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# Polystyrene Waste Treatment Using Zinc Oxide Nanocomposite

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**ABSTRACT**— In this research, a polymeric composite material with a polystyrene basis reinforced with zinc oxide (ZnO) nanoparticles was manufactured at a percentages of (5, 10, 15, 20 and 25%). Samples were subjected to the surface hardness, Flexural strength tests to identify their ability to endure the thermophysical effect (T= 40, 60 and 80C°) and in specified periods of time (3, 6 and 9 hours). Results showed that an increase in the values of surface hardness and flexural strength when adding ZnO nanomaterial to the polystyrene with a concentration of 20% and temperature of 80 Cº according to the control treatment. From the other hand, the values began to decrease when the percentage of the ZnO nanoparticles to 25%. These values differed with the difference in the temperature of the sample treatment and also with the period of the exposure of the samples to the thermophysical effect. Results of X-ray diffraction spectrum and Scanning Electron Microscopy images showed the beginning of decomposition of polystyrene reinforced with ZnO nanoparticles with a concentration of 20% under a temperature of 60 Cº.

**KEYWORDS:** Polystyrene, ZnO nanoparticles, Mechanical properties, X- Ray diffraction, Scanning Electron Microscope

## 1. INTRODUCTION

Plastic is long chains of organic polymers with high molecular weight and each one of them is called the monomer. The essential element in them is carbon and also it. Contains hydrogen and other elements that differ according to the type of the plastic as nitrogen, chlorine, oxygen and others [1]. The polystyrene is considered one of the homogeneous polymers that is thermoplastic and it is characterized by easy manufacturing, coloring and adaptability [2]. Due to the good mechanical properties of the polystyrene and its relatively low cost of its manufacture, it is widely used in many industrial fields. The wastes of the polystyrene takes hundreds of years to decompose and they are resistant to photooxidation [3], as a result, the plastic materials manufactured from the polystyrene, accumulated in the environment, causing pollution of environment and health problems to humans in addition to changes in the ecosystem due to its toxic and difficulty in decomposing [4]. The polystyrene is considered a carcinogen according to the reports of the international agency of cancer researches [5]. Studies revealed that the nanoparticles play an important role in supporting the decomposition of plastic materials and this aspect depends on the ability of the nanomaterials to change the physical and chemical properties of polymers [6], and this change in the properties made the plastic more susceptible to decompose by thermal and photo oxidation or the biodegradation. Therefore, the nanotechnology can be employed as an alternative that can contribute to restoring the plastic wastes and recycling them or changing their properties to make them more susceptible to be decomposed by the environmental effects and consequently the problem of plastic wastes accumulation in the environment is solved [7]. Nevertheless, the number of nano compounds integrated with the recycled plastic wastes after use or adding these compounds during the manufacture of the plastic is extremely small.

## 2. Objective

Due to the importance of the issue, the study aims at the following:

1. Studying the mechanical properties (hardness and flexural strength) of polystyrene reinforced with zinc oxide nanoparticles.
2. Using the X-Ray diffraction and Scanning Electron Microscope to analyze the results

## 3. MATERIALS AND METHODS

### *3.1 Samples preparation*

The disposable transparent plastic cups, which are made of polystyrene(PS) as a substrate. Zinc oxide (ZnO) was used as a nanomaterial to reinforce the polystyrene material with weight percentages (5, 10, 15, 20 and 25%), also, similar cups without any addition were used (control treatment). In order to fabrication samples, we used aluminum plates in the form of template with a thickness of (1mm) and the dimensions of the samples are (120×10×10mm). Zinc oxide nanoparticles were mixed with the pieces of the chopped plastic cups thoroughly until the mix becomes in a uniform state. Then the mix is heated with continuous stirring until it melts and then it is poured in templates, and the samples were treated superficially after the casting and drying process to ensure dimensional control using the smoothing papers from Silicon carbide type and granular sizes{(400,1000,2000)# } respectively.

### *3.2 Treatment with the thermophysical effect*

The samples manufactured from the polystyrene and reinforced by the ZnO nanomaterial were put in a German-made electrical oven type Dinder. The samples were subjected to specific degrees of temperature (T=40, 60 and 80 C°) for different periods of time (3, 6 and 9 hours).

### *3.3 Hardness*

The hardness of the samples was measured using the Japanese-made device (Shore Durometer) type (N. S. S.). this device determines the hardness value of the sample by means of creating a piercing by means of a needle on the sample surface, then the device records the reading directly [8].

### *3.4 Flexural strength*

The Flexural strength of the samples was measured using Hi-Tech British company device. The amount of the resistance of each sample to the constant loads posed on it. The value of the load that leads to the failure of the sample was recorded (the breaking of the sample) and then the value of the stress that results in breaking the sample is calculated using the following equation [9]:

$$\text{Max. bending stress } (\sigma) = PL / Z = 6\,P\,L / b\,t^2 = 1.2\,P$$

### *3.5 X-Ray Diffraction (XRD)*

The XRD device was used to study the crystal nature of the material by means of the reaction of the electromagnetic waves with the crystal structures that cause the diffraction of these waves that do have wavelengths that are approximate to distances between the atoms in the crystal [10].

### *3.6 Scanning Electron Microscopy(SEM)*

Photographs of topographic were taken to the surface of the polystyrene material reinforced by ZnO nanoparticales and treated with a temperature of 60 C° for 9 hours using the Scanning Electron Microscope [11].

## 4. RRSULTS AND DISCUSSION

### *4.1 Hardness Test*

Data in figures (1, 2 and 3) refer to the variations in the values of surface hardness of the samples made from the polystyrene according to the variation in the weight ratios of the ZnO nanomaterial added and the variation in the time periods and the temperatures.

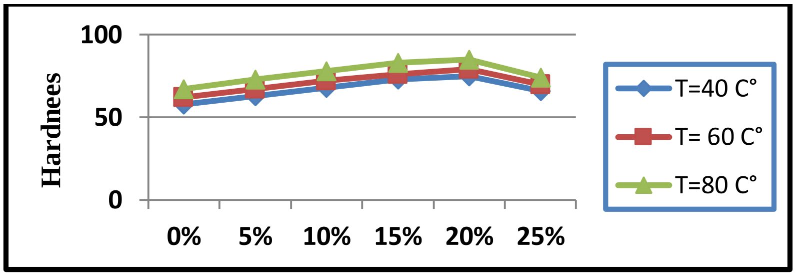

**Figure (1):** The hardness of the prepared samples as a function of the percentage of nanoparticles addition of ZnO for a 3 hour heat treatment.

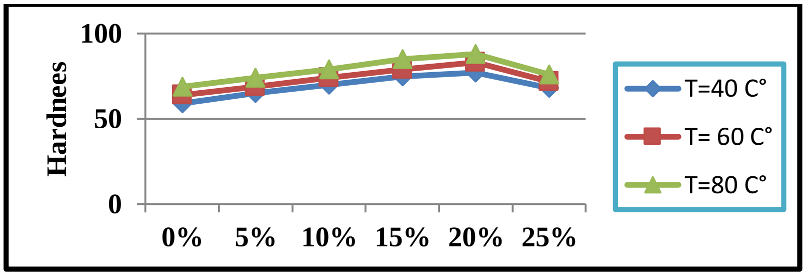

**Figure (2):** The hardness of the prepared samples as a function of the percentage of nanoparticles addition of ZnO for a 6 hour heat treatment.

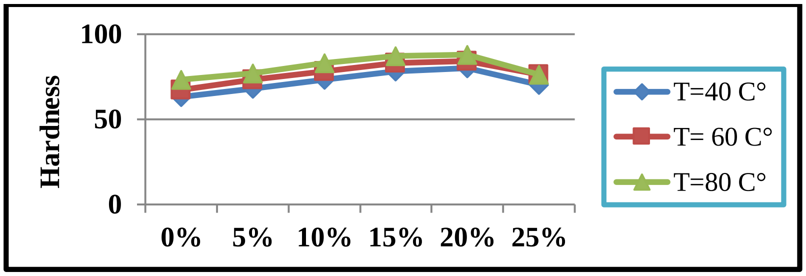

**Figure (3):** The hardness of the prepared samples as a function of the percentage of nanoparticles addition of ZnO for a 9 hour heat treatment.

The weight percentage (20%) of ZnO added recorded the highest hardness in 80 C° for 9 hours, valued at 88N/mm$^2$compared to the polystyrene that is not reinforced with the nanomaterial(73N/mm$^2$), this is due to the homogeneous diffusion of nanoparticles inside the substrate of polystyrene at this temperature. Also it is noticed that the hardness decreased when the concentration of the nanomaterial was increased to be 25% for all the treatment. To explain the change of the hardness values of the different samples, we should refer to the definition of hardness, which refers to the ability of the material to resist creating an effect on its surface, this is due to the nature of cohesion, adhesion and surface tension resulting from the viscosity and density of these material, in addition to the diffusion of the nanomaterial uniformly inside the essential material at those temperature degrees causing a uniform surface with free from manufacturing defects such as holes and cracks, with a dense distribution of the polymer that is equal in all the areas of the surface. All this makes this material characterized with resistance to specific temperatures. The materials have the ability to contain the thermophysical effect, that is, there are values of effects that these materials can deal with and that the range higher than that will have a negative impact causing the reduction of these values. This might be due to the increase of the nanomaterial agglomeration, which can't resist the penetration of the substances which are characterized with more hardness [12].

### *4.2 Flexural strength test*

From the figures (4, 5 and 6), it is showed that the flexural strength of the polystyrene reinforced with ZnO nanomaterial was higher than the control treatment (unreinforced with ZnO nanomaterial).

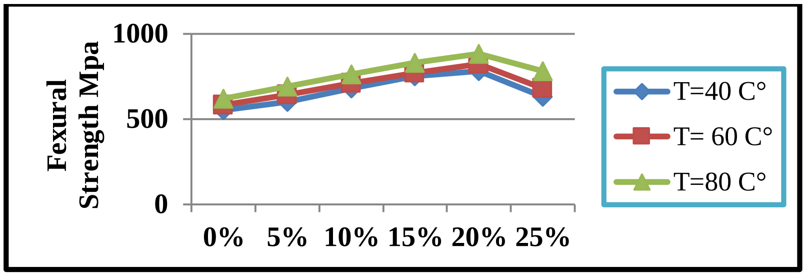

**Figure (4):** The Fexural strength of the prepared samples as a function of the percentage of nanoparticles addition of ZnO for a 3 hour heat treatment.

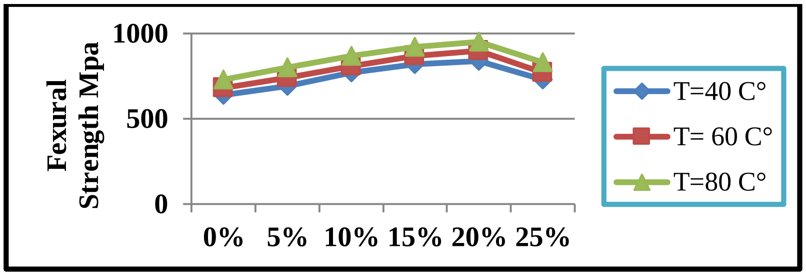

**Figure (5):** The Fexural strength of the prepared samples as a function of the percentage of nanoparticles addition of ZnO for a 6 hour heat treatment.

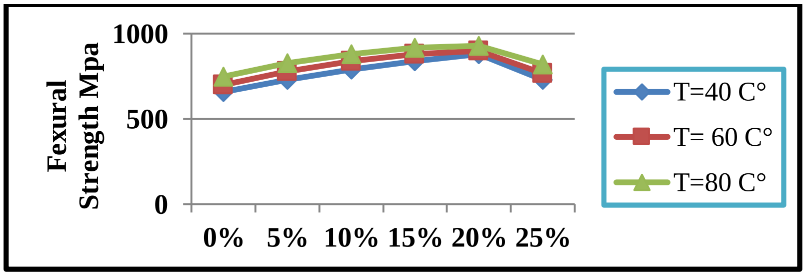

**Figure (6):** The Fexural strength of the prepared samples as a function of the percentage of nanoparticles addition of ZnO for a 9 hour heat treatment.

The highest flexural strength was obtained when adding the nanomaterial with a percentage of 20% as the flexural strength value was 950 Mpa at a temperature of 80 C° for 6 hours. Also it is noticed that the flexural strength decreased when the concentration of the nanomaterial was increased to be 25% for all the treatment. The reason behind the increase of the flexural strength to 20% and increasing the exposure time period to the temperature to be 6 hours is the ability of the material, under these conditions, to create a state of balance between the tension, compression and shear factors during the applying the load. This balance continues to a certain extent depending on the material and condition. As for the treatment with ZnO nanomaterial, the increase of exposure period to 9 hours led to a decrease in the values of flexural strength, i.e. the material loses its ability to maintain continuity due to the separation of the polymeric chains, thus the state of equilibrium between three factors decreases, and this, in turn, causes the material undergo load and thus bend [13]. Increasing the temperature of the polystyrene reinforced by ZnO nanomaterial increased the potential of the nanomaterial to create holes and cracks in the matrix in addition to its ability to absorb more oxygen compared to the low concentrations, releasing more free radicals like hydrogen peroxide, which attack the polymer chains and cause the internal decomposition of the matrix. In this case, the decomposition of plastic will be quicker when it is exposed to various environmental conditions [14].

### *4.3 X-Ray Diffraction analysis*

In figure (7), analyzing the X-ray spectrum of the samples prepared from the polystyrene (control treatment) can be observed.

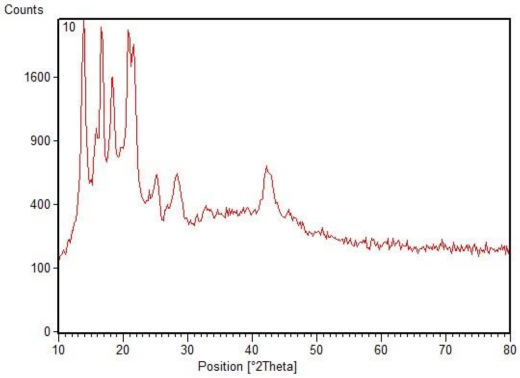

**Figure (8):** X-ray spectrum of the polystyrene

| Peak Search Report (11 Peaks, Max P/N = 22.6) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [1162AR#10#20220330-084747_200.mdi] XRD SSC 30KV/20mA Slit:1deg&1deg&.2mm Monochromator: ON Ts-Td 200 | | | | | | | | |
| PEAK: 13-pts/Parabolic Filter, Threshold=3.0, Cutoff=0.1%, BG=3/1.0, Peak-Top=Summit | | | | | | | | |
| 2-Theta | d(nm) | BG | Height | I% | Area | I% | FWHM | XS(nm) |
| 13.825 | 0.64002 | 201 | 2219 | 100 | 9483 | 71.1 | 0.727 | 11 |
| 16.623 | 0.53286 | 240 | 2054 | 92.6 | 10373 | 77.8 | 0.859 | 9 |
| 18.359 | 0.48285 | 260 | 1338 | 60.3 | 7607 | 57.1 | 0.967 | 8 |
| 20.848 | 0.42574 | 281 | 1972 | 88.9 | 13331 | 100 | 1.149 | 7 |
| 25.166 | 0.35358 | 307 | 302 | 13.6 | 1700 | 12.8 | 0.957 | 8 |
| 28.374 | 0.31429 | 316 | 301 | 13.6 | 1997 | 15 | 1.128 | 7 |
| 32.821 | 0.27265 | 316 | 81 | 3.7 | 422 | 3.2 | 0.886 | 9 |
| 36.255 | 0.24757 | 307 | 73 | 3.3 | 218 | 1.6 | 0.508 | 16 |
| 38.611 | 0.23299 | 298 | 84 | 3.8 | 646 | 4.8 | 1.307 | 6 |
| 42.211 | 0.21391 | 280 | 403 | 18.2 | 3329 | 25 | 1.404 | 6 |
| 45.618 | 0.1987 | 259 | 114 | 5.1 | 540 | 4.1 | 0.805 | 10 |

From the previous figure, it is noticed that there are linear spectra with high peaks at the angles with values of (13°, 16°, 18° and 20°) and these peaks are the dominant ones on the values of the linear spectrum values. Moreover, there are some peaks at the angles (25° - 45°), which are considered weak peaks that don't represent a big participation in the structure of the spectrum structure and also don't represent a secondary phase of basic peaks due to the absence of a uniformity in the shape of the peak. It is noticed that the end of the spectrum is the end of the rear and its height and it means that there is no reorganization in the crystallization and this means no mono properties.

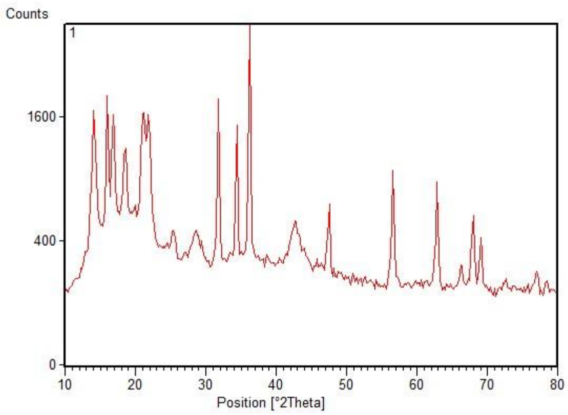

**Figure (9):** X-ray spectrum of the polystyrene reinforced with ZnO nanomaterial (20%)at 40C° for 9 hours.

| Peak Search Report (18 Peaks, Max P/N = 25.9) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [1162AR#1#20220330-075223_200.mdi] XRD SSC 30KV/20mA Slit:1deg&1deg&.2mm Monochromator: ON Ts-Td 200 | | | | | | | | |
| PEAK: 11-pts/Parabolic Filter, Threshold=3.0, Cutoff=0.1%, BG=3/1.0, Peak-Top=Summit | | | | | | | | |
| 2-Theta | d(nm) | BG | Height | I% | Area | I% | FWHM | crystal Size XS (nm) |
| 14.036 | 0.63042 | 148 | 1528 | 53.7 | 7486 | 73.1 | 0.833 | 9 |
| 16.007 | 0.55323 | 151 | 1724 | 60.6 | 4884 | 47.7 | 0.482 | 17 |
| 18.573 | 0.47733 | 155 | 1063 | 37.4 | 6257 | 61.1 | 1.001 | 8 |
| 21.203 | 0.41868 | 158 | 1489 | 52.3 | 10238 | 100 | 1.169 | 6 |
| 25.384 | 0.35059 | 162 | 311 | 10.9 | 2511 | 24.5 | 1.373 | 5 |
| 28.603 | 0.31182 | 165 | 302 | 10.6 | 2823 | 27.6 | 1.589 | 5 |
| 31.747 | 0.28162 | 167 | 1662 | 58.4 | 4177 | 40.8 | 0.427 | 19 |
| 34.375 | 0.26067 | 168 | 1324 | 46.5 | 3427 | 33.5 | 0.44 | 19 |
| 36.205 | 0.2479 | 169 | 2845 | 100 | 6104 | 59.6 | 0.365 | 23 |
| 42.603 | 0.21204 | 170 | 371 | 13 | 2866 | 28 | 1.313 | 6 |
| 47.499 | 0.19126 | 170 | 500 | 17.6 | 1495 | 14.6 | 0.508 | 17 |
| 56.553 | 0.1626 | 165 | 817 | 28.7 | 1697 | 16.6 | 0.353 | 26 |
| 62.797 | 0.14785 | 160 | 711 | 25 | 1495 | 14.6 | 0.357 | 27 |
| 66.263 | 0.14093 | 156 | 105 | 3.7 | 305 | 3 | 0.494 | 19 |
| 67.918 | 0.13789 | 154 | 424 | 14.9 | 1166 | 11.4 | 0.468 | 21 |
| 69.019 | 0.13596 | 152 | 267 | 9.4 | 639 | 6.2 | 0.407 | 24 |
| 72.517 | 0.13024 | 147 | 44 | 1.5 | 113 | 1.1 | 0.437 | 23 |
| 76.929 | 0.12383 | 140 | 86 | 3 | 239 | 2.3 | 0.472 | 22 |

It is noted from figure(9) the appearance of the background of ZnO nanomaterial is almost lower than the substrate(polystyrene),and the reason of the presence of the nanomaterial with the composition of the base material around a part of the continuous spectrum into a linear spectrum, which led to the appearance of peaks at the sites, which in turn was reflected in the reduction of the background and emergence of peaks that were originally hidden, it belongs to the substrate and not to the ZnO nanoparticles. When comparing the peaks of the ZnO nanomaterial, we note that the nanomaterial has very crystallization sites. Also it is noticed that the peaks of the substrate remained fixed in their position, which means that the material work as a single system.

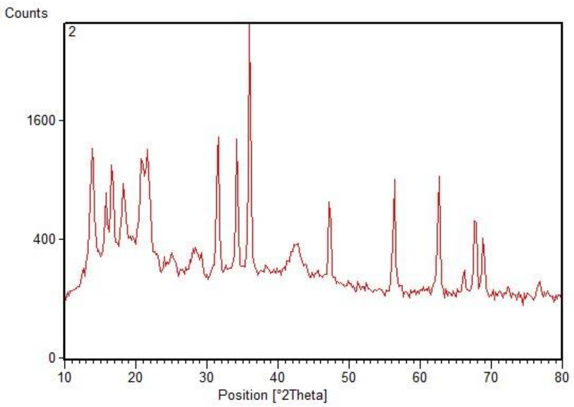

**Figure (10):** X-ray spectrum of the polystyrene reinforced with ZnO nanomaterial (20%) at 60C° for 9 hours.

| Peak Search Report (18 Peaks, Max P/N = 27.1) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [1162AR#2#20220330-075710_200.mdi] XRD SSC 30KV/20mA Slit:1deg&1deg&.2mm Monochromator: ON Ts-Td 200 | | | | | | | | |
| PEAK: 11-pts/Parabolic Filter, Threshold=3.0, Cutoff=0.1%, BG=3/1.0, Peak-Top=Summit | | | | | | | | |
| 2-Theta | d(nm) | BG | Height | I% | Area | I% | FWHM | XS(nm) |
| 13.83 | 0.63976 | 114 | 1129 | 36.9 | 4808 | 72.4 | 0.724 | 11 |
| 16.612 | 0.5332 | 117 | 946 | 30.9 | 4732 | 71.3 | 0.85 | 9 |
| 18.23 | 0.48624 | 118 | 744 | 24.3 | 4089 | 61.6 | 0.934 | 8 |
| 21.568 | 0.41168 | 122 | 1116 | 36.5 | 6640 | 100 | 1.011 | 8 |
| 25.022 | 0.35557 | 124 | 191 | 6.2 | 1615 | 24.3 | 1.437 | 5 |
| 28.384 | 0.31418 | 126 | 220 | 7.2 | 2006 | 30.2 | 1.55 | 5 |
| 31.529 | 0.28352 | 128 | 1259 | 41.2 | 3487 | 52.5 | 0.471 | 17 |
| 34.18 | 0.26211 | 129 | 1229 | 40.2 | 3213 | 48.4 | 0.444 | 19 |
| 35.988 | 0.24935 | 129 | 3057 | 100 | 5662 | 85.3 | 0.315 | 28 |
| 38.222 | 0.23528 | 129 | 115 | 3.8 | 893 | 13.4 | 1.32 | 6 |
| 42.762 | 0.21129 | 129 | 245 | 8 | 2071 | 31.2 | 1.437 | 6 |
| 47.231 | 0.19228 | 128 | 567 | 18.5 | 1634 | 24.6 | 0.49 | 18 |
| 56.339 | 0.16317 | 123 | 784 | 25.6 | 1646 | 24.8 | 0.357 | 26 |
| 62.589 | 0.14829 | 117 | 823 | 26.9 | 1649 | 24.8 | 0.341 | 28 |
| 66.178 | 0.14109 | 113 | 104 | 3.4 | 305 | 4.6 | 0.499 | 19 |
| 67.684 | 0.13832 | 111 | 425 | 13.9 | 1192 | 18 | 0.477 | 20 |
| 68.798 | 0.13634 | 109 | 301 | 9.8 | 710 | 10.7 | 0.401 | 24 |
| 76.725 | 0.12411 | 97 | 69 | 2.3 | 230 | 3.5 | 0.567 | 18 |

It is clear from the data in figure (10) that all the observations that were recorded in the sample of the polystyrene at 40C° appeared in the sample at 60° and the only observations is the emergence of a deformation in the spectrum at the angles 24° and 78°. This shows that the matrix began to decompose with the presence of the nano material at 60 C° because the increase in temperature with the presence of the nano material caused looseness in the bonds between the particles of the matrix and this gives an opportunity to absorb part of the energy causing deformation in the spectrum.

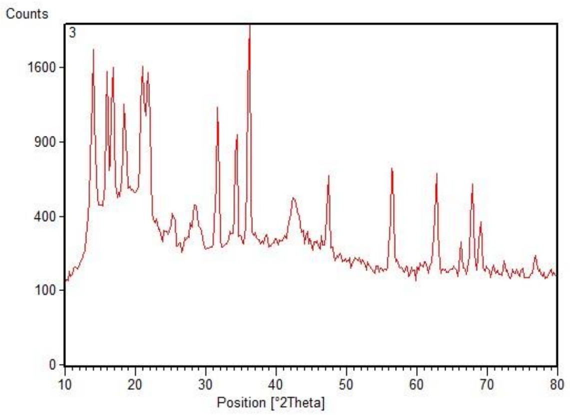

**Figure (11):** X-ray spectrum of the polystyrene reinforced with ZnO nanomaterial (20%) at 80C° for 9 hours.

<table>
<tr><th colspan="9">Peak Search Report (16 Peaks, Max P/N = 21.1)</th></tr>
<tr><th colspan="9">[1162AR#3#20220330-080129_200.mdi] XRD SSC 30KV/20mA Slit:1deg&1deg&.2mm Monochromator: ON Ts-Td 200</th></tr>
<tr><th colspan="9">PEAK: 11-pts/Parabolic Filter, Threshold=3.0, Cutoff=0.1%, BG=3/1.0, Peak-Top=Summit</th></tr>
<tr><th>2-Theta</th><th>d(nm)</th><th>BG</th><th>Height</th><th>I%</th><th>Area</th><th>I%</th><th>FWHM</th><th>XS(nm)</th></tr>
<tr><td>13.98</td><td>0.63293</td><td>142</td><td>1660</td><td>85.8</td><td>6717</td><td>80.2</td><td>0.688</td><td>11</td></tr>
<tr><td>16.775</td><td>0.52808</td><td>148</td><td>1451</td><td>75</td><td>5483</td><td>65.4</td><td>0.642</td><td>12</td></tr>
<tr><td>18.419</td><td>0.48128</td><td>151</td><td>1085</td><td>56.1</td><td>5953</td><td>71.1</td><td>0.933</td><td>8</td></tr>
<tr><td>21.031</td><td>0.42206</td><td>156</td><td>1455</td><td>75.2</td><td>8378</td><td>100</td><td>0.979</td><td>8</td></tr>
<tr><td>25.23</td><td>0.3527</td><td>162</td><td>252</td><td>13</td><td>1390</td><td>16.6</td><td>0.938</td><td>8</td></tr>
<tr><td>28.43</td><td>0.31368</td><td>167</td><td>297</td><td>15.4</td><td>2461</td><td>29.4</td><td>1.409</td><td>5</td></tr>
<tr><td>31.616</td><td>0.28276</td><td>170</td><td>1031</td><td>53.3</td><td>3061</td><td>36.5</td><td>0.505</td><td>16</td></tr>
<tr><td>34.327</td><td>0.26102</td><td>173</td><td>787</td><td>40.7</td><td>2755</td><td>32.9</td><td>0.595</td><td>14</td></tr>
<tr><td>36.124</td><td>0.24844</td><td>174</td><td>1934</td><td>100</td><td>4832</td><td>57.7</td><td>0.425</td><td>20</td></tr>
<tr><td>42.419</td><td>0.21291</td><td>177</td><td>331</td><td>17.1</td><td>2735</td><td>32.6</td><td>1.405</td><td>6</td></tr>
<tr><td>47.381</td><td>0.19171</td><td>177</td><td>475</td><td>24.6</td><td>1641</td><td>19.6</td><td>0.587</td><td>15</td></tr>
<tr><td>56.432</td><td>0.16292</td><td>173</td><td>530</td><td>27.4</td><td>1363</td><td>16.3</td><td>0.437</td><td>21</td></tr>
<tr><td>62.725</td><td>0.148</td><td>167</td><td>496</td><td>25.6</td><td>1232</td><td>14.7</td><td>0.422</td><td>22</td></tr>
<tr><td>67.801</td><td>0.1381</td><td>160</td><td>434</td><td>22.4</td><td>1009</td><td>12</td><td>0.395</td><td>25</td></tr>
<tr><td>68.968</td><td>0.13605</td><td>158</td><td>214</td><td>11.1</td><td>518</td><td>6.2</td><td>0.411</td><td>24</td></tr>
<tr><td>76.8</td><td>0.12401</td><td>143</td><td>72</td><td>3.7</td><td>219</td><td>2.6</td><td>0.517</td><td>20</td></tr>
</table>

It is noted from figure (11) that there is a distortion in the spectrum that has increased in different regions, and that this distortion has increased in different regions, and this distortion has increased in clarity with the increase in temperature to 80C°. It noted that there are a kind of peaks that arose in different region and locations and this means that the substrate began to decompose to show locations of elements that were not it was present neither in the substrate nor in the ZnO nanomaterial [15].

### *4.4 Scanning Electron Microscopic Test*

In figure (12-A, B) we observe the images of the SEM of the samples prepared from the polystyrene (control treatment) and the sample of the polystyrene that is reinforced with ZnO nanomaterial with a concentration of 20% at 60 C°.

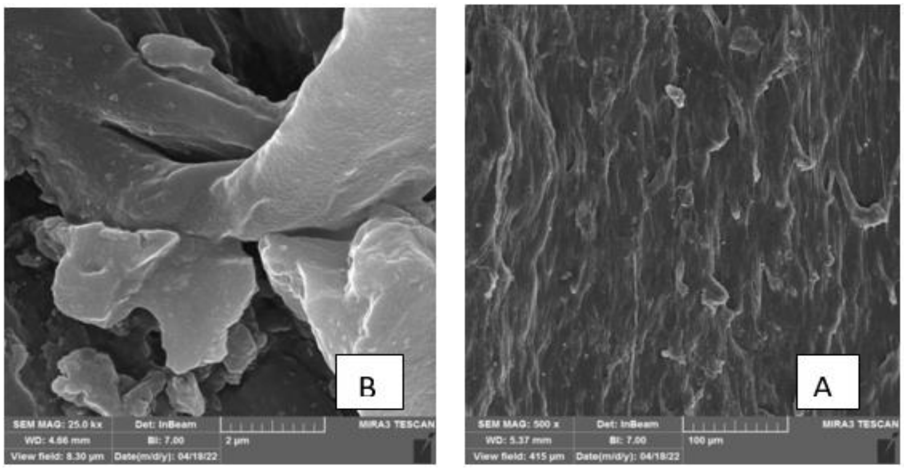

**Figure (12):** SEM images of polystyrene substrate (A) and treatment of polystyrene with ZnO nanomaterial(B).

It is noticed the emergence of short linear chains with side branches that may not a connection with other chains, it appears in the form of a semi-regular surface free of cavities, which is characterized by a directional structure to some extent and for this reason the inertness of the material (Fig: 12A), which differed when adding the nanomaterial (ZnO) to polystyrene (Fig:12B). It is observed that there is a continuous structure for a certain distance that is considered a long distance with the presence of separate structures above and below this structure. This means that the surface energy of nano ZnO is a very high surface energy that formed a continuous geometric structure and that what appeared from this structure did not appear completely because there are some connections between the basic and the secondary structures. The addition of nano ZnO to the polystyrene led to the weakness of the material cohesion and losing the cohesion properties, which makes it less able to resist external effects and consequently becomes more sensitive material to the environment and its factors, i.e. the material become more capable for decomposition [16].

## 5. CONCLUSIONS

1- An increase in the values of surface hardness and flexural strength when adding ZnO nanomaterial to the polystyrene with 20% and temperature of 80 C$^o$.

2- Values of surface hardness and flexural strength began to decrease when the percentage of the ZnO nanoparticles to 25%.

3- X-Ray diffraction and Scanning Electron Microscope revealed that the decomposition of waste polystyrene plastics started when the nano ZnO was added at 20% under thermophysical effect.

## 6. References

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