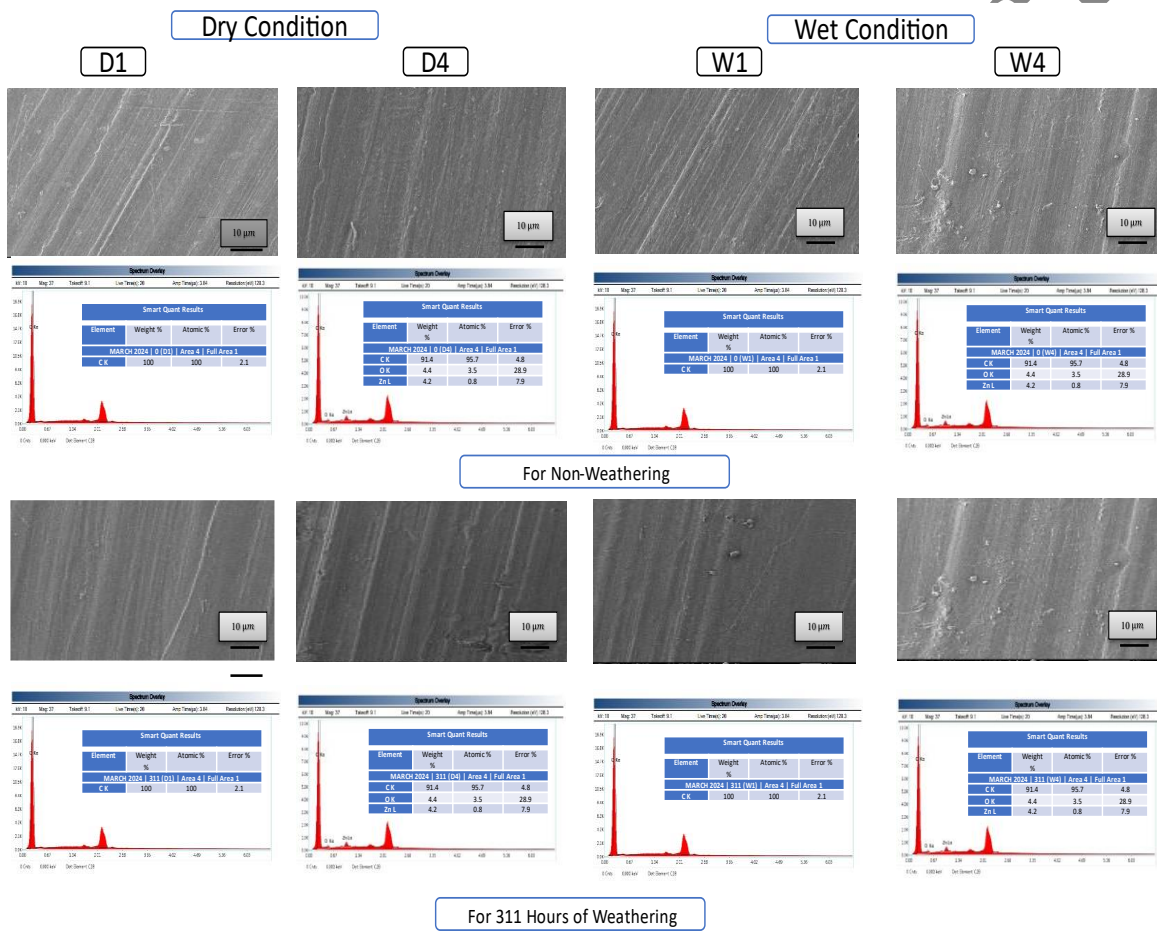
Once the UV light falls on the polymer material, it starts photodegradation, due to which the degradation of polymers starts and the mechanical strength of the polymer decreases. It also creates some heat that also degrades the material. We have added the UV-absorbing additives CB and ZnO to the HDPE polymer so the photodegradation can be avoided because the CB absorbs all wavelengths of UV light and is a very good UV light absorber. It also has radical scavenging properties, and ZnO also absorbs UV light. To avoid degradation, these two additives absorb the UV light and convert it into heat. This heat will modify the residual stress, which leads to thermal degradation or elevated temperature and also accelerates the aging of HDPE polymers (Audouin et al., 1998; Estrada-Núñez et al., 2006; White & Turnbull, 1994). From Table 2 observations, it is determined that the degradation rate for the samples that were floating in the water was lower than that for the samples exposed to UV outside of the water (A L Andradý, Pegram, and Tropsha 1993; Anthony L. Andradý 1990, 2011; Brandon, Goldstein, and Ohman 2016; White and Turnbull 1994).

3.2 External morphology and elemental composition of the composite after UV light irradiated on the sample:

The different external morphologies and elemental compositions of the samples W1 and W4 for wet conditions, and D1 and D4 for dry conditions, were evaluated using a scanning electron microscope and Energy-dispersive X-ray (JOEL JSM IT 200LV, Japan) after gold sputter coating (JEOL JEC-550 Twin coater). Several micrographs of the D1 and D4 batches, and the W1 and W4 batches,

were recorded at 10 kV accelerated voltage and 1000x magnification at different hours of weathering, as shown in Fig. 8. The samples of non-weathering and 311 hours of weathering were fairly smooth. However, as UV exposure hours increased, significant stages of degradation were observed. The surfaces of W1 and D1 batches (virgin HDPE) in wet and dry conditions started eroding, and crack and hole appearances were revealed due to the mechanical strength of the material simultaneously decreasing, as shown in Table 2. However, in W4 and D4 composites for wet and dry conditions, the effect of UV exposure was less, and the degradation of mechanical properties was also less. In general, the brittleness and cracks in pure HDPE and composites increased after 954 hours of weathering, and finally, at 2878 hours of weathering, virgin HDPE lost its mechanical strength, but D4 and W4 composites sustained their mechanical strength due to the addition of CB and ZnO as additives.

An energy-dispersive X-ray (EDX) study was conducted to verify the elemental composition of pure HDPE and composites both before and after weathering. The various EDX spectra, mapped using SEM images, are displayed in Figure 8. According to the spectra, polymer composites contain carbon (C), oxygen (O), and zinc (Zn), while pure HDPE contains carbon (C) under non-weathering conditions. The spectra did not significantly change after 954 hours of weathering. However, bond breaks in the polymer caused the oxygen content of pure HDPE to increase rapidly after 1403 hours of weathering. After polymer chain formation, photooxidation proceeds via the free radical chain mechanism, forming the carbonyl functional group that breaks down the polymer. However, in composites, ZnO combines with the carbonyl group to produce a carboxylate molecule, preventing deterioration (It & Table, 2015; Matuana et al., 2011).



AC

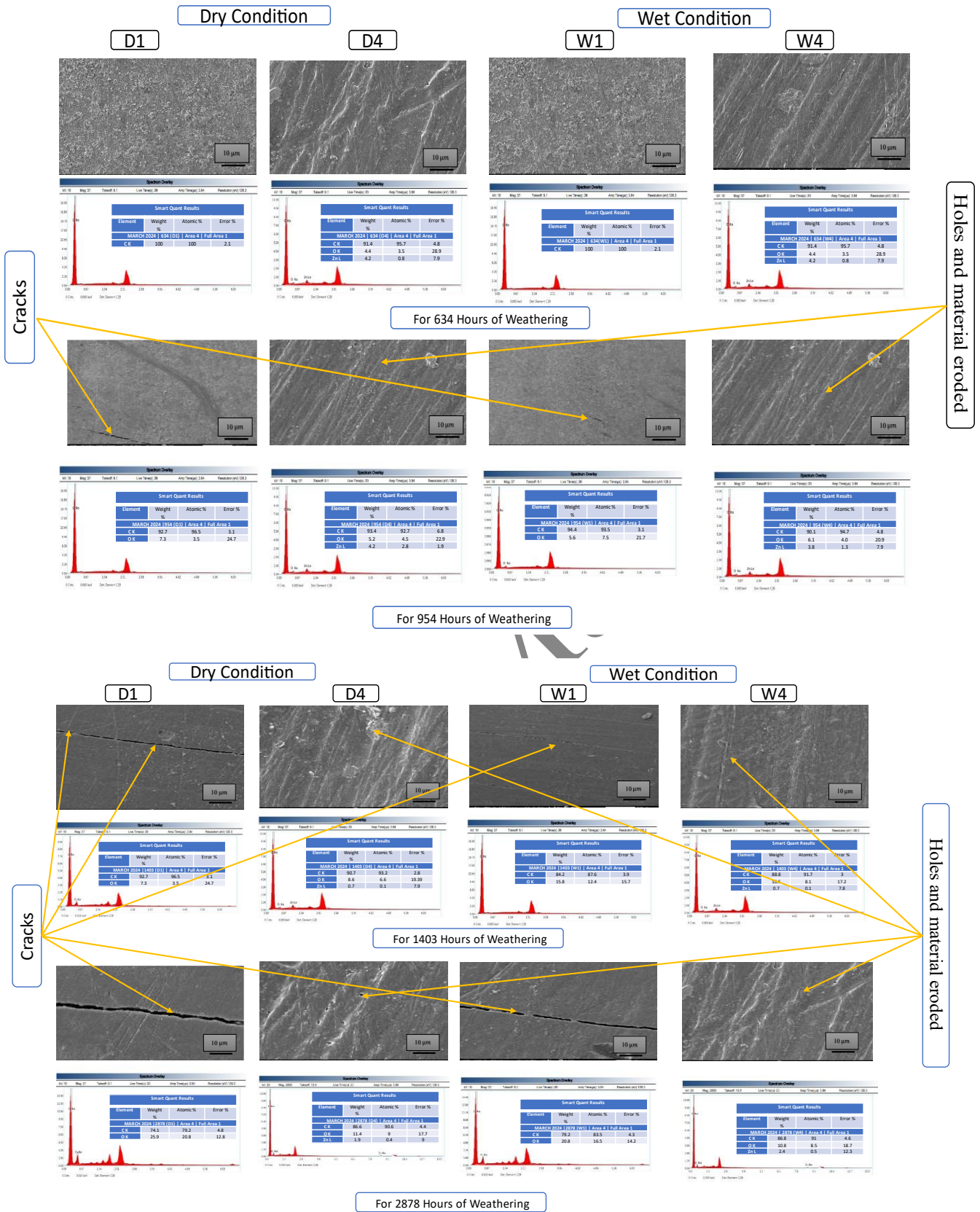


Figure 8. SEM and EDX of different samples at varying durations for wet and dry conditions for batch pure HDPE and Composite.

3.3 Effect of Carbon black and ZnO addition on thermal degradation of HDPE and Polymer composite.

The thermal properties and stability of the polymer composite and pure HDPE were analyzed using TGA (TGA model Q50, USA) with the sample heated at a rate of 20°C/min from room temperature to 600°C in a nitrogen atmosphere (Pavličević et al., 2014). Figure 9 displays the different thermographs of the polymer composite and pure HDPE for various batches. The thermal stability of the polymer composite is crucial for its potential applications. Figures a, b, and c illustrate that pure HDPE and polymer composites decompose in two stages when subjected to heat, leading to a loss of mass. The first stage occurs between 210°C and 450°C, during which pure HDPE loses only 5% of its mass, while polymer composites lose 4% of their mass between 212°C and 462°C, which is not significant. In the second stage, pure HDPE continues to lose mass until 522°C, with a total loss of 96% due to the formation of carbon and hydrogen bonds within the polymer chain. Beyond 450°C, an exothermic reaction occurs, leading to chain scission in the polymer and the reaction of carbon with oxygen, resulting in the decomposition of pure HDPE and the rapid evaporation of carbon monoxide from the polymer. However, polymer composites, containing carbon black and zinc oxide as fillers, prevent the breakage of bonds between hydrogen and carbon, thereby increasing the degradation temperature compared to pure HDPE and reducing mass loss. Additionally, hybrid fillers increase the thermal conductivity of the material. Nevertheless, contrary to popular belief, a higher addition of filler does not necessarily enhance the thermal stability of the material, as demonstrated in the results (Noer et al., 2018). There are specific limits to the amount of filler that can be added to improve thermal stability before it begins to decrease. Upon comparing different batches, the results indicate that batch B4 (2% CB and 1% ZnO) demonstrates optimal performance among all hybrid fillers (Kamalian et al., 2020; Pavličević et al., 2014; Vidakis et al., 2023).

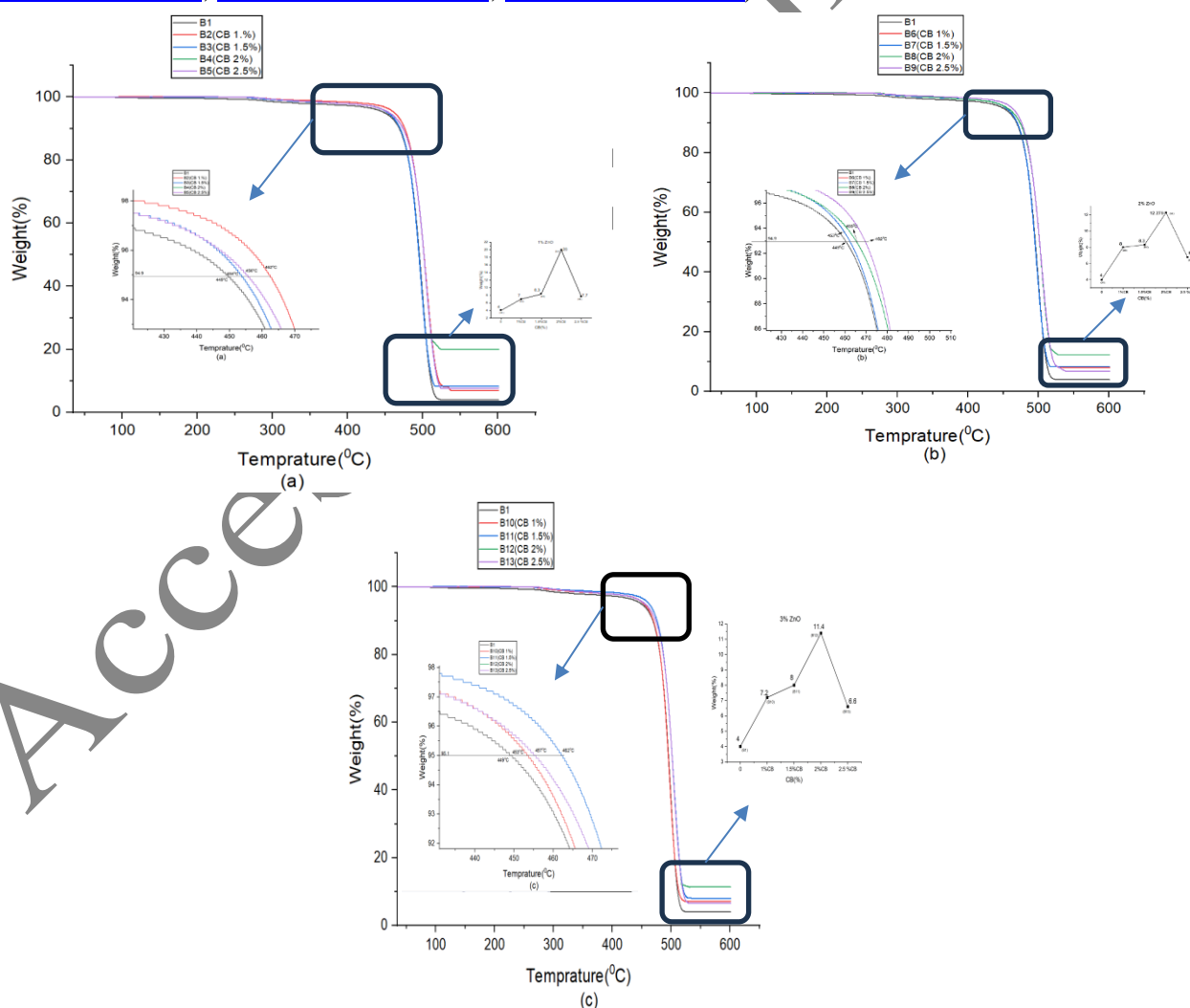


Figure. 9 Thermogravimetric analysis (TGA) (a) at 1% of ZnO; (b) at 2% of ZnO; (c) at 3% ZnO.

4. Conclusion:

From the above results, the following conclusions can be drawn:

1. Pure HDPE in both wet and dry conditions significantly loses its impact resistance, tensile strength, and elongation break after 634 hours of accelerated weathering and after 954 hours of accelerated weathering.
2. In the stabilized sample, only batches D4 and W4 showed better results compared to other composite batches in both dry and wet conditions.
3. It was observed that at 2% carbon black and 1% ZnO, mechanical properties such as tensile strength, elongation break, and impact resistance showed very good results in both wet and dry conditions.
4. With further increases of 2% CB and 1% ZnO, the mechanical properties decrease in both dry and wet conditions.
5. The hardness shore D of the different samples did not show any significant changes, but if carbon black is increased by more than 2%, the hardness value increases.
6. Degradation in dry conditions is more pronounced due to accelerated weathering compared to wet conditions.
7. Carbon black and zinc oxide work as very good additives to enhance mechanical strength in both wet and dry conditions.

Hence, it was found that HDPE with CB (2%) and ZnO (1%) was a good composite for manufacturing the floaters used in floating solar power plants. To optimize the life of the floaters, a few more mechanical tests can be performed, such as fatigue tests, etc. For more accurate results, UV exposure can be conducted under controlled conditions using an artificial weatherometer.

5. Conflict of Interest

No conflict of interest was declared by all authors.

6. ORCID iD

Mohammed Wasim Khan (<https://orcid.org/0000-0003-2654-1828>)

RSN Sahai (<https://orcid.org/0000-0003-1539-9520>)

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List of Abbreviations

Nomenclature

HDPE	Virgin high-density polyethylene	ASTM D638	Tensile test, Elongation at break
CB	Carbon black	ASTM D256	Notch Izod impact test
ZnO	Zinc Oxide	ASTM D2240	Hardness (Shore D) test
UV	Ultra-Violet		
FSPV	Floating solar power Voltic		
MDPE/LDPE	Medium-density polyethylene/ low-density polyethylene		
W/D	Wet/Dry		
SEM/EDX	Scanning electron microscope/ Thermogravimetric analysis		
TGA	Thermogravimetric analysis		

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