Malaysian Journal Of Science 39(3): 54-64 (October 2020)

PREPARATION AND CHARACTERIZATION OF FLEXIBLE PLASTIC PACKAGING USING AN ACRYLIC POLYMER SOLUTION

Seenaa I. Hussein[1a*]

[a]Department of Physics, College of Science, University of Baghdad, IRAQ. E-mail: seenaaibrahem76@ scbaghdad.edu.iq[1]
Corresponding author: seenaaibrahem76@ scbaghdad.edu.iq
Received: 17th Jul 2019 Accepted: 11th Mar 2020 Published: 31st Oct 2020
DOI: https://doi.org/10.22452/mjs.vol39no3.4

ABSTRACT In this study, industrial plastic packaging was prepared from acrylic polymer doped with different weight ratios (0.1%, 0.3%, 0.5%, 0.7% and 0.9%) of zirconium dioxide (ZrO_2) nanoparticles using the casting method. The mechanical properties (including tear resistance, hardness, impact, and tensile properties), and water permeability, and antibacterial activity of the prepared acrylic polymer composites were investigated. A significant improvement in the mechanical properties of the acrylic polymer composites was observed with an increase in the weight ratio of the ZrO_2 nanoparticles. Despite this enhancement, water permeability was decreased from 10.2 to 6.2 g/m^2 per day with an increase in the weight ratio up to 0.9%. The presence of ZrO_2 increased the tear resistance of the polymer–ZrO_2 composites from 22.1 to 38.8 kN/m. The doping acrylic polymer with 0.7% of ZrO_2 leads to an increase in the hardness, impact resistance, tensile strength, and tensile modulus from 82, 1335, 12.21, and 140 MPa to 94, 1550, 30.1 and 370 MPa, respectively. Besides, the elongation break was improved from 24.3% to 12%. Moreover, antibacterial activity and the zone of inhibition values were indicated that the optimized ratio of ZrO_2 is 0.7%, which corresponds to a value of 14 mm.

Keywords: Flexible Packaging, Tear Resistance, Impact Strength, Hardness, Tensile Strength, Antibacterial Activity, Polymer Solution, ZrO_2

1. INTRODUCTION

Acrylic polymers are used mainly for paints, coatings, and plastics films as their glass transition temperatures (T_g) are lower than the ambient temperature, thereby rendering these substances very useful (Canning et al., 2017). To date, plastic packaging has been used frequently, with usage reaching a greater extent in advanced industries (Hussein et al., 2018). Conventional plastics are characterized by unique properties related to long service life and thus dominate over other materials (Ezeoha1 & Ezenwanne, 2013). They are utilized for various applications such as automobile parts, packaging, and house components. Due to their enhanced film flexibility, plastics can be used to reduce internal hydrogen bonding between polymer chains and increase molecular space (Bastioli, 2005). Generally, thermoplastic polymers are lightweight and inexpensive; therefore, such plastic materials can be modeled into various products for use in the different applications mentioned above (Grigore, 2017).

Doping polymer with other metal and metal oxides to form polymer composites could be enhancing the properties of the composites for biomedical applications. Amongst, Zirconium dioxide (ZrO_2) which is typically called ‘ceramic steel’ is suitable for dental use because it has interesting mechanical properties, such as high strength, toughness, impact resistance, wear-resistance and fatigue resistance (Bona & Oscar, 2015). Notably, doping with nanofillers is the most popular method of fabricating composites, and the associate degree addition of a touch of nanofillers in the compound matrix substantially improves the thermal and mechanical properties of base materials. The addition process influences the T_g and the physical properties, especially mechanical and thermal parameters such as toughness, stiffness, and the storage modulus (Singh et al., 2018). Composite materials are commonly defined as the combination of a matrix and additives that have at least one material with characteristics that differ from those of individual components (Hussein et al., 2019).

Harunsyah et al. (2018) studied the influence of reinforcement with clay nanoparticles at concentrations of 0.2% to 1.0% (w/w), depending on the weight of starch; on the mechanical and structural properties of some bioplastic materials synthesized using the solution casting method. Their result showed that tensile strength (T_s) significantly was improved to 24.18 MPa and that plasticizer was increased by 25% for a clay nanoparticle loaded with 0.6%. Using various techniques, Amin et al. (2019) examined some physical properties of starch and bioplastic composites to reduce plastic pollution. The authors were prepared starch bioplastics using starch vinegar and glycerol and fabricated a bioplastic composite using starch, vinegar, glycerol, and TiO_2. The addition of TiO_2 has increased the T_s of the bioplastic composite from 3.55 to 3.95 MPa, while elongation was decreased from 88% to 62%. Besides, the melting point and T_g were significantly controlled by the change in the TiO_2 ratio.

With consideration for the above-mentioned issues, this research was aimed to prepare plastic packaging and tried to improve its specifications as regards mechanical properties, barriers, and antibacterial activity by incorporating environment-friendly materials, such as ZrO_2 nanoparticles, into the packaging.

2. EXPERIMENTAL

2.1. Materials

Acrylic polymer solution or AGCC was obtained from a product manufacturer in the UAE and ZrO_2 or zirconia nanoparticles were purchased from Sigma Aldrich (Germany).

Particle size was determined via atomic force microscopy (AFM) using an atomic force microscope connected to a scanning probe microscope (SPM). The particle size distribution and surface morphology of ZrO_2 are shown in Figures 1 and 2, respectively. Figure 1 indicates that the average diameter of the ZrO_2 particles is 56.9 nm. Figures 2a and 2b illustrate the distribution of the particles in two and three dimensions (2D and 3D), respectively.

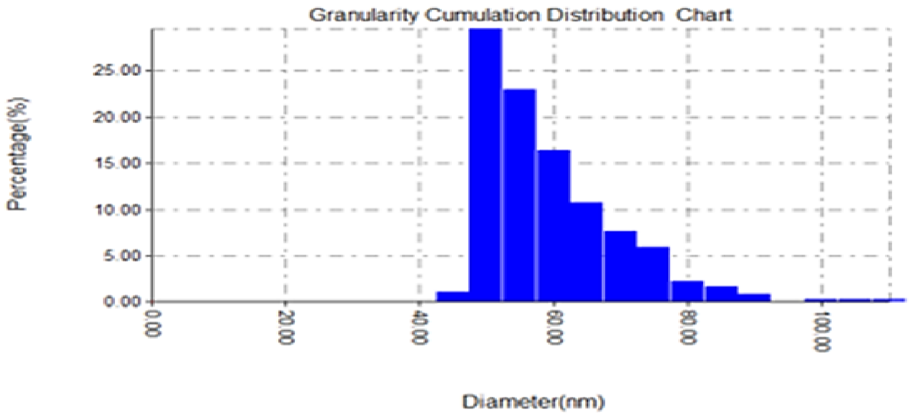

Figure 1. AFM analysis of the purchased ZrO_2 nanoparticles.

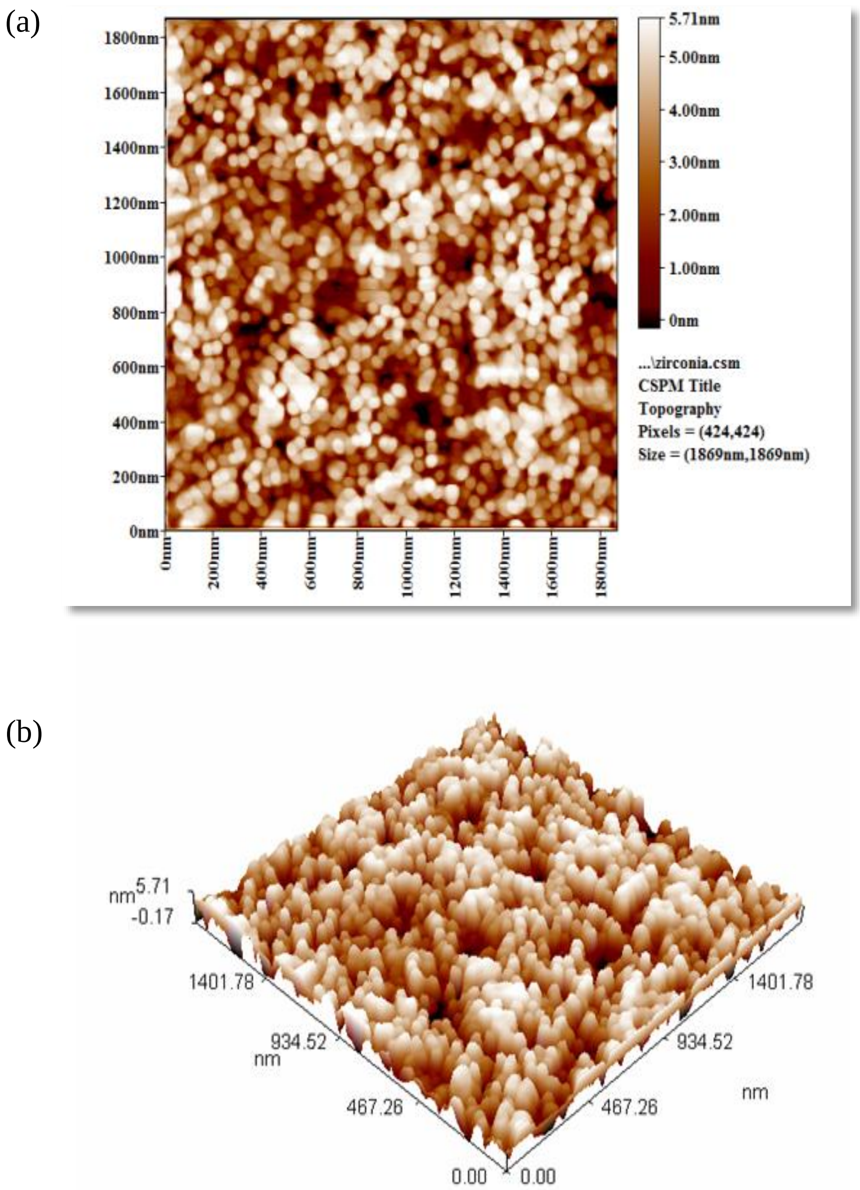

Figure 2. Plots show (a) two- and (b) three-dimensional AFM presentation of ZrO_2.

2.2. Preparation of polymer-ZrO2 nanocomposites

Samples were prepared from the polymer solution and poured into plastic moulds before being left to stand at room temperature (RT) for 24 h. Then, polymer–ZrO_2 nanocomposites were prepared using the casting method. ZrO_2 powder of various weight percentages (0.1%, 0.3%, 0.5%, 0.7%, and 0.9%) was added to the polymer, and the resulting solution was injected into a glass tube over a magnetic stirrer for 1 h. Finally, the polymer–ZrO_2 composites were left at RT for 24 h to form the polymer composites. The optical images of the prepared samples are shown in Figure 3.

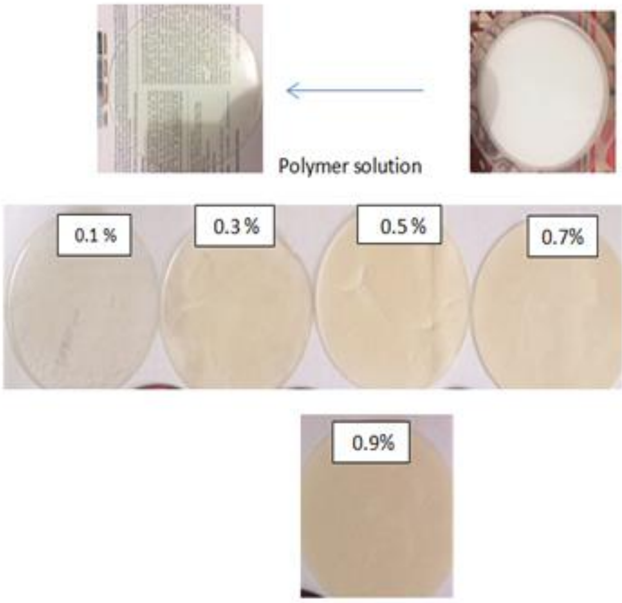

Figure 3. Optical images of the polymer–ZrO_2 composites as a function of the ZrO_2 weight ratio.

2.3. Mechanical parameters

Tear resistance is customarily checked to view the tear properties of prepared polymers. To do this, a particular 'cut' is created to initiate tearing, which is considered a smart descriptor of how well a given fabric can withstand physical demands.

The hardness of the synthesized polymers was tested as Type A penetration. The penetration, the softest durometer, was tested on a penetrometer. The penetrometer permits an outlined foot to push into the tested sample at an outlined force manufacturing an activity. Kind "A" durometer was measured by solidifying a sample a minimum of 0.25 in thickness and putting it on a take a look at the stand with kind "A" indenter. The indenter is forced down into the tested material at a continuing force then the activity is manually recorded.

Impact resistance, present ways to cover the estimation of the energy that causes the sheet to fail underneath specific conditions of impact of a free-falling dart. More details about the impact resistance measurements available elsewhere (ASTM D1709-98, 2001).

The tensile test provides information about T_m, T_s, and elongation break (E_b%). These measured parameters were employing an Instron according to the ASTM D882 (ASTM, 2012). The value of T_s was estimated using equation number (1), while the value of T_m was estimated from the slope of the fitted line in the stress-strain plot (Karim et al., 2018).

$$T_s = F/A \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where T_s is tensile strength (N/m²), F is applied load (N), A is a cross-section area of the measured sample (m²).

2.4. Water Vapor Transmission Rate

Water vapor transmission rate (WVTR) reveals a rate study gives knowledge about the steady vapor flow transmitted in the future (for 24 h) through a vicinity of a body ~ 50 cm^2 and thickness is a smaller amount than three metric linear units, with unit g/m^2 for 24 h (Bai et al., 2015).

2.5. Antibacterial activity

The antibacterial activity of the prepared polymer and polymer composites samples was investigated using the disc diffusion method with Muller-Hinton agar. The tested samples were cut into disc shapes of 6 mm in diameter, and then the discs were placed on the bacterial culture. Then the inhibition zone was obtained in millimeters (mm). The films were scrutinized Gram-positive Staphylococcus aureus (S. aureus) in 37 °C for 6 h for pure polymer solution, and polymer with ZrO_2 with different ratios.

3. RESULTS AND DISCUSSION

3.1. Tear resistance

The values for the tear resistance of flexible materials with smart tear properties square measure within the very 50-100 kN/m and values greater than 100 kN/m. As ascertained from Figure (4), tear-resistance for 0.4 mm thickness of the composites increases from 22.1 to 38.8 kN/m because of the ZrO_2 Rigid fillers are naturally resistant to staining. The polymer composites have a highly restrained mechanically and tear resistance increase with an increasing weight ratio of ZrO_2 from 0 to 0.9%.

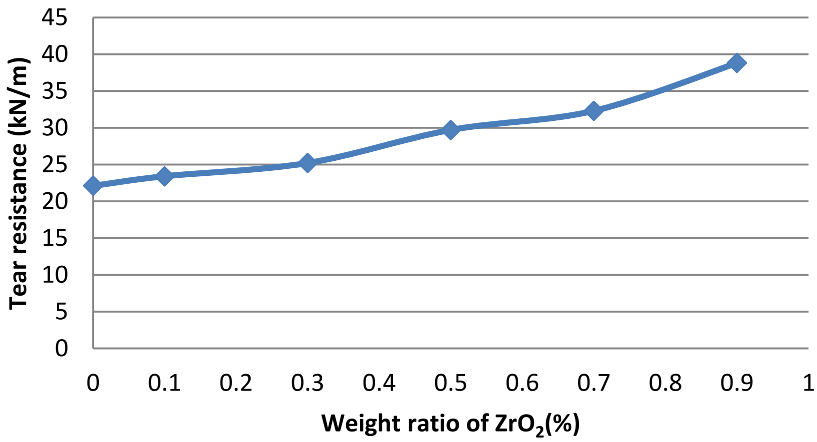

Figure 4. Tear resistance of the polymer/ZrO_2 composite as a function of the ZrO_2 weight ratio.

3.2 Hardness test

From Figure (5), the hardness values increase with an increase in the weight ratio of ZrO_2. The increase could be attributed to the increase in the proportion of zirconium, hence a higher surface area, and thus increase its resistance to scratching. The decrease in hardness value at 9% ZrO_2, may be attributed to agglomerates nanoparticles which results in less energy dissipation in nanocomposites and hence the good forces between particles of the ZrO_2 ceramic powder (Žmak et al., 2020).

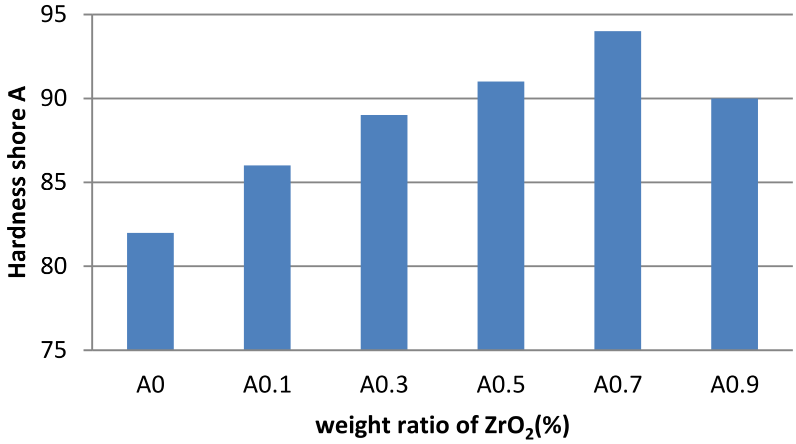

Figure 5. Hardness shore A of the polymer/ZrO_2 composite as a function of the ZrO_2 weight ratio.

3.3. Impact resistance

Figure (6) show an increase in impact resistance because of the high surface shear strength between the ZrO_2 nanoparticle and polymer matrix. This observation attributed to the formation of cross-links or above molecular bonding that covers or defends the nanofillers that successively stop the propagation of the crack. Conjointly the spread of the crack will be modified by good bonding between ZrO_2 and acrylic compound (Sun et al., 2009). Impact resistance increase with increasing weight ratio ZrO_2 reveals a good agreement with Ref. (Hameed & Rahman, 2015).

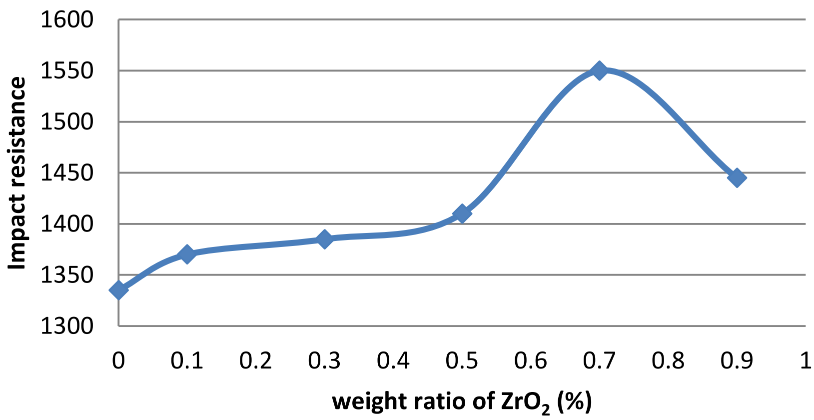

Figure 6. Impact resistance of the polymer/ZrO_2 composite as a function of the ZrO_2 weight ratio.

3.4. Tensile properties

Figure (7) shows the effect of the weight ratio of ZrO_2 on the T_s, T_m, and elongation break. From this chart can be noticed an increase in T_s and T_m with increasing the weight ratio of ZrO_2, while the elongation break shows the opposite trend as it decreases with increasing the ratio of ZrO_2. The observed changes because of the good properties of ZrO_2 such as higher strength and toughness compared with other ceramic and their good impact resistance. The improvement in the mechanical properties could attribute to the formation of high bondings strength between the ZrO_2 nanoparticle and polymer (Ahmed & Ebrahim, 2014).

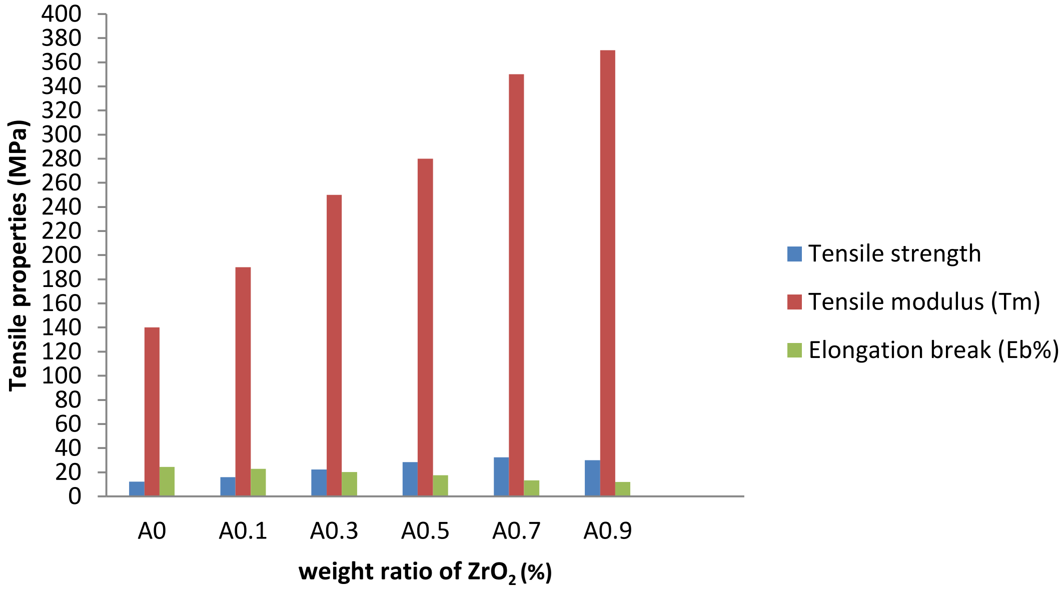

Figure 7. The tensile properties of the polymer/ZrO_2 composite as a function of the ZrO_2 weight ratio.

3.5. Water Vapor Transmission Rate

It is generally accepted those materials that obey Fick's Law called Fickian materials. When adding ZrO_2 to the polymer, may be resulted in improving the barrier performance of polymers. The polymer/ZrO_2 composites are characterized by very drying enhancements of polymer barrier properties compared to the pure polymer. This phenomenon can be interpreted by the concept of tortuous paths. To address this concern, when impermeable nanoparticles are incorporated into a pure polymer, the permeating molecules are forced to wiggle around them in a random walk, and hence diffuse by a tortuous pathway in the polymer composites as observed in Figure (8).

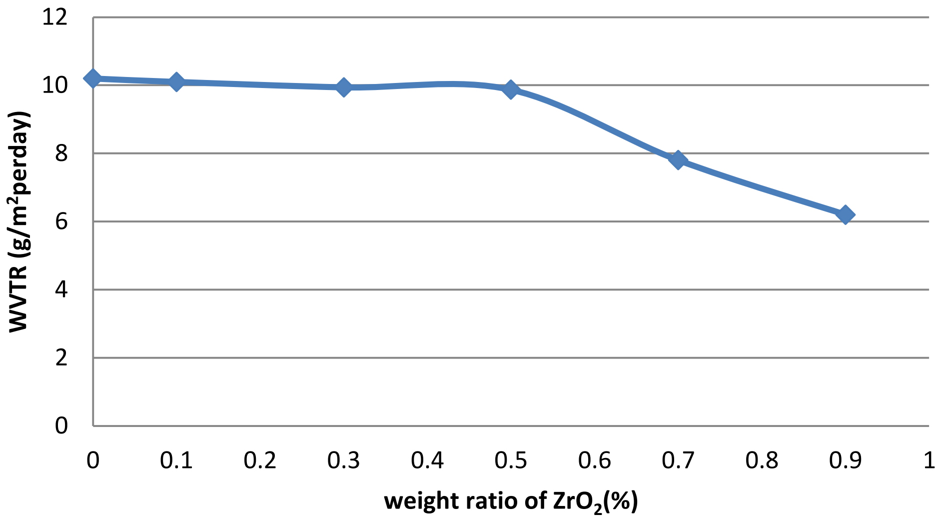

Figure 8. Water vapor transmission rate of the polymer/ZrO_2 composite as a function of the ZrO_2 weight ratio.

3.6. Antibacterial activity

Nanocomposites consisting of ZrO_2 nanoparticles are evaluated for its antibacterial activity using the S.aureus (gram-positive) by the Agar diffusion method. The zone of inhibition values was deduced for both polymer and polymer composites as summarized in Table (1) and also shown in Figure (9). The ZrO_2 nanoparticles show a significant growth inhibitory effect against bacteria. This observation attributed to their large surface area by their nanosize of ZrO_2. Also, the ZrO_2 nanoparticles superior antibacterial activity against S. aureus bacteria. The difference in antibacterial performance could be to the difference in active oxygen and radical species generated from ZrO_2 particles because of the difference in the weight ratio of ZrO_2. This concludes that the ZrO_2 can slow down bacteria cell growth.

Table 1. Zone of inhibition (mm) of the polymer/ZrO_2 composite as a function of the ZrO_2 weight ratio.

ZrO_2 ratio (%)	S. aureus
0	10
0.1	14
0.3	-
0.5	8
0.7	8
0.9	8

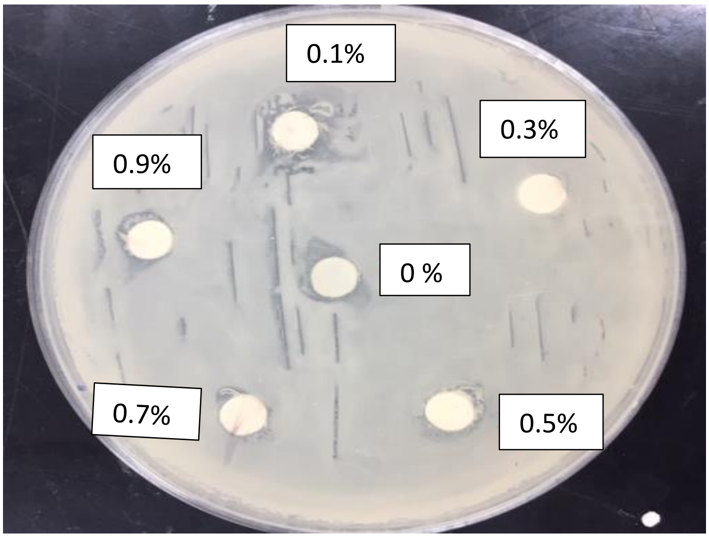

Figure 9. Antibacterial activity of the polymer/ZrO_2 composite as a function of the ZrO_2 weight ratio.

4. CONCLUSION

From the results the following conductions can be drawn:

- ZrO_2 nanoparticles enhance some mechanical properties (tear, hardness, impact, tensile), water vapor permeability, and antibacterial activity.
- Tear resistance and tensile properties increase with the increasing weight ratio of ZrO_2 and the optimum results obtained for a ratio of 0.9%.
- Hardness scratching and impact resistance increase with the increasing weight ratio of ZrO_2 up 7%, while decreasing for a further increase.
- Water vapor permeability rate decrease with the increase in the weight ratio of ZrO_2.
- Antibacterial activity, Zone of inhibition values determined for the best value 0.1% the 14 mm.

5. ACKNOWLEDGEMENTS

This project has been successfully carried out under self-funding.

6. REFERENCES

Ahmed, M. A., & Ebrahim, M. I. (2014). Effect of zirconium oxide nano-fillers addition on the flexural strength, fracture toughness, and hardness of heat-polymerized acrylic resin. World journal of nano science and engineering, 2014.

Amin, M. R., Chowdhury, M. A., & Kowser, M. A. (2019). Characterization and performance analysis of composite bioplastics synthesized using titanium dioxide nanoparticles with corn starch. Heliyon, 5(8), 2009.

ASTM D1709-98, Standard Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method, ASTM

International, West Conshohocken, PA, 2001, www.astm.org.

ASTM INTERNATIONAL. ASTM D882-12, Standard Test Method for Tensile Properties of Thin Plastic Sheeting. ASTM International, 2012.

Bai, H., Li, Y., Wang, W., Chen, G., Rojas, O. J., Dong, W., & Liu, X. (2015). Interpenetrated polymer networks in composites with poly (vinyl alcohol), micro-and nano-fibrillated cellulose (M/NFC) and polyHEMA to develop packaging materials. Cellulose, 22(6), 3877-3894.

Bastioli, Catia, ed. Handbook of biodegradable polymers. iSmithers Rapra Publishing, 2005.

Bona, A. D., Pecho, O. E., & Alessandretti, R. (2015). Zirconia as a dental biomaterial. Materials, 8(8), 4978-4991.

Canning, S. L., Cunningham, V. J., Ratcliffe, L. P., & Armes, S. P. (2017). Phenyl acrylate is a versatile monomer for the synthesis of acrylic diblock copolymer nano-objects via polymerization-induced self-assembly. Polymer Chemistry, 8(33), 4811-4821.

Ezeoha, S. L., & Ezenwanne, J. N. (2013). Production of biodegradable plastic packaging film from cassava starch. IOSR Journal of Engineering, 3(10), 14-20.

Grigore, M. E. (2017). Methods of recycling, properties and applications of recycled thermoplastic polymers. Recycling, 2(4), 24.

Hameed, H. K., & Rahman, H. A. (2015). The effect of addition nano particle ZrO2 on some properties of autoclave processed heat cure acrylic denture base material. Journal of baghdad college of dentistry, 325(2218), 1-17.

Harunsyah, Sariadi, and Raudah "The effect of clay nanoparticles as reinforcement on mechanical properties of bioplastic base on cassava starch", IOP Conf. Series: Journal of Physics: Conf. Series 953, 1-8 (2018).

Hussein, S. I., Abd-Elnaiem, A. M., Asafa, T. B., & Jaafar, H. I. (2018). Effect of incorporation of conductive fillers on mechanical properties and thermal conductivity of epoxy resin composite. Applied Physics A, 124(7), 475.

Hussein, S. I., Ali, N. A., Saleh, G. M., & Jaffar, H. I. (2019). Effect of Fiber (Glass, Poly Propylene) on Hardness, Water Absorption and Anti-Bacterial Activity of Coating Acrylic Polymer. Iraqi Journal of Science, 1-6.

Karim, A. A., Kader, E. E., Hamod, A. A., & Abdulrahman, A. J. (2018, November). Mechanical properties of a hybrid composite material (epoxy-polysulfide rubber) reinforced with fibres. In IOP Conference Series:

Materials Science and Engineering (Vol. 433, No. 1, p. 012050). IOP Publishing.

Singh, S. K., Kumar, A., & Jain, A. (2018, March). Effect of nanoparticles dispersion on viscoelastic properties of epoxy–zirconia polymer nanocomposites. In IOP Conference Series: Materials Science and Engineering (Vol. 330, No. 1, p. 012001). IOP Publishing.

Sun, L., Gibson, R. F., Gordaninejad, F., & Suhr, J. (2009). Energy absorption capability of nanocomposites: a review. Composites Science and Technology, 69(14), 2392-2409.

Žmak, I., Ćorić, D., Mandić, V., & Ćurković, L. (2020). Hardness and Indentation Fracture Toughness of Slip Cast Alumina and Alumina-Zirconia Ceramics. Materials, 13(1), 122.