Study to Improve Physical & Mechanical Properties of Pure Alumina Reinforced by PMMA

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Abstract

Alumina material was reinforced with thermoplastic polymer (Poly-methyl Methacrylate PMMA) by infiltration method in this study. Where pure alumina (α-Al$_2$O$_3$) powder was mixed with naphthalene as volatile material by weight fractions of naphthalene (0,15,30,45) wt% for a period of 3 hours by electric mixer to prepared the porous ceramic material. Specimens were prepared by pressing after added (PVA) binder. They were dried at (110 °C) and sintered at (1000 °C) and stay for 1 hour at that temperature. Then, the physical properties such as porosity, density and the mechanical properties such as compressive, impact strength were measured before infiltration.

Infiltration material (Poly-methyl Methacrylate PMMA) was prepared by mixing (83%) of chloroform as solvent material to granules PMMA and heating at (50 °C) with movement to convert that mixture into a liquid material with less viscosity. After that the samples was immersed in liquid (infiltration material) and left to allow the volatile material (chloroform) to escape by evaporation leaving PMMA alone as reinforcement materials. Then, mechanical and physical properties of the samples were tested after infiltration process. The results showed an improvement their physical and mechanical properties of the composite material.

Keywords: Poly-methyl Methacrylate, Alumina, Infiltration, Volatile material**,** Solvent material.

الخلاصة:

مادة الالومينا تم تقويتها بمادة بوليمرية تلدن حراريا (البولي مثيل ميتا اكرلت PMMA) بطريقة الترشيح في هذه الدراسـة. حيث تم خلط مسحوق الالومينا النقي (طور الفا) مع النفثالين كمادة متطايرة بنسب وزنية من النفثالين (0,15,30,45) بالمئة ولمدة 3 ساعة بخلاط كهربائي لتحضير مادة سيراميكية مسامية. العينات تم اعدادها بواسطة الكبس بعد اضافة مادة (PVA) الرابطـة. العينات تم تجفيفها بدرجة (C^0 110) ولبدت بدرجة (1000 ^{0}C)، ومكوث لساعة واحدة عند تلك الدرجة. بعد ذلـك، تــم حــساب الخواص الفيزيائية كالمسامية والكثافة والخواص الميكانيكية كمقاومة الانضغاط والصدمة قبل الترشيح.

المادة الراشحة (البولي مثيل ميتا اكرلك PMMA) تم اعدادها بخلط (83%) من الكلوروفورم كمادة مذيبة الى حبيبات البولي مثيل ميتا اكرلك مع التسخين عند (50 °C) والحركة لتحويل ذلك الخليط الى مادة سائلة وباقل لزوجة. بعد ذلك تم غمر العينــات بالسائل (المادة الراشحة) وتركها للسماح للمادة المتطايرة (الكلوروفورم) تغادر بالتبخير تاركة البولي مثيل ميتا اكرلك لوحده كمادة تقوية. ثم فحصت الخواص الفيزيائية والميكانيكية للنماذج بعد عملية الترشيح. حيث اظهرت النتائج تحسن في الصفات الفيزيائيـة والميكانيكية للمادة المركبة.

الكلمات المفتاحية: البولي مثيل ميتا اكرليت، الالومينا، الترشيح، مادة متطايرة، مادة مذيبة.

1-Introduction

Generally ceramic was stronger under compression than under tension, and it was weak with fracture toughness. The main aim of using composite ceramic materials to shift a stress from matrix to reinforcement and to improve more characteristics such as fracture toughness of composite and hardness, strength, creep and fatigue facture resistances, thermal performance and electrical characteristics.(Timothy, 2001).

They fracture easily under loads because of cracks initiated by small defects or scratches (Pavol *et. al.*, 2011) . To increase the crack resistance or fracture toughness, reinforcements were embedded into the matrix. However, the improvement was limited, and the products have found application only in some ceramic cutting tools..(Gao *et. al.*, 2010).

Researchers (Travitzky *et. al.*, 1998) infiltrated melted (Cu-O Alloy) melting inside porosity ceramic body (Al$_2$O$_3$), where an increase of strength was achieved.

(Ahmed *et. al*., 2004) obtained composite by infiltrating polymer (Acrylate) to porosity ceramic (Al_2O_3) that produces improve in impact strength. Reinforcement of porous ceramic with liquid of polymer by infiltration process is best with vacuum system (Glaus , 1984).

Typically, alumina include high hardness, low density, excellent dielectric properties, good thermal conductivity, good thermal stability, excellent size and shape capability, high strength and stiffness. There are two types of pure alumina (α-AL_2O_3), (γ- AL_2O_3) and non-pure (β - AL_2O_3), but all types of alumina change to (α-AL_2O_3) at 1000 ^{0}c. Alumina melting point at 2050 ^{0}c and sintering at(1700-1800 ^{0}c), (Worral , 1982).

PMMA was a linear thermoplastic polymer. It had high mechanical strength, higher of the hardest thermoplastics and was also high scratch resistant. It exhibits low moisture and water absorbing capacity, due to which products may have good dimensional stability. Both of these characteristics increase as the temperature rises. PMMA has density (1.15-1.19 g/cm^3) and Tensile Strength, Ultimate (47-79 MPa), Tensile Modulus (2.2-3.8 GPa), elongation at break (1-30%). The thermal stability of standard PMMA was only (65ºC). Heat-stabilised types can be withstand temperatures of up to (100ºC). PMMA can be withstand temperatures as low as (-70ºC). Its resistance to temperature changes was very good. (Harper *et. al.,* 2003).

To produce porous ceramic there are several ways such as the use organic material such as (Coke, Rice hush, Paper, Sawdust, etc.) but these materials left ashes inside the ceramic body and change of ceramic color. The ash was caused problems. The use of volatile materials with sublimation such as (sulfur, ammonia, chlorine, naphthalene, etc.) did not left ash and did not change of ceramic color (Singer *et. al*., 1963).

The present study was used pure (α-AL_2O_3) as matrix material and (PMMA) as reinforcement by infiltration method. Alumina was submerged gradually in order to allow the gas to escape and allow the mixture (chloroform and PMMA) to fill the pores. Chloroform was used to solve and reduce viscosity of Poly-methyl Methacrylate. After some time the chloroform can be volatile by evaporation leaving the polymer (PMMA) alone inside the samples as reinforcement to ceramic material. Aim of this process was to improve mechanical properties such as impact, compressive strength of pure alumina reinforced by PMMA with infiltration process after made porosity material from naphthalene and alumina powder.

2-Experimental

2.1 Samples preparation

The present study was achieved by taking basic material as a matrix of pure alumina (α-AL_2O_3), figure (1) referred to alumina powder analysis by X-Ray Diffraction. Figure (2) referred to particle size analysis by (Bettersize2000 laser particle size analyzer) of alumina powder, particle size of alumina was (1.184 μm) as shown in figure (2). Samples were achieved by pressing, draying, sintering, and reinforced by thermoplastic polymer PMMA (Poly-methyl Methacrylate) as will be seen later.

The samples were prepared as following; firstly, four quantity of alumina powder and naphthalene powder were mixed in order to obtain porosity material of alumina. Respectively, was included weight fractions (0,15, 30 and 45 wt. %) of naphthalene, the mixture were mixed by an electric mixer for 4 hours for each case. Then to obtain samples with suitable strength a load of 12 KN was chosen to press the samples after using polymer binders (e.g. PVA). The addition of PVA was achieved by added two drops into alumina powder of each sample. However, dimension of samples were achieved according to the ASTM for compression (C773-88) and impact (C368-88).

The infiltration material was prepared by mixing PMMA with 83% chloroform (e.g. 17% polymer) to make infiltration mixture. The mixture was treated in glass

beaker and mixed by magnetic stirrer with heating at (50 ^{0}C) to reduce viscosity of PMMA.

2.2 Drying and Sintering

The samples were dried at (110 ^{0}C) for 24 hours, as well as sintering the samples at (1000 ^{0}C) with heating rate 5 degree for 1 minute to prevent distortion of the samples and they was still at these degrees for a period of 1 hour. So that left them inside oven to 24 hours to reach at room temperature to be ready for testing the physical and mechanical properties before infiltration processes.

2.3 Physical and Mechanical Testing

2.3.1 Physical test;

The porosity and bulk density was carried out before and after infiltration processing. The porosity test and the apparent density (g/cm^3) test were achieved according ASTM standard (C373-88) as following.

A- Apparent Porosity;

The samples were dried at (110^{0}C for 24 hours.) and left in an oven to cool until room temperature and measured dry weight (W$_{dry}$). Samples was boiled in distilled water for (5 hr.), and left to be submerged inside distilled water for (24 hours.) and the submerged weight (W$_{sub.}$) was then measured. Lastly samples was dried by a cloth and then taken the submerged weight (W$_{sat.}$), then apply the porosity eq. (Frank *et. al.*,1998).

Apparent porosity = (W$_{sat}$- W$_{dry.}$ / W$_{sat}$- W$_{sub}$) %

B- Bulk Density

To conduct density test, the exterior volume eq. (Waffa, 1999) is applied.

V$_e$= (W$_{sat}$- W$_{sub}$)/ ρw

Since pw (water density)=1(g/cm3) and;

Bulk density = W$_{dry}$/ V$_{e.}$ (Gacek *et. al.*, 1981)

2.3.2 Mechanical Test;

Mechanical testing was carried out to check strength of samples before and after infiltration as follows ;

A- Compressive Strength Test

The compressive strength was calculated according to ASTM standard (C 773-88). The samples were cylindrical with dimension (D=10 mm, H=20 mm). The change after infiltration was calculated with the following compressive strength equation;

compressive strength= P/A (MPa), (Lahaska *et. al.*, 1987), since P: is a load (N), A: sectional area (mm^2).

B-Impact strength test

The impact strength, by (Charpy method), was performed according to ASTM standard (C368-88). The samples were blocks like square section with dimension (L=55mm, W=10mm, H=10 mm). The change after infiltration was calculated with the following equation;

Impact strength=W/A (KJ/m^2). (Subramanian *et. al.*, 1998).

Since W: is break energy (J), A: Sectional area (mm^2).

3-Results and Discussion

The test results showed improvement in physical and mechanical properties of ceramic composite were apparent in figures (3,4,5 and 6). Figure (3) referred to change in porosity before and after infiltration process. The porosity was increase before infiltration process and decreased after infiltration process due to filling the pores with PMMA substance.

Figure (4) showed change in bulk density before and after infiltration process though the change was little. The reason of composite density increase after

infiltration was due to density of PMMA as reinforcement material which added by infiltration process. But before infiltration the porosity was increase that due to lack in density as known fact (Ahmed *et. al.*,2004).

In figure (5) referred to effect of infiltration process on compressive strength. There was a reduction of compressive strength before infiltration but there was improvement in compressive strength of composite after filling of pores. So that the samples with less pores showed higher compressive strength than the other ones with increase of porosity (Patankar *et. al.*, 1998).

The test of impact strength aimed to calculate the substance toughness and ability to energy absorption till fracture, Figure (6) was indicated to result of impact strength. The improvement in mechanical properties was clear because disappearance of the crack (Singer *et. al.*, 1963) after filling of pores. Also the improvement in impact strength of samples was due to infiltration with less porosity and strength of reinforcement material.

4-Conclusion

1-The samples showed a difference of porosity with different compactions, and the high porosity showed weakness in strength.

2-The using of heating with mixing chloroform and PMMA will be better to reduce high viscosity of polymer.

3-The impact strength of brittle materials can be improved with additive polymer materials.

4-The results refer to the porosity causes reduced of mechanical properties such as impact, compressive strength.

5-Small pores can improve compressive, impact strength and this shows that the small pores absorb polymer more than the large pores do.

5-References

Ahmed A.A., David L.M., Douglass H.A., Ihan A.A, Robert K., 2004 ,"Strengthening of porous ceramics with polymers", Science &Engineering, Vol. 90,No.304,.

FrankR.Jr.,&Kevin P.T.,1998, "Tailored Porosity Gradients via Colloidal Infiltration of Compression-Molded Sponges" Ameer.Ceram.Soc., Vol.81, No.6.

Gacek S., Frydrych J., Stolarz S.,1981, "Powder Metallurgy International" Vol.13, No.1.

Gao Xiguang, *et al.*, 2010 ,"Numerical Simulation of Dynamic Response of Fiber Reinforced Ceramic Matrix Composite Beam with Matrix Cracks using Multiscale". Modeling, P(537-548), China.

Glaus G. Goetzel, 1984, "Metals Hand Book". V0lume 7, Powder Metallurgy, Amer. Soc.Metal.

Harper, Charles A., Edward M. Petrie ,2003, "Plastics Materials and Processes". John Wiley & Sons.

Lahaska J., Rutkowski W.,1987, "Infiltration of Liquid in Sintered Tungsten" Powder Metallurgy International, Vol. 19, No2.

Patankar A.N.,Mandal G.,1989, "The packing of someNon-SphericalSold Particles", Trans. Brit.Ceram. Soc., Vol.79.

Pavol Hvizdos, *et al.*,2011, "In Tech-Carbon Nanofibers Reinforced Ceramic Matrix Composites". P(241-262), Slovak Academy of Sciences. Slovakia.

Singer F., &Singer S.S. ,1963, "Industrial Ceramic". Chapman and Hall Ltd., London.

Subramanian R., Schneibel J.H.,1998, "Composites-Melt infiltration Processing" Materials Science and Engineering, A244,PP.103-112.

Timothy Carl Radsick,2001,"Fabrication of Ceramic Matrix Composite Tubes Using a Porous Mullite". P(1-10), University of Califonia.

Travitzky N,A.,Shlayen A.,1998,"Material Science &Engineering" A244, pp.154-160.
Wafaa A.Kh.AL.Rawi, 1999, Msc. Thesis, University of Technology, Baghdad.
Worral .W, 1982,"*Ceramic Raw Materials*". 2nd edition, Pergamon Press, Oxford, New York.
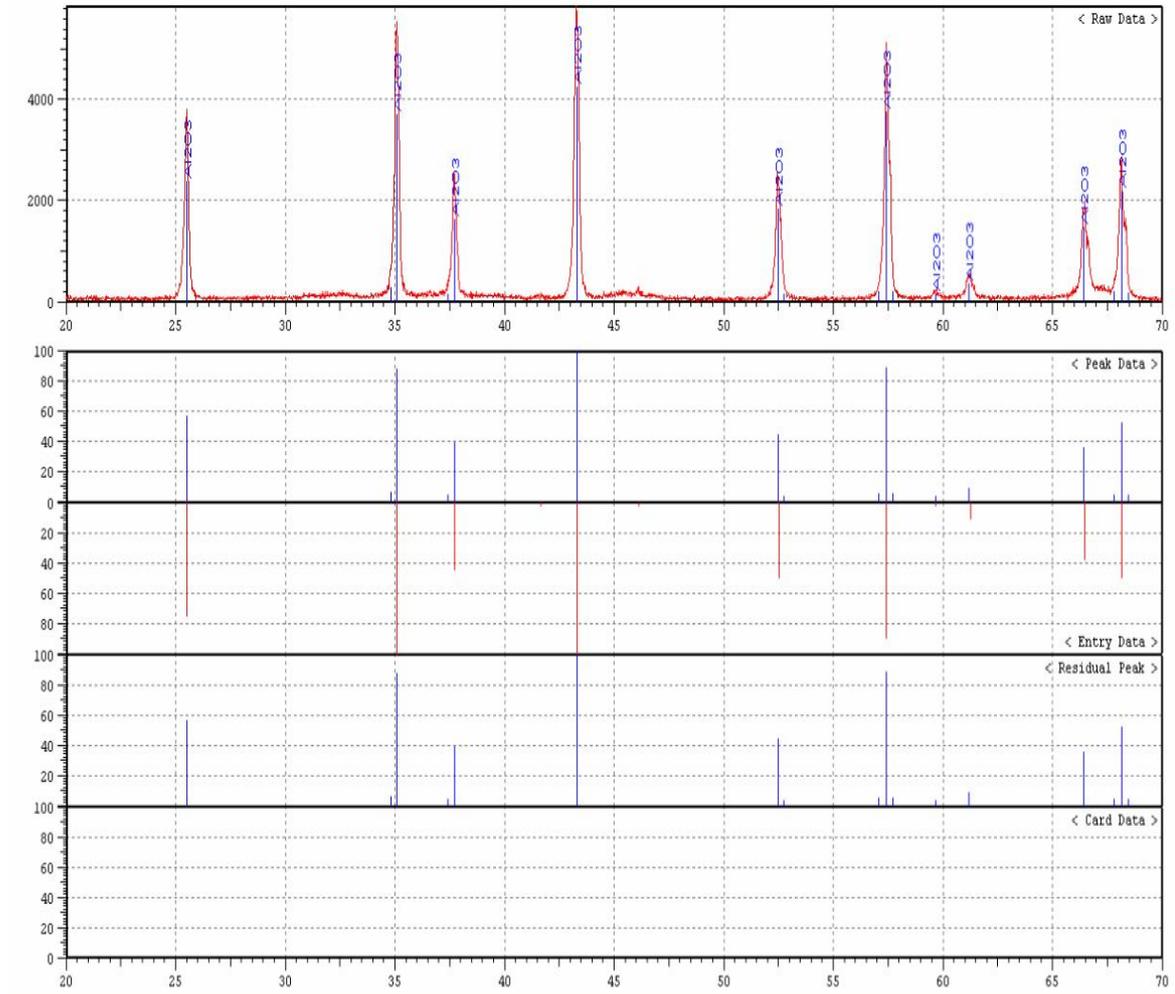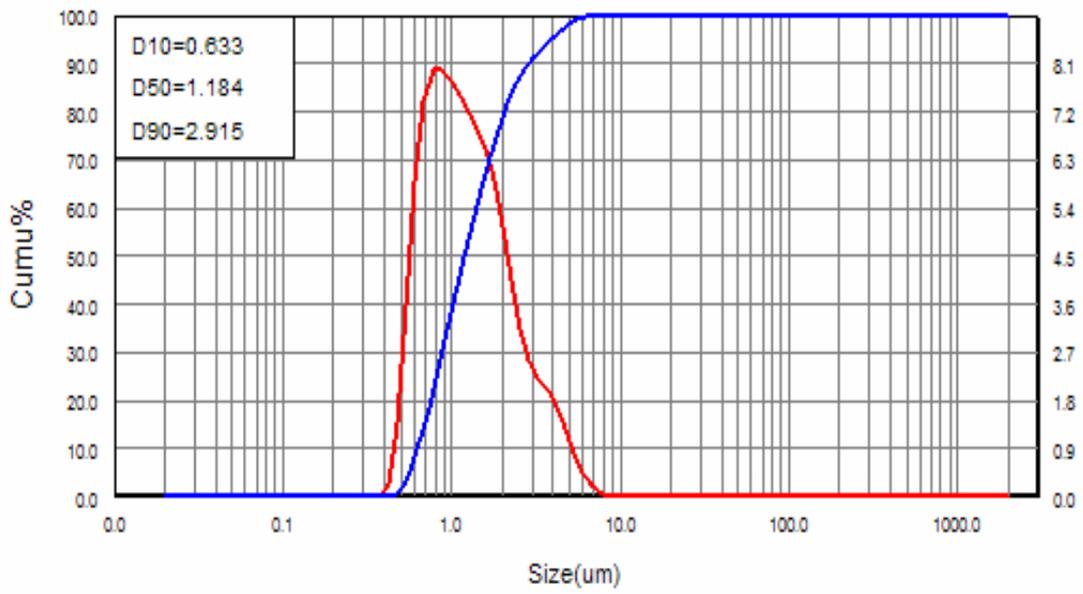

Figure (1) XRD of Alumina powder Analysis

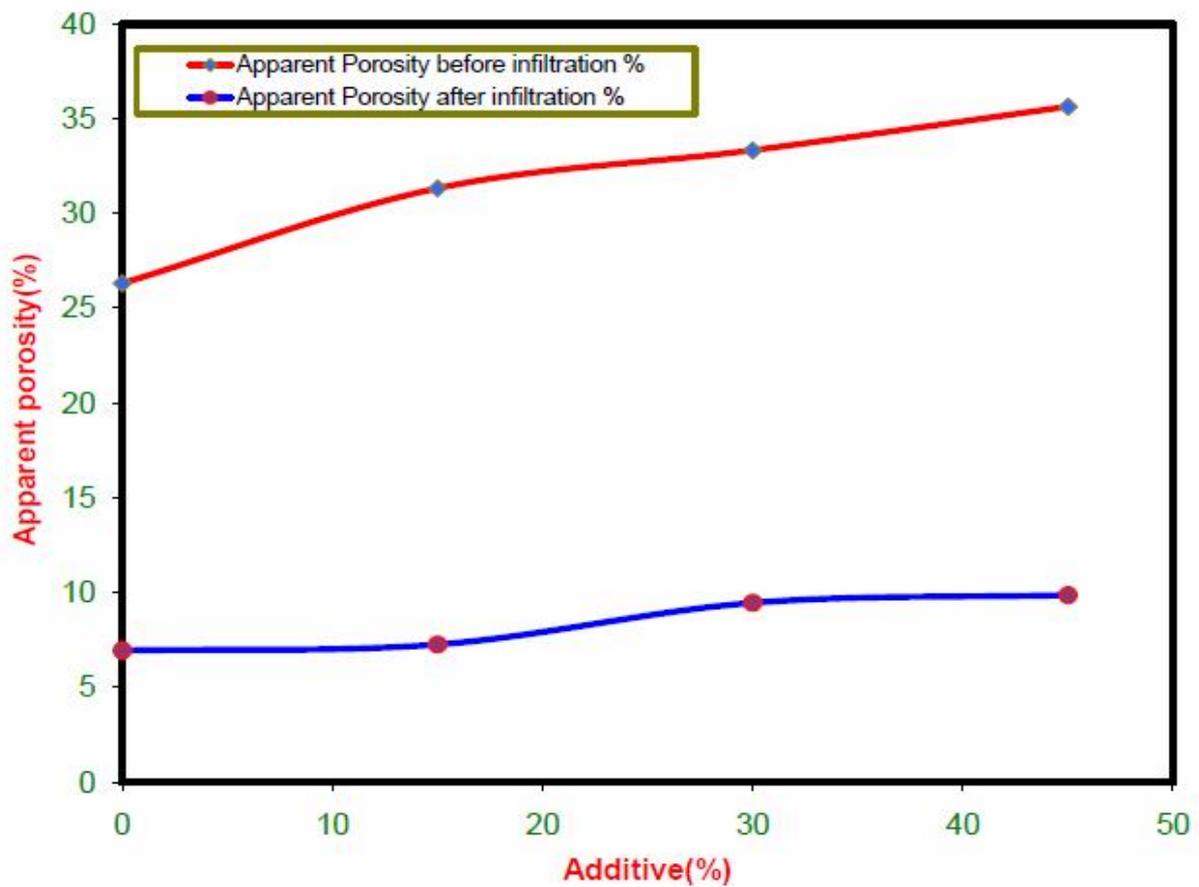Figure (2) Particle size analysis of alumina powder.

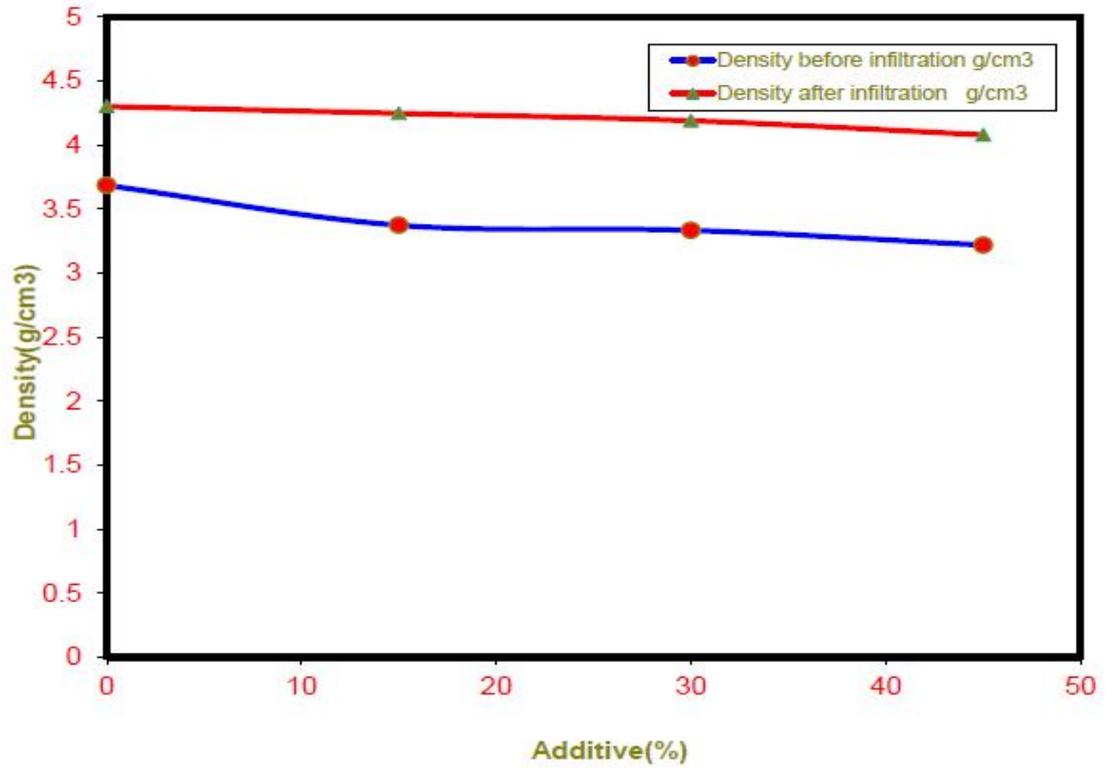Figure (3) Apparent porosity before and after infiltration process.

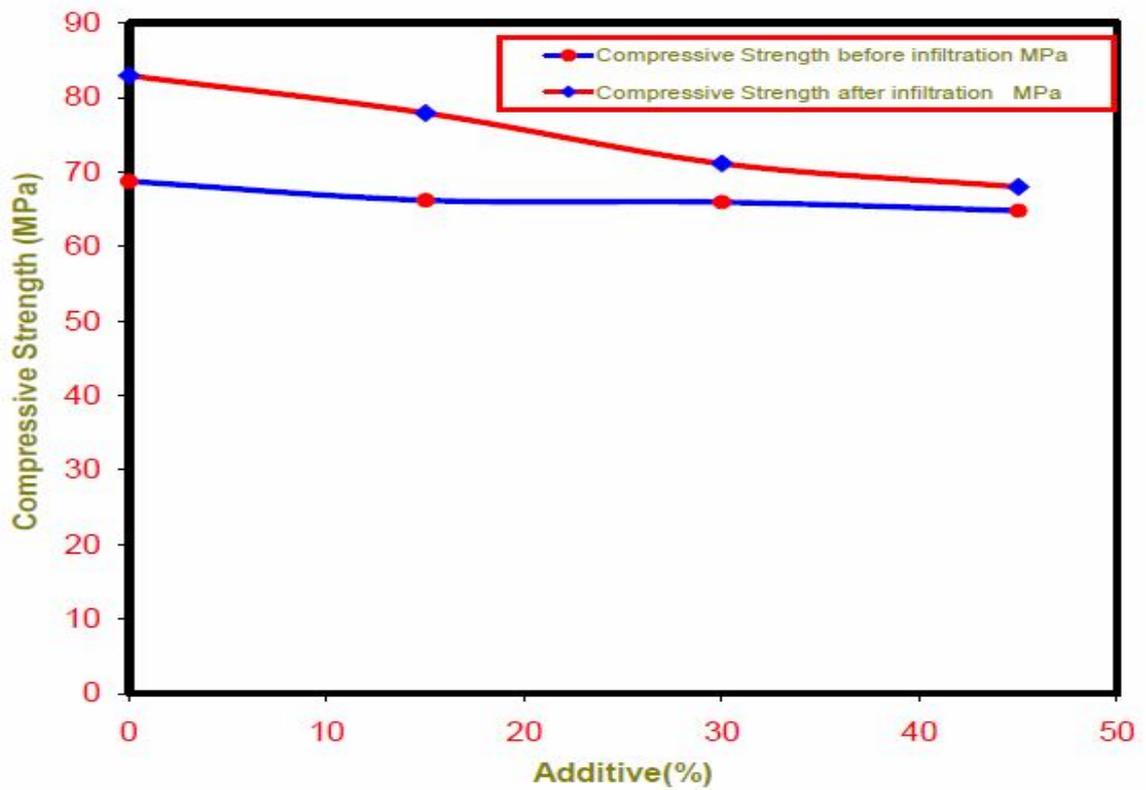Figure (4) Density before and after infiltration process.

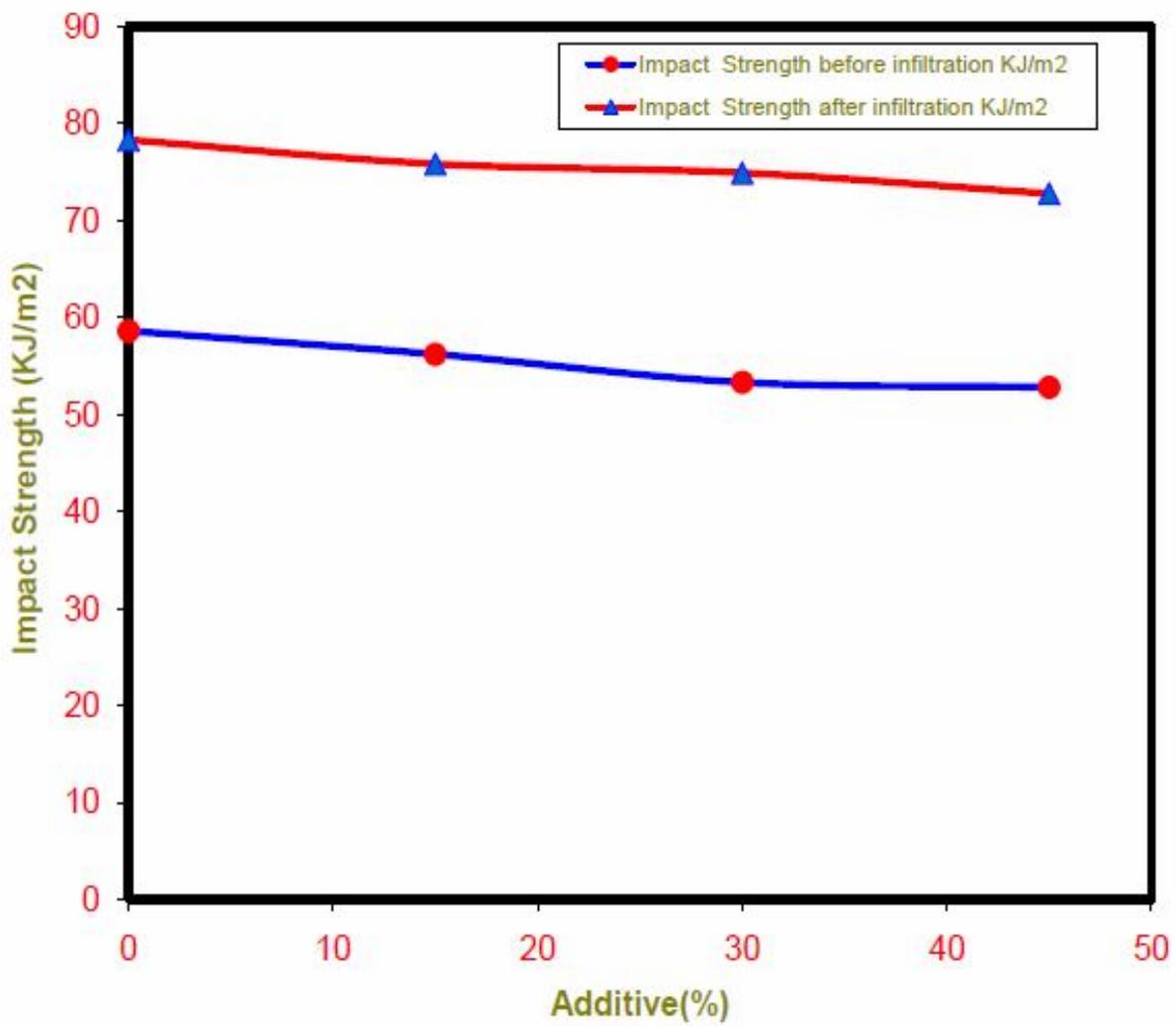Figure (5) Compressive strength before and after infiltration process.

Figure (6) Impact strength before and after infiltration process.