Determinant of Glass Material's Parameters for Fiber Optic Application Durability

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Abstract

The aim of this study was to determine the principle cause of variation in a measured glass durability using a melt-quenching method. Further goal for this study was to find the optimum level of the factor for producing the glass durability. For that purpose, One-Way Analysis of Variance (ANOVA) was performed. From the analysis, it was found that all longitudinal modulus, shear modulus 2 and shear modulus 3 were the significant parameters that produced high quality of glass durability ($p<0.05$). The mean analysis revealed that the best condition that maximizes the average of Longitudinal Modulus 1, 2 and 3 would be when the erbium concentration was 0.05. It was found that the erbium concentration with 0.03 produced the optimum Longitudinal Modulus 4 and 5. The findings also pointed out that the average of Shear Modulus 2 and 3 was maximized when the erbium concentration was 0.03 and 0.05, respectively.

Introduction

Glass material has been widely used for many types of applications. Glass applications that have been shown globally have gained the attention of many researchers around the world to find out the effectiveness of glass in various aspects. Nonetheless, the objective of making good glass should always focus on the foundation of elements used which will improve the efficiency of the glass system.

The compatibility of rare earth elements with tellurite oxide has gained a lot of interests nowadays. In the present study, the comparison between silicate and tellurite-based glass shown that rare earth in tellurite glass has lower nonradiative decay rates, larger values of the radiation cross-section, shorter fluorescence cross-section and a red shift of radiative transition. Consequently, the tellurite glass has higher possibility of being used as a potential fiber host material rather than silicate glass.

The importance of tellurite glass to be used as a laser emission has become a huge phenomenon in the world of photonic. In the development of tellurite glass as a laser glass, Bell et al. (2014) [1] has conducted a research on laser emission of Nd-doped mixed tellurite and zinc oxide glass. Based on the reports, the presence of neodymium oxide in tellurite glass provided a low laser threshold of 8mW and low internal losses. Subsequently, the studied tellurite glass was shown to have long emission lifetime of about 210μs and large stimulated emission cross section of 3.1×10^{-20} cm^2. Such features suggested that tellurite laser glass could act well as an efficient photonic devices and ultrashort mode-locked laser pulses.

Fares et al. (2014) [2] stated that tellurite oxide, TeO_2 consists of a lone pair of electrons at the equatorial position of TeO_4 units. This effect will result in the limitation of structural rearrangement of these units which gives a disadvantage to the glass formation. Consequently, the formation of pure TeO_2 glass was unstable and crystallized easily. However, the presence of modifie such as alkali, alkaliearth and transition meta oxides in the glass network was necessary to allow the formation of tellurite-based glass. It has been found that the presence of zinc oxide intends to reduce the intensity of TeO_4, trigonal bipyramidal. Meanwhile, the intensity of TeO_3, trigonal pyramidal increases with the addition of ZnO in the glass network. This trend has got good agreement by observing at the conversion of TeO_4 trigonal bipyramidal to TeO_3 trigonal pyramidal. The role of ZnO in the conversion of TeO_4 to TeO_3 structural units has also been studied by Ayuni et al. (2011) [3]. Ayuni et al. (2011) [3] proposed that ZnO was active as a glass former which was formed as ZnO_4 tetrahedra in tellurite glass network. The evidence of ZnO_4 has been found at around 300cm $^{-1}$. It has also been stated that the ZnO might form a bridging bond with B_2O_3 by Zn–O–B since the stretching force constant of Zn–O bonding was substantially lower than that of B–O.

The formation of TeO_3 polyhedra by Zn^{2+} modifier ions has been reported by Ma et al. (2014) [4]. In the statement proposed by Ma et al. (2014) [4], tellurite glass contains a variety of structural motives (TeO_4, TeO_3 and TeO_{3+1}) due to the presence of Zn^{2+} modifier ions, which give rise to a broad distribution of structural sites. This is important as it is strongly related to the strength of the glass as shown in some elastic studies. Up to date, only few researchers have done researches on elastic properties against zinc tellurite glasses doped erbium oxide [5]. However, none of the researchers has done a research on prediction and determining the significant factors contributing to the glass durability by using One-Way Analysis of Variance (ANOVA). In this study, the glass durability was measured by several parameters which included molar volume, density, thickness, longitudinal velocity, shear velocity, longitudinal modulus and shear modulus. Those parameters were influenced by erbium concentration (longitudinal velocity square, shear velocity square) and thickness. Furthermore, the findings from this study proposed the best condition that gives rise to the glass durability.

Density can be identified as the amount of matter filled up by a unit volume of such material. It is evaluated in units of g/cm^3, kg/m^3 or any other mass/Volume unit [6]. In the prospects of science in glasses, density can be identified using the principle of Archimedes. The molar volume of a glass material can be defined as the amount of space obtained by a mol of such material in space. Elasticity can be identified as an ability of the material to deform when force is exerted on it and return back to its original shape once force is taken off. Physically, glass can be defined as a brittle material which displays almost follows the Hookian behaviour. Hooke's law describes the transition energy from elastic potential energy to potential energy stored as a result of deformation of elastic object for instance stretching of spring. Some parameters that are crucial in elastic or glass durability study include longitudinal modulus and shear modulus. For ultrasonic measurement, the samples were required to have a thickness of 5 mm with parallel surfaces. According to Azianty *et al.*, (2012) [7], the evaluation of ultrasonic velocity in both longitudinal and shear modes for elastic properties of glasses can only be determined by non-destructively technique (NDT). NDT is a recommended technique because the properties of the glass samples can be tested using a computer controlled without destroying or changing the physical properties of the sample. The thickness of the sample that had been measured beforehand was entered into the computer whereby the thickness of the sample was required for the calculation of the ultrasonic velocity. The investigation on elastic properties using ultrasonic velocity is crucial especially in explaining and determining the longitudinal and shear velocity which profoundly provide the understanding of the mechanical behavior of the materials. Glasses have only two independent elastic constants which are longitudinal and shear elastic moduli. These two parameters can be attained from the longitudinal and shear velocities as well as the density of the glasses.

Therefore, in this study, a glass series involving five different concentration of erbium oxide were tested using ANOVA. The usage of the software can predict the optimization on the parameters in determining the dependent and independent variables to be applied as the most efficient fiber optic application especially in the perspective of durability in this work.

Materials And Methods

Weighing of chemicals

A glass series of zinc tellurite doped with erbium oxide was utilized in this work. A conventional melt-quenching method [8] was used to formulate a series of five different erbium oxide concentration. The raw materials for zinc tellurite glasses doped with erbium oxide were TeO_2 (Sigma-Aldrich, 99.995%), zinc oxide, ZnO (Alfa Aesar, 99.99%) and erbium oxide, Er_2O_3 (Alfa Aesar, 99.9%).

The raw materials were weighed by using an electrical balance with an accuracy of ±0.0001g and mixed thoroughly to obtain 13 g of mixed powder. The mixture was then transferred into the alumina crucible and was pre-heated at 400^0C for one hour by using the first electrical furnace. The purpose of pre-heating process is to remove the excess hydrogen molecules from the mixture. The mixture in the alumina crucible was then heated for a melting process at 900^0C by using the second electrical furnace for two hours whereas the stainless-steel mould was preheated at 400^0C in the first electrical furnace concurrently. This concurrent process would prevent the thermal shock to happen. The molten of the mixture was formed during this process and was poured into cylindrical stainless-steel mould that is the process of melt-quenching method. The cylindrical stainless-steel mould containing the glass sample was heated for annealing process at 400^0C for another one hour [9].

The aim of the annealing process was to enhance the mechanical strength and remove strain. The glass sample was then allowed to cool down at room temperature for the whole night. The obtained glass sample was polished at a thickness of ~5 mm by using different grade of sand papers (1000 grid, 1500grid, and 2000 grid) in order to obtain a smooth and parallel surface on both sides of the glass sample. Figure 1 displays the sequence of making the glass samples [10].

The experiment of this study applied the concept of randomization. Randomization is one of the principles of experiment which involves random allocation of treatments onto experimental units. In this experiment, the principle of randomization was applied to eliminate bias as well as to reduce the effect of extraneous factors which were not under the direct control of the experimenter. Finally, all the desired measurements of parameters were recorded.

Data analysis

One-Way Analysis of Variance (ANOVA) is extensively used in determining the principal cause of variation in a measured response. Hence, in achieving the aims of the study, ANOVA was hired. On top of that, the Post Hoc test was performed to further investigate the factor levels that are significantly different. Mean analysis was then employed in finding the condition (best combination of factor levels) that maximizes the average response. The variables involved in this study were illustrated in the following table [11].

Table 1
List of Response Variables and Factors

Response variables	
Parameters Units	
Molar volume	cm^3/mol
Density	g/cm^3
Longitudinal velocity	m/s
Shear velocity	m/s
Longitudinal modulus	GPa
Factors	
Shear modulus	GPa
Erbium concentration	molar fraction
Thickness	mm
Longitudinal velocity square	m^2/s^2
Shear velocity square	m^2/s^2
Longitudinal modulus	GPa

Table 2
Descriptive Statistics of Glass Properties.

	Erbium concentration				
Parameters	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**
Molar volume	26.10 ± 0.59	26.57 ± 1.86	26.65 ± 0.73	27.09 ± 1.88	27.08 ± 0.99
Density	5.31 ± 0.12	5.33 ± 0.35	5.39 ± 0.14	5.41 ± 0.41	5.49 ± 0.21
Longitudinal velocity	3.38 ± 0.04	3.37 ± 0.06	3.40 ± 0.04	3.41 ± 0.03	3.40 ± 0.15
Shear velocity	1.95 ± 0.00	1.92 ± 0.02	1.93 ± 0.03	1.94 ± 0.12	1.93 ± 0.01
Longitudinal modulus 1	61.17 ± 1.42	58.34 ± 3.84	59.72 ± 1.58	63.37 ± 4.76	66.97 ± 2.52
Longitudinal modulus 2	60.90 ± 1.41	61.77 ± 4.07	64.14 ± 1.70	64.33 ± 4.83	65.99 ± 2.48
Longitudinal modulus 3	62.46 ± 1.45	62.63 ± 4.12	62.71 ± 1.66	62.26 ± 4.68	68.09 ± 2.56
Longitudinal modulus 4	60.73 ± 1.41	61.75 ± 4.07	62.42 ± 1.65	62.07 ± 4.66	55.62 ± 2.09
Longitudinal modulus 5	58.86 ± 1.36	57.76 ± 3.80	62.69 ± 1.66	62.31 ± 4.68	59.73 ± 2.24
Shear modulus 1	20. 35 ± 0.47	19.93 ± 1.31	20.19 ± 0.53	20.51 ± 1.54	20.56 ± 0.77
Shear modulus 2	20.41 ± 0.47	19.24 ± 1.27	20.50 ± 0.54	20.32 ± 1.53	20.42 ± 0.77
Shear modulus 3	20.17 ± 0.47	19.41 ± 1.28	18.73 ± 0.50	19.97 ± 1.50	20.39 ± 0.77
Shear modulus 4	20.29 ± 0.46	19.54 ± 1.31	20.20 ± 0.53	20.30 ± 1.52	20.71 ± 0.82
Shear modulus 5	20.17 ± 0.47	20.06 ± 1.32	20.22 ± 0.53	20.64 ± 1.55	20.33 ± 0.76

Table 3
One-Way ANOVA Summary Table.

Factors Parameter		P-value
Erbium concentration	Density	.612
	Molar volume	.446
	Longitudinal velocity	.927
	Shear velocity	.062
Thickness	Longitudinal velocity	.927
	Shear velocity	.062
Longitudinal velocity square	Longitudinal modulus 1	.000
	Longitudinal modulus 2	.006
	Longitudinal modulus 3	.000
	Longitudinal modulus 4	.000
	Longitudinal modulus 5	.002
Shear velocity square	Shear modulus 1	.645
	Shear modulus 2	.039
	Shear modulus 3	.004
	Shear modulus 4	.165
	Shear modulus 5	.763

Table 4
Multiple Comparison Table of Glass Properties.

Factors	(I) Longitudinal velocity square (1)	(J) Longitudinal velocity square (1)	Mean Difference (I-J)	Sig.
Longitudinal modulus (1)	11.516 (Group 1)	10.947 (Group 2)	2.827954	.266
		11.084 (Group 3)	1.452796	.833
		11.705 (Group 4)	-2.197420	.516
		12.202 (Group 5)	-5.794292*	**.001**
	10.947 (Group 2)	11.084 (Group 3)	-1.375158	.858
		11.705 (Group 4)	-5.025374*	**.006**
		12.202 (Group 5)	-8.622245*	**.000**
	11.084 (Group 3)	11.705 (Group 4)	-3.650216	.082
		12.202 (Group 5)	-7.247088*	**.000**
	11.705 (Group 4)	12.202 (Group 5)	-3.596872	.090
	(I) Longitudinal velocity square (2)	**(J) Longitudinal velocity square (2)**	**Mean Difference (I-J)**	**Sig.**
Longitudinal modulus (2)	11.464 (Group 1)	11.590 (Group 2)	-.878728	.972
		11.906 (Group 3)	-3.248789	.171
		11.883 (Group 4)	-3.434314	.132
		12.025 (Group 5)	-5.100303*	**.007**
	11.590 (Group 2)	11.906 (Group 3)	-2.370061	.468
		11.883 (Group 4)	-2.555586	.391
		12.025 (Group 5)	-4.221575*	**.038**
	11.906 (Group 3)	11.883 (Group 4)	-.185526	1.000

* The mean difference is significant at the 0.05 level.

Note: Group represents the concentration of erbium (Group 1; 0.01), (Group 2; 0.02), (Group 3; 0.03), (Group 4; 0.04) and (Group 5; 0.05)

Factors	(I) Longitudinal velocity square (1)	(J) Longitudinal velocity square (1)	Mean Difference (I-J)	Sig.
		12.025 (Group 5)	-1.851515	.694
	11.883 (Group 4)	12.025 (Group 5)	-1.665989	.770
	(I) Longitudinal velocity square (3)	**(J) Longitudinal velocity square (3)**	**Mean Difference (I-J)**	**Sig.**
Longitudinal modulus (3)	11.757 (Group 1)	11.752 (Group 2)	-.178839	1.000
		11.638 (Group 3)	-.250022	1.000
		11.500 (Group 4)	.198035	1.000
		12.406 (Group 5)	-5.633164*	**.002**
	11.752 (Group 2)	11.638 (Group 3)	-.071183	1.000
		11.500 (Group 4)	.376874	.999
		12.406 (Group 5)	-5.454324*	**.003**
	11.638 (Group 3)	11.500 (Group 4)	.448057	.998
		12.406 (Group 5)	-5.383142*	**.004**
	11.500 (Group 4)	12.406 (Group 5)	-5.831199*	**.001**
	(I) Longitudinal velocity square (4)	**(J) Longitudinal velocity square (4)**	**Mean Difference (I-J)**	**Sig.**
Longitudinal modulus (4)	11.432 (Group 1)	11.586 (Group 2)	-1.023236	.945
		11.586 (Group 3)	-1.698529	.732
		11.465 (Group 4)	-1.339914	.866
		10.134 (Group 5)	5.109222*	**.005**
	11.586 (Group 2)	11.586 (Group 3)	-.675292	.988

* The mean difference is significant at the 0.05 level.

Note: Group represents the concentration of erbium (Group 1; 0.01), (Group 2; 0.02), (Group 3; 0.03), (Group 4; 0.04) and (Group 5; 0.05)

Factors	(I) Longitudinal velocity square (1)	(J) Longitudinal velocity square (1)	Mean Difference (I-J)	Sig.
		11.465 (Group 4)	-.316677	.999
		10.134 (Group 5)	6.132458*	**.001**
	11.586 (Group 3)	11.465 (Group 4)	.358615	.999
		10.134 (Group 5)	6.807750*	**.000**
	11.465 (Group 4)	10.134 (Group 5)	6.449135*	**.000**
	(I) Longitudinal velocity square (5)	**(J) Longitudinal velocity square (5)**	**Mean Difference (I-J)**	**Sig.**
Longitudinal modulus (5)	11.080 (Group 1)	10.838 (Group 2)	1.094781	.927
		11.637 (Group 3)	-3.837558	.052
		11.510 (Group 4)	-3.451842	.099
		10.884 (Group 5)	-.872223	.967
	10.838 (Group 2)	11.637 (Group 3)	-4.932339*	**.006**
		11.510 (Group 4)	-4.546623*	**.013**
		10.884 (Group 5)	-1.967004	.600
	11.637 (Group 3)	11.510 (Group 4)	.385716	.999
		10.884 (Group 5)	2.965335	.204
	11.510 (Group 4)	10.884 (Group 5)	2.579619	.331
	(I) Shear velocity square (2)	**(J) Shear velocity square (2)**	**Mean Difference (I-J)**	**Sig.**
Shear modulus (2)	3.840 (Group 1)	3.610 (Group 2)	1.161455	.090
		3.805 (Group 3)	-.100229	.999
		3.753 (Group 4)	.084453	1.000

* The mean difference is significant at the 0.05 level.

Note: Group represents the concentration of erbium (Group 1; 0.01), (Group 2; 0.02), (Group 3; 0.03), (Group 4; 0.04) and (Group 5; 0.05)

Factors	(I) Longitudinal velocity square (1)	(J) Longitudinal velocity square (1)	Mean Difference (I-J)	Sig.
		3.720 (Group 5)	-.018849	1.000
	3.610 (Group 2)	3.805 (Group 3)	-1.261684	.054
		3.753 (Group 4)	-1.077003	.134
		3.720 (Group 5)	-1.180305	.082
	3.805 (Group 3)	3.753 (Group 4)	.184682	.994
		3.720 (Group 5)	.081380	1.000
	3.753 (Group 4)	3.720 (Group 5)	-.103302	.999
	(I) Shear velocity square (3)	**(J) Shear velocity square (3)**	**Mean Difference (I-J)**	**Sig.**
Shear modulus (3)	3.797 (Group 1)	3.642 (Group 2)	.755347	.444
		3.476 (Group 3)	1.438464*	**.018**
		3.689 (Group 4)	.196142	.992
		3.715 (Group 5)	-.219782	.987
	3.642 (Group 2)	3.476 (Group 3)	.683117	.544
		3.689 (Group 4)	-.559205	.717
		3.715 (Group 5)	-.975129	.200
	3.476 (Group 3)	3.689 (Group 4)	-1.242322	.056
		3.715 (Group 5)	-1.658246*	**.005**
	3.689 (Group 4)	3.715 (Group 5)	-.415924	.881

* The mean difference is significant at the 0.05 level.

Note: Group represents the concentration of erbium (Group 1; 0.01), (Group 2; 0.02), (Group 3; 0.03), (Group 4; 0.04) and (Group 5; 0.05)

Table 5
Homogenous Subsets of Glass Properties

	Longitudinal velocity square (1)	N	Subset for alpha = 0.05		
			1	2	3
Longitudinal modulus (1)	**10.947 (Group 2)**	**10**	**58.34325**		
	11.084 (Group 3)	**10**	**59.71841**		
	11.516 (Group 1)	**10**	**61.17120**	**61.17120**	
	11.705 (Group 4)	**10**		**63.36862**	
	12.202 (Group 5)	**10**			**66.96549**
	Sig.		**.059**	**.121**	**1.000**
	Longitudinal velocity square (2)	**N**	**1**	**2**	**3**
Longitudinal modulus (2)	11.464 (Group 1)	10	60.89615		
	11.590 (Group 2)	10	61.77488	61.77488	
	11.906 (Group 3)	10		64.14494	64.14494
	11.883 (Group 4)	10		64.33047	64.33047
	12.025 (Group 5)	10			65.99646
	Sig.		.541	.097	.228
	Longitudinal velocity square (3)	**N**	**1**	**2**	**3**
Longitudinal modulus (3)	11.500 (Group 4)	10	62.25719		
	11.757 (Group 1)	10	62.45523		
	11.752 (Group 2)	10	62.63407		
	11.638 (Group 3)	10	62.70525		
	12.406 (Group 5)	10		68.08839	
	Sig.		.777	1.000	
	Longitudinal velocity square (4)	**N**	**1**	**2**	**3**

Note: Group represents the concentration of erbium (Group 1; 0.01), (Group 2; 0.02), (Group 3; 0.03), (Group 4; 0.04) and (Group 5; 0.05)

Longitudinal modulus (4)	10.134 (Group 5)	10	55.61721		
	11.432 (Group 1)	10		60.72644	
	11.586 (Group 2)	10		61.74967	
	11.465 (Group 4)	10		62.06635	
	11.586 (Group 3)	10		62.42496	
	Sig.		1.000	.269	
	Longitudinal velocity square (5)	**N**	**1**	**2**	**3**
Longitudinal modulus (5)	10.838 (Group 2)	10	57.76477		
	11.080 (Group 1)	10	58.85955		
	10.884 (Group 5)	10	59.73177	59.73177	
	11.510 (Group 4)	10		62.31139	62.31139
	11.637 (Group 3)	10			62.69711
	Sig.		.178	.064	.777
	Shear velocity square (2)	**N**	**1**	**2**	**3**
Shear modulus (2)	3.610 (Group 2)	10	19.24053		
	3.753 (Group 4)	10		20.31753	
	3.840 (Group 1)	10		20.40199	
	3.720 (Group 5)	10		20.42084	
	3.805 (Group 3)	10		20.50222	
	Sig.		1.000	.713	
	Shear velocity square (3)	**N**	**1**	**2**	**3**
Shear modulus (3)	3.476 (Group 3)	10	18.73186		
	3.642 (Group 2)	10	19.41498	19.41498	
	3.689 (Group 4)	10		19.97418	19.97418
	3.797 (Group 1)	10		20.17032	20.17032
	3.715 (Group 5)	10			20.39011
	Sig.		.131	.115	.384

Note: Group represents the concentration of erbium (Group 1; 0.01), (Group 2; 0.02), (Group 3; 0.03), (Group 4; 0.04) and (Group 5; 0.05)

All the outputs in this section suggesting the optimum (maximum/minimum) level of the factors for the response variables.

Results And Discussion

ANOVA was performed to determine which parameters were significantly affecting glass durability. Table 3 indicated that the longitudinal velocity square affected all the longitudinal modulus ($p \leq 0.05$). The finding also illustrated that the shear velocity square affected the shear modulus 2 ($p = 0.039$) and shear modulus 3 ($p = 0.004$). Hence, it could be concluded that all the longitudinal modulus, shear modulus 2 and shear modulus 3 were the parameters that produced quality glass durability. Duncan's post hoc tests revealed that there was a significant difference between some pairs of means of glass properties (Tables 3, 4 and 5). For longitudinal velocity square factor, the values of longitudinal modulus 1 have been observed to have ranged from (61.17 ± 1.42) to (66.97 ± 2.52) between erbium concentrations (Table 2). The highest mean value of longitudinal modulus 1 was found at 0.05 erbium concentration and the lowest at 0.02. The longitudinal modulus 1 was significantly different between concentrations of (0.02, 0.03, 0.01); (0.01, 0.04) and 0.05 (Tables 3, 4 and 5). Longitudinal modulus 2 showed a statistically significant increase in erbium concentrations from (60.90 ± 1.41) to (65.99 ± 2.48) ($p \leq 0.05$) (Table 2). The longitudinal modulus 2 was significantly different between (0.01, 0.02); (0.02, 0.03, 0.04) and (0.03, 0.04, 0.05 (Tables 3, 4 and 5). The same trend can be seen for longitudinal modulus 3. The erbium concentrations increased from (62.46 ± 1.45) to (68.09 ± 2.56) ($p \leq 0.05$) (Table 2). The highest mean erbium concentration for longitudinal modulus 3 was recorded at 0.05. The value of 0.05 concentration (subset 3) was not in the same subset as subsets 1 and 2. Therefore, 0.05 concentration was significantly different from 0.01, 0.02, 0.03 and 0.04 concentrations (Tables 3, 4 and 5). The mean values between erbium concentrations for longitudinal modulus 4 and 5, from (60.73 ± 1.41) to (55.62 ± 2.09) and from (58.86 ± 1.36) to (59.73 ± 2.24) respectively ($P \leq 0.05$) (Table 2). The lowest mean value was recorded at 0.05 concentration (subset 1) for longitudinal modulus 4 and 0.05 concentration was significant different from 0.01, 0.02, 0.03 and 0.04 concentrations as in subsets 2 and 3 (Tables 3, 4 and 5). For Longitudinal modulus 5, the erbium concentrations were significantly different between (0.02, 0.01, and 0.05); (0.05, 0.04) and (0.04, 0.03) (Tables 3, 4 and 5). For shear velocity square factors, the mean values for shear modulus 2 and 3 were observed to be fluctuated between erbium concentrations from (20.41 ± 0.47) to (20.42 ± 0.77) and from (20.17 ± 0.47) to (20.39 ± 0.77) respectively ($P \leq 0.05$) (Table 2). The 0.02 concentration value for shear modulus 2 was significantly different from 0.01, 0.03, 0.04 and 0.05 concentrations. Therefore, it was placed in one subset (subset 1) while other concentrations in another subset (subset 2) (Tables 3, 4 and 5). For shear modulus 3, the erbium concentrations were significantly different between (0.03, 0.02); (0.02, 0.04, 0.01) and (0.04, 0.01, 0.05) (Tables 3, 4 and 5). Therefore, there were 3 subsets produced (Tables 3, 4 and 5).

The analysis extended to the means plot in determining the optimum or the best condition for produced a quality glass durability. Figure 2 depicted that the average Longitudinal Modulus 1 was maximized when the Longitudinal Velocity Square 1 was 12.202 and the erbium concentration was 0.05. Figure 3, on the other hand showed that the optimum level of average Longitudinal Modulus 2 was reached at

Longitudinal Velocity Square 2 of 12.025 and erbium concentration of 0.05. It was also found that the best condition that could maximize the average of Longitudinal Modulus 3 was when the Longitudinal Velocity Square 3 was 12.406 and the erbium concentration was 0.05 (Figure 4). Meanwhile, in Figure 5, it could be seen that the Longitudinal Velocity Square 4 of 11.586 (erbium concentration – 0.03) could maximize the average of Longitudinal Modulus 4. Based on Figure 6, the best condition that could maximize the average of Longitudinal Modulus 5 was Longitudinal Velocity Square 5 of 11.637 with erbium concentration of 0.03. In additional, the finding presented that the best condition that could maximize the average of Shear Modulus 2 was Shear Velocity Square 5 of 3.805 with erbium concentration of 0.03 (Figure 7). Figure 8 revealed that the best condition that could maximize the average of Shear Modulus 3 was when the Shear Velocity Square 5 was 3.715 at erbium concentration of 0.05 [12].

As has been discussed, ($p \leq 0.05$) in statistics sight provide the most significant data to be applied. Effective prediction made for all longitudinal modulus, shear modulus 2 and shear modulus 3 can be strongly related to the respect of longitudinal and shear velocities, originally. Before longitudinal velocities been ruled by two, the original longitudinal modulus has acted as initial data to produce good values for longitudinal modulus. All the values of longitudinal velocities in the materials perspective based on data statistic provided are the values to produce glass that can withstand pressure longitudinally or called as longitudinal modulus. Meanwhile, shear modulus 2 is predicted having the most significant value when amount of shear velocity 2 has been applied to the glass samples. Therefore, glass samples are able to withstand the pressure in a shear and longitudinal directions as compared and depicted in Figure 9 among all the elastic moduli. Figures 9 and 10 depict the image of the exerted force of elastic moduli and Poisson’s ratio act on the glass samples.

The longitudinal and shear velocities are the other name of ultrasonic velocities. It is strongly related to the creation of non-bridging and bridging oxygen within the glass system. Kannapan *et al.*, (2009) [13] has determined that the small values of ultrasonic velocity are attributed to the small amount of electronegativity of element that causes the network to form a weak bond within the glass structure and allow easy creation of non-bridging oxygen. In this case, erbium oxide with the smallest electronegativity, 1.24 has less capability for the attraction of the atoms as compared to zinc (1.65) and tellurium (2.1). This occurrence will eventually create weaker bond, and this is predicted to happen during execution of shear wave throughout the experiment when erbium concentration is 0.01, 0.03, 0.04 and 0.05. Consequently, the glass network will loosen up and create more free spaces between the atoms which will cause the ultrasonic wave to be transmitted slower and decrease its velocity.

Besides that, the presence of erbium oxide in the glass series proves the ability of the elements to act as a glass modifier that modify the glass structure in the glass system. This condition will cause a decrease in shear velocity. Saddeek (2004) [14] had mentioned that the inclusion of erbium oxide would modify the glass structure by splitting the Te-O-Te bond and promote the conversion of bridging oxygen into non-bridging oxygen by forming a trigonal bipyramid into a trigonal pyramid [15]. Furthermore, the addition of erbium oxide into the glass interstices enables more ions to be opened up which will weaken the glass structure. These explain the reason for the insignificant values of all shear modulus except for shear modulus 2.

In the meantime, the replacement of lighter molecular weight of tellurium dioxide and zinc oxide by heavier molecular weight of erbium oxide will cause changes in the overall weight of the glass and promotes stronger connection between the bonds in the glass. This indirectly will be a strong indicator to conclude that all values of longitudinal modulus are significant as listed in Table 3 [16]. They have also reported that the formation of glass network with large concentration of dopants in the interstices space would increase the molar mass of the glass sample and improve the compactness as well [17].

Furthermore, the increasing compactness of the glass can also cause by the close distance between the molecules where it allows the transmission of the ultrasonic wave to pass through the glass sample easier. Closer distance between the molecules will result in formation of bridging oxygen in the glass system and contributes to the improvement of the connectivity within the glass network. This is relevant and can be inferred to follow all the significant values of longitudinal modulus that can be used for the fabrication of fiber optic. Other than that, large values of ultrasonic velocities can also be supported by large packing density as mentioned by Elokr and AbouDeif, (2016) [18].

Parameters such as density, molar volume, longitudinal velocity, shear velocity, shear modulus 1, shear modulus 3, shear modulus 4 and shear modulus 5 were not statistically significant at 0.05 level of significant ($P \geq 0.05$) as tabulated in Table 3. The insignificant difference of means between groups can be explained by several reasons. Factor of erbium oxide, initially have affected the significance of the parameters including density, molar volume and longitudinal and shear velocities. Density and molar volume are interrelated to each other in this work where both parameters are theoretically related. Nevertheless, in this work, erbium concentration has played a role in the glass sample. The insignificance of the parameters can first be attributed to the presence of erbium oxide the glass samples. The bond length, inter-atomic spacing within the atoms, the presence of non-bridging oxygen atoms and the rearrangement of the lattice [19–21] might affect the vicinity of the glass structure. The bond length of Er atoms which is 2.26 Å is longer than the bond length of Te atoms (1.6 Å) and Zn atoms (1.42 Å). The increase in the bond length of the dopants will enhance the inter-atomic spacing between the atoms which can influence the escalation of the molar volume in the glass sample [19] that produce numbers of non-bridging oxygen that causes the bond to break. Therefore, the spaces between the glasses are growing exponentially and more excess free volume are formed [22]. Numbers of bridging oxygen can be formed by the formation of more tellurite networks of trigonal pyramid compared to trigonal bipyramid [20]. In addition, the increment of the molar volume can also be predicted by large d-spacing obtained by XRD spectra.

Proper thickness with flat parallel surface of the glass sample is another crucial factor to be discussed. For elastic measurement, the thickness is required to be thicker and both surface of the glass sample must be as parallel as possible. This is to ensure the transmission of ultrasonic wave can propagate smoothly in the glass in order to obtain the smooth wave form. Due to the thinning of the glass sample and less parallel surface of the glass which actually should be equal or more than 5 mm, the ultrasonic wave was most probably can transmit in the glass sample unevenly making the obtained outcome not significant to be used.

Therefore, based on the statistical data been compared with physical data, some values of the parameters were highlighted and predicted to be used as indicator for the application. Table 6 list parameter estimates for the significant factors that will produce an efficient fiber optic durability.

Table 6
Values of significant parameters in materials perspective based on statistics sight

Longitudinal velocity square (m^2/s^2)	Longitudinal modulus (GPa)	Shear velocity square (m^2/s^2)	Shear modulus (GPa)
10130.0 – 12410.0	50.45 – 76.16	3480.0 – 3840.0	17.50 – 24.05

Conclusion

In conclusion, the application of One-Way Analysis of Variance (ANOVA) was quite rare in material science studies. The optimization of glass parameters was done to determine the best outcome that can be utilized for the experimental section. The ANOVA for longitudinal and shear velocities suggested that, at 5% level of significance, all longitudinal modulus, shear modulus 2 and shear modulus 3 have been recognized to be the important factors in gaining higher durability of fiber optic. In the perspective of physics or materials science, high values of longitudinal modulus and shear modulus were the result of good quality glass sample which can be associated with large values of longitudinal and shear velocities. Therefore, it could be inferred that the glass samples were at good state for fiber optic application durability.

Recommendation

There is opportunity to enhance the outcome for study. The future researcher should intensify in examining the cause of insignificant of a few parameters when using statistical analysis rather than theory. Furthermore, the future study should also consider the number of sample selected in the experiment. Moreover, the future research should contemplate the combination of the treatment involved in this kind of study as well. The implementation of this experiment should scrutinize in term of the calibration of the equipment in ensuring the precision and accuracy of the data that will be collected.

Declarations

Acknowledgement

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R.G.P,2/187/42.

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Figures

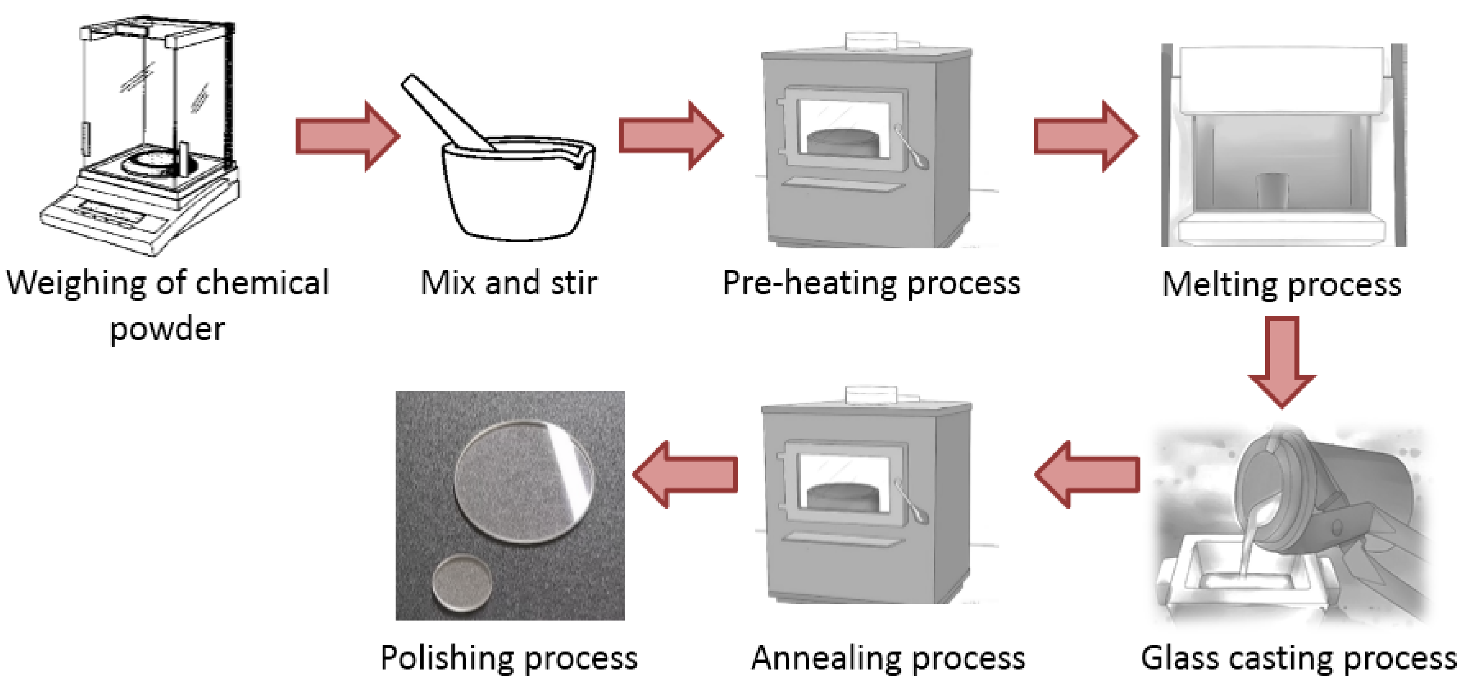

Figure 1

Steps of making glass samples

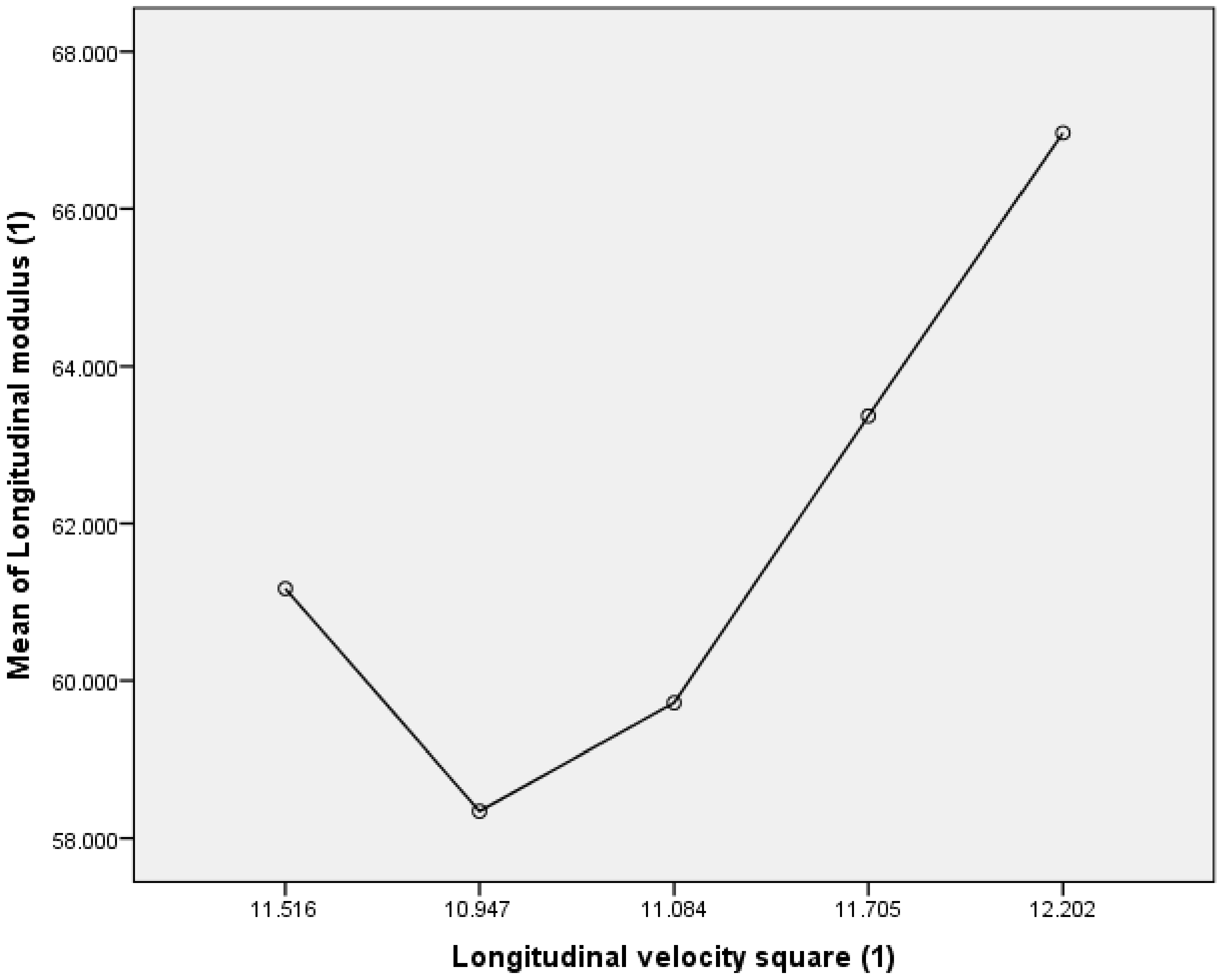

Figure 2

Mean of Longitudinal Modulus versus Longitudinal Velocity Square

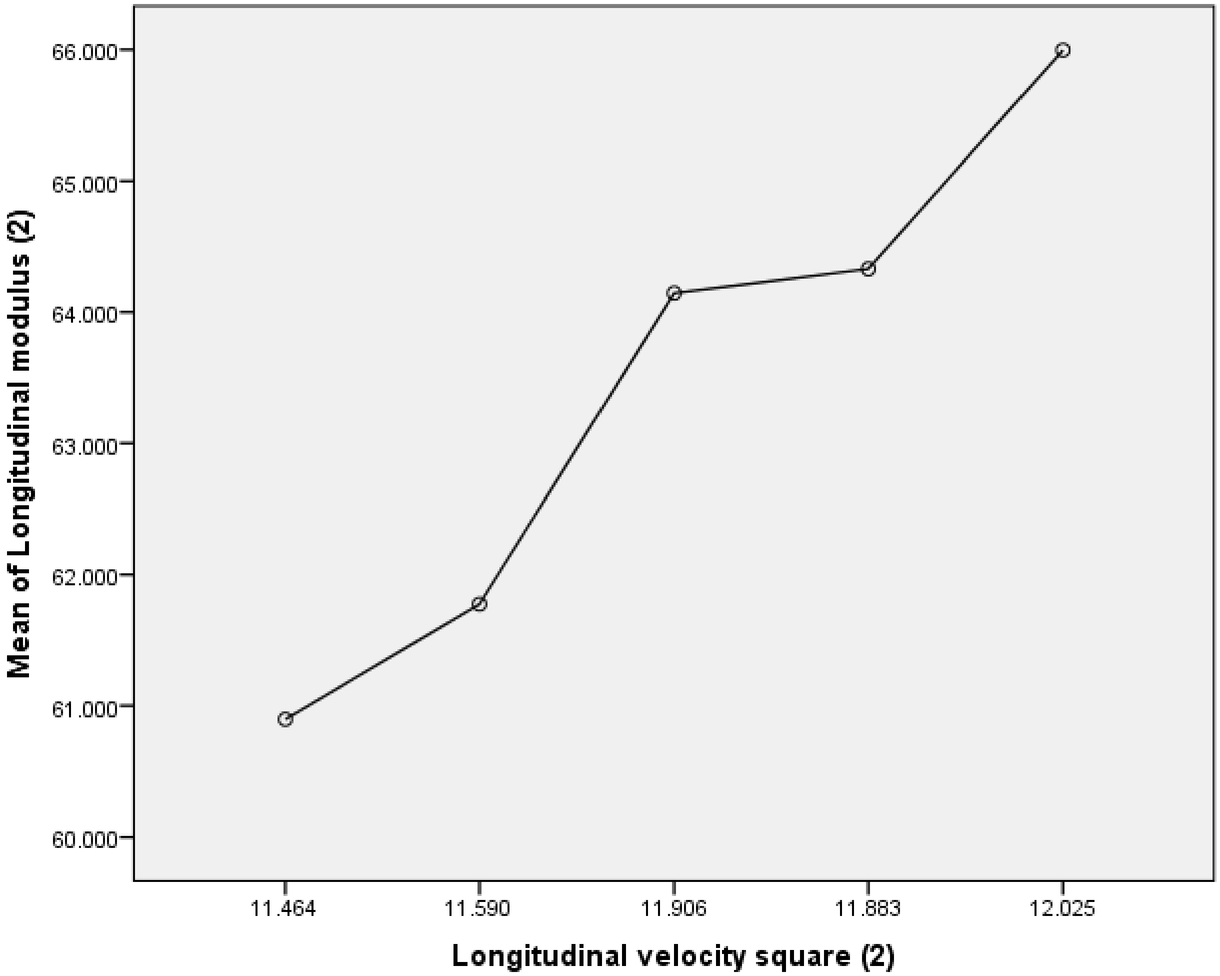

Figure 3

Mean of Longitudinal Modulus 2 versus Longitudinal Velocity Square 2

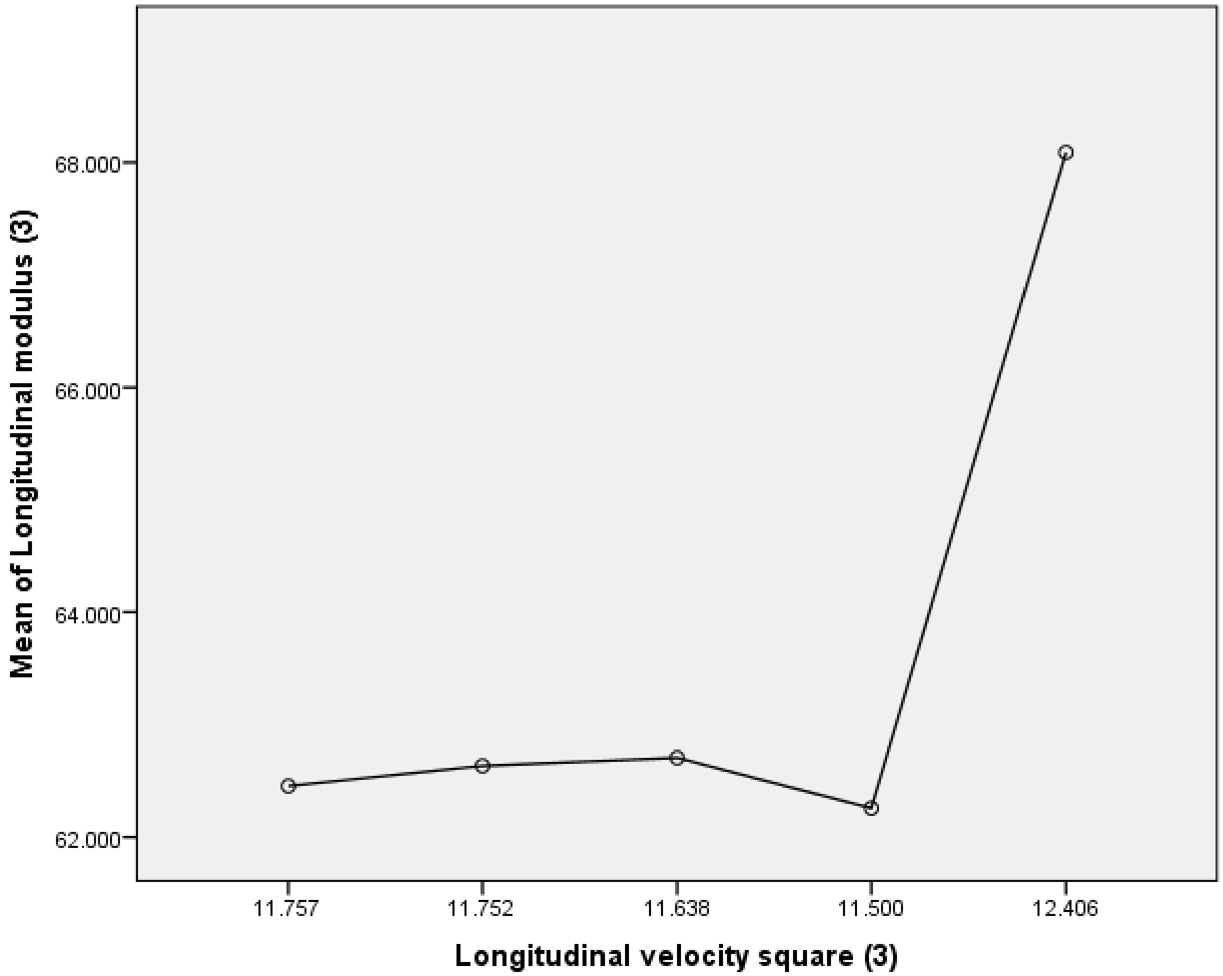

Figure 4

Mean of Longitudinal Modulus 3 versus Longitudinal Velocity Square 3

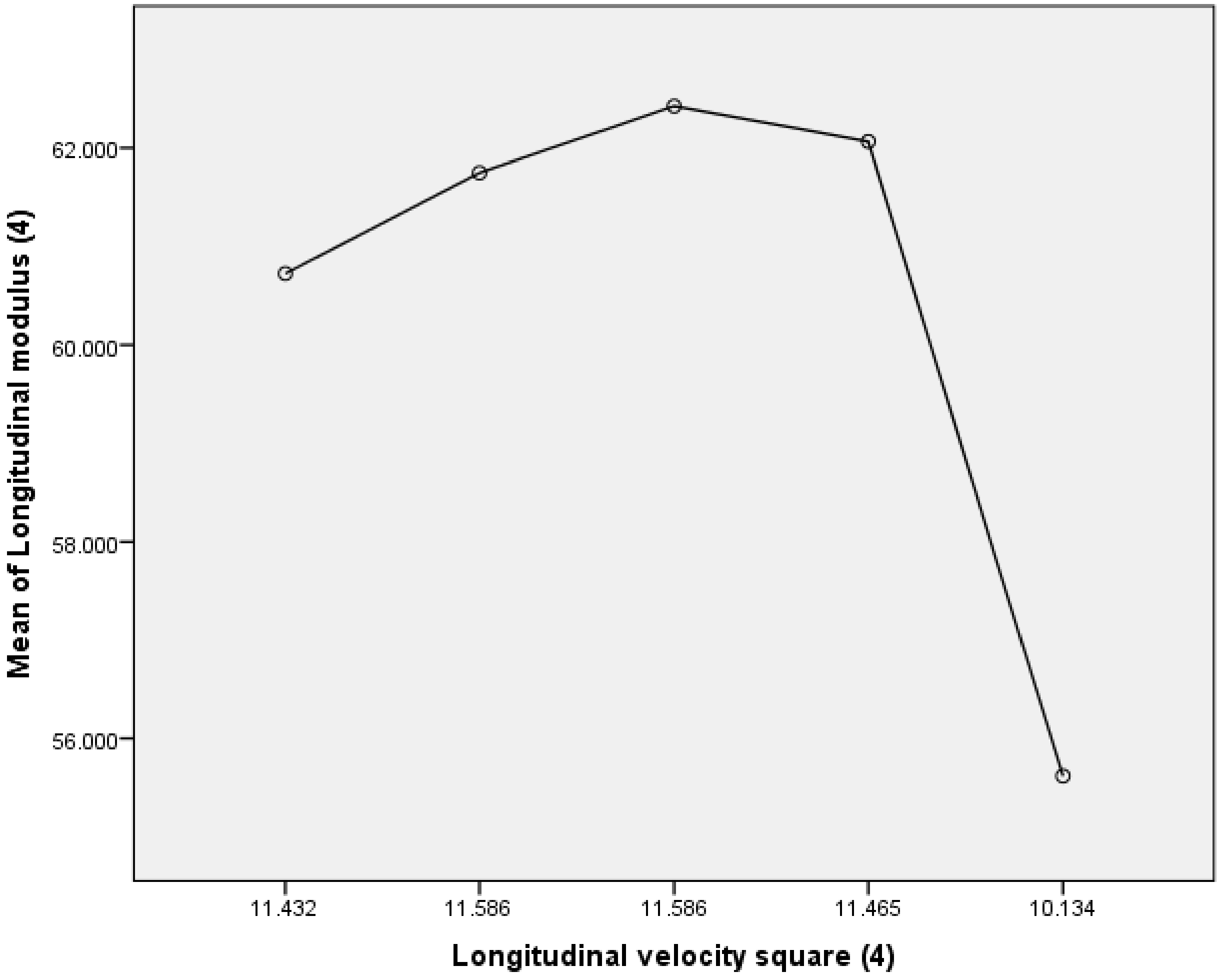

Figure 5

Mean of Longitudinal Modulus 4 versus Longitudinal Velocity Square 4

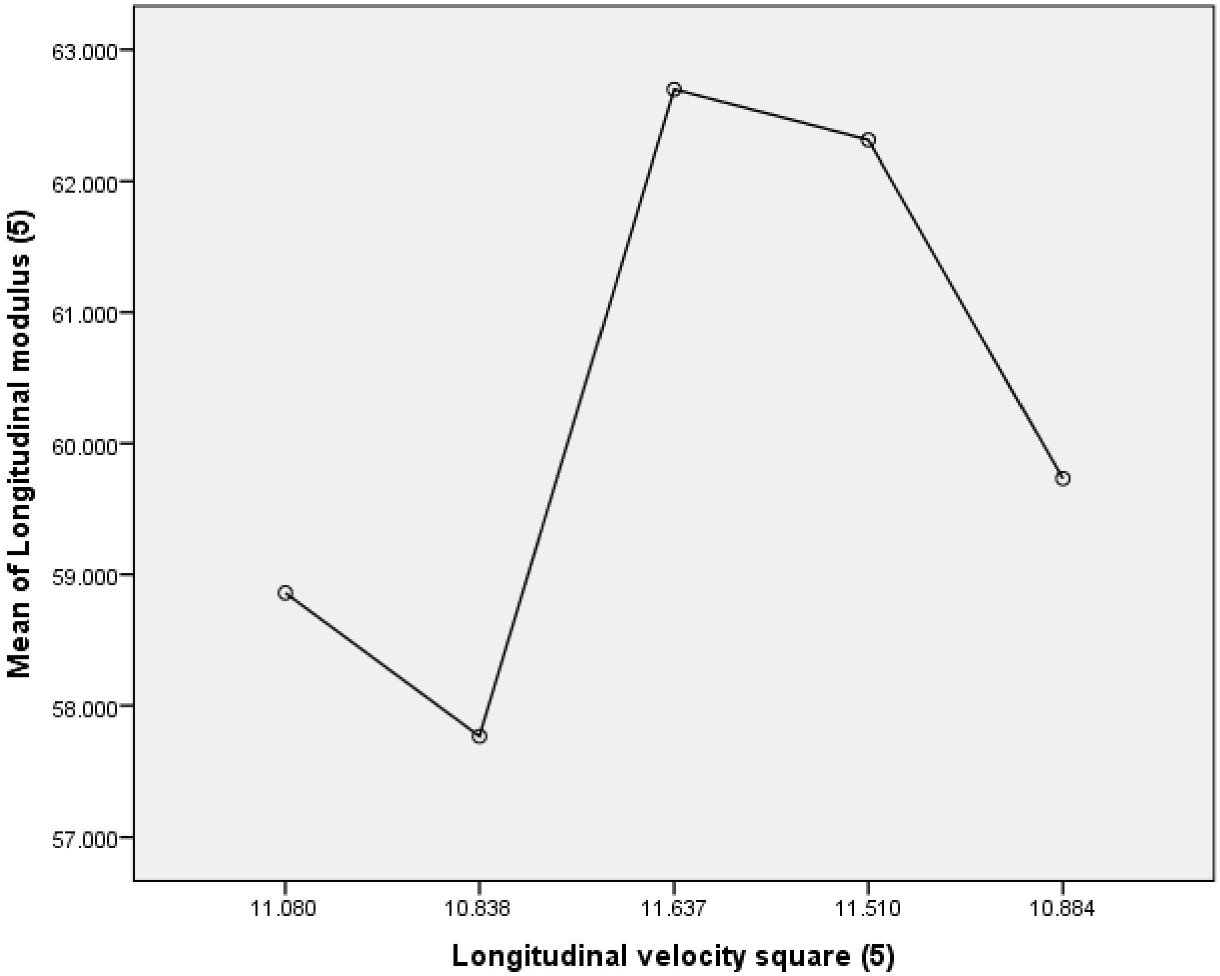

Figure 6

Mean of Longitudinal Modulus 5 versus Longitudinal Velocity Square 5

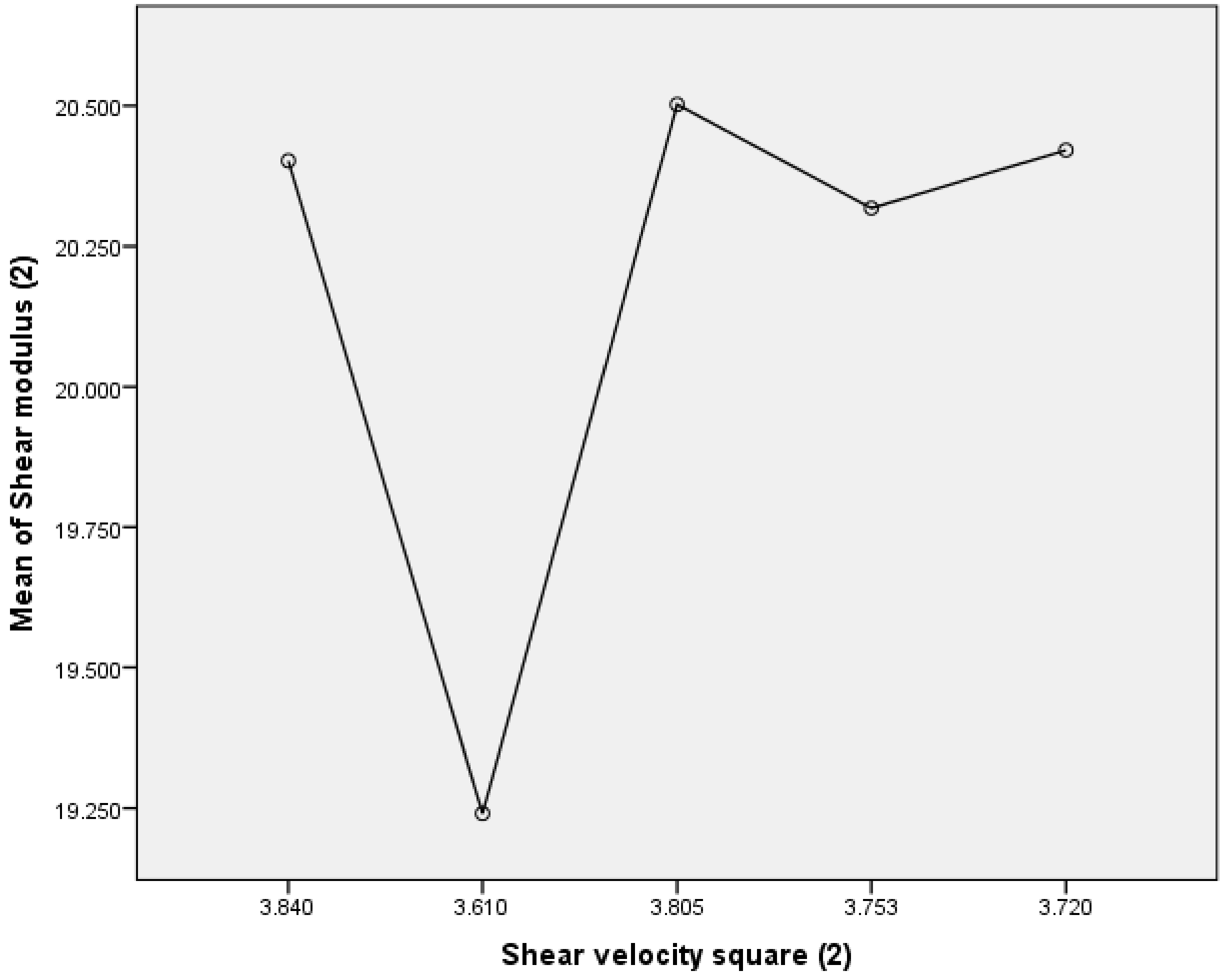

Figure 7

Mean of Shear Modulus 2 versus Shear Velocity Square 2

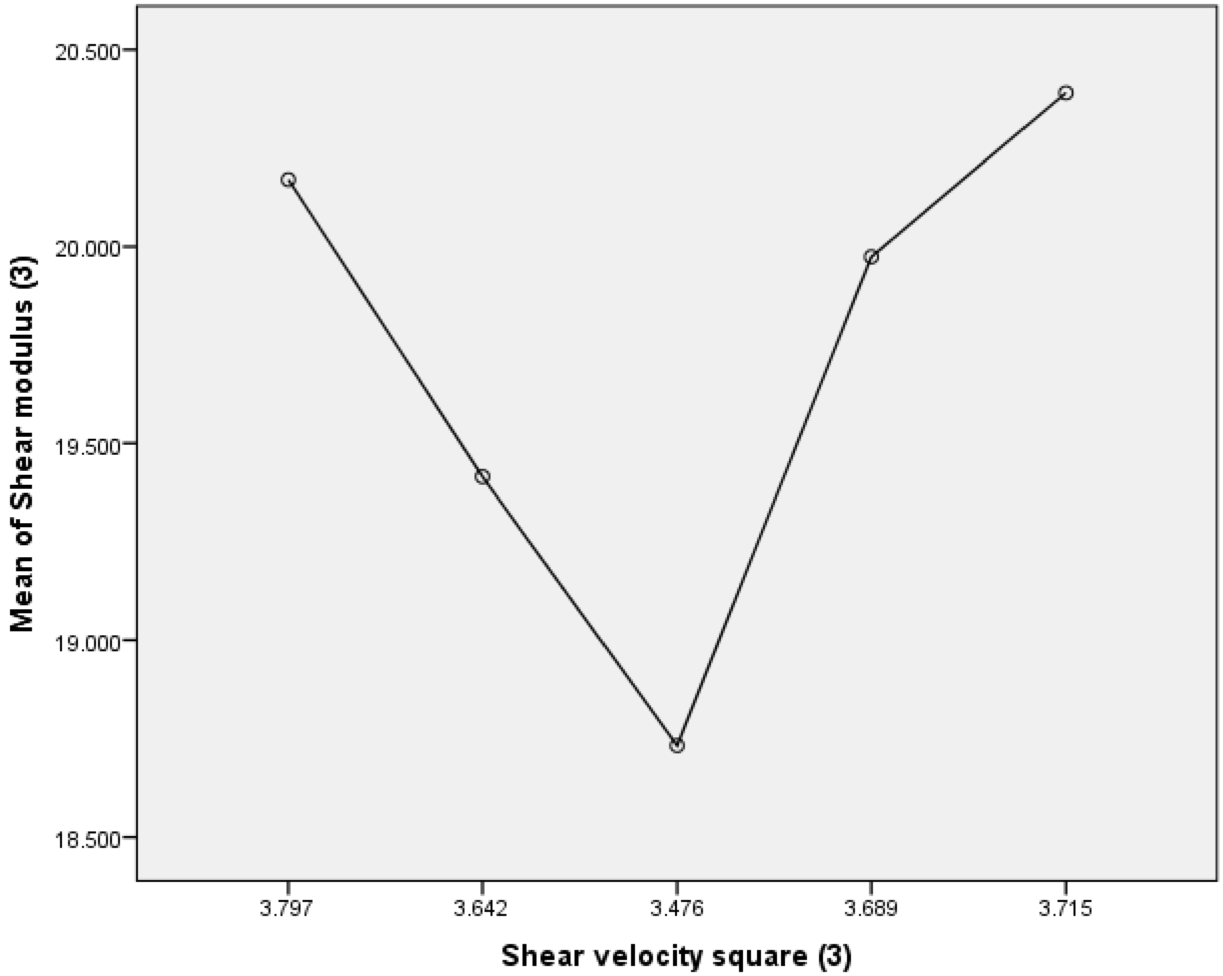

Figure 8

Mean of Shear Modulus 3 versus Shear Velocity Square 3

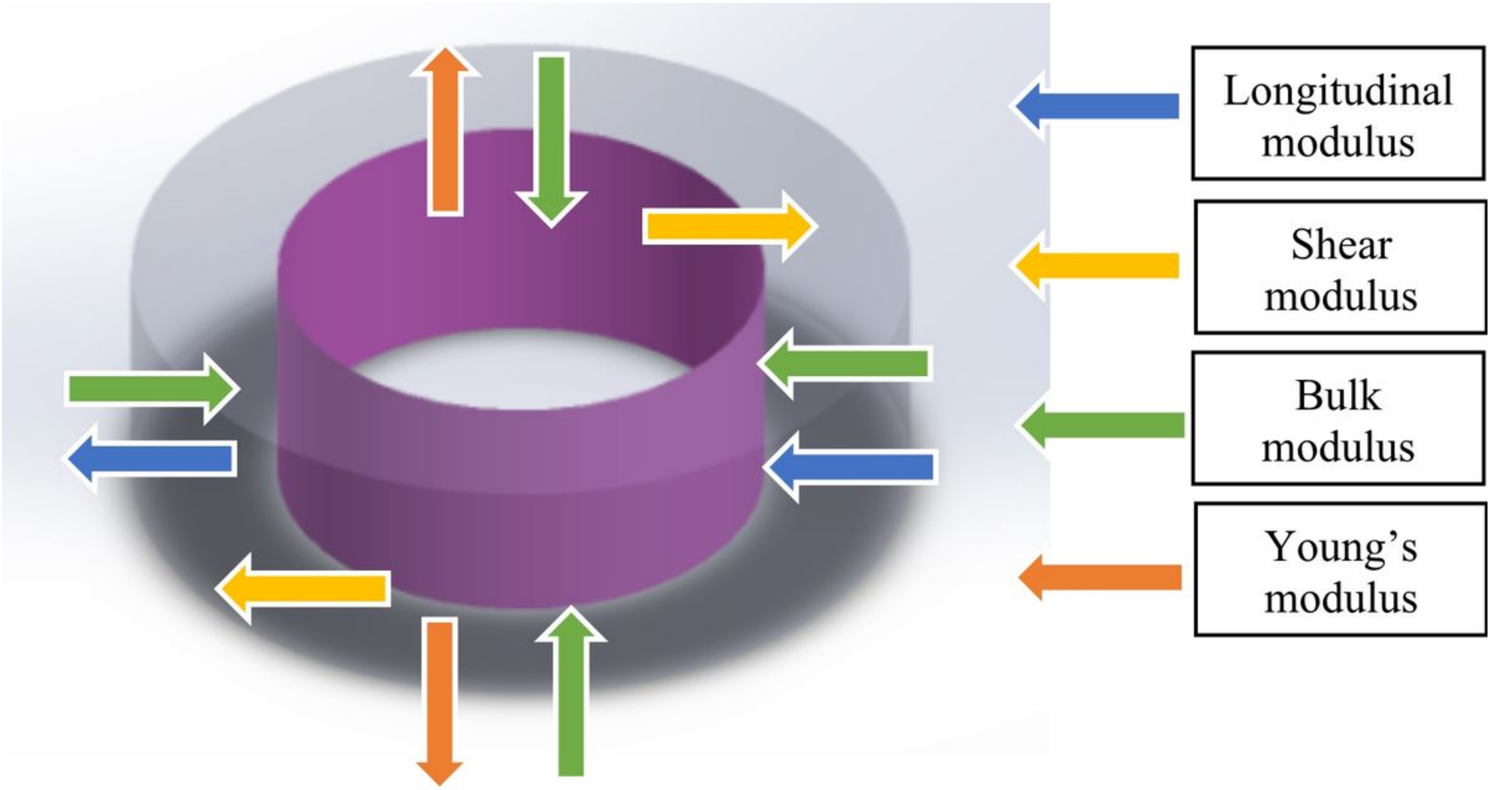

Figure 9

Image of direction of different elastic moduli against the erbium zinc tellurite glass

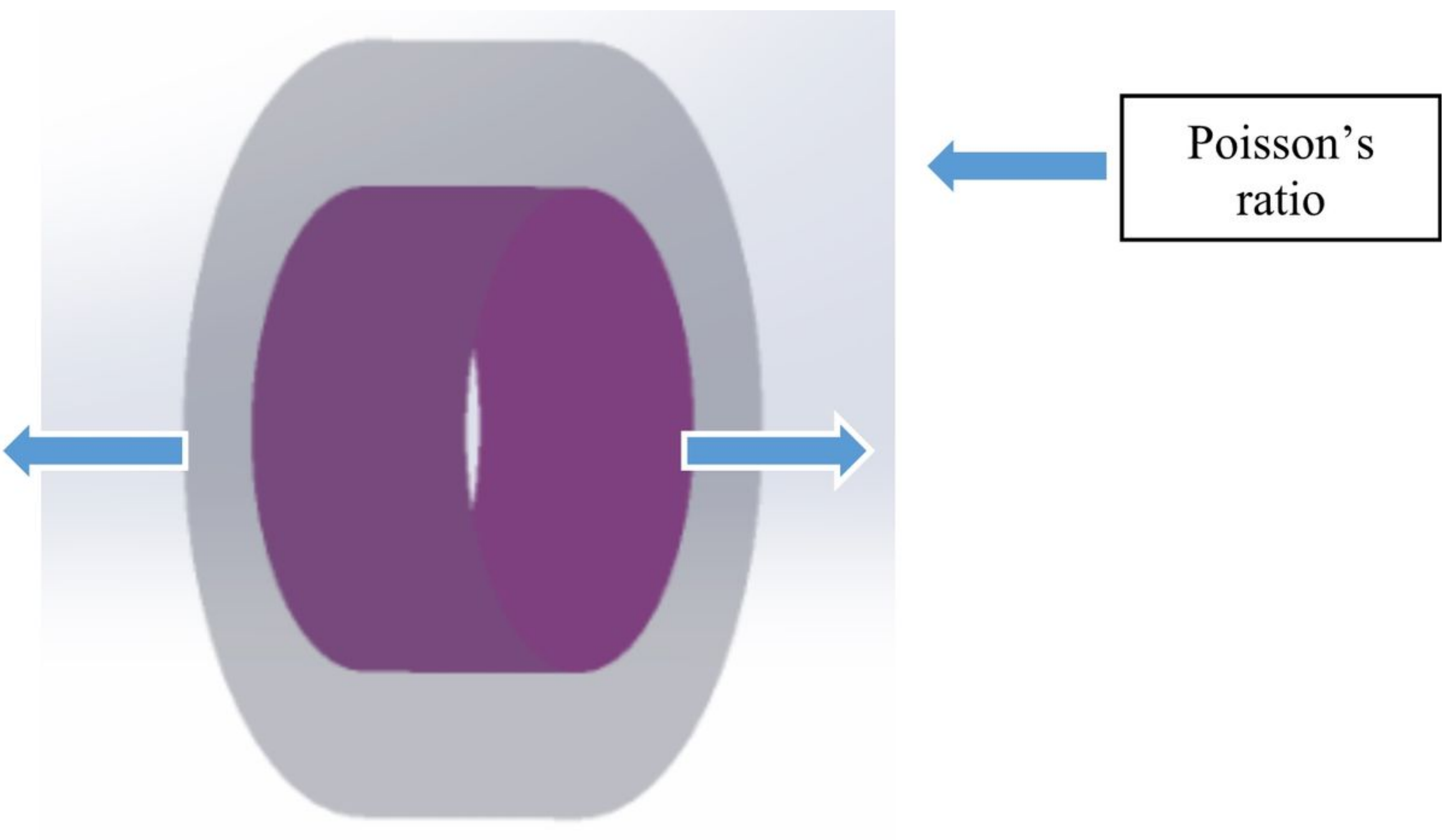

Figure 10

Image of direction of the Poisson’s ratio against the erbium zinc tellurite glass