Effect of Different Types of Highly Consumed Beverages on the Surface Structure of Orthodontic Restorative Material

A. Alhazza, B. Alnaser

Abstract—Orthodontic restorative materials are widely used for the direct restoration of teeth or for cosmetic dentistry purposes. These materials have helped to solve many dental problems, providing healthy and beautiful smiles for many patients. In this study, we aimed to investigate whether the pH value has an effect on the surface structure of a nanohybrid composite material. Five different types of highly consumed beverages were selected to examine their effect on the surface structure of the nanohybrid composite material. The beverages had different pH values in the range of 3–6, i.e., they were all acidic. The material was investigated under the hardest conditions of surface exposure to the drinks by immersing the material for a long period. The specimens were examined using scanning electron microscopy (SEM) at different magnifications to investigate the effect of these beverages on the morphology of the nanohybrid composite material discs. All specimens showed an effect including pores, cracks, protrusions, and surface roughness as a result of the beverages. The degree of effect differed from one experimental group to another, but there was no relationship between the pH (acidity) value and the degree of effect on the surface structure of the specimens.

Keywords—Acidity, beverage, SEM, dentistry.

I. INTRODUCTION

DENTISTRY is one of the most important sciences in human life, developed as an effort to solve the dental health problems of patients throughout their life. Today, dentistry helps to provide good smiles for patients not only for health purposes but also for cosmetic goals. Orthodontic restorative materials are widely used for the direct restoration of removed, damaged, or broken teeth or for cosmetic dentistry purposes in order to give patients' teeth a beautiful look [1].

Dental restorative materials have many types [1], with the most famous in use today being resin-based composite, whereas nanohybrid resin-based composite materials represent the most recent and most developed type today. They are called "nano" hybrid composites as a result of the nanotechnology used in their production. Nanotechnology is the production of functional materials and structures in the range of 0.1-100 nm—the nanoscale—using various physical or chemical methods [3], [15].

Nanocomposites are considered to have many advanced chemical, physical, and esthetic properties [1], [3], [9], [18]. They have high compressive and diametric strength [3], [9], and the fracture resistance of these materials is equivalent to or higher than that of other composites [9].

Dental composites are chemically composed of two main parts. The first is called the matrix, which is the organic part of the material. Most available composites contain a polymer matrix of dimethacrylate monomers, such as bis-GMA, UDMA, and TEGDMA [6], [13]. The second is called the inorganic part, constituting the filler. These fillers give a natural appearance to the artificial tooth, and they help to protect the composite from degradation according to their size, type, and concentration [2], [13]. Highly filled composites were found to have high resistance to degradation [2]. Both the organic and the inorganic parts are bonded together via the addition of a chemical coupling agent [1], [2]. Photoinitiators, accelerators, and pigments are added to the composite to maintain the natural look of the teeth, whereas inorganic filler particles coated with methyl methacrylate also contain a functional silane coupling agent to bond the filler to the organic matrix; lastly, a photoinitiator system is used to allow photoactivation by light units [2], [13].

Nanocomposites are used in anterior and posterior restorations [1]. When they are placed inside the oral cavity, they are subjected to different types of foods, which may affect their composition and structure [1], [2], [12]. Hot, cold, rough, and hard foods are consumed daily by different individuals; thus, as the composite material comes in contact with all these foods under different conditions, it undergoes degradation [1].

The erosion of a resin-based restorative material is a chemical process without the involvement of any micro-organisms [1]. Erosion can be intrinsic, extrinsic, or both. The consumption of easily and widely available beverages represents a potential source of resin-based composite erosion and degradation [1].

One of the most important factors that should be taken into consideration when investigating the chemical erosion of nano dental composites is the pH value of foods and drinks, while other factors include temperature changes, different masticatory stresses, and chemicals from food [1]. Exposure to various kinds of acidic solutions results in restoration failure. The acidity of food was found to be an effective factor causing the composite material to undergo chemical erosion [1], [6], [8], [10]. Studies also showed that cola [2], [8], [9] and orange juice [2], [8] affected the surface hardness of composite materials, while energy drinks caused dental erosion of the natural teeth

A. Alhazza is with Nanotechnology program, Kuwait Institute for Scientific Research, P.O.Box 24885 Safat 13109, Kuwait (phone: 965-24989055; fax: 965-24989059; e-mail: ahazza@kisr.edu.kw).

B. Al-Naser is with Ministry of Education, P.O.Box 24885 Safat 13109, Kuwait.

World Academy of Science, Engineering and Technology
International Journal of Chemical and Materials Engineering
Vol:16, No:4, 2022

[20]. Other studies showed that a lower pH value of food or drink leads to a greater ability to cause erosion [1], [6], [8], [10]. On the other hand, some studies denied the effect of low pH on the structure of nano dental composites, instead relating the erosion to another factor such as hydrolysis [13], [19].

Hydrolysis is a chemical process that splits the covalent bonds between polymers via the addition of water to ester bonds, leading to a loss of resin mass; it is quoted as one of the main reasons for the degradation of resin within the hybrid layer [1]. Several studies reported that the pH value was not the real cause of surface degradation of the nanohybrid resin; instead, it was related to the ability of the organic part of the composite material and matrix to absorb water and undergo hydrolysis, thus leading to damage [1], [9], [13], [19].

The aim of this study was to investigate the effect of pH value on the surface structure of a nanohybrid composite material (IPS Empress Direct, Invoclar Vivadent AG).

II. MATERIALS AND METHODS

IPS Empress Direct and Ivoclar Vivadent AG nanohybrid resin was used for the examination. Table I shows the chemical composition of this material. This material is available on the market as a soft paste inside plastic and nontransparent syringes to keep it away from air and light. It is stored in a temperature range of 2–28 °C.

TABLE I
CHEMICAL COMPOSITION NANOHYBRID RESIN

Component	Content (wt.%)	Chemical Composition
Monomer matrix	20–21	Dimethacrylates
Fillers	77.5–79	Barium glass
		Ytterbium trifluoride
		Mixed oxides
		Silicon dioxide
		Silicon copolymer
Additional contents	<1%	Catalysts, stabilizers, and pigments

Five common beverages (diet cola, instant coffee, orange juice, sparkling mineral water, and energy drink) were used for this study (Fig. 1). They were found to have a pH value ranging from 3-6, which was determined using a pH meter; measurements were repeated in order to obtained accurate values [9].

Fig. 1 Beverages used (from left to right: diet cola, orange juice, mineral sparkling water, instant coffee, and energy drink)

The energy drink was the most acidic (lowest pH value), followed by diet cola (Table II). The nanocomposite resin was prepared before the commencement of the experiment. The preparation included cutting and shaping the material, before a solidification process involving exposure of the material to light with a specific wavelength depending on the type of matrix included. In some studies, the composite material was formed into a tooth-like specimen [4]; however, other studies preferred making small discs [1], [4], [7], [9], [10], [12], [14], [19].

TABLE II
THE pH VALUE OF BEVERAGES USED

	Beverage	pH Value
1	Diet cola	3.96
2	Orange juice	4.28
3	Sparkling mineral water	5.09
4	Instant coffee	5.35
5	Energy drink	3.58

In this study, the material was shaped into small discs (9 mm diameter and 2 mm thickness) with the assistance of a dental specialist (Table III).

TABLE III
DIAMETER AND THICKNESS OF MATERIAL

Set	Radius	Thickness
	8.99	2.26
1	8.41	2.3
	8.77	2.3
	8.65	2.3
2	8.61	2.3
	8.63	2.0
	8.93	2.05
3	8.98	2.12
	8.63	2.15
	9.00	2.12
4	9.03	2.11
	9.2	2.2
	9.15	1.92
5	9.66	2.31
	9.32	2.31

The material was squeezed inside a metal mold and then exposed to an ultraviolet (UV) light of wavelength ranging from 400-500 nm to achieve solidification, using a light-curing quartz tungsten halogen unit (401 TM Demetron Research Corporation, Danbury, CT, USA).

In total, 15 small discs of the composite material were prepared for the investigation. The mass (1 g) and diameter (see Table I) of the discs were determined.

The specimens were grouped randomly into six groups: five were experimental groups (two discs for each drink), and the sixth one was the control group (inside an empty container full of air).

SEM images of the specimen were taken before immersion [10], [19] (they were all similar in terms of topography and shape, with one image as the control).

The specimens were then immersed inside the beverages, each within an airtight plastic container (Fig. 2) completely filled with the beverage.

World Academy of Science, Engineering and Technology
International Journal of Chemical and Materials Engineering
Vol:16, No:4, 2022

Fig. 2 Specimens grouped randomly

In previous studies, the degree of effect on the nanocomposite structure was proportional to the duration of immersion, whereby a longer immersion led to greater destruction being recorded [4], [5], [9]. In this study, two immersion periods of 30 and 60 days were considered in order to subject the specimens to a long experimental time. Both sets of specimens (30 and 60 days) were immersed at room temperature.

During the period of immersion, each beverage was carefully changed with a fresh amount of the same beverage, once every 5 days, in order to provide a strong chemical surface contact with the drinks and, thus, obvious results. Previous studies also implemented this step at different time points (24 h [1]; 7 days [5]).

At the end of each period of examination, the beverage was discarded, and specimens were carefully removed from the containers, washed gently using distilled water, and allowed to dry [10]. In previous studies, deionized water [9] or a diluted soap solution were used to clean the specimens [1]; however, in this study, soap was not used to avoid any contact between chemicals and the specimens. The dried specimens were sputter-coated with gold (SPI-Module sputter, SPI Supplies, West Chester, PA, USA) and then examined by SEM (JSM model 5800, JEOL, Tokyo, Japan).

Different powers of magnification were applied to investigate the effect of beverages on the morphology of nanohybrid composite material discs.

III. RESULTS

All specimens showed effects such as pores, cracks, protrusions, and surface roughness as a result of exposure to the different beverages [1], [5], [9]. Table IV shows the water content of the beverages used in this study.

TABLE IV
PERCENTAGE OF WATER IN EACH BEVERAGE

Beverage	Water Content (%)	Osmolality
Sparkling mineral water	100	7
Diet cola	100	23
Orange juice	89	570
Instant coffee	99	34
Energy drink	98	340

The degree of effect differed from one experimental group to another. The results as a function of the pH value are described below.

A. After 30 Days of Immersion

Group 1 (diet cola, pH = 3.96) exhibited some scratches and general surface roughness (Fig. 3).
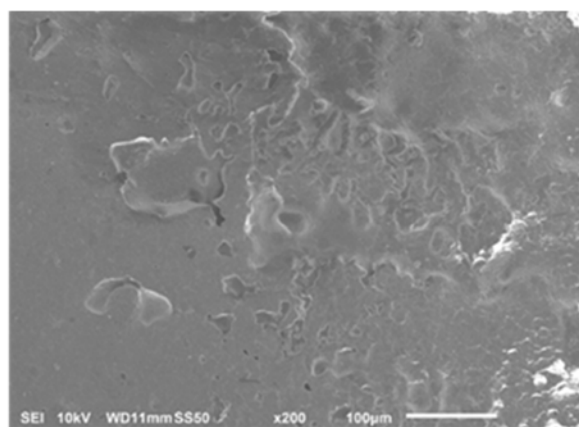

Fig. 3 The effect of the diet cola on the composite surface

Group 2 (orange juice, pH = 4.28) exhibited deep scratches, with the surface also showing some protrusions (Fig. 4).
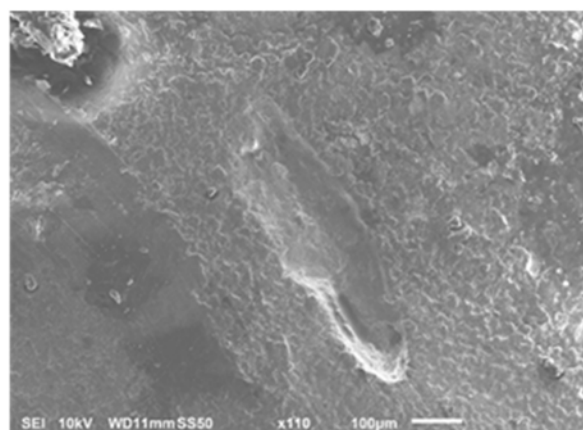

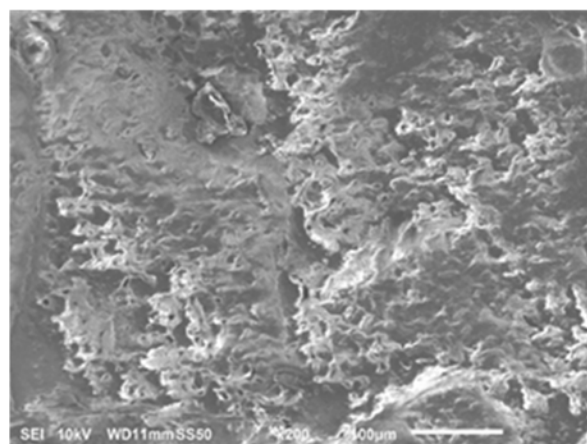Fig. 4 The effect of the orange juice on the composite surface

Fig. 5 The effect of the sparkling mineral water on the composite surface

Group 3 (sparkling mineral water, pH = 5.09) exhibited

World Academy of Science, Engineering and Technology
International Journal of Chemical and Materials Engineering
Vol:16, No:4, 2022

obvious surface roughness, with waves and many protrusions (Fig. 5).

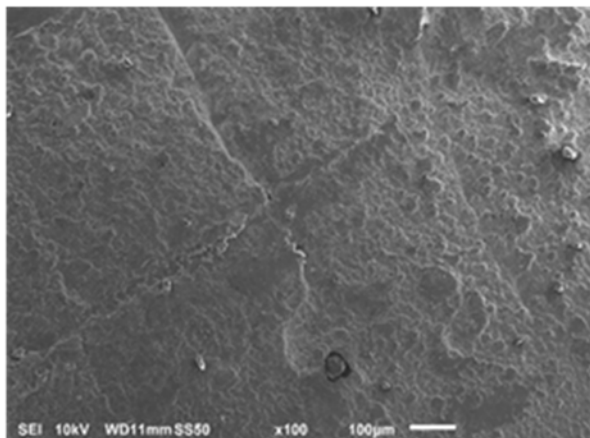Group 4 (instant coffee, pH = 5.35) exhibited some cracks and protrusions (Fig. 6).

Fig. 6 The effect of the instant coffee on the composite surface

Group 5 (energy drink, pH = 3.58; the most acidic) exhibited the lightest effect among all groups, whereby only slight protrusions were observed (Fig. 7).
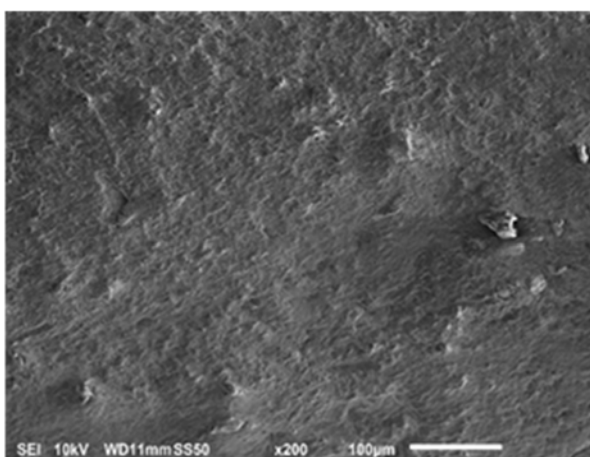
Fig. 7 The effect of the energy drink on the composite surface

For comparison with the above figures, Fig. 6 shows the control sample without any damage or pores.

As a primary result, there was no relationship between the pH value (acidity) and the degree of effect on the surface structure of the specimens. Neither the most acidic solution nor the least acidic solution had the largest effect on the composite material, with the results showing a random pattern as a function of the pH value.

After 60 Days of Immersion.Group 1 (diet cola, pH = 3.96) exhibited several waves, surface roughness, small pores, and thin deep cracks (Fig. 9).

Group 2 (orange juice, pH = 4.28) exhibited general surface roughness, some long thin cracks, pores, and protrusions (Fig. 10).
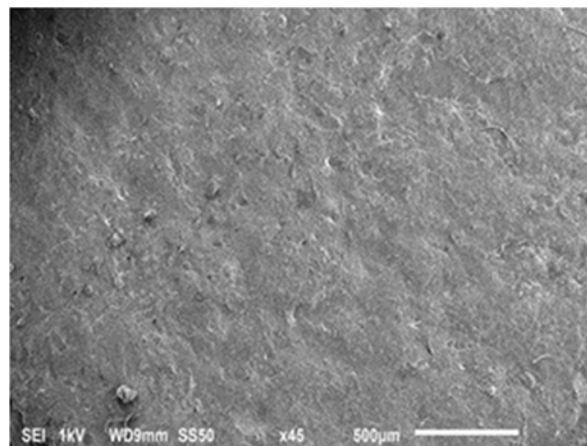

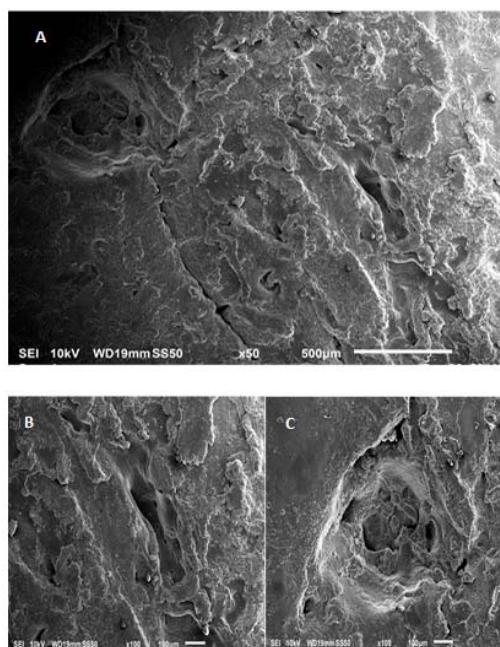Fig. 8 Control sample showing the surface without any damage or pores

Fig. 9 SEM micrographs of diet cola after 60 days of immersion: (A) 50× magnification, showing waves, small pores, and thin cracks; (B) 100× magnification, showing waves; (C) 100× magnification, showing surface roughness, one deep curve, and thin cracks

Group 3 (sparkling mineral water, pH = 5.09) exhibited many obvious protrusions, pores, and cracks (Fig. 11).

Group 4 (instant coffee, pH = 5.35) exhibited general surface roughness with widespread protrusions on the surface (Fig. 12).

Group 5 (energy drink, pH = 3.58; the most acidic) exhibited a minimal effect, with only slight protrusions and scratches observed on the surface (Fig. 13).

In groups 2 and 4, a large curve was observed on the edges of the specimens, which could have resulted from a technical error during shaping of the specimen mold.

World Academy of Science, Engineering and Technology
International Journal of Chemical and Materials Engineering
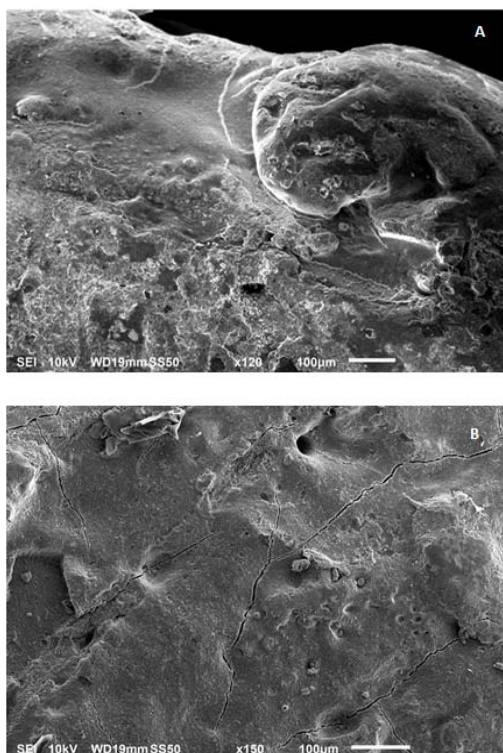Vol:16, No:4, 2022

Fig. 10 SEM micrographs of orange juice after 60 days of immersion: (A) 120× magnification, showing waves and surface roughness; (B) 150× magnification, showing surface roughness, one deep curve, thin cracks
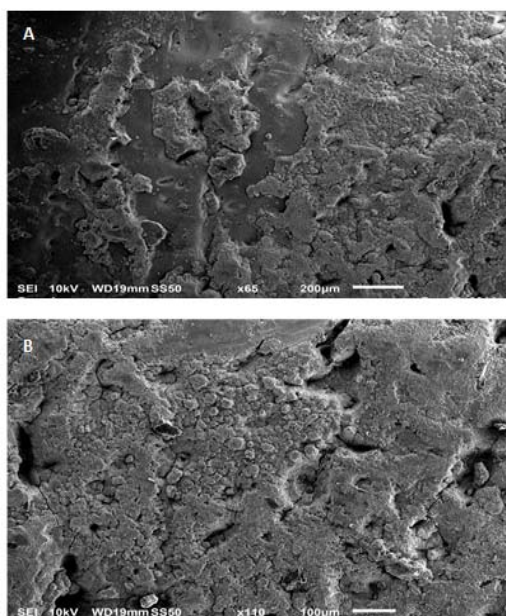

Fig. 11 SEM micrographs of sparkling mineral water after 60 days of immersion: (A) 65× magnification, showing deep cracks and surface roughness; (B) 110× magnification, showing deep pores

IV. DISCUSSION

According to the obtained results, immersion of the specimens into the solutions caused their surface structure to be affected, whereby the nanohybrid composite materials showed different levels of damage on their surface including scratches, cracks, protrusions, pores, and waves. This was observed in all experimental groups with all types of nutritional beverages [1], [5], [9].
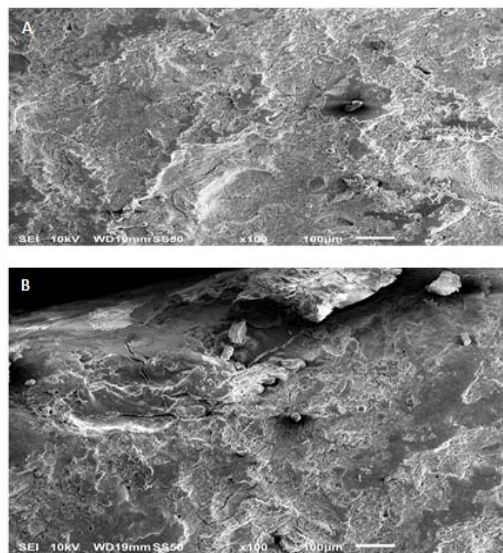

Fig. 12 SEM micrographs of instant coffee after 60 days of immersion: (A) 40× magnification, showing surface roughness, protrusions, and cracks; (B) 100× magnification, showing surface roughness, some protrusions, small cracks, and waves
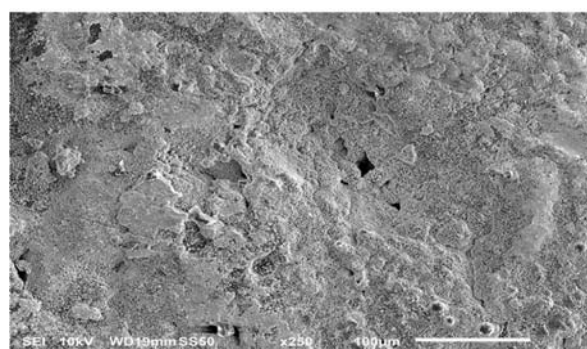

Fig. 13 SEM micrograph of energy drink after 60 days of immersion: 250× magnification, showing pores and protrusions

Previous study results showed that a longer period of immersion results in a greater effect of the beverage on the specimen surface [4], [5], [9]. In this study, clear effects were observed after 60 days of immersion, which were seen even under low powers of magnification.

After studying the SEM images of the specimens, while considering the pH value and its expected relationship with the effect on the composite surface structure, we found no definite patterns as a function of these two factors. The beverage with the lowest pH value (energy drink, pH = 3.58) had the smallest effect on the surface morphology of the specimens, whereas the beverage with the highest pH value (instant coffee) did not have the largest effect.

Specifically, diet cola had the largest effect on the composite resin specimens; different signs of distortion were clearly

World Academy of Science, Engineering and Technology
International Journal of Chemical and Materials Engineering
Vol:16, No:4, 2022

observed even under low powers of magnification, in comparison to the other groups [9]. Orange juice resulted in the specimens having waves on their surface. Under high powers of magnification, some thin, long cracks were observed, as well as pores spread throughout the surface.

Pores and protrusions were widespread on the surfaces of specimens immersed under sparkling mineral water. The observed morphology was granulated and rough, with short cracks seen under 65× and 110× magnification.

The specimens immersed in coffee (the least acidic beverage with a pH value of 5.35) exhibited many waves in addition to protrusions, thin cracks, and some pores; thus, it was more affected than the specimen immersed in sparkling mineral water.

The specimens immersed in the energy drink, (pH = 3.58, i.e., the most acidic beverage) exhibited a very minor effect, with only small scratches appearing on the surface after 60 days of immersion; this was the only notable change seen in the images, even under 250× magnification.

Taken together, the above-described results show that the pH value of a beverage is not the primary factor affecting the integrity and surface hardness of the nanocomposite material.

When hydrolysis is considered as the cause of nanocomposite material destruction, [12] stated that the restorative materials must be in contact with the oral fluids for a long period to allow fluid absorption, thereby affecting the mechanical properties of the material.

Nanocomposite materials are composed of two parts: an organic part (the matrix) and an inorganic part (the fillers) [10], [13]. Fillers help to protect the composite from being damaged, whereby the concentration, type, and size of fillers affect their ability to support the composite material [1], [2], [13]. The mechanism of hydrolytic degradation is enhanced when the filler particles have metallic ions [19]. These ions are electropositive and tend to react with water, thereby resulting in a change in the balance of charge inside the silica network, causing hydrogen ions to replace the lost metal ions and fill their spaces, leaving hydroxide ions behind. The concentration of the hydroxide ions then increases, leading to the siloxane bonds of the silica network breaking; this results in an autocatalytic cycle of surface degradation [19]. It is important to note that a tendency of water uptake by a composite is due to the presence of filler particles in its microstructure [11]. It is also important to note that hydroxide ions cause destruction upon an increase in their concentration. Maughan et al. [16] and Bagheri et al. [17] examined the effect of immersion of a nanocomposite material in NaOH, lactic acid, and distilled water, where it was observed that the NaOH solution had the largest effect on the surface structure. The SEM images showed degradation of the outer surface of the material, whereby protrusions spread throughout the surface were a result of the filler particles in the material [6].

The water content of sparkling mineral water, diet cola, and instant coffee was high (Table III), whereas energy drink had the lowest water percentage of 0.05% [20], which may explain its minor effect on the nanocomposite specimens.

V. Conclusion

The SEM images in this study showed significant damage on the composite surface. This destruction occurring in the specimens was caused by the hydrolysis process, resulting from exposure to aqueous solutions for a long period. The pH value of the studied beverages was not found to have a significant effect on the surface structure of the composite material.

During hydrolysis in materials with a large filler content, the concentration of hydroxide ions increases resulting in the siloxane bonds of the silica network breaking; this leads to an autocatalytic cycle of surface degradation. It is important to note that the tendency of water uptake is also due to the presence of filler particles in the composite microstructure, which agrees with the findings of [9] and [11].

References

[1] Aftab, A.K.; Adel, Z.S.; Abdulaziz, A.A.; Ambreen, Z.; Darshan, D.D., Pak. J. Med. Sci. 2015, 31, 854–859.
[2] Fan, H.Y.; Gan, X.; Liu, Y.; Zhu, Z.L.; Yu, H., J. Nanomater. 2014, 2014, 1–9, doi:10.1155/2014/759038.
[3] Hegde, M.N.; Hegde, P.; Bhandary, S.; Deepika, K., J. Conserv. Dent. 2011, 14, 36–39, doi:10.4103/0972-0707.80734.
[4] Maganur, P.C.; Prabhakar, A.R.; Satish, V.; Namineni, S.; Kurthukoti, World J. Dent. 2013, 4, 32–40, doi:10.5005/jp-journals-10015-1199.
[5] Yonikoğlu, N.; Duymuş, Z.Y.; Yilmaz, B., Dent. Mater. J. 2009, 28, 344–351, doi:10.4012/dmj.28.344.
[6] Ana, C.V.; Beatriz, G.N.; da Silva, E.M, J. Appl. Oral Sci. 2008, 16, 257–265, doi:10.1590/S1678-77572008000400006.
[7] Aliping-McKenzie, M.; Linden, R.W.A.; Nicholson, J.W., J. Oral Rehabil. 2004, 31, 1046–1052, doi:10.1111/j.1365-2842.2004.01348.x.
[8] Wongkhantee, S.; Patanapiradej, V.; Maneenut, C.; Tantbirojn, D., J. Dent. 2006, 34, 214–220, doi:10.1016/j.jdent.2005.06.003.
[9] Saijai, T.; Boonlert, K.; Chantima, S.; Nawanda, O.; Wathu, M.; Salinla, L.; Sulawan, W., J. Conserv. Dent. 2014, 17, 261–265.
[10] Hengtrakool, C.; Kukiattrakoon, B.; Kedjarune-Leggat, U., Eur. J. Dent. 2011, 5, 89–100, doi:10.1055/s-0039-1698863.
[11] Santos, C.; Clarke, R.; Braden, M.; Guitian, F.; Davy, K., Biomaterials 2002, 23, 1897–1904, doi:10.1016/s0142-9612(01)00331-3.
[12] El-Sharkawy, F.M.; Zaghloul, N.M.; Ell-Kappaney, A.M., Int. J. Compos. Mater. 2012, 2, 7–10, doi:10.5923/j.cmaterials.20120202.02.
[13] Münchow, E.A.; Ferreira, A.C.A.; Machado, R.M.M.; Ramos, T.S.; Braz. Dent. J. 2014, 25, 321–326, doi:10.1590/0103-6440201300058.
[14] Fontes, S.T.; Fernández, M.R.; De Moura, C.M.; Meireles, S.S., J. Appl. Oral Sci. 2009, 17, 388–391, doi:10.1590/s1678-77572009000500007.
[15] Mitra, S.B.; Wu, D.; Holmes, B.N., J. Am. Dent. Assoc. 2003, 134, 1382–1390, doi:10.14219/jada.archive.2003.0054.
[16] Maughan, R.J.; Watson, P.; Cordery, P.A.; Walsh, N.P.; Oliver, S.J.; Dolci, A.; Rodriguez-Sanchez, N.; Galloway, S.D., Am. J. Clin. Nutr. 2016, 103, 717–723, doi:10.3945/ajcn.115.114769.
[17] Bagheri, R.; Tyas, M.; Burrow, M.F., Dent. Mater. 2007, 23, 944–951, doi:10.1016/j.dental.2006.06.035.
[18] Ferracane, J.L. Resin, Dent. Mater. 2011, 27, 29–38, doi:10.1016/j.dental.2010.10.020.
[19] Martos, J.; Osinaga, P.W.R.; de Oliveira, E.; de Castro, L.A.S., Mater. Res. 2003, 6, 599–604.
[20] Gopala, K.; Fatima, M.A.; Hajer, M.A.; Khlood, N.A.; Kethani, D., Int. J. Anal. Bioanal. Chem. 2015, 5, 19–23.