

# Influence of Reinforcement Oxides on Structural and Mechanical Properties of Glass-Ceramics: A Review Article



Amr Ali, Sabreen Abdallah Abdelwahab, Khaled Abdelwahed, Ibrahim Ahmed, Ahmed I. Ali

**Abstract:** This review studied the mechanical behaviors of Glass ceramics (GC) based on the  $Al_2O_3/SiO_2$  system. Glass ceramics are great interest due to their wide variety of applications, which have the ability to fulfil the recent demands of advanced mechanical, optical and biomedical applications. Glass-ceramics are typically heat-stable and have greater mechanical features than glasses. In addition, mechanical properties can be customized to provide variable volume fractions of crystalline phases by regulating nucleation and growth of the crystalline phases. The distribution of these crystalline phases in the glass matrix increases the consistency of the material and, in comparison, effectively limits the growth of cracks. The crystallization process resulted in substantial improvements in micro-hardness and density values such as sodium calcium phosphate ( $Na_4Ca(PO_3)_6$  and calcium pyrophosphate ( $\beta-Ca_2P_2O_7$ ) had sufficient properties for bone grafts and dental applications. This article outlines recent developments in the field of doping Oxides as reinforced with  $SiO_2-Al_2O_3$ -based Glass-ceramics, to enhance the mechanical properties of Glass-ceramics combination. The research focused on the mechanical and the tribological behaviour of Biomedical, Electronics applications and selection of fabrication methods.

**Keywords:** Glass-ceramics - Synthesis - Reinforcements - Structure - Mechanical behavior

## I. INTRODUCTION

Now a day, promoting clean energy initiatives and urge for ecofriendly innovative materials for their usage at the present time world have brought the researchers from where over the world on the common ground to develop ecofriendly innovative materials which are simple to fabricate with sufficient mechanical and Chemical features and economically viable, these are the materials now the need of the hour considered the Glass-ceramics are one of them [1][2]. Actually, because of their theoretically superior mechanical properties, a great deal of interest is paid to ceramic matrix composites Oxide ceramics, non-oxide ceramics,

Manuscript received on March 15, 2021.

Revised Manuscript received on March 24, 2021.

Manuscript published on March 30, 2021.

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Glass and Glass-ceramics are all called matrix materials, the ideal matrix, based on factors such as cost and the necessary mechanical properties [3].

Glass-ceramics can be identified by the controlled crystallization of glasses as composite materials formed in their bulk [4]. Light concentrations of nucleating agents such as  $TiO_2$  and  $ZrO_2$  must be applied to the glass formulation to induce their bulk homogeneous crystallization [5]. Nucleation or crystallisation of glasses may be promoted by such agents using the following techniques: (1) the nucleating agent dissolved in the melt will serve as a site for the creation of additional crystalline phases [6][7], (2) The nucleating agent may facilitate the immiscibility of glass or the differentiation of phases, leading to crystallization [8], and (3) the composition can be transferred to a phase region that is more readily crystallized by the agent applied in appropriate amounts. Alumina-ceramics are now widely used as bone and joint repair materials because of their useful biocompatibility and high mechanical strength [9]. In the other hand, the bones do not form a close chemical bond, and their fixation inside the body involves a mechanical interlocking of the bone. This interlocking is prone to become loose over a long period [10]. Despite the great downside of high aluminum content Glasses have very high melting temperatures of up to  $1650^\circ C$  and high viscosity, which make them difficult to melt, homogenize and refine. Given this fact, it has been proposed that the use of  $TiO_2$  as a nucleating agent rather than  $ZrO_2$  decreases the system's melting temperature. When  $TiO_2$  is used, nucleation is based on the notion of an ultra-fine size, highly uniform liquid phase separation into  $SiO_2$  and  $TiO_2/Al_2O_3$ -rich zones. The octahedral position of the spinal structure can be occupied by charge balanced replacement  $Ti^{+4}$  [11].

The most common methodologies for the preparation of Ceramic Matrix Nano composites are the powder metallurgy method; Polymer precursor method; Spray pyrolysis; Vapor systems and Chemical methods, which involve the Sol-Gel process, colloidal and precipitation approaches and the template installation [12]. Ceramics are usually brittle and easy to fracture as a consequence of crack propagation. Ceramics are made suitable for engineering applications by integrating into the matrix a ductile metal phase or another ceramic. This leads to improved mechanical characteristics such as hardness and fracture strength, which occur due to the relationship between the various phases, matrix and reinforcements at phase boundary [13]. Glass-Powder compact sintering is a public processing tool for extracting favorite properties of Glass-ceramic (GC) materials [14].



The glass powders with high specific surface area substantially progress uniformly distributed nucleus sites in the entire volume of the glass[15][16]. Crystalline phases precipitated from the glass reservoir decide the characteristics of GCs, while an overly high degree of crystal growth should be avoided in order not to boost coarse microstructure, restricting the achievement of high mechanical power[17][18]. Furthermore, sintering should preferably occur previously crystallization thus both events being independent processes.

prepared from the living body. Ceramics typically have unique characteristics associated with them, most ceramics are weak at room temperature, but not always at elevated temperatures, weak electrical and thermal conduction, greater compression than tension stress, a large amount of ceramics are stable in both cruel chemical and thermal conditions, and many ceramics are transparent because they have a high  $E_g$ . The uses for these materials are diverse, from bricks and tiles to electrical and magnetic components. These applications use the broad variety of properties that ceramics display. Any of these properties, along with examples of particular ceramics and applications, are given in Table.1. Each of these fields would later be discussed in greater detail. Ceramic products' occupations depend on their chemical composition and microstructure, which define their properties. A central feature in materials science and engineering is the interrelationship of structure and properties.

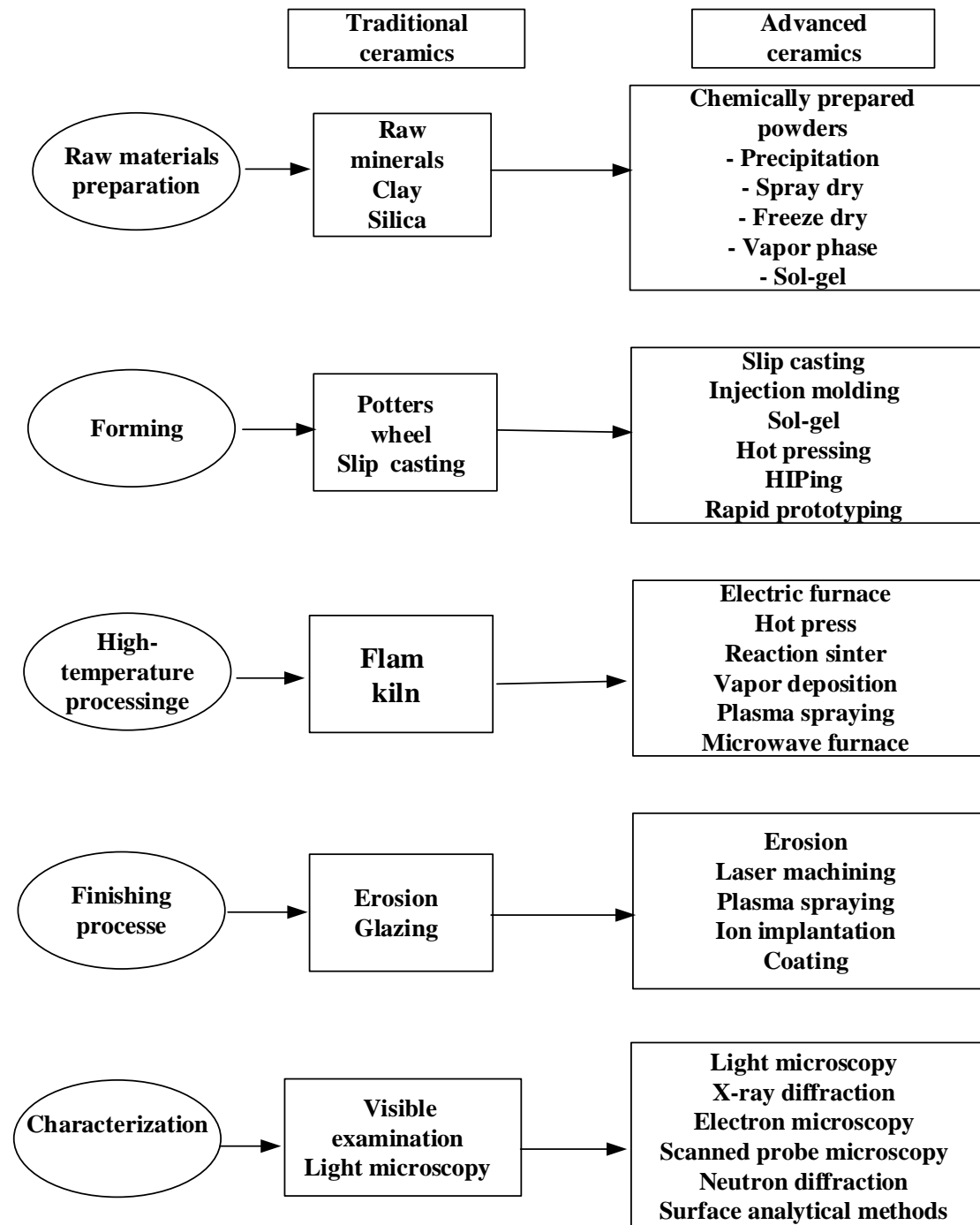
## II. CERAMIC, GLASS-CERAMICS AND THEIR APPLICATIONS

A mixture of covalent, ionic, and sometimes metallic ceramics is typically associated with varying bonding. They consist of interlinked atom matrices; there are no isolated molecules. We still classify Diamond and Graphite as ceramics, though. In the most fundamental sense of the word, these sources of carbon are inorganic: they were not

**Table.1 Ceramics Applications and Properties.**

Property	Example	Application
Electrical	Doped $ZrO_2$ , $TiO_2$	Electrolyte in fuel cells with solid-oxide [19]
	SiC	Elements for the furnace for resistive heating [20]
	$SnO_2$	Electrodes for molten furnaces of electric glass [21]
Dielectric	$\alpha-Al_2O_3$	Insulator with spark plug [22]
	$SiO_2$	Bricks for furnace [23]
Mechanical	$Al_2O_3$	Implants of the Thigh [24]
	TiN	Coatings that are wear-resistant [25]
	SiC	Abrasives designed for polishing [26]
	Diamond	Tools to Cut [27]
Thermal	$SiO_2$	Tiles of space shuttle padding [28]
	$Al_2O_3$ and AlN	Packages for built-in circuits [29]

In addition to separating ceramics according to their properties and uses, you may find that it is prevalent to label those as conventional ceramics, typically based on clay and silica. And specialized so-called special ceramics, scientific or engineering ceramics. They demonstrate superior mechanical characteristics, resistance to corrosion or electrical, optical and magnetic characteristics.



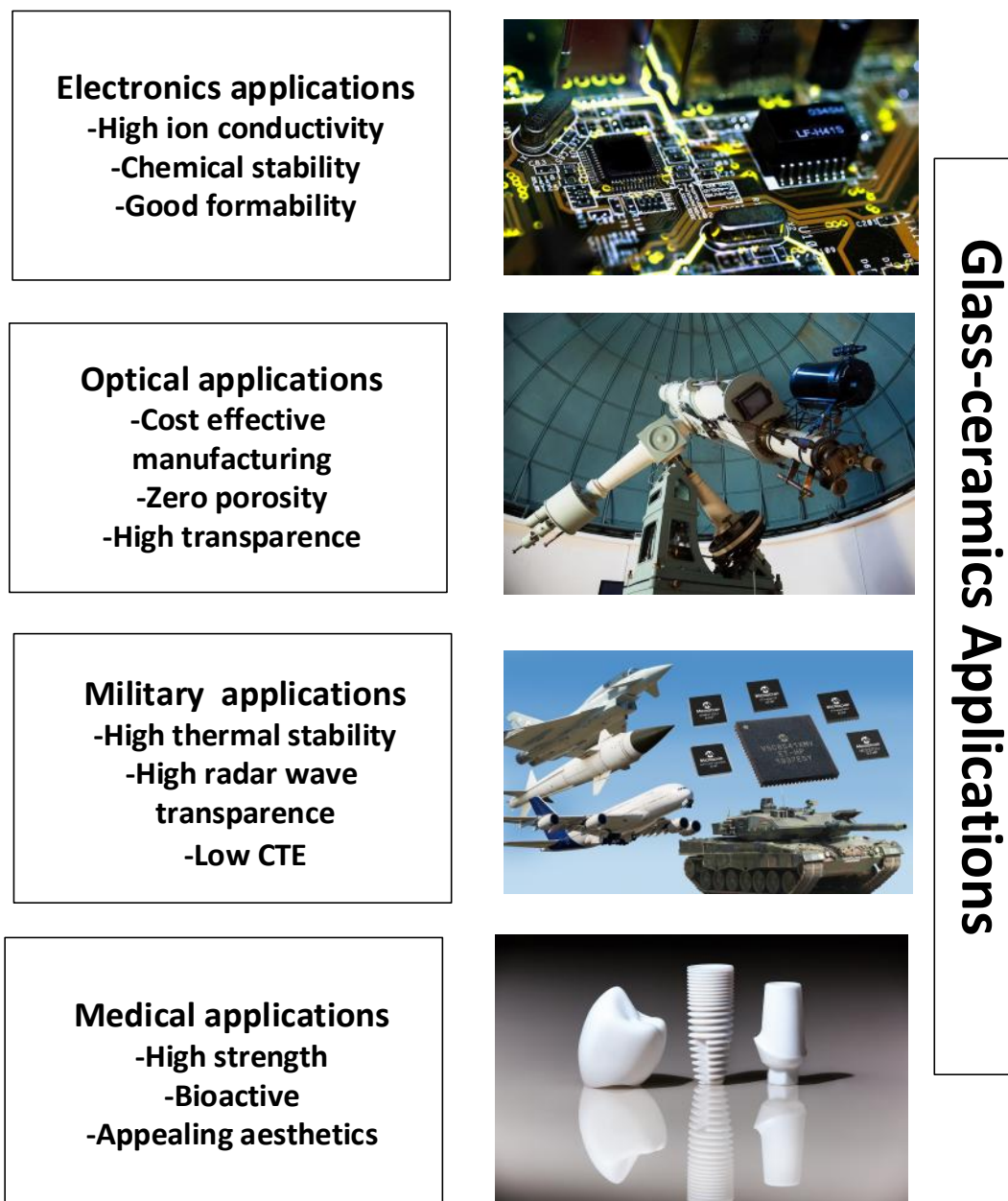
**Fig.1 Conventional and modern ceramics are contrasted in terms of the type of raw materials used in the formation and shaping processes and the techniques used for characterization. reproduced[14].**

The Glass-ceramics applications in several fields are shown in Fig. 2. In a wide variety of fields in our everyday life, Glass-ceramics have been commonly used. Many Glass-ceramics exhibit high translucency in the optical field or can even be translucent since zero porosity can be achieved reasonably easily[30][31][32]. For optical applications, these make Glass-ceramics excellent stuff. For example, Transparent and low thermal expansion system-based Lithium Alumino-silicate (LAS) Glass-ceramics have been used as telescope mirror blanks and laser gyroscopes. [30]. Glass-ceramics are now used in high-performance aircraft and missile nose cones in the defense industry. The components used in these applications must have a complicated combination of properties to survive the critical conditions of high-speed atmospheric flight: Low thermal expansion coefficient; high mechanical strength; high resistance to abrasion; clarity of high radar waves for

navigation; [33]. Glass-ceramics combine Glass and crystalline ceramics properties in the medical field, attracting significant attention because of their strong mechanical properties and biological activity in dental reconstruction and bone filler products[34][35][36][37]. Currently there are three types of Glass-ceramic systems that have been mostly developed for dental reconstruction, including mica-based, leucite-based and lithium disilicate Glass-ceramic systems. Based on the  $\text{SiO}_2\text{-Li}_2\text{O}$  material system, lithium disilicate Glass-ceramic has been recognized as a suitable dental restorative material due to its outstanding mechanical properties and excellent translucency [32][38][39][40].

In the electronic sector, secondary all-solid-state batteries with inorganic solid electrolytes are anticipated to be high-output batteries for the next decade. Various types of inorganic solid electrolytes produced by Glass-ceramics have been developed, and there is evidence that Graphene plays a key role in a variety of applications such as energy storage batteries [41]. In various solvents such as water, organic solvents, and several different matrices, Graphene have been distributed, which is very significant in enhancing electrical and mechanical characteristics [42]. **Yalcin and Yakuphanoglu**[43] In Graphene-TiO<sub>2</sub> dependent systems,

the voltage and frequency dependence of negative capacitance output has been studied. Besides, **Fan et al.** [44] The electrical and dielectric properties of graphene/PPS composites were analyzed and the negative permittivity in the radio frequency area was investigated. Furthermore, **Ashery et al.** [41] The dielectric and electrical characteristics of devices based on GO have been tested. A higher emphasis on GO-based systems will yield fascinating results that is more critical for the long-term longevity of prepared devices and the widespread use of different microelectronic implementations.



**Fig. 2. Glass-ceramic uses in a large variety of areas, reproduced[32].**

Glass-ceramics are prepared by (a) the conventional method of melting-casting-annealing; (b) simultaneous sinter-crystallization. Three general phases are involved in processing Glass-ceramic using the classic melting-casting-annealing technique. Firstly, the preparation of parts and nucleating agents for glass products. Homogeneous batch mixtures that are obtained by ball milling. Secondly, at melting point, the batch of materials is heated into crucibles,

then cast into a mould to the desired shape and then cooled to room temperature to create a precursor Glass. Finally, the precursor glass is recycled to cause crystallisation, much like the Glass-ceramic formation process[45][46].



### III. INFLUENCE OF THE PRESENCE OF TITANIUM DIOXIDE (TiO<sub>2</sub>) ON THE CRYSTALLIZATION OF GLASS-CERAMIC STRUCTURES

The structure of engineering materials is the most important aspect, so researching a material's microstructure offers knowledge related to its composition, manufacturing, and performance. Several scholars have researched and documented the microstructural properties of TiO<sub>2</sub> hardened or doped Glass-ceramics. Now in recent written papers, the findings are presented.

**Weiwei et al.** [47] Studied Kinetics of crystallization, microstructure, and phase evolution for Y<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>. Glass-ceramics with eutectic composition have been applied to TiO<sub>2</sub> and CaF<sub>2</sub> as nucleating agents. The results show that by reducing the activation energy from 310 kJ/mol to 280.4 kJ/mol, TiO<sub>2</sub> is effective in promoting the crystallization of YAS Glass. However, the addition CaF<sub>2</sub> into YAS Glass leads to an increase in from 310 kJ/mol to 385.2 kJ/mol activation energy. Due to, the formation of [AlO<sub>4</sub>] tetrahedrold by means of Ca<sup>2+</sup> ions and facilities Glass forming.

**Rebekah and Elizabeth.**[48] Studied effect adds Titanium Dioxide in a system Calcium-Magnesium Alumina Silicate Glass in addendum of 5-20 wt%. Over a series of temperature profiles, the crystallization activity of the blends was characterized and compared to that of CMAS alone. The results appear that, the crystallinity of model cooled at a rate of 10°C/min from 1300/1500°C decrease at additions TiO<sub>2</sub> between 5 and 10 wt%. The behavior of crystallization appears improving to be at 12.5 wt% TiO<sub>2</sub>. With increased TiO<sub>2</sub> additions (15, 20 wt% TiO<sub>2</sub>), CaTiO<sub>3</sub> is formed. Holding CMAS + TiO<sub>2</sub> compositions with a TiO<sub>2</sub> content of ≥10 wt% at 900°C. After cooling, the melting assisted in the crystallization of additional phases, including melilite, paqueite, and a Ticontaining diopside TiO<sub>2</sub>, in sufficient quantity, may be useful as a coating constituent, from a thermochemical standpoint, in the crystallization of model-Glass [49].

**Aygun et al** [50] Studied combined TiO<sub>2</sub> into an yttria stabilized Zirconia to determine its ability to promote crystallization of (CaO-MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>) and prevent coating penetration. The authors reported increased barrier

resistance (compared to yttria stabilized Zirconia alone) for samples containing 20 mol% Al<sub>2</sub>O<sub>3</sub> and 5 mol% TiO<sub>2</sub>. They concluded that Al solutes within the coating shifted the Glass to a phase more easily crystallized while Ti acted as nucleation sites for the new phase.

**Chavoutier et al.** [51] Glass-ceramics produced by controlling Li<sub>2</sub>O-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> parent crystallization Glasses are well-known for their low thermal expansion and transparency. In order to facilitate bulk crystallization, it is essential to add nucleating agents such as TiO<sub>2</sub> and ZrO<sub>2</sub> to the Glass composition which leads to ZrTiO<sub>4</sub> nuclei during heating, continued by the crystallization of a β-quartz phase that converts into β-spodumene at high temperature.

### IV. EFFECT DOPING ON MECHANICAL CHARACTERISTICS OF GLASS-CERAMICS

Composite material is needed to be homogeneous for effective load-bearing capability for effective use as a candidate material in engineering applications, such as vehicles and aircraft. Several of the results are discussed below in recently published papers.

**Bhaskar Raju et al.** [52] Studied mechanical properties of Zinc-Aluminum-27 reinforced with silicone carbide have been investigated. The ZA-27 alloy was strengthened with SiC of 0,3,6, and 9 percent by weight. Reports revealed that with an improvement in packing material over the unreinforced alloy, the hardness, impact strength, tensile strength and compressive strength of the ZA-27/SiC composites increased substantially. This enhancement was therefore attributed to the presence of the hard ceramic spots in the matrix alloy [53].

**Dalmis et al.** [54] studied the physical and mechanical properties of ZA-27 composites, Graphite (Gr) Nano-Particles studied addition. Reports suggested that hardness and ultimate tensile strength decreased as the content of Gr increased as shown in Table .2 This phenomenon was attributed to weekly bonding with the matrix alloy between the Gr particles, aggregation, indeed that Gr applications of metal matrix composites are known to decrease tensile and compression strength due to the growing brittle existence of Gr particles, which quickly tends to plastically deform the composites.

**Table. 2 Hardness and Effective Elastic Modulus.**

GO contents wt. %	Effective Elastic Modulus	Vickers Hardness (GPa)
0	118	9.25
1	119	9.5
2	124	9.3
3	121	9.1

**Sharma et al.** [55] Studied the effect of short Glass-fibers on the mechanical properties of cast ZA-27 alloy composites has been investigated. In the cast ZA-27 alloy, the inclusion of short Glass-fibers varied from 0 to 5 percent by weight.

Reports revealed that with an improvement in reinforcement, but at the expense of ductility and impact strength, the ultimate tensile strength, stiffness, and Young's modulus improved dramatically as shown in Table. 3.

**Table. 3 Hardness and Ultimate tensile strength of Zinc-Aluminum-27 at variation doping material.**

Chemical Composition	Doping Contents	Hardness (HRA)	Ultimate Tensile Strength(MPa)
Zinc-aluminum (ZA-27)	SiC	70	220
Zinc-aluminum (ZA-27)	Graphite	135	183
Zinc-aluminum (ZA-27)	Glass fibers	137	381

**Alaneme et al.** [56] Studied the mechanical and wear behavior of ZA-27 composites reinforced by steel chips. The composites based on ZA-27 contain 5, 7.5 and 10 weights of percent of steel machining chips, while unreinforced ZA-27 alloy and a 5 weight of percent Alumina formulation were also prepared as control samples[57]. Reports showed that the composites' hardness and wear levels improved between 5 and 10 weights of percent with an improvement in weight of percent of the steel chips. Higher hardness was due to the comparatively higher hardness of the steel chips compared to Zn-Al based alloys, although lower strength was due to the less consistent dispersion of steel chips and agglomeration above 5 weights of percent. However, increased fracture resistance of the ZA-27 reinforced steel chips over non-reinforced alloy and 5 weights of percent reinforced Aluminum composite was attributed to the comparative durability of the steel chips over the ZA-27 matrix.

**Manuela et al.** [58] Studied the analysis of mechanical properties the crystallization and microstructure of cordierite is one of the most important phases within the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> model. The cordierite was prepared for four samples, which were thermal treatment at a temperature of 1200 °C with a permanent time of 2 h. Depending on the critical working temperature, specific applications like Glass-ceramic material coatings were chosen for the temperature of the thermal treatment. The average crystal size of the crystalline phases in the study was greater without an introduction of NiO, and the crystals sizes, especially  $\alpha$ -cordierite with higher NiO concentrations, and the crystals within the domains decrease, which results in better a mechanical properties and microstructure (hardness=8–11 GPa and effective elastic modulus=11–14 GPa), than those reported in the literature (hardness=7–8 GPa and effective elastic modulus=10–13 GPa). The Glass-ceramics showed the highest effective elastic modulus and a marginal decrease in hardness with the higher %wt of  $\alpha$ -cordierite phases. Noticeable, the increase of %wt NiO encouraged crystallization of  $\alpha$ -cordierite, encouraging a uniform and dense distribution of cordierite-structures embedded in a vitreous matrix, enabling an increase in compactness of the composite homogenize its mechanical efficiency, which can then be used as an effective composite for large machinable applications, attributed to this well controlled property. **Li Chen et al.** [11] Studied the density, hardness, physical and crystallization properties of MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> Glasses with different La<sub>2</sub>O<sub>3</sub> additions (0–10 wt.%). The results showed significant improvements in Hardness values, The densities of of MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub>-La<sub>2</sub>O<sub>3</sub> Glasses increased from 2.69 to 2.88 g/cm<sup>3</sup> as the La<sub>2</sub>O<sub>3</sub> content increased from 0 to 10 wt.%. The hardness and coefficient of thermal expansion of the glasses increase as increasing La<sub>2</sub>O<sub>3</sub> content as well. There was an increase of 12% for an addition of 10% La<sub>2</sub>O<sub>3</sub> to MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> alloy.

**Mukherjee and et al.** [59] Studied the effect of MgF<sub>2</sub> on the different properties of the SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>-MgO-K<sub>2</sub>O-B<sub>2</sub>O<sub>3</sub> Glass system, such as crystalline behavior, microstructure phases, and hardness. The growth of crystal in three-dimensions is observed. Mica crystals are known as fluorophlogopite, the predominant crystal phase for all three heat treated glass specimens at a temperature of 1050 °C. In incremental addition of the MgF<sub>2</sub> content, the hardness value for Glass-ceramic specimen decreases, high fluorine Glass-ceramic specimen containing mica with strongly interlocking microstructure has lower Hv (5.03 GPa) as well as highest machinability parameter (0.029) and lowest cutting energy (37.89 J mm<sup>-3</sup>) than specimens without MgF<sub>2</sub>. Therefore, 5 wt.% MgF<sub>2</sub> containing mica Glass has better machinable characteristics.

**Mollazadeh and et al.** [60] Studied the impact of TiO<sub>2</sub>, ZrO<sub>2</sub>, BaO and extra silica on an apatite-mullite-based Glass-ceramic model's crystallization behavior, mechanical properties and microstructure. The accelerated crystalline phases were fluorapatite [Ca<sub>10</sub>(PO<sub>4</sub>)<sub>6</sub>F<sub>2</sub>] and mullite [Al<sub>6</sub>Si<sub>2</sub>O<sub>13</sub>], which in addition to the extra bearing SiO<sub>2</sub> specimen, were rod-like in the other specimens. Limited lengths of the rod-like crystalline phases were, i.e. <20  $\mu$ m. The intensity of crystalline phases increased to around 50  $\mu$ m in the TiO<sub>2</sub> and BaO containing Glass-ceramics, but a limited edition of ZrO<sub>2</sub>. Flexural strength and fracture strength of prepared glasses and Glass-ceramics have also been tested. The results showed that both parameters were influenced differently by the additive oxides. The highest fracture strength and fracture strength values were TiO<sub>2</sub> and BaO containing Glass-ceramics with a lower crystal size. The mechanical properties of the prepared Glass-ceramic samples were not substantially different and/or were even decreased by addition of ZrO<sub>2</sub> and extra SiO<sub>2</sub> [60].

**Wei and et al.** [61] Studied the development of alpha-cordierite Glass-ceramics without and with the inclusion of B<sub>2</sub>O<sub>3</sub> in the MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system. The findings show that B<sub>2</sub>O<sub>3</sub> mainly plays the role of two elements as an additive used in MgO-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> Glass-ceramics. Glass-ceramics' properties are influenced by the transition in the conduct of crystallization.

The coefficient of thermal expansion rises from  $1.70 \times 10^{-6}$  °C<sup>-1</sup> to  $3.72 \times 10^{-6}$  °C<sup>-1</sup> and Glass-ceramics' Vickers hardness decreases from 9.4 GPa to 6.9 GPa with the increase of B<sub>2</sub>O<sub>3</sub> content from 0 mol% to 12 mol%. The proper quantity of B<sub>2</sub>O<sub>3</sub> will greatly shorten the crystallisation pathway, decreasing the temperature of forming and facilitating the direct precipitation of alpha-cordierite in the Glass-ceramics system [61].

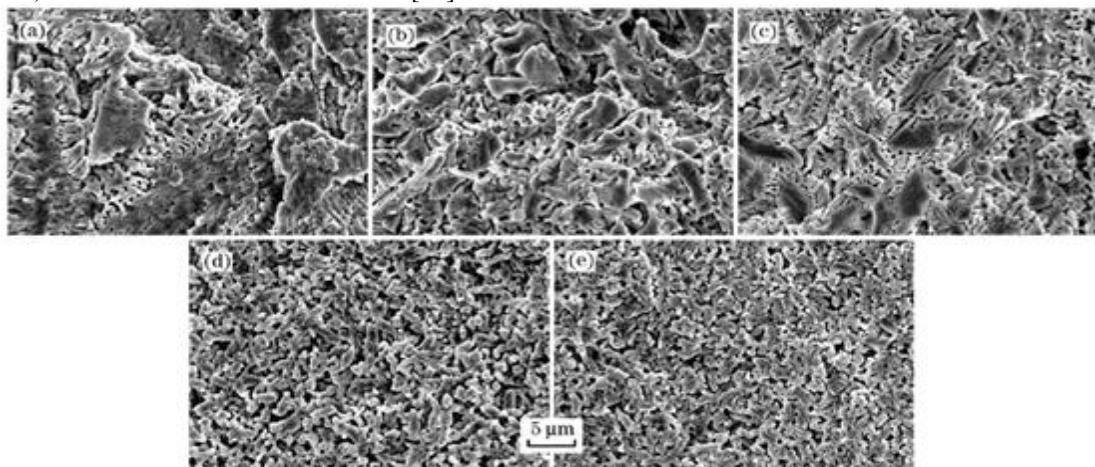


**Muroya and et al.** [62] Studied densification of ceramic coatings based on  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-TiO}_2$  in a wet process-based system was investigated by optimizing the quantity of alkali silicates. From the present analysis, the following conclusions are drawn.

- 1) The number of through-holes of the coating decreased drastically with increasing concentrations of alkali silicates. It is assumed that the Glass phase arising from the alkali silicates effectively fills large pores within ceramic grains, contributing to densification.
- 2) With the concentrations of alkali silicates, the reliability of thermal shocks that cool down from high temperatures to room temperatures has been enhanced.
- 3) The corrosion resistance of the coating in 1 mol/l HCl solution was observed to improve with an increase in the quantity of alkali silicates and calcination temperature.
- 4) The adhesive strength of coatings containing larger concentrations of alkali silicates has been increased by a factor of three, with a median adhesion of 700 °C[62].

**JianYANG and et al.** [63] Studied the effect of  $\text{TiO}_2$  addition on the crystallization behavior and mechanical properties of the stainless steel slag Glass-ceramics. It was found that the addition of  $\text{TiO}_2$  to the parent Glass changed the phase composition; refined grain sand and the addition of  $\text{TiO}_2$  increased both the quantity and the uniformity of the crystal nuclei.[64] As shown **Table .4** improved the Vickers hardness and the bending strength. Besides, the addition of  $\text{TiO}_2$  was effective in suppressing the akermanite phase formation by capturing  $\text{Ca}^{2+}$  and forming the perovskite phase. On the other hand, the micro structure with fine and uniform grains corresponds to excellent mechanical [65].

The optimal amount of  $\text{TiO}_2$  was 7 mass% as shown **Fig.5** the main crystal phase of the Glass-ceramics were diopside. The bending strength and Vickers hardness were determined as 147 MPa and 6.68 GPa, respectively, for the sample with 7 mass%  $\text{TiO}_2$ .



**Fig.4 SEM images of samples with different  $\text{TiO}_2$  contents: (a) 0 mass%; (b) 3 mass%; (c) 5 mass%; (d) 7 mass%; (e) 9 mass%, reproduced[63].**

**Table . 4 Bending strength and Vickers hardness dependence on  $\text{TiO}_2$  content.**

$\text{TiO}_2$ content wt. %	Bending Strenght (MPa)	Vickers Hardness (GPa)
0	50	5
3	60	5.25
5	120	6.2
7	142	6.6
9	140	6.75

**M. Feng et al.**[66] Studied the effects of addition of  $\text{Cr}_2\text{O}_3$  on wear behavior of the  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-ZrO}_2\text{-Ba}(\text{Sr,Ca})\text{O}$  based Glass-ceramics with are investigated. The system contains varied inclusion of 0 and 6wt.%  $\text{Cr}_2\text{O}_3$  were added to Glass frit when smelted and ball-milling process. Adding  $\text{Cr}_2\text{O}_3$  reduces resistance to wear. But with the add method  $\text{Cr}_2\text{O}_3$  is applied, this retardation effect varies. When  $\text{Cr}_2\text{O}_3$  is implemented by ball milling,  $\text{BaSi}_2\text{O}_5$  precipitation is only partially retarded, and the wear rate is reduced moderately. However, the precipitation of  $\text{BaSi}_2\text{O}_5$  is almost totally prohibited when adding  $\text{Cr}_2\text{O}_3$  during the smelting process, and  $\text{BaCrO}_4$  and/or  $\text{BaCr}_2\text{O}_4$  substituting  $\text{BaSi}_2\text{O}_5$  precipitate out.

The Nano barium chromate scale facilitates the development of a lubricating glaze coating on worn surfaces, greatly decreasing the wear and friction rate[67].

**D. Herman et al.** [68] Studied evaluate the wear resistance of  $\text{CaO-MgO-ZnO-Al}_2\text{O}_3\text{-B}_2\text{O}_3\text{-SiO}_2$  systems with different heat treatment temperature. The values of the wear rate fluctuate within  $10^{-4} \text{ mm}^3/\text{Nm}$ . Compared to the wear resistance of Glass-ceramics, this is still a high wear resistance with the addition of mica being comparatively tinny[67].



In fact, precipitation from Glass-ceramic only of the ghanite phase induces a relative increase in its fracture strength and wear resistance compared to the two phase materials.

**Wang et al.** [69] Studied the mechanical characterization of  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-K}_2\text{O-CaO-P}_2\text{O}_5$  fluorapatite Glass-ceramic has been investigated. A sintering process with varying CaO contents and heat treatment regimens has been used to manufacture Glass-ceramics. The findings demonstrate that the crystallinity of the main fluorapatite crystal can be modified by the different CaO content and heat treatment temperatures. Larger crystallinity enhances the mechanical properties, significantly affecting the behavior of friction and wear. By can heat treatment temperatures, the pore size of the Glass-ceramic may also decrease and make it denser. Adjusting the content of CaO and increasing the heat treatment temperature is both valid ways of optimizing mechanical properties[70]. The 6.0-wt specimens. The highest detailed efficiency is percent CaO and sintered at 1100 °C, showing outstanding mechanical characteristics and wear tolerance.

**Houg et al.** [71] Studied investigating the effects of  $\text{K}_2\text{O}$  in the  $\text{Li}_2\text{O-K}_2\text{O-Al}_2\text{O}_3\text{-SiO}_2$  system on sintering and crystallization of Glass powder compacts. On the basis of general formula  $23.7 (71.78-x) \text{SiO}_2\text{-}2.63 \text{Al}_2\text{O}_3\text{-(}2.63 + x) \text{K}_2\text{O-}23.7 \text{Li}_2\text{O}$ , where x modified from 0 to10, a total of 8 formulations were prepared [72]. High mechanical strength (173-224 MPa) Glass-ceramics have led to the prevalent crystallization of lithium disilicate in low- $\text{K}_2\text{O}$  formulations, chemical resistance (25-50 g/cm<sup>2</sup>) and low overall conductivity ( $2\text{-}10^{-18}$  S/cm) making materials suitable for a range of practical applications. In recently published papers, some of the results are introduced below.

**Tsuru et al** [73] and **Yabuta et al.** [74] Using PDMS, TEOS and  $\text{Ca(NO}_3)_2$  via a Sol-Gel process, bioactive organic-inorganic hybrids were manufactured. Via incorporation of highly reactive Ti alkoxides (TiPT) **Chen et al** [75] Hybrids with greater mechanical efficiency obtained [76]. A comparable technique was proposed by **Aburatani et al.** [77] Who changed the method of synthesis suggested by **Tsuru** [73]To improve the mechanical properties by the addition of colloidal silica. The higher compressive strength of these hybrids resulted in increased colloidal silica content [77].

**Yongxin et al.** [78] Studied Titanium dioxide ( $\text{TiO}_2$ ) decorated Graphene Oxide (GO) was processed as a Nano filler and incorporated into the chemically bonded ceramic coatings. GO- $\text{TiO}_2$  composites are prepared and introduced as a Nano filter in chemically bonded ceramic coatings to enhance corrosion resistance performance. On the surface of GO, the  $\text{TiO}_2$  nanoparticles are decorated with chemical bonds, as shown by TGA, XRD, SEM and TEM. The surfaces of the fracture SEM explores ceramic coatings without and with GO- $\text{TiO}_2$ . The findings show that GO- $\text{TiO}_2$  is well embodied in a ceramic matrix with less pores and cracks. In addition, potentiodynamic polarization tests show that corrosion resistance of ceramic coatings increases with an increase in GO- $\text{TiO}_2$  content. It can be assumed that the GO- $\text{TiO}_2$  can take advantage of this. Both GO and  $\text{TiO}_2$  are designed to enhance corrosion resistance of chemically bonded ceramic coatings.

We authors studied, Glass-ceramics, were successfully synthesized using GO doping  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-TiO}_2$  system. The effect of the  $\text{TiO}_2$ /GO weight ratio was extensively studied

on the structure, mechanical and electrical properties of Glass-ceramics, under publishing.

- 1) The Glass-ceramic density decreased, but the micro-hardness of the samples improved to 14 GPa. In addition, the Glass-ceramics' primary crystalline phase  $\text{TiO}_2$ -Anatase was refined. The second phase (Graphite), onset appeared at the addition of GO. The Graphite phase intensity increased with the increase of GO contents.
- 2) The coefficient of friction decreased during rising GO contents, wear rate variation in the order of  $10^{-5}$  mm<sup>3</sup>/Nm, and a systematic decrease in wear rate was recorded in both cases of the testing medium. The specimen which contained the highest GO content, showed excellent low friction and wear in both dry and lubrication conditions.

## V. BIOMEDICAL APPLICATIONS

Research has been performed on (GC) products for biomedical and dental applications. Nevertheless, in recent years, some scholars have studied and documented mechanical properties for materials used in biomedical.

**Jainxia et al.** [37] Studied the objective of the research was to assess the mechanical and bioactive efficiency of Glass-ceramic lithium disilicate mixtures provided by the Sol-Gel and melting routes of the  $\text{SiO}_2\text{-Li}_2\text{O-ZrO}_2\text{-K}_2\text{O-P}_2\text{O}_5\text{-Al}_2\text{O}_3$  system. The SBG was prepared using the Sol-Gel and molar ratio system of TEOS, TEP,  $\text{LiNO}_3$ ,  $\text{Zr(NO}_3)_2\cdot 5\text{H}_2\text{O}$ ,  $\text{KNO}_3$  and  $\text{Al(NO}_3)_3\cdot 9\text{H}_2\text{O}$  in conjunction with the  $50\text{SiO}_2\text{-}36\text{Li}_2\text{O-}8\text{ZrO}_2\text{-}3\text{K}_2\text{O-}2\text{P}_2\text{O}_5\text{-Al}_2\text{O}_3$  (mol. percent) system. Schematic representation for SBG, MBG and Glass-ceramic processing. Flexural strength and bioactivity were studied. The findings show that the Glass-ceramic 8M2S (MBG: SBG=8:2) has the highest crystallinity and flexural strength consistent with the unique cross-linked interlocking microstructures of all obtained Glass-ceramic products. The flexural strength of the samples can first be shown to rise progressively and then decrease with rising MBG content. The 0M10S sample exhibits the lowest flexural resistance ( $84.64 \pm 8.89$  MPa), and the 8M2S sample has the highest flexural strength of all Glass-ceramics with apparent intertwined  $\text{Li}_2\text{Si}_2\text{O}_5$  grain colonies ( $153.06 \pm 10.28$  MPa)[54]. These findings indicated that in this analysis, the Glass-ceramics obtained have potential mechanical and bioactive performance. This knowledge can be useful for more study and practical applications for the restorative dental medicinal use of these Glass-ceramics.

**Molla et al.** [79] Studied in dry and artificial saliva (AS) conditions, the  $\text{K}_2\text{O-B}_2\text{O}_3\text{-Al}_2\text{O}_3\text{-SiO}_2\text{-MgO-F}$  Glass-ceramic device with 70% mica crystals was thermally treated at 1040 °C for 12 hours and subjected to fretting wear against steel. The initial contact stress of Hertzian was 196MPa for the selected operating parameters. During the initial run-in cycle, the coefficient of friction increased and then entered a phase of steady state, independent of the fretting environment. However, at dry contact, a higher value of steady state COF-0.88 was calculated, while much lower COF 0.67 was reported in the AS medium. In atmospheric conditions, higher COF is well suited to the intensity of abrasion.





The wear rate ranged from  $10^{-4}$  to  $10^{-5}$  mm<sup>3</sup>/Nm and a systematic decrease in the wear rate with test period was recorded in both test medium cases. Table. 3 Description of the findings of the tribology test obtained from some of the

GCs previously produced as well as human teeth and compared with the GC currently tested. The difference in the rate of friction/wear depends on the variation in conditions of operation.

**Table. 3 Description of the findings of the Tribology test obtained for some of the GCs previously produced as well as human teeth and compared with the GC currently tested.**

Tribocouple	Operating conditions	COF	Wear rate (mm <sup>3</sup> /Nm)	Wear mechanisms	Reference
Human teeth vs. steel	20 N, dry/AS, 0.002 m/s	0.8–1.2 (dry) 1.0 (AS)	–	Oxidative wear and microfracture	[80]
Human teeth vs. Al <sub>2</sub> O <sub>3</sub>	1N, AS, 0.0005 m/s, 8000 cycles	0.12–0.55	–	Fretting fatigue; adhesive wear	[81]
Dicor vs. Al <sub>2</sub> O <sub>3</sub>	4.9 N, 0.0014 m/s, dry	0.7–0.077	$2.6 \times 10^{-3}$	Microfracture	[82]
Dicor vs. Al <sub>2</sub> O <sub>3</sub>	1N, 0.0025 m/s, distilled water	0.4–0.6	$10^{-3}$ to $10^{-4}$	Localized fracture	[83]
CaO–MgO–Al <sub>2</sub> O <sub>3</sub> –SiO <sub>2</sub> (self-mated)	0.01–0.5 m/s, dry, contact Pressure 0.1–1.4MPa	0.05–0.65	$10^{-3}$ to $10^{-4}$	Microcracking, abrasion	[84]
MgO–CaO–SiO <sub>2</sub> –P <sub>2</sub> O <sub>5</sub> –F vs. ZrO <sub>2</sub>	10 N, 0.025 m/s, dry	0.75	$0.7 \times 10^{-4}$	Abrasive and adhesive wear	[85]
K <sub>2</sub> O–B <sub>2</sub> O <sub>3</sub> –Al <sub>2</sub> O <sub>3</sub> –SiO <sub>2</sub> –MgO–F vs. steel	1N, 0.0016 m/s, dry/AS, 100,000 cycles	0.88 (dry); 0.67 (AS)	$12 \times 10^{-5}$ (dry); $2 \times 10^{-5}$ (AS)	Tribomechanical wear (dry); tribochemical wear (AS)	[79]

Shibayan et al.[81] Studied the mechanical properties studied show variations in hardness. On the outer surface (near 3.5 GPa), the enamel is the toughest and dentin is softer than enamel. With the depth of the base, the steadily diminishing hardness was assessed. This variation is partly dependent on the abundance of enamel and dentin minerals, with a possible reliance even on local microstructural characteristics, such as the orientation of the enamel rod and the density of the dentinal tubule. Human tooth/alumina tribocouple exhibits steady state COF in tribological testing, varying under the unlubricated fretting conditions for various times in the range of 0.12–0.55. It was not possible to definitively associate the observed steady state COF and the number of cycles.

## VI. CONCLUSION

An effort has been prepared in this review article to address recent advances in the synthesis, reinforcement, microstructure and mechanical features of Glass-ceramics. With regard to doping of Glass-ceramics, an analysis of available literature shows that crystallization of the bulk; promote the addition of nucleating agents such as TiO<sub>2</sub> to the composition of Glass.

- 1- Titanium Dioxide, in appropriate quantity, can be useful as a coating component, from a thermochemical point of view, in the crystallization of Glass-ceramics.
- 2- Tensile strength, hardness, wear resistance, and elastic modulus, mechanical characteristics have been reported to improve dramatically with an improvement in reinforcement material, but at the cost of ductility.
- 3- With increasing reinforcing content, the fracture strength also decreases, particularly for particle reinforced Glass-ceramics.

- 4- Glass-ceramics has been a promising material for engineering applications and research is still going on to explore the promise of this flexible material.

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