The Effect of Structure on the Mechanical Properties of Phosphate Glass Fibers

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Introduction

Phosphate glasses are used in a growing number of applications and as such it becomes increasingly important to understand their physical behavior. This work is focused on finding the relationships between the strength of phosphate glasses and their composition/structure. The glasses used in this study vary from Fe-phosphates developed for nuclear waste encapsulation to commercial laser glasses. A two-point bend technique is used to measure the strain at failure. Stress is calculated using an acoustically determined elastic modulus. Phosphate glasses are weaker than silicate glasses and exhibit an anomalous dynamic fatigue behavior.

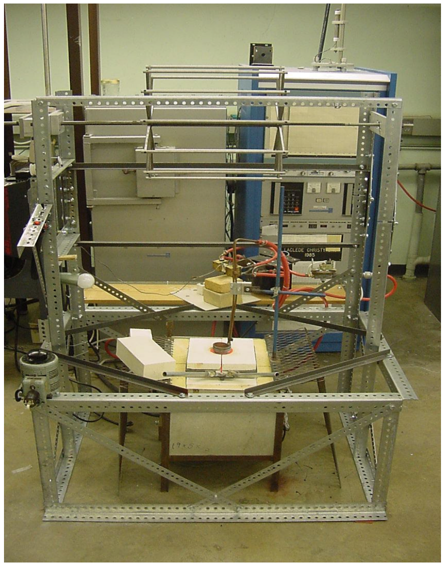
Glass Compositions

Glass	Composition in Mole %											
	Na_2O	K_2O	ZnO	MgO	CaO	BaO	Fe_2O_3	Al_2O_3	P_2O_5	Nd_2O_3	B_2O_3	SiO_2
LG-770*	--	20 - 25	--	5-10	--	--	--	6-10	58 - 62	0 - 2	--	--
LHG-8*	--	13 - 17	--	--	--	10-15	--	8-12	55 - 60	0 - 2	--	--
NAP	30	--	--	--	--	--	--	10	60	--	--	--
KAP	--	30	--	--	--	--	--	10	60	--	--	--
CAP	--	--	--	--	30	--	--	10	60	--	--	--
BAP	--	--	--	--	--	30	--	10	60	--	--	--
MAP	--	--	--	30	--	--	--	10	60	--	--	--
ZAP	--	--	30	--	--	--	--	10	60	--	--	--
ZAP-Z40	--	--	40	--	--	--	--	10	50	--	--	--
ZAP-A15	--	--	20	--	--	--	--	15	65	--	--	--
ZP-Z50	--	--	50	--	--	--	--	--	50	--	--	--
F-40	--	--	--	--	--	--	37	--	63	--	--	--
60-20-20	20	--	--	--	20	--	--	--	--	--	--	60
E-glass	--	--	--	7	19.5	--	--	8.5	--	--	9	56
Silica	--	--	--	--	--	--	--	--	--	--	--	100

- "Pristine fibers" (80 – 200 micron diameters) drawn for strength measurements.
- Fibers ~ 1 to 2 mm diameter (10 - 15 cm long) are used for elastic modulus measurements.

* J.H. Campbell et al., J. Non-Cryst. Solids 263&264 (2000) 318.

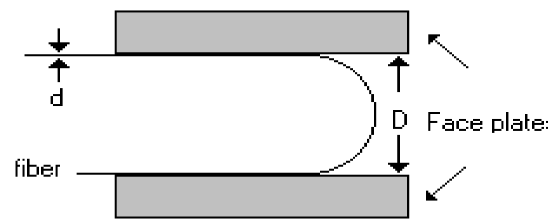
Measuring Strain and Elastic Modulus



• Fiber is continuously up-drawn from a small box furnace onto a wheel with open sides. The fiber are supported by threaded rods held in place by radial spokes at either end of the wheel. This setup produces pristine sections of fiber roughly 3.5” long.

•A computer controlled two-point bend* apparatus is used to fracture the fibers. The equation used to relate gap at fracture to strain is:

$$?_f \; ? \; 1.198 ? \frac{d}{D \, ? \, d} ?$$



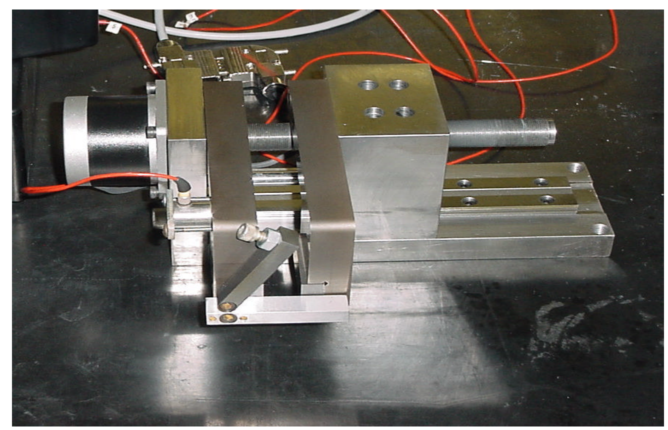
• An acoustic wave setup was used to determine the elastic modulus of the glasses. Transverse wave velocity (V_T), longitudinal wave velocity (V_L) and density (?) are measured for the calculation of elastic modulus (E):

$v = (1-2(V_T/V_L)^2) / (2-2(V_T/V_L)^2)$

$E = V_L^2 \times ? \times ((1+v)(1-2v))/(1-v)$

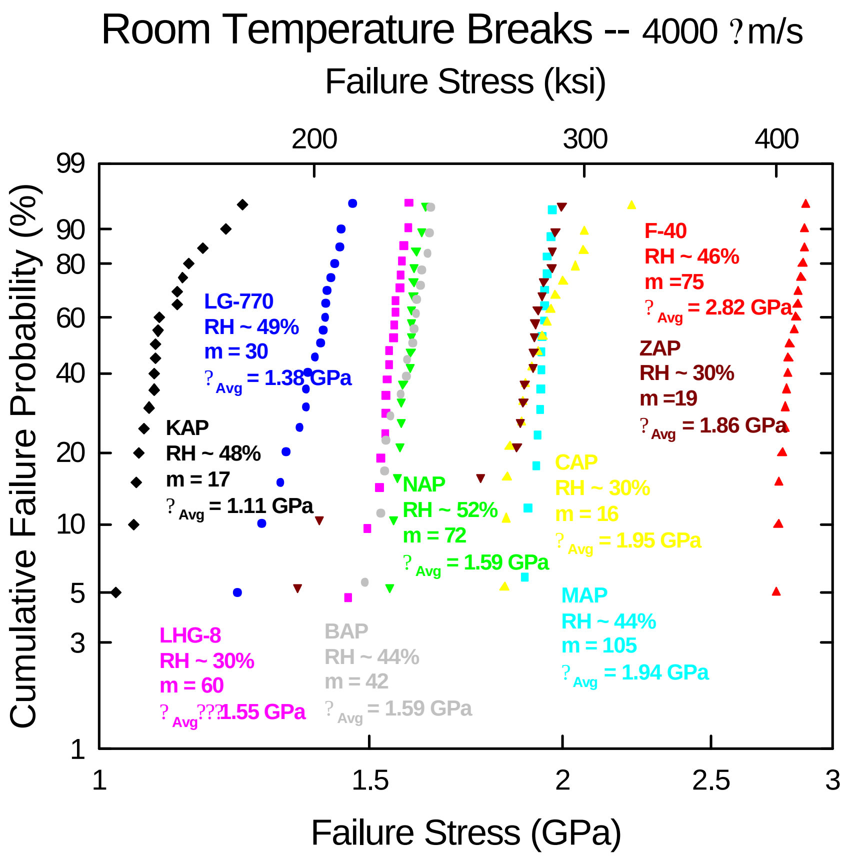
v = Poisson’s ratio.

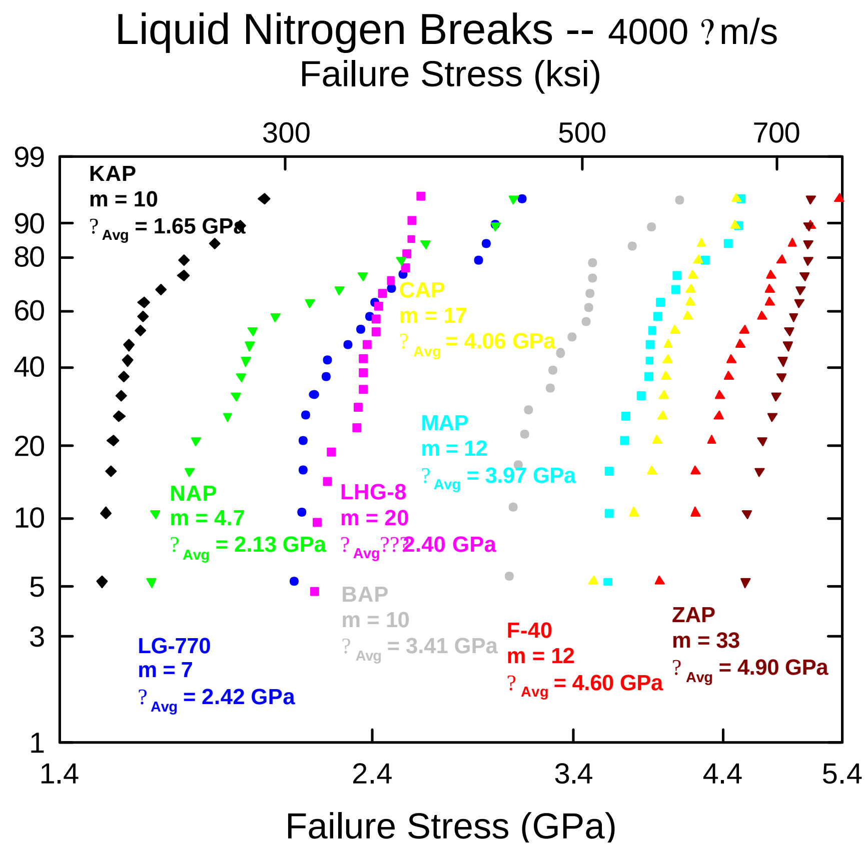
? = Density.



*M.J. Matthewson, C.R. Kurkjian, S.T. Gulati, *J. Am. Ceram. Soc.*, **69**, 815 (1986).

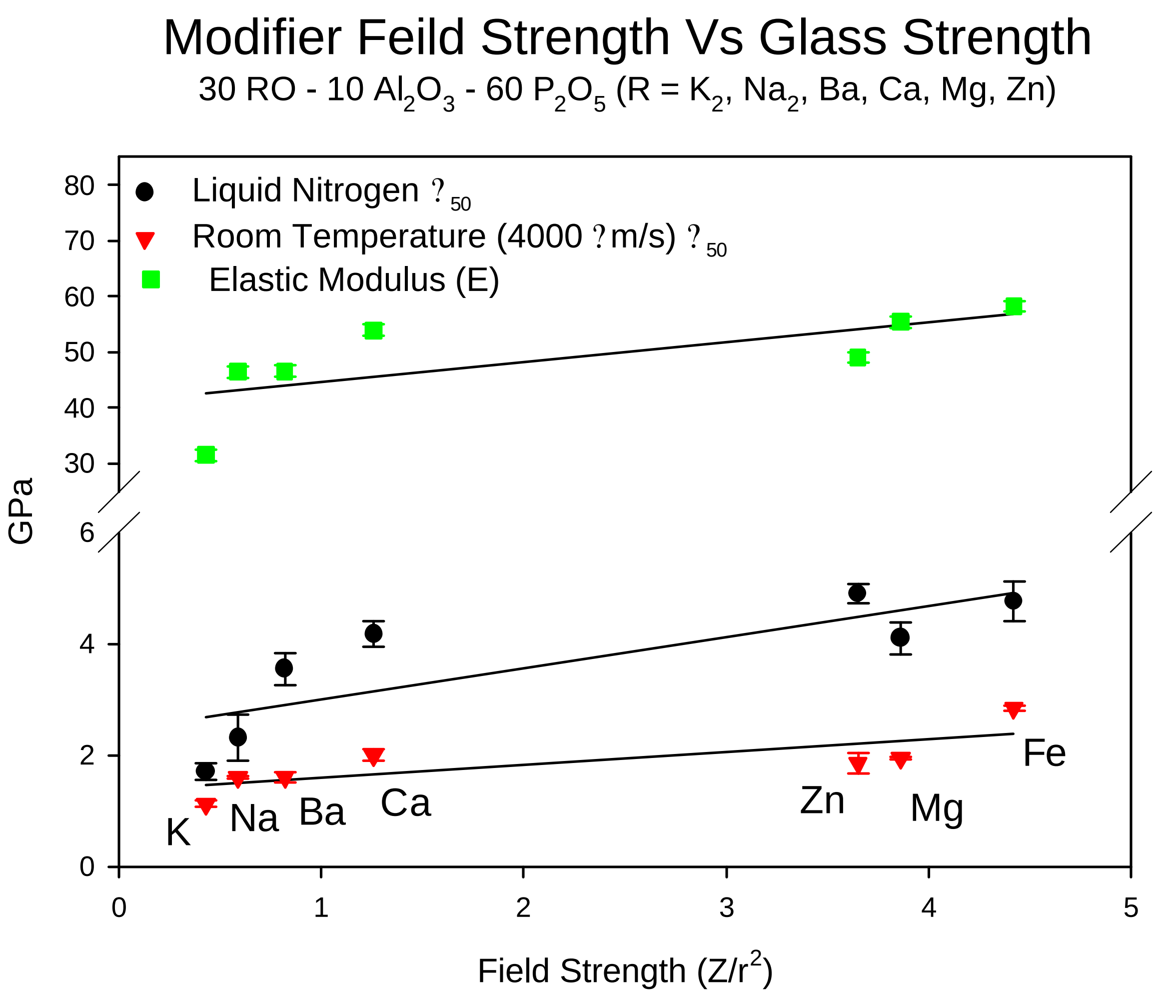
Fiber Strength Depends on Composition





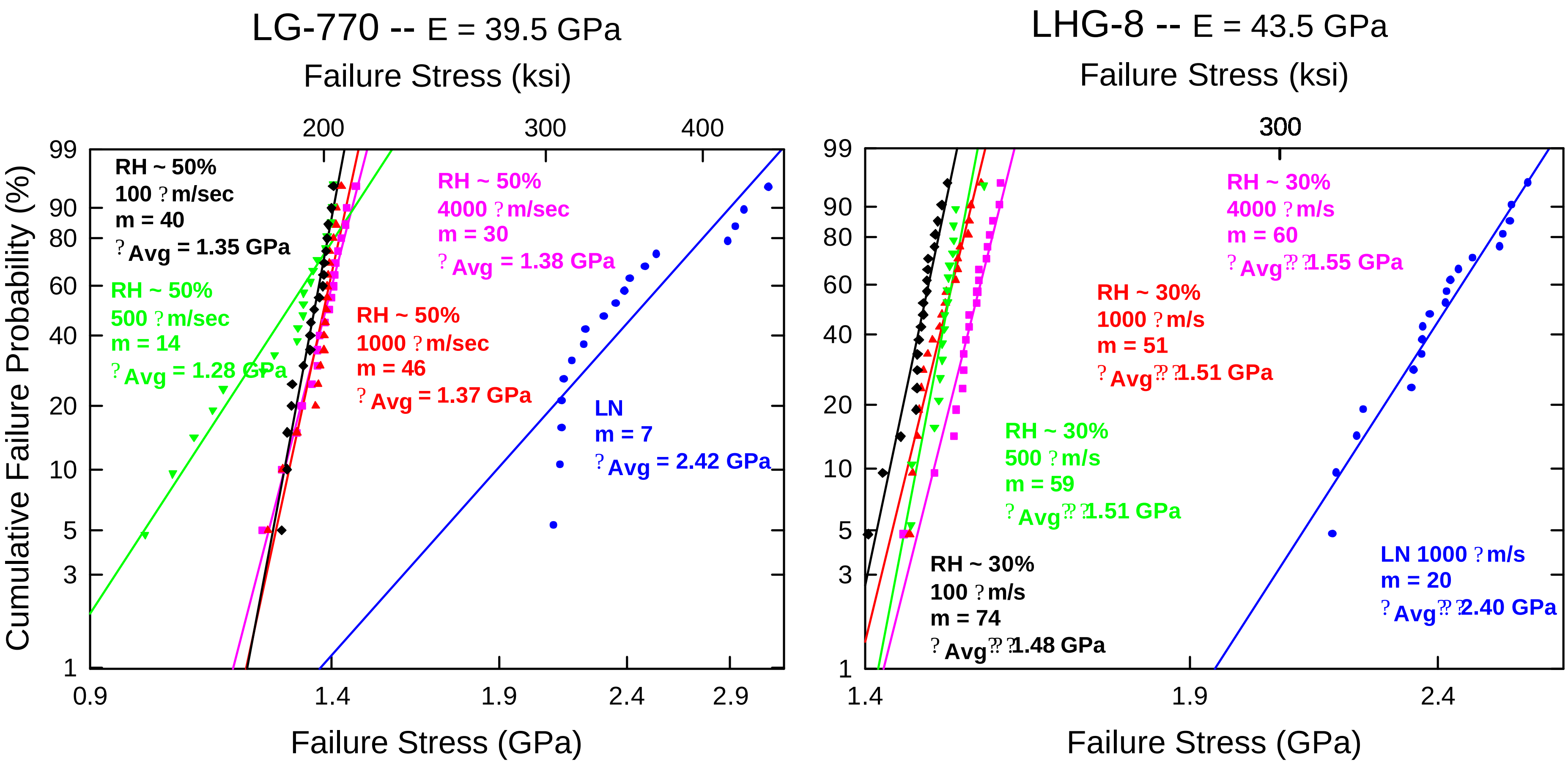
- Unusual strength distributions in liquid nitrogen fractures.
- Fiber strength depends on composition (higher strength for greater field strength modifiers).

Modifier Field Strength



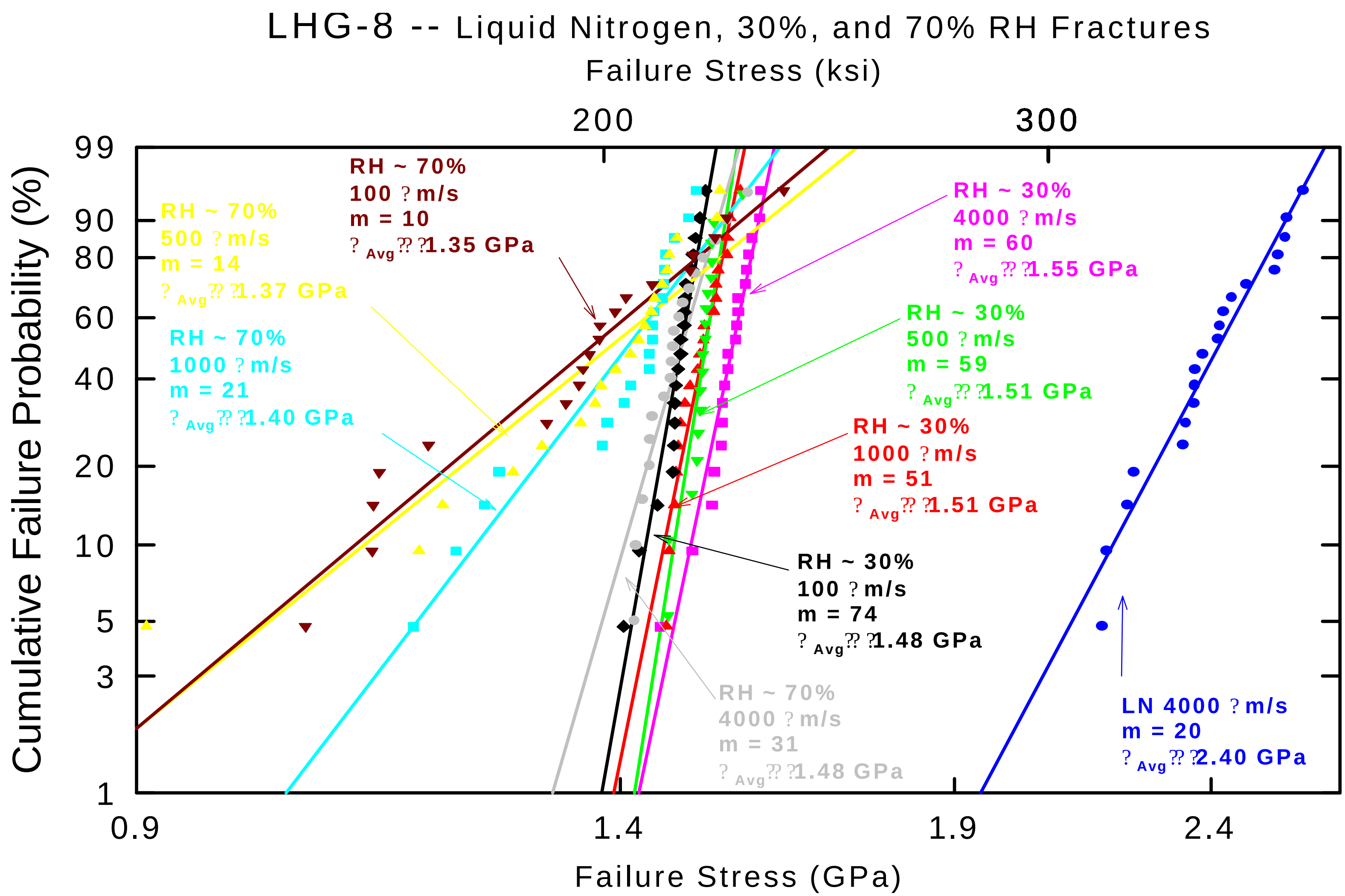
- Failure strength and Elastic modulus increase with modifier field strength.
- Fe field strength is weighted average of 18% Fe^{2+} and 82% Fe^{3+}

Phosphate Laser Glasses



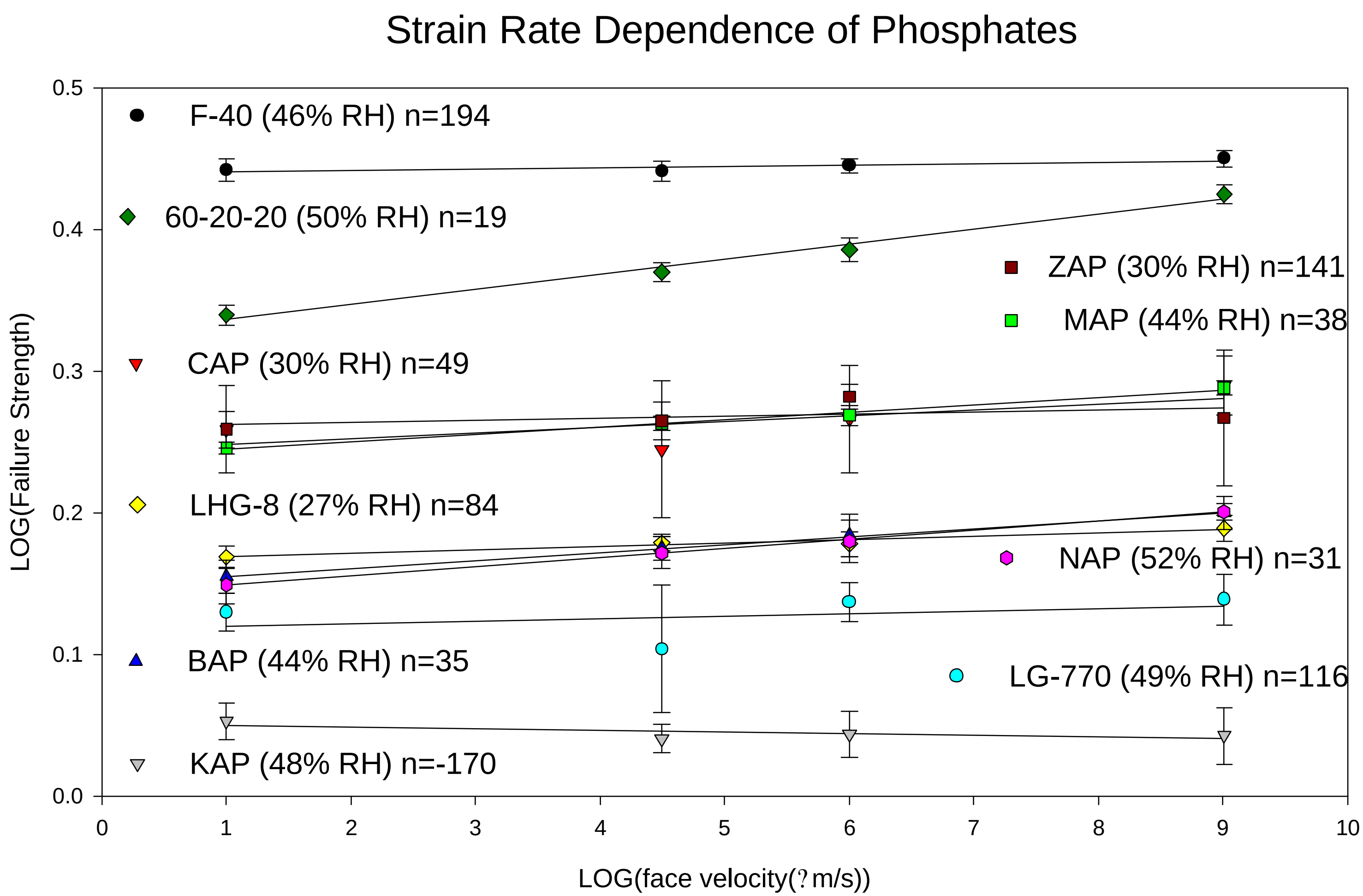
- Similar strengths at room temperature and in liquid nitrogen
- Weaker than silicate glasses
- Fractures in air show limited fatigue effects

Fatigue Effects



- Weaker in higher humidity air
- Little dependence on “face plate velocity” (~ strain rate)

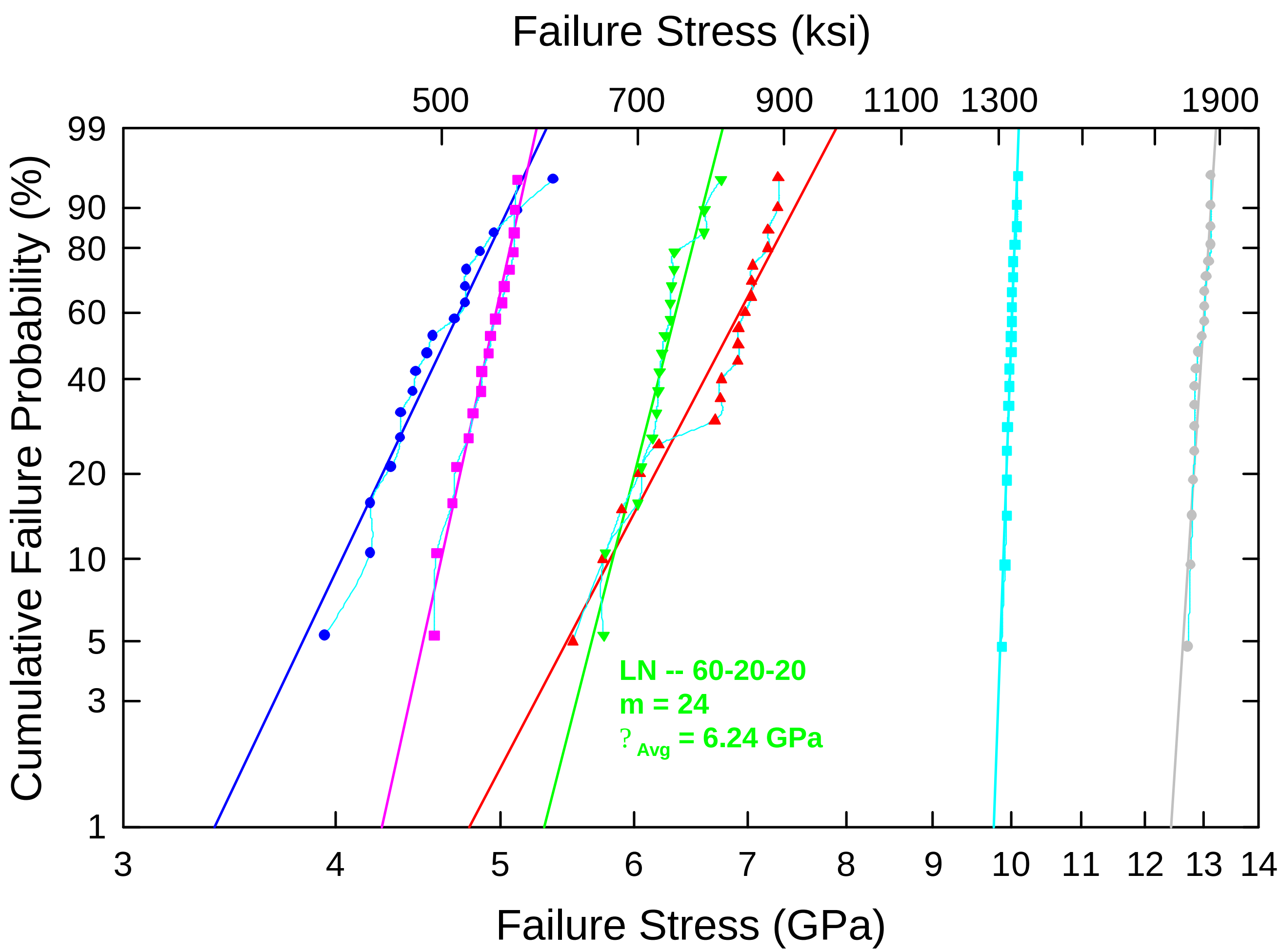
Dynamic Fatigue Dependence



- The fracture strength dependence on face plate velocity provides the fatigue parameter, n from n = (dlog ? $_{50}$/dlog(?/s))$^{-1}$.*
- Phosphate glasses exhibit little strength dependence on strain rate.

*W. J. Duncan et al., in "Strength of Inorganic Glass," ed. C.R. Kurkjian, Plenum Press, NY, (1986).

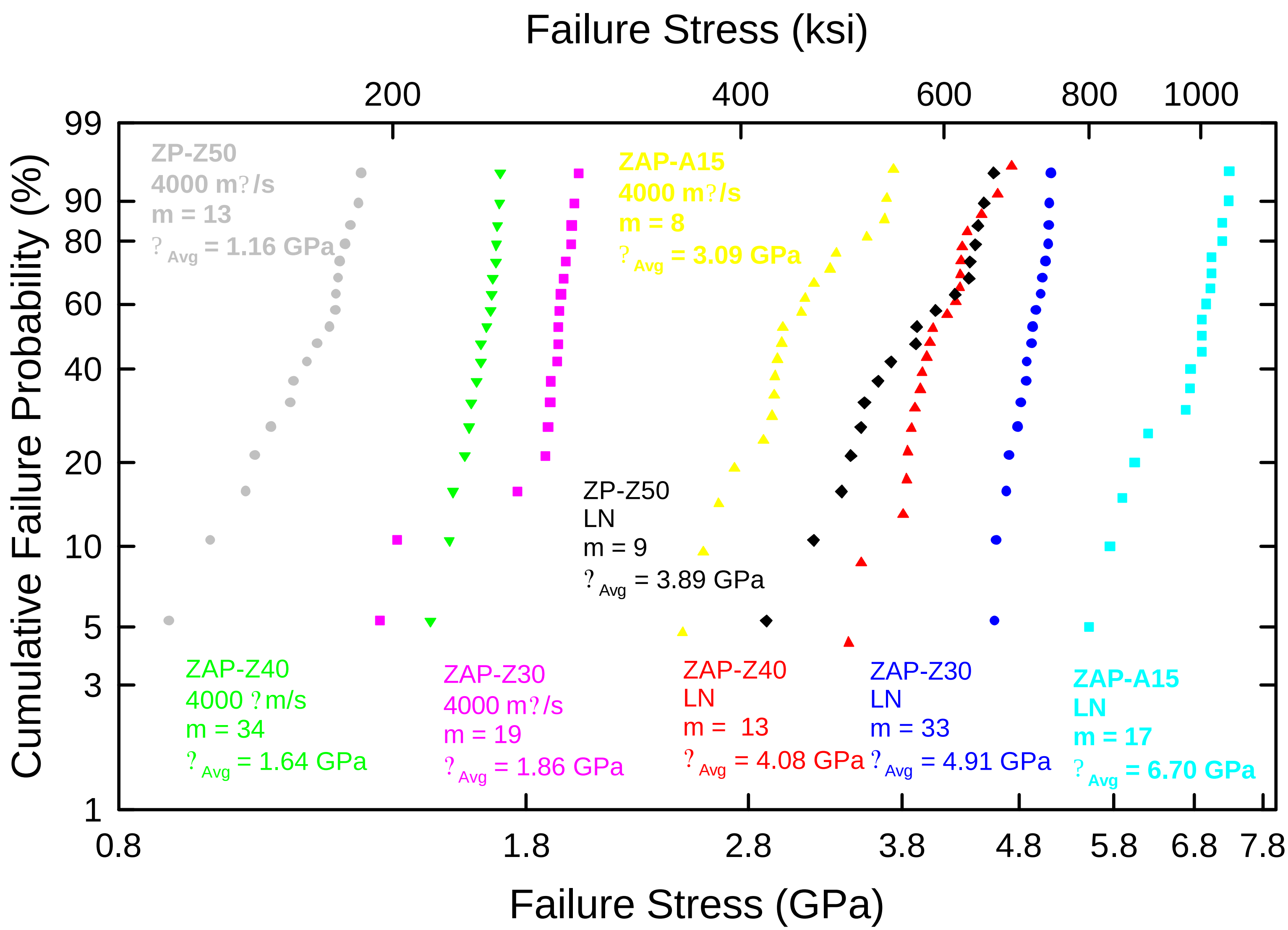
Some Phosphate Glasses Are Relatively Strong



•Zn-aluminophosphate fibers have the highest strength of any phosphate glasses to date.

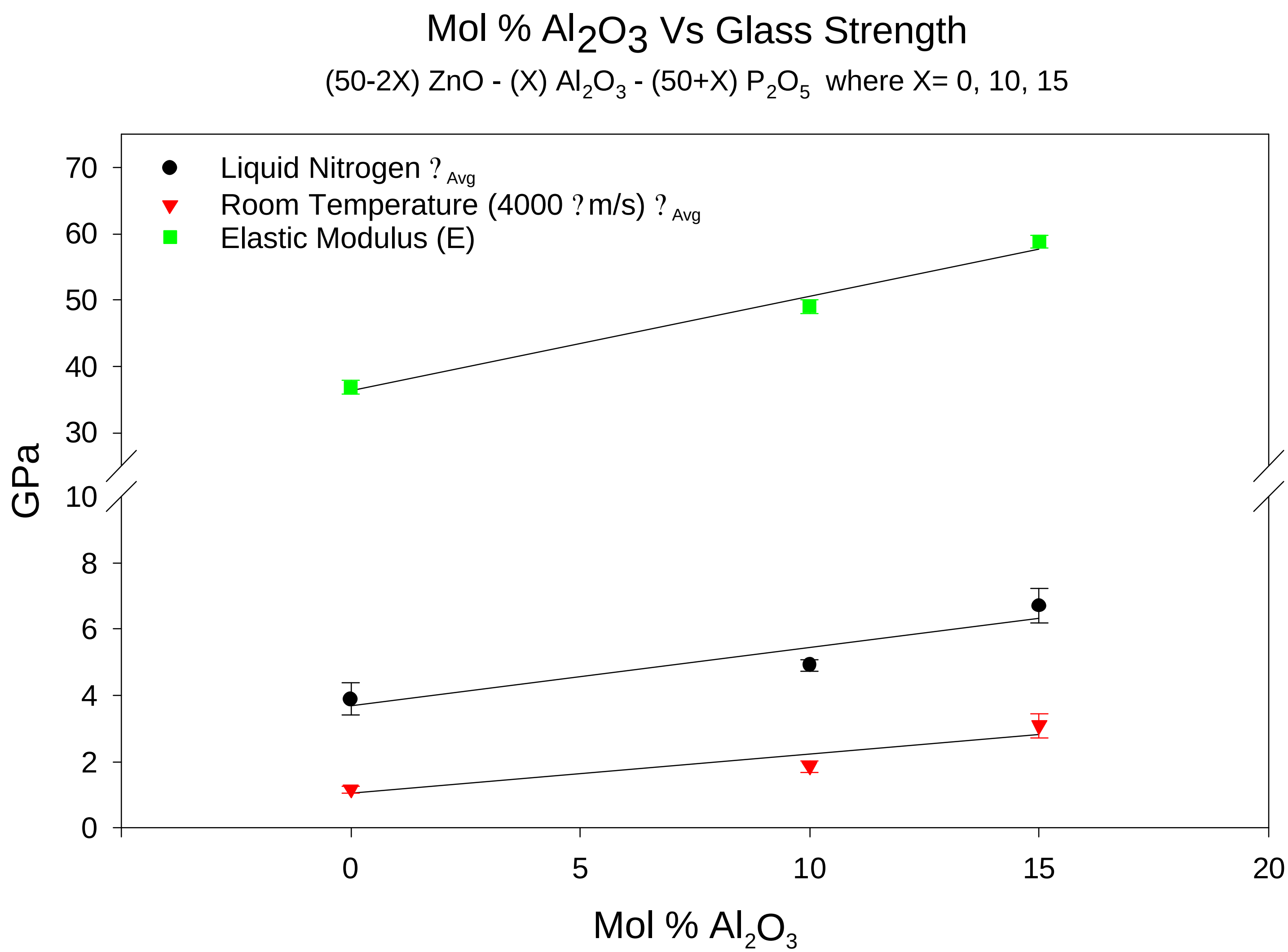
•Fe-phosphate glasses have aqueous durability's greater than common window glass.

Zinc Aluminophosphate Comparison



- Adding Alumina to Zinc Phosphates increases ?.

Alumina Increases Zinc-Metaphosphate Strength



Conclusions and Questions

- Strength of phosphate gasses increases with the field strength of modifying ions.
- Phosphate glasses show limited strength dependence (high dynamic fatigue parameters) on strain rate.
- Phosphate glasses exhibit a decrease in strength with increasing humidity. How is this effect related to the limited dynamic fatigue response.
- Why is there always more scatter in liquid nitrogen strengths than room temperature strengths for phosphate glasses?

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