Plastic deformation of silicates and tensile strength

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Abstract:

We raise the question of the relation between the "intrinsic" tensile strength of silicate *fibers* and amorphous silicate plastic deformation.
An issue which has been strongly debated recently is the type of mechanical processes active at the crack tip in amorphous silicates (ductile vs brittle). Interesting results have emerged which limit the possible extent of plastic deformation at the crack tip. However a full description of the processes active at the crack tip is still lacking. The question is how bond breaking defines the crack path and to what extent does irreversible material rearrangement occur around the crack tip. This configurational rearrangement goes through bond breaking and reformation and is directly related to plastic deformation.
For small scale yielding, general considerations allow estimates of plastic zone sizes *c* to be made. In the case of silicates (brittle materials), it is generally small, of the order of 10 nm. From brittle fracture theory, the crack size *a* can be determined. When typical sample sizes shrink, it is often found that tensile strength increases so that *a* decreases. For the very high strengths found in pristine fibers, it may be argued that *a* and *c* are of the same order of magnitude. In this case, it is possible that local rearrangement then becomes a process of some significance.
In this contribution we would like to discuss the relevance of high strength fiber experiments to the understanding of amorphous silicate rupture. We will review some of the parameters affecting fiber strength such as

- temperature
- ageing
- water (at the surface or in depth)

and try to bring them in relation with silica rearrangement processes[1]. We will also raise the question of the development of advanced micro-mechanical experiments and modelling which could help in this area.
Finally we would like to emphasize the connexion between the local picture of fracture, corrosion, rearrangement mechanisms in silicates and other macroscopic processes of practical interest such as

- Strength degradation of silicate glass from surface contact damage.
- Mechanics and strengthening of sol-gel coatings
- Chemo-mechanical polishing

but also other interesting phenomena in other areas such as geochemical compaction.or lubrication of silicates in water.

[1] As an example a parallel between the impact of water activity on hardness and its impact on tensile strength seems to hold for various types of silicate glasses. Is this a mere coincidence ?

Questions to be answered:

1. What are the main R&D topics in your research field and what happened in the last 5-10 years in that research field?

The field of plastic deformation of amorphous systems is very active. The case of silicates is a (small) subset. To support these claims let us mention :

- BMGs (Bulk Metallic Glasses): very different materials but they show the way in terms of plastic deformation in amorphous systems
- Modelling at various lengthscales of disordered materials. For multi-scale modelling amorphous materials are an opportunity because fewer lengthscales are involved.
- A number of recent experiments on plastic deformation of silicates
- The opportunity of using new micromechanics tools

2. What will happen in the next 3 years (short term), 8 years (mid term) and 15 years (long term) in your research field?

Development of micromechanics driven by semiconductor industry: an opportunity for micromechanics at small scale.
Modelling of the rearrangement processes and understanding of the impact of chemistry
What is the limit of sol-gel systems in terms of mechanics (does one need high temperature condensation and sintering) ?

3. What would be a topic stating an exceptional success to be published in a well known journal in 2025 concerning your R&D field
(Comment: Please make a short statement; also unrealistic scenarios are welcomed because we should open our mind beyond the existing boundary)

BPSG (Bulk Plastic Silicate Glasses)[2]. ☺

4. Please name five key challenges for the future (till 2025) with regards to your R&D field

a) High throughput micromechanical testing of glasses as a function of environment
b) Constitutive equation including plastic deformation in tension for silica. Merge with viscous response at high temperature.
c) same for soda-lime silica glass (with non-bridging oxygens) and alkali-aluminosilicate (with no non-bridging oxygens)

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[2] This result has been published I[st] century AD. Indeed plastic glass is one of the many colourful inventions strewn around Petronius' Satyricon. In chapter LI, a glassmaker proudly presents the stunned emperor with a marvellous glass vase which does not shatter when thrown to the ground: the bumps can even be mended with a hammer. For more on the enlightened marketing policy developed for this technological breakthrough and why the results were lost, the reader is referred to the original text (T. Petronius, Satyricon, ch. LI).