Study of bagasse and cassava rhizome effects on the physical, mechanical and structural properties of soda-lime borate glasses

P. Sopapan¹ · R. Laopaiboon¹ · J. Laopaiboon¹ · P. Gunhakoon¹ · T. Thongklom² · O. Jaiboon¹

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Abstract

The glass prepared from sustainable raw materials yields interesting properties, besides the low cost and environmentally friendly. Two series of glass compositions based on B_2O_3 – P_2O_5 – Na_2O – CaO added with bagasse (BG) and cassava rhizome (CR) were fabricated by melt-quenching technique, and their physical, mechanical and structural properties were studied. The physical properties such as density and molar volume were calculated and discussed. The elastic moduli, Poisson's ratio, Debye temperature, acoustical impedance and microhardness have been estimated based on pressure-controlled ultrasonic technique at 4 MHz frequency with normal and angle probes. It was found that the addition of bagasse and cassava rhizome leads to an increase of elastic constants, Debye temperature and microhardness of the prepared glass. Vickers hardness tester was also applied to determine microhardness of the glass using an applied load of 0.98 N. The values of microhardness obtained from both techniques were compared and a good correlation was observed. Moreover, the internal structural units of the glass samples have been estimated by FTIR. XRD spectroscopy was applied to confirm the amorphous nature in the glasses.

Keywords Bagasse · Cassava rhizome · Glass · Pressure-controlled ultrasonic technique · Elastic constants · FTIR spectroscopy

1 Introduction

Biomass developed from agricultural production wastes and energy crops is discovered abundantly in nature, especially tropical countries like Thailand [1, 2]. Bagasse and cassava rhizome ashes are the biomass sources derived from valuable by-products in sugar extraction and waste of cassava fructification, respectively. However, incineration of bagasse and cassava rhizome as an energy source causes serious disposal problems, especially air pollution ($PM_{2.5}$ and PM_{10}) [3, 4]. There are several studies of using bagasse and cassava rhizome ashes in many alternative applications such as production of glasses, ceramics, bio-composites, biomaterials, cements and concretes, etc. [5–8]. Converting these ashes into a glass system is one

of alternative ways that may provide enormous benefits, because research in various capacities are being carried out on the applicability of glasses in various areas of glass applications such as biomaterials, radiation shields, optical devices, semiconductor microelectronics, etc. [9–11]. Bagasse and cassava rhizome ashes not only contain SiO_2 and CaO that can be the main composition, but also contain some elements acting as a modifier oxide in glass network such as Al, Mg, Sr, Ti, etc. (see in Table 1). Therefore, the replacement of pure raw materials by these agricultural wastes for fabrication of a glass system can be an interesting way in recycling these wastes.

Borate as glass host has received great attention and plays a key role for applying in many applications. It is one of technologically important groups of commercial

✉ O. Jaiboon, oruethai.j@ubu.ac.th | ¹Department of Physics, Faculty of Science, Ubon Ratchathani University, Ubon Ratchathani 34190, Thailand. ²Department of Industrial Engineering, Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani 34190, Thailand.

Table 1 Chemical compositions of bagasse and cassava rhizome by WDXRF method

Compounds	Bagasse (wt%)	Cassava rhizome (wt%)
MgO	1.430	16.300
Al ₂ O ₃	5.990	1.230
SiO ₂	77.100	16.700
P ₂ O ₅	0.900	12.100
K ₂ O	3.530	14.600
CaO	5.180	37.080
TiO ₂	0.395	0.227
Cr ₂ O ₃	0.019	0.034
MnO	0.184	0.618
Fe ₂ O ₃	5.181	0.787
CuO	0.013	–
ZnO	0.021	0.063
SrO	0.016	0.226
ZrO ₂	0.040	0.036
Total	100.000	100.000

glasses owing to their unique characteristics which include a low melting point, a high thermal stability, transparency, mechanical and chemical durability [12–14]. In borate glasses, it is an established fact that boron is a laminar network consisting of three and/or four coordination numbers. Hence, the glassy B₂O₃ can have a triangle and/or tetrahedron forming three and four oxygen coordinated neighbors as structural units, and the high strengths of covalent B–O bonds enables borates to form stable glasses [15, 16]. However, the structure of borate glass not only depends on the network formers, but also on the additive's attendant in the constituent of glasses [17]. Introduction of some trace elements into glass network rearranges the glass internal structure by converting [BO₃] to [BO₄] structural units and leads to the formation of various borate groups. These additives also act as a modifier oxide in the glass matrix, and consequently an improvement their properties [18, 19]. Therefore, borate glass system has been under intense research to understand the physical, mechanical, and structural properties through various experimental techniques.

Among the diverse methods required high precision, ultrasonic non-destructive technique is found to be the versatile tool for understanding the association of the structural characteristics and mechanical properties of amorphous materials [20]. The ultrasonic examination helps to understand the interatomic and ionic forces including the potentials in lattice structure [21, 22]. The acoustic velocity as well as the density of glasses can be considered as parameters of elastic constants related directly to changes in the glass structure. Combined with

the use of FTIR, the confirmation of the structural units of glass components has been received continuous attention. Moreover, this measurement can also describe the microhardness of materials, which is correlated directly with its strength, wear resistance and other mechanical properties [23, 24]. As a result, hardness investigation by various techniques is widely considered for material evaluation. Since the values of elastic moduli and microhardness depended on an applied load, the design to control pressure on the ultrasonic measurement is required. Therefore, the consideration of the most appropriate glasses for specific application requires a knowledge of their mechanical and structural properties.

A spacious investigation has been carried out to study many properties in borate glass added with some pure elements. However, there are quite a few studies about new series of the borate glass prepared from bagasse and cassava rhizome. Therefore, the concept of this research is to introduce bagasse and cassava rhizome ashes as a component for glass system in order to maximize the use of resources. Preparation of the borate glasses with fly ash of bagasse and cassava rhizome was carried out by using rapid quenching method and in order to predict the mechanical and structural properties of these prepared glasses via the pulse-echo ultrasonic method. The pressure-controlled technique for measuring ultrasonic wave velocities was designed to control a suitable applied load. To compare and evaluate the accuracy of the microhardness, Vickers indentation has also been applied. Moreover, the glass structure has been confirmed by FTIR spectroscopy.

2 Materials and methods

2.1 Bagasse and cassava rhizome characterization

Ashes of bagasse and cassava rhizome were collected from electric power plant and agricultural plantation in north-east region of Thailand, respectively. Each ash was crush in an agate mortar and was graded to obtain particle size of 180 µm using a sieve shaker machine. After that, the fly ashes of bagasse and cassava rhizome were calcined in an electric furnace for 1 h at 1073 and 1273 K, respectively. The corresponding constituents of both wastes were analyzed by using WDXRF instrument (Panalytical, MagiX) with super sharp x-ray tube (rhodium anode) and two detectors (gas-filled proportional and scintillation). The constituents of both ashes were listed in Table 1.

2.2 Sample preparation

Two glass series of composition $(68-x)\text{B}_2\text{O}_3-3\text{P}_2\text{O}_5-17\text{Na}_2\text{O}-12\text{CaO}-x\text{BG}$ and $(68-x)\text{B}_2\text{O}_3-3\text{P}_2\text{O}_5-17\text{Na}_2\text{O}-12\text{CaO}-x\text{CR}$, where $x = 0, 5$ and 10 wt%, were prepared. These glasses were fabricated from reagent-grade powders of H_3BO_3 , $(\text{NH}_4)_2\text{HPO}_4$, Na_2CO_3 , and CaO as well as fly ashes of bagasse (BG) and cassava rhizome (CR), mixed together in appropriate amounts until obtaining homogeneous in alumina crucibles. The homogeneous mixture was then calcined and melted in an electrically heated muffle furnace under normal laboratory condition without controlling the atmosphere. Temperature range of $1373-1473$ K, depending on the composition, for 2 h-melting were employed to ensure the homogeneity before pouring onto a graphite block. Vitreous samples were then placed again into the furnace at appropriate temperature of 723 K for an annealing process to reduce any internal residual stress in the glass. After 2 h, the furnace was switched off and such glass sample was allowed to cool slowly to environmental temperature. Glass samples with parallel flat and smooth surface were then obtained by cutting and polishing for ultrasonic velocity and Vickers hardness measurements.

2.3 Density and molar volume studies

A simple Archimedes' technique using n-hexane (C_6H_{14}) as the reference worked liquid was used to determine density of the fragments of bulk glass. Knowing the apparent weight of the glass samples measured in air and reference fluid (W_a and W_r) allows us to calculate the density (ρ) by the expression in Eq. (1) where ρ_r is the density of C_6H_{14} solution equal to 0.6600 g/cm³. The obtained density and total atomic mass (M) of the glasses were applied to calculate the molar volume (V_a) of the glass samples with Eq. (2) [25, 26].

$$\rho = \rho_r \left(\frac{W_a}{W_a - W_r} \right) \quad (1)$$

$$V_a = \frac{M_{\text{glass}}}{\rho} \quad (2)$$

The theoretical density and molar volume for borate glasses with correlation factor 99.4% can be calculated by following expressions [27, 28]:

$$\rho_{\text{cal}} = 0.90 \sum_i \rho_i x_i \quad (3)$$

$$V_a(\text{cal}) = \sum_i \frac{M_i x_i}{\rho_{\text{cal}}} \quad (4)$$

where ρ_{cal} is the theoretical glass density, whereas x_i and M_i are the weight fraction and its molecular weight of the i th component respectively.

2.4 Ultrasonic velocity and elastic modulus

The suitable pressure-controlled ultrasonic method was applied to find the sound velocity values. The longitudinal (v_l) and shear (v_s) wave velocities were generated from SLG4-10 and SA04-45° transducer probes, respectively. Both velocities were operated at a fundamental frequency of 4 MHz along with ultrasonic flaw detector (GE Phasor XS) in mode A-scan, and a constant pressure of 0.98 N was also applied to control their pressures on the glass surface. The velocities of the studied glasses are obtained by measurement of the time intervals between transmission of the pulse and reception of the reply appearing directly on the monitor.

After receiving the density and sound velocity of the glass samples, elastic moduli (L, G, K, E), Poisson's ratio (σ), microhardness (H) and Debye temperature (θ_D) were calculated in the following equations [10, 29]:

$$\text{Longitudinal modulus: } L = \rho v_l^2 \quad (5)$$

$$\text{Shear modulus: } G = \rho v_s^2 \quad (6)$$

$$\text{Bulk modulus: } K = L - \left(\frac{4}{3} \right) G \quad (7)$$

$$\text{Young's modulus: } E = 2(1 + \sigma)G \quad (8)$$

$$\text{Poisson's ratio: } \sigma = \frac{L - 2G}{2(L - G)} \quad (9)$$

$$\text{Microhardness: } H = \frac{(1 - 2\sigma)E}{6(1 + \sigma)} \quad (10)$$

$$\text{Debye temperature: } \theta_D = \left(\frac{h}{K_B} \right) \left(\frac{9N_A}{4\pi V_a} \right)^{1/3} v_m \quad (11)$$

where h is the Planck's constant, K_B the Boltzmann's constant, N_A the Avogadro's number, and v_{mean} the mean ultrasonic velocity defined by the expression:

$$v_{\text{mean}} = \left(\frac{1}{3} \left(\frac{1}{v_l^3} + \frac{2}{v_s^3} \right) \right)^{-1/3} \quad (12)$$

The transmitted and reflected sound waves in the glass samples is determined using the acoustical impedance (Z)

which is determined as the multiplication between its density and mean velocity as following equation [24]:

$$Z = \rho V_{mean} \quad (13)$$

2.5 Vickers hardness determination

Figure 1 shows the geometry of Vickers indentation using a square-base diamond pyramid as the indenter with an angle of 136° between opposite faces. This microhardness tester and ASTM standard (Mitsubishi, Mitutoyo MVK-H1) was applied to determine the Vickers hardness number (H_v) of the glass samples at room temperature. An average of three values of each glass sample was taken and any crack is not observed on the indents of the glass surface. Then, the H_v value was generally calculated directly as [30]:

$$H_v = 1.8544 \frac{F}{d^2} \quad (14)$$

where H_v is expressed in GPa, if the applied load (F) is in N unit and d is the arithmetic average of the diagonals of the indent (d_1 and d_2) in μm .

Fig. 1 The geometry of Vickers pyramid diamond indenter indentation

2.6 XRD analysis

The non-crystalline phase in the glasses was confirmed by using X-ray diffractometer (X'Pert Phillips) with Cu target and Ni filter. X'pert highscore plus software was applied to analyze the obtained data. In the XRD analysis, the diffractograms were recorded in 2θ range from 10° to 70° with a speed of $2^\circ/\text{min}$.

2.7 FTIR

The IR transmission spectra of the prepared glasses have been carried out in the spectral range of $400\text{--}4000\text{ cm}^{-1}$ using FTIR spectroscopy (Thermo Scientific, Nicolet 6700). The samples for IR measurement were prepared by the KBr pellet method. In order to obtain good-quality spectra, the glass and KBr powders were crushed and mixed in an agate mortar to obtain small particles in the ratio of 1:100. Then, the homogeneous mixture was pressed under pressure of 5 ton/cm^2 into a clear block with hydraulic pressure machine. Before the spectrum of all samples were recorded at ambient temperature, the blank KBr pellet was measured for the background spectrum.

3 Results and discussion

3.1 Density and molar volume

Density and molar volume are an important tool to understand the structural changes with composition of the glass. The structural changes include a geometrical configuration and an interatomic spacing of constituent atoms as well as the number of ions and the way by which ions can enter the glass network [31]. The experimental and theoretical values of density and molar volume of the whole glasses have been listed in Table 2. It was found that as the content of bagasse and cassava rhizome increased, the density of the prepared glasses increased while its molar volume decreased. This behavior indicates that the total molecular weight of bagasse and cassava rhizome is higher than the molecular weight of the borate agent in the glass system. Moreover, the substitution of B_2O_3 by the cassava rhizome yields the density values greater than that by the bagasse. This might be due to the change in the net molecular weight of its constituent component. The density and molar volume, generally, reveal adverse manner to each other. The decreased behavior in molar volume can be attributed to closing up of structure of glasses. Furthermore, the results of experimental density

Table 2 Glass compositions, measured density (ρ_m), calculated density (ρ_{cal}), measured molar volume (V_a (M)), calculated molar volume (V_a (cal)) of studied glasses

Sample	Composition (wt%)						Density (g/cm ³)		Molar volume (cm ³)	
	B ₂ O ₃	P ₂ O ₅	Na ₂ O	CaO	BG	CR	ρ_m	ρ_{cal}	V_a (M)	V_a (cal)
GS0	68	3	17	12	–	–	2.3403	2.3332	49.2197	49.3711
BGS1	63	3	17	12	5		2.3550	2.3446	48.9029	49.1245
BGS2	58	3	17	12	10		2.3857	2.3561	48.2646	48.8803
CGS1	63	3	17	12	–	5	2.3692	2.3534	48.6523	48.9944
CGS2	58	3	17	12	–	10	2.4051	2.3736	47.9563	48.6240

BG is the bagasse

CR is the cassava rhizome

and molar volume are in good agreement with the values of theoretical density and molar volume.

3.2 Ultrasonic velocity, elastic modulus, Poisson's ratio, Debye temperature, and acoustical impedance

The behavior of the acoustic velocities in borate glasses changes with the formation of glass network. Table 3 collects the ultrasonic velocities, elastic moduli, Poisson's ratio, Debye temperature, and acoustical impedance of the different glasses with respect to change in wt% of bagasse and cassava rhizome. As seen, from Table 3, the ultrasonic velocities increased with the contents of bagasse and cassava rhizome. It is well known that an increase in ultrasonic wave velocity in borate glass is associated with the switch of the trigonal BO₃ to tetrahedral BO₄ units, resulting in the increase of glass rigidity [32]. According to reports of Manupriya et al. [33] and Saddeek et al. [34], an increase of small amounts of CaO and SiO₂ in borate glass led to the conversion of BO₃ to BO₄. This supported the increase in sound wave velocities in the glass. Likewise, the increase in both longitudinal and shear acoustic velocities of the glass samples in this study can be clarified by an increase of network-forming groups in the internal glass structure when the glass was partially substituted by bagasse (representative of SiO₂) and cassava rhizome (representative of CaO). The longitudinal and shear velocities of the bagasse-added glasses were found to change from 5786 to 6112 m/s and 3405 to 3622 m/s, respectively. For the

cassava rhizome-added glasses, both sound velocities increase from 5786 to 6005 m/s and 3405 to 3571 m/s, respectively. It is clear that the bagasse-added glass yields the higher values of ultrasonic velocities than the cassava rhizome-added glass. This indicates that the glass containing bagasse can form the BO₄ structure units more than that containing cassava rhizome when compared at the same content.

Then the ultrasonic velocities were applied to compute the elastic modulus, Poisson's ratio, Debye temperature, acoustical impedance and microhardness. According to Table 3, it was found that the longitudinal, shear, bulk, and Young's modulus of the glass samples increased with bagasse and cassava rhizome contents. The enhanced elastic modulus in the borate glass points out the increase in bonding strength in the borate structure [35]. Almost all elements of the bagasse are SiO₂, while CaO is a most common representative in the cassava rhizome. Both substitutes can act as a network-forming groups in borate glass. When elements representing bagasse and cassava rhizome were added in the borate glasses, oxygen bond in the glass structure are formed. This may be led to the conversion of triangle to tetrahedron in structural units.

As well known, Poisson's ratio value has sensitive on the variation in glass network which include both changes in its cross-link density and dimension of the glass structure while Debye temperature supersedes the temperature at which nearly all the vibrational modes are excited [36, 37]. Both Poisson's ratio and Debye temperature can be computed by using ultrasonic velocities according to

Table 3 Ultrasonic velocities (v_l , v_s , v_{mean}), elastic moduli (L , G , K , E), Poisson's ratio (σ), Debye temperature (θ_D) and acoustical impedance (Z) of glass samples

Sample	Ultrasonic velocities (m/s)			Elastic moduli (GPa)				$\sigma \pm 0.001$	θ_D (K) ± 1	$Z \times 10^6$ (kg/m ² s) ± 0.01
	$v_l \pm 3$	$v_s \pm 5$	$v_{mean} \pm 5$	$L \pm 0.08$	$G \pm 0.08$	$K \pm 0.14$	$E \pm 0.13$			
GS0	5786	3405	3773	78.36	27.13	42.19	67.02	0.235	373	8.83
BGS1	5956	3524	3904	83.54	29.25	44.54	71.99	0.231	387	9.19
BGS2	6112	3622	4011	89.12	31.29	47.40	76.94	0.229	399	9.57
CGS1	5875	3482	3856	81.78	28.72	43.49	70.61	0.229	383	9.14
CGS2	6005	3571	3954	86.73	30.68	45.83	75.24	0.226	395	9.51

Eqs. (9) and (11). The values of Poisson's ratio of all glass samples are less than 0.25 and almost constant values as the bagasse and cassava rhizome content increases. This indicates that a part of the energy results in the distortion of bond bending of the borate structure. Moreover, the addition of the bagasse and cassava rhizome increased the values of Debye temperature from 373 to 399 K and acoustic impedance from 8.83 to 9.57×10^{-6} (kg/m² s). In our glasses, Debye temperature presents a similar behavior to the dependency of glass composition with increase in weight fraction of bagasse and cassava rhizome. The increase in Debye temperature results in a monotonic increase in the total vibrational energy of the system. Acoustic impedance is significant in the determination of transmitted and reflected acoustic at the boundary of different materials and assessing absorption of sound in a medium. As well known, the sound wave travels through solid materials under the influence of sound pressure. The excess pressure leads to a wave propagating via the material because molecules of a solid are bound elastically to one another [38]. Therefore, the increase of acoustical impedance in our glasses indicates that our glasses can absorb more sound waves when bagasse and cassava rhizome content are increased.

3.3 Microhardness

Microhardness is an important parameter often used to specify the mechanical properties of a material on a

Table 4 Microhardness obtained from ultrasonic (H_{UT}) and Vickers indentation (H_V) techniques of glass samples

Sample	Microhardness (GPa)		%Difference
	$H_{UT} \pm 0.04$	$H_V \pm 0.20$	
GS0	4.79	3.71	25.41
BGS1	5.25	4.33	19.58
BGS2	5.64	4.99	13.63
CGS1	5.18	4.07	24.00
CGS2	5.60	4.84	14.56

Table 5 Assignment of absorption bands in the infrared spectra of glass system

Wave number (cm ⁻¹)	Assignment
3200–3600	Water, H–O–H, Si–OH vibrations
2300–2400	Carbonate groups (C–H)
1632	Indicates that BO ₃ changes to BO ₄ and Hydrogen bonding
1200–1500	B–O–B in BO ₃ triangles
900–1100	B–O bond stretching of tetrahedral BO ₄ units
680–730	B–O–B in BO ₃ triangles
708	Bending vibrations of Si–O–B bridges and B–O–B in BO ₃ units
400–600	Si–O–Si, O=P–O linkages and Modifier cation vibrations

microscopic scale. It suggested the disposed stress in its free volume and the dislocations deformation, or damage under an applied stress, and consequently its values depends on an applied load [23, 39]. The microhardness value has been evaluated using both pulse echo ultrasonic and Vickers indentation techniques for all the glasses. Tables 4 and 5 demonstrates the increase of microhardness of the studied glasses in both measurements as bagasse and cassava rhizome content increased. This increment may point out an increase in its rigidity by addition of bagasse and cassava rhizome content due to the conversion of BO₃ into BO₄ glass network. The values of microhardness in the glasses added with the bagasse is higher than that added with cassava rhizome. Moreover, the microhardness values obtained from the ultrasonic and Vickers techniques were consistent. The minimum and maximum percentage differences between both values were 13.63% and 25.41%, respectively.

3.4 X-ray diffraction (XRD) analysis

The non-appearance of sharp diffraction peaks in the typical XRD patterns indicates the absence of long-range atomic arrangement confirming the amorphous phase in the studied glasses as displayed in Fig. 2. According to the figure, the five glass samples exhibit similar XRD patterns and two broad humps are clearly observed. The formation of two amorphous phases with different intensities in the XRD patterns has been depicted by phase separation. The major mechanisms for phase separation, generally, are termed spinodal decomposition, nucleation and growth [40, 41]. The first broad hump was found between $15^\circ < 2\theta < 35^\circ$ which confirms strongly amorphous nature (short-range order) of all the glass samples. The medium range order is received from the XRD patterns which exhibit either a pre-hump on the low angle side of the main peak or a more developed first diffraction peak [42]. Thus, another broad band with lower intensity was observed in the angle range of 40° – 50° , implying the presence of another phase with medium-range order. Similar observation of two broad bands in sodium borate glasses

Fig. 2 X-ray diffraction (XRD) patterns for B_2O_3 – P_2O_5 – Na_2O – CaO glass with different mix proportions of bagasse and cassava rhizome

has also been reported by Alajerami et al. [43]. However, the lack of apparent changes in the bands between the glass samples suggested that the small addition of bagasse and cassava rhizome has no significant effect on phase separation.

3.5 FTIR

The IR spectroscopy is a powerful analysis tool for confirming the internal structural transformations in a glass material. Under changes the glass composition, the IR spectra have been recorded to understand the changes of a specific vibrational mode of glass structure due to the process of structural grouping rearrangements [22, 44]. The infrared spectra of the selected glasses in the region rang of 400 – 4000 cm^{-1} presented in Fig. 3. These spectra showed three main groups of vibrational modes in the areas of 600 – 700 cm^{-1} , 800 – 1200 cm^{-1} , and 1200 – 1500 cm^{-1} . As Fig. 3, it is observed that the vibrational peak values were positioned at ~ 442 , ~ 566 , ~ 708 , ~ 960 , ~ 1085 , ~ 1225 , ~ 1382 , ~ 1632 , ~ 2369 , ~ 3289 , ~ 3442 , and $\sim 3529\text{ cm}^{-1}$ in all the glasses. However, other weaker bands observed at various frequencies (400 – 500 cm^{-1}) are also presented after the glass sample was added with bagasse and cassava rhizome.

The absorption peaks around 400 – 600 cm^{-1} are attributed to the Si–O–Si and bending vibration of O=P–O linkages overlapped by the vibration of metal cations (Ca^{2+} ,

Mg^{2+} , Al^{3+} , Na^{+} , Zn^{2+} , etc.) in their respective sites within the glass network [45, 46]. From the spectra in Fig. 3, it is obviously observed that there are a greater number of peaks observed in this region with addition of bagasse and cassava rhizome contents. This apparently predicates an increase in SiO_4 units and the cationic vibrations in the network with increase in bagasse and cassava rhizome content.

It is generally accepted that broad bands in region of 680 – 730 cm^{-1} and 1200 – 1500 cm^{-1} are attributed to bending and stretching vibrations of B–O–B in BO_3 triangles of the boron–oxygen network, respectively [47, 48]. The peak at about 708 cm^{-1} is due to the vibrations of B–O–Si bridges [49]. The vibrational area at 900 – 1100 cm^{-1} originates from B–O bond stretching of tetrahedral BO_4 units in various structural groups [50].

In our glass system, the decrease of intensity of observed broad bands in areas at 680 – 730 cm^{-1} and 1200 – 1500 cm^{-1} indicates that the conversion of BO_3 into BO_4 units, and the conversion can be enhanced by increasing bagasse and cassava rhizome contents. In addition, the peak at roughly 1632 cm^{-1} is indicated the transformation of BO_3 into BO_4 units [51], and also this peak may be assigned to the deformation modes of O–H groups and water molecules [52]. As well as the consideration of many researches, the IR absorption region extending from 2300 to 3600 cm^{-1} are originating from hydrogen bonding, carbonate and OH groups [53, 54].

Fig.3 IR spectra of studied glasses with different mix proportions of bagasse and cassava rhizome

4 Conclusions

Two series of the glass were successfully fabricated by the addition of treated bagasse and cassava rhizome with 0–10 wt%. The effects of bagasse and cassava rhizome in B_2O_3 – P_2O_5 – Na_2O – CaO glass systems were evaluated to predict their physical, mechanical and structural properties. The XRD patterns confirmed the amorphous phase in all the glass. From FTIR measurement, vibrational intensity of BO_3 trigonal units in the broad band regions at 680 – 730 cm^{-1} and 1200 – 1500 cm^{-1} decreased while the number of peaks of modification vibrations in region range 400 – 600 cm^{-1} increased as the bagasse and cassava rhizome contents. These suggest the conversion of BO_3 into BO_4 by addition of bagasse and cassava rhizome to borate glass. This supports the results from ultrasonic testing that the partial replacement of B_2O_3 by bagasse and cassava rhizome leads to the increase of acoustic velocities, elastic moduli, Debye temperature, acoustical impedance and microhardness in the glasses due to the formation of glass network by converting BO_3 to BO_4 units. Furthermore, it is suggested that the microhardness values of the proposed glass obtain from ultrasonic technique are in good agreement with Vickers indentation method.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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