

Research Article

Effect of Beryllium and Lithium Addition on Physical and Mechanical Properties of Machinable Glass Ceramic Materials

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Abstract

Machinable glass – ceramic material have a good chemical properties, the optical properties , as well as mechanical and thermal properties, that allow glass – ceramic material to be used as main component in aerospace application (shuttle), bio-material for the veneering of metal restoration in destroy. In this work prepare glass-ceramic from raw material (Oxides + BaO), then obtain density , Young modulus and Hardness. After that studies effect of Lithium and Beryllium additions in properties of glass ceramic. You can see that the porosity decrease with increase of %Wt Li to reach 4% and %wt Be to reach 5%.Li addition leads to decrease density of glass-Ceramic to ($\rho \approx 1.89 \cdot 10^3 \text{ Kg/m}^3$ when add 9% Li), also Be addition decrease density of glass-Ceramic to ($\rho \approx 2.06 \cdot 10^3 \text{ Kg/m}^3$ when add 9%Be), this result prefer in application of glass-Ceramic, especially in aerospace application (window of shuttle). The addition of 9% Li lead to increase young modulus (E) to (73.5 Gpa) also addition of 9% Be lead to increase (E) to (69 Gpa) and the addition of (5%) of Li and (5%) of Be together increase young modulus to (78 Gpa). Lithium addition on glass-Ceramic leads to decrease Hardness to (259 HB at 9% Li), but Beryllium addition lead to increase Hardness to (312 HB), and addition of Li and Be together (5%Be + 5% Li)lead to increase Hardness to (289 HB). Impact energy was found to increase with increase in Li and Be addition to reach (25.1 Nm) and (27.1 Nm) when add (9%) of Be and Li respectively. In microstructure test the addition of Be and Li metal through the specimens leading to a consolidate for all the alternative properties. See the diffusion process occurred of Li as base metal in glass-Ceramic and precipitation of Be as a second phase in glass-Ceramic.

Keyword: Glass-ceramic , composite materials, Lithium, Beryllium, mechanical properties, physical properties.

1. Introduction

For many years, ceramists have known that certain glaze compositions are susceptible to large visible crystallization effects when they are applied as coatings on decorative ceramic wares (S. Buchner et al,2011). Similarly, in the past there have been glassy beads that were not amorphous, but opaque or opalescent due to crystallization in either the bulk or surface, giving rise to different heterogeneity colors and appearances similar to those of natural stones (R. D. Rawlings et al,2006). Both controlled nucleation and crystallization of glasses have been widely developed since the 1960s, due to the wide interest in the production and commercial exploitation of glass ceramic products in domestic and technological applications (P.W. McMillan et al,1979). Not much investigation, however, has been devoted to the production of glass-ceramics in thin layers, although surface crystallization phenomena in glasses have been investigated (Cristina Doneda, 2000; P.W. McMillan, 1979) However, these latter studies have focused more on associating surface crystallization with

defects in conventional glasses or as an intermediate stage in the bulk crystallization of glass-ceramics (P.W. McMillan et al,1979). In recent years, there has been a growing interest in ceramic glazes and frits for developing new glaze compositions that can be crystallized in order to improve the mechanical and chemical properties of fast-fired glazed tiles. Nucleation and crystallization of thin layers of certain glasses covering ceramic substrates (glazes) to obtain high-performance glass-ceramic coatings (J. Deubener et al,1992) are scientific and technological challenges due to the difficulties of controlling crystal growth homogeneously. Therefore, the aim of this research has been to explore the capabilities of commercial and other new glass-ceramic compositions for use as glass-ceramic glazes and to show and discuss the different crystalline microstructures that can be obtained in these special glass-ceramics (J. Schmelzer et al,1995).Glass ceramics are polycrystalline materials prepared by the controlled crystallization of highly viscous glass-forming melts. Their properties depend on the amount and composition of crystal phase formed and also on the residual glass composition. Again the crystal phase formation is a strong function of heat treatment time,

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temperature, heating rate, presence of nucleating agent, and impurity etc. Glass ceramic materials are already used in several applications as engineering materials and new uses constantly appears (R. D. Rawlings et al,2006).

2. Literature review

S. Buchner, A.Mikowski, 2011 , studies mechanical and tribological properties of a partially crystallized sintered glass-ceramic $\text{Li}_2\text{O}-\text{LiO}-\text{ZnO}-\text{Al}_2\text{O}_3-\text{SiO}_2$ (stuffed β -quartz solid solution), $\text{Li}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ (β -spodumene solid solution), $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ (nepheline) and $\text{K}_2\text{O}-\text{LiF}_2-\text{LiO}-\text{SiO}_2$ (mica), the sintered glass-ceramic and porcelainized stoneware presented similar mechanical and tribological properties, the results suggest that this glass-ceramic is suitable to be used as industrial tile (S. Buchner et al,2011).

R. D. Rawlings, 2006 , studies the production of Numerous silicate based wastes, such as coal combustion ash, slag from steel production, fly ash and filter dusts from waste incinerators, mud from metal hydrometallurgy , he find that the general process involves the verification of a silicate waste, or a mixture of wastes, followed by crystallization to form a glass-ceramic. Pilot plants have been successfully operated for the manufacture of these glass-ceramics, but unlike the situation with technical glass-ceramics produced from high purity raw materials for specific applications, industrially produced glass-ceramics from waste are not yet widely commercially available (R. D. Rawlings et al,2006).

Dr. James Shelby, 2003 , designed to study the effect of additives on the crystallization behavior of E-glass under a specific heat treatment. He found that the effects of nucleating agents such as TiO_2 are not significant. The only way to get the material to crystallize in an acceptable manner is to shift the composition of the crystalline phase by adding either Al_2O_3 or CaO (the latter being preferred)⁽³⁾. Cristina Doneda Gomes , 2000 , studies Glass and nepheline glass-ceramics were obtained from $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ system using additives and nucleating agents like TiO_2 , ZrO_2 , SnO_2 e ZnO . The results showed that TiO_2 and ZnO , when together, decrease the melting viscosity and treatment temperatures, producing a refined microstructure and the fine microstructure showed disk shaped crystals, with a medium diameter around 120 nm and a thickness of 30 nm⁽⁴⁾.

3. Experimental and Materials

Table 1 Materials used in this study

Material	Particle size (μm)	Purity%	Source	Weight%
LiO	25	99.5	Germany	17
Al_2O_3	20	99.8	Germany	15
ZnO	30	99.3	Australia	14
SiO_2	30	99.5	Australia	49
BaO	25	99.9	England	5
Li	25	99.98	England	
Be	25	99.9	England	

Table 1 shows that the materials that used in this study, its properties and weight percentage for batches.

3.1 Experimental Works

Step 1: Mixing the powder of oxides that used to product glass-ceramic materials by mixture in speed 80 rpm for(3hrs.). After mixing batches were put in furnace and fired to (1200°C) for (4hrs.).The formed glass was quenched to room temperature and milled to a fine powder in ball mill for (7hrs.) at a speed of (80rpm).

Step 2: Adding of Lithium and Beryllium to glass-ceramic materials powder that produced by step 1 in different weight percentage which(1,3,5, 7and 9) % then mixed by (80rpm) for (4 hrs.), then formed specimens by pressing to a cylinder shapes under pressure (175 MPa), finally putting in furnace at (1000°C) for (3hrs.).

Step 3: Grinding and polishing all the specimen by subject it to a period of grinding and machining on a machine type (MP 200, Germany) and the time were recorded.

3.2 Testing

1-Apparent Porosity: this test carried according to ASTM standard (C373-88) by the following step:

- Drying the samples in furnace at 150°C for 24 hrs. then cooling in furnace to temperature room, then take it weight.
- Putting the samples in glass flask then immersion in distilled water and heating for boiling temperature for 5 hrs. , then left in water for 24 hrs. and taking its pendent weight.
- Drying the samples by cotton then take the weight that saturated by water.

$$\text{Porosity}\% = \frac{M-D}{M-S} * 100$$

$M = \text{saturated weight.}$ $D = \text{Dry weight.}$ $S = \text{pendent weight.}$

- 2. Density:**the bulk density (ρ) in grams per cubic centimeter was measured according to (ASTM C 373– 88), of a specimen is the quotient of its dry mass (M) per grams divided by the exterior volume (V) per cubic centimeter, including pores. Calculate the bulk density as follows:- $\rho = \frac{M}{V}$
- 3. Young's Modulus E:** the test was occurred according to (ASTM C 623– 92), by using a set type (Instron1195 Tensile Test).The device was connected to a digital reading.
- 4. Hardness:** this test consider a destructive testing where the hardness of the specimen were measured by a Brinell testing device type (Wilsoninstrument, , Hardness tester)with a ball diameter of and according to (ASTM C 730 – 98).
- 5. Impact Test:** Impact specimens of (60mm×10mm×10mm) dimensions were notched at the middle to a depth of (3mm) to create an area of stress concentration for initiating fracture. Each of the specimens (reinforced and unreinforced) was successively fixed on a Charpy impact testing machine to receive a blow from the fast moving

hammer released from a fixed height on the machine. The reading on a dial gauge on the machine showed the impact energy absorbed by the respective specimen. Repeated tests, carried out to confirm initial readings, indicated an accuracy of $\pm 3\%$ in the recorded impact energy values.

6. Micrographs: the specimens were pictured by optical microscope type (Hern & R.W. Newman) with a maximizing degree of 400x.

4. Result and Discussed

Figure (1) shows the relationship between porosity versus (%Li, %Be).

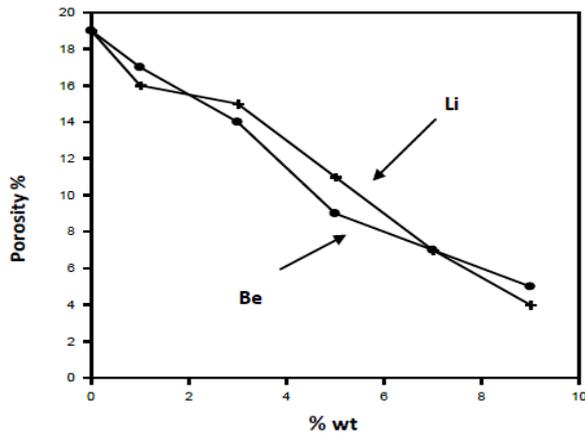


Figure 1: Relationship between porosity versus (%Li,%Be).

In this figure see that the porosity decrease with increase of %Wt Li and %wt Be. because that the Lithium will dissolve and spread (Li melt at 180.5 °C) within the specimen , while Beryllium spread as particle in structure and this lead to increase of porosity. Figure (R. D. Rawlings et al,2006) shows the relationship between densities versus (%Li).

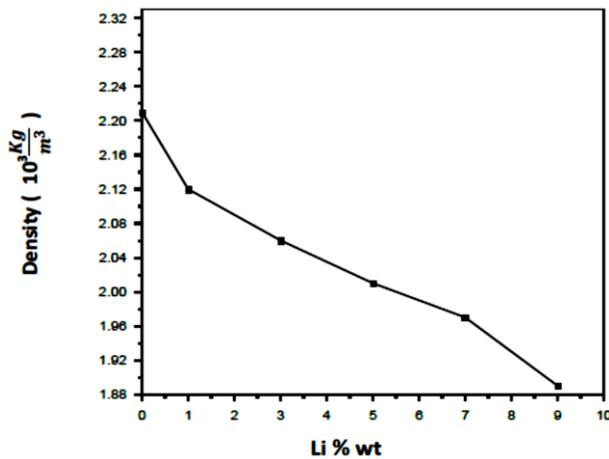


Figure2: Relationship between densities versus (%Li).

Lithium characterized by relatively low density ($0.534 \times 10^3 \text{Kg/m}^3$) which is less than the density of glass ceramic where its density is ($2.21 \times 10^3 \text{Kg/m}^3$). Thus it

better on the applications that need low weight. This is clearly shown in fig. (R. D. Rawlings et al,2006) which illustrate the relation between (Li% wt) and density of specimens, at early stages the decrease in density is small but when weight percent exceeds (3% Li) the decrease become sharp and clear comparing with early stages. In spite of this decrease the density of glass ceramic-Li composite still higher than that of Lithium, so in this way we get the most important property of glass ceramic materials which is the low weight. Beryllium have density about ($1.848 \times 10^3 \text{Kg/m}^3$) which is less than the density of glass ceramic, thus decrease density of glass-ceramic materials to ($2.06 \times 10^3 \text{Kg/m}^3$) when add 9% Be, this is acceptable value for application of it (Fig.3)

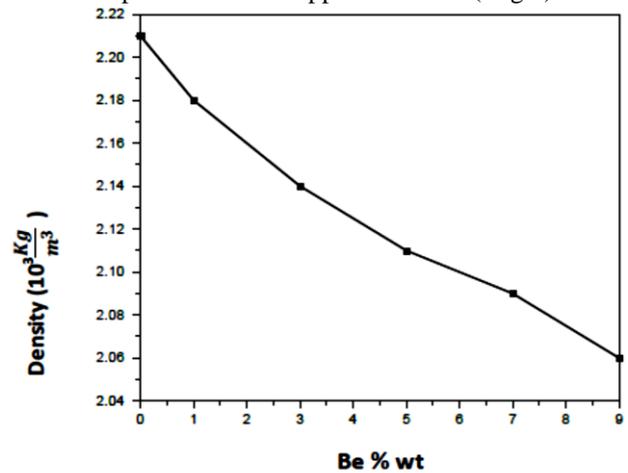


Figure 3: Relationship between densities versus (%Be).

Fig.(4) indicates the effect of Li addition on Young's Modulus of (glass ceramic-Li) composite, it is clear that Lithium increase modulus of elasticity of glass ceramic material, this may be a large benefit since this increase mean more ductility and less brittleness which is a very restricted property for ceramic materials as they are remarked to be brittle materials(P.W. McMillan et al,1979).

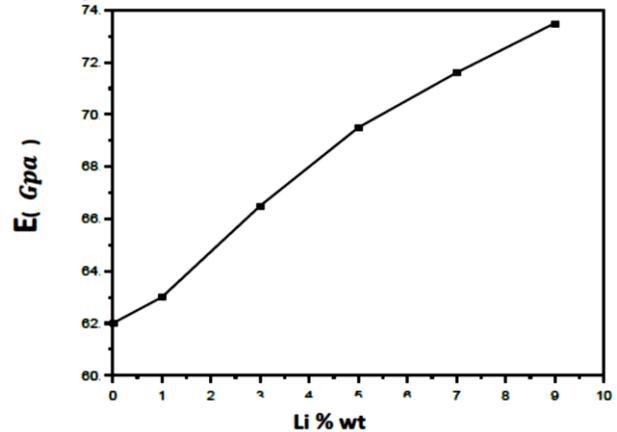


Figure 4: Effect of Li addition on Young's Modulus.

Lithium metal as an additive to glass ceramic fired in (1000°C) we be ensure that all the Lithium will dissolve and spread (Li melt at 180.5°C) within the specimen giving us a tightly bond of composite glass ceramic and

Lithium (J. Deubener et al,1992). Fig.(P.W. McMillan et al,1979) show effect of Beryllium addition on Young's modulus of glass ceramic composite, Beryllium melt at 1277 °C, therefore don't melt when fire glass-ceramic at (1000 °C), that make (Be addition) effect on Young's modulus less than Li addition, also decrease the porosity of glass-ceramic by addition of Li and B, that lead to increase Young's modulus

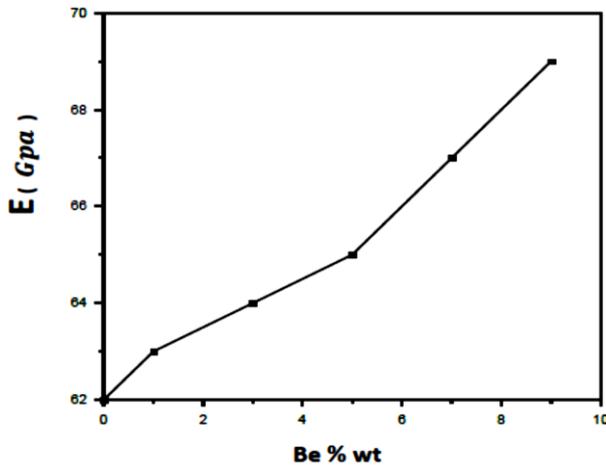


Figure 5: Effect of Be addition on Young's Modulus.

Fig.(6) show effect of Beryllium and Lithium addition on Young's modulus (E) of glass ceramic composite, at which we have the maximum value (78 GPa) of (E) when add (5%Be + 5% Li) together.

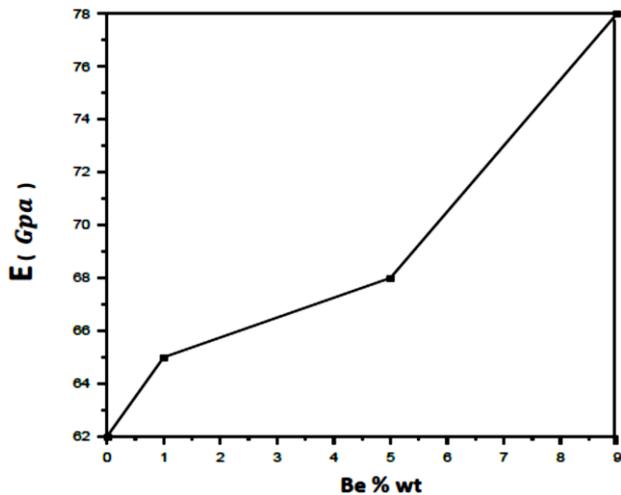


Figure 6: Effect of (5%Be + 5%Li) addition on Young's Modulus.

In fig. (7) we see the effect of Lithium addition on Brinell hardness of glass ceramic-Li composite the addition lead to decrease in hardness number of glass ceramic materials to some extent it is very acceptable value for any material to have a hardness (260).

Fig. (8) show effect of Beryllium addition on Hardness of glass-ceramic composite, from figure found hardness increase by increasing (%Be), which reach to (≈311HB), Be particle represent as second phase

distributed in matrix (glass-ceramic), this lead to increase hardness of composite (J. Schmelzer et al,1995).

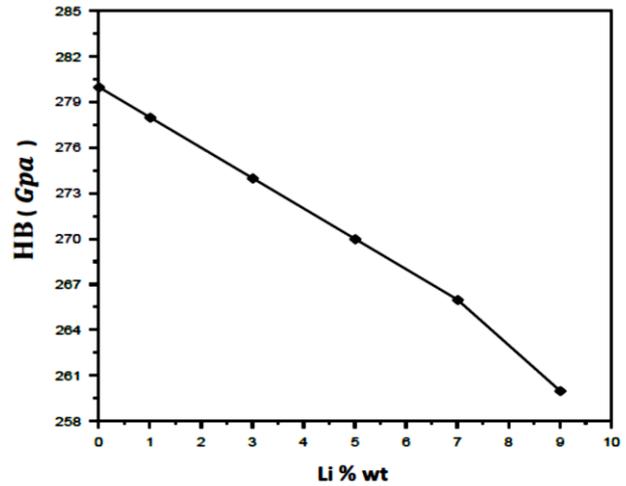


Figure 7: Effect of Li addition on Brinell hardness.

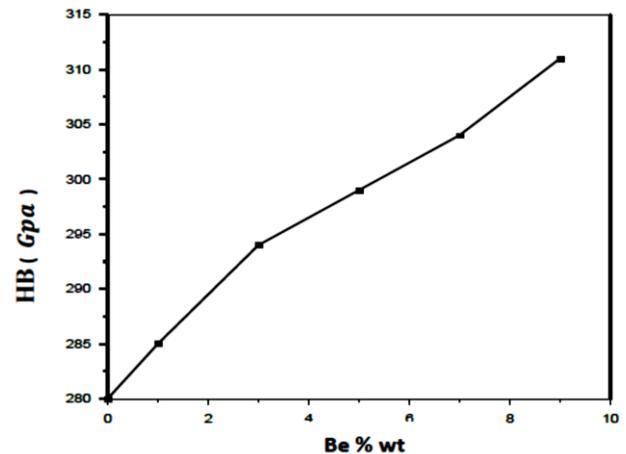


Figure 8: effect of Be addition on Brinell hardness.

Fig.(9) show effect of Beryllium and Lithium addition on Hardness of glass-ceramic composite, from figure found hardness increase to (≈ 289 HB).

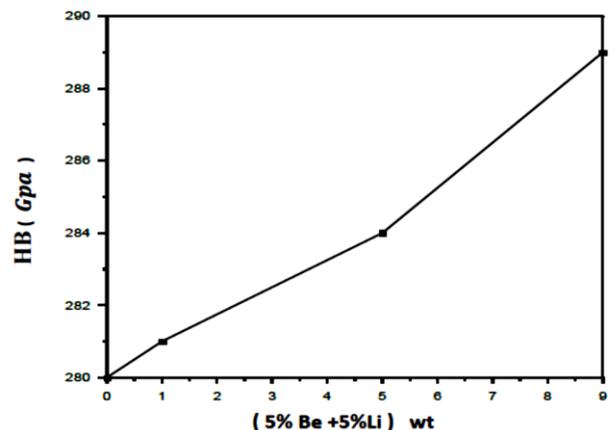


Figure 9: effect of Be and Li addition on Brinell hardness. Fig (10) show effect of Beryllium and Lithium addition on impact energy of glass-ceramic composite. Impact

energy was found to increase with increase in Li and Be addition to reach (25.1 Nm) and (27.1 Nm) when add (9%) of Be and Li respectively. This could be attributed to the improved internal stress, due to the particulate reinforcement, and enhance of ductility of the specimen (J.Ma. Rincon, et al,1997; Phinney R, 2002; Risse T, Ferro, 2000; US Census Bureau, 2002; Pelino, M..2000)

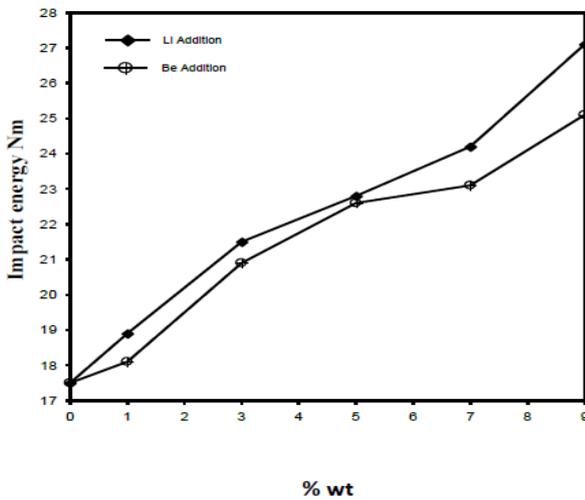
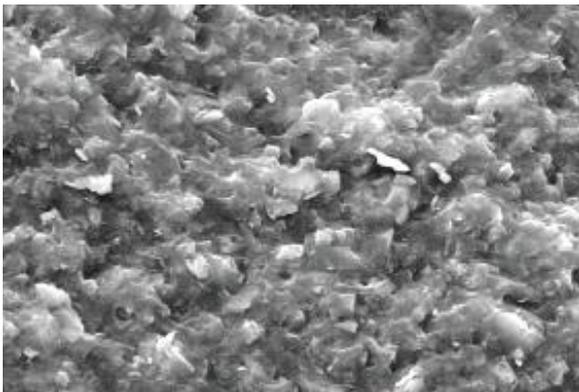
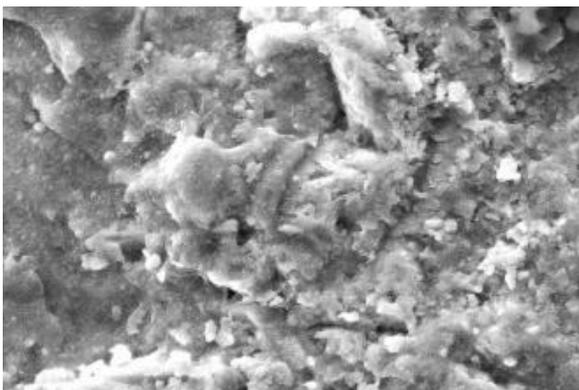


Figure 10: Effect of Be and Li addition on impact energy.

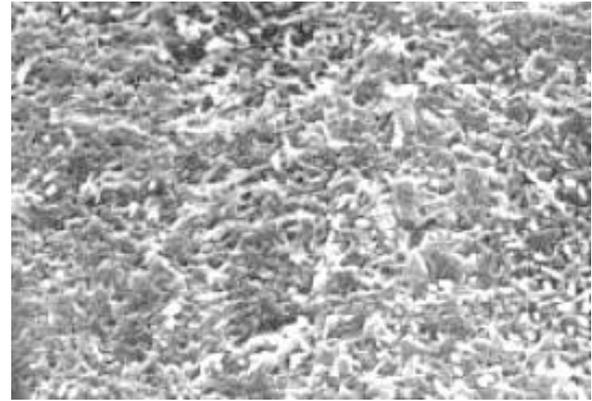
Fig (11) illustrates the effect of Beryllium and Lithium addition on the microstructure of Machinable glass ceramic.



(A)



(B)



(C)

Figure 11: Effect of Li, Be addition on the microstructure of MACOR 1200X. A: before addition, B: (MACOR + 9%Be), C: (MACOR + 9%Li.)

At first we saw a pure glass ceramic (A), fig (10: B and C) show the gradually spread of Be and Li metal through the specimens leading to a consolidate for all the alternative properties. See the diffusion process occurred because of low melting point of Li-metal (180.5°C) , and precipitation of (Be) as a second phase.

5. Conclusions

1. The porosity decrease with increase of %Wt Li and %wt B addition
2. Both Beryllium and Lithium addition decrease density of glass ceramic materials , ($\rho \approx 1.89 \cdot 10^3 \text{ Kg/m}^3$ when add 9% Li and $\rho \approx 2.06 \cdot 10^3 \text{ Kg/m}^3$ when add 9% Be).
3. Both Beryllium and Lithium addition Increase density of glass ceramic materials , ($E \approx 73.5 \text{ Gpa}$ when add 9% Li and $E \approx 69 \text{ Gpa}$ when add 9% Be), but when add (5%Be + 5%Li) together we get ($E \approx 78 \text{ Gpa}$).
4. Lithium addition in lead to decrease in hardness value of glass ceramic materials to ($\approx 259 \text{ HB}$ at 9% Li), but Beryllium addition lead to increase hardness to reach ($\approx 312 \text{ HB}$), then at addition (5%Be + 5% Li) lead to increase hardness relatively which that up to ($\approx 289 \text{ HB}$).
5. Impact energy was increase with increase in Li and Be addition.
6. In microstructure the addition of Be and Li metal through the specimens leading to a consolidate for all the alternative properties. See the diffusion process occurred and precipitation of Be as a second phase.
7. Addition of Beryllium and Lithium together give the best required properties (low density , raise hardness and increase Young modulus at the same time).

6. Reference

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