Improving the Mechanical and Radiation Shielding Parameters of Sodium Cobalt Zinc Borate Glass for Radiation Shielding Purposes

*M.S. Sadeq[1, *], M.R. Maamoon[1]*

[1]Basic Science Department, Faculty of Engineering, Sinai University, Kantara, Egypt
**Corresponding author*

Correspondence:

Mohammed S. Sadeq
mhmd_sa3d@hotmail.com

Citation:

Sadeq, M .S. , Maamoon, M. R. " Article Improving the Mechanical and Radiation Shielding Parameters of Sodium Cobalt Zinc Borate Glass for Radiation Shielding Purposes", SINAI International Scientific Journal (SISJ), volume 1,Issue 2, pp. 5-17, 2024

Received: 2 May 2024

Accepted: 30 June 2024

ABSTRACT

This study has examined the impacts of adding various cobalt oxide (CoO) to the mechanical and radiation shielding properties of the B2O3-Na2O-ZnO glass system. A glass system $62B_2O_3 + 18Na_2O + (20\text{-}x)\ ZnO + (x)\ CoO$, where x = 0, 0.5, 1.0 and 1.5 mol%, was prepared by the melt-quenching process. The study has examined various elastic parameters, including Young's modulus, shear modulus, bulk modulus, and Poisson's ratio, as well as the ionizing radiation shielding properties of all glass samples. The inclusion of CoO significantly enhances the ionizing radiation shielding capabilities and elastic moduli. The inclusion of CoO significantly enhances the elastic parameters and stability of the present glass samples. The radiation shielding properties were compared to several commonly used materials. Based on this analysis, the current glass samples outperform numerous widely used materials. The present glass samples can be used for radiation shielding applications, based on the results obtained.

KEYWORDS: B_2O_3 glasses; ZnO; CoO; radiation shielding applications; mechanical properties.

1. INTRODUCTION

Ionizing radiations are utilized in several sectors, including manufacturing, energy generation, food sterilization, and diverse medical applications. Despite the beneficial sides of these radiations, there are harmful effects that occurred in the human body and equipment due to the exposure of these radiations. The reduction of harmful radiation is a crucial necessity for achieving sustainable development. Examples of ionizing radiation are x-ray and gamma rays. The key point of gamma ray is that it is a form of high-energy radiation of low wavelength and high frequency; this enables it to pass all substances except those with high atomic mass [1]. Gamma rays cause a significant risk due to their high-energy ionizing radiation, which makes them harmful to living organisms. In addition to this, gamma rays have the ability to travel distances of thousands of meters in the air without losing their energies [1,2]. The greatest hazard produced by gamma rays occurs when they pass through the living tissues of humans and animals [3]. Within this particular setting, the personnel who handle the radioactive sources are the most susceptible to these detrimental hazards. Workers in various industries, such as medical radiotherapy, nuclear accelerators and power plants, food production and sterilization, etc., are at a high risk of developing cancer and experiencing harmful effects on their nervous and immune systems. Modern scientific study has endeavored to provide efficient methods to protect workers in connected industries. An effective solution to this problem involves using high-density materials as shielding to protect against harmful radiation.

A recent scientific study is currently searching for clean and environmentally acceptable materials to reduce the harmful effects of radiation. So, numerous materials have demonstrated their efficacy in shielding against ionizing radiation. Out of all the sustainable materials, glass stands out as a very promising material for various applications because of its appealing physical and chemical qualities [1-3]. Glass has become an essential material to shield against ionizing radiation because of its exceptional transparency, environmentally acceptable nature, lightweight composition, and strong radiation absorption capabilities. Glass has several advantages, such as toxicity and opacity, which are present in materials like lead and concrete. Glass is structurally distinguished by many properties, including the incorporation of heavy metal's oxides that are necessary for shielding applications. One of the glass family's is borate glass, which has been widely investigated for shielding applications, and it has shown increased efficacy in this area recently [7,8]. Borate glass, which is a foundational material that possesses a strong capacity to retain appropriate oxides for desired characteristics. Further, this borate glass has exceptional thermal stability and transparency, as well as its low melting temperature. Moreover, borate glass is an excellent material for hosting transition metal (TM) oxides with functional properties. Borate glass containing TM has advanced optical and electrical properties, making them appropriate for potential applications in the modern technology industry. Additionally, they have the capability to be doped with high concentrations of additives [9,10]. However, zinc oxide (ZnO), which is a type of transition metal oxide, has gained significant attention because of its ability to behave as an intermediate in glass systems [11]. Additionally, it has remarkable effects on magnetic, optical and electrical properties [12]. More specifically, it has been revealed that ZnO is an oxide with intermediate properties, characterized by electric fields' intensity of 0.59 N/C and a bonds' length of 1.98Å [13,14]. Therefore, depending on the quantity of ZnO and/or alkali oxide present in the glass system, ZnO can function as [ZnO_4] units for glass formation and/or [ZnO_6] units for glass modification [13,14]. Moreover, it is assumed that the existence of Zn^{2+} alters the structure of the glass matrix [15]. Doping ZnO into glassy systems, together with alkali metal oxide, can reduce the glass melting temperatures without compromising the inherent qualities of the glass. Szumera *et al*. [16] reported that Zn^{2+} cations transitioned from being modifiers to formers in a phosphate-silicate glass system at higher contents of ZnO. In addition, numerous studies have documented successful efforts to estimate the ability of different shielding materials, such as radiation shielding glasses, to reduce the intensity of radiation [17-24].

Conversely, the mechanical characteristics of certain materials, such as hardness and resistance to cracking, are required in numerous technologically advanced applications like building, transportation, and electronics [25]. Additionally, glasses must possess high mechanical strengths, necessitating the need for certain safeguards to be taken into account. The mechanical characteristic study is an appropriate method that was utilized to assess the elastic characteristics of the different glassy systems. Nevertheless, the widely recognized inherent brittleness of glass materials limits their usefulness in contemporary applications. Researchers in the field of glass science have been interested in finding ways to enhance hardness and resistance to cracks. The Vickers hardness (HV) is commonly used to measure the hardness of glassy materials [25].

In these regards, the main goal of the present work is to investigate the impact of cobalt oxide additions on the improved mechanical and radiation shielding parameters of B_2O_3-Na_2O-ZnO glass samples.

 Online ISSN: 3009-7800

2. EXPERIMENTAL SECTION

The glassy system was prepared in the published work by El-Daly et al. [8]. Furthermore, the glass compositions and names were listed in Table 1.

Table 1: The chemical composition, of BZnNaCo glass system.

Sample Code	B_2O_3 (mol%)	ZnO (mol%)	Na_2O (mol%)	CoO (mol%)
BZnNaCo-0.0	62	20	18	0
BZnNaCo-0.5	62	19.5	18	0.5
BZnNaCo-1.5	62	19	18	1
BZnNaCo-2.0	62	18.5	18	1.5

3. THEORETICAL SECTIONS

3.1 Radiation Shielding Properties

The linear attenuation coefficient (LAC) is a crucial parameter for quantifying the shielding efficacy of the absorbing shields. The LAC quantifies the proportion of photons that are reduced when passing through a material of a specific thickness. The subsequent formula can be utilized to get this coefficient:

$$LAC = \frac{1}{thickness}\, ln\frac{N_0}{N} \tag{1}$$

The variables N_0 and N represent the intensities of incident and transmitted photons. The units of LAC are expressed in reciprocal centimeters (cm^{-1}) or reciprocal millimeters (mm-1). The LAC is influenced by both the atomic numbers and density of the shielding material. Additionally, it is a parameter that relies on energy. The mass attenuation coefficient (MAC) is obtained by dividing the LAC by the density of the absorbing shields.

$$MAC = \frac{LAC}{density} = \frac{1}{thickness \times density}\, ln\frac{N_0}{N} \tag{2}$$

The term "*Half Value Layer*" (HVL) denotes the minimum thickness of an absorbing shields needed to decrease the intensity of incident radiations by 50%. In terms of numbers,

$$HVL = \frac{0.693}{LAC} \tag{3}$$

From the LAC, values the mean free path (MFP) parameter can be calculated as follows:

$$MFP = \frac{1}{LAC} \tag{4}$$

To understand the radiation shielding features of the manufactured glass samples, we can utilize the Phy-X free and online software utilizing a package software accessible on the internet https://phy-x.net/PSD [26].

Online ISSN: 3009-7800

3.2. Elastic Parameters

To calculate the elastic parameters such as bulk modulus (K), Young modulus (E), shear modulus (S), and Poisson's ratio (σ) for different glass system, there is a proposed method by Makishima–Mackenzie [27]. In this method the dissociation energy density ($G_{B_2O_3}$) of B_2O_3. The rest of elasticity parameters can be obtained using the following formulas:

$$G_{B_2O_3} = N_4G_4 + N_3G_3 \tag{5}$$

The atomic packing density

$$APD = \frac{\sum V_i X_i}{V_m} \tag{6}$$

The dissociation energies density

$$G_t = \sum G_i X_i \tag{7}$$

where N_4 is [(ratio of BO_4units/ (BO_3+ BO_4) units] in BZnNaCo glass samples, and G_4 (=82.8 kJ/cm^3) and G_3 (=16.4 kJ/cm^3) refer to the dissociation energy density of BO_4 and BO_3 units. Xi is the molar fractions of oxide i. Herein, the N_4 values were imported from Ref. [8]. These values are 0.48, 0.49, 0.51 and 0.52 for to 0, 0.5, 1, and 1.5 mol% of CoO concentrations, respectively).

Young's modulus (E)

$$E = 2 * APD * G_t \tag{8}$$

Poisson's ratio (σ)

$$\sigma = 0.5 + \frac{1}{7.5APD} \tag{9}$$

Shear modulus (S)

$$S = \frac{E}{2(1+\sigma)} \tag{10}$$

Bulk modulus (K)

$$K = 1.2\, APD * E \tag{11}$$

4. RESULTS AND DISCUSSION

4.1. Moduli of Elasticity

Young's modulus (E) quantifies the glass's capacity to resist elastic deformations [28]. In order for glass materials to be suitable for a variety of applications, they must possess favorable mechanical characteristics. Moreover, greater values of elasticity moduli indicate superior rigidity. The moduli of elasticity consist of bulk (K), Young (E), shear (S), and Poisson's ratio (σ). K is a term that specifically refers to the decrease in volume that happens when uniform pressure is applied to its entire surface. Furthermore, K represents the pressure that is exerted on the strain ratios. E represents the ratios of stress to strain, specifically in a linear relationship. Furthermore, S represents the stress/strain (shear) ratios of the glass. Specifically, it pertains to the alteration of the shape of the glass materials without any changes in their volume. σ is a parameter that determines the ratio of transverse shrinkage to longitudinal expansion per unit length [29,30]. Glasses have the characteristic of being fragile and prone to immediate fracture when experiencing thermal or mechanical strains, unlike metallic and plastic materials. The durability of glass against thermal shock fractures is a highly significant feature. The attribute in question is directly related to Young's modulus (E), which is primarily determined by the chemical compositions of the glasses. Therefore, the calculation of Young's modulus considering the composition of glass is valuable for the development of glassy materials [31]. The composition and properties of borate glass are influenced by the concentrations of tetrahedral (BO_4), trigonal (BO_3) units, and non-bridging oxygen atoms (NBOs). The quantities of BO_4, BO_3, and NBOs are mostly determined by the chemical compositions of the glassy materials, which are modified by the glass's modifier, former, and intermediate. The value of E is significantly affected by the content of BO_3, BO_4, and NBOs. The values of different parameters used in Eqs. (5-11) such as the oxides' dissociation energy density and packing density, are mentioned before elsewhere [31].

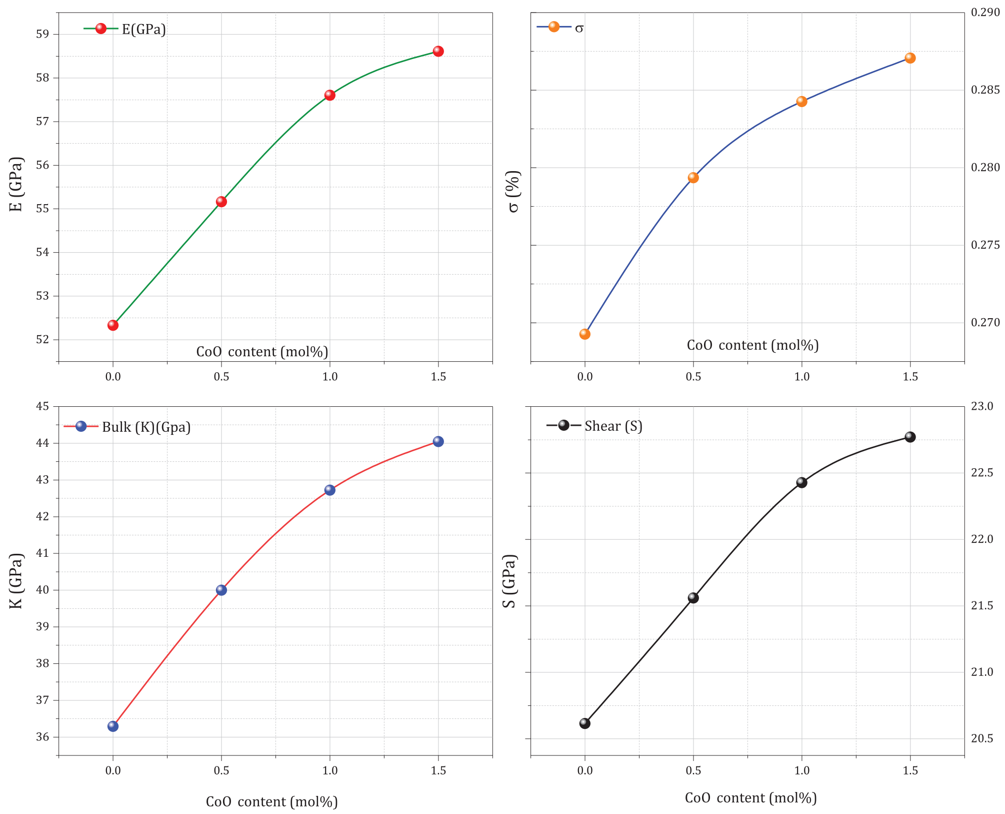


Fig. 1: The change of the elastic moduli of BZnNaCo glasses versus different CoO contents.

The obtained values of E are shown in Fig. 1. They rose from 52.33 GPa, reaching 58,61 GPa, with additional CoO concentrations. The heightened behavior of E is a result of the enhanced capacity of BZnNaCo-glasses to endure changes in their length when subjected to

 Online ISSN: 3009-7800

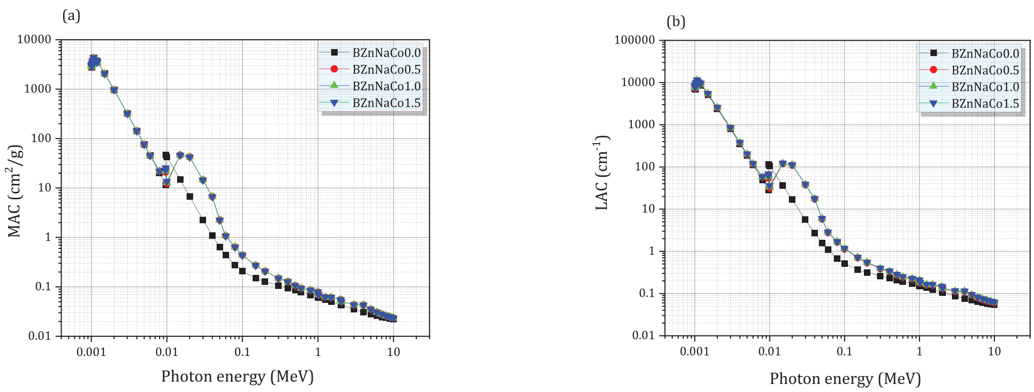
longitudinal tensile or compressive forces, particularly when combined with further concentrations of CoO. This increase in E can be linked to the increase in the bonding strength. Moreover, the values of σ for BZnNaCo-glass system were computed from Eq. (9).

As displayed in Fig. 1, σ has increased values for BZnNaCo- glass system with further concentrations of CoO. These increased values of σ mean if the BZnNaCo-glass under stress, they experience lateral strains greater than the longitudinal strains. Furthermore, S and K values can be computed by means of E values, as aforementioned in Eq. (10). The computed values for S and K are shown in Fig. 1. Fig. 1 obvious that the values of S and K show enhanced trends for BZnNaCo-glasses with additional concentrations of CoO in the glassy matrix. The S values increased from 20.61 GPa up to 22.77 GPa, while the K values changed from 36.29 GPa up to 44.04 GPa, with increasing the concentrations of CoO to the glass matrix. Similar behaviors were reported in Refs [33-35]. These increments are in good agreement with the results of structural analysis mentioned in Ref [8]. An increase in the BO_4 units' content inside BZnNaCo-glasses, accompanied by a reduction in the nonbridging oxygens inside the glass structure, results in an enhancement in the elastic characteristics of the glass. The obtained values of σ for BZnNaCo-glasses range from 0.27 to 0.29. The observed range indicates a high level of cross-linked densities and rigidity. Consequently, the rise in cross-link densities, indicative of greater interconnectedness, leads to a further enhancement in the elastic characteristics of the glass samples that were created. The present elastic parameter values are equivalent to the previously published values for borate glassy systems [33,34].

4.2 Radiation Shielding Parameters of BZnNaCo-Glasses

4.2.1 Photon Energy Dependence

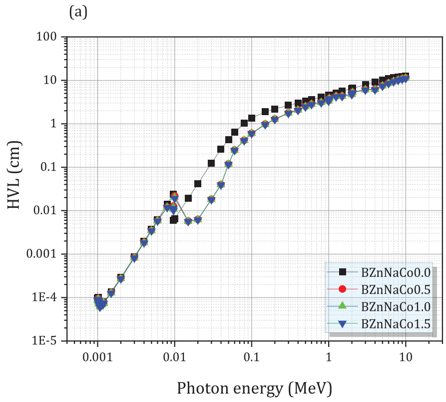
The significance of using theoretical and quantitative assessments for shields against ionizing radiation in pre-decision evaluations is currently being actively researched [35]. In this study, the Phy-X program [26] was employed to calculate several radiation shielding coefficients, such as MAC, LAC, HVL and MFP in different energy ranges from 0.001 to 10 MeV.



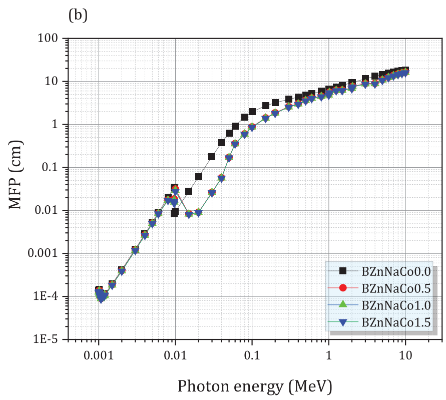
(a) **(b)**

Fig. 2: (a) The mass attenuation coefficient (MAC) as a function of the energy for BZnNaCo -glasses and (b) The linear attenuation coefficient (LAC) as a function of the energy for BZnNaCo-glasses.

The MAC and LAC values for BZnNaCo-samples were computed and represented as a function of photon energy in Fig. 2a and 2b, considering various CoO concentrations. Exploring Fig. 2a and 2b, we can notice that the MAC and LAC show fast decrements when the gamma ray energy changed from 0.001 to 0.01 MeV. This behavior can be attributed in terms of the photoelectric effect with cross-sections (σ_{PE}) which refers to photon-matter interactions that major at low photon energy range, where σ_{PE} proportional to $\frac{(\text{atomic number})^{4-5}}{(\text{photon energy})^{3.5}} = \frac{Z^{4-5}}{E^{3.5}}$. The sharp increase from 0.01 MeV to 0.015 MeV is associated with the K-shell absorptions edge of large atomic number elements, such as Co and Zn comprised in BZnNaCo-glass. When the photon energy increased more than 0.1 MeV to be in the intermediate energy range, the major interaction considered is Compton Scattering (CS) with cross section (σ_{CS}), where $\sigma_{CS}\alpha \frac{Z}{E}$ [36]. At photon energy more than 1 MeV, slight reductions were observed in both mass attenuation and linear attenuation coefficients. These slight reductions were ascribed to the predominance of pair production mechanisms (PP) with cross-section (σ_{PP}); where (where $\sigma_{PP}\alpha Z^2$) [35].



(a)

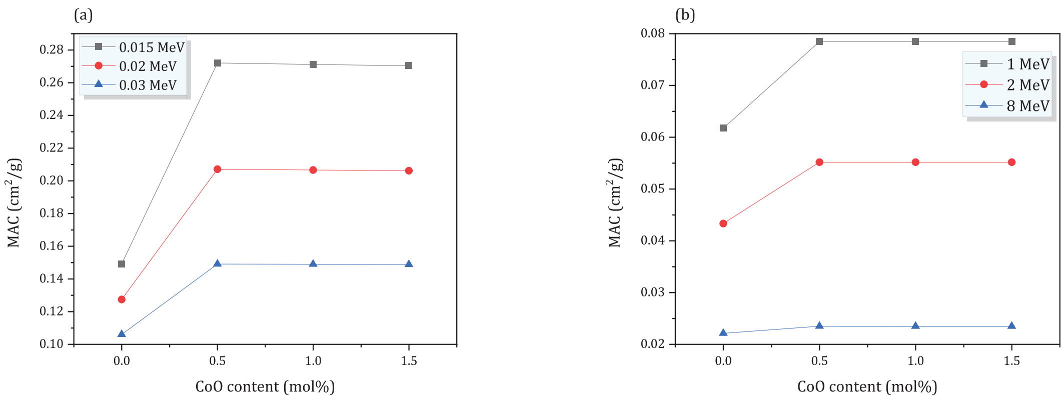


(b)

Fig. 3: (a) The half value layer (HVL) as a function of the energy for BZnNaCo -glasses and (b) The mean free path (MFP) as a function of the energy for BZnNaCo -glasses.

Fig. 3a and 3b depict the HVL and MFP as they vary with photon energy for various contents of CoO. The HVL and MFP values exhibit a rapid rise within the energy range of 0.001 to 0.1 MeV. Then, there are gradual increases in the HVL and MFP values between 0.1 MeV and 10 MeV. All BZnNaCo-glass samples exhibit consistent HVL and MFP characteristics across all ranges of photon energy. Moreover, these behaviors can be comprehended in the following manner. At low photon energies, the shielding materials require a slim layer (with lesser values of HVL) due to the photoelectric effects. Conversely, at intermediate energy levels, shielding materials need a thick layer (with greater values of HVL) due to secondary Compton's scattering [35]. Furthermore, when photons have higher energies, a substantial amount of them can penetrate within the shielding material. In order to decrease the number of photons transmitted by 50%, it is essential to increase the thickness of the absorber [37].

Online ISSN: 3009-7800

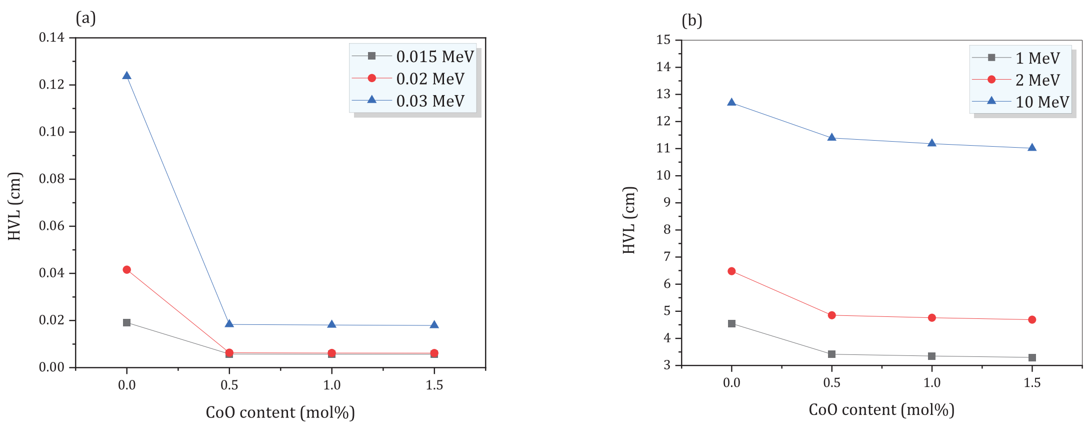


(a) **(b)**

Fig. 4: The mass attenuation coefficient versus CoO content for BZnNaCo -glasses at (a) low energy range and (b) high energy range.

4.2.2 Compositions Dependency of BZnNaCo-glass Samples

Fig. 4a and 4b displays the MAC values corresponding to different CoO concentrations, separately for the lower and higher energy ranges. The provided data shows the impacts of CoO concentration on the values of the MAC, which demonstrate rising trends in the energy range of 0.015 to 15 MeV, both at low and high energy levels. Indeed, these trends can be rationalized by the influences of CoO on the structural characteristics of BZnNaCo-glasses, such as the increased values of their density values. The density of a medium is considered a significant factor that affects its ability to reduce the intensity of radiation photons. Further the MAC values depend on both mass and the incidents photon energy. To clarify the impacts of the photon energy and the density on the MAC values changes, the slope of the MAC vs CoO plots is higher at low energy compared to high energy, as shown from the comparison of Fig. 4a and 4b. Thus, the presence of CoO significantly influences the MAC values of the BZnNaCo-samples at low energies.



(a) **(b)**

Fig. 5: The half value layer versus CoO content for BZnNaCo -glasses at (a) low energy range and (b) high energy range.

The data shown in Fig. 5a and 5b clearly demonstrate that the half-value layer (HVL) values drop as the amount of CoO increases from 0 to 1.5 mol% across the lower and higher photon energy range of 0.015 to 10 MeV. The declines can be attributed to the inverse relationship between the densities of the shielding materials and the HVL. The higher density values lead to a substantial decrease in HVL values. In addition, the reduced HVL values indicate enhanced and efficient shields against ionizing radiation dangers. This remark indicates that the existence of CoO significantly affects the shielding capabilities of the present BZnNaCo-glass.

4.3. Comparative Analysis of the Current Glass Samples and Conventional Shielding Materials.

To include the current glass samples into radiation shielding usage, it is essential to make a comparative analysis with known and commonly used shielding materials. The materials utilized consist of commercial window glass, ordinary concretes, Ilmenite concretes, Hematite serpentine, serpentine, and RS253 from SCHOOT. Fig. 6 illustrates a comparison of the HVL values for BZnNaCo-glass and other materials used for shielding, specifically at a photon energy of 0.662 MeV. The HVL values of these materials at 0.662 MeV can be found in the literature [37-39]. Fig. 6 obviously shows that the HVL values of the present BZnNaCo-glass materials are lower than those of commercial window glasses, ordinary concretes, and serpentines. Thus, it can be inferred that the present glass materials have higher degrees of shielding effectiveness when employed for the purpose of ionizing radiation shielding.

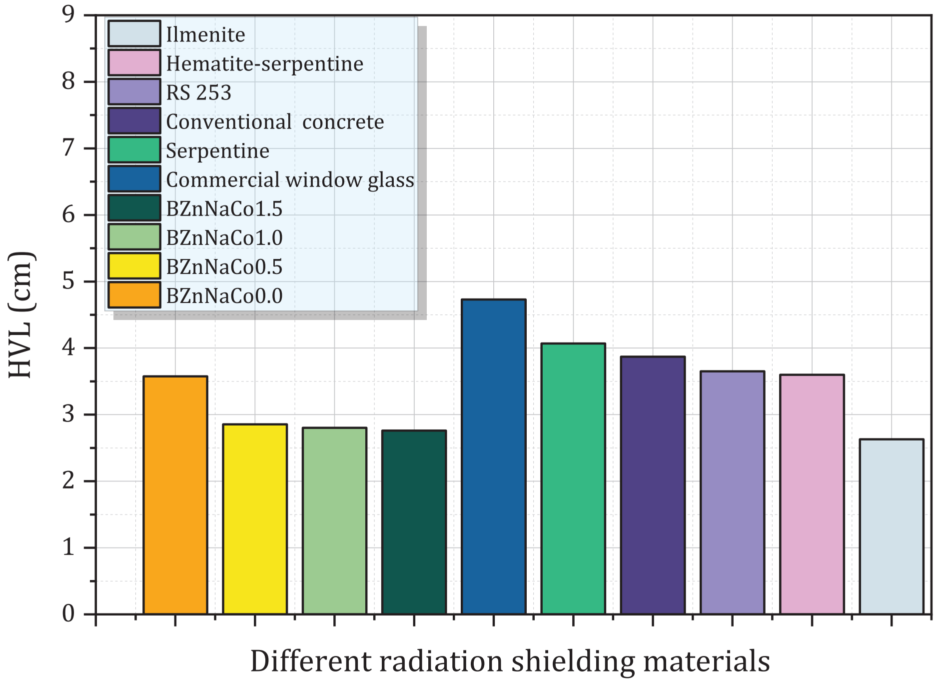


Fig. 6: The half value layer (HVL) of the BZnNaCo -glasses in comparison to some standard shielding materials at 0.662 MeV.

5. CONCLUSION

This study presents the results of an investigation into the mechanical and radiation shielding features of borate glass that has been doped with varying amounts of cobalt oxide (CoO), sodium oxide (Na_2O) and zinc oxide (ZnO). The main conclusions of this study are: (i) the elastic moduli values have demonstrated a rise as the content of CoO within the glass network increases, as indicated by mechanical measurements. The increasing in these values can be attributed to the additions of CoO, which leads to the incorporation of additional tetrahedral units (BO_4) inside the glassy network, and (ii) the results of the radiation shielding characteristics have been improved with higher concentrations of CoO. The current glass samples exhibit a beneficial combination of enhanced radiation shielding characteristics and enhanced mechanical parameters, making them very appropriate for use in radiation shielding applications. (iii) Furthermore, in future studies, our aim is to produce the aforementioned glass system containing higher levels of CoO to produce glass systems that have enhanced properties for shielding against radiation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1.] N.J. AbuAlRoos, N.A. Baharul Amin, R. Zainon, Conventional and new lead-free radiation shielding materials for radiation protection in nuclear medicine: A review, Radiat. Phys. Chem. 165 (2019) 108439.

[2.] P. Kaur, K.J. Singh, S. Thakur, Evaluation of the gamma radiation shielding parameters of bismuth modified quaternary glass system, AIP Conf. Proc. 1953 (2018) 3–6.

[3.] M.I. Sayyed, M.S. Sadeq, K.S. Shaaban, A.F.A. El-Rehim, A.M. Ali, H.Y. Morshidy, Elucidating the effect of La2O3–B2O3 exchange on structure, optical and radiation shielding improvements of Na2O–NiO–B2O3 glass, Opt. Mater. (Amst). 142 (2023) 114051.

[4.] A.M. Babeer, M.I. Sayyed, H.Y. Morshidy, A.E. Mahmoud, M.A. Abdo, M.S. Sadeq, High transparency of PbO–BaO–Fe2O3–SrO–B2O3 glasses with improved radiation shielding properties, Opt. Mater. (Amst). 145 (2023) 114387.

[5.] M.I. Abbas, J.S. Alzahrani, M.I. Sayyed, D.I. Tishkevich, M.T. Alabsy, A.M. El-Khatib, M. Elsafi, Gamma-ray attenuation and exposure buildup factor of novel polymers in shielding using geant4 simulation, Materials (Basel). 14 (2021) 5051.

[6.] A. Samir, M.A. Hassan, F. Ahmad, M.S. Sadeq, S.Y. Marzouk, H.Y. Morshidy, Impacts of BaO additives on the mechanical, optical and radiation. 143 (2023) 114195.

[7.] M.S. Sadeq, M.I. Sayyed, M.A. Abdo, H.E. Ali, A.E. razek Mahmoud, H.A. Ahmed, Compositional dependence of transparency, linear and non-linear optical parameters, and radiation shielding properties in lanthanum, iron and calcium borate glasses, Radiat. Phys. Chem. 212 (2023) 111027.

[8.] A.A. El-Daly, M.A. Abdo, H.A. Bakr, M.S. Sadeq, Structure, stability and optical parameters of cobalt zinc borate glasses, Ceramics International. 47 (2021) 31470

[9.] N. Deopa, S. Saini, S. Kaur, A Prasad, AS Rao. Spectroscopic investigations on Dy3+ ions doped zinc lead alumino borate glasses for photonic device applications. J Rare

 Online ISSN: 3009-7800

Earths. 37 (2019) 37-52.

[10.] S.M. Salem, S.F. Mansour, I.I. Bashter, M.S. Sadeq, A.G. Mostafa, Effect of mixed heavy metal cations on the A.C. conductivity and dielectric properties of some borosilicate glasses, Ceram. Int. 44 (2018) 14363–14369.

[11.] H.A. Abo-Mosallam, H. Darwish, S.M. Salman, Crystallization characteristic and properties of some zinc containing soda lime silicate glasses, J. Mater. Sci.: Mater. Electron. 21 (2010) 889–896.

[12.] X.J. Hao, Z.W. Luo, X.L. Hu, J. Song, Y. Tang, A.X. Lu, Effect of replacement of B2O3 by ZnO on preparation and properties of transparent cordierite-based glass-ceramics, J. Non-Cryst. Solids. 432 (2016) 265–270.

[13.] H. Gui, C. Li, C. Lin, Q. Zhang, Z. Luo, L. Hana, J. Liu, T. Liu, A. Lu, Glass forming, crystallization, and physical properties of MgO-Al2O3-SiO2- B2O3 glass-ceramics modifed by ZnO replacing MgO, J. Euro. Ceram. Society. 39 (2019) 1397–1410.

[14.] A.B. Rosenthal, S.H. Garofalini, Structural role of zinc oxide in silica and soda-silica glasses, J. Am. Ceram. Soc. 70 (1987) 821–826.

[15.] A.M.F. Alhalawani, M.R. Towler, The effect of ZnO ↔Ta2O5 substitution on the structural and thermal properties of SiO2-ZnO-SrO-CaO-P2O5 glasses, Mater. Charact. 114 (2016) 218–224.

[16.] M. Szumera, I. Wacławska, J. Sułowska, Influence of CuO and ZnO addition on the multicomponent phosphate glasses: Spectroscopic studies, J. Mol. Struct. 1114 (2016) 78–83.

[17.] M.H.A. Mhareb, M. Alqahtani, F. Alshahri, Y.S.M. Alajerami, N. Saleh, N. Alonizan, M.I. Sayyed, M.G.B. Ashiq, T. Ghrib, S.I. Al-dhafar, T. Alayed, M.A. Morsy, The impact of barium oxide on physical, structural, optical, and shielding features of sodium zinc borate glass, J. Non. Cryst. Solids. 541 (2020) 120090.

[18.] D.A. Aloraini, A. Kumar, A.H. Almuqrin, M.I. Sayyed, Optical and gamma ray shielding properties BaO doped K2O-TiO2-P2O5 glasses, Optik (Stuttg). 247 (2021) 167893.

[19.] D.A. Aloraini, M.Y. Hanfi, M.I. Sayyed, K.A. Naseer, A.H. Almuqrin, P. Tamayo, O.L. Tashlykov, K.A. Mahmoud, Design and Gamma-Ray Attenuation Features of New Concrete Materials for Low- and Moderate-Photons Energy Protection Applications, Materials (Basel). 15 (2022) 4947.

[20.] M.U. Khandaker, D.A. Bradley, H. Osman, M.I. Sayyed, A. Sulieman, M.R.I. Faruque, K.A. Naseer, A.M. Idris, The significance of nuclear data in the production of radionuclides for theranostic/therapeutic applications, Radiat. Phys. Chem. 200 (2022) 110342.

[21.] S. Arunkumar, K.A. Naseer, M. Yoosuf Ameen, K.A. Mahmoud, M.I. Sayyed, K. Marimuthu, D. James Silvia, R. Divina, M.S. Alqahtani, E.S. Yousef, Physical, structural, optical, and radiation screening studies on Dysprosium ions doped Niobium Bariumtelluroborate glasses, Radiat. Phys. Chem. 204 (2023).

[22.] M.I. Sayyed, N. Dwaikat, M.H.A. Mhareb, A.N. D'Souza, N. Almousa, Y.S.M. Alajerami, F. Almasoud, K.A. Naseer, S.D. Kamath, M.U. Khandaker, H. Osman, S. Alamri, Effect of TeO2 addition on the gamma radiation shielding competence and mechanical properties of boro-tellurite glass: an experimental approach, J. Mater. Res. Technol. 18 (2022) 1017–1027.

[23.] S.A. Bassam, K.A. Naseer, V.K. Keerthana, P. Evangelin Teresa, C.S. Suchand Sangeeth, K.A. Mahmoud, M.I. Sayyed, M.S. Alqahtani, E. El Shiekh, M.U. Khandaker, Physical, structural, elastic and optical investigations on Dy3+ ions doped boro-tellurite glasses for

radiation attenuation application, Radiat. Phys. Chem. 206 (2023) 110798.
[24.] S.A. Bassam, K.A. Naseer, A.J. Prakash, K.A. Mahmoud, C.S. SuchandSangeeth, M.I. Sayyed, M.S. Alqahtani, E. El Sheikh, M.U. Khandaker, Effect of Tm2O3 addition on the physical, structural, elastic, and radiation-resisting attributes of tellurite-based glasses, Radiat. Phys. Chem. 209 (2023) 110988.
[25.] M.Yamane & J.D Mackenzie. Vicker's hardness of glass. J. Non-Cryst. Solids. 15 (1974) 153–164.
[26.] E. Şakar, Ö.F. Özpolat, B. Alım, M.I. Sayyed, M. Kurudirek, Phy-X / PSD: Development of a user friendly online software for calculation of parameters relevant to radiation shielding and dosimetry, Radiat. Phys. Chem. 166 (2020) 108496.
[27.] A. Makishima, J.D. Mackenzie, Direct calculation of Young's modulus of glass, J. Non-Cryst. Solids 12 (1973) 35–45
[28.] Jianchao Lu, Zhitao Shan, Jun Zhang, Yucai Su, Kangfeng Yi, Yanfei Zhang, Qiuju Zheng, Mechanical properties of mixed modified oxide glasses, Journal of Non-Crystalline Solids 16 (2022) 100125
[29.] G. Lakshminarayana, M.G. Dong, M.S. Al-Buriahi, Najeh Rekik, Dong-Eun Lee, Jonghun Yoon, Taejoon Park, Physical, structural, thermal, and mechanical features combined with neutron and gamma radiation attenuation qualities of Sm2O3 doped transparent borate-rich glasses, of Materials Research and Technology. 22 (2022) 1268-1296.
[30.] M.S. Sadeq, M.I. Sayyed, K.A. Mahmoud, A.M. Abdel-Ghany, The structural, optical, mechanical and radiation shielding features of transparent borate glasses containing bismuth and lead cations, Applied Physics A, 128 (2022) 104.
[31.] S. Inaba, S. Fujino, K. Morinaga, Young's Modulus and Compositional Parameters of Oxide Glasses, J. Am. Ceram. Soc., 82 [12] (1999) 3501–507.
[32.] S. Inaba, S. Oda, K. Morinaga, Heat capacity of oxide glasses at high temperature region, Journal of Non-Crystalline Solids 325 (2003) 258–266.
[33.] H.D. Shashikala, N.K. Udayashankar, Influence of Fe3+ ions on optical, structural, thermal and mechanical properties of Li2O–Na2O–K2O–ZnO–B2O3 based glass system, Ceramics International 46 (4) (2020) 5213–5222
[34.] T. Rouxel, Elastic properties and short-to medium-range order in glasses, J. Am. Ceram. Soc. 90 (2007) 3019–3039.
[35.] M. Ezzeldin, Laila M. Al-Harbi, M.S. Sadeq, A.E. Mahmoud, M.A. Muhammad, H. A. Ahmed, Impact of CdO on Optical, structural, elastic, and radiation shielding parameters of CdO–PbO-ZnO-B2O3-SiO2 glasses, Cerm. Int. 49 (2023)19160–19173.
[36.] S. Stalin, D.K. Gaikwad, M.S. Al-Buriahi, Ch Srinivasu, Shaik Amer Ahmed, H. O. Tekin e, Syed Rahman, Influence of Bi2O3/WO3 substitution on the optical, mechanical, chemical durability and gamma ray shielding properties of lithium-borate glasses, Ceram. Int. 47 (2021) 5286–5299.
[37.] M. S. Sadeq, B. O. El-bashir, A. Almuqrin, M. I. Sayyed, The tungsten oxide within phosphate glasses to investigate the structural, optical, and shielding properties variations, J. Mater. Sci. Mater. Electron. 32 (2021) 12402–12413.
[38.] W. Cheewasukhanont, P. Limkitjaroenporn, M.I. Sayyed, S. Kothan, H.J. Kim, J. Kaewkhao, High density of tungsten gadolinium borate glasses for radiation shielding material: effect of WO3 concentration, Radiat. Phys. Chem. 192 (2022) 109926.
[39.] A. Samir, M.A. Hassan, F. Ahmad, M.S. Sadeq, S.Y. Marzouk, H.Y. Morshidy, Impacts of BaO additives on the mechanical, optical and radiation shielding properties of BaO–

K2O– CoO–Al2O3–B2O3 glasses, Opt. Mater. (Amst). 143 (2023) 114195.
[40.] A. Ibrahim, M.A. Farag, M.S. Sadeq, Towards highly transparent tungsten zinc sodium borate glasses for radiation shielding purposes, Ceram. Int. 48 (2022) 12079–12090.