EFFECT OF DIFFERENT CALCIUM SALT COATING ON MECHANICAL AND BIOACTIVITY PROPERTIES OF CORDIERITE

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UNIVERSITI SAINS MALAYSIA

2022

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by

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Thesis submitted in fulfilment of the requirements
for the degree of
Material Engineering

July 2022

DECLARATION

I hereby declared that I have conducted, completed the research work and written the dissertation entitled: " Effect of different calcium salt coating on mechanical and bioactivity properties of cordierite". I also declared that it has not been previously submitted for the award for any degree or diploma or other similar title of this for any other examining body or University.

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ACKNOWLEDGEMENT

Praise be to Allah, the Almighty, alhamdulillah. If it hadn't been for His guidance, I would have never finished this thesis. Thanks to the kindness of the Dean of SMMRE, Assoc. Prof. Ir. Dr. Mariatti Binti Jaafar and the School of Materials and Mineral Resources Engineering (SMMRE), I was given the opportunity to see what it is like to conduct research. Thank you to my supervisor, Assoc. Prof. Dr. Hasmaliza Mohamad, for guiding and supervising my project, inspiring me with her guidance, inspiration, and support, as well as for the opportunity to work with her.

My thanks go out to the Ministry of Education for the RUI under grant 8014045, which provided some of the funding for my research. To the technicians, Abdul Rashid Selamat and Mohammed Syafiq Abdul Majid, as well as my postgraduate members for instruction and emotional support, I extend my gratitude.

The final words of thanks and admiration go to my beloved parents, Mat Radzi Bin Abu Bakar and Fauzila Binti Dan, who have always been there for me. To me, her unwavering support and encouragement are a constant source of warmth and strength. She was always there for me, whether I was happy or sad, and she was always there for me. It is because of their encouragement, understanding, and patience that I was able to finish this thesis. Thank you everybody for inspiring me to get my degree, especially Alia Suraya Binti Mat Radzi and Nur Yasmin Binti Mat Radzi.

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FTIR	Fourier transform infrared spectroscopy
XRD	X-ray diffraction
XRF	X-ray fluorescence
Rpm	Revolutions per minute
HA	Hydroxyapatite

ABSTRAK

Magnesium (MgO), aluminium (Al_2O_3), dan silikat (SiO_2) bergabung untuk membentuk seramik cordierite, yang digunakan secara meluas dalam aplikasi yang memerlukan daya tahan tinggi terhadap kejutan haba. Kerana pengembangan haba yang terhad dan penebat elektrik yang kuat, seramik kordierit adalah bahan yang berharga. Apabila diuji untuk rintangan kepada daya luaran, kordierit, sebaliknya, menunjukkan kekuatan mekanikal yang minimum. Kami berharap untuk mengetahui lebih lanjut tentang kesan salutan garam kalsium yang berbeza pada sifat mekanikal dan biologi larutan garam Kalsium tulen ($CaCl_2$, larutan Kalsium Asetat ($C_4H_6CaO_4$), larutan Kalsium Nitrat ($Ca(NO_3)_2$) dan ujian bioaktiviti, yang melibatkan merendam sampel dalam cecair badan simulasi, semuanya digunakan dalam kajian ini untuk melihat kesannya terhadap kordierit. Hasil daripada ujian in-vitro, kordierit menunjukkan tindak balas yang menggalakkan terhadap pengeluaran apatit di bawah mikroskop elektron pengimbasan (SEM). Puncak apatit dalam kajian XRD menunjukkan bahawa apatit telah terbentuk. Keputusan ujian bioaktiviti menunjukkan peningkatan keamatan pada spektroskopi inframerah transformasi Fourier (FTIR). Keputusan menunjukkan bahawa kordierit yang diperoleh daripada kajian ini berpotensi untuk digunakan sebagai bahan implan tulang, dan ini adalah kesimpulan yang dicapai.

EFFECT OF DIFFERENT CALCIUM SALT COATING ON MECHANICAL AND BIOACTIVITY PROPERTIES OF CORDIERITE

ABSTRACT

Magnesium (MgO), aluminium (Al_2O_3), and silicate (SiO_2) combine to form cordierite ceramic, which is widely used in applications needing high resilience to thermal shock. Because of its limited thermal expansion and strong electrical insulation, cordierite ceramic is a valuable material. When tested for resistance to external force, cordierite, on the other hand, demonstrated minimal mechanical strength. It is to learn more about the effects of different calcium salt coatings on the mechanical and biological properties of pure calcium salt solutions (calcium chloride ($CaCl_2$), calcium acetate ($C_4H_6CaO_4$) solution, calcium nitrate ($Ca(NO_3)_2$) solution) and a bioactivity test, which involves immersing the sample in a simulated bodily fluid, are all being used in this study to see what effect they have on cordierite. The reason why the pellet need to coating with the calcium salt is, to see which calcium salt produce formation of hydroxyapatite faster. The function of calcium salt in this experiment will act as a catalyst. As a result of characterization testing, cordierite showed a favourable reaction to hydroxyapatite production under the scanning electron microscope (SEM). The apatite peaks in the XRD study suggest that apatite has formed. Bioactivity test results show an increase in intensity on the bonding in Fourier transform infrared spectroscopy (FTIR). Results reveal that cordierite obtained from this study has the potential to be used as a bone implant material, and this is the conclusion reached.

CHAPTER 1

INTRODUCTION

1.1 Research Background

A ceramic is the hard, brittle, heat-resistant, and corrosion-resistant materials created by moulding and burning an inorganic, non-metallic substance, such as clay, at a high temperature. Earthenware, porcelain, and brick are common examples. Ceramics may be found everywhere around us (Heimann, et. al, 2010). Tile, bricks, plates, glass, and toilets are examples of materials in this category. Ceramics may be found in a variety of items, including watches (quartz tuning forks-the time keeping components in watches), snow skies (piezoelectric-ceramics that stress when a voltage is applied to them), vehicles (sparkplugs and ceramic engine parts used in race cars), and phone lines. They're also on space shuttles, appliances (enamel coatings), and aeroplanes (nose cones). Ceramics can be thick or lightweight depending on how they are formed (Carter et. al, 2007). They typically have high strength and hardness qualities; nonetheless, they are frequently fragile in nature. Ceramics may also be made to be electrically conductive materials (things that enable electricity to travel through their bulk) or insulators (materials that hinder the flow of electricity). Some ceramics, such as superconductors, have magnetic characteristics as well. Ceramics are often created by moulding combinations of clay, earthy materials, powders, and water into desired shapes (Black et. al, 2012).

Ceramics are inorganic materials that harden at high temperatures and are composed of metallic and nonmetallic components. It is usual that glassware and ceramics have been widely utilised outside the body for a number of reasons. They are commonly utilised in large industrial applications such as housewares, chemicals, building construction, and health care. Ceramic may currently be utilised in the body as implants and in dentistry. Ceramic materials utilised in medical and dental applications such as healing and restoring ill or injured body parts are known as bioceramics. Bioceramics are a type of biomaterial that comes in a variety of forms and phases and is employed in a variety of applications across the human body. A biocompatible ceramic, such as hydroxyapatite (HA) which is composed of calcium and phosphate. It can be either permanent, such as coating gliding surfaces to reduce wear in prosthetic joints, or temporary, such as bioresorbable pins, plates, and screws. A material must have a few specialised features in order to be used in medical applications, the most essential of which are related to biocompatibility. Biomaterials are ideal materials because of their biocompatibility. Biocompatibility is a descriptive term that refers to a material's ability to carry out the required host reaction in a specific application (Seeram Ramakrishna, 2004).

Cordierite is a mineral that occurs naturally and belongs to the cyclosilicate or ring silicate family of minerals. Cordierite, one of the three six-member rings, has a magnesium, iron, and aluminium foundation, with magnesium being the most durable component. The material is frequently used in ceramic compositions, giving them good unidirectional thermal expansion properties (Klein, 2002). These ceramics are very useful in the production of insulators, catalytic converters, and refractory linings. Cordierite may also be found in clear, violet-colored gem grade variants known as iolite, which are valued for their colour, and density.

Cordierite is another name for indialite. Cordierite was named after the French geologist Louis Cordier when it was found in 1813. (Louis, 1853) MgO, Al_2O_3, and SiO_2 are the three primary components found in cordierite. In glass ceramic technology, the glass's viscosity can be optimised through careful compositional selection, allowing for more efficient processing. Because cordierite and copper are co-fired at low temperatures (below 1000 ^oC). As a result, it became more popular than aluminium nitride. Cordierite's sintering temperature range is near to its melting temperature. Sintering the cordierite product might be tough for research organisations at times).

Cordierite is most commonly found at the contact or regional metamorphism of pelitic rocks. It is notably frequent in hornfels formed by pelitic contact metamorphism. Sillimanite-cordierite-spinel and cordierite-spinel-plagioclase-orthopyroxene are two frequent metamorphic mineral assemblages (Boccaccin, 2007). Garnet (cordierite-garnet-sillimanite gneisses) and anthophyllite are also related minerals. Cordierite may also be found in gabbroic magmas in the form of granites, pegmatites, and norites. Mica, chlorite, and talc are examples of alteration products. Cordierite may be found in the granite contact zone at Geevor Tin Mine in Cornwall, for example.

Cordierite was chosen for its high chemical resistance and mechanical strength (243 MPa). Mengucci et al. (1998) demonstrated the viability of cordierite as a biomaterial, notably in the form of a sintered honeycomb monolith. Cell growth, in addition to its low production costs, can be viewed as the greatest alternative for improving mechanical and chemical resistance, insolubility, and porosity of cells. As a result, Krajewski et al. (1996) discovered that cordierite may successfully promote cell proliferation. Furthermore, the inclusion of magnesium ions (Mg^{2+}) in a cordierite composition may increase cell binding in the body via a positive reaction between the surface electrostatic charge and the potential cell membrane (Krajew et al. 1997).

1.2 Problem Statement

$MgO-Al_2O_3-SiO_2$ ternary system cordierite is an useful crystalline phase with noteworthy qualities such as high chemical resistance and good mechanical properties (243 MPa) (Sanad et al., 2014). Ola Saleh Mahdi et al. (2021) tested cordierite and zirconia-doped cordierite composites for cytotoxicity and cell attachment to see if they might be used as biomaterials. Cordierite in bioglass is largely employed in orthopaedic and periodontal applications as a synthetic bone transplant. Both of these applications use glass to replace and treat bone defects (holes in bone) induced by trauma or tumor/cyst removal. Periodontal abnormalities are frequently discovered in the jawbone around the tooth root. Orthopaedic surgeons utilise autografting, which is the transplanting of bone from another place of the body (a donor site) to the defect location. Biomaterials such as cordierite are suitable for bone and tooth replacement due to the ionic dissolution products produced, which may help cells to renew and self-repair.

Cells adhered to the cordierite surface without any dead cells, indicating that the cordierite was not poisonous (Saleh Mahdi, 2021). The calcium chloride solution treated HA on cordierite is shown by Yong Kim et al., (2014). (Yong et al., 2014). Additionally, the presence of magnesium ions in the cordierite demonstrates the importance of biomaterials, which is the fourth most common element in the human body (Neill et al., 2018). Enhancing osteoblast cell activity and preventing osteoclast formation are additional significant roles of magnesium in bone development (Moghanian et al., 2018). In addition, magnesium is an effective antibacterial element (Qin et al., 2015).

Cordierite are a type of inorganic bioactive ceramic that may react with physiological fluids to build strong linkages with bone through the production of bone-like HA layers and the biological interaction of collagen with the material surface. HA is a key component and necessary component of proper bone and teeth. HA is a mineral found in bone and the matrix of teeth. The stiffness of bones and teeth is due to HA. In the present work the cordierite are expected to produce high strength bio ceramic. When the cordierite is coated with the calcium salt, employing a different calcium salt will allow us to determine which one promotes the development of HA at a faster rate than the others.

However, even the cordierite has the higher strength but the cordierite still has lack on the bioactivity properties in the industry. This aim of experiment is to differentiate the properties of cordierite using different type of parameter of calcium salt and to differentiate the mechanical and bioactivity of the cordierite.

1.3 Research Objectives

The primary goal of this research is to optimise the cordierite properties, with the following specific goals as sub-targets:

i. To determine the effect of different coating of calcium salt on mechanical and bioactivity properties of cordierite.
ii. To determine the bioactivity properties of the cordierite after coating with a calcium salt and immersion in simulated body fluid.

1.4 Scope of Research

The utilization of cordierite in bone implant research is the primary emphasis of this study. As a direct consequence of this finding, the research was split into two halves. The first half of this discussion focused on the production of cordierite powder. At this stage, the particle size of the cordierite powder was altered by adjusting the mixing at 6 hours before the powder was subjected to the melt and quench process. In this stage also the coating of different calcium salt also done before enter the seconf stage. The second stage consisted of analysing the characteristics of the cordierite. X-ray fluorescence (XRF), density and porosity, diametral tensile strength (DTS), X-ray diffraction (XRD), fourier transform infrared (FTIR), and scanning electron microscopy were all used to evaluate the cordierite pellets (SEM). In addition to this, the efficiency of the bioactivity was evaluated with the help of the simulated bodily fluid.

1.5 Thesis Structure

This thesis is divided into five chapters where the first chapter is introduction, second chapter is literature review, third chapter is methodology, fourth chapter is result and discussion, and fifth chapter in conclusion.

The first chapter presents a introduction of the overall study strategy, what problem statement that have, objectives, and scope of research activities.

The second part of this thesis offers a comprehensive review of the literature. The most recent study on this issue, as well as how it pertains to this research, is discussed. Cordierite fundamentals are explored such as what component that have in cordierite, when the cordierite is found. Finally, the effects of calcium salt on cordierite are explored.

The third chapter describes the overall methodology of the investigation. Material specifications and chemicals employed, experimental protocols, and the procedure involved in the production of cordierite are all explained. The characterisation equipment and its operation are described briefly.

The fourth chapter discussed the effect of different calcium salts on the cordierite pellets before and after immersed in simulated body fluid (SBF) on the bioactivity of cordierite using characterization methods such as X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF), Scanning Electron Microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, the diametral tensile strength (DTS) , the shrinkage test, pH test and the density and porosity test.

Chapter five, the last chapter, the conclusion of the full thesis. An overview of the obtained results is provided, as well as suggestions and recommendations for future studies related with cordierite.

CHAPTER 2

LITERATURE REVIEW

2.1 Ceramic

The three primary types of materials are metal, ceramic, and polymer. Metal and non-metal components make up the oxides, nitrides and carbides that make up ceramics (Wang, 2012). Advanced ceramics and traditional ceramics are two types of common ceramics. Zirconia, silicon dioxide, zinc oxide, silicon nitride, and other such advanced ceramic materials are examples. Traditional ceramics are made of clay, cement, and glass, but modern ceramics are built of polymers. Crystalline and non-crystalline ceramics can also be subdivided (Maccauro et al., 2011). Slow cooling to solid state produces crystalline ceramics, which have an ordered atomic structure. When rapidly cooled from a liquid state, ceramics such as silica, SiO2, display amorphous solid silica glass, also known as noncrystalline (Zhang et al., 2011).

The key features of ceramics that people are interested in are their great stiffness, strength, and hardness (Rosso, 2006). Ceramic engineering has improved the brittleness properties, alleviating some of ceramic's other drawbacks, such as its tendency to break easily (Bouville et al., 2014). Ceramics, on the other hand, can preserve their qualities even when subjected to extremely high temperatures and harsh conditions. In addition to being utilised in diesel engines, tiles and bricks, electrical components such as thermistors, and even in medicinal applications, ceramics with fascinating properties are frequently employed (Jones, 2015).

Ceramics for medical usage were developed in the 1970s, when glass was employed to make a link with the host tissue (Best et al., 2008). Due to the interfacial layer of fibrous tissue that forms on the surfaces of metals and synthetic polymers in the human body, ceramics have become popular in the biomedical industry. One reason for this is that living tissues such as cells and bones aren't made of polymers and metals like many other types of tissues (Jones and Hench, 2004).

2.2 Biomaterials

Biomaterials is a substance that has been created to interact with biological systems for either a therapeutic (treating, augmenting, repairing, or replacing a tissue function of the body) or diagnostic purpose. Biomaterials is a science that has been around for nearly fifty years. Biomaterials science or biomaterials engineering are terms used to describe the study of biomaterials. It has grown steadily and rapidly throughout its history, with numerous corporations investing enormous sums of money in the creation of new goods. Medicine, biology, chemistry, tissue engineering, and materials science all play a role in biomaterials science. It is important to note that biomaterials is distinct from a biological material, such as bone, which is created by a biological system. Furthermore, because biomaterials are application-specific, it is important to take caution when categorising them as biocompatible. A biomaterial that is biocompatible in one application may not be biocompatible in another (Schmalz, 2008).

Bioactivity refers to an engineered biomaterial's capacity to elicit a physiological reaction that is beneficial to the biomaterial's function and performance. This phrase most usually refers to the capacity of implanted materials to bind well with surrounding tissue in either osteo conductive functions in bioactive glasses and bioactive ceramics (Wanpeng et al 1996). The materials used in bone implants are frequently engineered to encourage bone formation while dissolving into the surrounding bodily fluid (Zhu, H et al. 2018). As a result, for many biomaterials, strong biocompatibility, as well as strength and dissolution rates, are desirable. Bioactivity of biomaterials is commonly measured by surface biomineralization, which results in the formation of a native layer of hydroxyapatite at the surface (Navarro et al. 2008). The emergence of computer procedures that can anticipate the molecular effects of biomaterials in a therapeutic situation based on limited in vitro testing has considerably aided the creation of therapeutically effective biomaterials (Ferreira Marcel et al 2020).

Briefly put, a biomaterial is a substance that interacts with or replaces biological system tissue, organ or function in live bodies (Baino and Vitale-Brovarone, 2014). Uses for biological materials include cell transport and growth factors. If living organisms are exposed to the implant material, it must not produce hazardous behavioural responses and inflammation and must disintegrate at an appropriate rate without producing toxic effects (Rahaman et al., 2011). Inflammatory responses and foreign body reactions must be kept to a minimum in the substance (Anderson et al., 2008). In addition, it is critical to ensure that the implant material has a long enough lifespan. As a result, the degradation time of the implant material matches to the regeneration cycle of new tissues. In addition, the degrading composition must be non-toxic and capable of being excreted from the body via metabolic processes (Costa et al., 2012).

In addition, biomaterials must be able to withstand mechanical stress, which is the primary need for biomaterials. There must be a minimum level of mechanical strength in biomaterials that matches the strength of imitation tissue or implants (Goudouri et al., 2011). Biomaterials for dental use must be able to tolerate a wide range of stresses and strains in the mouth (Karthick et al., 2014). It is also important that the biomaterial utilised in orthopaedics provides stability at the implanted site (Ghomi et al., 2012).

When it comes to the mechanical properties of biomaterials, they must be strong enough to allow for surgical manipulation during the procedure. Materials with low mechanical strength will only find limited use. Structural failure will occur if biomaterials lack sufficient mechanical strength during or after implant. A difficult process is required to replace and repair the failure site if it fails, and this will result in additional discomfort for the patient because of the new surgery. A wide range of materials can be used for biomaterials include metal, polymer, ceramic and composite.

2.2.1 Bioceramics

Bioceramics and bioglasses are biocompatible ceramic materials. Bioceramics are a significant class of biomaterials (Ducheyne , 1984). Bioceramics range in biocompatibility from ceramic oxides, which are inert, to resorbable materials, which are finally removed by the body after assisting healing (Shackelford, 1999). Bioceramics are widely employed in a variety of medical operations. Although certain bioceramics are flexible, they are commonly employed as stiff materials in surgical implants. The ceramic materials used are not the same as those used in porcelain-type ceramics. Bioceramics, on the other hand, are either closely connected to the body's own components or are exceptionally durable metal oxides. Prior to 1925, the majority of implant materials were relatively pure metals. Given the rather crude surgical procedures, the effectiveness of these materials was remarkable. biocompatible ceramic materials with high biocompatibility, thermal stability, and chemical resistance make form the field of bioceramics. Bone tissue injury and disease can be repaired using these in the dental and medical fields (Balakrishnan and Thomas, 2018; Kaur et al., 2016a). Bioinert, bioactive, and biodegradable bioceramics can all be found in the same product (Malhotra et al., 2014).

The most commonly used biomaterials are bioinert ceramics like alumina and zirconia. Alumina bioceramics have been used to replace the traditional metallic femoral heads of hip prostheses in some of the most advanced applications (Affatato et al., 2015). For acetabular cups, ceramic materials were used because of their great wear and corrosion resistance as well as their biocompatibility and high strength. When used in a medical device, zirconia is one of the strongest ceramic materials available (Ghalme et al., 2016). In addition to alumina, zirconia was used as an alternate material because of its better fracture toughness and strength (Chevalier and Gremillard, 2009). No harm is done to hard or soft tissues by either alumina or zirconia, whereas increased cell development is observed in both materials (Kanchana and Hussain, 2020; Schickle et al., 2012).

The 1930s saw the advent of improved surgical procedures as well as the first usage of alloys such as vitallium. L. L. Hench and colleagues found in 1969 that several types of glassware and ceramics may attach to live bone (Hench, 1991). On his way to a materials conference, Hench was inspired by the notion. He was sitting behind a colonel who had recently returned from the Vietnam War. The colonel said that following an accident, troops' bodies would frequently reject the implant. Hench became fascinated and began researching biocompatible materials. The end result was a novel substance he termed bioglass. This work sparked the development of a new discipline known as bioceramics. The discovery of bioglass sparked a surge in interest in bioceramics.

2.2.2 Coating

From the perspective of surface engineering, a coating is a layer of material that is placed onto a substrate in order to improve the surface qualities with the purpose of providing protection against corrosion and wear. The selection of a coating is determined by a number of factors, including the component's shape and size, the service environment, the expected lifespan, the substrate material's compatibility, and the cost. A covering that is applied on the surface of an object, which is typically referred to as the substrate, is referred to as a coating. The application of the coating could have either a practical or a decorative purpose, or both (Howarth, 1997). Powder coatings are an example of a type of coating that can be applied in solid, liquid, or gas form.

Paints and lacquers are types of coatings that, for the most part, serve the dual purposes of protecting the substrate and being decorative. However, there are some paints that are only used for decoration, such as paints used by artists. The paint used on large industrial pipes serves the dual purposes of preventing corrosion and identification; for example, blue paint is used for process water, while red paint is used for fire-fighting control. It is possible to apply functional coatings to the surface of a substrate in order to change its surface properties, such as its adhesion, wettability, corrosion resistance, or wear resistance, for example. In other circumstances, such as the fabrication of semiconductor devices (in which the substrate is a wafer), the coating contributes an entirely new property to the finished product, such as a magnetic response or electrical conductivity, and is therefore an indispensable component of the end result (Howarth, 1997).

The application of the coating at a controlled thickness is a major consideration for the majority of coating processes. To achieve this control, a number of different processes are used, ranging from a simple brush for painting a wall to some very expensive machinery that applies coatings in the electronics industry. Controlling where the coating is placed is a necessary component of "non-all-over" coatings, which is an additional factor to take into consideration. Printing methods account for a significant portion of these non-all-over coating procedures. The application of a functional substance in the form of a thin film to a substrate, which may be in the form of paper, cloth, film, foil, or sheet stock, is a common step in many industrial coating processes. The coating process may be referred to as "roll-to-roll" or "web-based" depending on whether or not the substrate begins and concludes the process wound up in a roll (Grainger, 1998).

There is a vast variety of coating methods that may deposit a wide variety of materials at thicknesses ranging from just a few microns up to several millimetres. The thicknesses can range anywhere from a few microns to several millimetres. There are numerous different ways in which one might classify the various kinds of coatings. The method by which the coating material is coated onto the surface of the substrate is a standard strategy that is used in many situations. This encompasses atomic deposition, particle deposition, and bulk coating or cladding, among other processes. The following table provides an overview of some typical coating types (Mutyala, 2016). For this experiment the types coating that used is the soaking. This is because soaking technique was the simples’ types of technique that can be used and it is easier to handle it.

2.2.3 Mechanism of Apatite Layer Formation

Bone growth and bone bonding on the glass surface can be separated into several stages after the establishment of a hydroxyapatite (HA) layer. Apatite and silicon dioxide crystals form on glass surfaces, whether in a test tube or a living organism. After conducting an in vitro test on the surface of glass, a layer of calcium phosphate (CP) is generated in the Si-rich layer in vitro environment (Loty et al., 2000). Calcium phosphate ceramics (CPCs) are a type of adjustable bioactive material that has been widely utilised to repair and enhance bone tissue (Dorozhkin, 2002). They have surface characteristics that promote osteoblast adhesion/proliferation (osteoconduction) and new bone production (osteoinduction). CPCs have also been found to enhance bone development in vivo (Mastrogiacomo, 2006) and to attract bone marrow stromal cells (BMSCs) to ectopic locations to induce bone formation. However, not all CPCs have the same biological impact in vivo; whereas the majority are osteoconductive, just a few are osteoinductive.

There is little to no inflammatory response and little risk of disease transfer when using ceramics. There is no need for a donor site because they are available in an endless number of numbers. Ceramics have a number of limitations, including low tensile strength and fracture resistance. Posterolateral fusions using ceramics have had mixed results in animal studies. Posterolateral fusions in patients with idiopathic scoliosis performed with ceramics and local bone have been shown to have similar results to those performed with local bone and autograft in clinical trials (Delecrin et al., 2000). Clinically, ceramics have been most successful when used in anterior interbody fusion of the cervical spine. Most series show that this graft material has a fusion rate of about 100% when used in conjunction with strict internal fixation (McConnell et al., 2003). Until recently, nothing was known about the appendicular skeleton.

It is possible that these differences in osteoblastic stimulation are attributable to variations in the chemical and physical properties of CPC. It is possible to influence biological events such as protein adsorption (Barrere, 2006) via cell-extracellular matrix (ECM) interactions through surface chemistry and charge. Cell differentiation can be aided by surface roughness, for example, which alters cell adhesion. In addition, some surface properties can facilitate the adsorption of cell-adhesive proteins, resulting in conditions favourable for the establishment of stable focused adhesive complexes (Bulnheim, 2008). As a result, designing osteoinductive CPCs requires an understanding of the material properties that influence cell activity.

Calcium phosphate ceramics make up the majority of bone minerals. So, calcium phosphate ceramics are a viable option for orthopaedic applications because of this. The biocompatibility, osteoconductive, and even osteoinductive properties of calcium phosphate have been demonstrated in research (LeGeros et al., 2003). Bone minerals are composed primarily of hydroxyapatite, which is the most common phase (HA). HA's chemical formula is $Ca_{10}(PO_4)_6(OH)_2$. Grain size and porosity, as well as nitric oxide synthesis and cell activity, are all influenced by the Ca/P ratio (Liu et al., 2008). HA particles can be produced in a range of morphologies (Zhou and Lee, 2011), increasing their resemblance to human bone tissue, where HA takes on a rod-like shape (Zhou and Lee, 2011). Also promising is the creation of scaffolds, coatings, and enhancing osteoinductivity with HA particles of diverse shapes (Zhou and Lee, 2011).

The use of HA as a pharmaceutical carrier is also gaining traction among academics. For most drug carriers, polymers are suitable, but HA offers special advantages in bone tissue regeneration (Ginebra et al., 2006). Bone fillers can also contain HA. To generate cement fillers, HA is commonly mixed with aqueous phase and injected into fault areas. As a result, future work on HA is likely to involve a variety of disciplinary approaches, including biofunctionalization, mechanical property enhancement, and combinations with other phases.

A biomimetic method for coating hydroxyapatite with simulated body fluid (SBF) or similar solutions has been described in the past (Miyamoto, 2001). SBF and bioactive glass can be used to coat the substrate with a thin layer of hydroxyapatite, according to Kokubo and coworkers (Kokubo, 1995). An entirely new class of material is created by applying hydroxyapatite on cordierite in a biomimetic coating process. In biomimetic processing, hydroxyapatite coating can be applied in two ways. When silanol (Si-OH) groups are introduced into materials, hydroxyapatite nucleation occurs in a non-uniform manner, according to a study on the growth of hydroxyapatite on SiO_2-based systems.

Nuclear growth occurs as calcium and phosphate ions from the environment are taken up by newly formed nuclei. A hydroxyapatite coating can benefit from calcium treatment as the release of calcium ions from hydroxyapatite enhances supersaturation with relation to the substance (Kuramoto, 2003). As a result, the production of Si-OH by hydration or treatment with a calcium salt solution is required for hydroxyapatite synthesis on cordierite. The hydration of cordierite by H_2O was previously discovered (Vernon, 1972). Cordierite hydration triggered hydroxyapatite nucleation by producing hydroxide on its surface. Biomimetic techniques were used to cover cordierite with hydroxyapatite. After being submerged in a calcium chloride ($CaCl_2$) solution, the hydration status of cordierite was evaluated. calcium-treated cordierite specimens' ability to synthesise hydroxapatite was tested using an artificial body fluid model (SBF).

Implants' ability to generate apatite is tested in vitro by immersing them in biological solutions. When the bioactive material is subjected to simulated body fluid (SBF), pH 7.4 and buffer solutions such as Hank's Balanced Salt Solution (HBSS), pH 7.2 for a few days, apatite production is evaluated (Ozawa et al., 2007; T. T. Swe et al., 2019).

It's also possible to conduct cell culture experiments on bioactive glass in vitro in order to study cell response, cell survival, and cytocompatibility on the material. Incubation of cells at 37 °C for several days is also required (Li et al., 2006).

Because of the formation of an apatite layer, glass will be more readily attached to biological tissues. Apatite formation is aided by collagen crystallisation beneath the apatite layer. The apatite layers are formed as a result of osteoblasts reacting to the glass surface. The matrix is generated if cell interaction and differentiation have been established on the glass surface. The aggregation of collagen fibres and mucopolysaccharides around apatite crystals improves bone-implant bonding. Chemical interaction between glass and bone surfaces creates an interface layer that supports new bone-bone bonding. Ca-P layer adhesion promotes chemical bonding between collagen and proteins (Jones, 2013).

2.3 Cordierite

Cordierite ceramic is a magnesium (MgO), aluminium (Al_2O_3) and silicate (SiO_2) material that has found widespread usage in applications requiring thermal shock resistance. Cordierite ceramic is also valuable because, when compared to other ceramic materials, it has a low thermal expansion and high electrical insulation (Cornelis, 1985). It may be moulded into a wide range of complicated shapes using a number of production processes including axial pressing, isotactic pressing, injection moulding, and extrusion. Cordierite is a mineral that occurs naturally and belongs to that same cyclosilicate or circle silicate group of minerals.

There are other noteworthy mechanical features of cordierite, such as strong compressive and bending strength, and great resistance to fracture, that make it a fascinating material (Zhang et al., 2011). Because of its great mechanical strength, cordierite can be employed in numerous applications, including high-pressure dust collection, load-bearing surgical implants (Zhang et al., 2011), as composite reinforcing materials, and more (Naga et al., 2017).

Cordierite is often formed during the contact or regional metamorphism of pelitic rocks. It is especially frequent in hornfels formed by contact metamorphism of pelitic rocks. Sillimanite-cordierite-spinel assemblages and cordierite-spinel-plagioclase-orthopyroxene assemblages are two frequent metamorphic mineral assemblages (Hurlbut, 1985). Other minerals found in the area include garnet (cordierite-garnet-sillimanite gneisses) and anthophyllite (Klein, 1985). Cordierite can also be found in granites, pegmatites, and norites in gabbroic magmas. Mica, chlorite, and talc are examples of modification products. Cordierite can be found, for example, in the granite contact zone at Geevor Tin Mine in Cornwall. Table 2.1 show the properties of cordierite :-

Table 2.1 the properties of cordierite

CHARACTERISTIC	VALUE
Density(g/cc)	2.26 – 2.30
Colour	Tan
Flexural strength MPa	92(13)
Young modulus GPa	220
Dielectric constant 25 ^{o}C / 1 KHz	3.7
Dissipation Factor 25 ^{o}C / 1 KHz	0.018
Volume Resistivity 25 ^{o}C ohm-cm	$>10^{14}$

In 1813, French geologist Louis Cordier placed the mineral in a well-known geological exhibit at Paris's National Museum of Natural History. Although the exact naming procedure is unknown, Cordier was the first to describe the chemical in full. It soon bore his name. Corning scientists developed a synthetic form of cordierite in the 1970s. They eliminated the iron while including magnesium, aluminium, and silicon to create a new material for Corning's emissions-control devices. This synthetic cordierite could be rapidly heated and cooled while retaining its dimensions, making it very resistant to thermal shock. Corning's cordierite lends itself well to a modified extrusion manufacturing method, permitting the fabrication of a honeycomb-like thin-walled cell structure with thousands of parallel walls. Catalytic converters are frequently built of ceramics that include a high amount of synthetic cordierite. The cordierite crystals are purposefully aligned throughout the manufacturing process to take advantage of the relatively low thermal expansion along one axis. When the catalytic converter is employed, this avoids thermal stress cracking (Andrzej et al, 2005).

Cordierite phase formation is shown in Figure 2.1, which depicts the magnesium-aluminum-silicate phase systems or ternary system. Three polymorphic forms of cordierite are expected to be discovered. It's common for and cordierite to form (Goren et al., 2006). Sintering cordierite at 900 °C results in metastable material. There are no other phases that can be synthesised from oxide materials other than cordierite through chemical reactions in the solid state. Cordierite is a stable phase with orthorhombic symmetry (-cordierite) below 1300 °C and is generated by hexagonal symmetry above 1330 °C. At the same moment, this is created. Cordierites often have a pseudohexagonal structure, notwithstanding their variability. It is thus possible to compare the properties of synthetic cordierites and those found naturally, and the results of these studies frequently exhibit behaviour midway between orthorhombic and hexagonal symmetry (González-Velasco et al., 2005).

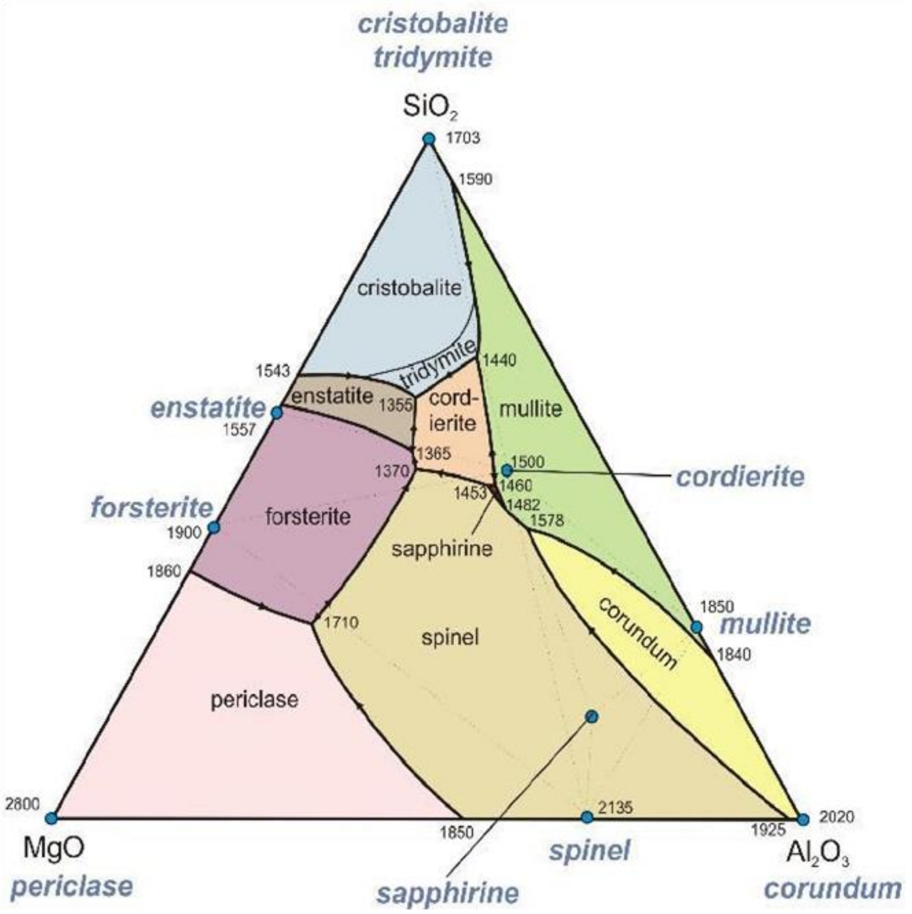

Figure 2.1 Ternary phase diagram of MgO. Al_2O_3.SiO_2 (Camerucci et al., 2003)

Nanotechnology provides a new approach for developing bioactive glasses with a larger surface area. Nanotechnology is described as the science of developing materials and technologies at the nanoscale. When cordierite are manufactured at the nanoscale scale, certain qualities may be enhanced and regulated. As a result, nanoscale nanomaterials exhibit higher biocompatibility and bioactivity. This novel technique is crucial for bioactive glasses utilised as particulates, coatings on biomedical equipment, and fillers in composite materials. Bioactive glasses have been used in a variety of dental specialties over the years, including periodontics, endodontics, and implantology.

A bioactive substance is defined generically as a material that has been designed to produce particular biological activity. A bioactive substance has been defined more narrowly as a material that, when transplanted into the body, exhibits particular surface reactions that result in the formation of a HA-like layer responsible for the formation of a strong link with hard and soft tissues. The capacity of a material to form a HA-like surface layer in vitro when immersed in simulated bodily fluid (SBF) is widely employed to assess its bioactivity (Kokubo & Takadama, 2006).

Additive manufacturing techniques have emerged as a result of industrial advancements in manufacturing processes. Among these, dry-press moulding was deemed the most cost-effective and simple technique of production, with no influence on the structure of bioactive glass particles. The cordierite powder is formed by dry pressing into tablet shape. The physical nature of bioactive glass tablets contributed to their high activity and osteogenic properties (Chen et al., 2017).

Cordierite and bioactive glasses also are frequently utilised to regenerate tooth-supporting hard tissues in intrabony deficiencies caused by periodontal disorders (Kuru et al., 2006). In intrabony defects, cordierite implantation has the potential to promote healing as well as clinical and radiological results. Long-term stability of cordierite and BG in conjunction with directed tissue regeneration membranes has been demonstrated (up to 5 years in BG implanted locations) (Mengel et al., 2006). However, using BG alone may not result in a substantial improvement in periodontal results (Sculean et al., 2002). When enamel matrix derivatives (EMDs) are added to BG, new cementum with an accompanying periodontal ligament is formed, as well as increased mineralization surrounding the BG particles.

2.3.1 Synthesis of Cordierite

Milan Kanti Naskar employed agro based waste materials such as rice husk ash, Fumed silica, and Tetraethaylorthosilicate (TEOS) as a silica source to reduce the cost of cordierite synthesis. They discovered that rice husk ash is abundant and is an agricultural waste. By employing rice husk ash for cordierite processing, the product will be less expensive and more environmentally friendly. The crystallisation of cordierite in rice husk ash silica occurs via the intermediary phases of cristobalite and $MgAl_2O_4$ spinel, whereas it occurs via the intermediate phases of $MgAl_2O_4$ spinel and cordierite for Tetraethaylorthosilicate (TEOS) source and $MgAl_2O_4$ spinel for fumed silica (Milan, 2004).

Shiang-Po Hwang and Jenn-Ming Wu investigated the effects of (P_2O_5, B_2O_3) additives on phase-transformation kinetics and microstructural development of stoichiometric cordierite glasses. They discovered that additives such as B_2O_3 and P_2O_5 influence -cordierite formation but have a significant impact on cordierite. Heterogeneous nucleation of -cordierite occurs at the parent surface impurities and generates a spherulitic dendritic structure. Between residual glass and cordierite, the B_2O_3 additive creates a dendritic arm and an inter-dendritic interface. P_2O_5 promotes cordierite development and transitions it from diffusion to interface control, as well as removing the dendritic aspect of cordierite and assisting in the transformation to hexagonal crystal structure (Po Hwang, 2004).

There are two forms of α-cordierite phase transformations. In the first situation, α-cordierite nucleation occurs at the interface of the inter-dendritic residual glass and the cordierite dendritic arms. This α-cordierite development occurs at the cost of the glass