International Journal of Materials Physics.
ISSN 0974-309X Volume 6, Number 1 (2015), pp.1-6

http://www.irphouse.com

A review paper on Glass-Ceramics

M. S. Shekhawat
Department of Physics,
Govt. Engineering College,
Bikaner-334001 (India).
E-mail: manoj.shekhawat1@gmail.com

Abstract

A systematic study is presented in this paper about the glass-ceramics. Materials that are initially fabricated as glasses and converted to a ceramic to enhance their properties are called glass-ceramics. Glass-ceramics also can be adjusted to match the CTE of the material to which they will be bonded. LAS glass-ceramics were originally developed for use in mirrors and mirror mounts of astronomical telescopes. They now have become known and have entered the domestic market through their use in cooktops, cookware and bakeware as well as high-performance reflectors for digital projectors. Glasses and glass-ceramics (GCs) are also used for sealing, coating and high voltage applications In this paper review work was carried out on uses of glass ceramics in various field.

AMS subject classification:
Keywords: Glass-Ceramics, Bioactive Glass Ceramics, Dental Ceramics.

1. Introduction

Mostly we think glass as the transparent materials found in windows and cars. The term glass describes a state of matter where the atoms or molecules are randomly arranged. Glass describes the inorganic, amorphous, product of a rapidly cooled melt. Using this definition, rapidly cooled metals can also be said to be glassy. Terms such as glassy, amorphous and vitreous all describe the same thing that a material with a randomly arranged atomic structure. Glasses shows a glass transition temperature, below which they are true solids and above which they flow although as a very viscous liquid. It is possible to turn a glass into a ceramic; by heating it up. This allows rearrangement from a random to an ordered structure and an ordered structure is more stable than a disordered one. Materials that are initially fabricated as glasses and converted to a ceramic to enhance their properties are called glass-ceramics.

Glass-ceramics were discovered accidently in 1953. Since then, many papers have been published on glass-ceramics by research institutes, and universities. Glass-ceramics are produced by controlled crystallization of certain glasses induced by nucleating additives. They always contain a residual glassy phase and one or more embedded crystalline phases. The crystallinity varies mostly between 30 to 70 percent. Controlled ceramization gives an array of interesting materials, sometimes unusual, combinations of properties. Unlike sintered ceramics, glass-ceramics are inherently free from porosity. However, in some cases, pores may develop during the latter stages of crystallization. Glass-ceramics have several advantages.

1. They can be produced by any glass-forming technique.
2. It is possible to design their microstruture and nano-structure for a given application.
3. They have very low porosity.
4. It is possible to combine a variety of desired properties.

For production of glass-ceramics, first, a glass is formed by a standard glass-manufacturing process. Second, the glass article is shaped, cooled and reheated above its glass transition temperature. In these heat treatments, the article partly crystallizes in the interior. In most cases, nucleating agents (e.g., noble metals, fluorides, ZrO_2, TiO_2, P_2O_5, Cr_2O_3 or Fe_2O_3) are added to the base glass composition to boost the nucleation process. A less frequently used method is to induce and control internal crystallization during the cooling path of a molten viscous liquid. This process is used sometimes to form relatively coarse-grained glass-ceramics from waste materials to be used in the construction industry. Glass-ceramics also can be produced by concurrent sinter-crystallization of glass-particle compacts. In this case, crystallization starts at glassâŁ“particle interfaces. A main advantage of the sinter-crystallization process is that nucleating agents are not necessary, because the particle surfaces provide nucleation sites.

The most important system is the Li_2O–Al_2O_3–SiO_2 (LAS) system with additional components, such as CaO, MgO, ZnO, BaO, P_2O_5, Na_2O and K_2O. ZrO_2 in combinations with TiO_2 are the most commonly used nucleation agents. The main crystalline phase is a Î²-quartz solid solution, which is highly anisotropic and has an overall negative coefficient of thermal expansion (CTE). LAS glass-ceramics can sustain repeated and quick temperature changes of 800 °C to 1000 °C. The negative CTE of the crystal phase contrasts with the positive CTE of the residual glass. Adjusting the proportion of these phases offers a wide range of possible CTEs in the finished composite.

Glass-ceramics also can be adjusted to match the CTE of the material to which they will be bonded. LAS glass-ceramics were originally developed for use in mirrors and mirror mounts of astronomical telescopes. They now have become known and have entered the domestic market through their use in cooktops, cookware and bakeware as well as high-performance reflectors for digital projectors [1–5].

2. Various field of Glass-Ceramics

Nowadays glass ceramic emerges a very importent and applicable field for industries. Some of many user areas of glass ceramics are discussed here.

2.1. Construction materials

Many glass-ceramics made from a wide variety of waste materials, such ashes, blast furnaces residue, and steel residue. Their composition and predominant crystal phases vary widely. These low-cost materials are generally strong, hard and chemically resistant. Their intended use is for abrasion and chemically resistant parts or floor and wall tile used in chemical, mechanical and other heavy-duty industries or construction. Neopari's is a unique crystallized glass material, which is an ideal alternative to stone for interior and exterior walls, interior floors, counters and table tops. With a marble-like appearance, it is available in large, flat or curved panels [6].

2.2. Thermal uses

A particularly important material is lithium aluminosilicate glass-ceramic. This has an extremely low CTE ($0.00 \pm 0.02 \times 10^{-6}/K$ between 0 °C and 50 °C), which can even become zero or slightly negative in some temperature ranges. Other unique characteristic of this glass-ceramic is good homogeneity. Its good transparency in the range 400 to 2,300 nanometers allows a verification of internal quality. So, it can be ensured that neither bubbles nor inclusions go undetected.

Another relevant thermal property of glass-ceramics is their limiting use temperature. Because of their residual glass phase, most glass-ceramics flow and deform at relatively low temperatures, typically below about 700 °C. However, some notable exceptions exist. An example is a celsian glass-ceramic in the SrO–BaO–Al_2O_3–SiO_2 system, which has use temperatures as high as 1,450 °C and CTEs that match silicon, SiC and S_3N_4. This material is meltable at commercial temperatures (1,650 °C).

Machinable glass-ceramics rely on mica crystals in their microstructure. Their high CTE readily matches most metals and sealing glasses. They exhibit zero porosity and, in general, are excellent insulators at high voltages, various frequencies and high temperatures [7–9].

2.3. High-strength glass-ceramics

Glass ceramic based on chain silicates exhibit a combination of high fracture strength and high fracture toughness. Some are enstatite ($MgSiO_3$), Potassium fluorrichterite ($KNaCaMg_5Si_8O_{22}F_2$) and Fluor-canasite ($K_2Na_4Ca_5Si_{12}O_{30}F_4$). Other way to increase strength and toughness include fiber reinforcement, chemical strengthening by ion-exchange methods and development of a thin surface layer with a lower thermal expansion than the interior to induce a compressive surface layer [10–11].

2.4. Dental glass-ceramics

Dental ceramics are materials that are part of systems designed with the purpose of producing dental prostheses that in turn are used to replace missing or damaged dental structures. Current lithium disilicate glass-ceramics are ideal for fabricating single-tooth restorations. This innovative glass-ceramic produces highly esthetic results. Its hardness is similar to that of natural teeth, and it is two to three times stronger than other dental glass-ceramics [12–15].

2.5. Bioactive glass-ceramics

Heat treatment of an MgO–CaO–SiO_2–P_2O_5 glass gave a glass ceramic containing crystalline apatite ($Ca_{10}(PO_4)_6O$, $F2$) and beta-wollastonite (CaO, SiO_2) in an MgO–CaO–SiO_2 glassy matrix. It showed bioactivity and a fairly high mechanical strength which decreased only slowly, even under load-bearing conditions in the body. It is used clinically as artificial vertebrae, iliac bones, etc. The bioactivity of this glass ceramic was attributed to apatite formation on its surface in the body. Dissolution of calcium and silicate ions from the glass ceramic was considered to play an important role in forming the surface apatite layer. It was shown that some new kinds of bioactive materials can be developed from CaO, SiO_2-based glasses. Ceramics, metals and organic polymers coated with bone-like apatite were obtained when such materials were placed in the vicinity of a CaO, $SiO2$-based glass in a simulated body fluid. A bioactive bone cement was obtained by mixing a CaO, SiO_2-based glass powder with a neutral ammonium phosphate solution. Its compressive strength is around 80 MPa. A bioactive and ferromagnetic glass ceramic containing crystalline magnetite (Fe_3O_4) in a matrix of CaO, SiO_2-based glassy and crystalline phases was obtained by a heat treatment of a Fe_2O_3–$CaO.SiO_2$–B_2O_3–P_2O_5 glass. This glass ceramic was shown to be useful as thermoseeds for hyperthermia treatment of cancer [16–18].

Some researchers have showed the possibility of producing glass fibers of the famous BISCO ($Bi_2Sr_2CaCu_2O_8$) system – which are not superconducting – and then crystallizing them to produce glass-ceramic superconductors. Last, but not least, several glass-ceramics-containing piezoelectric and ferroelectric phases have been studied. These areas for glass-ceramics applications have not yet been fully explored [19–21].

3. Conclusion

An impressive variety of glass-ceramics has been developed during the past six decades. Yet, many others with unusual and unforeseen properties and applications are likely to be discovered in the future. From several thousand patents, only a few dozen glass-ceramics products have reached the market. Much is already known about glass-ceramic technology, but many challenges in glass-ceramic research and development are ahead. They include the search for new compositions (and there are many alternatives to explore), other and more potent nucleating agents, and new or improved crystallization processes. Challenges include microwave heating, biomimetic microstructures. A wide range of potential properties of glass-ceramics is possible because of the ability to design their composition, thermal treatment and resulting microstructure. This, combined with the flexibility of high-speed hot-glass forming will ensure continued growth of glass-ceramic technology. From their glorious past, starting with their accidental discovery, to their very successful commercial products as well as their impressive range of properties listed above (and not listed) and their exciting potential applications, glass-ceramics have indeed a bright future.

References

[1] M. O Prado, M. L. F. Nascimento and E. D. Zanotto, *On the Sinterability of Crystallizing Glass Powders*, J. Non-Cryst. Solids, 354, 4589–97 (2008).

[2] M. J. Pascual, A. DurÃ¡n, M. O. Prado and E. D. Zanotto, *Model for Sintering Devitrifying Glass Matrix with Embedded Rigid Fibers*, J. Am. Ceram. Soc., 88, 1427–34 (2005).

[3] M. O. Prado, C. Fredericci and E. D. Zanotto, *Isothermal Sintering with Concurrent Crystallization of Polydispersed Soda–Lime–Silica Glass Beads*, J. Non-Cryst. Solids, 331 [1–3]145–56 (2003).

[4] K. Kelton and A. L. Greer, *Nucleation in Condensed Matter* Elsevier, New York, 2010.

[5] V. M. Fokin, E. D. Zanotto, N. S. Yuritsyn and J. W. P. Schmelzer, *Homogeneous Crystal Nucleation in Silicate Glasses: A Forty Years Perspective*, J. Non-Cryst. Solids, 352, 2681–714 (2006).

[6] E. B. Ferreira, E. D. Zanotto and L. A. M. Scudeller, *Nano Glass-Ceramic from Steel-Making Slags*, Quim. Nova, 25, 731–35 (2002).

[7] W. Hoeland and G. H. Beall, Eds., *Glass-Ceramic Technology*, 2nd ed. The American Ceramic Society/Wiley, New York, 2010.

[8] P. F. James, *Glass-Ceramics: New Compositions and Uses*, J. Non-Cryst. Solids, 181, 1–15 (1995).

[9] W. Pannhorst, *Glass-Ceramics: State-of-the-Art*, J. Non-Cryst. Solids, 219, 198–204 (1997).

[10] J. W. Zwanziger, U. Werner-Zwanziger, E. D. Zanotto, E. Rotari, L. N. Glebova, L. B. Glebov and J. F. Schneider, *Residual Internal Stress in Partially Crystallized Photo Thermorefractive Glass: Evaluation by Nuclear Magnetic Resonance Spectroscopy and First Principles Calculations*, J. Appl. Phys., 99, 083511–083523 (2006).

[11] V. R. Mastelaro and E. D. Zanotto, *Anisotropic Residual Stresses in Partially Crystallized LS2 Glass-Ceramics*, J. Non-Cryst. Solids, 247, 79 (1999).

[12] G. H. Beall and L. R. Pinckney, *Nanophase Glass-Ceramics*, J. Am. Ceram. Soc., 82, 5–16 (1999).

[13] M. J. Davis, *Practical Aspects and Implications of Interfaces in Glass-Ceramics: A Review*, Int. J. Mater. Res., 99, 120–28 (2008).

[14] S. D. Stookey, Ed., *Explorations in Glass* American Ceramic Society, Westerville, Ohio, 2000.

[15] G. H. Beall, *Refractory Glass-Ceramics Based on Alkaline-Earth Aluminosilicates*, J. Eur. Ceram. Soc., 29, 1211–19 (2009).

[16] T. Kokubo, *Bioceramics and Their Clinical Applications*, Woodhead Publishing, Cambridge, U.K., 2008.

[17] L. L. Hench and J. Wilson, *An Introduction to Bioceramics*, World Scientific, Singapore, 1993.

[18] O. Peitl, E. D. Zanotto and L. L. Hench, *Highly Bioactive* $P_2O_5 - -Na_2O - -CaO - -SiO_2$ *Glass-Ceramics*, J. Non-Cryst. Solids, 292, 115–26 (2001).

[19] A. M. Cruz, E. B. Ferreira and A. C. M. Rodrigues, *Controlled Crystallization and Ionic Conductivity of a Nanostructured* $LiAlGePO_4$*Glass-Ceramic*, J. Non-Cryst. Solids,

[20] E. D. Zanotto, J. P. Cronin, B, Dutta, B. Samuels, S. Subramoney, G. L. Smith, G. Dale, T. J. Gudgel, G. Rajendran, E. V. Uhlmann, M. Denesuk, B. D. Fabes and D. R. Uhlmann, *Melt Processing of Bi-Ca-Sr-Cu-O Superconductors*, pp. 406–18 in Proceedings of the 90th Annual Meeting of American Ceramic Society, Special Superconductivity in Ceramics Symposium (Cincinnati, Ohio, 1988).

[21] O. S. Dymshits, *Optical Applications of Glass-Ceramics*, J. Non-Cryst. Solids, (2010), accepted for publication.