ISSN: 0067-2904
GIF: 0.851

Effect of Molding Pressing Force on the Properties of High-Voltage Porcelain Insulators

Muthafar F. Al-Hilli*
Department of Physics, College of Sciences, University of Baghdad, Baghdad, Iraq

Abstract

The effect of molding pressing force (1, 2, 3, 4, 5 and 6 tons) on the properties of 80% kaolin + 20 % soda-lime glass (bottle glass) high voltage porcelain were investigated. The samples were prepared by powder processing technique of semi-dry uniaxial pressing and sintered at 1100^{o}C. Both water absorption % and apparent porosity showed zero value at molding pressing force of 2-3 ton. The linear shrinkage (LS %) was determined by measuring the sample dimensions before and after sintering. The water absorption (WA), apparent porosity (AP) and apparent density (AD) were determined using the vacuum/boiling technique. Vicker's micro-hardness was measured for the samples. The flexural strength (R_f) was measured by the diametrical compression of a solid disk referred to as the Brazilian disk fracture test. The breakdown voltage of the prepared samples was measured at room temperature.

Keywords: molding pressing force, high-voltage insulators, kaolin, and breakdown voltage.

تأثير قوة ضغط التشكيل على خواص عوازل البورسيلين للفولتيات العالية

مظفر فؤاد جميل الحلي*
قسم الفيزياء، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصة

تم دراسة تاثير قوة ضغط التشكيل بين (1 ، 2 ، 3 ، 4 ، 5 ، 6 طن) على خواص النموذج المتكون من 80 % كاؤلين + 20 % زجاج جير الصودا (زجاج القناني) من عوازل الفولتيات العالية المحضر بواسطة تكنولوجيا المساحيق للكبس شبه الجاف والملبدة بدرجة حرارة 1100 ^{o} م. اظهرت نتائج فحص النسبة المؤية للامتصاص السطحي للماء و المسامية الظاهرية للنموذج قيم صفرية عند قوة ضغط تشكيل يبلغ 3 طن. التقلص الخطي للعينات نتيجة التلبيد تم قياسه من خلال قياس ابعاد العينة قبل وبعد الحرق. النسبة المؤية لامتصاص الماء و الفجوات الظاهرية والكثافة الظاهرية تم قياسها بطريقة الفراغ/ الغليان. تم قياس الصلادة المايكروية للعينات بطريقة فكرز. تم قياس متانة الكسر للعينات بطريقة الانضغاط القطري والتي تدعى اختبار الكسر للعينة القرصية البرازيلية. تم قياس فولتية الانهيار للعينات عند درجة حرارة الغرفة.

Introduction

High voltage insulator plays an important role in an electrical power system including generation, transmission, and distribution of electricity [1]. The insulators constitute one of the most important parts of the transmission lines as the flashover of polluted insulator can cause breakdown of the transmission network [2]. The great development of porcelain bodies was in the 80s as a very compact vitrified product with high technical performances. Porcelain bodies are made from clay, fluxing agent and filler. Usually the clay is kaolinite, the fluxing agent is feldspar and the filler is quartz [3]. Porcelain bodies are characterized by very low values of water absorption (<0.5% according to the ISO 13006 standard [4]) and usually by 93-97% of theoretical density. Such densification is achieved

*Email: m.alhilli@scbaghdad.edu.iq

by reactive viscous flow sintering involving the formation, at temperatures over 1100 °C, of a large amount of liquid phase (50-70 wt. %) by melting feldspars and partially quartz and clay minerals [5]. It is also reported that there are many failures of ceramics insulators especially in polluted areas. One method to improve the performance of these insulators is optimizing, first, their chemical composition and second, the shaping up and elaboration processes [6]. Pressing exigencies for the porcelain bodies industry are: a) enhancing the sintering kinetics; b) actually controlling firing shrinkage to achieve a uniform densification; c) keeping adequate mechanical strength in large size porcelain bodies [7].

Experimental

The chemical compositions of the kaolin and soda-lime glass used in the porcelain preparation were given elsewhere [8]. The glass obtained from high transparency soda-lime glass bottles free of coloring oxides. Both kaolin and glass were milled using pestle and mortar then sieved through (63 μm) screen. The glass powder was added to kaolin in proportion of 20 wt. %, and then dry mixed using a ball mill to homogenize the mixture. Samples in the shape of pellets (radius=5 mm and thickness=5 mm) were prepared by uniaxial semi-dry pressing using pressing force 1, 2 ,3 , 4 , 5 and 6 tons, corresponding to pressure of 124.7, 249.5, 374.3, 499.1, 623.8 and 748.6 MPa, respectively . The samples were sintered at temperature 1100 ^{o}C at rate of 3 ^{o}C/ min and soaking period 30 min. The linear shrinkage (LS %) was determined by measuring the sample dimensions before and after sintering. The water absorption (WA), apparent porosity (AP) and apparent density (AD) were determined using the vacuum/boiling technique [9, 10]. Vicker's micro-hardness instrument HPO250 equipped with microscopic screen and diagonal measuring device was used to measure the hardness. The Vicker's hardness (H_V) was determined from

$$H_V = 1.8544 \frac{F_a}{d^2} \quad (1)$$

Where F_a is the applied indenter load (N) and d is the average diagonal length for the indent (mm) [11]. The flexural strength (R_f) was measured by the diametrical compression of a solid disk referred to as the Brazilian disk fracture test. The test performed on a disk sample height = 5 mm and diameter= 13 mm using INSTRON instrument. The specimen was fixed between the device platens to start compressing at a crosshead speed = 0.5 mm/min until fracture occurred. The flexural strength (diametrical compression strength) was determined by applying Eq. 2 [12].

$$\sigma_f = \frac{2\,F_{fracture}}{\pi\,D\,h} \quad (2)$$

Where $F_{fracture}$ is the fracture load (N), D is the sample diameter and h is the sample thickness in (mm). The dielectric strength was performed on ''High Voltage Potronics Device" at 50 Hz with maximum negative voltage of 80 kV. The testing medium was pure transformer oil with breakdown voltage 40 kV/mm. The voltage rising rate was 1 kV/s to eliminate any thermal effects until breakdown occurs at the maximum breakdown voltage ($V_{br.}$). The dielectric strength ($E_{br.}$) was determined from

$$E_{br.} = \frac{V_{br.}}{t} \quad (3)$$

Where t is the sample thickness in mm.

Results and Discussion

Figure-1 and Figure-2 show the water absorption and apparent porosity versus moulding pressing force, respectively. The water absorption and apparent porosity were correlated to each other. However, knowing that the water absorption must not exceeds (0.5%) for the electrical porcelain, highlights the importance of the zero W.A and A.P which was attained at moulding pressing force 2 and 3 ton. The water absorption and apparent porosity decreases as moulding pressing force increases, as a result of the higher densification. However, close porosity experiments a significant decrease as pressing force increases up to 3 ton, but it increases at higher pressing force likely due to bloating that occurs because of the difficulty to release gases entrapped in bodies pressed at high pressing forces, as in the first stage of sintering a high green compactness locks the microstructure and inhibits the rearrangement of particles [12].

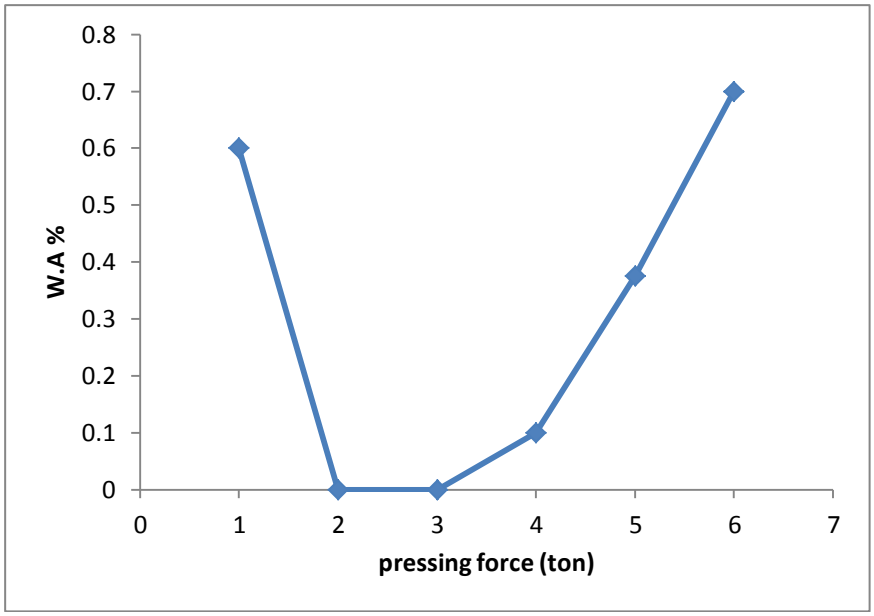

Figure 1- Water absorption vs. forming pressing force

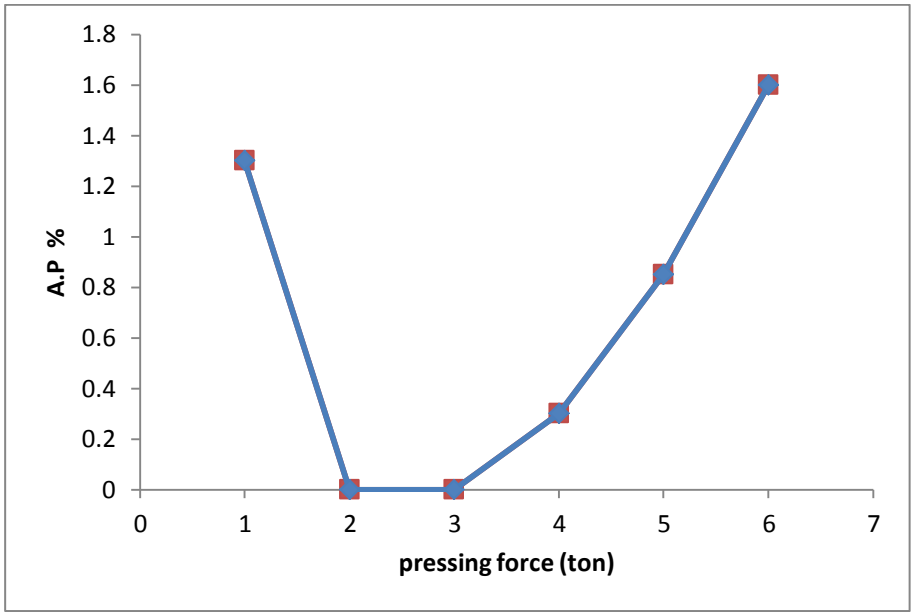

Figure 2- Apparent porosity vs. forming pressing force

Figure-3 shows the apparent density versus moulding pressing force. The density of the samples increased with molding pressing force up to 3 ton due to the higher compaction and decrease in porosity. After 3 ton there was slight decrease in density due to the increase in closed pores with the expansion of O_2 gases released from the reaction of Fe_2O_3 to Fe_2O_4, and the expansion of the air enclosed within the pores.

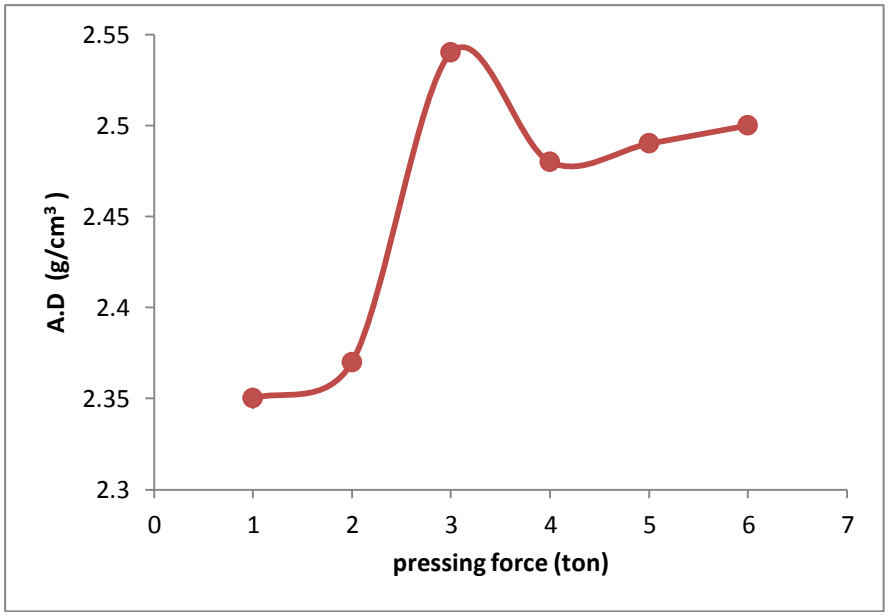

Figure 3- Apparent density vs. forming pressing force.

Vickers hardness relation with moulding pressing force is shown in Figure-4. This behavior may be discussed based on the surface vitrification and self-glazing by the molten glassy phase which increases with moulding pressing force. The decreases in apparent porosity and enrichment of the glassy phase leads to increase in hardness up to moulding pressing force equal 3 ton. The decrease in hardness after 3 ton may be related directly to the increase in open porosity on the surface.

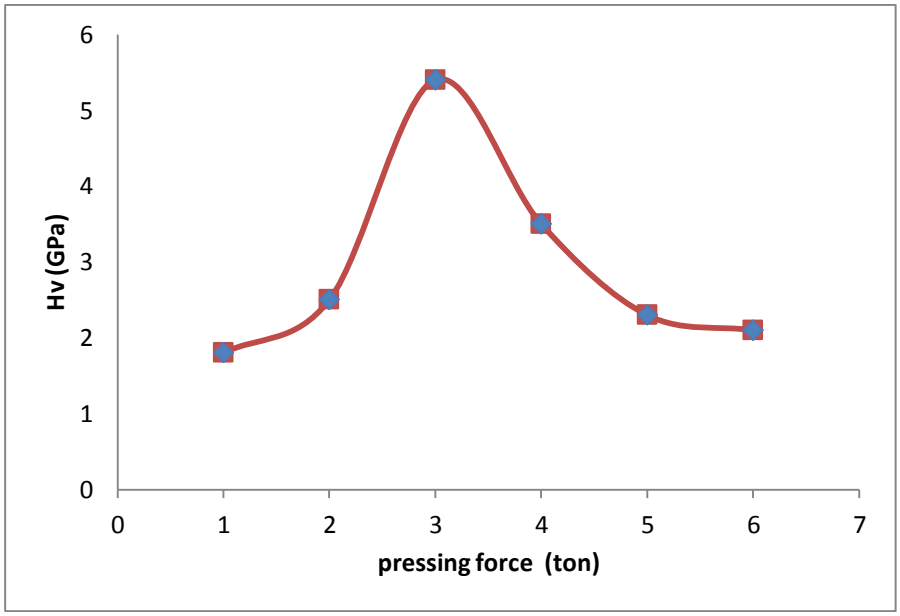

Figure 4- behavior of Vicker's microhardness against forming pressing force.

Figure-5 depicts the variation of flexural strength of the porcelain bodies as a function of moulding pressing force. However, this variation in flexural strength is not linear. What does seem to have a positive effect on bending strength is the decrease in open porosity of the sample. The flexural strength showed higher results with moulding pressing force of 3-4 ton. This result indicates that although bending strength is influenced by open porosity, it is not the only factor having an effect. Regarding the relationship between flexural strength and apparent density showed higher values beyond 3 ton.

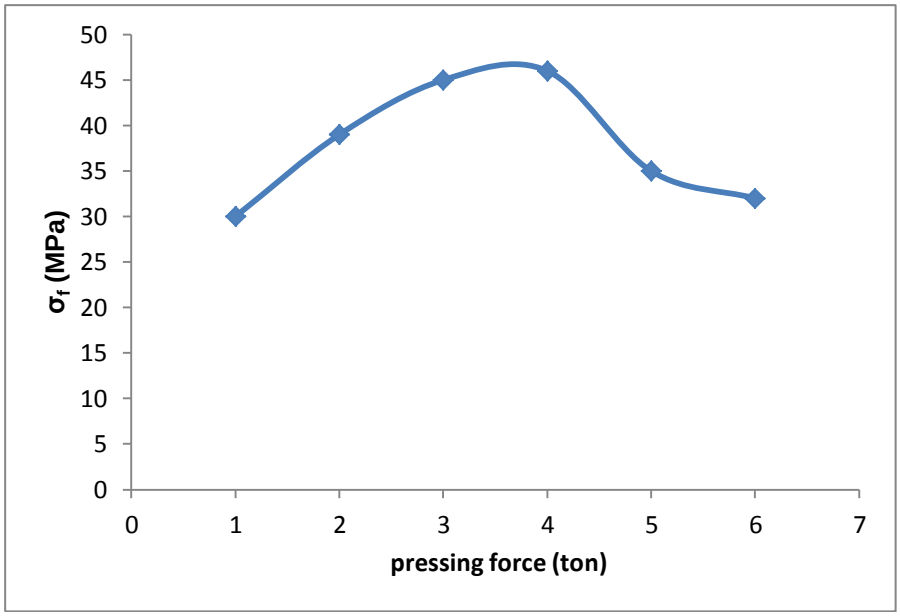

Figure 5- Relationship of flexural strength with forming pressing force.

The dielectric strength is plotted in Figure 6 as a function of moulding pressing force. The increase in moulding pressing force increased the dielectric strength. This may be attributed to the decrease of the porosity and/or increase of density with moulding pressing force. These parameters mutually determine the "size" of the responsible defect. However, since the dielectric strength has to be above 30 kV/mm for high-tension electrical insulators [13]. It may be noticed that moulding pressing force above 3 ton produced breakdown voltage exceeds 30 kV/ mm. The dominant mechanism of electric breakdown here is, a small number of carriers in the conduction band are accelerated in the electric field and these collide with atoms, ionizing them. This releases more carriers for further impact ionization and the current rapidly builds. However, the resultant Joule heating causes insulators to become better conductors that can pass more current. The process feeds on itself until a thermal runaway result in local failure. Shaping insulators in special ways can effectively reduce their tendency to break down or conduct at high voltages.

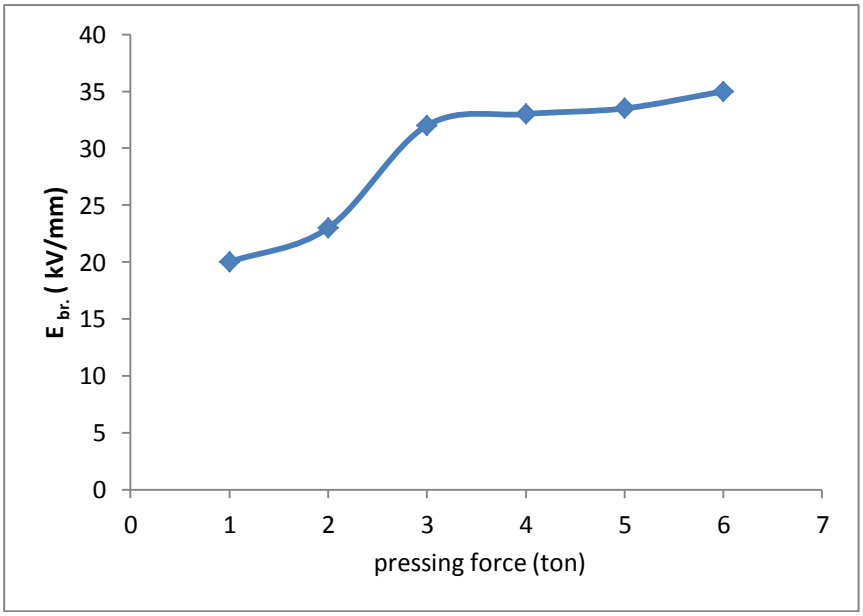

Figure 6- Relationship of dielectric strength with forming pressing force.

Conclusion

Water absorption and apparent porosity decreases with moulding pressing force up to a certain limit where the structure deformation give rise to increase in both factors. The increase in density with molding pressing force is related to the open porosity while the decrease in density is related to the closed pores. The mechanical properties of the porcelain are largely dependent on the molding pressing force. The dielectric strength was remarkably influenced by the moulding pressing force. Moulding pressing force below 3 ton is not feasible in the preparation of high-voltage porcelains.

References

1. Ibrahim, A., Nasrat, L. and Elassal, H., **2014**, Improvement of Electrical Performance for Porcelain Insulators Using Silicone Rubber Coating, *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*,2(8),pp:1884-1888.
2. EL-Tayeb, A., Maowed, M. and Moussa, Adel Zein El Dein Mohammed. **2014**. Performance of Ceramic Insulator String for 132kV under Different Polluted Conditions, *J. Energy Power Sources*, 1(3), pp: 152-160.
3. Juan, M. Pe´rez, Jesu´s Ma. Rinco´n and Maximina, R. **2012**. Effect of moulding pressure on microstructure and technological properties of porcelain stoneware, *Ceramics International*, 38,pp: 317–325.
4. ISO 13006, Ceramic Tiles – Definitions, Classification. **1998**. Characteristics and Marking, *International Organization for Standardization*.
5. Mariarosa, R., Chiara, Z., Guia, G., Michele, D., Roberto, F. and Tiziano, C. **2009**. Process of pyroplastic shaping for specialpurpose porcelain stoneware tiles, *Ceramics Internationa*l, 35, pp:1975-1984.
6. Roula, A., Boudeghdegh, K. and Boufafa**,** N. **2009**. Improving usual and dielectric properties of ceramic high voltage insulators, *Cerâmica* , 55, pp: 206-208.
7. Zanelli, C., Baldi, G. Dondi, M. Ercolani, G. Guarini, G. and Raimondo, M. **2008**, Glass ceramic frits for porcelain stoneware bodies: effects on sintering, phase composition and technological properties, *Ceramics International*, 34, pp: 455-465.
8. Al-Hilli, M. F. and Al-Rasoul, K.T. **2010**. Influence of glass addition and sintering temperature on the structure, mechanical properties and dielectric strength of high-voltage insulators, *Materials and Design* ,31(8),pp: 3885–3890.
9. Ryan, W. and Radford, C. **1987.** White wares: production testing and quality control. UK: Pergamon Press.
10. Martín-Márquez, J., Rincón, JMa and Romero, M. **2008**. Effect of firing temperature on sintering of porcelain, stoneware tiles. *Ceram Int* ,34, pp:341867–73.
11. Quim, Goerge D., Patel, Parimal J. and Lloyd, Isabel. **2002**. Effect of loading rate upon conventional ceramic hardness. *J Res Natl Inst Stan*, 107, pp: 299–306.
12. Ranogajec, J. Djuric, M. Radeka, M. and Jovanic, P. **2000**. Influence of particle size and furnace atmosphere on the sintering of powder for tiles production, *Ceram. Silik.*, 44, pp:71–77.
13. Rashed, Adnan Islam, Y.C., Chana, Md. And Fakhrul Islam, **2004**, Structure–property relationship in high-tension ceramic insulator fired at high temperature, *Materials Science and Engineering B*, 106, pp: 132–140