Exp. Theo. NANOTECHNOLOGY 9 (2025) 39-50 https://doi.org/10.56053/9.S.39

Study the physical, mechanical and electrical properties of ceramics prepared from Iraqi raw materials and their improvement

Hajir Maher Abdullah[1,3,*], *Mojahid M. Najim*[2], *Ban A. Yousif*[3]

[1]University of Anbar, AL-Anbar, Iraq
[2]Department of Medical Physics, College of Applied Science, Hit, University of Anbar, AL-anbar, Iraq
[3]Department of Applied Science, University of Technology- Iraq
[*]) Email: Mojahid.M.Najim@uoanbar.edu.iq

Received 25/10/2024, *Received in revised form* 31/11/2024, *Accepted* 9/12/2024, *Published* 15/2/2025

In this study, locally available raw materials are the main ingredients in the preparation of cordite and mullite, such as kaolin clay, bauxite, etc. Silica prepared from rice husk ash is also used, in addition to magnesium oxide and magnesium carbonate. The materials are crushed and ground to a size of less than 45 microns. The samples are subjected to physical and chemical analysis. The materials are burned and dried in a burning program at an increase of 50 °C/hour for two hours (1300 - 1450). Physical (Apparent Porosity and Water Absorption) Mechanical (compressive strength) and electrical (breakdown voltage) tests are performed on the samples. From the results of these testes, we saw that 1300°C firing temperature is not enough to get the sintering between mullite and the addition of cordierite. The evaluations given by the samples fired in 1400°C are the most favorable. Samples that fired in 1450°C have not good Mechanical and electrical, specifications because the samples containing 50%, 60% and 70% cordierite are melted. Samples containing 30% and 40% cordierite are the best in our current study because they have good mechanical and electrical specifications, their mixtures could be used in production Ceramic insulators.

Keywords: Bauxite; Cordierite; Kaolin clay; Ceramic.

1. INTRODUCTION

aluminum silicate [1]. It has a variety of qualities, they are characterized by A low dielectric constant results in a low dielectric loss, Chemical durability is high despite low thermal expansion, and low thermal conductivity, and high hardness ranging from 7-7.5 on the Moh's scale [2-4]. As a result, electronic packaging uses it, primarily for integrated circuit substrates, and for coating metals, kiln furniture, sound insulating boards, and electromagnetic wave absorbers [5]. Cordierites can be classified into three distinct types. When the temperature is low, cordierite crystalizes into β-cordierite or low-temperature orthorhombic cordierite. The crystal system transforms into a hexagonal system when the temperature rises, Indialite is also known as high-temperature cordierite (α -cordierite) figure (1) [6-7].

Another stable cordierite phase known as μ-cordierite can crystallize either from a melt or be prepared from fine materials [4]. Cordierite mineral can stay stable up to 1460°C, but after that it starts to melt incongruously, consisting of mullite and glass figure (2) [8-9].

Mullite ($3Al_2O_3 \cdot 2SiO_2$) is widely recognized for its ability to improve the mechanical properties of cordierite, but it is also utilized in electronic substrates, this product is well-suited to microelectronic packaging and reinforced composites due to its excellent electrical resistance, thermal shock resistance, at high temperatures, the thermal and chemical stability is excellent, and the dielectric and mechanical properties are good [10-11].

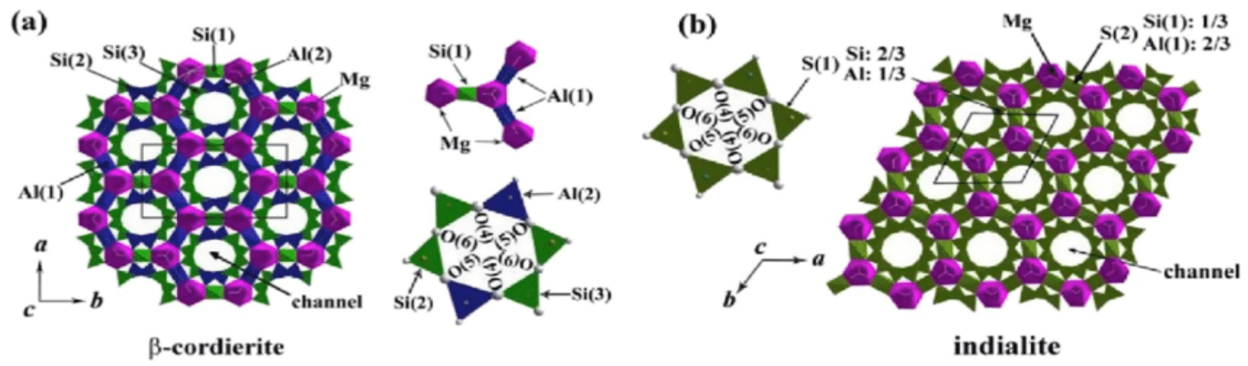

Figure 1 Structure of cordierite when (A) low temperature, (B) heigh temperature.

2. MATERIAL AND METHODS

2.1 Raw Materials Testing

Duekhla kaolinite claystone particles that are ground have undergone particle size distribution tests, Urdhuma silica sand, bauxite, and Porcelains are sieved using a mesh size of 45μ. The grinded powder of each raw material is passed through the sieve. [12-13]. The correction rate of chemical analysis is determined by testing those materials using the analysis methods. The chemical analyzing results of raw materials are presented in Table1.

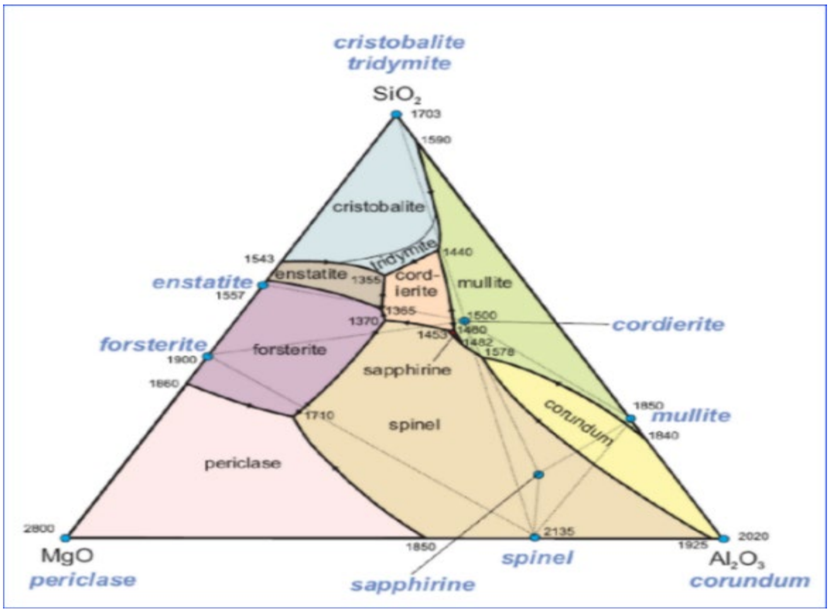

Figure 2 Silica-alumina-magnesia system and the location of cordierite mineral.

Table 1 Chemical analysis of the materials used in the study.

Sample type	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	P_2O_5 %	L.O.I %
Kaolin	49.46	33.40	1.15	0.53	0.37	0.41	0.48	-	12.24
Flint Clay	43.86	38.01	0.54	0.04	0.60	0.18	0.10	-	13.9
Silica Sand	98.35	0.03	0.14	0.23	0.32	0.42	0.06	0.09	0.37
Bauxite	21.00	58.08	1.15	0.75	0.80	-	-	-	13.76
Porcelanite	67.36	2.55	1.05	5.4	5.46	0.73	0.14	1.1	10.54
Pure Silica Sand (Kaaem)	96.4	-	-	-	-	-	-	-	3.4
Mg CO_3	-	-	-	43.5	-	-	-	-	56.5
$Mg(OH)_2$	-	-	-	68.1	-	-	-	-	31.9
* Amor phous Silica	87.89	0.39	0.14	0.34	1.40	1.10	3.80	-	1.98

* Rice hush ash (1000 °C)

2.2 Preparation of The Mixes

2.2.1 Steps to Prepare Mullite Metal

For mullite metal ($3Al_2O_3.2SiO_2$) Mixing is configured with weight (1kg) Consisting of (91% bauxite, 9% silica from burning rice crusts, 0.5% $MgCO_3$), Ingredients (bauxite and silica are mixed from Burning rice crusts) and ground dryly previously and well and passed from sieve (1mm); So, for the best homogenization. Grinded for (5) hours using a grinder Porcelain balls, the ratio of weight of porcelain balls to the weight of the mixture (1500g: 500g), then added magnesium carbonate ($MgCO_3$) by 0.5% (as mineral material) to the mixture, then blended well and re grinded for (5) Other hours, after the completion of the grinding process moisturized the mixture by adding water to it by 8%. then put in a nylon bag and closed tightly and left for more than (24 hours); To completing moisture homogenization in the mixture.

2.2.2 Steps to Prepare Cordierite Metal

White kaolin and silicon sand can be used in two popular sizes: 45 microns or 20 microns. The remainder of the raw materials are utilized, and each sweetheart is 45 microns in size. The components of each previously ground raw material are well mixed after completing the weighing process, each mixture is moisturized by adding 8% water and re-grinding it for 5 hours. Each mixture is homogenized consistently by the grinded sieve (2 mm) and then the sieve (1 mm) after the grinding process is finished. The moisture homogenization process can be completed by tightly storing it in nylon bags for 24 hours.

2.3 Forming of Samples

Formed sample in the form of cylindrical tablets with diameter (4cm) and thickness (0.5cm), weight (8g) per sample, using a single axis hydraulic piston type (HERZOG) and by pressure of 1000kg/cm2; So, to get higher Convergence of granules facilitating the process of sintering and the acquisition of chemical reactions Granules with each other during the burning process, as well as to reduce longitudinal contraction [14].

2.4 Drying and Firing

The samples are drained at a temperature of 105°C and for a period of 24 hours; To remove water Addendum; To perform the formation process slowly, so that no cracks occur as a result of the contraction Sudden, which may occur if water is quickly expelled during the burning process; the samples are then burned at a temperature of (1300°C) by oven mediation Electrician at the rate of temperature increase is (50) per minute and mature time is 2 hours. To allow time for the metallic phases to react and crystallize, it is important to shut off the furnace. The firing stage is regarded as the most complicated and important stage due to the numerous physical and chemical operations that give the ceramic body strength and toughness [15].

3. RESULT AND DISCUSION

3.1 Cordierite and Mullite Preparation

The first stage of the research project involved the preparation of Raw materials obtained from Iraq are used to make cordierite and mullite ceramics. Figure (3) and (4) presents the pattern of x-ray diffraction in mullite and cordierite. A porcelain ball crusher is used to crush Mullite and cordierite separately, then each powder is sieved with a 45µ-degree sieve, before being stored in bags secured with nylon.

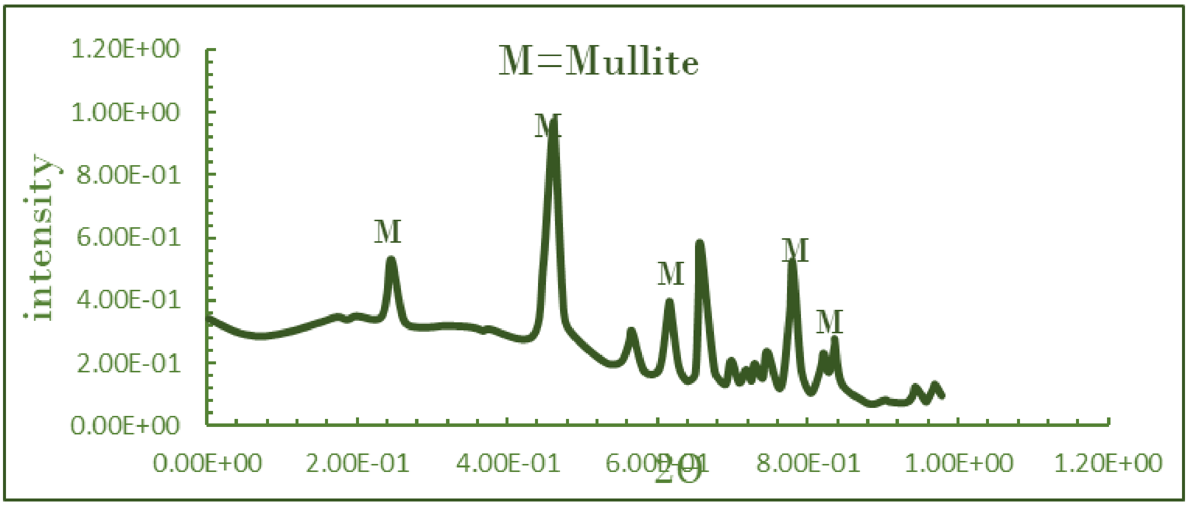

Figure 3 X- ray diffractograms mullite.

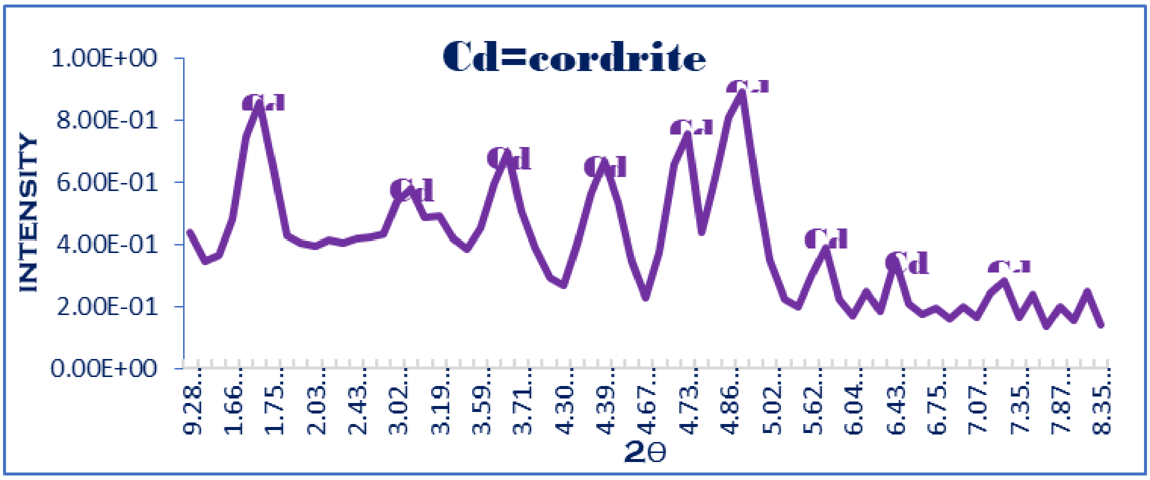

Figure 4 X- ray diffractograms cordierite.

3.2 Physical Properties (Apparent Porosity and Water Absorption)

Fig. (5), Table 2, and Table 3 Presents the There is a correlation between water absorption and apparent porosity at different firing temperatures, with the percentage of cordierite remaining constant. Note that all samples of aggregates (A), (B) and (C), (D) and (E) contain (30, 40, 50, 60 and 70%) Cordierite metal, respectively, when the burn temperature rises from (1300-1400 °C). High and abrupt reductions in phenomenal porosity and water absorption of total samples (A), (B) and (C) are observed. Then it is observed that there is a small increase in the apparent porosity and water absorption of the above group samples with an increase in burning temperature to (1450°C) . This is attributable to the fact that, as the burning temperature of the above collections' samples increases in convergence of granules due to the sintering process, as well as the effect of the liquid glass phase factor, which fills the pores in the ceramic samples causing a decrease in their ratio [16-17], and the decrease in porosity will directly result in a decrease in the water absorption ratio. With a high burning temperature of 1450 °C, the cordierite metal begins to fuse; This causes an increase in the proportion of pores (closed and open); This directly increases the proportion of water absorption of samples. Groups (D) and (E) have a high decrease in phenomenal porosity and water absorption with increased burning temperature from (1300-1450°C)

This is due to the increased convergence of granules due to the process of sintering, as well as the appearance of the liquid phase (Cordierite glass + glass), which fills the pores and reduces their proportion, and then exposes them to vitrification at high temperatures, which increases surface tightness and reduces apparent porosity, directly resulting in a decrease in water absorption.

Table 2 Water absorption values for samples fired at 1300, 1350, 1400, and 1450 °C.

Sample	Firing temperature °C			
	1300	1350	1400	1450
A	9.86	0.98	0.90	1.20
B	10.05	1.05	1.05	1.25
C	10.46	1.46	1.10	1.31
D	11.39	1.56	1.19	1.02
E	11.71	1.87	1.71	1.02

Table 3 Apparent porosity values for samples fired at 1300, 1350, 1400, and 1450 °C.

Sample	Firing Temperature °C			
	1300	1350	1400	1450
A	22.30	2.63	2.03	2.42
B	22.42	2.76	2.03	2.42
C	22.61	3.73	2.44	2.86
D	23.11	3.90	2.75	2.15
E	24.15	4.73	2.90	2.00

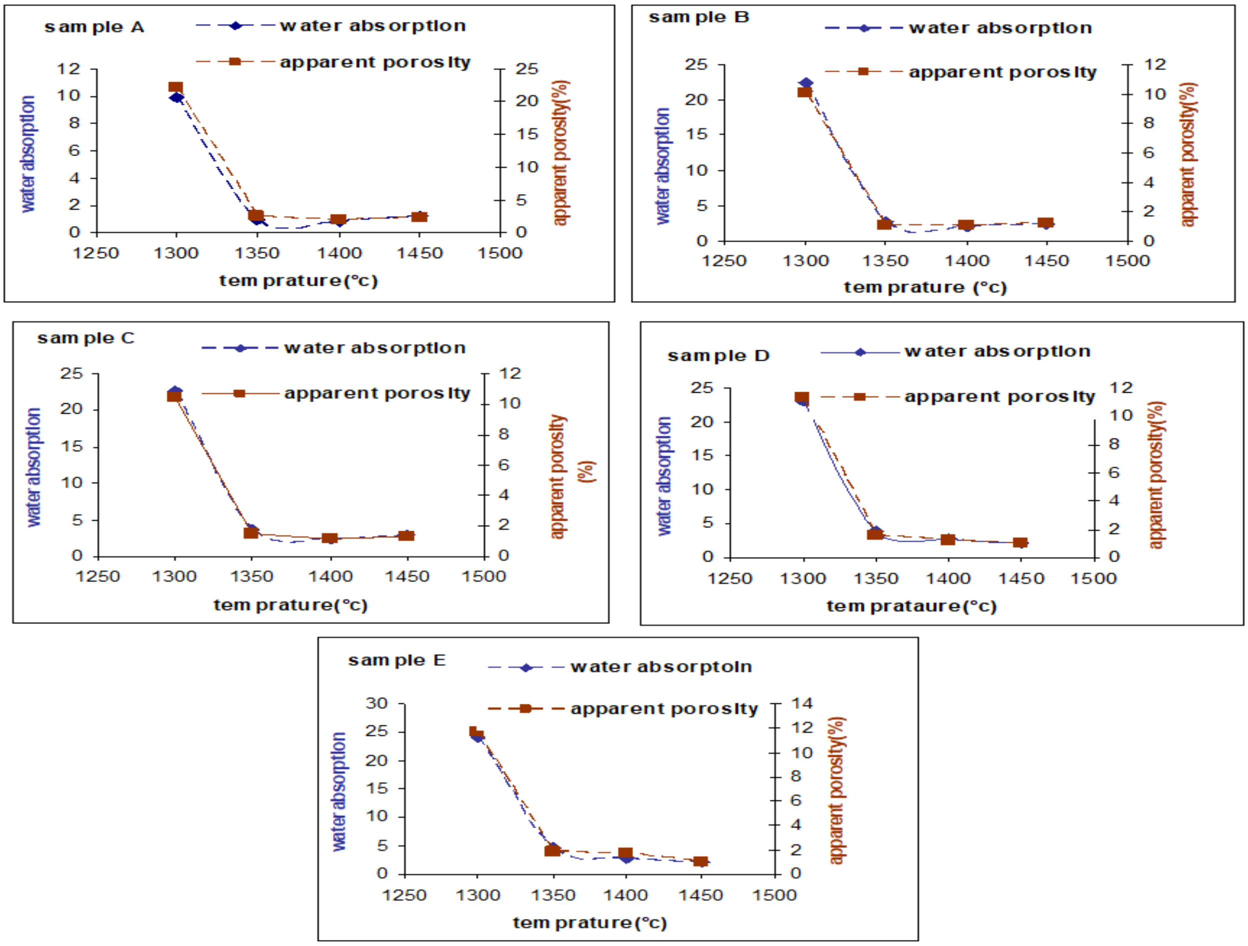

Figure 5 (A), (B) , (C) , (D) and (E) The relationship of the water absorption and apparent porosity with changing burning temperatures.

3.3 Mechanical Properties (Compressive Strength)

Table 4 Fig. 6 shows the results of the compressive strength tests for samples that are fired at 1300, 1350, 1400, and 1450 °C, samples can be sorted into five groups which are: A, B, C, D, and E. It is noted that the samples with the symbol (A), (B) And the(C) And the(D) And (E)All of them are characterized by a gradual increase in their compressive strength values with increasing firing temperature from (1300-1400 °C).

When the burning temperature rises to (1450) It is noted that there is a decrease in the values of the compressive strength of the samples. The reason for this is that with the increase in the burning temperature from (1300-1400) The structural structure of the cordierite mineral begins to break down (softening), which helps the sintering process take place. This leads to an increase in the proximity of the grains to each other, as well as the appearance of a liquid phase that works to reduce the size of the pores and close them, which hardens upon cooling, leading to an increase in density and the samples become stronger and more durable, which in turn leads to increased compressive resistance. As for the decrease in compressive strength values at a temperature of (1450°C), which is due to the increase in the number of pores (opened and locked) caused by the melting of cordierite mineral, so the porosity percentage enhance and the total density reduction, which lead to a reduction in the compressive resistance values of the samples [18].

Table 4 Compressive strength values for samples fired at 1300, 1350, 1400, and 1450°C.

Sample	Firing temperature °C			
	1300	1350	1400	1450
A	69.10	93.20	96.20	90.40
B	67.80	90.40	94.60	90.10
C	65.20	89.80	94.30	89.60
D	63.70	88.40	92.30	86.60
E	61.50	87.50	90.10	80.30

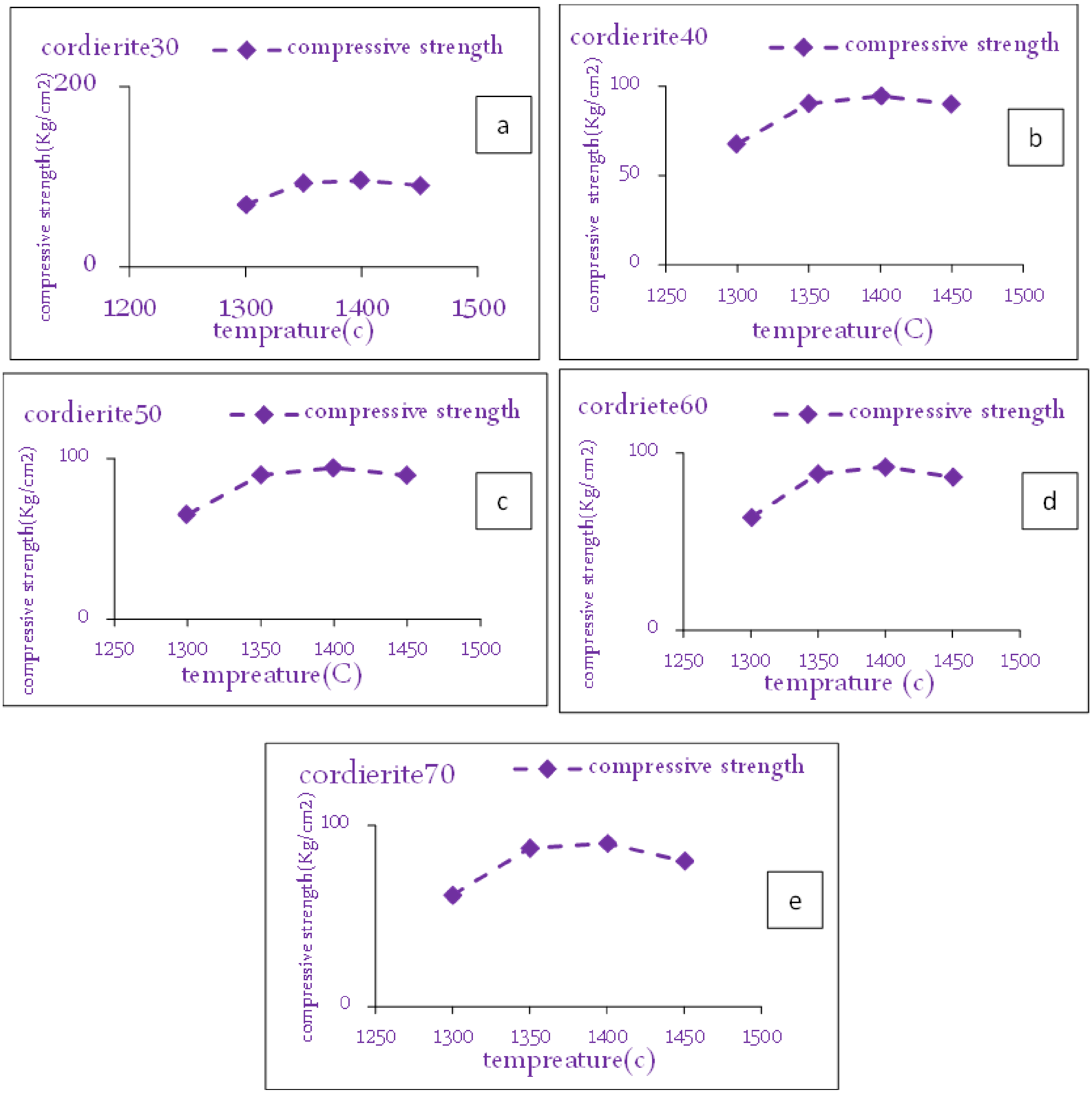

Figure 6 (a), (b), (c), (d) and (e) the relationship of the compressive resistance with changing burning temperatures.

3.4 Electrical properties (Breakdown Strength)

Tables (6), (7) show the results of the breakdown voltage test for the study samples when a voltage of (5kv/sec) and (0.5kv/sec) is applied. Figure (8) shows the relationship of breakdown voltage values with changing burning temperatures with constant added percentages of cordierite. It is noted that the samples of groups (A), (B), (C), (D), and (E) are all characterized by their voltage values. The breakdown of its samples increased with increasing burning temperature from (1300-1400°C) when applying a voltage of (5kv/sec) and a voltage of (0.5kv/sec). When the burning temperature reaches 1450 °C, the breakdown voltage values for the samples of the above aggregates decrease. This is due to the breakdown voltage values increasing with increasing firing temperature due to the decrease in the apparent porosity of the samples. The breakdown effort increases with the decrease in porosity [19-22] and with the increase in the burning temperature to (1450 °C), the apparent porosity percentage of the samples increases due to the melting of the cordierite mineral. Therefore, the breakdown voltage values decrease.

It is noted that the samples of groups (A), (B), (C), (D), and (E) behave similarly in terms of breakdown voltage values, as with increasing firing temperatures, they have similar breakdown voltage values for their samples, but with lower values when voltage is applied. Its amount is (0.5kv/sec); This is due to the high temperature of the samples due to the long period of time that the testing voltage is applied to them. As the temperature of the samples increases, a number of excited electrons will become available that jump to the conduction band, so the electrical conductivity increases quickly with the increase in temperature; Which causes a decrease in the breakdown voltage.

Table 5 The results of the breakdown voltage test for the study samples when a voltage of (5kv/sec).

Sample	Firing temperature ° C			
	1300	1350	1400	1450
A	36.55	38.125	50.5	32.866
B	35.733	46.1	49.00	18.9166
C	33.266	41.90	50.9	19.933
D	33.9	45.71	49.95	22.2
E	32.5	42.2625	48.266	33.475

Table 6 The results of the breakdown voltage test for the study samples when a voltage of (0.5kv/sec).

Sample	Firing temperature ° C			
	1300	1350	1400	1450
A	28.15	31.725	48.166	30.466
B	33.6	38.266	40.6	21.8
C	33.25	37.05	39.5	20.6
D	31.6	38.186	45.6	17.933
E	30.4	41.075	44.433	33.6

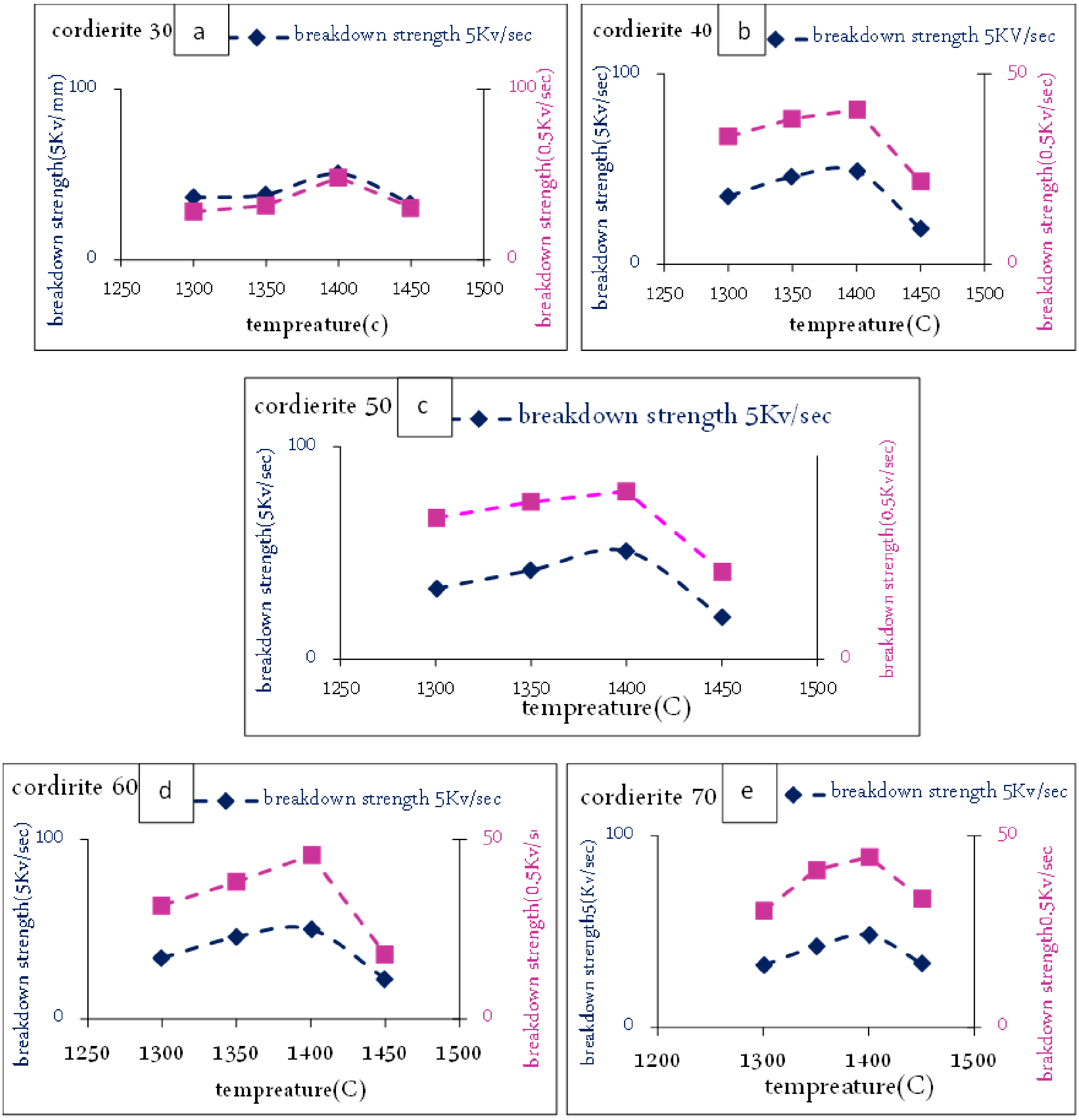

Figure 7 (a), (b), (c), (d) and (e) the relationship of the Breakdown strength with changing burning temperatures.

4. CONCLUSIONS

1. Increase the burning temperature to 1450 degrees Celsius if the percentage of cordierite in the samples remains constant. The samples showed a decrease in apparent porosity and water absorption.
2. The samples' physical, mechanical and electrical characteristics can be improved mullite can be burned at temperatures of 1350 and 1400°C by adding 30% and 40% cordierite to it.

3. It was found that samples with constant firing temperature and increasing cordierite (30-70%) showed a gradual decrease in breakdown voltage.
4. The optimal sample for each study sample must contain 30% cordierite and 70% mullite, and burn at 1400 °C.

References

[1] Y. Sung, J. Mater. Sci. 31 (1996) 5421
[2] R. Rodney, M. Irwin, H. Paul, U.S. Patent 4,001,028 (1977)
[3] M. Karkhanavala, F. Hummel, J. Am. Ceram. Soc. 36 (1953) 389
[4] A. Blodgett, R. Barbour, IBM J. Res. Devel. (1982) 30
[5] McMillan, Soc. Glass Tech. 6 (1985) 286
[6] M.M. Najim, B.A. Yousif, Iraqi Geol. J. 54 (2021) 23
[7] K. Song, S. Wu, P. Liu, H. Lin, Z. Ying, P. Zheng, W. Su, J. Deng, L. Zheng, H. Qin, J. Alloy. Comp. 628 (2015) 57
[8] M.M. Najim, B.A. Yousif, Iraqi Geol. J. 53 (2020) 49
[9] A.A. Albhilil, M. Palou, J. Kozánková, M. Bohá˘c, Arab J. Sci. Eng. 40 (2015) 151
[10] F. Sadegh Moghanlou, M. Vajdi, H. Jafarzadeh, Z. Ahmadi, A. Motallebzadeh, F. Sharifianjazi, M. Shahedi Asl, M. Mohammadi, Ceram. Int. 47 (2021) 10057
[11] Muhammad Ismail, Exp. Theo. NANOTECHNOLOGY 7 (2023) 95
[12] P.J. S.-Soto, D. Eliche-Quesada, S. Martínez-Martínez, L. Pérez-Villarejo, E. Garzón, Materials 15 (2022) 583
[13] A.S. Ibrahim, A.A. Baba, SSRN Electron. J; 4 (2022) 45
[14] E.M. Hadi, S.I. Hussein, Energy Procedia 157 (2019) 241
[15] L. Carbajal, F. Rubio-Marcos, M.A. Bengochea, J.F. Fernandez, J. Eur. Ceram. Soc. 27 (2007) 4065
[16] R. Kumar, B. Bhattacharjee, Cem. Concr. Res. 33 (2003) 155
[17] E.I. Ezenwabude, T.C. Madueme, Int. J. Multidiscip. Sci. Eng. 6 (2015)
[18] V.M. Nardo, G. Cassone, R.C. Ponterio, F. Saija, J. Sponer, M. Tommasini, S. Trusso, J. Phys. Chem. A 124 (2020) 10856
[19] C.J.F. Böttcher, Recueil Trav. Chim. Pays-Bas 64 (2010) 47
[20] X. Wang, J. Whitaker, Exp. Theo. NANOTECHNOLOGY 7 (2023) 67
[21] R. Sahnoun, Exp. Theo. NANOTECHNOLOGY 7 (2023) 78
[22] J. Christ, M. Filips, R. Nowak, M. Reed, Exp. Theo. NANOTECHNOLOGY 7 (2023) 87