SYNTHETIC FIBERS EFFECT ON PMMA COMPOSITES USED IN DENTURE FABRICATION: FLEXURAL AND IMPACT STRENGTH EVALUATION

Hassan A.Sharhan[1] as.18.36@grad.uotechnology.edu.iq
Jawad K. Oleiwi[2] 130041@uotechnology.edu.iq
Zaynab N. Rasheed Alraziqi[3] Zaynab.n.rasheed@uotechnology.edu.iq

[1,3] Applied Science Department, University of Technology, Iraq.
[2] Materials Engineering Department, University of Technology, Iraq.

ABSTRACT

PMMA (poly-methyl methacrylate) acrylic resin is commonly utilized in the manufacture of denture bases. However, its mechanical characteristics may be inadequate for this purpose. The purpose of this research is to look at the mechanical characteristics (flexural strength, flexural modulus, impact strength, fracture toughness) of PMMA composite by adding two kinds of synthetic fibers Polypropylene (PP) and Polyacrylonitrile (PAN). Numbers of PMMA composite samples were generated at specified weight ratios of (1.5, 3.5, 5.5, and 7.5 wt.%) in this study. Research results showed that during fibers ratio increased until max. point (7.5wt. %), a decrease in flexural strength value was observed. Notably, PMMA/PAN composite sample has more influence than PMMA/ PP composite. Also, a decrease in the flexural modulus during fibers ratio increases until maximum (7.5wt. %), flexural modulus for PMMA/PAN composite were higher than the values PMMA/PP composite specimens. When it came to I.S, it was discovered that when the fiber ratios were raised, the impact strength rose at a ratio (7.5wt. %). Finally, the results of fracture toughness showed an improvement for the composite specimen (PMMA/7.5 wt. % PAN fiber). In contrast to (the PMMA/7.5wt.% PP fiber) composite specimen, there was a decrease compared to the neat sample.

Keywords: PMMA Composite, Polypropylene (PP), Poly Acrylonitrile (PAN), Flexural Strength, Flexural Modulus, Impact Strength, Fracture Toughness.

INTRODUCTION

Polymethyl methacrylate (PMMA) resin is the most widely used material for denture fabrication because it combines a number of advantageous properties, including ease of laboratory manipulation, lightweight, low fabrication cost, stability in the oral environment, appropriate esthetic and color-matching ability, and lack of toxicity (Carlsson and Omar, 2010, and Meng and Latta,2005) However, it is not perfect in every way and has a number of flaws that must be corrected owing to its poor mechanical performance. These characteristics include poor impact resistance and have low fracture toughness. Because of their low strength, acrylic dentures commonly shatter during use (Yadav et al. 2012). The addition of fibers to the mixture, for example, might improve the mechanical characteristics of the resin (Mowade et al. 2012). The inclusion of various reinforcing fibers to increase the flexural and impact strengths of the composite resin material is one of these changes (Alla et al.2013). The industry's development of fibrous composite. materials have inspired a novel method to improve the performance of dental acrylic resins. Several types of industrial fibers (Sharhan et al., 2021), including carbon, aramid, woven polyethylene fibers, and glass fibers, have been studied with various degrees of success (Schreiber,1971, Noe,1994).

Received : 3-1-2022
Accepted :31-1-2022

Although carbon and aramid fibers were beneficial in reinforcing PMMA, they caused significant clinical issues, including difficult cleaning and poor esthetics. (Ekstrand et al. 1987 and Larson,1991). The PMMA denture base resin is typically reinforced with fibers to improve fracture toughness, flexural strength, and impact strength (Kim and Watts, 2004 and Gad et al.,2017). Ultra-high modulus polyethylene (UHMPE), aramid fiber, nylon fiber, carbon fiber, and glass fiber have all been studied. (Uzun et al., 1999). Carbon and aramid fibers (Kim et al. 2014) glass fiber (Solnit, 1999 and Vallittu,1997). The other method involves reinforcing PMMA denture base resin with different fillers as powder, seashell Nanopowder, and natural shell powder (Hussein and Rasheed,2019, Rasheed and Hussain,2019, and Alraziqi and Mansoor,2020), Al_2O_3 particles as single and hybrid (Alhareb et al. 2015), TiO_2(Mosalman et al.2017), ZrO_2 (Gad et al.,2016. In this paper, two types of synthetic fibers were used (PP and PAN) to modify and enhance PMMA denture base mechanical properties. Flexural strength, flexural modulus, impact strength, and fracture toughness were investigated in this work. The major objective of this research was to investigate if these synthetic fibers might help composites perform better in dental applications

MATERIALS AND METHODS

Materials Used

In this study synthetic fibers (PP and PAN) were used in four concentrations (1.5,3.5,5.5 and 7.5wt %) as fillers to strengthen the acrylic resin PMMA polymer Spofa Dental Company produces (Duracryl Plus self-curing base) resin, as shown in Figure (1) Polypropylene (PP) fibers possess natural color and good mechanical properties due to their excellent biocompatibility (Mowade et al. 2012). Also, Polyacrylonitrile (PAN) is a multipurpose polymer having outstanding chemical, mechanical, and thermal properties (Kausar,2019).

Preparation methods of composite specimens

The used PMMA polymers are prepared by mixing the self-curing base resin in a volume ratio of 3:1 (three parts of powder, one part of liquid). While, the PMMA composite was prepared by adding fibers (PP) or (PAN) to the matrix according to the selected ratio (1.5, 3.5, 5.5, and 7.5 wt.%). Using a balance of scale (0.0001) the total weight of PMMA and other additives were measured according to the mixture base of the used mold with dimension (15x 20 x 0.4) cm^3. Essentially, the fibers were treated with 5% (weight /volume) alkaline solution Na OH for 24 hours at room temperature. Then, the alkaline-treated fibers were washed with distilled water to get rid of the additional NaOH solution adhering to their surface. Finally, they were dried for five days at room temperature, put in an oven at nearly (65°C) to dry. The mixture of one type of (PP) or (PAN) fibers with (PMMA) powder was first added in a special baker according to the selected measurement. Later on, the monomer liquid is added (MMA) to the specified amount to each mixture secondly at room temperature, with continued stirring for about two minutes until reaching the dough stage. Third, all samples are dried at room temperature for 24 h in order to remove the residual pressure due to the loosening of the samples from the mold cavity. All samples are placed in a drying oven at a temperature of (65°C) for 30 minutes, then they were cut precisely using a (CNC) machine and immersed in distilled water at (37°C) for 48 hours (specification ADA.1999, No. 12) (C. D. M. and

Devices 1975). Finally, the samples were examined according to the required characteristics. Table (1) shows the composition of the composite sample.

Flexural test

The primary aim of the flexural test is to characterize the linear behavior of material specimens subjected to stress applied on the vertical axis at the outer surface. The flexural test was carried out at room temperature using universal test equipment, which was also used in the tensile test and relied on the three-point bending test technique. To generate the (load-displacement) curve for each composite specimen, the vertical load was gradually applied in the center of the composite specimens at a strain rate of (2mm/min.) until a fracture occurred. The characteristics acquired from this test for each composite specimen created in this study according to the international standard are flexural modulus and flexural strength (ASTM D-790) (Oleiwi et al.2018, and Oleiwi and Hamad,2018), and maybe calculated at any position along the load-deflection curve (Chowdhury et al., 2007).

$$FS = 3FL / 2bd^2 \quad (1)$$

where: F.S: Flexural strength (MPa.), F: Load at fracture (N), L: Support span (mm), b: Width of the specimen(mm), d: Thickness of specimen (mm),
The flexural modulus can be evaluated by the following equation (ASTM D790-07, 2007).

$$E_F = L^3F / 4bd3\delta \quad (2)$$

Where: E_F : Modulus of Flexure (GPa.), L: Specimen length (mm), b: Specimen width (mm), d: Specimen depth (mm), δ: Specimen deflection (mm). Figure (2) shows the sample of the specimens before and after the test. Figure (3) shows the device used and the sample according to the standard specifications.

Impact Test

The impact characteristics of materials indicate their ability to absorb and disperse energy, which is used to calculate the strength of a material under impact or shock loading. Impact strength is a critical feature for acrylic denture base materials, which have a propensity to shatter when dropped on a hard surface. The impact test was carried out in accordance with (ISO-180)(Oleiwi and Salih, 2018). In this test, the Charpy for XJU Impact Test device manufactured by (testing machine INC.AMI TYVILLE, New York) company was used where the sample designed is placed horizontally without causing a notch on the samples. Figure (4) shows the samples before to and following the test. Figure (5) shows the device used and the sample according to the standard specifications. The test was conducted according to international standards that include Pendulum velocity (3.4m/s), and Pendulum energy (2J).
The impact strength can be evaluated by the following equation (Groover,2020).

$$G_C = U_c / A \quad (3)$$

Where: Gc: Impact resistance (KJ/m²), Uc: Energy of impact (J), and A: represent the sample's cross-sectional area (m²). The toughness of a fracture can be characterized as the ability of materials to withstand the crack propagation when it is present in the material and depends on the Impact strength and modulus of flexure for each composite sample (Groover,2020, Salih,1982). The fracture toughness can be evaluated by the following equation:

$$Kc = \sqrt{GcEF} \quad (4)$$

where: Kc: Fracture toughness (MPa. √ m), Gc: Impact strength (KJ/m²), and E_F: Modulus of Flexure (GPa.)

RESULTS AND DISCUSSION

Flexural Test

Figure (6) depicts the flexural strength evaluation findings for PMMA/PP and PMMA/PAN at all ratios. It is possible to deduce that raising the weight percentage of both (PP and PAN) fibers lowers flexural strength values. This might be because the presence of the fibers was congested, which had a detrimental effect on the interfacial bonding between fiber and matrix, resulting in a reduction in load transfer from matrix to fiber (Zhu et al.2018 and Mohanty et al.2014). Also, because of stress concentrates on specific points in the PMMA resin quickly spreads the crack through the PMMA resin matrix unfilled sections and reduction in cross section of load bearing PMMA matrix which results in a fracturing of the matrix and decreases flexural strength to reach the lower values at higher concentration about (7.5 wt. %). Through the sample due to the increase in the proportion of reinforcement fibers, as well as the presence of voids, porosity and moisture from the trapped air. It can also be noticed that the addition of PAN fibers had a remarkable effect on the flexural strength more than PP fibers. This could be due to the high flexural strength of PP fibers compared to PAN fibers. Therefore, the flexural strength value of PMMA/PAN composite had more influence than PMMA/ PP composite. Thus, the flexural strength is decreased from (69.87MPa) for neat PMMA (as referenced) to reach to the lower value of (45.8MPa) for PMMA/PAN composite (Sreekanth et al.,2009and Salih et al.,2018).

Flexural Modulus Behavior

The flexural modulus of neat PMMA and PMMA composites reinforced with (PP and PAN) fibers obtained from flexural tests as shown in Figure (7). It's worth noting that the flexural modulus of both group of PMMA composite materials dropped as the weight ratio of fibers increased. This is may be due to the lack in the wettability lead to weaken the physical bonds between the matrix and the fibers during increase the weight ratio to reach the super saturated state. All that tend to aggregate these fibers and so reduces the flexural modulus. Furthermore, this reduction happened because the fibers were crowded, therefore it had negative effect on the interfacial connection between fiber and matrix, resulting in a reduction in load transfer from matrix to fiber. (Zhu et al.2018and Mohanty,2014). The voids formation from entrapped air and moisture may be also responsible of this behavior and lead to weaken the composite materials (Salih et al. 2018) . This figure also shows that the inclusion of PP fibers had a greater impact on the flexural modulus of composite specimens than the addition of PAN fibers. As a result, the observed flexural modulus values for PMMA/PAN fiber composite specimens are greater than the flexural modulus values for PMMA/PP fiber composite specimens. Thus, the flexural modulus is decreased from (4.09GPa) for neat PMMA (as referenced) to reach to the lower value of (1.99GPa) for PMMA /PP composite specimens (Sreekanth,2009, Salih,2018and Rahseed,2022).

Impact Test

The impact strength of composites is primarily determined by two factors: first, the fibers' capacity to absorb energy, which can prevent fracture propagation, and second, weak interfacial bonding, which creates tiny gaps between the fibers and the matrix, making crack propagation easier (Mohanty et al. 2014). The impact strength of a PMMA/PP composite with higher content is bigger than the impact strength of a PMMA/PAN composite at same value. The development of strong cross-links connecting between the PMMA matrix and these fibers may be linked to the increased impact strength behavior, which prevents fracture propagation inside the PMMA matrix. Because of the excellent interfacial connection between fiber and matrix, as well as increased crystallinity, which allows the loud to be transferred from matrix to fiber, composite materials have become more impact resistant (Hussain and Rafiq,2012 and Mahmood,2017). This is also attributable to the increased toughness of the PMMA material, which may be ascribed to the fact that PP and PAN fibers have a greater impact strength than the PMMA matrix, resulting in an improved impact strength composite (Askeland et al.,2011and Varadharajan et al.,2005). Thus, the impact strength values increase from (5.31 KJ/m^2) for PMMA to (15.12 KJ/m^2) for (PMMA / 7.5wt. % PP) composite specimen and to (11.17 KJ/m^2) for (PMMA / 7.5 wt. % PAN) composite, as presented in Figure (8). It was clear, in comparison to neat PMMA, the inclusion of both types of fibers at both resulted in a substantial improvement in the value of impact strength. When PP fiber was added to the composite material, the maximum value of impact strength was attained.

Fracture Toughness Behavior

The impact strength and flexural modulus of each sample are used to calculate fracture toughness (Varadharajan,2005). Figure (9) show the link between (PP and PAN) fiber weight ratios in PMMA resin and fracture toughness tests, respectively. From the figure, fracture toughness value increases with increasing weight ratio of both type composites. Also, it noticed a slight decrease in the PP fibers as the weight ratio increased of these fibers until reach the minimum value at maxi. reinforcement (7.5 wt. %) for PP fiber only. Therefore, there were a proven increase in PMMA/PAN in comparison. The reason behind this was the fracture toughness depend on the impact strength value and flexural modulus value and had a similar behavior to the behavior of fracture toughness that explained in this Figure. So, any kind of these fibers added in the PMMA composite work as obstacle to the crack propagation inside the PMMA materials. Yet, decreasing fracture toughness during weight ratio increases of PP fiber reinforcing at (7.5 wt.%) may be related to the decreasing in the wettability and mixing between PMMA matrix and PP fiber when increasing the proportion of them that it leads to reduction in the adhesive force between these reinforcing materials and PMMA matrix. In this Figure it can also be noticed that the addition of PAN fiber had a remarkable influence on the fracture toughness of composite prepared compared to PP fiber. Thus, fracture toughness measured for PMMA/PAN are higher than the fracture toughness for PMMA/ PP, and increased with a higher rate comparing to the behavior of these composite. The enhancement of the mechanical properties mainly related to the usage of PAN fiber, which associated with the fibers that have high fracture toughness comparing with PP fiber. Furthermore, the fracture toughness values improved from (4.66MPa. $\sqrt{m}$) for PMMA (as referenced) to reach a maximum value of (5.28 MPa. $\sqrt{m}$) for (PMMA / 7.5 wt. % PAN).

CONCLUSIONS

1. The impact strength showed a high increase, when reinforcing with a ratio (7.5wt.%) of PP fiber.
2. The Fracture Toughness showed a high increase, when reinforcing with a ratio (7.5wt.%) of PAN fiber.
3. Flexural strength decreases when reinforcing with a ratio (7.5wt.%) of PAN fiber.
4. The Flexural modulus showed decrease when reinforcing with a ratio (7.5wt.%) of PP fiber.
5.

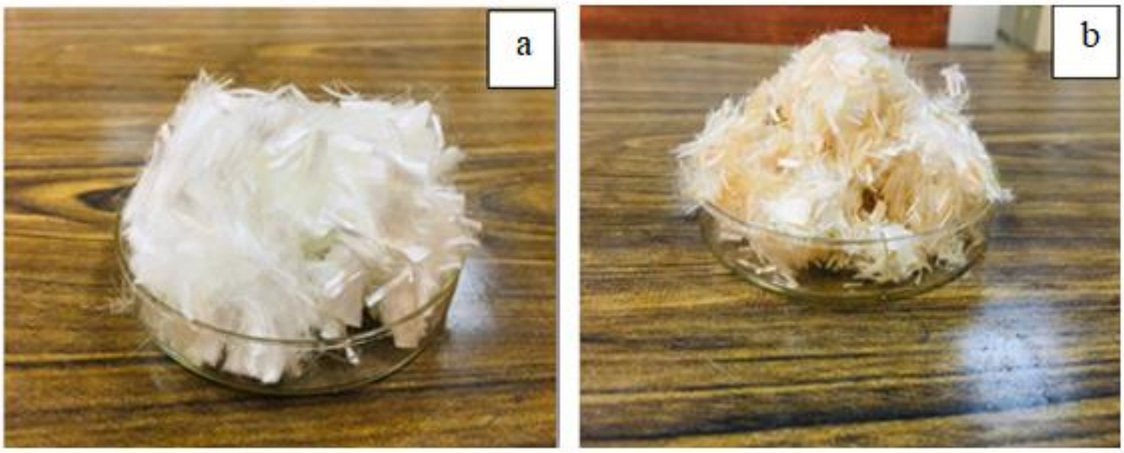


Fig. 1.(a) Polypropylene (PP) Fibers, (b) Polyacrylonitrile (PAN) Fibers.

Table 1. Composition of composite sample.

Sample No.	PMMA weight fraction%	Fiber weight fraction%	Weight fraction % of PMMA+MMA liquid(g)	weight fraction % of fiber
S	100	0	142.55	0
S1	98.5	1.5 PP	140.45	2.1
S2	96.5	3.5 PP	137.57	4.9
S3	94.5	5.5 PP	134.63	7.8
S4	92.5	7.5 PP	131.85	10.7
S5	98.5	1.5 PAN	140.45	2.1
S6	96.5	3.5 PAN	137.57	4.9
S7	94.5	5.5 PAN	134.63	7.8
S8	92.5	7.5 PAN	131.85	10.7

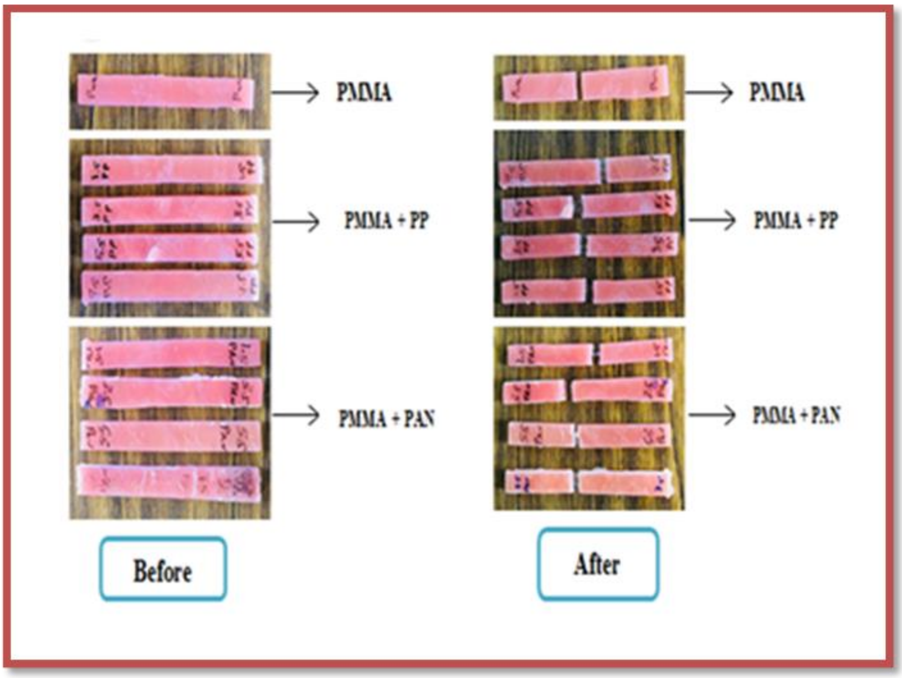


Fig. 2. The specimens before and after the test

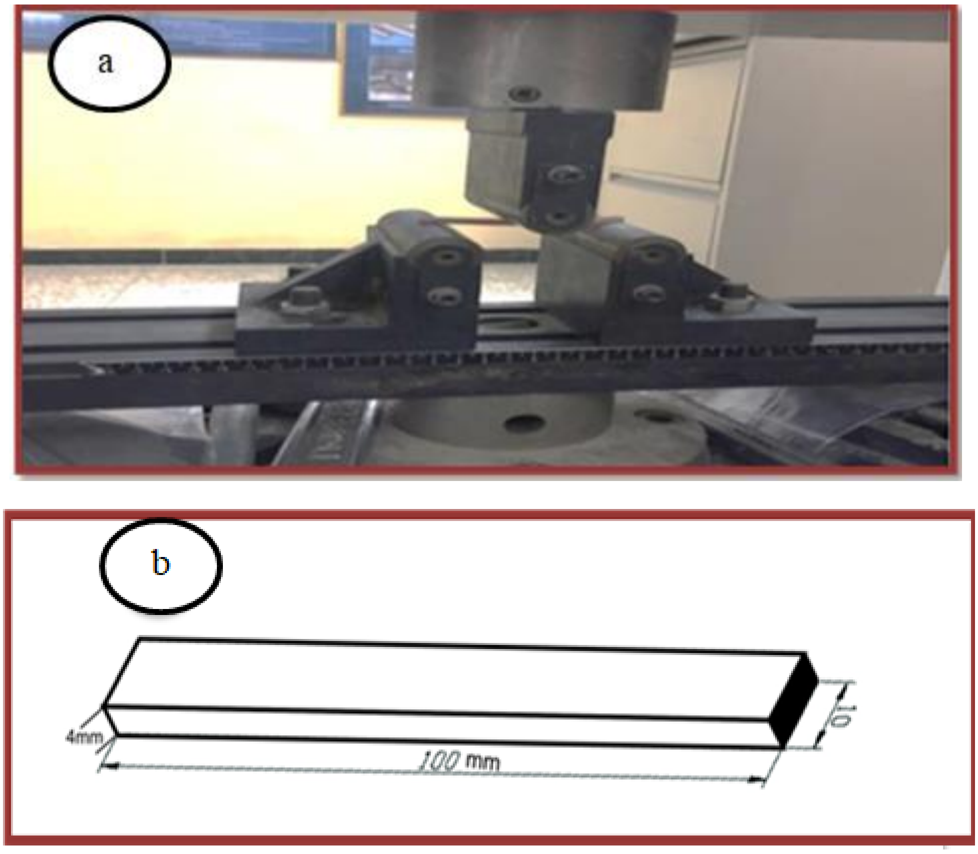


Fig. 3. (a) The flexural testing apparatus, (b) The dimension of specimens.

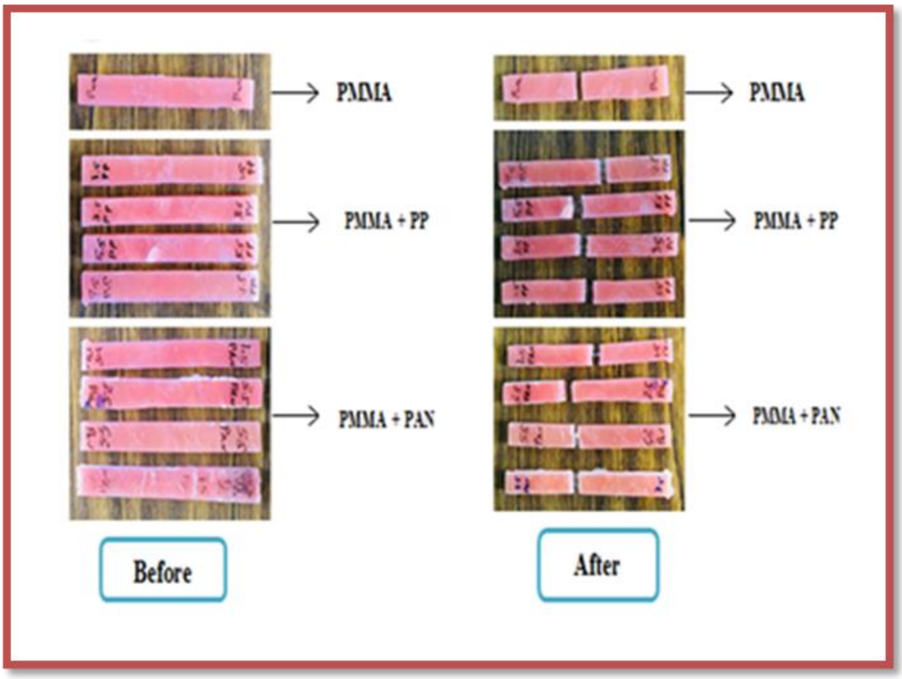
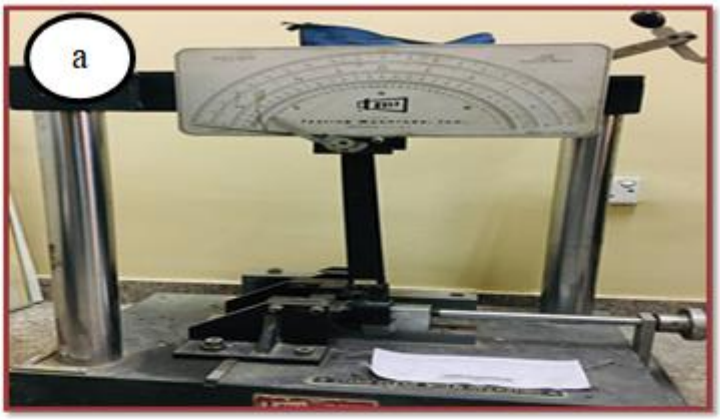


Fig. 4: Sample before and after impact test.



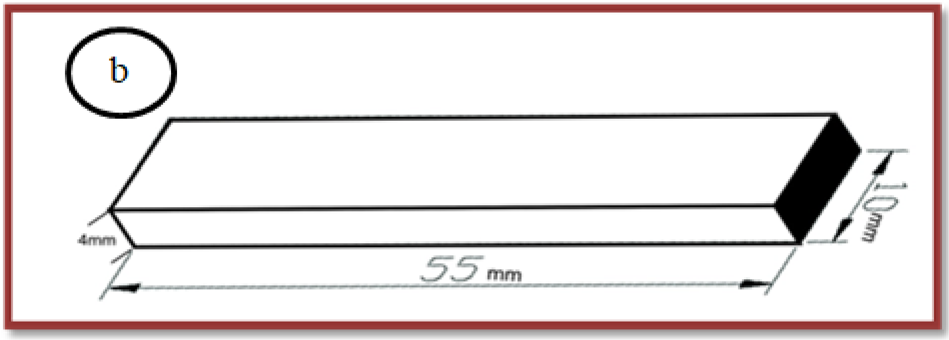


Fig. 5. (a) Charpy impact test instrument, and (b) The standard specimen of an impact test is shown

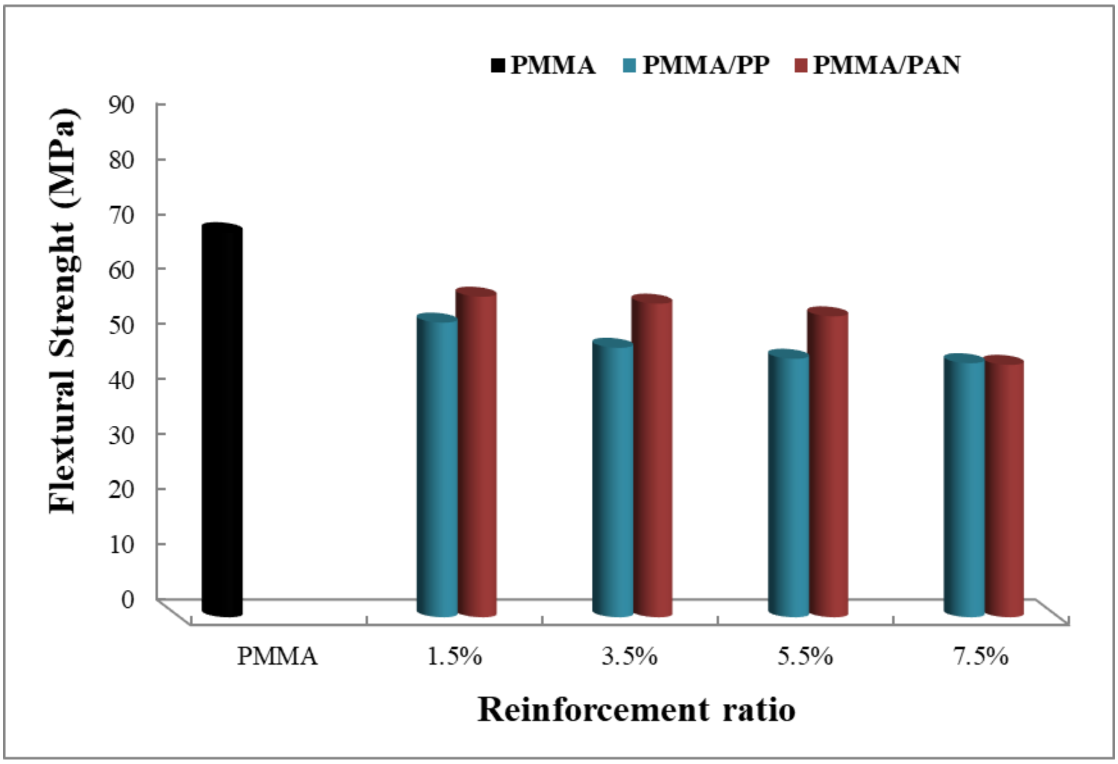


Fig.6. Flexural Strength as a Function of (PP and PAN) fibers (wt.%) in Composite.

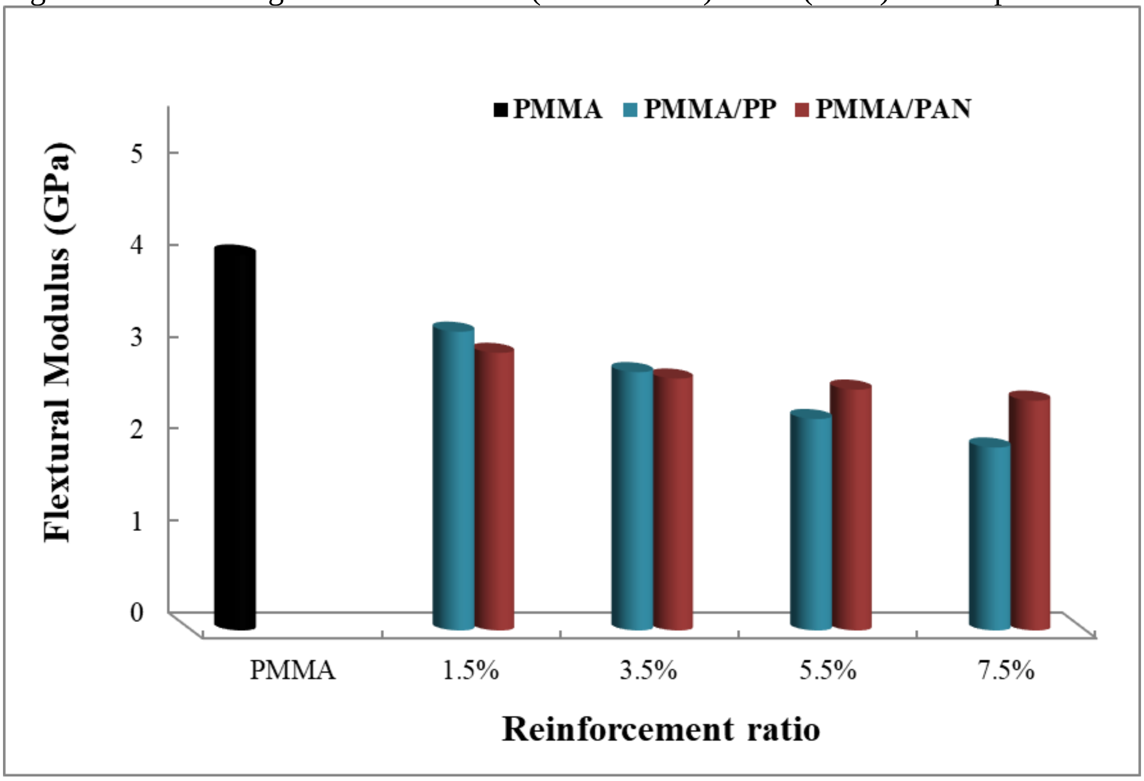


Fig.7. Flexural Modulus as a Function of (PP and PAN) fibers (wt.%) in Composite.

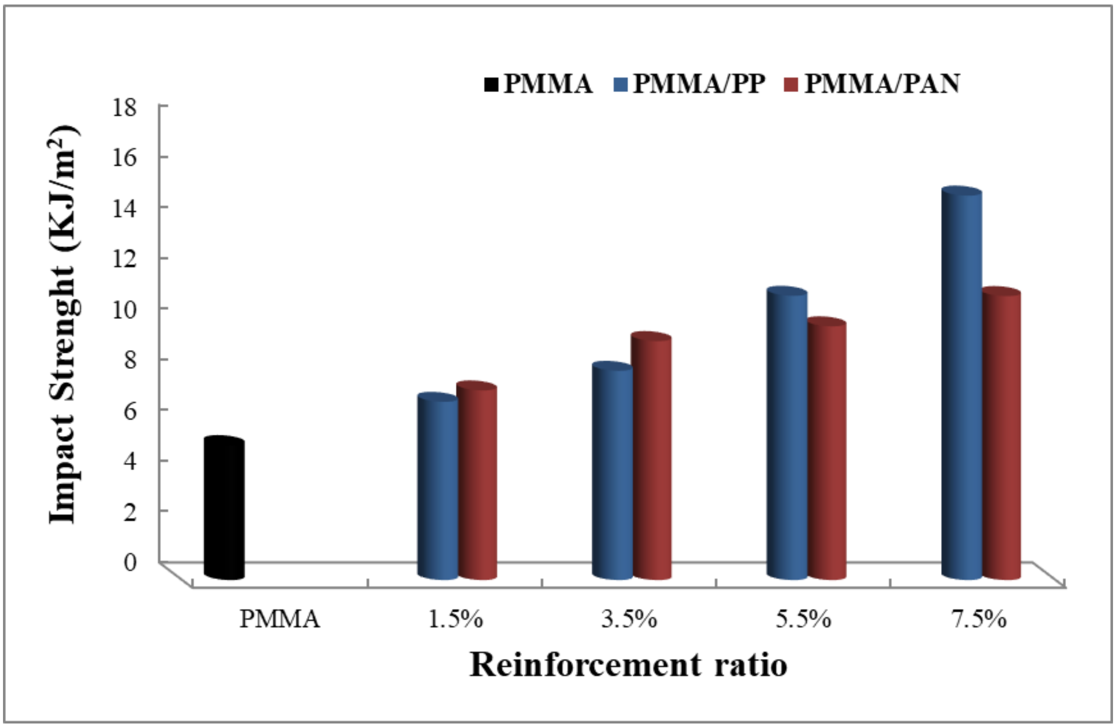


Fig. 8. Impact Strength of PMMA Composite Materials as Function of (PP and PAN) fibers (wt.%) in Composite.

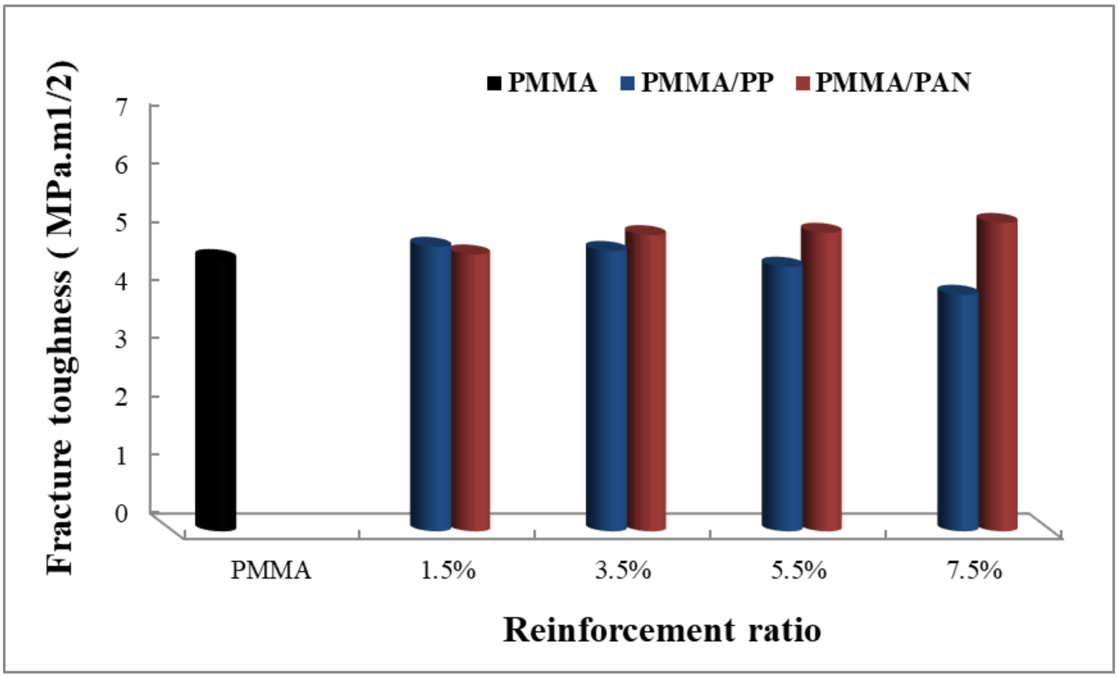


Fig. 9. Fracture Toughness of PMMA Composite Materials as Function of (PP and PAN) fibers (wt.%) in Composite.

REFERENCES

A. O. Alhareb, H. M. Akil, and Z. A. Ahmad, “Mechanical properties of PMMA denture base reinforced by nitrile rubber particles with Al_2O_3/YSZ fillers”, Procedia Manufacturing, Vol. 2, pp. 301–306, 2015.

A. Kausar, “Polyacrylonitrile-based nanocomposite fibers: A review of current developments”, Journal of Plastic Film & Sheeting, Vol. 35, No. 3, pp. 295–316, 2019.

ASTM, “Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials”, ASTM D790-07, 2007.

A. R. Salih, “Design of Fractal Optical Modulator”, Journal of strain, Vol. 17, No. 5, 1982.

B. R. Varadharajan, W. N. P. Hung, and H. J. Sue, “Fatigue of Epoxy A-Zirconium Phosphate Nanocomposites”, 2005.

C. D. M. and Devices, “Revised American dental association specification no. 12 for denture base polymers,” The Journal of the American Dental Association, Vol. 90, No. 2, pp. 451–458, 1975.

D. C. K. Schreiber, “Polymethylmethacrylate reinforced with carbon fibres”, British Dental Journal, Vol. 130, No. 1, pp. 29–30, 1971.

E. R. Askeland, “PradeepP,” Fulay and Wendelin J. Wrigth", The Science and Engineering of Materials, 6th edition, Cengage Learning Inc, 2011.

F. H. Chowdhury, M. V Hosur, and S. Jeelani, “Investigations on the thermal and flexural properties of plain weave carbon/epoxy-nanoclay composites by hand-layup technique”, Journal of materials science, Vol. 42, No. 8, pp. 2690–2700, 2007.

G. E. Carlsson and R. Omar, "The future of complete dentures in oral rehabilitation. A critical review", Journal of Oral Rehabilitation, Vol. 37, No. 2, pp. 143–156, 2010.

G. Uzun, N. Hersek, and T. Tincer, “Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin”, The Journal of prosthetic dentistry, Vol. 81, No. 5, pp. 616–620, 1999.

G. S. Solnit, “The effect of methyl methacrylate reinforcement with silane-treated and untreated glass fibers,” The Journal of prosthetic dentistry, Vol. 66,No. 3, pp. 310–314, 1991.

H. A. Sharhan, Z. N. Rasheed, and J. K. Oleiwi, “Synthesis and Physical Characterization of PMMA/PP and PMMA/PAN Composites for Denture Applications”, Journal of Applied Sciences and Nanotechnology, Vol. 1, No. 3, pp. 13–23, 2021.

H. Noe, “Denture base reinforcement using woven polye—thylene fiber”, Int J Prosthodont Vol. 7, No. 4, pp. 307–314, 1994.

H. Kim, M. Kim, H. Kwon, Y. Jun Lim, S. Kim, and J. Koak, “Strength and cytotoxicity in glass-fiber-reinforced denture base resin with changes in the monomer”, Journal of applied polymer science, Vol. 126, no. S2, pp. E260–E266, 2012.

J. K. Oleiwi, Q. A. Hamad, and H. J. A. Rahman, “Experimental investigation of flexural and impact properties of PMMA reinforced by Bamboo and rice husk powders”, International

Journal of Mechanical Engineering and Technology, Vol. 9, No. 10, 2018.

J. K. Oleiwi and Q. A. Hamad, "Studying the mechanical properties of denture base materials fabricated from polymer composite materials", Al-Khwarizmi Engineering Journal, Vol. 14, No. 3, pp. 100–111, 2018.

J. K. Oleiwi and Salih, S. I. "Study Compression and Impact Properties of PMMA Reinforced by Natural Fibers Used in Denture", Engineering and Technology Journal, Vol. 36, No. 6A, 2018, doi: 10.30684/etj.36.6a.9.

J. R. Mohanty, S. N. Das, and H. C. Das, "Effect of fiber content on abrasive wear behavior of date palm leaf reinforced polyvinyl pyrrolidone composite", International Scholarly Research Notices, Vol. 2014,pp.1-10, 2014.

K. Ekstrand, I. E. Ruyter, and H. Wellendorf, "Carbon/graphite fiber reinforced poly (methyl methacrylate): properties under dry and wet conditions", Journal of biomedical materials research, Vol. 21, No. 9, pp. 1065–1080, 1987.

L. Zhu, D. Wu, B. Wang, J. Zhao, Z. Jin, and K. Zhao, "Reinforcing high-density polyethylene by polyacrylonitrile fibers", Pigment & Resin Technology, 2018.

M. M. Gad, S. M. Fouda, F. A. Al-Harbi, R. Näpänkangas, and A. Raustia, "PMMA denture base material enhancement: a review of fiber, filler, and nanofiller addition", International journal of nanomedicine, Vol. 12, pp. 3801, 2017.

M. M. Gad, A. Rahoma, A. M. Al-Thobity, and A. S. ArRejaie, "Influence of incorporation of ZrO2 nanoparticles on the repair strength of polymethyl methacrylate denture bases", International journal of nanomedicine, Vol. 11, pp. 5633, 2016.

M. P. Groover, Fundamentals of modern manufacturing: materials, processes, and systems. John Wiley & Sons, 2020.

M. S. Sreekanth, V. A. Bambole, S. T. Mhaske, and P. A. Mahanwar, "Effect of concentration of mica on properties of polyester thermoplastic elastomer composites", Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No. 4, pp. 271–282, 2009.

N. Y. Mahmood, "Studying the effect of mixture of pomegranate peel and licorice on the mechanical properties of epoxy", Al-Nahrain Journal for Engineering Sciences, Vol. 20, No. 4, pp. 871–875, 2017.

P. Yadav, R. Mittal, V. K. Sood, and R. Garg, "Effect of incorporation of silane-treated silver and aluminum microparticles on strength and thermal conductivity of PMMA," Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry, Vol. 21, No. 7, pp. 546–551, 2012.

P. K. Vallittu, "Glass fiber reinforcement in repaired acrylic resin removable dentures: Preliminary results of a clinical study", Quintessence International, vol. 28, no. 1, 1997.

R. K. Alla, S. Sajjan, V. R. Alluri, K. Ginjupalli, and N. Upadhya, "Influence of fiber reinforcement on the properties of denture base resins," 2013.

S.-H. Kim and D. C. Watts, “The effect of reinforcement with woven E-glass fibers on the impact strength of complete dentures fabricated with high-impact acrylic resin”, The journal of prosthetic dentistry, Vol. 91, No. 3, pp. 274–280, 2004.

S. M. Hussein and Z. N. Rasheed, “Nano-reinforcement effect on PMMA denture base mechanical properties after immersing in different solution”, Iraqi Journal of Science, vol. 60, pp. 57–68, 2019.

S. Mosalman, S. Rashahmadi, and R. Hasanzadeh, “The effect of tio2 nanoparticles on mechanical properties of poly methyl methacrylate nanocomposites (research note)”, International Journal of Engineering, Vol. 30, No. 5, pp. 807–813, 2017.

S. I. Salih, J. K. Oleiwi, and A. S. Mohamed, “Investigation of mechanical properties of PMMA composite reinforced with different types of natural powders”, ARPN Journal of Engineering and Applied Sciences, Vol. 13, No. 22, pp. 8889–8900, 2018.

T. R. Meng and M. A. Latta, “Physical properties of four acrylic denture base resins”, J Contemp Dent Pract, Vol. 6, No. 4, pp. 93–100, 2005.

T. K. Mowade, S. P. Dange, M. B. Thakre, and V. D. Kamble, “Effect of fiber reinforcement on impact strength of heat polymerized polymethyl methacrylate denture base resin: in vitro study and SEM analysis”, The journal of advanced prosthodontics, Vol. 4, No. 1, pp. 30–36, 2012.

W. R. Larson, D. L. Dixon, S. A. Aquilino, and J. M. S. Clancy, “The effect of carbon graphite fiber reinforcentent on the strength of provisional crown and fixed partial denture resins”, The Journal of prosthetic dentistry, Vol. 66, No. 6, pp. 816–820, 1991.

W. A. Hussain and S. N. Rafiq, “Mechanical properties of carrot fiber-epoxy composite”, Baghdad Science Journal, Vol. 9, No. 2, pp. 335–340, 2012.

Zaynab N. Rasheed, Samah M. Hussain“Impact strength behaviour of PMMA denture base through addition of different nanoparticles after immersion in some nutrition liquids”, Iraqi Journal of Physics (IJP), Vol. 17, No. 41, pp. 40–50, 2019.

Z. N. R. Alraziqi and H. S. Mansoor, “Experimental Investigation for Some Properties of PMMA Denture Base Strengthened by Different Nanoadditives”, Iraqi Journal of Science, pp. 2913–2925, 2020.

Z. N. Rahseed, “Water Temperature Effect on Hardness and Flexural Strength of (PMMA/TiO2 NPs) for Dental Applications”, Baghdad Science Journal, Vol. 19, No. 4, 2022.