Modelling of glass matrix composites by the Coupled Criterion and the Matched Asymptotic Approach. The effect of residual stresses and the volume fraction.

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Ceramic platelets are used as a reinforcing constituent in glass matrices to improve mechanical properties such as the fracture toughness [1]. One example is the borosilicate glass Al_2O_3 platelet composite, an interesting material for industrial applications due to its low production cost and environmental safety.

One of the most important characteristics of this composite material is the thermal expansion mismatch between glass and alumina [2]. The latter has a higher thermal coefficient than the one in glass, and consequently, compressive and tensile residual stresses will appear after cooling in the matrix and the platelet, respectively. These residual stresses have been studied experimentally [2] and numerically [3].

In [4], a new methodology to design and study platelet composite was presented, based on the application of the Coupled Criterion (CC) [5] together with the Matched Asymptotic Expansion (MAE) [6]. The tool studied only the role of a single platelet, without including residual stresses. Thus, the objective of this work is to complete the numerical method introduced in [4] including the influence of the volume fraction and the thermal mismatch mentioned above. The model is validated by comparison with experimental results found in the literature.

The improvement of fracture toughness is related to a change in the path of a pre-existing crack assumed in the specimen, under the presence of a platelet with a certain orientation. Two cases are studied, when the platelet is parallel to the pre-existing crack and when it is perpendicular. In the latter the predominant mechanism is determined among different possibilities: a penetration of the crack in the platelet, a deviation through the interface glass/alumina, a decohesion of the lateral face of the platelet or a crack jump into the glass. Results are shown at the scale of experiments [1] and at different scales, in order to study the platelet size effect on the composite fracture toughness.

Therefore, a complete design tool for this kind of composites is presented, particularized for the case of a glass matrix reinforced by alumina platelets. The key novelty of this methodology is the possibility to study separately different factors that contribute to the improvement of the fracture toughness: geometrical factors, such as the volume fraction, the size and the orientation of the platelet, or environmental factors, in particular the effect of residual stresses. Furthermore, this design tool seems to have an important reduction in the computational complexity with respect to other analysis found in the literature. The method can be used to optimize the design of platelet composites.

References

[1] M. Kotoul, J. Pokluda, P. Šandera, I. Dlouhý, Z. Chlup, A. Boccaccini, Toughening effects quantification in glass matrix composite reinforced by alumina platelets, Acta materialia 56 (12) (2008) 2908–2918.

[2] R. Todd, A. Boccaccini, R. Sinclair, R. Yallee, R. Young, Thermal residual stresses and their toughening effect in al2o3 platelet reinforced glass, Acta materialia 47 (11) (1999) 3233–3240.

[3] V. Cannillo, C. Leonelli, A. R. Boccaccini, Numerical models for thermal residual stresses in al2o3 platelets/borosilicate glass matrix composites, Materials Science and Engineering: A 323 (1-2) (2002) 246–250.

[4] S. Jiménez-Alfaro, D. Leguillon, Modelling of glass matrix composites by the coupled criterion and the matched asymptotics approach. the role of a single platelet, Theoretical and Applied Fracture Mechanics 122 (2022) 103650.

[5] D. Leguillon, Strength or toughness? a criterion for crack onset at a notch, European Journal of Mechanics - A/Solids 21 (1) (2002) 61–72.

[6] D. Leguillon,E. Sanchez-Palencia, Computation of singular solutions in elliptic problems and elasticity, 1987.