Glass research and training initiative for Brazil

Edgar Dutra Zanotto, Hellmut Eckert and Mauro Akerman describe the creation of a glass research centre and technical training course in Brazil.

The success of today's high tech glass industries is based on the possibility of tailoring the chemical composition and physical properties of glass to the particular application considered. Therefore, the development of glass and glass-ceramic compositions and technologies is an enormously active area for research and development.

For example, an indication of the scientific and commercial importance of glass-ceramics comes from a search on Free-patents Online. About 2400 granted or filed US patents appear with the keywords 'glass-ceramic' in the abstract. There are also about 1500 European and 2700 Japanese patents. A parallel search of the patent literature for all types of non-crystalline materials using the Derwent Innovations Index covered patents granted between 1963 and 2013 using the keywords (glass* or amorphous or vitreous or non-crystalline) in the patent titles. This search resulted in about 370,000 patents issued worldwide. These are impressive numbers for a single field within all the numerous materials classes and types.

Finally, despite the current declining economic trends in several areas, Brazil is still undergoing significant growth in glass production. For instance, the production of float glass in 2008 was 2900 tonnes/day, whereas in 2015, it reached 6630 tonnes/day. In the period 2013/2014, two new float plants started: AGC with a 350 tonnes/day plant. For 2015, two new container furnaces of 350 tonnes/day are expected to start up.

The Centre for Research, Technology and Education in Vitreous Materials (CeRTEV) started operations in July 2013, with generous funding from FAPESP (The Sao Paulo State Research Foundation in Brazil). Following a two year competition process that initially had 90 proposals, FAPESP awarded funds to a total of 17 research centres in various strategic research areas, deemed particularly important for the Brazilian economy and supported by research expertise at the applicant institutions. All 17 Sao Paulo research centres are expected to have a strong international impact. In fact, FAPESP used international review panels to evaluate the 90 proposals to avoid conflicts of interest within Brazil.

CeRTEV is an 11 year, US$22 million (excluding salaries) effort, with funding at about US$2 million per year for five years, after which FAPESP will evaluate the programme before authorising funding for the next six years.

The centre brings together an interdisciplinary team of 14 faculty members, advising 60 research students and post-docs from two state universities, University of Sao Paulo (USP) and Sao Paulo State University (UNESP), as well as the Federal University of Sao Carlos (figure 1).

It includes a mix of young faculty and world experts in vitreous materials and structural characterisation techniques, such as nuclear magnetic resonance, Raman spectroscopy and extended X-ray absorption fine structure (EXAFS), optical spectroscopy, Electron Spin Resonance Spectroscopy (ESR) and Molecular Dynamics (MD) simulations. All eight research laboratories are located within 30km of each other.

Like the other 16 centres, CeRTEV focuses on three 'actions': Fundamental research, technological development and education. These support industry, providing training and outreach to generate sustainability. CeRTEV's research progress, as well as the realisation of its technological and education/outreach objectives, are monitored by an international advisory board, consisting of 21 international professionals who are active in glass research in industry and academia.

The installed capacity of the Brazilian glass industry is significant - 12,000 tonnes/day - and about 65% is located in the State of Sao Paulo.
Over the next nine years, CeRTEV aims to expand its international collaboration network. International exchanges of students, postdocs and faculty will be an integral part of this endeavour.

**RESEARCH AGENDA**

CeRTEV's activities in fundamental research aim to research and develop or improve active glasses and glass-ceramics, presenting application-relevant functionalities, such as high mechanical strength, ionic conductivity, biological, optical or catalytic activity and/or combinations of these properties. As illustrated in figure 2, promising innovative technologies are expected in five main fields of application: (1) strong GCs for mechanical reinforcements; (2) bioactive materials; (3) energy storage and conversion systems; (4) photonic devices; and (5) catalytic systems. In all of these areas, the centre is seeking a fundamental understanding of these properties on the basis of the structural organisation of these materials on different length scales. To this end, NMR, EPR, EXAFS and vibrational spectroscopies are applied to characterise the local and medium-range order, as well as the full resolution range of optical and electron microscopies, XRD and microanalyses for elucidating nano- and microstructures.

This comprehensive experimental approach is complemented by molecular dynamics simulations. With these tools at hand, a fundamental understanding of glass sintering and crystallisation is being developed in terms of the mechanisms, thermodynamics and kinetics of diffusion, relaxation, viscous flow, crystal nucleation and growth, enabling the centre to exercise control of these processes by developing appropriate formation and thermal treatment protocols.

In a concerted effort, participating laboratories are jointly investigating a number of important benchmark systems, which are deemed particularly promising for applications, either as structural reinforcement materials (e.g. glass-ceramics for armour, architecture and constructions, as well as dental implants), bio-active glasses and glass-ceramics for bone and tissue regeneration, optical materials (e.g. laser glasses, amplifiers and other photonic devices), materials for electrochemical energy storage and conversion devices (electrolytes, high temperature seals for solid-state batteries) and catalytically active systems for the conversion of biomass to fuels and industrially important chemicals (figure 2).
TECHNOLOGY AGENDA

Glass products are part of a multi-billion national and international market. The sector is dominated by large global companies but there are also thousands of small and medium-sized glass producers. For example, the overall flat glass market is estimated to be worth €51 billion and in 2009, Europe, North America and China accounted for 70% of world float/sheet glass demand. In the same year, South America consumed only 4% of the flat glass produced worldwide. However, this situation is changing, as Brazil becomes an international industrial player. Since 2007, several float glass companies have built plants in the country and installed capacity will soon rise from 3ktonnes/day to almost 7ktonnes/day, increasing demand for engineering solutions and qualified human resources in this particular area.

The main idea behind the research and technology agenda is to develop the genome of different glasses, from the recognised structure to controlled dynamic processes (diffusion, viscous flow, relaxation and crystallisation) brought about by special thermal treatments, which may or may not result in crystallisation and to develop glass-ceramic with nano- or microstructures to achieve certain combinations of properties for special applications. This has been planned with the explicit goal of generating new technologies and patents, all the way to new products and processes ('science to business approach').

In all the fields described in figure 2, CeRTEV is vigorously pursuing the transfer of fundamental and applied research activities to the productive sector, by establishing co-operation agreements and licensing of on-demand technologies commissioned by industry, as well as nucleating spin-off companies from the group activities. The organisation is also extensively promoting innovation and technology transfer via the responsible university channels. Figure 3 highlights some of the objects based on bio-active glasses and glass ceramics currently under study and development at CeRTEV.

In collaboration with industry partners, the technological core of the group is establishing infrastructure for the production of prototypes, on a scale beyond the laboratory, bringing its activities closer to the productive sector. Examples include a melting furnace for larger glass volumes than the conventional laboratory-scale and a disc mill that can be continuously operated for a high output of glass powders.

Furthermore, to ensure efficient co-operation between academic and industrial laboratories, it is crucial to increase the exposure of students and postdoctoral fellows to the R&D environment in the industrial sector, significantly beyond the current practice in national postgraduate programmes. To this end, a new fellowship programme will be established, with the explicit purpose of enabling students to conduct part of their master and doctoral projects in the laboratories of industrial partners.

EDUCATIONAL AGENDA

The educational and outreach agenda will create sustainability of this effort. It is of utmost importance to attract talented students to glass research and to train them to become accomplished glass and glass-ceramic scientists. Outreach channels beyond the traditional education provided at the university have to be established. CeRTEV’s efforts in this direction include (1) the development of a technical training course for the glass industry and (2) a highly diversified effort to increase public awareness of the enormous technological role of glass and glass-ceramics in modern society.

At the present time, all the technical training of workers in glass factories is conducted 'on the job' by the companies themselves. CeRTEV is in the process of changing this highly unsatisfactory situation with the help of a governmental institution, called Centro Paula Souza, which provides technical teaching and practical training through 218 medium level technical schools located in 161 different cities, as well as 64 higher level technical schools spread over 58 cities in the state of Sao Paulo. These technical schools cover wide areas such as, for example, electronics, mechanics, construction and IP technologies. A few months ago, by a CeRTEV initiative, the Paula Souza Center established a partnership with the Brazilian Technical Association of Glass Producers (ABIVIDRO) and CeRTEV to create a Technical School on Glass, which is planned to start up in 2016. The course will be composed of three semesters in a total of 1500 hours of theoretical and practical lessons. The school will be taught with all the usual equipment in the glass industry for testing raw materials, glass and glass products. The classes will comprise three principal subject areas: (1) Basic science to provide an understanding of the physical and chemical phenomena involved in all phases of production and in the final products; (2) general knowledge about informatics, projects, security, plant maintenance, documentation etc; and (3) specific subjects relevant to glass production, such as glass structure and properties, raw materials, mixing, glass furnace design, combustion, environmental issues, conformation, transformation etc.

It is hoped that the newly trained researchers, engineers and technicians will significantly contribute to increase the quality and productivity of a sustainable, environmentally-friendlier glass industry in this country!

We also consider it essential to increase public awareness of the enormous technological role of glass and glass-ceramics in modern society. Thus, the CeRTEV outreach concept includes various effective measures of dissemination, promoting both the importance of glass and glass-ceramics as strategic materials, as well as emphasising the main underlying scientific concepts of this research field, such as the structure of solids and liquids, experimental techniques and electrical, optical, biological, chemical and mechanical properties. Targeted audiences include the general public, high school students and teachers, university undergraduate students, university professors and industrial researchers. Besides public presentations, school visits and receptions at universities and the development of physical demonstration kits and various web-based activities, CeRTEV plans to assemble a museum devoted to object processes related to glass science, manufacturing and applications.

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