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STUDYING THE ELASTIC PROPERTIES OF GLASSES BASED ON CKD USING ULTRASONIC TECHNIQUE

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Large amounts of powder of cement kiln dust waste are accumulating all over Egypt every year and disposal of this tailing is needed. Recycling of the waste into glassy material is one from the best ways for eliminating their hazardous impact on the people and environment. Glasses based on this tailing were prepared by conventional melt-quenching method. The composition dependence of the elastic properties of these glasses was discussed in association with the effects of adding CDK. The addition of CDK was expected to produce significant changes such as an increase in density, ultrasonic velocities and elastic moduli.

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1. Introduction

Huge amounts of CKD were produced in every year in the process of cement manufacturing. Cement Kiln Dust (CKD) is a fine powdery material similar in appearance to Portland cement**.** Cement dust can cause ill health by skin contact, eye contact, or inhalation. Risk of injury depends on duration and level of exposure and individual sensitivity. Recycling of the CKD is the best way for eliminating their hazardous impact on the people and environment [1]. Many possible applications were suggested to incorporate proportions of the wastes in the processing of glass ceramics products. Therefore, this work directly aims at recycling both of these wastes for production of glass [2]. These glasses are used for many applications such as optical glasses, oven wares, nuclear waste materials, and in the electronics industry [3].

On the other hand, studies of the elastic constants of the glassy materials give considerable information about the structure of these non-crystalline materials, since they are directly related to the interatomic forces and potentials [4]. The elastic properties, micro-hardness, Poisson's ratio, or other related parameters are of great interest to investigate the linear and anomalous variations as a function of composition of glass and have been interpreted in terms of the structure or transformation of cross-linkages in the glass network [5]. To study the structure of oxide glasses, the coordination number of the network former and the change of oxygen bonds in the frame work, induced by the cations, need to be investigated. Furthermore, many author's studies on borosilicate glass have been reported for structural properties of glass, by using ultrasonic techniques [6]. The determination of the elastic parameters of glasses by ultrasonic pulse-echo methods becomes a more interesting subject, due to the non-destructive nature and the high precision of the technique. This measurement yields valuable information regarding the forces operating between the atoms or ions in a solid [7]. Recently, many authors have used the ultrasonic

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technique to study the velocity of sound waves in sodium borate glasses with CKD [8]. In view of the aforementioned perspective, the aim of the present work is to recycling wastes cements kiln dust for glass production and studying the elastic properties of these glasses by using a nondestructive ultrasonic method**.**

2. Experimental procedures

The chemical composition of the used cement kiln dust was analyzed with X-ray fluorescence technique and their results were listed in Table 1. The tailings were heated in opened air until the remaining carbon and the other decomposable components can be removed before adding it to the glass batch. For preparation of a glass sample, appropriate amounts of reagent grade of $Na_2O_4B_7.10H_2O$ powder were thoroughly mixed with raw materials in an agate mortar and melted in a platinum crucible to obtain glass system. The nominal batch compositions (the starting mixture) were listed in Table 2 and the weight losses were found to be less than 10%. The electric furnace was kept at a temperature 1100 ^oC for half an hour under normal atmospheric conditions, after which the glass was poured into a preheated stainless steel mold and then slowly cooled to room temperature. To assure the homogeneity of the glass, the well-mixed components were added in small portions and the melt was swirled frequently. The glasses were annealed at 400 ^oC for 2 h to relieve the internal stresses and allowed to cool gradually to room temperature at a rate of about 30°C h^{-1}. The prepared samples were polished with different grades of SiC emery powder on a soft leather piece fixed on a flat platform for the ultrasonic velocity measurements. Non-parallelism of the two opposite side faces was measured with a micrometer, which could measure down to 0.01 mm.

Table 1: XRF for raw materials by wt. %

Constituent Oxide	Cement dust	borax
SiO_2	6.96	-
Al_2O_3	1.36	-
Fe_2O_3	1.85	-
CaO	60.63	-
MgO	1.54	-
Na_2O	0.03	16.93
K_2O	1.74	-
SO_3	5.16	-
TiO_2	0	-
B_2O_3	-	35.97
P_2O_5	0	-
L.O.I.	20.27	47.1
TOTAL	99.54	100

Table 2: preparation of sample by wt. %

Sample name	Chemical composition by wt. %		Melting temperature	Annealing temperature
	borax	Cement dust		
1BC	90	10	1100 ^oC	400 ^oC
2BC	80	20	1100 ^oC	400 ^oC
3BC	70	30	1100 ^oC	400 ^oC
4BC	60	40	1100 ^oC	400 ^oC
5BC	50	50	1100 ^oC	400 ^oC
6BC	40	60	1100 ^oC	400 ^oC

The density of each sample was measured by Archimedes' principle by using toluene as the immersion fluid. Four samples of each glass were used to determine the density (ρ). A random error in the density values was found as ±25 kgm^{-3}.

The ultrasonic velocities, longitudinal (v_L) and shear (v_T), at room temperature (~300 K) were obtained using the pulse-echo method. In this method, x-cut and y-cut transducers (KARL DEUTSCH) operated at a fundamental frequency 4 MHz along with a digital ultrasonic flaw detector (KARL DEUTSCH Echograph model 1085) were used. The uncertainty in the measurement of the ultrasonic velocity is ±10 m/s. The two velocities besides the density were utilized to determine two independent second-order elastic constants, C_{11} and C_{44}. For pure longitudinal waves $C_{11} = \rho v_L^2$, and for pure transverse waves $C_{44} = \rho v_T^2$. The elastic bulk modulus (K) and Young's modulus (Y) can be determined using the standard relations adopted in previous work [9]. The uncertainty in the measurement of the elastic moduli is ± 0.15 GPa.

Table 3: The values of density (d), molar volume (V_m), sound velocities (v_L and v_T), elastic moduli and Poisson's ratio (σ) of the studied glass system

Sample name	d (gcm^{-3})	V_m (cm^3mol^{-1})	v_L ($m\ s^{-1}$)	v_T (ms^{-1})	C_{11} (GPa)	C_{44} (GPa)	K_e (GPa)	Y (GPa)	σ
1BC	2.534	26.33	6077	3090	101.964	26.362	66.814	69.894	0.326
2BC	2.569	25.75	6107	3120	101.108	26.39	65.921	69.899	0.323
3BC	2.623	25.14	6160	3177	101.467	26.99	65.48	71.188	0.319
4BC	2.674	24.33	6211	3282	101.186	28.34	63.4	73.994	0.305
5BC	2.711	23.79	6276	3322	101.188	28.351	63.387	79.017	0.305
6BC	2.761	23.16	6480	3570	106.404	32.296	63.343	82.813	0.282

3. Results and dissections

The prepared glasses were subjected to ultrasonic measurements at room temperature. Table 3 presents the values of density (ρ), molar volume (V_m), sound velocities (both longitudinal (v_L) and transverse (v_T)), the calculated elastic constants ($C_{11}$and C_{44}), bulk modulus (K_e), Young's modulus (Y) and Poisson's ratio (σ).

3.1. Density and molar volume

The density is an intrinsic property capable of casting the light on the structure of a glass. It was reported that, modification of B_2O_3 glass causes a conversion of its basic structural unit BO_3 into four-fold BO_4-coordinated boron atoms. The BO_4 structural groups are denser than BO_3 structural units and are responsible for the increase in the connectivity of the glass network and the degree of the structural compactness.

Analysis of the oxides in this study revealed that as the concentration of cement dust was increased at the expense of the NaO_2 and B_2O_3concentrations, i.e., the concentrations of CaO, was increased. In the studied glasses, it was observed that, the density increases linearly with a linear decrease in the molar volume as shown in Fig. 1 which was attributed to the higher density of CaO than that of NaO_2 and B_2O_3. The values of the density and the molar volume are in good agreement with that previously published [10-12].

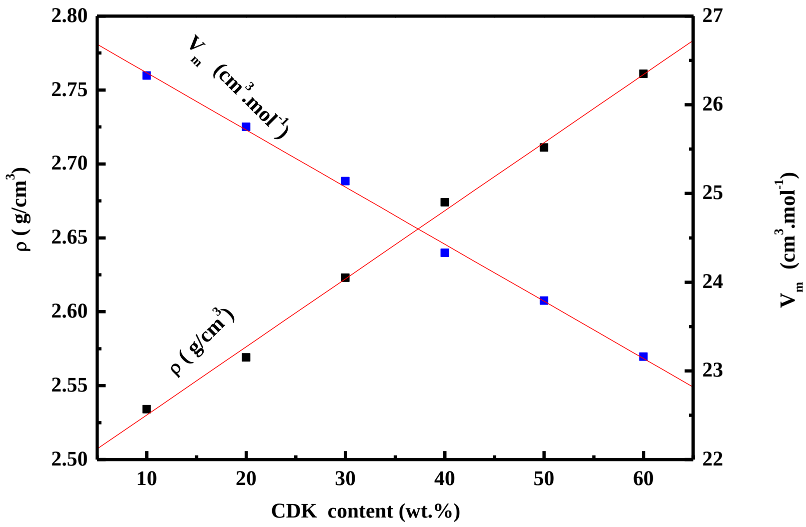

Fig. 1: Variation of density and molar volume versus CKD wt. %

3.2 Ultrasonic measurements

The longitudinal (v_L) and shear ultrasonic (v_T) velocities of the glass system with different wt. % of CKD content are depicted in Fig. 2. It can be seen that the ultrasonic velocities increased with the increase of CKD concentration and the values of (v_L) are higher than that of (v_T). The changes of glass structure depending on the propagation of both longitudinal and shear wave velocities in the bulk samples [13]. It was known that CaO acted as a glass modifier which increased the number of bridging oxygens (BOs) in the glass structure and so there will be a conversion of BO_3 into BO_4 structural units will be occurred and the free volumes will be reduced. Thus, filling of Ca^{2+} ions into the sodium borate glass network would result in a compaction of the glass structure. As a result, both velocities (v_L) and (v_T) were increased, respectively. The increase in ultrasonic velocity of the studied glass revealed the fact that the addition of CKD would cause a swift movement of the ultrasonic wave inside the network of the glass structure. Due to this factor, the ultrasonic velocities of the glasses would increase as the CKD content was increased.

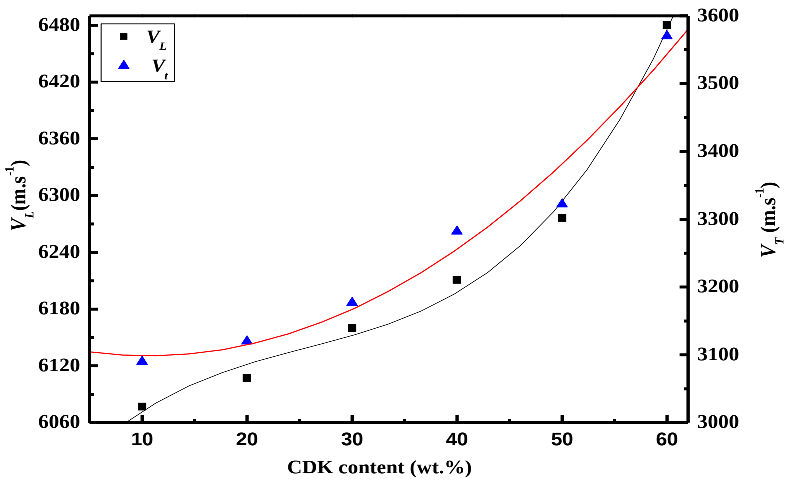

Fig. 2: Variation of ultrasonic velocity versus CKD wt. %

Young's modulus (Y) determined from the sound velocity was defined as a ratio of the linear stress over the linear strain [13], whereby this Young's modulus was related to the bond strength of the materials. The bulk modulus (K) was defined as the changing in volume when a force is acted upon it at all directions [13]. Fig. 3 shows the variation of elastic moduli: K and Y with CKD concentration. The attainment of a higher value of *Y* than *K* indicated that the glasses were able to with stand a higher longitudinal stress than transverse stress. A comparison between K and Y (K< Y) indicated that the samples were more tolerant to the stress from one direction than the stress from all directions. The increase in K was due to the changing in the coordination number with an increasing in the CKD content. Since the addition of CKD would increase the rigidity of glass structure, the velocity and Young's modulus would also increase.

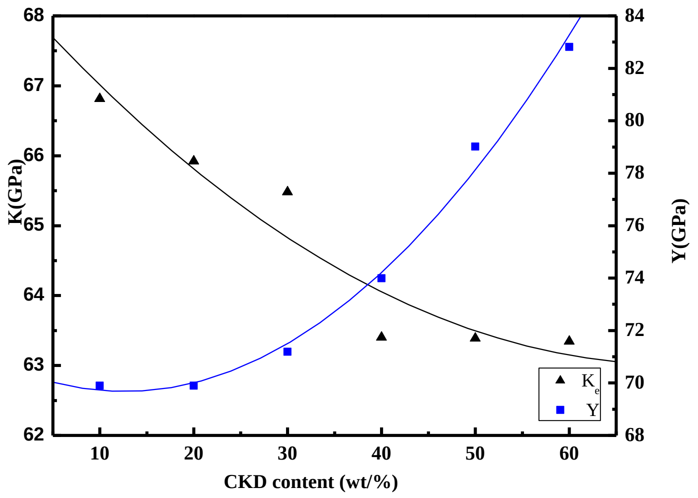

Fig. 3: Variation of elastic moduli versus CKD wt. %

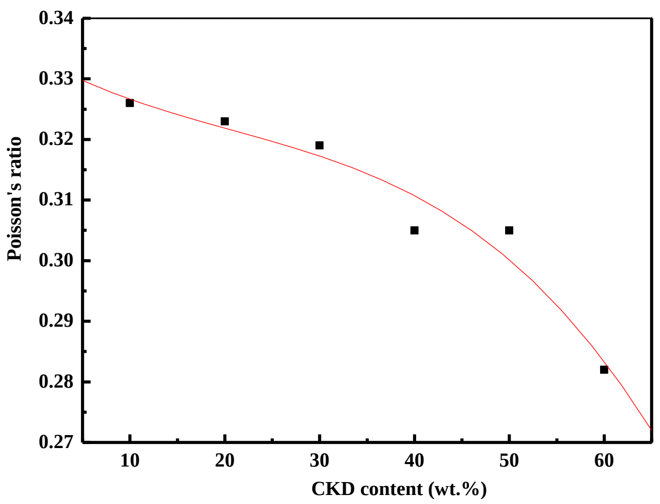

Fig. 4: Variation of Poisson's ratio versus CKD wt. %

The obtained Poisson's ratio from the elastic moduli as listed in Table 3 was affected by the crosslink density of the glass structure. A decrease in Poisson's ratio as a function of CKD content suggested that an equal amount of stress was applied throughout the whole range of the glass composition and the lateral strain was gradually leveled out [14]. In addition, the observation made in Poisson's ratio supported that there were changes in cross link densities.

4. Conclusions

Huge amounts of tailings were produced in every year in the process of cement manufacturing in Egypt. Glass industry is one of the solutions of this problem which is the aim of this study. As the content of CKD was increased in the glass batch, the concentrations of CaO increase while the sodium and boron oxides were decreased. As the content of CKD was increased the density were increased while the molar volume was decreased. As a result, both velocities (V_L) and (V_T) were increased. Therefore, the values of elastic moduli were decrease with the increase of CKD content.

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