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A Comparative Study of the Fatigue Properties of Synroc and Borosilicate Glass

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Comparative measurements have been made of the dynamic fatigue response of synroc and borosilicate glass specimens in water, using an indentation flaw technique. The results are presented in terms of a universal plotting scheme which allows for simple appraisal of the "lifetime" capabilities of the materials. Synroc is intrinsically stronger than borosilicate glass, but the fatigue susceptibilities are similar.

Synroc (synthetic rock) and borosilicate glass are prime candidate materials for high-level nuclear waste immobilization. Long-term stability under potentially hostile chemical and thermal conditions is of course the paramount issue in establishing guidelines for selecting any one material system over another, particularly in the context of a cumulative radiation damage environment. Susceptibility to fracture is one factor, even if a secondary one, which enters into this consideration. A potential danger is that progressive microcracking could lead to enhanced leaching rates, especially if the cracks were to form an intersecting network. Fatigue properties would appear to warrant particular attention in this regard, bearing in mind that conditions in the repository could be conducive to slow crack growth.

In this communication we present results from a comparative dynamic fatigue (i.e. constant stressing rate) study of representative synroc[1] and borosilicate glass[2] materials, using a controlled indentation flaw technique.[3,4] The compositions of the materials are given in Tables I and II. Although these compositions may ultimately prove to differ considerably from the optimum for containment of a range of waste species, and although our test conditions are confined to those of the laboratory ambient, the results should provide some guide to intrinsic slow crack growth tendencies.

Specimens of both materials were prepared in a form suitable for indentation/strength testing.[4] The synroc was sawed from a billet into bars 40 by 6 by 4 mm; the borosilicate glass was cut from cane 5 mm in diameter into rods 210 mm long. Special care was taken to nullify any spurious surface stresses in the specimens: for the synroc, a nominated test surface on each bar was polished to a final finish with 3-μm diamond paste, thereby removing the sawing damage layer[5]; for the glass, each rod was annealed at 610°C for 24 h. A Vickers diamond pyramid was used to indent each test piece midway along its length, with symmetrical alignment so as to produce radial cracks[3] perpendicular to the subsequent tensile loading. The contact loads were maintained for 10 s in air. The load was fixed at 100 N for the synroc but was varied over a range of 5 to 100 N for the glass. (The variation in the latter case provided the means for a separate study of crack size effects.[2]) A drop of distilled water (for fatigue strength tests) or silicone oil (for inert strength tests) was placed onto each indentation site prior to bending. The inner and outer spans used in the actual bending tests were 10 and 35 mm for synroc and 20 and 60 mm for borosilicate. Individual test pieces were carefully aligned to ensure that the indentation site experienced maximum tension and were taken to failure at specified stress rates.

The results are shown as a plot of time-to-failure, T, vs dynamic fatigue strength, S, in Fig. 1, with contact load, P, incorporated into the coordinates in such a way as to reduce the data for a given material/environment system onto a universal curve.[2] Each data point represents the mean and standard deviation limits for 6 to 15 water-environment specimens, evaluated in logarithmic coordinates, at a fixed stressing rate. The curves through these points are least-squares fits, with data from oil-environment tests (minimum of 20 specimens in each case at the fastest available stressing rates of >1 GPa·s^{-1}) determining the inert-strength cutoffs. It is readily apparent from the inert strength levels that synroc is intrinsically the stronger of the materials. However, the two sets of data have comparable slopes in the fatigue region, indicating similar susceptibilities to slow crack growth. This susceptibility can indeed be quantified, in terms of the familiar crack velocity exponent, n, as $-1.31 \times$ slope of the fatigue curves (the numerical factor representing a correction term in the strength equations to allow for the effect of residual contact stresses on the crack evolution)[2-4]; from the least-squares fits the values obtained, together with standard error estimates, are $n=34.5\pm3.0$ (synroc) and $n=36.4\pm2.5$ (borosilicate).

The utility of this method in obtaining fatigue data is not so much the facility for evaluating basic fracture parameters, although indentation flaws certainly offer several unique advantages in this aspect of testing,[4] but rather a simple route to materials selection. Thus from Fig. 1 we may conclude that under conditions of given fracture driving force (as quantified by S) and flaw severity (as quantified by P) synroc is likely to survive for greater periods than borosilicate glass without crack-growth instabilities, at least over the data range covered. There are, of course, other factors that need to be considered in such reckonings of "lifetime" capabilities, such as the tendency for the crack driving force to be augmented by internal stress fields caused by microstructural or radiation damage inhomogeneities. The controlled-flaw approach could equally well be used to

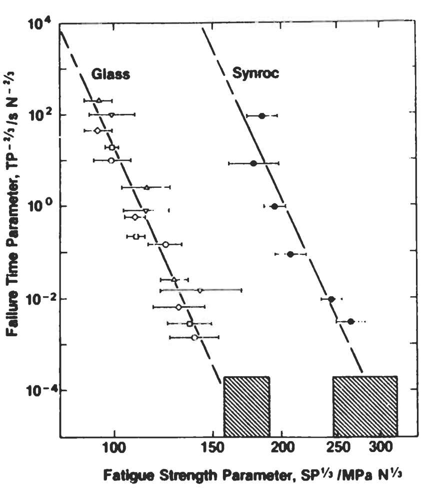

Fig. 1. Plots of reduced time-to-failure vs dynamic fatigue strength for synroc and borosilicate glass in water. For glass data, different symbols indicate different contact loads; shaded areas indicate inert strength cutoffs.

Table I. Composition of Synroc B*

Component	Amount (wt%)
TiO_2	59.5
ZrO_2	11.4
Al_2O_3	6.0
BaO	7.2
CaO	15.9

*Without simulated radwaste, hot-pressed at 1250°C and 6.9 MPa to ≈98% theoretical density.

Table II. Composition of Borosilicate Glass*

Component	Amount (wt%)
SiO_2	81
B_2O_3	13
Na_2O+K_2O	4
Al_2O_3	2

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examine effects of this kind, e.g. by conducting comparative tests on specimens exposed to accelerated radiation damage in a nuclear reactor,[6] and at the same time to investigate the importance of such variables as composition, temperature, and pressure.

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