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Study the Effect of Glass and Carbon Fibers on the Firebrick Properties

Abstract- *This work was carried out to investigate effect of glass fiber (GF) and carbon fiber (CF) on kaolin-clay firebrick properties. GF and CF are considered inorganic fibers with application of high temperatures. Kaolin clay is mixed with short GF and CF separately by different percentages (0, 0.5, 1, 1.5 and 2) wt%. Kaolin-GF and kaolin-CF mixtures were compacted by using the semi-dry pressing method. The compacted specimens were fired at different temperatures (1100, 1200 and 1300)°C. Properties which include bulk density, apparent porosity, water absorption, thermal conductivity and fracture strength were obtained from the firebrick specimens. The results show that the addition of GF has beneficial in lowering of firing temperature, and consequently accelerating the densification via enhanced grain boundary diffusivity. Increasing GF content in the firebrick mixture enhances the fracture strength due to increase amount of glassy and mullite phases. Incorporation of CF has inversely affected than GF on the firebrick properties. As the percentage of CF increased the density of firebrick decreased, and the porosity and water absorption increased.*

Keywords- *Firebrick, glass fiber, carbon fiber, thermal conductivity, fracture strength.*

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1. Introduction

Fireclay is a refractory ceramic material consisting essentially of hydrated aluminum silicates with minor proportions of other minerals. The typical chemical composition for fire clays are 23-34% Al_2O_3, 50-60% SiO_2 and 6-27% loss on ignition with various amounts of Fe_2O_3, CaO, MgO, K_2O, Na_2O and TiO_2 [1,2]. Fire clay refractories are usually used in boiler furnaces, metallurgical furnaces for melting, reheating and heating treatment of iron, steel or nonferrous metals [3].

Refractories of firebricks could be classified into two types depending on the porosity namely porous and dense. Dense firebricks refractory contain porosity not more than 20% [3,4]. These refractories might be used in contact with hot liquid metal and gases. Porous firebricks constitute one of the lightweight refractories that have much lower thermal conductivity and heat capacity than other refractories. These refractories are commonly used for heat insulation in industrial applications for greater energy efficiency [4,5]. The thermal conductivity of firebrick refractory not only depends on their total porosity, but also on their pore shape and size, beside to the chemical and mineralogical composition [6].

Kaolin clay used for making firebrick products is becoming important as structural and insulating refractory materials for high temperature applications [7]. The firebricks are primarily produced by semi-dry pressing or plastic molding. Both processing methods rely on additives to enhance the densification; usually Al_2O_3 is added as improver to the physical, mechanical and thermal properties of final product [7,8].

Refractory kaolin clay undergoes a number of transformations during the firing process, resulting in a product consist of a crystalline mullite phase ($3Al_2O_3.2SiO_2$) and a vitreous siliceous matrix (glass) of high viscosity. The physical, mechanical and thermal properties of fireclay product improved with increasing of mullite phase formation [7-9]. The mechanism of mullite formation depends upon the method of combining the alumina-silica containing reactants [10].

Many researchers have been conducted by using various additives to kaolin clay product. For example, Johari et al. [11], investigated the chemical and physical properties of fireclay bricks at different type of rice husk ash (RHA). They found that lightweight brick could be produced by increasing the RHA. Abdul-Sattar [7], established the production of high alumina firebrick from Iraqi clay. The result shows that the addition of Al_2O_3 in the range of 35% to the fire clay is sufficient to improve the physical, mechanical and thermal properties of the final products. Sadik et al. [4], produced firebrick from mixtures of clay and recycled refractory waste with different proportions of expanded perlite (up to 30 vol. %). The results revealed that the increasing addition of expanded perlite to the

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firebrick mixture produces, after firing, porous and lightweight firebricks with acceptable flexural strength.
The aim of the present study is to investigate the physical and mechanical properties of firebrick product containing different types of fibers (glass or carbon).

2. Experimental Work

I. Raw Materials

The raw materials used in this work were Dwaikhla kaolin clay, glass fiber and carbon fiber. Dwaikhla kaolin clay is supplied by the Iraq Geological Survey in natural size rocks. The chemical analysis of the kaolin clay is shown in Table 1. Glass fiber (type E-glass) was supplied by Mowding LTD.UK Company as a woven form with density 2.58 g/cm^3. The chemical composition of the glass fiber is shown in Table 2. Carbon fiber (density 1.78 g/cm^3) was provided from Protech Inc. Company. The carbon fiber composed mostly of carbon (> 90% carbon). Kaolin clay is milled using porcelain ball mill and then sieved to obtain kaolin powder in particle size of (<53 μm). The glass fiber (GF) and carbon fiber (CF) are cut in lengths of (1 cm) and then washed separately in ethanol for removing any inclusions and binders on the fiber surface. The washed fibers are then dried at 60°C. The prepared raw materials in this work are shown in Figure 1.

II. Preparation of Firebrick Specimens

The powder of kaolin clay is mixed with the chopped GF and CF separately at different percentages (0, 0.5, 1, 1.5 and 2) wt% for each one of these fibers. Kaolin-GF and kaolin-CF mixes specimens were compacted by using the semi-dry pressing method. The pressing process was done by a hydraulic press machine with a stainless steel die of (3 cm) in diameter with pressing pressure of (25 MPa) and water content of (10-12) wt%. The compacted specimens are dried at 105°C for 6 hours using an electric oven.
The dried specimens were fired in a laboratory-type electrical furnace at different temperatures (1100, 1200 and 1300)°C with a heating rate of (7°C/min) and 2 hour soaking time and then the specimens were left to cool in the furnace. Figure (2) shows some of the prepared firebrick specimens.

III. Physical and Mechanical Tests

The average of two samples for each mix specimens was determined for calculation the physical and mechanical properties. Bulk density, water absorption and apparent porosity of fired specimens were measured by Archimedes method according to ASTM C373-88 with using the following equations [9,11]:

$$\text{Bulk density} = \frac{D}{W - A}\left(\frac{g}{cm^3}\right) \quad (1)$$

$$\text{Apparent porosity} = \frac{W - D}{W - A}.100\% \quad (2)$$

$$\text{Water absorption} = \frac{W - D}{D}.100\% \quad (3)$$

Where:
D: weight of fired specimen,
A: weight of fired specimen in water, and
W: weight of soaked specimen suspended in air.
Thermal conductivity was measured by the hot disk method. The hot disk TPS 500 thermal constants analyzer is used for determining the thermal conductivity (K). This method is designed for measuring the convenient thermal conductivity, thermal diffusivity and specific heat capacity of a wide range of materials.
Fracture strength is measured using the diametrical compression disc test and the equation (4) was applied to calculate the strength of the specimens [12]:

$$\sigma_s = \frac{2F}{\pi d t} \quad (4)$$

Where:
σs: fracture strength,
F: applied load (N),
D: diameter of the disc (mm) and
t: thickness of the disc (mm).

Table 1: The chemical composition of kaolin clay

Content	SiO_2	Al_2O_3	Fe_2O_3	K_2O	Na_2O	MgO	CaO	L.O.I
wt%	51.16	33.32	1.17	0.4	0.41	0.41	0.23	12.9

Table 2: The basic composition of glass fiber (E-glass)

Content	SiO_2	CaO	Al_2O_3	MgO	B_2O_3	TiO_2	Na_2O	Fe_2O_3	F_2
wt%	53	22	13	3	6	0.5	1.6	0.8	0.1

Figure 1: The raw materials in this work

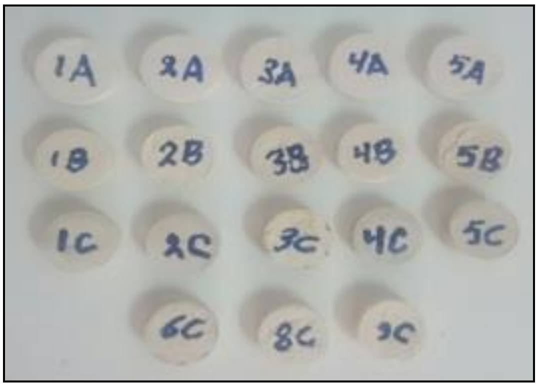

Figure 2: The firebrick specimens

3. Results and Discussion

All results obtained of the different experiments, which carried out in this work, are presented in Table 3 and the property trends are discussed below.

I. Effect of Glass Fiber (GF) Addition on Firebrick Properties

Figures 3, 4, 5, 6 and 7 present the effect of glass fiber (GF) addition on the bulk density, apparent porosity, water absorption, thermal conductivity and fracture strength of firebrick specimens that fired at different temperatures (1100, 1200 and 1300)°C respectively.

1) Bulk Density

As shown in Figure 3, the bulk density increases progressively with increased GF content in the firebrick specimens. This may be attributed to the effect of GF composition that works as a fluxing material in the kaolin matrix. This effect tends to reduce the firing temperature and produce materials having low melting point leading to increase the densification rate, and eventually increasing in the densities of firebrick samples. On other hand, mass transportation and elimination of pores through bulk diffusion are two important factors that determine the final density during the consolidation process of the ceramics [13].

It is also noted that as firing temperature increases (from 1100°C to 1300°C), the density increases. This is due to increase the amount of liquid phase (glassy phase), that fills the pores resulting in increasing the diffusion rates between kaolin particles and more densification occur. The pore density extremely influences on the densification of the ceramic composites [14].

2) Apparent Porosity and Water Absorption

Figures 4 and 5 show that the apparent porosity and water absorption of the firebrick specimens is decreased with increasing of GF content. This is related to increasing in the firebrick specimen's density. As known, the porosity is inversely proportional with the density of composites. In addition, it can be noticed that there is a reduction in the percentage of porosity with increasing of firing temperatures. A possible explanation that could be given for this is that high temperatures tend to make the pores shrink. Furthermore, the high firing temperature increases formation of liquid phase. This liquid phase fills the pores resulting in considerable reduction of pore size [13,14]. All these results are directly reflected on the percentage of water absorption.

3) Thermal Conductivity

Figure 6 presents that the thermal conductivity of the firebrick specimens is increased with increasing both of the GF content and firing temperature. This is because thermal conductivity is a function of the chemical composition and density of the refractory materials [6]. Therefore, by observing the curves, the thermal conductivity increases with the decrease of porosity for all firebrick specimens.

4) Fracture Strength

It is seen from Figure 7 that the fracture strength is enhanced with raising of firing temperature and GF content of the firebrick specimens. This is because of the increasing amount of liquid glassy phase with increasing GF percentage and firing temperature. This phase assists to increase the bonding strength and adhesion force between kaolin particles. In addition, increase formation of mullite phase that has good mechanical properties. The improvement in densification with fewer pores, which leads to increasing the particles bonding and consequent strength enhanced [15,16].

II. Effect of Carbon Fiber (CF) Addition on Firebrick Properties

Incorporation of carbon fiber with the kaolin clay has inversely affected on the firebrick properties by comparing with the glass fiber in kaolin. This attributed of exhibit carbon fiber to the oxidation at high temperatures exposure (temperature > 500°C) and this behavior allows to generating some gases. The carbon fibers also exposed to loss in mass during its oxidation. The driving force for mass loss is the oxidation of carbon fibers as [17]: $C + O_2 = CO_2$ and $C + 0.5O_2 = CO$.

The specimens of firebrick which containing CF and fired at 1100°C have been crumbled during firing. This may be due to oxidation of CF, beside to the tendency of CF to reducing the plasticity of kaolin. These effects increase the difficulty of obtaining good densification for the firebrick specimens, especially at low firing temperature. Therefore, the physical and mechanical properties were done just for the specimens of kaolin-CF that fired at 1200°C and 1300°C.
Figures 8, 9, 10, 11 and 12 presented the effect of CF addition on bulk density, apparent porosity, water absorption, thermal conductivity and fracture strength of firebrick specimens that fired at temperatures of 1200°C and 1300°C respectively.

1) Bulk Density

Figure (8) shows that the bulk density of firebrick specimens is decreased with increasing of the CF percentage. This is due to the oxidation of CF during firing process, and this could result in weight loss as a result of the gases emitted and the porosity increased obviously. Increasing of firing temperature from 1200°C to 1300°C leads to increasing the density of firebrick specimens. This increasing in the densities is attributed to increasing in densification and diffusion rates between kaolin particles at high firing temperature.

2) Apparent Porosity and Water Absorption

Figures (9 and 10) present that the apparent porosity and water absorption of the firebrick specimens is increased with increasing of CF content. This is because the porosity is directly related to the specimen density [13]. Furthermore, the porosity decreases when the firing temperature increases resulting in increasing the particles packing and more densification [14,18]. Consequently, the water absorption of the specimens is also related to the porosity and because CF leaves plenty of pores, which leads to increase the water absorption by that specimens.

3) Thermal Conductivity

Figure (11) shows that the thermal conductivity of the firebrick specimens is decreased as the CF percentage increase. This is as a result of the CF oxidation which leads to increase the number of pores and air holes within the specimens and thus reduced in the thermal conductivity. In general, the size and shape of porosity in structure of ceramic materials is known to play an important role in determining the thermal conductivity [6,18]. In addition, it found that the thermal conductivity of firebrick specimens increased with increasing firing temperature, and thus due to the density increases.

4) Fracture Strength

The fracture strength of firebrick specimens is decreased with increasing of CF content as shown in figure (12). This is because that the presences of CF inhibit closing up of kaolin clay particles as well as the increasing in porosities due to the CF oxidation at high temperature.

Table 3: All experimental results obtained in this work

Fiber type	Fiber content (wt%)	Firing temperature (°C)	Fired dry weight (D) (g)	Suspended weight (A) (g)	Soaked weight (W) (g)	Bulk density (g/cm^3)	Apparent porosity (%)	Water absorption (%)	Thermal conductivity (W/m.K)	Fracture strength (MPa)
	0	1100	11.27	6.89	14.27	1.53	40.61	26.59	0.24	5.02
	0	1200	11.12	7.01	13.58	1.69	37.43	22.13	0.26	7.44
	0	1300	12.36	7.68	13.28	2.21	16.41	7.44	0.36	8.83
Glass Fiber (GF)	0.5	1100	11.06	6.32	13.20	1.61	31.11	19.37	0.26	6.67
	1		10.74	5.99	12.62	1.62	28.35	17.50	0.27	6.88
	1.5		10.14	5.37	11.36	1.69	20.31	12.00	0.31	10.10
	2		9.99	5.20	11.16	1.68	19.64	11.72	0.32	11.27
	0.5	1200	10.93	7.22	12.22	2.19	25.78	11.79	0.30	8.29
	1		11.02	7.05	11.78	2.33	16.04	6.88	0.38	9.09
	1.5		10.91	6.96	11.60	2.35	14.90	6.34	0.40	11.75
	2		10.83	6.70	11.21	2.40	8.46	3.53	0.47	14.38
	0.5	1300	12.16	7.66	12.63	2.45	9.39	3.84	0.37	9.66
	1		12.19	7.57	12.39	2.53	4.08	1.61	0.48	12.73
	1.5		11.93	7.38	12.05	2.56	2.62	1.02	0.53	13.75
	2		11.78	7.37	11.95	2.58	3.55	1.38	0.54	14.13
Carbon Fiber (CF)	0.5	1100	-	-	-	-	-	-	-	-
	1		-	-	-	-	-	-	-	-
	1.5		-	-	-	-	-	-	-	-
	2		-	-	-	-	-	-	-	-
	0.5	1200	11.05	6.37	14.23	1.41	40.52	28.84	0.25	5.35
	1		10.49	6.16	13.90	1.35	44.07	32.55	0.21	5.28
	1.5		9.64	5.83	13.66	1.23	51.40	41.76	0.21	3.68
	2		8.11	4.89	12.76	1.03	59.17	57.43	0.18	3.19
	0.5	1300	12.16	7.46	13.24	2.10	18.70	8.89	0.36	8.55
	1		11.96	6.37	13.16	1.76	17.68	10.04	0.35	8.16
	1.5		10.74	5.72	12.96	1.48	30.72	20.72	0.28	5.13
	2		9.11	5.29	12.35	1.29	45.95	35.60	0.27	4.85

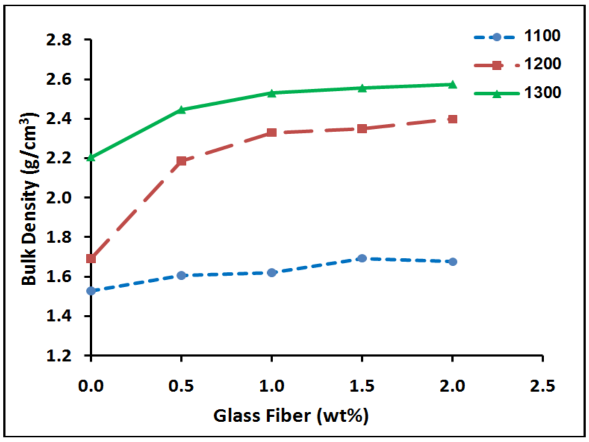

Figure 3: Effect of GF addition on bulk density of the firebrick at different firing temperatures

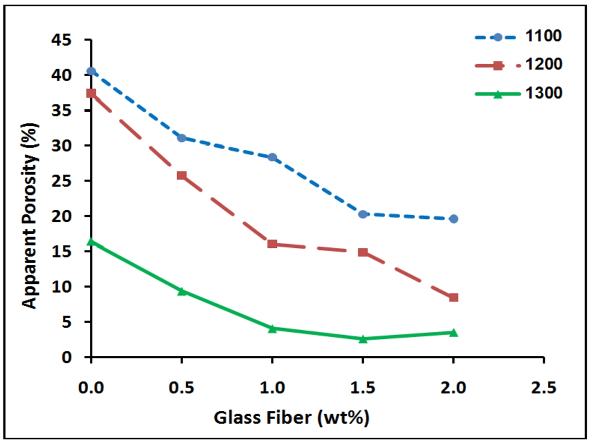

Figure 4: Effect of GF addition on apparent porosity of firebrick at different firing temperatures

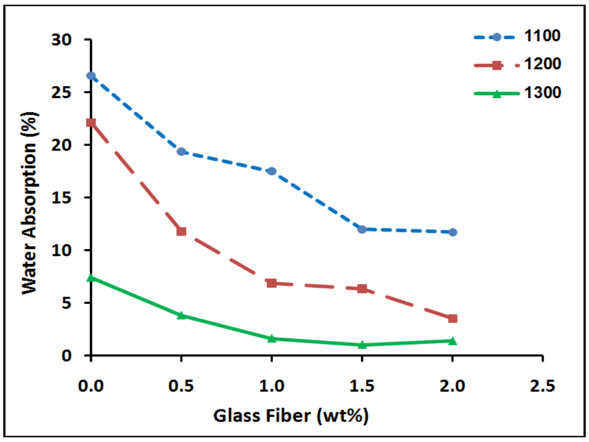

Figure 5: Effect of GF addition on water absorption of firebrick at different firing temperatures

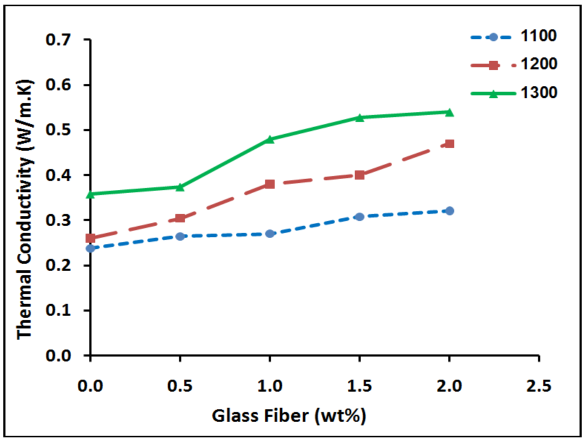

Figure 6: Effect of GF addition on thermal conductivity of firebrick at different temperatures

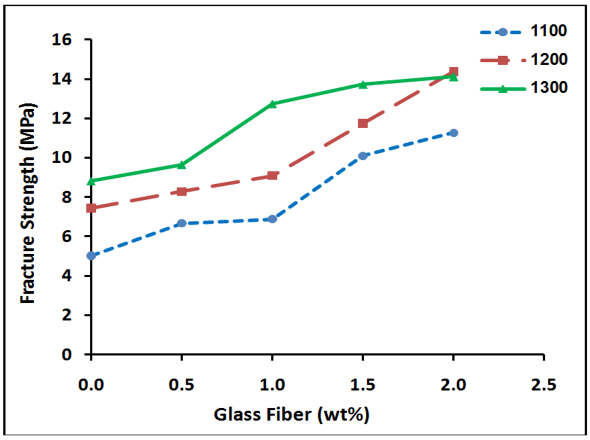

Figure 7: Effect of GF addition on fracture strength of firebrick at different firing temperatures

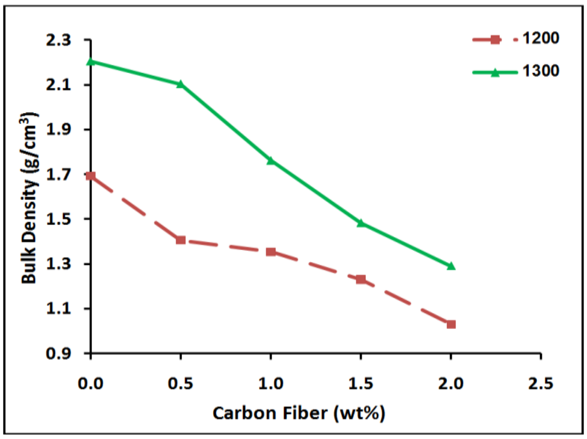

Figure 8: Effect of CF addition on bulk density of the firebrick at different firing temperatures

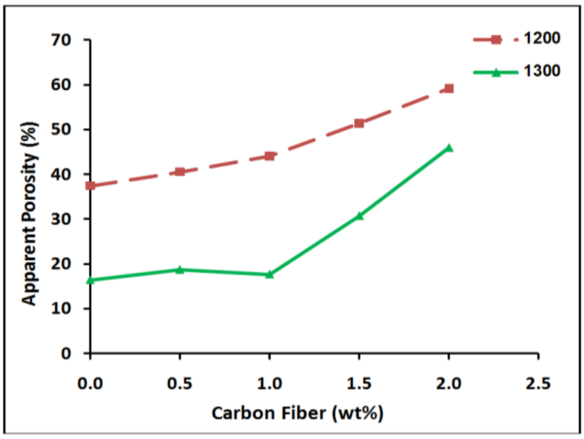

Figure 9: Effect of CF addition on apparent porosity of firebrick at different firing temperatures

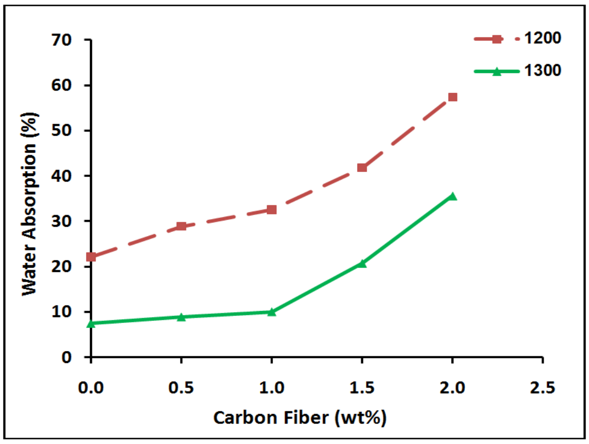

Figure 10: Effect of CF addition on water absorption of firebrick at different firing temperatures

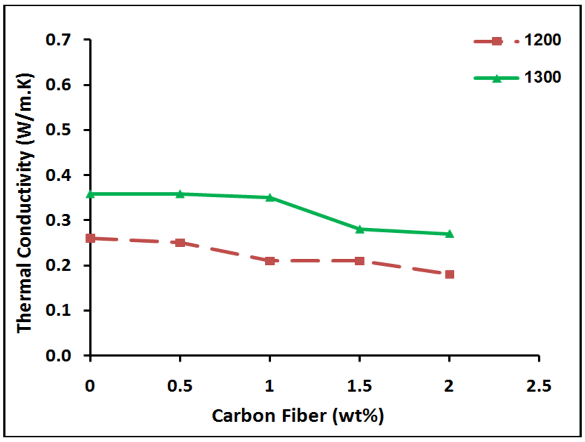

Figure 11: Effect of GF addition on thermal conductivity of firebrick at different temperatures

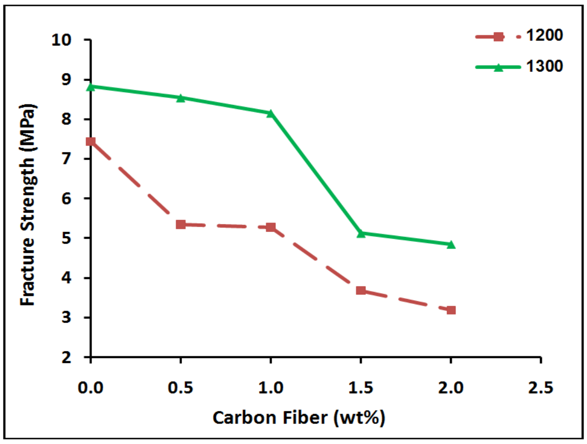

Figure 12: Effect of GF addition on fracture strength of firebrick at different temperatures

4. Conclusions

In this work, the effect of glass fiber (GF) and carbon fiber (CF) addition on the kaolin-clay firebrick properties was investigated. With the results obtained, it could be concluded that:

1) The addition of glass fiber has beneficial in lowering the firing temperature of the firebrick products, consequently accelerating the densification via enhanced grain boundary diffusivity.

2) Increasing of glass fiber content in the firebrick mixture enhances the fracture strength, since it increases formation of glassy and mullite phases.

3) Incorporation of the carbon fiber has inversely affected than glass fiber on the kaolin-clay firebrick properties. Higher CF percentage causes increasing the difficulties for obtaining good densification of firebrick specimens, especially at low firing temperatures.

4) As the percentage of CF increased the density of firebrick decreased, and the porosity and water absorption increased.

5) Thermal conductivity of firebrick is decreased as the CF percentage increase.

References

[1] D.F. Mahdi, "Preparation of Refractory Mortar from Iraqi Raw Materials," Iraqi Journal of Applied Physics, Vol. 11, No. 2, pp. 37–40, 2015.

[2] M. Al-Amaireh, "Improving the Physical and Thermal Properties of the Fire Clay Refractory Bricks Produced from Bauxite," Journal of Applied Sciences, Vol. 6, No. 12, pp. 2605–2610, 2006.

[3] M.A.G. Elngar, F.M. Mohamed, S.A.H. El-Bohy, C.M. Sharaby and M.E.H. Shalabi, "Factors Affected the Performance of Fire Clay Refractory Bricks," Published by Górnictwo i Geoinżynieria, Vol. 33, No. 4, pp. 49–61, 2009.

[4] C. Sadik, A. Albizane, I. El-Amrani, "Production of Porous Firebrick from Mixtures of Clay and Recycled Refractory Waste with Expanded Perlite Addition," J. Mater. Environ. Sci., Vol. 4, No. 6, pp. 981–986, 2013.

[5] C. Sadik, A. Al-Albizane and I. El-Amrani, "Characterization of Elaborated Moroccan Mullite to Improving Porous Refractories Quality," Cerâmica, Vol. 59, pp. 609–613, 2013.

[6] A. Abdul-Kadir, A. Mohajerani, F. Roddick and J. Buckeridge, "Density, Strength, Thermal Conductivity and Leachate Characteristics of Light-Weight Fired Clay Bricks Incorporating Cigarette Butts," International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, Vol. 3, No. 5, pp. 242–247, 2009.

[7] Q. Abdul-Sattar, "Production of High Alumina Fire Brick from Iraqi Clay," Journal of Kufa- Physics, Vol. 4, No. 1, pp. 63–74, 2012.

[8] J. Anggono, "Mullite Ceramics: Its properties, Structure, and Synthesis," Jurnal Teknik Mesin, Vol. 7, No. 2, pp. 1–10, 2005.

[9] A.S. Merzah, Y. Muhsin and Y.k. Mahmood, "Improvement of Iraqi Red Kaolin as a Refractory Material," Eng. & Tech. Journal, Vol. 32, Part (A), No. 4, pp. 952–959, 2014.

[10] H.A. Jaber, "Synthesis of Mullite Powder from Aluminum Nitrate and Precipitated Silica using Sol-Gel Process," Eng. & Tech. Journal, Vol. 34, Part (A), No. 8, pp. 1491–1498, 2016.

[11] I. Johari, S. Said and Z.A. Ahmad, "Chemical and Physical Properties of Fired-Clay Brick at Different Type of Rice Husk Ash," International Conference on Environment Science and Engineering, IPCBEE, Vol. 8, pp. 171–174, 2011.

[12] F.A. Chyad, M.H. AL-Taie and H.A. Jaber, "Synthesis of B4C/YTZP Composite Powder and Studying Effect of its Addition on Mechanical Properties of B4C," Eng. & Tech. Journal ,Vol. 32, Part (A), No. 5, pp. 1158–1170, 2014.

[13] M.N. Rahaman, "Ceramic Processing and Sintering," 2nd edition, Marcel Dekker, Inc., New York, 2003.

[14] M.W. Barsoum, "Fundamentals of Ceramics," Series in Materials Science and Engineering, Institute of Physics (IOP) Publishing, Ltd, 2003.

[15] S. Karaman, S. Ersahin and H. Gunal, "Firing Temperature and Firing Time Influence on Mechanical and Physical Properties of Clay Bricks," Journal of Scientific & Industrial Research, Vol. 65, pp. 153–159, 2006.

[16] N. Phonphuak and S. Thiansem, "Effects of Charcoal on Physical and Mechanical Properties of Fired Test Briquettes," Science Asia, Vol. 37, pp. 120–124, 2011.

[17] Y. Yin, J.G.P. Binner, T.E. Cross and S.J. Marshall, "The Oxidation Behaviour of Carbon Fibres," Journal of Materials Science, Vol. 29, Issue 8, pp. 2250–2254, 1994.

[18] M.H. Al-Taie, A.H. Ali and A.F. Al-Attar, "Study the Physical Properties and Thermal Conductivity of Light Weight Refractories Bricks Produced by Adding porcelanite to Kaolinite," Eng. & Tech. Journal, Vol. 33, Part (A), No. 1, pp. 51–60, 2015.

Author biography

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