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PREPARATION OF CERAMIC MATERIAL (CORDIERITE) USING LOCAL ORES

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ABSTRACT

The research aims to prepare cordierite by using sources of alumina, silica, and magnesia from local and available raw materials (kaolin and dunite rocks). Cordierite ceramic was prepared by different mixtures of raw materials, different preparation methods (molding and hydraulic pressing) were used to form the starting materials, also magnetic separation was used to purify dunite from iron. Sintering the prepared samples at different temperatures (1200, 1250, 1300, and 1350 °C) for 2 hours. The prepared sintered samples were characterized by chemical analysis, X-ray diffraction, porosity, and bulk density. The proportions of oxides affect the preparation of cordierite also sintering temperature is a very important factor. For samples prepared by molding at temperatures (1200 – 1250) °C, different minerals appeared with cordierite (mullite, cristobalite, and corundum) by increasing the sintering temperature to 1300 – 1350 °C the cordierite peaks increased. Samples prepared by using dunite 30 wt.% and 40 wt.% cordierite was the only mineral that appeared. The preferred dunite rocks content was 30 wt.% because increasing the percentage of dunite in the mixture at 1350 °C leads to deforming of the sample. The chemical analysis of the sample prepared by 30 wt.% dunite and 70 wt.% kaolin is close to the chemical composition of cordierite. Different mixtures were pressed and sintered at temperatures 1250 °C and 1300 °C. The only mineral that appeared at 1250 °C was cordierite but with lower intensity compared to the sample sintered at 1300 °C. At 1300 °C, cordierite peaks are accompanied by small peaks of clinoenstitate. Samples prepared with 20 wt.% and 30 wt.% dunite sintered at 1300 °C had high peaks intensities of cordierite, the sample prepared with 20% dunite is closer to the chemical composition of cordierite. Magnetic separation was used to reduce iron in dunite to 1.21%, and different quantities of dunite were used (20 wt.%, 30 wt.%, and 40 wt.%) sintered at 1350 °C. In mixtures containing 30 and 40% dunite, cordierite was the only mineral. By using magnesium oxide instead of dunite rock in the mixture and sintered at different temperatures of 1200 – 1350 °C, cordierite appeared with mullite and cristobalite in all samples.

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تحضير مادة سيراميكية (كورديرايت) باستخدام خامات محلية

زينب كريم نصرالله و ابتسام غازي عيسى

المستخلص

يهدف هذا البحث الى تحضير الكورديرايت من اكاسيد المغنيسيوم والالمنيوم والسيلكا من مصادر محلية متوفرة هي الكاؤولين وصخور الدونايت. تم تحضير عدة خلطات لتجارب تحضير المواد السيراميكية الحاوية على الكورديرايت. تم استخدام طرق مختلفة لتشكيل نماذج الخلطات المحضرة (الصب و الكبس). ايضا تم استخدام جهاز الفصل المغناطيسي لتقليل نسبة اوكسيد الحديد في الدونايت قبل استخدامه في تحضير الخلطات. النماذج التي تم تحضيرها تم معاملتها بدرجات حرارية مختلفة 1200، 1250، 1300 و 1350 °م لمدة ساعتين. تم فحص النماذج بالاشعة السينية الحائدة والتحليل الكيميائي وفحص المسامية وفحص الكثافة الكلية. نسبة المواد الداخلة للخلطة لها تاثير على تحضير الكورديرايت ودرجة الحرارة المستخدمة في المعاملة عامل مهم في التحضير. بالنسبة للنماذج التي تم تحضيرها بطريقة الصب وبدرجة حرارة 1200 و 1250 °م عدة معادن ظهــرت مصاحبة للكورديرايت (مولايت، كريستوبلايـت، وكوروندوم)، بزيادة درجة الحرارة الى 1300° م ارتفعت شدة منحنيات الكورديرايت في النماذج، بدرجة حرارة 1350 °م ونسبة دونايت في النموذج 30% و 40% ظهر الكورديرايت بمفرده، في النموذج الحاوي على 40% دونايت بدء ظهور انصهار طفيف، لذلك اعتبرت النسبة 30% دونايت هي الأفضل ومن ناحية التركيب الكيميائي كانت النسب قريبة للنسب النظرية مع انخفاض في نسبة اوكسيد السيليكون. استخدم المكبس الهايدروليكي لتحضيرعدة نماذج وتم معاملتها بدرجات حرارة 1250و 1300 °م. النماذج الناتجة بدرجة حرارة 1250 °م تكونت من الكورديرايت فقط ولكن بشدة منخفضة، وبدرجة حرارة 1300 °م ارتفعت قمم الكورديرايت وخصوصا مع 20 و 30% دونايت ولكن ظهرت أطوار أخرى. لدراسة تاثير اوكسيد الحديد تم استخدام جهاز الفصل المغناطيسي الجاف لتقليل نسبته في الدونايت الى 1,21% قبل استخدامه في تحضير الخلطات وبنسب 30، 20، 40%، ومعاملته بدرجة حرارة 1350 °م. النماذج المكونة من 30 و40% دونايت ظهر فيها الكورديرايت بمفرده. استخدم اوكسيد المغنيسيوم في تحضير بعض الخلطات بدلا من الدونايت، وتمت المعاملة الحرارية بدرجات حرارة 1200، 1250، 1300، 1350 °م، ظهر الكورديرايت مصاحبا للمولايت والكريستوبلايت في جميع النماذج.

INTRODUCTION

Cordierite (magnesium aluminum silicates) is one of the important phases of the MgO-SiO_2-Al_2O_3 ternary system; it is an important ceramic material that has a low thermal expansion coefficient, high thermal shock resistance, low dielectric constant, and high chemical stability (Almeida *et al*., 2018). Ceramic materials can form with heat; they may be crystalline, vitreous, or both; chemically, nonreactive and noncombustible; so, they can be used in high temperature, corrosive and different applications. Cordierite ceramics contain more than 80% of the crystalline has of cordierite as well as several other phases containing magnesium, aluminum, or silica. The significant interest in cordierite ceramics is due to a number of its valuable properties, for example, high chemical stability and dielectric properties; so, it may be used as heat-resistant electrically insulating materials, and as a refractory coating on metals. Also, used as catalyst carriers for the purification of the exhaust gases for internal combustion engines, and in filters for water purification. Cordierite is permitted to be a replacement for the currently used corundum electrical components (Yurchuk and Dogrgganov, 2012), and (Rundāns, 2021). Cordierite has three polymorphic forms, the stable high-temperature disorder form known as indialite (α-cordierite is stable below 1450 °C), orthorhombic cordierite (β-cordierite stable below 830 °C), and metastable cordierite (μ-cordierite 800 – 900 °C) (Valaášková, 2015) and (Emrullahoğlu *et al*., 2013). There are several methods to synthesize cordierite, such as solid-state reaction, sol-gel, and crystallization of glass. Chemical routes generally produce high purity cordierite and natural raw materials used in industrial production for refractory applications (Orosco *et al*., 2014). The disadvantages of the chemical process include expensive starting materials, complicated processing procedures, and unsuitable for large-scale applications. As a low-cost method using inexpensive materials such as ores, and industrial wastes, it is suitable for the direct preparation of cordierite ceramic by sintering process (Zhu *et al*., 2012). The solid-state sintering of individual oxides of magnesium, aluminum, and silicon, or sintering of the natural raw materials, which are commonly used in the solid-state synthesis are; talc, kaolinite; feldspar attapulgite, alumina, and quartz (Almeida *et al*., 2018), dolomite, mullite, spinel, forsterite and many others (Rundāns *et al*., 2012). Kaolin is used in many different industries. It is a mixture consisting principally of the mineral kaolinite and containing varying amounts of other minerals such as quartz, feldspar, and anatase. Dunite rock consists of more or less pure olivine. It typically contains 36 to 42% MgO and 36 to 39% SiO_2. Olivine is a commercial source of magnesia combined with silica. Natural raw materials kaolinite and dunite rocks, containing oxides of Al_2O_3, MgO, and SiO_2 can be used for cordierite synthesis; so, this study aims to use these raw materials to produce cordierite without accompanied phases by a solid sintering process.

LITERATURE REVIEW

Sumi *et al.* (1998) used kaolinite and magnesium carbonate in different mole ratios after calcination. μ-cordierite was prepared at 940 °C, and α- cordierite prepared at 1300 °C. Emrullahoğl *et al.* (2013) used olivine, halloysite, and alumina raw material and sintered at 1200 – 1400 °C. Shukur *et al.* (2015) prepared cordierite from kaolin and magnesite at temperatures 1050 – 1400 °C. Rundāns and Sperberga (2015) used illite clays containing carbonates and quartz sand resources studied, using different temperatures (1250 °C and 1300 °C). The test results show that these materials contain cordierite as their main crystalline phase with different porosities. Almeida *et al.* (2018) used kaolin waste with talc and magnesium oxide, sintered at different temperatures of 950 to 1350 °C. Rundāns *et al.* (2012) studied the effect of grinding raw materials, fired at 1200 °C, increase in grinding time causes densification and promotes the formation of cordierite. Tamar-Agha *et al.* (2013) used kaolin and bauxite with serpentinite, formed and fired at different temperatures, cordierite appeared at 1200 °C, while by adding mineralizer (LiF and NaF) it appeared at 1100 °C. Najim (2021) used different raw materials (silica sand, kaolinitic claystone, flint clay, porcelanite, and bauxite) with other materials, formed by pressing, fired at temperatures 1100 – 1300 °C, a mixture of kaolin, silica, and magnesite fired at 1300 °C, consist of cordierite. The effect of mechanical activation on cordierite synthesis at different sintering temperatures was studied by Kumar and Kumar (2014). Orosco *et al*. (2014) prepared cordierite using thermal treatment between 700 °C and 1000 °C in a chlorine atmosphere of kaolinite clay and dolomite.

EXPERIMENTAL WORK

Kaolin clay and dunite rocks were crushed, grinded, and sieved through a 0.075 mm sieve, the chemical analysis and X-ray diffraction are shown respectively in (Table 1 and Figs.1 and 2).

Table 1: Chemical and mineral analysis of kaolin and dunite rocks

	SiO_2%	Al_2O_3%	MgO%	mineral phases
Kaolin clay	46.84	32.41	0.22	kaolinite$Al_2O_3.2SiO_2.2H_2O$, quartzSiO_2
Dunite rocks	48.74	0.19	33.73	forsterite $2MgO.SiO_2$, lizardite$3MgO.2SiO_2.2H_2O$

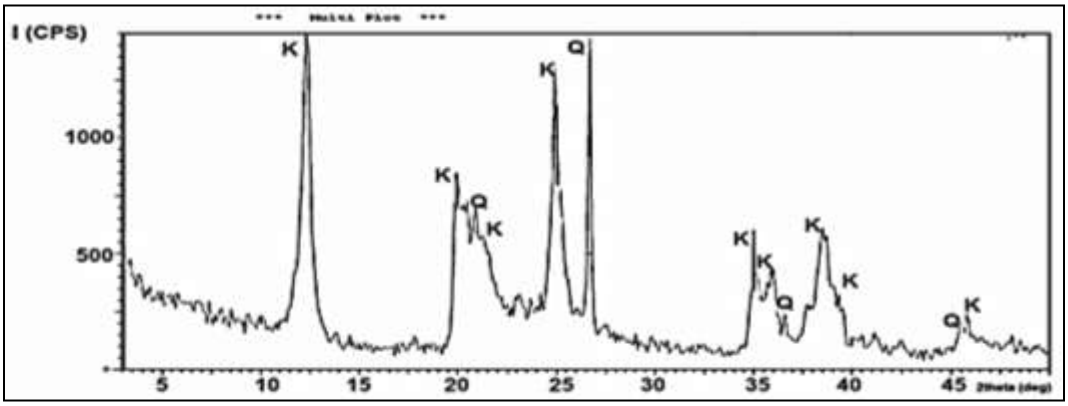

Fig.1: XRD pattern of kaolinite clay (K=kaolinite, Q = quartz)

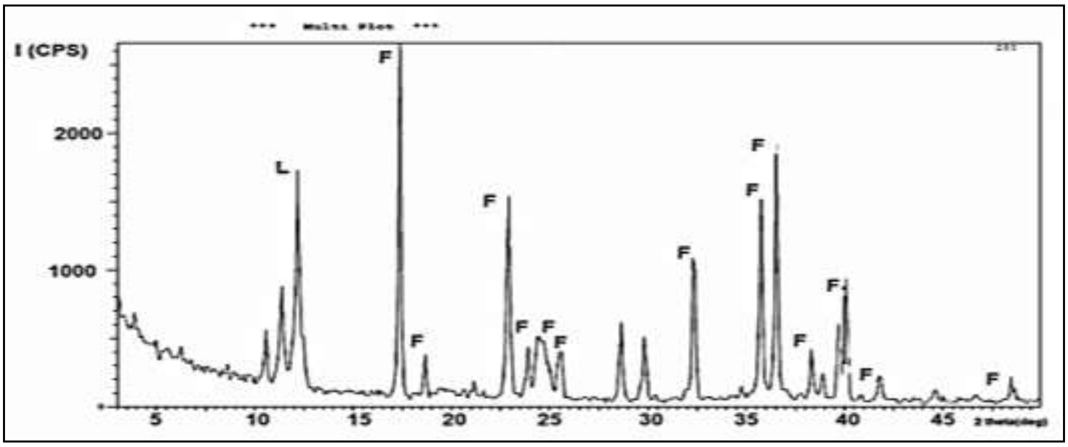

Fig.2: XRD pattern of dunite rocks (F = forsterite, L = lizardite)

Also, magnesium oxide produced by Reachim/USSR and aluminum oxide produced by Riedel-deHaen AG seize Hannover Germany. Theoretically, cordierite $2MgO.2Al_2O_3.5SiO_2$ is composed of 13.8% MgO, 34.9% Al_2O_3, and 51.4% SiO_2.

The percentage of aluminum oxide in kaolin clay is not satisfactory to prepare cordierite; so, the required stoichiometry was adjusted by adding aluminum oxide. The starting materials were (20, 30, 40, and 50% dunite, mixed respectively with, 80, 70, 60, and 50% kaolin clay), wetted with water, and placed in a mold as a disk. The shaped samples were lifted for several days to dry at room temperature and then for four hours at 100 °C. The dried-shaped samples were sintered for two hours at 1200 °C, 1250 °C, 1300 °C, and 1350 °C with a heating rate of 7 °C per minute. In another experiment, the mixtures (20, 30, and 40% dunite with, respectively, 80, 70, and 60% kaolin clay) were compacted by a hydraulic press into square samples, in the Geological Laboratories of Iraq Geological Survey, with dimensions ratio 1: 1, left for several days to dry at room temperature and then for four hours at 100 °C, sintered for two hours at 1250 °C, and 1300 °C with heating rate 7 °C. min^{-1}. Dunite rocks were purified by a dry magnetic separation device, iron oxide was reduced from 12% to 1.21%, and different mixtures were prepared (20, 30, and 40% of iron-free dunite, mixed with 80, 70, and 60% kaolin clay), then molded. The dried-shaped samples were sintered for two hours at 1350 °C with a heating rate of 7 °C. min^{-1}. To compare the difference in preparing cordierite ceramic by ores and oxide, dunite was replaced totally by magnesium oxide. The mixture was selected to form the theoretical composition of cordierite, the mixture was molded, dried, and sintered at different temperatures 1200 °C, 1250 °C, 1300 °C, and 1350 °C with a heating rate of 7 °C. min^{-1} for 2 hours. Phase compositions of the sintered samples were determined by X-ray diffractometer in the Chemical Laboratories of Iraq Geological Survey. The basic physical properties were determined for heat-treated samples, (porosity and bulk density), tested by the Geological Laboratories of Iraq Geological Survey.

RESULTS AND DISCUSSION

1. Structural, Chemical, and Physical Analysis of Samples Prepared by Molding

The minerals phases identified in each sample were prepared by molding method for different mixtures compositions at different sintering temperatures (Table 2). Phases of minerals were identified by using the X-ray diffraction method, at 1200 °C and 1250 °C different minerals phases appeared with cordierite, this may due to the effect of temperature and there is a need to increase the sintering temperature to obtain the cordierite phase without any other phases. At 1300 °C most of the accompanied phase disappeared, except mullite ($3Al_2O_3.2SiO_2$), which appeared in the mixture containing 80% kaolin as a result of the high ratio of Al_2O_3/SiO_2. By increasing the dunite content, the mullite phase disappeared and clinoenstatite ($MgO.SiO_2$) appeared. By increasing the temperature to 1350 °C, cordierite was the only mineral that appeared with slightly more intense peaks with 30% dunite than 40% dunite. With mixtures of 20% and 50%, dunite and other minerals appeared with cordierite. From these results, it can be concluded that the effect of sintering temperature and starting materials composition is important to obtaining pure cordierite. Almeida *et al.* (2018) mentioned that cordierite showed increasingly intense peaks at 1350 °C, at 1250 °C the reaction between the alumina, silica, and magnesia in the system resulted in the emergence of cordierite as a dominant phase with cristobalite and mullite peaks. The other prepared samples which had different phases with cordierite also can be used as ceramic material, because cordierite ceramics are terms for not only pure cordierite products but also materials based on cordierite with various additives (Valaáŝková, 2015).

Table 2: the minerals phases of samples prepared by molding

Sintering temperature °C	Dunite %	Kaolin %	mineral phase
1200	20	80	cordierite, cristobalite, mullite, and corundum
	30	70	cordierite, cristobalite, mullite, corundum, and forsterite
	40	60	cordierite, mullite, corundum, forsterite, and clinoenstatite
	50	50	cordierite, mullite, corundum, forsterite, and clinoenstatite
1250	20	80	cordierite, cristobalite, mullite, forsterite, and corundum
	30	70	cordierite, cristobalite, mullite, and corundum
	40	60	cordierite, cristobalite, mullite, and corundum
	50	50	cordierite, cristobalite, mullite, corundum, and clinoenstatite
1300	20	80	cordierite and mullite
	30	70	cordierite and clinoenstatite
	40	60	cordierite and clinoenstatite
	50	50	cordierite and clinoenstatite
1350	20	80	cordierite and mullite
	30	70	Cordierite
	40	60	Cordierite
	50	50	cordierite, enstitate, and spinel

Also, ceramics based on cordierite and mullite (as samples prepared by 20% dunite and sintered at 1300 °C and 1350 °C) can have good high temperatures properties, excellent electrical insulating ability, and high melting point, have a wide use area in refractory brick and electronic component (Albhilil *et al.*, 2013). The best preparation condition for cordierite by molding method was kaolin 70% and dunite 30%, and sintering temperature 1350 °C (Fig.3 shows the XRD pattern of the sample).

The theoretical chemical analysis of cordierite ($2MgO.2Al_2O_3.5SiO_2$) is 13.7% MgO, 34.9% Al_2O_3, and 51.4% SiO_2. Table 3 shows the chemical analysis of prepared molded sintered samples. MgO and Al_2O_3 percentages, which are near theoretical values, were for the samples prepared with 30% dunite and 70% kaolin. All samples had a little lack in SiO_2 values.

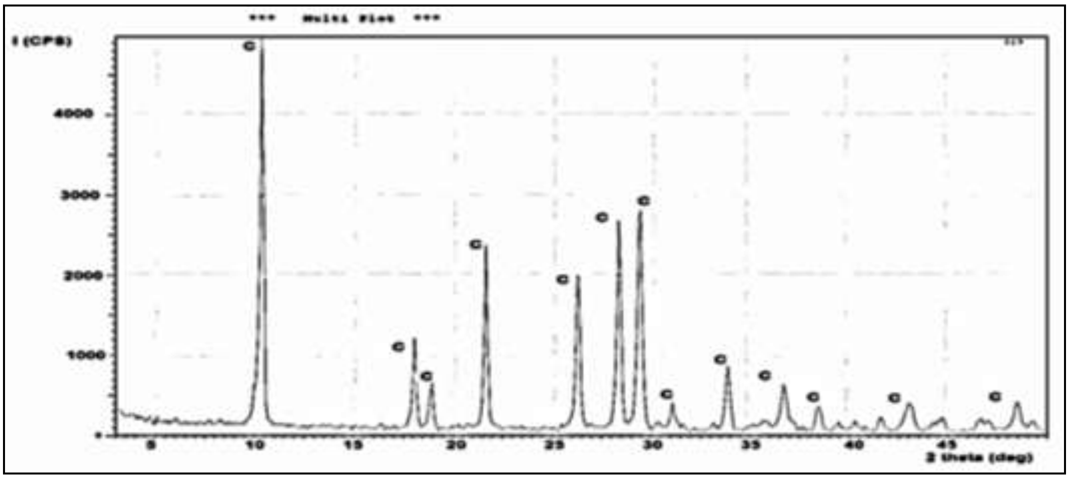

Fig.3: XRD of the sample prepared at temperature 1350°C with 30% dunite (C = cordierite)

Table 3: chemical analysis of the prepared samples

sintering temperature °C	Dunite %	MgO%	Al_2O_3%	SiO_2%
1200	20	10.50	30.80	42.62
	30	13.50	33.23	46.90
	40	17.80	33.00	43.76
	50	19.60	36.60	48.30
1250	20	10.00	35.69	48.02
	30	13.70	33.94	45.24
	40	17.60	32.46	44.52
	50	21.00	30.82	41.28
1300	20	9.80	35.17	48.04
	30	13.60	32.30	47.38
	40	17.30	31.22	45.08
	50	19.70	30.05	44.16
1350	20	10.40	37.65	46.80
	30	14.80	36.21	44.68
	40	15.80	32.72	44.44
	50	19.60	35.10	38.54

The bulk density and porosity of the prepared samples are illustrated in (Table 4). By increasing dunite percentage, bulk density was decreased and porosity increased at a sintering temperature of 1200 – 1300 °C. By increasing the temperature to 1350 °C with 40% and 50% dunite, bulk density was increased as a result of the deformation of samples at this temperature, and porosity was decreased as a result of closing the pores in the samples. At 1350 °C with 40% dunite, the sample started to deform and with 50% dunite the deformation was noticeable, the deformation and glazing may occur as a result of impurities present in the ore acting as fluxes, like iron oxide which is existed in dunite rocks. Trumbulovic *et al*. (2003) and Valaáŝková (2015) referred that cordierite based on kaolin, talc, and alumina is highly sensitive to sintering, the increase of temperature results in the glazing phase, which requires the increase in heat expansion coefficient and decrease of the product thermal stability. The sample prepared with 30% dunite and a sintering temperature of 1350 °C has high porosity due to the high cordierite content as indicated by high peaks intensities in the sample. High porosity in cordierite has a positive effect on its properties during its use as a ceramic material.

Table 4: Physical results of the prepared molded samples

Sintering temperature °C	Dunite%	Porosity%	Bulk density g/cm^3
1200	20	15.78	1.866
	30	36.90	1.786
	40	41.12	1.772
	50	43.22	1.729
1250	20	32.02	1.956
	30	36.10	1.840
	40	42.16	1.729
	50	46.00	1.659
1300	20	25.80	1.909
	30	30.06	1.888
	40	34.04	1.800
	50	38.20	1.803
1350	20	4.33	2.00
	30	30.62	1.830
	40	16.35	2.310
	50	11.26	2.510

2. Structural, Chemical, and Physical Analysis of Samples Prepared by Pressing

Using pressing increase the contact area of materials, favoring higher reactivity and greater interdiffusion of constituent ions and thus contributing to accelerating the process of cordierite formation. So that to study the effect of pressing on the preparation of cordierite, different mixtures were pressed under a pressure of 75 KN, dried, and sintered at temperatures 1250 °C and 1300 °C. The only mineral that appeared at 1250 °C was cordierite with low intensities compared with the sample prepared at 1300 °C.

Almeida *et al.* (2018) mentioned that the mineralogical identify revealed the beginning of characteristic formation, peaks of cordierite phase at 1250 °C, and more intense peaks were identified at 1350 °C.

At 1300 °C cordierite peaks were accompanied by small peaks of clinoenstitate, samples prepared with 20% and 30% dunite sintered at 1300 °C had higher cordierite peaks intensities than samples prepared at 1250 °C so that sintering temperature 1300 °C was preferred.

Increasing dunite to 40% leads to an increase in the intensities of clinoenstitate.

In the chemical analysis of the sintered samples shown in (Table 5), the chemical composition of the sample prepared with 20% dunite is closer to the theoretical composition of cordierite but also there is a need to increase the silica content in all samples by an external source.

Porosity and bulk density are given in (Table 6). By increasing dunite% and decreasing kaolin clay% in the mixture the porosity was increased, the difference in the porosity% is slight, while bulk density decreased by increasing dunite%. By comparing the effect of molding and pressing on the properties of the samples, pressing gave purer cordierite minerals than molding and lesser porosity, especially at a sintering temperature of 1250 °C. By increasing the sintering temperature, the effect of the pressing process decreased, the accompanied minerals appeared and the porosity was approximately the same as that of a molding process.

Table 5: Chemical analysis of prepared pressed sintered samples

sintering temperature °C	Dunite%	Kaolin%	MgO%	Al_2O_3%	SiO_2%
1250	20	80	11.50	36.52	45.14
	30	70	13.00	34.71	43.84
	40	60	17.50	32.27	41.62
1300	20	80	14.50	35.87	45.32
	30	70	14.50	32.76	46.10
	40	60	19.00	31.76	41.68

Table 6: Porosity and bulk density of the prepared pressed samples

Sintering temperature °C	Dunite%	Kaolin%	Porosity%	Bulk density g/cm^3
1250	20	80	24.10	2.07
	30	70	32.96	1.94
	40	60	36.40	1.86
1300	20	80	24.40	1.97
	30	70	31.42	1.86
	40	60	35.84	1.80

3. Structural, Chemical, and Physical Analysis of Sample Prepared by Dunite Purified from Iron

The raw dunite contains 12% iron oxide, which acts as a fluxing element during the firing process. The fluxing agent is usually used to reduce the sintering temperature in ceramic production (Ahmed, *et al*., 2017). Iron oxide has an effect on the increase of thermal expansion coefficient (Valaáŝková, 2015), and it is also responsible for giving the material an undesirable reddish color, as well as for reducing its refractory properties, therefore it is necessary to remove or avoid the presence of iron (Orosco *et al*., 2014). Experiments were carried out to reduce the iron oxide in the dunite by dry magnetic separation. The iron oxide decreased to 1.21%, and iron-free dunite was used to prepare samples, sintered at 1350 °C, this sintering temperature was used because at this temperature some samples (prepared by molding) started to deform.

XRD of the sample prepared with 20% dunite appeared that cordierite was the major peak with a minor peak of mullite which was formed as a result of using a high percentage of kaolin clay. Samples prepared with 30 and 40% dunite had cordierite as the only mineral. The chemical analysis of the samples is shown in Table 7.

Table 7: Chemical analysis of sintered samples prepared by purified dunite

Sintering temperature °C	Dunite%	Kaolin%	MgO%	Al_2O_3%	SiO_2%
1350	20	80	9.80	36.44	47.68
	30	70	23.30	32.02	41.80
	40	60	14.60	33.45	45.60

Table 8 shows the porosity and bulk density of the samples. Porosity decreased and bulk density increased by increasing purified dunite. The porosity and bulk of the sample prepared with 40% purified dunite were close to the sample prepared by 40% dunite rock, but the sample did not show deformation after sintering opposite to the sample prepared by dunite rock. The use of magnetic separation adds cost in comparison to the benefits, which was gained.

Table 8: Physical analysis of sintered samples prepared by purified dunite

Sintering temperature °C	Dunite %	Kaolin %	Porosity%	Bulk density g/cm^3
1350	20	80	23.93	1.96
	30	70	27.49	1.90
	40	60	15.64	2.57

4. Structural, Chemical, and Physical Analysis of Samples Prepared by MgO

Replacing the magnesium oxide from ore (dunite) in the starting mixtures with synthetic magnesium oxide powder. The composition of the sample mixture was designed based on the content of main oxides in cordierite composition (13.7% MgO, 34.9% Al_2O_3, and 51.4% SiO_2).

The sintered samples prepared by synthetic MgO, none of them contained only cordierite. Cordierite was found to prepare more in kaolin clay and dunite bodies than in kaolin clay and magnesium oxide bodies, this may be due to the availability of the bonds resulting from the rupture of the lattice when water is released will guarantee a complete reaction in ores.

Table 9 shows the chemical composition of samples prepared by MgO. After sintering at different temperatures, the chemical composition for all the samples was almost the same with a little difference.

Table 9: Chemical analysis of sintered samples prepared by MgO

Sintering temperature °C	MgO%	Al_2O_3%	SiO_2%
1200	11.80	35.18	48.98
1250	12.00	33.84	49.60
1300	11.80	33.58	49.68
1350	12.00	32.25	50.26

Table 10 shows the porosity and bulk density of samples prepared by MgO. The change from kaolin ($Al_2O_3.2SiO_2.2H_2O$) into mullite and cristobalite, by increasing the temperature to 1250 °C cristobalite disappeared and only mullite appeared with cordierite in the samples.

The samples had almost the same minerals, the lesser cordierite peak at 1200 °C, cristobalite had a lower density than mullite (theoretical density of mullite 3.05 g/cm^3, and cristobalite 2.27 g/cm^3 Wildan, and Marpaung (2020), this may cause the decrease in the bulk density at this temperature. Porosity is in opposite relation to bulk density, the lower bulk density had the higher porosity.

Table 10: Physical analysis of sintered samples prepared by MgO

Sintering temperature °C	Porosity%	Bulk density g/cm^3
1200	33.88	1.80
1250	28.63	1.83
1300	25.56	1.86
1350	30.78	1.83

CONCLUSION

- The use of kaolin clay and dunite rocks to obtain cordierite was succeeded.
- Increasing the sintering temperature had a positive influence; the bodies sintered at 1350 °C contained a higher content of cordierite.
- Many factors are important like the chemical composition of raw materials, method of processing (formation process), and sintering temperature.
- Sample prepared with 30% and 40% dunite, with sintering temperature 1350 °C and formed by molding method have cordierite as the only phase, but by using 40% dunite the external appearance of the sample started to deform.
- Pressing the samples gave cordierite at a lower sintering temperature (1250 °C), but with lower peak intensities, the cost of the pressing method compared with the molding method should take into consideration.
- Using 30% and 40% purified dunite gave cordierite as the only mineral in the samples at a sintering temperature of 1350 °C, the magnetic separation process is an additional step used to purify the dunite.
- Using magnesium oxide instead of dunite at different sintering temperatures produce cordierite but with accompanying minerals.
- The best sample was prepared with kaolin 70% and 30% dunite, with a sintering temperature of 1350 °C, and formed by the molding method, having cordierite as the only phase. The prepared samples, which had cordierite as the main phase, are suitable for refractory products.

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