8th Pacific RIM Conference on Ceramic and Glass Technology
Sponsored by the American Ceramic Society

International Commission on Glass

TNO Science & Industry

Improving Strength in Industrial Glass
"The Future of Glass Strength – A Society Changing Symposium"

Thursday June 4, 2009

8:00 a.m. to 5:00 p.m.

Hyatt Regency

Vancouver BC Canada

Notes and Comments

Below are the notes recorded on "flip charts" supplemented by some notes made by Michael Greenman in the course of the day. Yellow Highlighted comments are subsequent input provided by Dr. Chuck Kurkjian, the "Technical Facilitator" for the workshop.

All readers are invited to provide additional feedback to GMIC that could/should be added to the permanent record, which will be posted on the GMIC website.

Presentations

8:20 -9:00 a.m.

David Hartman and Peter McGinnis, Owens-Corning Fiberglass: Development of High Strength Fiberglass Compositions and their Applications to Address Current Global Issues

Abstract

The development of cost effective, high strength glasses and their applications are a critical component to address today's global issues.

The need for increased energy efficiency, greater security from growing military threats, and reduced environmental impact presents opportunities for high strength glasses to provide lighter and safer airplanes, more fuel efficient alternative fuel vehicles, clean renewable energy, and improved safety for military personnel.

This paper will provide a brief review of the history of high strength glass fiber reinforcements and their applications, the state-of-the-art in fiberglass compositions today, and the challenges and opportunities facing the development of future high strength glasses.

High Strength Glass Fiber

1. What accounts for real difference in strength of S-glass and E-glass? While it is clear that composition per se is the main reason for this increase, it is also possible that the composition (which is relatively simple) is not as sensitive to processing conditions and their effects on strength as for E-glass.
    a. Role of Griffith Flaws? If by Giffith flaws is meant a type of 'intrinsic' flaw related to the structure, e.g., variation in bond strength, interstice size, ring size, etc., this may be a useful way to look at the problem.

2. As glass strength increases, typically cost increases (e.g., E→S)
    a. Need to look beyond just the difference in composition cost - have also reduced the cost of forming/manufacturing these high strength fibers.

3. How much of 8.5 strength (MPa) in S-glass is transferred into composite performance (8500 →250?) this is an important question. I believe people in the composite area have looked into this some detail.
4. What can sizing (Note: not sure about this word) do to get back some loss of strength in composites??

BeO>MgO>CaO>SrO>BaO

Griffith Flaw is critical, but its effect can be mitigated by other elements see above

Increasing content of "networkers". Suresh suggested making everything out of borosilicates

Can better glasses be made at lower cost?

HIGH STRENGTH GLASS FIBERS

Need understanding of strain rate within environment

1. What are function of sizing in glass fiber?
   a. "healing" = allow structure ↑life, be "durable" (H_20 env.)
   b. Chemistry at glass allows fiber to work as matrix
      i. Not enough work yet in individual fibers!
   c. Moisture at interface of fiber/matrix is critical factor

Carlo discussed all issues of coatings, interfaces, etc. see below

9:00 – 9:40 a.m.

Emilio Spinosa, Owens-Illinois, Inc.: Issues and Opportunities in the Development of High Strength Glass Containers

HIGH STRENGTH GLASS CONTAINERS

1. Low tail critical ≈ 99% of data useless. Should encourage better data taking and sharing of data, together with a good description of the fiber and how it was made.
   a. Process
2. What does "mean" really mean?
3. Impact > issue mostly inside of bottle (forming method puts defects on inside)
4. Most critical flaws are flaws on bottom of bottle – on cold plate in process (looking for general coatings for both side/bottom)

15,000 people in containers – 35 billion containers made in US every year.

2.5 Mjoules/container to manufacture – if drop to 2.2, emissions down, less fuel usage.

If could double to 20,000 psi could take 25% of weight out of bottle

Glass Container Strength

Have to design for worst case

Flaw Healing Coatings – Organic coating – in lab – see Carlo again

Develop Surface Compression 30-40 MPa

Thermal Tempering – Blow Cold air onto surface

Chemical Tempering – exchange larger ion for smaller

Surface Layer of Lower compression Glass

Thermal Tempering

Wall Thickness variation very critical

Process Control Inadequate

Spontaneous Failure Occurred

Another company recently filed several patents, but data is sparse, progress

Ion Exchange – Brockway glass and Domglass. There are other instances of patents/processes/products that are either unknown or not well known (as Guardian carbon coating) that would be very useful, interesting and important to know more about. Share!!!

Spray solution of K-salt onto bottle after forming

Heat treat at 850 oF 1-2 hours

Successfully increased strength

To make progress:

Technically: heal or blunt flaws; eliminate low-strength tail; match returnable bottle thickness at non returnable thickness; decrease influence of inside surface flaws; compatible with container glass chemical composition

Industrially: accommodate wide range of forming speeds; integratable into current process

Benefits – reduce weight – reduce energy, green house gases, natural

Stippled surfaces – would that help?

10:00 – 10:40 a.m.

Adam Ellison, Corning, Incorporated: Post-forming Methods to Increase the Strength of Glass

(Not Present)

10:40 – 11:20 a.m.

Carlo Pantano, Pennsylvania State University: Role of Coatings and Other Surface Treatments in the Strength of Glass

Coatings/Other Surface Treatments – Glass Strength

- "Collaboration" is critical – a lot of fragmented work is going on but not an integrated effort
- High temperature surface treatments have great potential
  - Na Lime surfaces particular issue
- Need better way to "mimic" production/process environment in lab scale experiments ("pilot scale lab"). See comments about Emhart?? pilot lab
- Radiation treatments? Some indication of ↑ in "Ce" glasses
- Maybe a factor of "5X" improvement is sufficient for many new applications
- Strength cannot be just "skin" deep. Products have to last years. We look at strength increases in seconds.
- Crystallized surfaces – opportunity vs. impact on sustainability.
- Implications of "graphene" as a portion of costing = what about surface treatment of nano material? – nano-composite coatings? See comments of Steve Freiman
- Attracted to pristine surface by vander wood forces - ↑ adhesion
- Functionize nano tubes

- Always see a "distribution" of strengths even with "pristine" materials. Not true. See RK Brow et al UMR!!
- Polyamide coating performance – N- surface glass (amines) are "pulling" fatty acids down into flaws. In lightguide studies it was found that polyimide coatings had an effect on strength/fatigue that is not completely understood.

Fundamental issues in glass strength

-Mechanical damage – flaws at the glass surface

-Intrinsic strength – fracture toughness of the glass

-Fatigue (water chemisorptions and corrosion)

-Residual stress and bond strain

Important role for coatings in strength

-mechanical barrier: modulus and thickness

-Abrasion resistance – hard and low friction (smooth and lubricious)

-Water barrier

-Compressive residual stress

-Flaw healing, especially in cut edges

What about coating-glass interface

Coatings for strength are necessarily application specific

Could be a universal multi-functional "platform" for coatings that could be tweaked to various applications.

Surface Treatments

Flaw healing – flame polishing or acid etching. It would be interesting to study etching with less hazardous chemicals than HF.

Compressive residual strength – ion exchange

Dealkalization treatments – fluorine treatment

Ion-Exchange

If problem is cost, where is the cost, and why not pursued. Believe problem is "case-depth".

Can we combine surface treatment that by itself may not be enough, but with coating could be good.

Coca Cola – problem was not cost, but "manufacturability". Patented because believe it's viable.

Where are critical events that prevent application of technologies.

Real challenge is to figure out a way to address all the issues in a better way than we have in the past, through working together.

"Graphene" possible coating – not yet applied.

11:20 – 12:00 p.m.

Bulent Yoldas and Refika Budakoglu, Sisecam: The Improvement of Fracture Toughness of Glass by Surface-Modifying Coating

Abstract

Commercially produced glasses commonly exhibit strength values less than 1% of the theoretical strength values. In this work, strength of float glass was increased 3 to 5 fold by hybrid coatings. Besides developing different compositions of coatings, other parameters that control the coating performance, such as mechanical performance and fracture characteristics of the coated film, thickness of the coating, curing conditions and various glass surface treatments have been studied. Hybrid coatings have been studied by many others. Need to fully document these preliminary studies.

Fracture Toughness

- Coating can improve both the mean strength (5X) and also the minimum strength (2X). Need to see detailed data.
- Coatings have been focused on flat glass

Work with Sisecam at strength from perspective of chemist.

Realized it's not a single property of the material. Many different aspects:

-Stiffness (resistance to bending, tension or compression) (mega or gigapascals)

-Tensile strength (resistance to breaking during pulling) (mega or gigapascals)

-Fracture toughness (resistance to impact, NO (instantaneous crack propagation)) (joules)

12:00 – 1:20 p.m.

Lunch

1:00 – 1:20 p.m. (overlaps with last 20 minutes of lunch)

Mark Doyle, World Kitchen: FILM – Commercial Applications Yielding Strong Glass Tableware

Arun Varshneya, Alfred University - On invitation, Arun Varshneya, professor of glass science and engineering at Alfred University and president of Saxon Glass Technologies, Inc in Alfred presented a 4-minute preview of his next day's invited paper entitled, "High-Strength, Large Case-Depth, Chemically Strengthened Lithium Aluminosilicate Glass". He showed that a lithium aluminosilicate flat glass obtained from NEG (Japan) could be chemically strengthened using a mixed potassium/sodium nitrate salt bath to as high as 1 GPa surface compression with as much as 1 mm case depth. Such technology could be useful for transparent armor, other commercial and civilian vehicle transparencies, hurricane-resistand architectural windows, and display glass markets.

1:20 – 2:00 p.m.

Tanguy Rouxel, University of Rennes: Indentation Damage and Residual Strength of Glass

- Other glasses than window glass being studies? – A: starting some work
  - Problem in window glass in Europe drove interest
- Did work both on "tin" side and "float side" of process
- Important to study same "surface" and "same glass"
- Elastic Modulus Δ What Δing in going from lower temp
- Fracture Surface Energy Δ lower temp to high temp (brittle failure mode)
- Application of work to glass bottles? Could probably make some application to bottle, but would have to factor in process complexity in bottles vs float glass
- Wait 4 hours before indenting (hold at temperature to establish thermal balance – new equipment is unavailable

  This was an interesting paper, but Rouxel and his people have been doing VERY important work on indentation. See several other papers during the meeting. Some not presented because of absence of 1st author, J C Sanglebouef

2:00 – 2:40 p.m.

Frederic Lechenault, University of Montpellier: Nano-Scale Fatigue and Failure Process in Glass,. This is interesting work using AFM to study crack propagation. This and similar/complimentary work was presented by Wiederhorn at the meeting. There are still some disagreements between groups. This may be an area where some funding of joint work would be helpful and speed resolution of the problem.

Nano-Scale Fatigue/Failure in Glass

Q: Any work on different glass composition
A: Not yet

- Need to understand
  - how ion exchange at the surface related to stress
- FFM/Can scan surface of slow moving cracks then look at broken surface separately

- Get condensation on fresh formed glass surface fiber before you can get sample in the AFM
- Fracture surfaces are very inactive
- Environment of studies
  - controlled humidity
  - complex chemical reactions

Saint Gobain did studies of two glasses
During this and the paper by Wiederhorn, there questions about doing AFM in vacuum. St. Gobain had a vacuum AFM. I have seen no results using this.

2:40 – 3:20 p.m.

Alastair Cormack, Alfred University: Modeling Glass Failure and the Strength of Oxide Glasses

Q: Strain capability under tensile load?
A: 1-15%

- Have not done simulation under compression of load – could do that! Good exercise!
- Could you determine elastic properties
- Can get strain dependence of modulus in silica system (currently working on this. Done!!)
  - High strains might Δ¨ elastic modules??can go up or down with strain

If have a composition within limits can model be a broad range of glasses:
  - E.g., aluminosilicates, alkali earth aluminosilicates
  - B still a challenge (B-true systems not problem)

Concern – very high strains rate at maximum bends? Yes!

<u>Modeling Glass</u>

Can you study impact of coating?
(layer of H_20 is now taxing computational capabilities might limit range of coatings that could be studies)
- Reactive force field models might be more applicable to coating systems

3:25 – 3:40 p.m.

Mark Doyle, World Kitchen: FILM – Commercial Applications Yielding Strong Glass Tableware. Corelle is a magnificent example of what can be done with glasses. This cladding work was anticipated by ~75 years!!! See WRP AND CRK

Comments on the June 4th Symposium Given by June 5th Review Participants

"It is almost impossible to get speakers to do what they are asked to do. I was unimpressed with most of the presentations, except Carlo Pantano's."

"I would have liked the speakers to have included more about what others are doing in their specific areas, in addition to just their own specific research activities."

"Great discussion at the meeting"

"The talks drew people together and the program was well attended, but more time was needed for discussion – a longer meeting more like the NATO glass strength meeting convened in 1983".

"Good symposium format. The timing was good. We need more attention to be directed at what we do next – strategy and next steps."

"Need deeper discussion on several of the topics – progress or lack of progress"

"Good start with the first two talks, but the quality dropped off as the day proceeded."

"The meeting served a great purpose – there is a lot of interest in this topic. The room was full and overflowing."

"It is the intent of the TC committees of the ICG to work more closely as the organization moves forward. Are there some things the TC mechanical properties committee (TC-6) could do as a follow-up to this meeting?"

"The various organizations serving the glass industry are "stove-piped" with little interaction except for individuals who are members in more than one glass organization."

“I was impressed with the level of attendance”.

“There was too much to do in one day. I was disappointed in the afternoon sessions. We need to develop a roadmap for glass strength and specific next steps for follow-up soon after this meeting.”

“There are two sets of responses. One – what do we do to enhance glass strength overall and two – what can we do day in and day out to make stronger glass products in the individual sectors, bottles, fiber, etc.? We need new research initiatives in the bottle industry and a quantum step improvement in our process. “

“The mix of attendees was impressive, including representatives from academia, industry, and glass users.”

“We took a small step in looking at ways to improve glass strength, but need more input from the perspective of glass manufacturers to turn this into something useful for the glass.”

“We need to keep going; specifically we need to define the critical problems and propose scientific approaches to solve them.”

“It worked very well to have glass manufacturers/users and the theoretical scientists together in a common forum. The glass practitioners help by asking the right technical questions; the research and theory folks can then propose useful solutions.”

“Don’t try to separate the user groups from the manufacturers. The companies that purchase glass products have glass scientists that are working on glass strength technical issues that may relate to the manufacturing process and its technical issues”. (This comment from a representative of the glass user community was in response to a question about the need to form users groups to discuss and drive glass research needs). More attention needs to be directed to stating goals and objectives for specific glass research programs. For example, it would be easier to attract funding to a program with an objective to “increase production efficiency by 1%” than to find sponsors for work to “understand contact damage”. “We need to focus on the greater purpose for the list of proposed fundamental work. A proposed pilot scale facility to conduct experiments that mimic production operations may not be needed for research on strength for bottles, since Emhart has already built a $20 million pilot facility."

"I was impressed with the attendance. The discussion was more important than the presentations and it highlighted the depth and breadth of the problems. The challenge now is to determine how to distill the output into two or three key problems and structure ways to more forward on these few selected key problems."

"I was pleased with the discussion during the day. The first two papers stimulated very good discussion. I did not see the group getting to any solutions. We need people getting together for deeper discussions in small groups or one-on-one to develop new ideas and concepts further."

"I liked the idea proposed by someone yesterday that university researchers be given a "sabbatical" to leave the university setting and spend time in production operations for a more in-depth study of the opportunities to improve and preserve glass strength."

"There are three key areas related to surface condition that need more effort – edge strength, fatigue and scratch resistance. The strongest glass may not be the best solution for all conditions. We need more study of the environmental conditions glass will see. The surface is the most important area for expanded research. We need to find ways to change the surface where we want it changed and we need to explore hybrid materials, combinations of materials and selective use of specific materials."

"This was a very useful forum, but we need to put ideas through a technological process and focus on better results."

"No one gave any good reason not to have better coatings. We need more dialogue about coatings and greater collaboration. We also need to more aggressively pursue funding sources for this work."

"What we did not do yesterday is to define what "strength" really means. "

“As an industry we have not pursued any improvement in the quality and purity of raw materials used in production of our glass products. We have not studied the impact of better raw materials on performance.”

“We need to continue the dialogue started at the conference and focus on the real needs of the industry including cost performance. We need to pursue new sources of research funding. We also need to continue to engage greater industry cooperation and, in particular, conduct more round robin studies beyond the current efforts of the ICG (TC-6 Committee).”

“We need to focus on keeping the glass strength we have through production and product use versus trying to improve short term strength.”

“Great session, but I did not get any real new insights. Our efforts should be focused on preserving strength. Preserving strength is largely an engineering problem. We need to develop alternative forming processes and better coatings. We need a focused follow-up with a multidisciplinary groups working with clear goals and objectives.”

3:40 – 5:40 p.m.   Panel Discussion

The Panelists

Julide Bayram is currently Research and Engineering Manager of Sisecam a company in the manufacture of glass and chemicals, encompassing all the key areas of glassmaking: flat glass, glassware, glass packaging and glass fiber. Sisecam's global rank varies from third to eigth in its field amongst the world's most distinguished glass manufacturers. Sisecam reached its current position with a concentration on corporate standarts and a focus on R&D.

Jülide began her career as a Project Engineer in the Technical Group at Sisecam's Headquartes. As part of the RD& E team she worked on various furnace design projects, regenerative, recuperative and oxyfuel furnaces. She was part of the team doing various development work, Improving the energy efficiencies of furnaces and environmental management . She has taken part in the project management of many greenfield investment projects like float, tableware, container glass plants both in Turkey and abroad.

Additionally, Julide has received bachelor's degree in chemical engineering from the University of Bosphorous in Istanbul. She had MSc degree in chemical engineering from the University College of Swansea in U.K.After she joined Sisecam she has taken courses in glass technology held for ten weeks for students from the ındustry in University of Sheffield,

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Problems facing in our company – related to float glass. Faced with energy efficiency concerns. Trying to lower energy consumptions, also producing glasses that are helping to lower CO_2 emissions. Demands are changing – Automotive glass – trying to make cars lighter – tempering and annealing to permit lighter glass is important.

Offline coating needs to be improved – need to improve soft coatings, if can handle during transportation.

Edge strength is important – cutting. At least Corning and Schott are studying/using laser cutting. At some level this work should be shared.

Container – interest in coatings. No development work. Not found yet good coating that is scratch resistant and doesn't peel off.

Tableware – Corelle is known, but some products are saying their glass is unbreakable, but how do we test to know. Need to develop standard test methods to judge.

Fiberglass – not really involved in improving that at this time.

Many issues on which we can work together but how do we do this without getting into competitive issues. We hope that with work of Bulent/Refika, hope we can develop to other lines as well.

Have not seen glass projects on international basis that we can join.

Lack of communication between European and American institutions. Need to find a way to make it work. We are ready to cooperate, but need to find a way to do so.

Steve Freiman, PhD graduated from the Georgia Institute of Technology with a B. ChE. and a M.S. in Metallurgy. After receiving a Ph.D. in Materials Science and Engineering from the University of Florida in 1968, Dr. Freiman worked at the IIT Research Institute and the Naval Research Laboratory. He joined NIST (then NBS) in 1978. From 1992 to 2002 Dr. Freiman served as Chief of the Ceramics Division at NIST. Prior to his leaving NIST in 2006 to start a consulting business (Freiman Consulting Inc.), Dr. Stephen Freiman served for four years as Deputy Director of the Materials Science and Engineering.

Dr. Freiman has published over 150 papers focusing on the mechanical properties of brittle materials. He was the first Chairman of the ASTM Subcommittee addressing brittle fracture and a past Chair of the VAMAS steering committee. In the American Ceramic Society, he served as Chair of the Glass and Optical Materials Division, Chair of the Program and Meetings Committee, Treasurer, and President of the Society. He is a Fellow and Distinguished Life Member of the American Ceramic Society.

Is there a way to reduce the sensitivity of glass to crack growth, while still retaining transparency?

Combination of alumina and zirconia as a composite results in steeper curve (?) than either one by itself. Steve described the above literature excerpts, and suggests that this might be possibility in glass. Good for follow-up by him with glass company support.

Jill Glass manages the Materials Reliability Department at Sandia National Laboratories in Albuquerque, New Mexico. Her department encompasses expertise in corrosion, electrochemistry, cleaning and contamination, gas analyses, multivariate data analysis methods, and the mechanical behavior and reliability of glasses and ceramics. Jill joined Sandia in 1990, and as a Principal Member of the Technical Staff, led and contributed to research, development, production, and failure analysis activities primarily focused around the mechanical behavior or glasses and ceramics. Her areas of research included joining, ceramic powder compaction, stressed glasses, fragmentation of brittle materials, cermets, and glass ceramics. Jill obtained her B.S. in Ceramic Engineering (1984) from McMaster University in Hamilton, Ontario, and her M.S degree (1987) and Ph.D (1990) in Ceramic Science from Penn State University. Her graduate work under Dr. David Green covered the processing and mechanical properties of novel infiltrated alumina-zirconia composites.

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Interested in performance of glass around safety issues coming out of Murrah Building explosion (Oklahoma city). May not be desirable to make glass stronger – acts as a "pressure vessel" in an explosion. Perhaps we need to make glass behave in certain way at some times, different way at other times: "Smart Glass".

We're often stuck with what we have – would like to control the structure of the glass. A lot of what we do is correcting defects that develop after making the glass. Exactly!! Adjust glass composition for increased toughness and crack resistance – less brittle – bad name!!!

Can we think of making things layer by layer, atom by atom? Interesting for high tech glasses.

Importance of doing failure analysis, collecting data. This is certainly true as others have said.

Suresh Gulati, PhD is a Senior Scientist, with over 30 years of experience in catalytic converter technology with Corning, Inc. Dr. Gulati is an expert consultant for the Company. He is an authority in the catalytic converter business with his extensive experience in the development of emissions control catalysts and ceramic substrates for catalytic converter application. He is a regular speaker at Society of Automotive Engineers (SAE) conferences and technical courses. Dr. Gulati has authored or co-authored over 25 papers related to emissions control and received numerous company and industry awards, including Corning Research Fellow (1983). Dr. Gulati holds a Ph.D. in Applied Mechanics from the University of Colorado, an M.S. in Mechanical Engineering from the Illinois Institute of Technology and a B.S. from the University of Bombay, India.

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Interest in strength goes back – motivating factor is to make money for my company. True, but it is JUST possible that increased collaboration will help all. The rising tide will lift all the boats!!! "Strength" – value of stress that is sustainable by glass for a very short time. During measurement of strength are putting under stress.

What is usable strength of glass? Size of specimen you're working for.

Talk of strength of glass in fibers. Fibers don't have edges. Flat glass has its own issues with edges. People are studying this. Need to share data/experiences.

Statistical variability we heard about today can be more important than the mean. Reliability analysis of product – Japanese wanted slope of 20. Difficult to get.

Surface compression by coatings or protection. Compression is important, but so is the depth of compression – gives additional protection of the flaw not to go into tension. Attempt to measure strength of glass in interior is higher than on surface. Believe have a way to measure.

Why not switch to borosilicate glass in a massive way? Expansion from 20 to 60.

Can get "thermal checks" or "surface cooling" of defects. Very durable – acidic. Viscosity, melting temperature – very similar to soda-lime glass.

Kes a few seconds or milliseconds before it gets a coating. Important what is happening to glass in that period. A lot can happen before it gets a coating.

Jim Varner, PhD – Professor of Ceramics Engineering and Materials Science at the Inamori School of Engineering, Alfred University, Alfred, N.Y. His group is interested in mechanical properties of glasses and ceramics. Within that broad area, they focus on fundamental studies of contact damage in glasses and how processing affects strength and fracture toughness of ceramics. Issues include how glass structure affects crack formation and scratch resistance, and how waste materials can be turned into high-strength, high-toughness SiAlON ceramics. They are beginning studies on a new type of composite armor material. Finally, they investigate issues that relate to failure analysis of brittle materials (fractography).

Current Research:
Recording microindentation study of crack-initiation behavior in optical glasses
Recycling of production wastes from silicon wafers to produce SiAlON ceramics with improved mechanical properties
The use of fly ash in the production of SiAlON-based structural ceramics
Improving scratch resistance of alkali-silicate glasses
Optimizing the properties of a novel composite armor material

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Today – listening to talks and comments – provide summary of things that are key from today:

When talking about strength of glass – two issues:

Fundamentals – apply to all glass objects: relationship between strength and glass structure (not composition) good!. Alastair Cormack said can calculate the structure of any composition - except for boro-silicates (modulus of elasticity, toughness, hardness). Eliminate low-strength tails.

Preserving strength for long term – very important – resistance to contact damage (coatings, surface compression), resistance to the effects of water.

Fracture toughness of glass – what is it? Always say 0.8 or 0.9. Can we increase the fracture toughness? Can we do it with commercially viable glasses?

Better understanding of structure level flaws (intrinsic flaws).

Objects – specific strength issues: edge strength, melting, handling, interactions.

Coordination of efforts – Have an organization set-up to do that: ICG. Within ICG "Coordinating Technical Committees" and individual technical committees. Rene Vacher taking over as chair of CTC. Trying to provide a better sense of coordination and overall direction for Technical Committees.

Identified relationship between structure and properties as an issue.

GMIC, DGG, GOMD, other national organizations – cooperation between national organizations.

David Pye – impressed with advantages made. But lot of things have stayed the same. If want to go forward – what do we know for sure?

Except under special situations rarely address theoretical strength of glass. Brow, UMR, Rolla

Degradation during forming process. Degrade strength of glass and spend all time trying to recover the strength towards theoretical limit. Could there be a better approach: once it's formed, try to maintain the strength? Many others have said this. It is true. Look at increasing cracking load, etc. study stress birefringence during indentation/scratching CRK!!!$$$ If could save one cent on 35bn bottles made each year could make enormous difference.

Could be technology out there to form a glass bottle and prevent it from having contact that will damage it.

Chuck – need to develop a means to cooperate internationally.

Steve – Do people feel they have access to the data they need? SciGlass and Interglad. These are both good, but what is needed is more practical/engineering/strength/mechanical data.

Asahi Glass has a data base, but Spin says it's limited interest: focused on optical glass

Arun – As officer of ACERS say that on Monday a whole new web site will be launched. Can attach a data base to it.

Suresh – govt. should maintain a data base.

NSF has financed "Data shift partnerships". $10mm to bring industry together to develop (Carl Muller – Penn State) look into this!!!!!

Chuck: Developing stronger glass intrinsically is highly desirable. Stronger to start with and stronger after fatigue at any time. Also, it is likely that higher strength glass will be less susceptible to contact damage.

Data base – Have hardly any mechanical, physical data of materials at all.

Manoj – Perspectives – Presentations lead me to conclude that over last 10 years understanding of issues have become more refined. But had no real insight to allow me to go back to do anything different from what I've been doing until now. Not completely so. Rouxel/Yoshid have made great strides in understanding indention behavior (also Tomozawa/Koike/Gross) On industrial side – Collaboration needed – at micro level: Carlo, Dick Brow – spend six month sabbatical to understand parameters of glass strength. At Macro level – GMIC could undertake an initiative – commonalities between glasses: glass-polymer interactions.

David P. – Ceramic Properties data base – one of highest priorities of members some years ago. New web site.

Steve Freiman – 1983 – Chuck organized NATO meeting in Portugal. Talked about data base of glass toughness.

Jill – what are the highest values of fracture toughness? B2O3 at 1.5 – real???

Bulent – need to be looking at combining with different materials.

Statements of things we could work on next – to improve glass strength

Criteria

1. Potential for collaboration
2. Opportunity for Improvement – improving glass strength (what do we mean?)
3. Application Breadth
4. Impact on Society – improve glass industry.

Priority Votes

- (13) Change Mfg process to get glass coated sooner – low cost. (Concerted effort to work on new coating or coating methods. (Consortium or collaboration with people who could bring this)
- (10) Completely understand contact damage.
- (9) Realistic Simulations (simulate glass structures with realistic strain rates, quench rates) (could tie in with surfaces) (What simulations? Structural? Other?) Want models to do "this".
- (8) Bridge between manufacturing process and mechanical lab work
  - Small laboratory that mimics production processes – between manufacturing processes and measurement
- (8) Make greater use of nanotechnology (to improve glass) (fit in with coatings?)
- (6) More Fundamental Research (glass properties at very high stress rate).
- (5) Eliminate surface brittleness
- (5) Non-destructive evaluation methods.
- (5) Database – data re-use
- (4) Double working strength (preferably through composition change)
- (3) Improve or combine current strengthening processes ion exchange, tempering, lamination.
- (2) Forming platform does not degrade the mechanical properties of glass without losing all process benefits we now have (economics, speed, safety).
- (2) Program on flaw healing – same failure mode in E and S glass.
- (1) Develop better ways to measure mechanical properties, new techniques.
- (1) Surface strength renewal methods – self-healing
- (1) Why soda lime? Are there other chemistries that should be considered? Get out of box!
- Understand where low strength "tails" come from (fibers, bottles).
- (1) Process Development to desensitize the glass to presence/size of flaws
- (1) Develop a business case for higher strength glass in each sector of interest.
- (1) High profile projects (Eg: glass submersible – raise public awareness)
- (1) Include mechanical and chemical engineers together with scientists to look at forming processes with material scientists.
- Revisit 1983 NATO meeting outcome that drove research for a long time.
- Chemical reactions at glass surface.

- Preserve what has been achieved. (properties)
- Need longer symposium like this one –
- Study how we can maximize use of the mechanical properties data we already have.
- Sort out the weak products – specialty apps.
    - proof-testing product specific.