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ABOUT MECHANICAL CHARACTERISTICS OF OPTICAL GLASS

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Abstract: The optical glass is a special glass used at fabrication of optical parts: glasses, lenses, medical device, etc. It's characterized by a multiple optical properties, chemical, thermal and mechanics properties, etc. Inside of the mechanical properties, the hardness and fracture strength have an important aim inside of design and manufacturing process by cutting of optical workpieces. In this paper is presented the determination mode of the fracture coefficient for the optical glass as starting from its mechanical characteristics and sizes for variety grades of optical glass.

1. SPECIFIC PROPERTIES OF OPTICAL GLASS

The colorless optical glass [27] is a glass with a special composition, which is used at fabrication of optical parts and components, such as: lenses, prisms, glasses, etc. This glass has a certain specific properties [7, 14, 16], as:

- High homogeneity, as optical glass is isotropic material;
- Exactly and constant values, in time and in glass volume, for refractive index of 1.47 to 2, respectively for dispersion coefficient of 20 to 90;
- It's brittle;
- The spectrum of optical radiations has a non-selective transmission in visible range;
- Chemical stability in relation with atmospheric agents and solutions of weak acids;
- High mechanical strength at scratching and automation;
- Then the optical density is altering in accuracy limits the colorless optical glass - becomes toughness of predictable ionizing radiation;

Now, on marketplace of optical glass are found significant grades of optical glass, more of 200 [14], fabricated of specialized manufactures, as Ohara, Schott, Corning, etc.

In general, these grades of optical glass are classified, in function of lead's content from their composition, in two major groups:

1. Crown glasses, dominated with *K*, which don't have lead (lead oxide);
2. Flint glasses, dominated with *F*, which have lead (lead oxide).

Inside of each group have remarked five categories of optical glasses: very lightweight, lightweight, normal, heavy, and very heavy. In Tab.1 are presented the mainly characteristics of optical glasses for Crown and Flint glasses.

Tab.1. Specific characteristics for Crown glasses and Flint glasses [14, 16]

Characteristics of optical glass	**Crown glasses**	**Flint glasses**
Content of lead oxides	Low	High
Mechanical characteristic	In general, hard	In general, soft
Chemical stability	Stable	Unstable
Refractive index- n_d	Lower, from 1.5 to 1.55	higher, from 1.54 and up to 1.65
Dispersion	High; from 50 to 70	Low; light glass: from 47.5 to 40; normal glass: from 40 to 35; heavy glass: less of 34

Within of these major groups are fabricated some intermediary glasses, named Crown-Flint and nominated KF. These glasses content between 3-15% of PbO. From this category are the glasses with barium (BaK and BaF) and glasses with boron (BK and BF).

Variety optical glasses are presented by manufactures in their catalogs. Here, is presented a synthetic diagram of these types of optical glasses that is built from relatives refractive indexes-n_d and dispersion coefficients (Abbe coefficient-v_d).

In Fig.1 is presented this diagram and also, is remarked the historical evolution of range of refractive properties [23], and line-*L* delimitation for v_d=50 the Crown glasses (left) to Flint glasses (right).

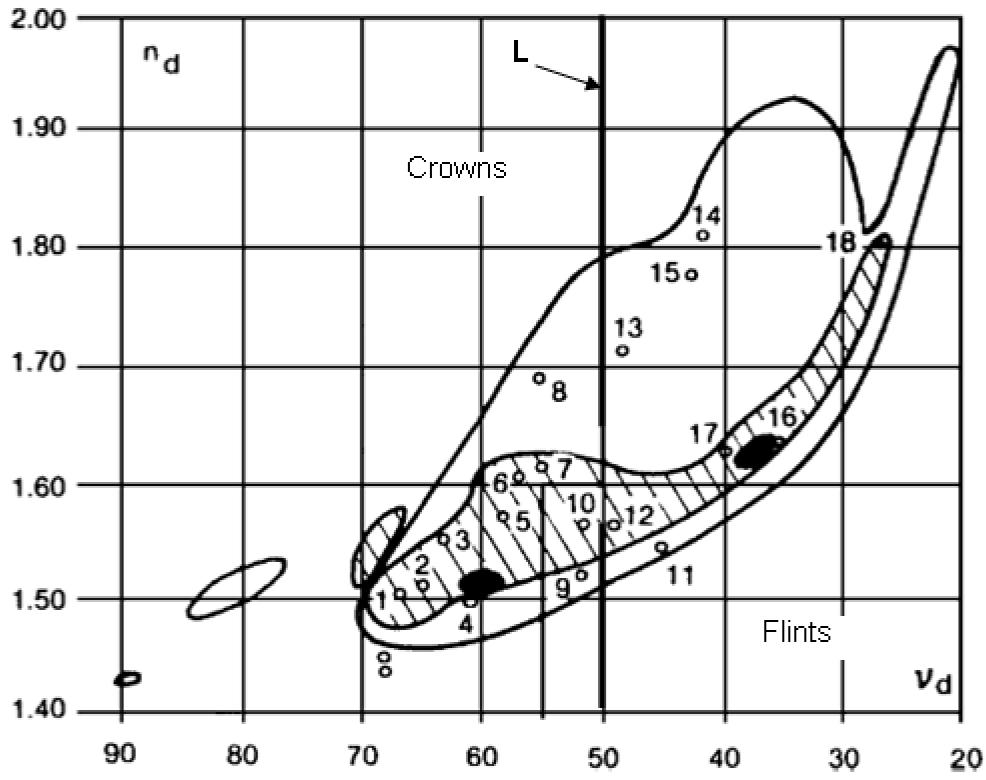

Fig. 1 Representation of optical glasses in the (n_d,v_d) plane. Glasses listed by numbers correspond approximately to nominal compositions given in Tab. 2. Solid dividing line L separates crowns (left) and flints (right) glasses. Diagram also contains historically significant boundaries: solid areas = 1870, hatched area = 1920, solid boundaries only = 1984 [23].

In Tab.2 are presented the composition of optical glasses grades from Fig.1. Essentially, the optical glasses [20] with the values of n_d>1.60 and v_d>50 or n_d<1.60 and v_d>55 are named Crown glasses (*K*). Other categories of optical glasses are named Flint glasses (*F*).

Tab.2. Characteristics of certain optical glasses grades [20, 23, 24]

Grade of Optical Glass					Composition		
No. from Fig.1	**Type**	**Symbol**	**Name**	**Composition**	**SiO_2**	**BaO**	**PbO**
1	CROWN	PK (PC)	Phosphate crown	P_2O_5-B_2O_3-R_2O-BaO	68	1	-
2		BK (BCC)	Borosilicate crown	SiO_2-B_2O_3-R_2O-BaO	72	1	-
3		PSK (DPK, PCD)	Dense phosphate crown	P_2O_5-$(B,Al)_2O_3$-R_2O-MO	55	22	-
4		K (C)	Crown	SiO_2- R_2O-(Ca,Ba)	75	-	-
5		BaK (BaC, LBC)	Barium crown	$SiO_2(B_2O_3)$- BaO-R_2O	48	29	-
6		SK (DBC, BCD)	Dense barium crown	SiO_2-B_2O_3- BaO	41	42	-
7		SSK(EDBC , BCDD)	Extra dense barium crown	SiO_2-B_2O_3- BaO	37	40	4
8		LaK (LaC, LaCL)	Lanthanum	$B_2O_3(SiO_2)$-La_2O_3-ZnO-MO	6	--	
9	FLINT	KF (CF, CHD)	Crown flint	SiO_2- R_2O-PbO-MO	67	-	13
10		BaLF (LBC, BCL)	Barium light flint	SiO_2-B_2O_3-BaO-PbO-R_2O	54	14	11
11		LLF (BLF, FEL)	Extra light flint	SiO_2- R_2O-PbO-MO	61	-	26
12		BaF (BF, FB)	Barium flint	SiO_2-B_2O_3-BaO-PbO-R_2O	56	12	17
13		Laf (LaFL)	Lanthanum flint	$B_2O_3(SiO_2)$-La_2O_3-MO-PbO	4	8	6
14		LaSF	Dense lanthanum flint	$B_2O_3(SiO_2)$-La_2O_3-MO-PbO	0	11	-
15		LF (FL)	Light flint	SiO_2- R_2O-PbO-MO	53	-	34
16		F (DF;FD)	Flint	SiO_2- R_2O-PbO-MO	44	-	46
17		BaSF (DFB, FBD)	Dense barium flint	SiO_2-B_2O_3-BaO-PbO-R_2O	42	11	34
18		SF (EDF, FDS)	Dense flint	SiO_2- R_2O-PbO-MO	27	-	71

2. ASPECTS ABOUT FRACTURE OF OPTICAL GLASSES

The quality of optical glass is analyzed from two major defects categories [5]:

1. Volume defects (failures into glass body);
2. Surface defects.

Both types of defects are important for the study of strength and mechanism of fracture for glass [9]. Carre [5] classified these defects in four groups:

- Long microscopic cracks on size of hundreds of millimeters;

- Microscopic defects, than generally occurred during of glass fabrication;
- Defects determined by adhesion of particles at glass surface during of glass fabrication;
- Altering of glass surface than occurred during of glass fabrication on the action of environmental agents.

In generally, the factors which promote the occurring of glass defects are grouped in three categories (Fig.5):

1. Structural factors or of glass elaboration;
2. Factors due to the fabrication process of glass.
3. External factors represented by the conditions of handling, environmental factors, etc.

The problem of analysis for mechanical properties of optical glass [14, 16, 20, 23-25] from that is remarked the fracture, is directed linked by identification and accentuation of cracks. The optical glass has a fragile fracture, and the fracture mechanism (fragile) is development in three conditions [5, 14]:

- Existence of initial defects or cracks into glass material. These cracks can be generated (Fig.2) by the material elaboration and machining, or created under effect of external stress system. The initial cracks action and as stress concentrators.
- Presence of the fracture temperature below the critic fragility temperature of material glass.
- Presence of the internal stress generated of fabrication process.

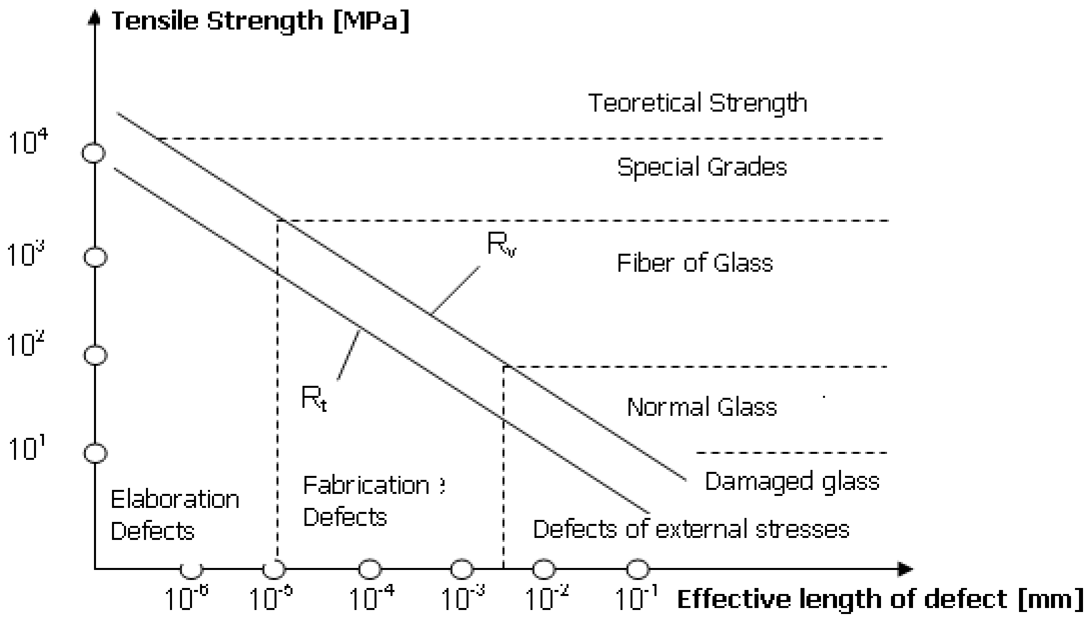

Fig.2. The size and nature of defects in glass.
R_t- the strength on long-term; R_v-the strength at high speed [5].

The analysis of fragile fracture is performed on the base of two approaches [5, 8, 20], such as the material is homogenous isotropic and also, has a linear elastic behavior. For the study of materials cracks can be used three fundamental modes of loading that are presented in Fig.3. From all, the firs mode-I that in general is more sever [17, 22] is used for fracture of glass [5].

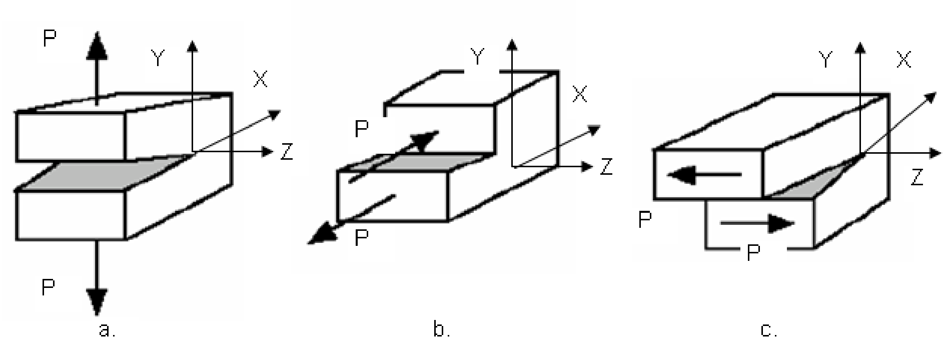

Fig.3. The representation of three fundamental modes of fracture:
a.- opening; b.- sliding, and c.- tearing [8, 17].

On base of stress field representation in proximity of crack front (Fig.4) can be described the expressions of stress dry basis of XYZ system [20]:

$$\sigma_{xx} = \frac{K_I}{2\pi r} \cos\frac{\phi}{2} \left(1 + \sin\phi/2 \times \sin 3\phi/2\right) \tag{1}$$

$$\sigma_{yy} = \frac{K_I}{2\pi r} \cos\frac{\phi}{2} \left(1 + \sin\phi/2 \times \sin 3\phi/2\right) \tag{2}$$

$$\sigma_{zz} = \mu\left(\sigma_{xx} + \sigma_{yy}\right) \tag{3}$$

$$\sigma_{yx} = \sigma_{xy} = \frac{K_I}{2\pi r} \sin\phi/2\ x \cos\phi/2\ x \cos 3\phi/2\varphi \tag{4}$$

$$\sigma_{zx} = \sigma_{zy} = 0 \tag{5}$$

Where: K_I is the stress intensity factor for mode-I.

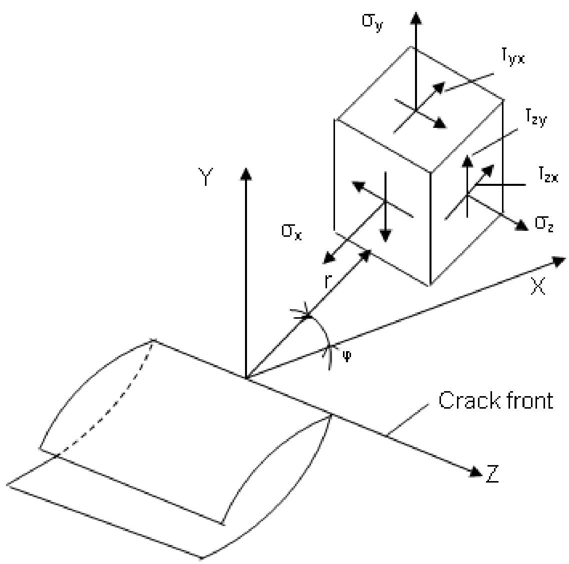

Fig.4. The representation of stress field in proximity of crack front [20].

For a crack of length-*2a*, subjected on a stress-*σ*, the stress intensity factor for mode-*I* is expressed by the relation:

$$K_I = \sigma \sqrt{\pi a} \tag{6}$$

Which corresponding for situation with a crack into infinite plate; and respectively:

$$K_I = Y\left(\frac{a}{w}\right)\sigma \cdot \pi^{1/2} \tag{7}$$

Where: *Y* is geometric factor of crack, and *w*-width of finite plate. The theoretical and experimental researches were showed that corrosion strength of glass is a form of static fatigue [9]. Essentially, the crack velocity of glass is influenced by the humidity level. So, were accentuated the ratio between cracking speed and factor-K_I for the humidity influence levels- *I*, *II* and *III*. One that diagram is presented in Fig.5.

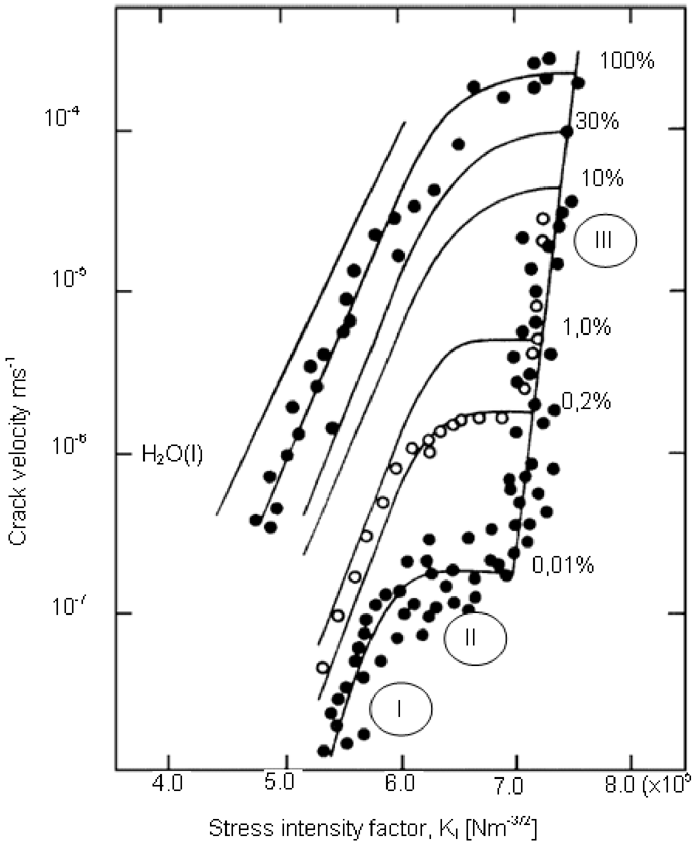

Fig.5. Variation of crack speed with stress intensity factor and relative humidity [23]

Occurring of defect into glass material take place when the size of factor-K_I excesses the fracture strength of material-K_c:

$$K_I > K_C \tag{8}$$

The size of fracture strength can be expressed means of Vickers indentation [1, 2, 6]. In this case is used the relation:

$$K_C = \frac{P}{c^{3/2}} \cdot \frac{1}{\beta_0} \tag{9}$$

The signification of items results from Fig.6 [2].

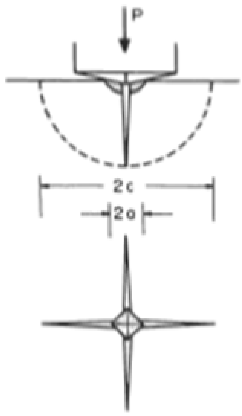

Fig.6. Parameters of well-developed deformation/median-crack system at Vickers indentation [2].

For determination of fracture strength at a glass grade, Schwertz [18] used the relation:

$$K_c = H \bullet \sqrt{\frac{d}{2}} \bullet (E/H)^{0,4}\, 10^{f(x)} \text{ [Pa m}^{1/2}\text{]} \qquad (9)$$

Where: c- is half crack size;
H – Vickers hardness;
d - indentation diagonal;
E - Young's Modulus.

On the base of relation (9), Schwertz calculus a certain of approximate values of fracture strength for some optical materials than are presented in this paper.

The limitation of fragile fracture is important in design and fabrication of optical parts. In this sense, in papers [14,16] are presented some methods used for stopping of cracks propagation.

3. CONCLUSIONS

The quality of optical glass is assessing by two major categories of defects, such as volume defects (defects into glass body), respectively surface defects. The study of these defects has a theoretical and practical importance for the analysis of fracture strength for optical glass. From these two modes of analysis of a material fracture the mode-*I* is used for the glass.

The values of stresses and displacements at crack extremity that is generated by application of force-*P* are functions of the stress intensity factor-K_I and the coordinates-*r* and *φ.*

The value of fracture strength can be determined on the base of Vickers indentations.

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