The International Journal of Engineering and Science (IJES)
|| Volume || 13 || Issue || 3 || Pages || PP 09-15 || 2024 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

The Effect of Weight Fraction Composition and Sintering Temperature on Hardness of Ceramic Composites Made By Fly Ash and Waste Glass

Faisal Habib
Mechanical Engineering Department, Moslem University of Indonesia, Indonesia

---***ABSTRACT***---

This research is intended to find the best combination of sintering temperature and weight fraction composition in the formation of ceramic composites made from glass powder with fly ash which produces the highest hardness. Material engineering is expected to be able to develop new materials that are environmental friendly by utilizing glass waste and coal dust (fly ash) which is often found around power plants and cement industries in Barru districts, South Sulawesi province. Glass waste is cleaned and ground into glass powder up to 200 mesh then mixed with coal powder waste (fly ash) which has been calcined in furnace at 800°C then formed in a stainless steel metal mold with composition of 3 weight fractions, namely 40% fly ash:60% glass, 50% fly ash:50% glass and 60% fly ash:40% glass then compressed 1000 N/cm2 to obtain a green body and sintered separately at temperatures of 900°C, 950°C and 1000°C respectively, which produces the highest average hardness on Vickers scale of HRV = 33.11 N/mm2 in specimen with a composition of 60% fly ash:40% glass (FAGL64) at 1000°C heating. The overall result of hardness test shows a tendency that the greater of fly ash weight fraction percentage, the higher hardness value of the composite specimen, as well as the influence of sintering temperature. The higher sintering temperature, the higher hardness value. Thus, it can be stated that the fly ash content and sintering temperature are very helpful in increasing the hardness level of this fly ash-glass composite.

KEYWORDS; *Fly ash, glass powder, weight fraction, temperature and hardness*

Date of Submission: 01-03-2024 Date of acceptance: 08-03-2024

I. INTRODUCTION

Using coal as fuel for power plants can produce electricity at relatively low costs, but the residue it produces needs serious attention to avoid pollution of the surrounding environment. Coal burning waste is mostly generated from steam power plants and the rest comes from several other industrial sectors such as the cement industry, textile industry, paper industry, metal industry and several other small industries that use coal as their main fuel, waste produced from burning coal consists of fly ash and the rest in the form of bottom ash, economizer ash, flue gas desulphurization (FGD), combustion gas emissions (SOx, NOx, CO2), liquid waste, pollutants radioactive and some other waste [4], [5]. This accumulated waste is produced in large quantities every year, while its utilization is only around (20 to 30)%. As one of the raw materials that needs attention, coal waste is in the form of solid ash (solid residual). Fly ash is classified as hazardous and toxic waste (B3) because it contains several percent of dioxins and heavy metals which evaporate during combustion at concentrations that can exceed permitted limits. The chemical composition of fly ash is mostly dominated by oxides such as Fe2O3, Al2O3, SiO2, CaO, MgO and other oxides with percentages depending on the waste source [14], [20], [21] where these compounds are good basic materials for manufacture of CaO-SiO2-Al2O3 glass-ceramics [11], [12]. The utilization of all types of coal burning waste (fly ash, bottom ash and boiler slag) in several developed countries is a serious concern, even several countries in Europe have issued special regulations that encourage the utilization of this waste despite the limited storage space [10]. Meanwhile, glass waste is also increasing, especially waste resulting from building construction renovations, electronics, beverage bottle packaging, pharmaceutical products, cosmetic products and other utility products that use glass bottles as storage containers, therefore it is deemed necessary to utilize glass waste. a number of studies have been carried out in order to obtain strong and hard materials originating from waste raw materials that are abundant and easy to obtain with a technological process that is easy and relatively low cost, namely by utilizing coal dust (fly ash) and glass waste. Fly ash and glass powder as basic ingredients for making ceramic composite materials are considered to have advantages in terms of strength, stiffness, lightness, low coefficient of thermal expansion, good vibration dampening, wear resistance, corrosion resistance and good shape appearance. On the other hand, ceramic materials in general also have weaknesses such as brittle and porous properties so that their use in certain construction fields is still very limited. The physical, mechanical, thermal and chemical properties of Fly ash-Glass composite materials are highly dependent on various factors such as the percentage and composition of the base material, grain size, sintering temperature and the heat treatment given [6], [9], [13]. In general, the sintering process for ceramic composite materials is carried out at a temperature interval of 850–1050 °C with varying heating rates. The choice of mixture composition, compaction pressure, grain size and appropriate sintering temperature will influence the properties of the resulting material, one of which is the level of hardness. database.

II. MATERIAL AND METHODS

From this research, using fly ash and glass powder as basic materials will product a ceramic composite material which can be used for construction purposes and at the same time is able to contribute to the handling of fly ash waste and glass/glass waste. Ceramics can be defined as a solid compound formed using heat often pressure containing at least two elements, one of which is a non-metal or nonmetallic solid element. Other elements can be metals or other solid nonmetallic elements [7], [8]. Ceramic materials consist of phases which are compounds of metal and nonmetal elements. Ceramic phases generally have a crystalline structure with fewer free electrons than metal crystals [4], [12]. A simpler definition is given [14], [15] who describe ceramics as an art and science about the manufacture and use of solid particles, which are generally made from inorganic nonmetallic materials. Ceramics consist of an arrangement of interconnected atoms where there are no independent molecules and this property is what differentiates ceramics from other solid molecules. By adjusting the percentage composition of the weight fractions of the two raw materials, namely fly ash and glass, which in this research are called FA-GL composites, The fly ash used in this research was obtained from waste from the Barru PLTU, South Sulawesi Province and to avoid lost on ignition (LOI) during the sintering process, a calcination process is first carried out on fly ash at a temperature of 800 C for 120 minutes with results as in Figure1 below:

Figure 1. Fly ash (a) before calcination and (b) after calcination

The glass waste powder used in this research was obtained from broken glass waste of the same type and color. Glass waste that has been cleaned and crushed with a Jaw crusher and ball mill is then sieved using a Screen sieve. Glass waste powder and glass powder resulting from sieving are as shown in Figure 2, below:

Figure 2. Photos of (a) glass waste and (b) glass waste powder.

in preparing the basic research materials, several equipment were used including a Jaw crusher to crush glass waste into small pieces and a Ball-mill to grind glass waste powder which was then sieved with a screen sieve to obtain a size of 200 mesh, in this sieving process, 100 gram samples are used with a vibration duration of 10 minutes, [6], [7], [23]. These three tools belong to Minerals Processing Laboratory, Department of Mining, Industrial Engineering Faculty, Moslem University of Indonesia. Next, a digital scale type HZY – B1000 with an accuracy of up to 0.0001 grams is used to weigh the weight of each basic ingredient then use a mixing container to stir and rotate for 60 minutes to ensure the mixture is homogeneous, then to form the composite specimen a mold made of stainless steel is used, for compaction a Uni-axial hydraulic press is used with a maximum capacity of 6000 kg, as well as the Ney Vulcan D-550 hot furnace belonging to the Engineering Materials Laboratory of Mechanical Engineering Department.

III. MANUFACTURING AND TESTING OF SPECIMENS

Before mixing the basic ingredients, a calcination process is first carried out on the fly ash to remove elements that easily evaporate due to high temperatures such as carbon and sulfur. [1], [20], [22]. The calcination process is carried out at a temperature of 800°C and left for 120 minutes then cooled in furnace. Composites specimen are made through a weighing process to measure weight fractions and then mixed in a container to stir/spin for 30 minutes to obtain an even and homogeneous mixture [16], [17], then molded with respective weight fractions in composition of 40% Fly ash + 60% Glass (FAGL46), 50% Fly Ash + 50% Glass (FAGL55), and 60% Fly Ash + 40% Glass (FAGL64) in a shaped mold tube with a diameter of d = 44.8 mm, a height of 18 mm (figure 3) then compacted to obtain a green body with a pressure of 1000N/cm2.

Figure 3. Formed specimen

The sintering process was carried out at various temperature variations, i.e. 900°C, 950°C and 1000°C with a heating rate of 20°C/minute and maintained for 90 minutes at each temperature determined in the research [19], [21]. For materials engineering, especially waste utilization, of course requires technical identification, especially mechanical strength criteria such as the level of hardness [2]. Through the sintering process at different temperatures on each composite specimen to find out which weight fraction ratio can produce a composite with the best hardness, a hardness test was carried out using the Vickers method hardness tester, hardness testing by determining 7 different points on each specimen surface as shown in figure 4 below in order to obtain test results that can represent the entire surface of the composite and then the results are averaged.

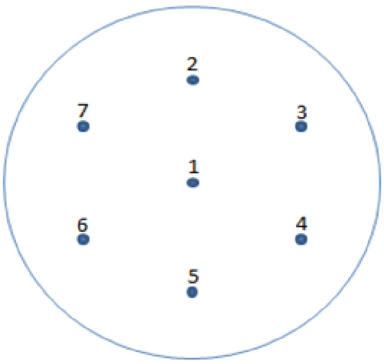

Figure 4. Position of pressing points on hardness testingVickers
hardness is expressed by the equation:

$$H_V = 1{,}8544 \frac{P}{d^2}$$

Where :

HRV = Vickers hardness value, (MPa)
P = pressing load, (N)
d = average diagonal of the indenter stamping mark, (mm).

IV. RESULTS AND DISCUSSION

The hardness level testing results in this research can then be described and compared based on the weight composition of the base materials in the composite, 3 types of specimens with different weight fractions of the base material were made into 3 pieces to be sintered at different temperatures, i.e. 900C, 950C and 1000C so that in total there were 9 composite specimens and the test result data was obtained as shown in tables 1, 2 and 3 below:

Table.1 Hardness data (HRV) at each testing point with a temperature of 900°C

Position of testing point	*hardness Value (N/mm^2)*		
	FAGL46	*FAGL55*	*FAGL64*
1	*11,6*	*14,0*	*17,7*
2	*12,8*	*14,5*	*20,5*
3	*13,4*	*12,3*	*19,9*
4	*12,4*	*15,4*	*18,3*
5	*11,8*	*17,5*	*17,3*
6	*10,6*	*13,1*	*18,8*
7	*12,3*	*12,3*	*17,6*
average	*12,13*	*14,16*	*18,58*

In graphic form can be seen in Figure 5 below, which shows the relationship between the composition of the weight fraction and the hardness value (HRV) at various testing points for a sintering temperature of 900°C.

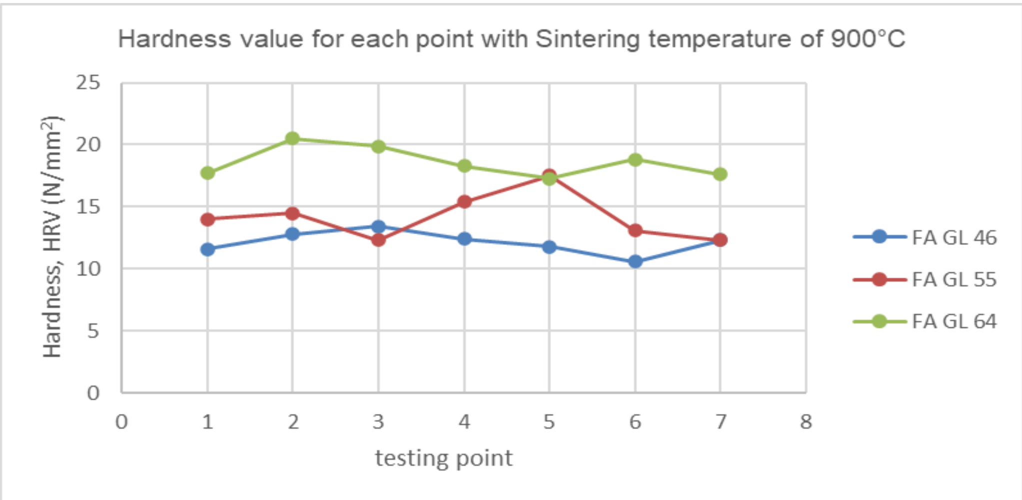

Figure 5. Relationship between hardness values (HRV) at various pressing points on sintering temperature of 900°C

Table 2. Hardness data (HRV) at each testing point with a temperature of 950°C

Position of testing point	*hardness Value (N/mm²)*		
	FAGL46	*FAGL55*	*FAGL64*
1	*17,0*	*19,8*	*21,2*
2	*15,8*	*17,2*	*20,4*
3	*16,1*	*17,3*	*20,2*
4	*11,2*	*16,2*	*19,9*
5	*11,2*	*17,3*	*23,1*
6	*14,0*	*18,8*	*21,9*
7	*13,0*	*19,0*	*21,2*
Average	*14,04*	*17,94*	*21,13*

In graphic form can be seen in Figure 6 below, which shows the relationship between the composition of the weight fraction and the hardness value (HRV) at various testing points for a sintering temperature of 950°C.

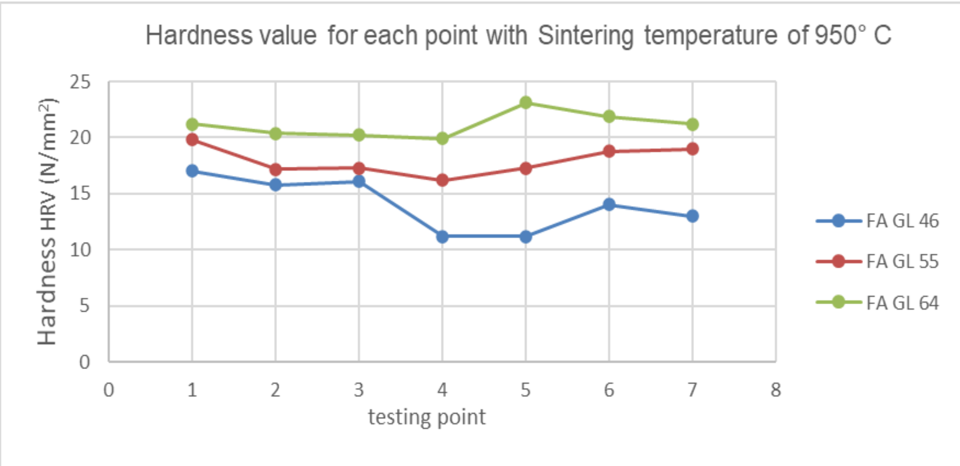

Figure 6. Relationship between hardness values (HRV) at various pressing points on sintering temperature of 950°C

Table 3. Hardness data (HRV) at each testing point with a temperature of 1000°C

Position of testing point	*Hardness Value (N/mm²)*		
	FAGL46	*FAGL55*	*FAGL64*
1	*16,2*	*21,5*	*28,9*
2	*20,3*	*24,2*	*29,3*
3	*15,7*	*24,6*	*34,1*
4	*17,4*	*20,5*	*34,5*
5	*15,8*	*22,4*	*34,3*
6	*19,8*	*20,6*	*37,3*
7	*15,5*	*20,3*	*33,4*
Average	*17,24*	*22,01*	*33,11*

In graphic form can be seen in Figure 7 below, which shows the relationship between the composition of the weight fraction and the hardness value (HRV) at various testing points for a sintering temperature of 1000°C.

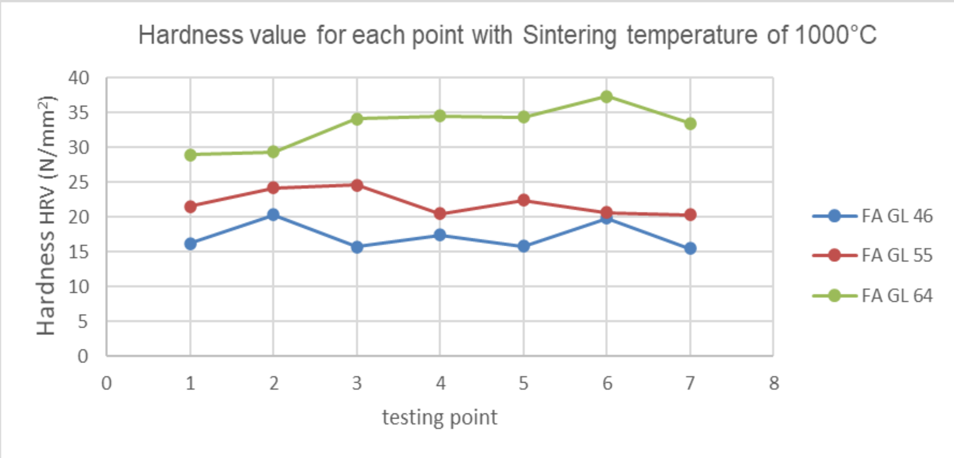

Figure 7. Relationship between hardness values (HRV) at various pressing points on sintering temperature of 1000°C

Overall, the highest average level of hardness was found in composite specimens that had been heated to 1000°C. as can be seen in the graph in Figure 8 below, the FAGL64 specimen has very good hardness HRV = 33.11 N/mm2 compared to specimens with different content compositions.

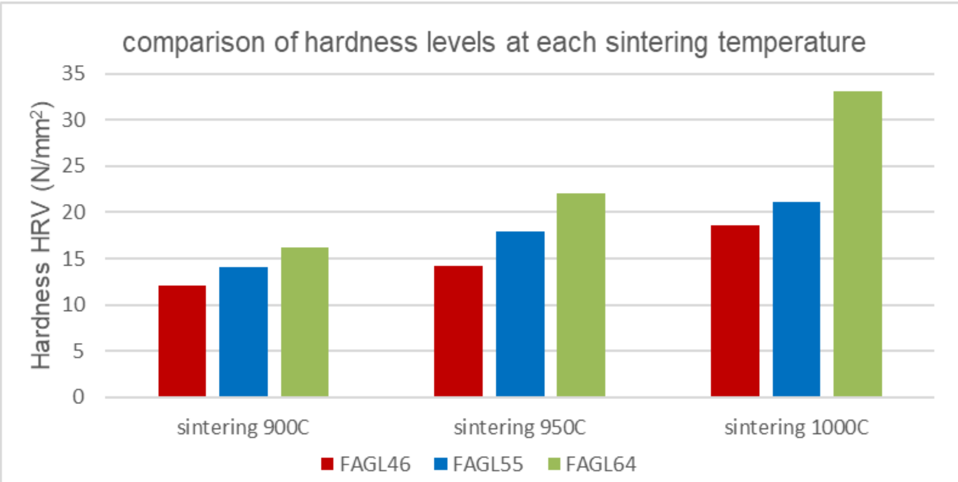

Figure 8. Average level of hardness on different sintering temperature

V. CONCLUSION

From the test results on the 3 types of composite specimens, i.e. FAGL46, FAGL55 and FAGL64, evidence was found that the greater the Fly Ash content in the composite material, the higher the level of hardness in the material. As evidence, it can be observed that the FAGL64 specimen has a hardness HRV = 33.11 N/mm2 which has a different level of hardness with the FAGL55 specimen HRV = 22.01 N/mm2, which means there is an increase of 11.10 N/mm2 with the addition of 5% Fly Ash elements. (with a sintering temperature of 1000oC), This fact indicates that the effect of sintering temperature is very significant on the hardness of this type of composite, especially at the sintering temperature which is close to the melting point of ceramic composites, around 1000oC up. [5], [12] and [15]. From observing the hardness test results of 3 types of specimens with different weight fractions of base material, it was found that the average hardness of the specimens increased along with the increase in the percentage of Fly Ash content, it can be stated that the Fly Ash factor is quite influential in increasing the hardness of the composite.

REFERENCE

[1]. ASTM C 618 – 03, 2003, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, Annual Book of ASTM Standards, Volume 04.02, ASTM International, Philadelphia, USA.

[2]. ASTM C 1327 – 99, 2002, Standard Test Methods for Vickers Indentation Hardness of Advanced Ceramics, Annual Book of ASTM Standards, Vol.15.01, ASTM International, Philadelphia, USA.

[3]. A, Mayurbhai Desai, T. Rudra Paul, and M. Mallik, 2020 "Mechanical properties and wear behavior of fly ash particle reinforced Al matrix composites," Mater. Res. Express, vol. 7, p.165.

[4]. Barbieri, L., Corradi, A., Lancellotti, I. (2002), "Thermal and Chemical Behaviour of Different Glasses Containing steel Fly Ash and their Transformation inti Glass-Ceramics", Journal of European Ceramics society 22, p1759-1765.
[5]. Barbieri, L., Corradi, A., Lancellotti, I., 2000, Bulk and sintered glass-ceramics by recycling municipal incinerator bottom ash, Journal of the European Ceramic Society**,** 20,pp. 1637-1643.
[6]. Barbieri, L., Lancellotti, I., Manfredini, T., Queralt, I., Rincon, J.M., Romero, M., 1999,
[7]. Design, Obtainment and Properties of Glasses and Glass-ceramics from Coal Fly Ash,
[8]. Fuel 78, Journal of European Ceramics society pp. 271–276.
[9]. Barsoum, M.W., 1997."Fundamentals of Ceramics", Mc Graw-Hill Book Co. New York.
[10]. Bernardo, E., Castellan, R., Hreglich, S., 2007, Sintered glass-ceramics from mixtures of wastes, Ceramics International 33 (2007) 27–33
[11]. Bethanis, S., Sollas, C .J., and Cheeseman, C.R., (2003), Properties and Microstructur of Sintered Incinerator Bottom Ash, U K Engineering and Physical Sciences Reserch Council (ESPRC) WMR 3 Programme.
[12]. Boccaccini, A. R., Bucker, M., Bossert, J. and Marszalek, K., 1997, Glass matrix composites from coal fly ash and waste glass, Waste Management, 17(1), pp. 39-45
[13]. Cheng, T.W., Ueng, T.H., Chen, Y.S., Chiu, J.P., 2002, Production of Glass ceramics from Incinerator Fly Ash, Interceram, 28, pp. 779-783.
[14]. Erol, M., Kucukbayrak, S., Mericboyu, A.E., Ovecoglu, M.L., 2001, Crystallization Behaviour of Glasses Produced from Fly Ash, Journal of the European Ceramic Society 21, pp. 2835–2841.
[15]. Erol, M., Demirle, U., and Kűcűkbayurk, S., (2003), Characterization Investigation of Glass - Ceramic Developed from Syntomer Thermal Power Plant Fly Ash, Journal of Europen Ceramic Society 23, p757-763.
[16]. Harper, C.A., 2001, Handbook of Ceramics, Glasses, and Diamonds, McGraw- Hill Companies, Inc., New York.
[17]. Hlavac, J., 1983, The technology of glass and ceramics An introduction, Glass science and technology 4, Elsevier, Amsterdam,
[18]. Kim, J.M. and Kim, H.S., 2004, Processing and Properties of a Glass-ceramic from Coal Fly Ash from a Thermal Power Plant Through an Economic Process, Journal of the European Ceramic Society 24, pp. 2825–2833
[19]. Kim, J.M. and Kim, H.S., 2005, Temperature-Time-Mechanical Properties of Glass-Ceramics Produced from Coal Fly Ash, Journal of American Ceramics Society, 88, pp. 1227 – 1232.
[20]. Leroy, C., Ferro, M.C., Montreiro R.C.C., and Fernandes M.H.V., 2001.Production of Glass-ceramics from Coal Ashes, Journal of the European Ceramic Society Vol. 21, pp. 195-202.
[21]. Mangutova, B., Angjuseva, B., Milosevski, D., Fidancevska, E., Bossert, J., Milosevski, M., 2004, "Utilisation of Fly Ash and Waste Glass in production of glass-ceramics composites", Bulletin of the Chemists and Technologists of Macedonia, Vol. 23, No. 2, pp. 157–162.
[22]. Park, C.Y., Yoon, S.D., Yun, Y.M., 2007, The Characterization of Glass ceramics Made from Waste Glass and Fly Ash, Journal of Ceramic Processing Research Vol. 8, No. 6, pp. 435-439.
[23]. Rahaman, M.N., 2003, Ceramic Processing and Sintering, Marcel Dekker, Inc.,
[24]. Madison Avenue, New York, U.S.A.
[25]. R. Manimaran, I. Jayakumar, R. Mohammad Giyahudeen& L. Narayanan (2018) Mechanical properties of fly ash composites—A review, Energy Sources, Part A: Recovery, Utilization, and EnvironmentalEffects, 40:8, 887-893, DOI: 10.1080/15567036.2018.
[26]. R. Raja, K. Manisekar, and V. Manikandan, 2021 "Effect of fly ash filler size on mechanical properties ofpolymer matrix composites," researchgate.net, Accessed: Aug. 06, 2021 doi: 10.1016/J.MSPRO.2014.07.324.