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REINFORCING THE MECHANICAL PROPERTIES OF WINDSHIELD WITH INTERLAYER-POLYCARBONATES GLASS COMPOSITE

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Abstract

The safety of automobiles has been the concern of billions of people who used cars for various purposes. The windshield is probably the first issue that automobiles companies must keep into consideration. This research provides very important insight information regarding enhancing the mechanical properties of the windshield while monitoring transparency. The glass used in this research and the subsequent preparation and testing were performed according to the Standard Specification for Laminated Architecture Flat Glass (ASTM C1172) and Glass in Building – Laminated glass and Laminated Safety (ISO 12543). Three groups of a double-layered glass laminated with a resin of polycarbonates at 5%, 10%, and 15% volume fraction were prepared and tested for the mechanical properties of the impact value, compression test, and modulus of elasticity. The results have shown that the 5%-polycarbonates has the maximum effect by enhancing the mechanical properties by 21.9%, 12.6%, and 15.9%, respectively. The mechanical properties of only those samples of the 5% polycarbonates were further investigated after UV exposure at 30 h, 60 h, and 90 h. The results showed that the mechanical properties were deteriorated; yet, showing various effects of exposure time. The impact value was reduced by 3%, 24%, and 35% after exposure of 30 h, 60 h, and 90 h, respectively. The compression strength and modulus of elasticity were enhanced by 17% after 30 h exposure while the modulus enhanced by 16 % after 60 h exposure -both before deteriorating. SEM images have shown that the effect of UV effect has caused better smoothness as the UV radiation increased from 30 h to 90 h.

Keywords: Glass, Impact test, Mechanical tests, Polycarbonate, SEM, UV exposure.

1. Introduction

Recently, glass has been employed in building construction as a structural-material for load-bearing components such as beams, columns, facades, and plates for roofs due to its main effect of aesthetic-related benefits [1, 2]. Besides, the role of the structural glass was also involved in other applications such as the automotive industry, where windshield may contribute to the overall crashworthiness of cars [3-5]. The use of conventional glass is unsafe for most applications. Alternatively, designing laminated glass with high bearing capacity does not impose real harm upon failure or cracked [6]. Polyvinyl butyral (PVB) polymer was recently discovered and became the standard material for laminated glass used in cars and others. PVB is a high transparent and tolerable weather condition [7].

The transparent polymeric materials such as polystyrene (PS), poly-methyl methacrylate (PMMA), and polycarbonate (PC) have been opening the way to more applications of the glass in the automobile. The shortcoming of glass-polymer materials is the relative unsatisfactory of the mechanical properties of the tensile, compression strength, hardness, and elastic modulus [8]. Polymer materials such as polyvinyl butyral (PVB) is added to the intermediate layer for laminated glass used in the front screen of the automobile industry to improve the mechanical properties like fracture toughness, hardness, and impact strength [9].

PC has another effect as it behaves as an adhesive material for the adhesive interlayer [10]. The adhesive joints at the edge of laminate-glass with various geometric shapes such as L-shaped, U-shaped, or rectangular improves shear loading, tensile strength, and compression strength [11]. *PC* is the most important technical thermoplastic because of its excellent heat resistance, outstanding impact strength, and good dimensional stability. PC was the first of the rigid thermoplastics to offer good temperature stability up to 130℃ and impact strength [12].

The process of reinforcing of the front layer of the windshield was done by adding PC with different volumetric ratios to improve mechanical and thermal properties. The reinforcement was performed using heat and pressure to conduct the test samples by manual moulding and using the commercial brand polystyrene adhesive (Mozilla Epoxy) for gluing the glass plates with the interlayer. As a result, solid material for the original polymer paste is formed after adding the supporting material due to fusion (95%) compared to the original (TRIPLEX) layers used in the windshield of the car [13].

This supporting material increases the strength of the windscreen, prevents the shattered glass from falling in accidents, improves the mechanical properties of the polymer and prevents the spread of the shock wave. This means that the risk is significantly reduced in terms of causing injury due to accidents [14]. The supporting material also works on the cohesion of the interstitial material and reduces the degradation rate when exposed to different weather conditions of temperature and the effect of ultraviolet radiation, oxygen, and moisture. The overall outcome can be seen through improving the physical properties to resist the chromatic changes obtained in polymeric material and increase the degree of transparency by preventing decomposition in chain polymers [7]. Meanwhile, it is important to note that the effect of X-ray conditions and polymerization processes can occur in the polymer age stages including the manufacturing phase, the moulding phase, the formation, or the phase of use. The exposure of the polymeric interferometer to atmospheric factors of moisture and temperature by the presence of oxygen and ultraviolet radiation results in a change in its physical properties. Examples for these changes are the colour that becomes obscured or transformed into a brittle state, and the enhancement and improvement of polymer resistance by adding support materials to the interstitial layer. UV of the wavelength of 290-315 nanometres (part of the solar spectrum) has a significant impact on mechanical properties because of breaking the bonds and causes degradation in the synthesis of the bonding material. The maximum tensile strength at lower glass fold was estimated at 83.8 MPa and the maximum deflection was reported at 10.7 mm which means interlayer is lowering bending stiffness of the laminate glass [15]. The glass layers including PVB, EVA, or thermoplastic polyurethane (TPU) cause changes in the Poisson ratio, density, and Young's modulus [16].

The hardness is defined as the resistance of the material to permanent indentation and its values range between 70 to 75 kJ/m for scale M and between 114 and 126 kJ/m for C scale [9]. The compression ratio is defined as the maximum stress that a material can sustain over a period under a load (constant or progressive) [9]. Compression testing is often done to a break (rupture) or a limit. In the numerical simulations, the software (MEPLA) was used while *FEA* program was utilized for measuring dynamic and static computations of glass structures. The stiffness was found at 200 N/mm [17]. EVA and TPU were used also in non-laminated glass [16].

The PC molecules absorb the energy of certain wavelengths in the UV range because of the ester groups are strong UV absorbers. As UV is being absorbed the covalent bonds start initiating photo-oxidation and photo-Fries reactions due to rupturing the bonds. Apparently, the mechanism is a wavelength-dependent [18]. Photo-Fries is triggered by wavelengths smaller than 310 nm while photo-oxidation is triggered by wavelengths in between 290-350 nm range [19]. Photo-oxidation results in chain scission process, not a cross-linking process where the polymer chain ends at which the polymer has low molecular weight compounds. The short wavelengths degrade free radicals that recombine into products, while under long wavelengths they react separately forming structures with phenolic end-groups [20].

Currently there is a lack in the knowledge about adding PC in specific ratios on the glass properties. Thus, in this study, the impact of adding PC to glass to strength the windshield was investigated. This work for the first time compares between sample without polymer materials and other with PC in a percentage of 5, 10, and 15%. The investigation of the impact strength, compressive strength, and modulus of elasticity tests were performed. These tests were to show how the additive will withstand weather conditions, reduce degradation of the interstitial layer and resistance change in colour, improve transparency properties, and make polymer material more cohesive to prevent polymer chains from breaking [21]. In addition, another test is to expose these samples to the photovoltaic light using electric xenon light 2.5 W/m² and normal temperature up to 36 ° C in the optical spectrometer.

2. Methodology

2.1. Materials and instrumentation

Polycarbonate (melting temperature $(T_m) = 280$ C, density 1200 kg/m^3) was obtained from M/S, SRF, New Delhi, India. The glass sheets were manufactured by Ramadi Company for Glass Manufacturing, Anbar Province, Iraq under specifications of American Society for Testing and Materials (ASTM) C1172 and International Organization for Standards (ISO)12543. The properties of the glass are glass melting temperature $T_m = 155℃$, glass transition temperature $(T_g) = 147℃$, and elastic factor of 2.4 GPa (kN/mm^2) [22]. The Scanning Electron Microscope (SEM) was Type: VEGA 3 LM, Origin: Germany, 30 kV and more details are available elsewhere [23, 24]. These samples were exposed to the optical spectrometer (Yuanchenwujin) containing (UV).

2.2. Sample preparation

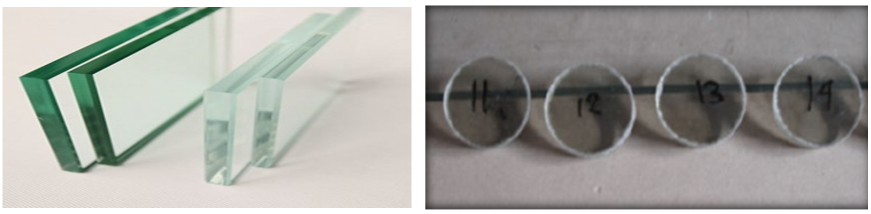
Three groups of samples were prepared according to the following dimensions and on two types of shapes.:

i. The dimension of first group samples was 120 mm length supported laminated glass 10 mm wide, 8 mm height (thickness) for bending test

ii. The dimension of second group samples was 55 mm length, 10 mm width, 8 mm height (thickness) to test the resistance of the shock. The first two samples were rectangular in shape and consisting of two glass layers with a height of 3 mm for each layer and an interlayer of 2 mm high. The interlayer consists of a thin layer of polycarbonate (PC) with a thickness of 0.75 mm surrounded by two layers of polyvinyl butyral (PVB) adhesive in the shape of a sandwich and on a weight basis of (5%) and (10%) for the first and second samples.

iii. As for the third sample, it is circular in shape with a diameter of 10 mm and a height of 10 mm. The height is distributed as follows: two layers of glass with a thickness of 4 mm for each layer and 2 mm for the adhesive interlayer, as we mentioned its components above. The glass panels were cleaned with soap and water, the edges and sharp edges of the panels were trimmed, and the panels were heated inside the oven (autograph) to a degree of 700 ºC and it was left for gradual cooling, where the interlayer material was placed and then the second panel was placed over and pressed with pressure until air leaked between the layers.

These groups were prepared at different volume fractions of polycarbonate-supported laminated glass to study their mechanical properties. The shape of the samples was chosen to be rectangular and circular as shown in Fig. 1.

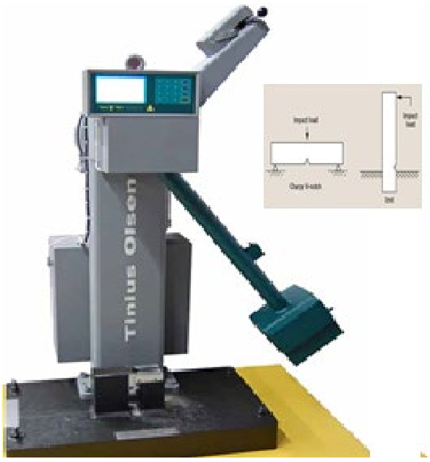


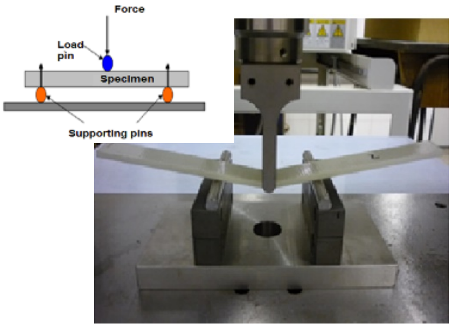
(a) **(b)**

Fig. 1. The samples (a) Rectangular; and (b) Circular.

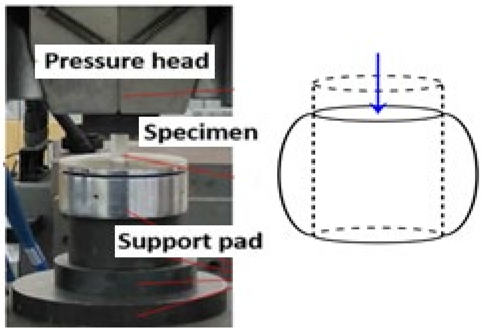
2.3. Mechanical properties measurements

The mechanical tests were carried out for normal glass samples according to ASTM-790 while for the polycarbonate-glass composites, the tests were carried out according to ASTM 1349. The mechanical properties can be measured by several tests such as the impact strength test, the bending test instrument, and the hydraulic piston to perform compression test (Compression test instrument) as shown in Figs. 2(a)-2(c), respectively.





(a) **(b)**



(c)

Fig. 2. Mechanical tests (a) Impact test instrument; (b) bending test instrument; and (c) Compression test instrument.

2.4. UV Exposure

To detect the change in the mechanical properties after exposure for different periods equivalent to years of service of the material used, the material supported by a lamp (xenon) of 2.5 W/m² using the spectrometer (prism) at the following exposures shown in Table 1. The exposure period is equivalent to years of service life for the materials used to demonstrate their tolerance to sunlight conditions and not to change their mechanical and physical properties [21].

Table 1. Exposure period.

Period of Exposure (h)	Equivalent Service
30	Short period of service life
60	Average period of service life
90	Long period of service life

3. Results and Discussion

3.1. Effect of adding polycarbonate

The effect of adding polycarbonate to the glass at 5%, 10%, and 15% on the impact values, compression ratio, and the modulus elasticity of the glass is presented in Figs. 3-5, respectively. Graphically, Fig. 3 shows that the impact values reached its maximum of 7.23 J/m at 5%-polycarbonate addition. This represents an enhancement of about 21.9% compared to the normal glass. This increase is consistent with the findings of Girish and Manjunath [25]. As the polycarbonate increased, the impact values decreased significantly recording a decrease of about 41.8% from the highest value. The decrease in the impact strength was observed with increasing glass fibre amount; this is due to the lower critical length of glass fibre [26]. As the polycarbonate percentage increased further, the impact strength decreased slightly reaching the saturation level of the polycarbonate effect.

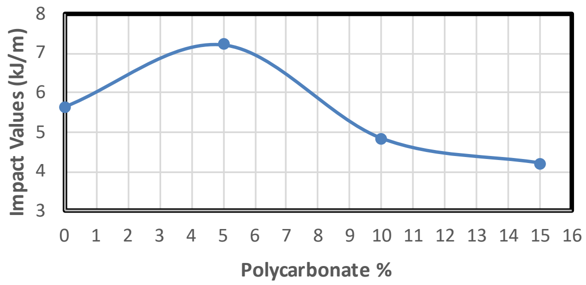


Fig. 3. Impact resistance values at different volume fraction polycarbonate.

The second test was performed to evaluate the compression strength for different volumetric fractions of samples before and after polycarbonate addition as shown in Table 2. Figure 4 shows the compression strength at different volume fraction polycarbonate indicates that at a polycarbonate percentage of 5%, the supported glass has shown the maximum compression at 96.55 MPa which is higher than free-supported-glass by 12.6%. The increase in the compression reflects that the maximum of the bulk can bear the polymeric materials against the external stress on the interstitial material [13]. However, beyond this percentage, the compression is deteriorated by 20.6% at 10% polycarbonate and 25.8% at 15% polycarbonate because of the amount of tolerance is inversely proportional to the increase in volumetric fracture [13].

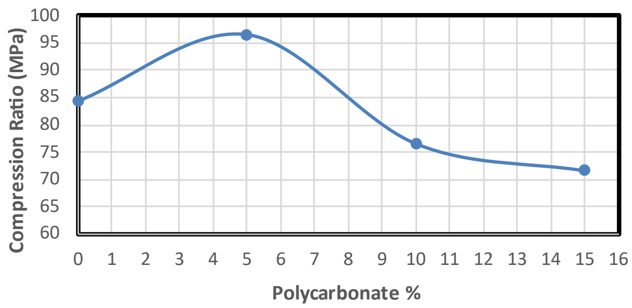


Fig. 4. The compression strength at different volume fraction polycarbonate.

Table 2. The effect of polycarbonate on mechanical properties.

No.	Polycarbonate Added %	Impact Values (kJ/m)	Compression Ratio (MPa)	Modulus Elasticity (GPa)
1	0	5.64	84.34	5.21
2	5	7.23	96.55	6.04
3	10	4.84	76.59	4.76
4	15	4.21	71.64	4.29

The third test is to investigate the modulus elasticity of the normal glass and the reinforced glass as shown in Fig. 5. The modulus of the non-supported glass was found to 5.21 GPa. As 5% polycarbonate was added to the glass, the modulus increased to 6.04 GPa (16%) and then decreased to 4.76 GPa (21.2%) at 10% and further to 4.29 GPa (28.9%) at 15% polycarbonate. The increase followed by a decrease has a similar trend as it was reported for the impact values and compression ratio shown in Figs. 4 and 5. This behaviour depends on the cohesion energy of the internal layer because of the presence of polarized groups in these polymers [7].

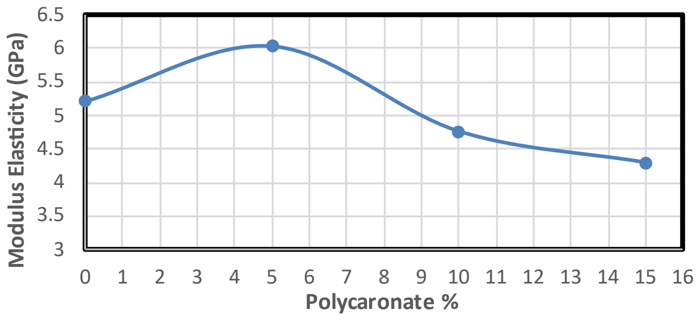


Fig. 5. The modulus of elasticity values at different volume fraction polycarbonate.

3.2. The effect of UV exposure

A set of experiments to investigate the effect of UV exposure at 30 h, 60 h, and 90 h on the three measured parameters of impact values, compression ratio, and modulus elasticity. The test was carried out on the samples that have shown the maximum effect of adding polycarbonate to the glass which occurred at the 5%-polycarbonate reinforced as shown in Figs. 3-5. The reason for considering these samples was because samples are experiencing the maximum effect on the three parameters of impact values, compression ratio, and modulus elasticity.

The first investigation was performed to investigate the effect of UV exposure on the impact values of the 5%-polycarbonate enforced sample as presented in Fig. 6. The sample was treated with UV radiation for the exposure period which was characterized as short (30 h), medium (60 h), and long (90 h). The results showed that the impact resistance has been deteriorated slightly after 30 h (3%); however, after 60 h, the impact resistance was lowered by 24% and the after 90 h treatment it became 36% compared to untreated sample.

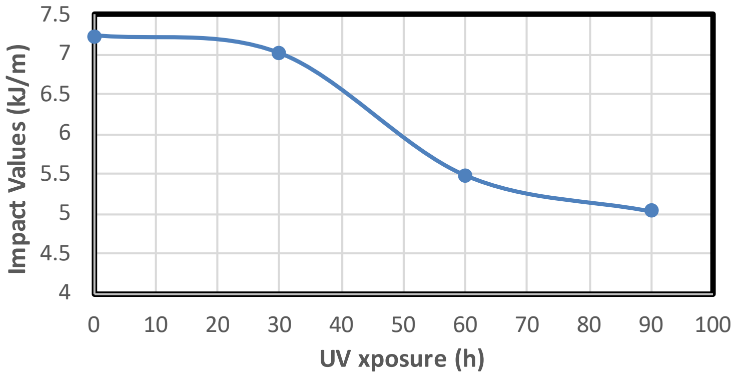


Fig. 6. The impact resistance values at different time of exposure radiation.

The second investigation was performed to show the effect of UV exposure on the compression strength of the 5%-polycarbonate enforced sample as it is explained in Table 3 and corresponding Fig. 7. The sample was treated with UV radiation for the exposure period which was characterized as short (30 h), medium (60 h), and long (90 h). The results shows that the compression strength reached its maximum at 112 MPa after about 30 h UV exposure showing enhancement by 18%. The compression strength then decreases reaching 107 MPa after 60 h and 102 MPa after 90 h of UV exposure. However, the compression strength was still higher than the original value of that without UV treatment.

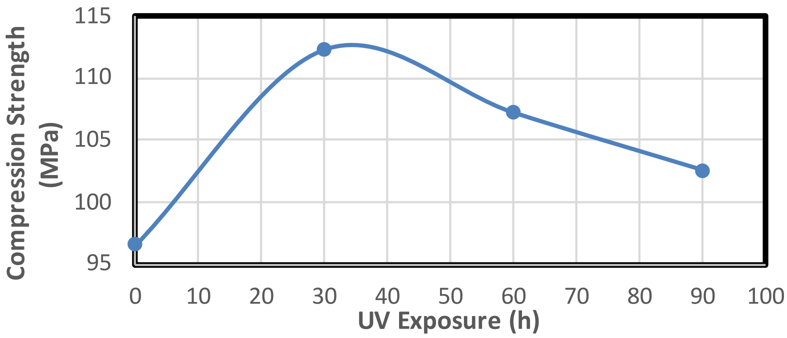


Fig. 7. The compression strength values at different time of exposure radiation.

The third investigation was performed to show the effect of UV exposure on the modulus of elasticity of the 5%-polycarbonate enforced sample as explained in Table 3 and corresponding Fig. 8. The sample was treated with UV radiation for the exposure period which was characterized as short (30 h), medium (60 h), and long (90 h). The results showed that the modulus of elasticity has increased to 6.27 GPa (enhanced by 3%) and has reached the maximum of 6.99 GPa after 60 h *UV* exposure showing enhancement of about 16% compared to the original non-*UV* treated sample. The modulus of elasticity reached almost the same as the original modulus of elasticity after 90 h UV treatments.

Table 3. The effect exposure period of radiation on mechanical properties.

No.	Exposure Status	UV Exposure (h)	Impact values (kJ/m)	Compression Strength (MPa)	Modulus of Elasticity (GPa)
1	None	0	7.23	96.55	6.04
2	Short Period	30	7.01	112.36	6.27
3	Medium Period	60	5.49	107.24	6.99
4	Long Period	90	5.04	102.60	6.03

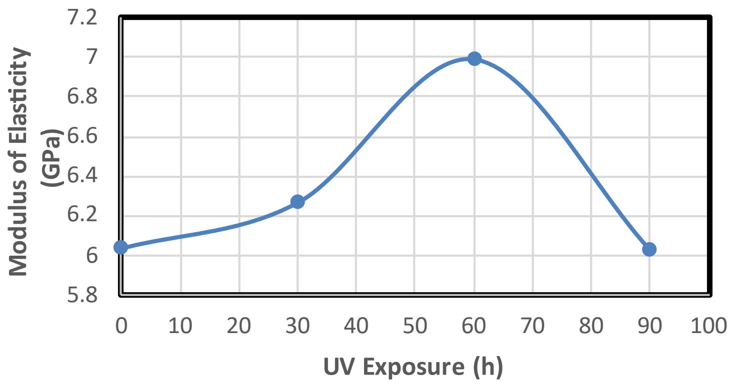
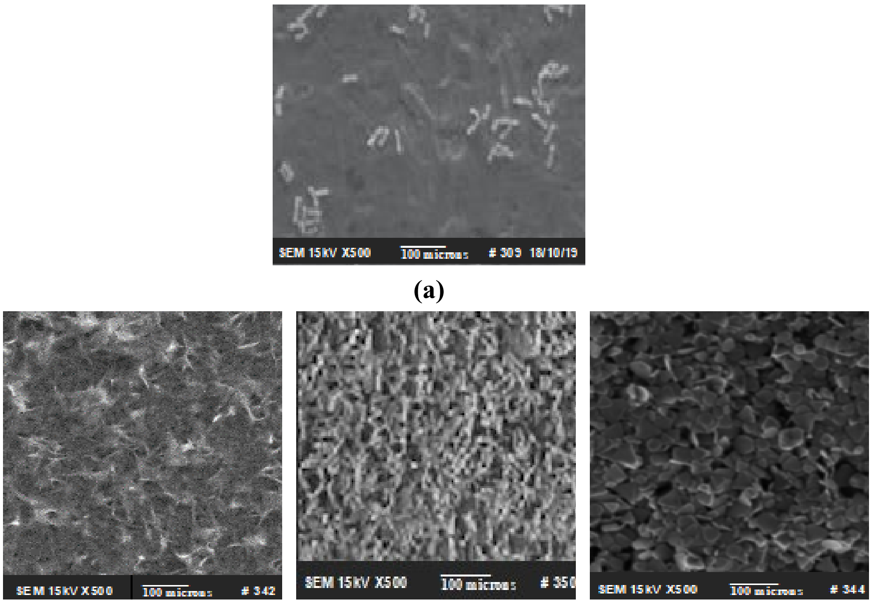


Fig. 8. The modulus of elasticity values at different time of exposure radiation.

3.3. SEM investigation

The surface morphology of the glass, glass-polycarbonate composites, and the samples after UV-exposure treatment was investigated by SEM. Figures 9(a)-9(d) shows the surface morphology of the glass plate, the glass-5% polycarbonates, the glass-10% polycarbonates, and the glass-15% polycarbonates, respectively. All images were taken at room temperature either for pure glass or immediately after the glass was laminated with polycarbonates at 5%, 10%, and 15% volume fraction. The pure glass surface shows traces of some impurities which might come during the preparation of the glass. However, the polycarbonates, which is a resin, can be seen on the surface of the glass. The amount of polycarbonates increases or becomes denser as the volume fraction of the polycarbonates increases. The surface of the glass treated with polycarbonates does not look smooth; it is rather microscopically a coarse surface.

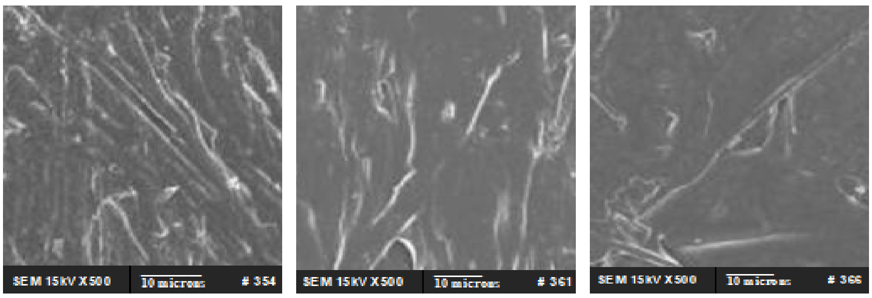
SEM investigation for the surface morphology was carried out by taking the sample of 5% polycarbonates-glass composite shown in Fig. 9(b) which was exposed to 30 h, 60 h, and 90 h. The polycarbonates resin is considered resistive to UV radiation [27]. However, prolonged UV radiation may cause molecular degradation, colour change, and rupture of covalent bonds initiating photo-oxidation and photo-Fries reactions [28]. For this reason, it is expected that other higher-polycarbonates volume fractions behave similarly and no reason to test the morphology of each of the nine samples. SEM images for the 5% polycarbonate-glass composite are shown in Figs. 10(a)-10(c) for UV exposure of 30 h, 60 h, and 90 h, respectively. It seems that the surface has become smoother as the UV exposure increases. This observation might reflect the heat developed by UV during this long period. The heat could be enough to slightly melt the polycarbonate resin and made the surface smoother. *SEM* image for the surface after 60 h and 90 h also shows smoother surface because of more hear developed during the UV exposure.



(a)

(b) **(c)** **(d)**

Fig. 9. SEM image (a) Original; (b) 5% polycarbonates; (c) 10% polycarbonates; and (d) 15% polycarbonates.



(a) **(b)** **(c)**

Fig. 10. SEM images of 5% polycarbonate after UV exposure for (a) 30 h; (b) 60 h; and (c) 90 h.

4. Conclusions

A glass manufactured according to ASTM C1172 and ISO 1253 was used to prepare a composite double layer by inserting a resin of polycarbonates at 5%, 10%, and 15% volume fraction to enhance the mechanical properties of the windshield for automobiles. The main purpose of the study was to increase the safety of the automobiles' windshield without affecting its transparency as visually observed. The mechanical test was carried out to investigate the impact value, compression test, and modulus of elasticity. The preparation of the samples and the relevant tests were performed according to ASTM and corresponding ISO standards. The effect of adding a layer of polycarbonates between the two-glass layers at a volume fraction of 5%, 10%, and 15% was tested. The results have shown that the 5%-polycarbonates has the maximum effect by enhancing the mechanical parameters by 21.9%, 12.6%, and 15.9%, respectively. The effect of UV exposure was also investigated by considering those samples of the maximum effect at 5% polycarbonates. The UV exposure was tested after 30 h, 60 h, and 90 h. The results showed that the mechanical parameters behaved differently. The impact value was deteriorated by 3%, 24%, and 35% after exposure of 30 h, 60 h, and 90 h, respectively. The compression strength and modulus of elasticity were enhanced by 17% after 30 h exposure while the modulus enhanced by 16 % after 60 h exposure. SEM images have shown that UV effect caused better smoothness as the UV radiation increased from 30 h to 90 h.

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