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Influence of the fracture toughness on durability of the silicate structures

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Abstract. Generally, the crack propagation is a problem of equilibrium and stability of silicate structures. The critical crack length depends on fracture toughness. The relationships between fracture toughness, bulk density, modulus of elasticity, and compressive strength are depicted in silicate material diagrams. Those diagrams have numerous application in engineering structural design.

1. Introduction
The basic imperfection of classical theory of calculation of material strength is a fact, that those calculations neglect material defects and discontinuities. Usually, the materials are comprehended as a homogenous continuum, which is getting damaged suddenly after reaching limit conditions in the whole exposed body. In other words, the failure is detected according to highest average stress (sheer, compressive, tensile, etc.) or highest strain energy in the vicinity of the critical cross-section [1]. However, such an interpretation is insufficient for a description of complex processes of cracks formation and propagation. The propagated crack will reach its critical length eventually implying fracture of the whole body. The illustration of the dependence between crack length and durability is given in figure 1.

Figure 1. Relationship between durability of silicate materials and crack development.
In figure 1, the critical crack length $l_{CR}$ varies in time. The length is shortening during material’s service life period due to decreasing of fracture toughness as the material ages. The aging is usually due to various operational loadings and their intensities given by the environmental conditions. Typically, the material properties are changing in complex processes taking place across the whole body such as strain or precipitation aging, degradation due to solar radiation, moisture effects, intercrystalline corrosion etc. For that reason, a significant spread is apparent in the critical crack length $l_{CR}$. The static material fatigue is accompanied by the loss of the ability of plastic strains, which is apparent after long-lasting loading periods especially when the material is exposed to the effect of high temperatures. The final fracture comes then from small macrocrack or system of cracks in the form of brittle fracture as shown in figure 2. The formation of major macrocrack can be observed also in brick columns or pillar loaded by concentric pressure (see figure 3).

![Diagram](image)

**Figure 2.** Connecting of small cracks into a macrocrack in concrete, stone, and bricks.

![Diagram](image)

**Figure 3.** Formation of major macrocrack in columns loaded by concentric pressure.
Therefore, the description should not be limited to the description of stress fields from point to point only, but it should be also aimed, regarding the limit state, at the respective quantities in the vicinity of the initial inhomogeneity, macroscopic defect or developed cracks after loading (figure 3). Thus, practically new type of material is defined in continuum mechanics. Its deformation is given not only by elastic strain but also the local strain of ideal zone having size $d_y$ (figure 2).

The stress intensity factor $K_I$ is an important variable in continuum mechanics of deformable bodies containing macrocracks and narrowly bounded fracture development zones.

The critical value of stress intensity factor $K_I$ with respect to the dynamic character of fracture process is referred to as fracture toughness $K_{IC}$.

The size of fracture development zone $d_y$, defined as a distance between the end of opening microcrack (where $\delta_y$ is tensile strength and $K_I = 0$) and to the root of equivalent elastic crack for the type of loading I (crack opening), is defined as:

$$d_y = \frac{1}{\pi} \frac{K_{IC}^2}{\delta_y^2}.$$

According to the theory of nonlinear fracture mechanics, the stress concentrated in the root of actual crack creates a development zone where the material is fatigued and fractured. The crack that is to be developed (if tensile stress equals the tensile strength of the material with a fragile matrix, i.e. silicates or thermosetting plastics) has the length according to (1), which means that the critical crack length $l_{CR}$ is equal to the size of fracture development zone $d_y$.

![Figure 4. The dependence of fracture toughness on bulk density.](image)
2. Discussion

It generally applies for silicates that plastic strain in the top of the crack reduces the stress peak by rounding the sharp edge of the crack (figure 2) as the energy absorbed in the plastic zone makes the
crack development more difficult. The plastic strain in the root of crack in burnt clay-ceramics is very limited because the stress peak is reduced by a network of cracks. Thus, both the absorbed energy and fracture toughness are low. This results in the fact that fracture toughness $K_{IC}$ for ceramic materials is approximately 15 times lower than fracture toughness of metals.

Due to low fracture toughness and presence of cracks and voids in the material structure the strength of ceramic is quite low. The voids weaken the material, however, if they are spherical in the ideal case, the stress concentrated in the vicinity of such voids is quite low. More dangerous for the material integrity is the presence of small cracks, which can result from thermal expansion (during wet clay burning, wetting of unprotected brick masonry by driving rain etc.) or isotropy in modulus among grains. Nowadays, there exist two ways of producing ceramics with increased strength:

- reducing the length of crack by technological solutions (for example by adding fine brick grinding powder), precision in manufacturing, curing etc.,
- increasing $K_{IC}$ by using fine aggregates (from 1.0 to 0.4 $\mu$m), utilization of phase transformation, designing of composite structures.

Note that for a reasonable value of fracture toughness $K_{IC} = 2.0$ MPa is the highest length of crack approximately 60 $\mu$m, which corresponds to the size of aggregate. Therefore the use of ceramic grinding from brick block production seems to be an ideal solution [6].

The values of fracture toughness as a function of bulk density (figure 4), modulus of elasticity (figure 5) and compressive strength (figure 6) are shown in diagrams of silicate materials [4]. The diagrams show the limiting values of particular quantities. If the combination of values lies inside the zone in the diagram, it can be considered as safe. Position outside of that zone is questionable.

3. Conclusions

The damage of structural masonry walls is one of the most widespread deterioration and reason of service life shortage and reduction of building seismic capacity. Synergic effects are considered as a key element in the assessment of the durability and structural performance of brickworks. New observation highlight the importance of rain penetration effect on the durability and structural integrity of brick masonry [5].

Acknowledgement

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References

[1] Flinn A R and Trojan P K 1990 Engineering Materials and Their Applications (Boston: Houghton Mifflin)
[2] Bazant Z P and Cedolin A 1991 Stability of Structures: Elastic, Inelastic, Fracture and Damage Theories (New York, Oxford: Oxford University Press)
[3] Emmons H P, Drochytka R and Jerabek Z 1999 Saving and Maintenance of Concrete in Illustrations (Brno: CERM s.r.o.)
[4] Ashby F M 1999 Acta Metall. Mater. 37 1273-1293
[5] Cacciotti R 2018 Brick Masonry Response to Wind-driven Rain (Prague: Czech Technical University)
[6] Heluz s.r.o., available at http://www.heluz.cz