THE ASSESSMENT OF A FAILURE CRITERION FOR INDUSTRIAL APPLICATION OF PMMA AND HI-PMMA UNDER STATIC LOADING

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Tensile creep measurements were carried out both on dry and on water-saturated PMMA and HI-PMMA specimens , as a function of temperature,of grafted rubber content and of molecular weight.
The occurence of critical strains for craze formation was unexpectedly found to be independent of temperature.The data obtained allowed an optimization of the techniques used for the design of transparent roofings, by using a dimensioning criterion based on craze formation.

INTRODUCTION

In designing plastic items with structural functions, it is possible to optimize the dimensioning techniques by decreasing the safety coefficients values, only through a more thorough testing of the properties of the material under the actual working conditions and of its mechanisms of failure.

The major failure mechanism that can be considered as the precursor of fracture in the amorphous polymers, is the crazing phenomenon.
The parameters affecting resistance to craze formation can be related to the material, like molecular weight, orientation, internal tensions and inherent flows, or can be related to the manufacturing conditions, like temperature, type of stress, rate of load application or environment, as widely described by Kambour(1) and Rabinowitz(2).

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APPLICATION TO ACRYLIC ROOFINGS OF THE CRITERION OF DIMENSIONING BY CRAZES

Crazing in PMMA and HI-PMMA

In transparent polymers such as PMMA, crazing appears like an aggregate of micro-cracks lying on a plane perpendicular to the strain direction and with a formation kinetics strictly related to the magnitude of the applied stresses and to the application rate, as demonstrated by Franck and Lehmann(3).

Studies on craze resistance in the propagation phase and on its transformation into crack were carried out on the basis of fracture mechanics according to Williams (4).

A recent attempt was carried out to increase the intrinsic resistance of PMMA to craze formation, by introducing small (0.2 μm) particles of grafted rubber with the same refraction index as PMMA in order not to affect the transparency of the material, as described by Bucknall (5).

Craze dimensioning criterion

Among the various polymer dimensioning criteria described by Pavan et al (6), the craze dimensioning criterion is particularly indicated for amorphous polymers like PMMA.

Several Authors, like Kambour (1), Menges and Schmidt (7) and Ziegler and Brown (8) demonstrated that it is possible to define a critical level of stress and strain for craze induction below which the crazing phenomenon does not occur even following prolonged load application times either in air or in the presence of corrosive substances (7).

Data repored in commercial pubblications (10,11) show that, for the dimensioning of acrylic structures , the resistance criterion normally used is that based on on the maximum stresses admissible for crazes according to the equation:

where is: $\sigma = \sigma_f / M$

according to the equations reported on Construction Theory textbooks.

EXPERIMENTAL PART

Materials and test method

Tests were carried out on PMMA and HI-PMMA manufactured by VEDRIL S.p.A.; PMMA specimens consisted in commercial low molecular weight extruded material (VEDRIL E) and very high molecular weight cast material (VEDRIL C); HI-PMMA specimens were all experimental materials with different types and amounts of graft contents.

Tensile creep tests were carried out on dumbell specimens (140 x 8 x 3 mm).

All specimens were subjected to a thermal ageing treatment of 4h at Tg -10°C, followed by a slow cooling in a switched off stove ; the tests were carried out after a further conditioning at room temperature for three weeks at 23°C and 50% relative humidity.

Determination of the craze formation curves

Creep and craze formation curves. Figure 1 shows the typical creep behaviours obtained on PMMA and HI-PMMA at different applied stresses ranging from 5 to 40 MPa; the higher the applied stress the shorter the times at which craze formation was detected.

On both diagrams the areas showing craze formation as a function of time are delimited by a broken line. In the following diagrams only these data will be reported and the creep curves will be omitted to simplify the graphic representation.

Effect of test temperature. Fig.2 shows the behaviour of the critical crazing deformation values as a function of time at different test temperatures ranging from 23° to 90°C.

It is surprising to observe how the data obtained in such a wide range fit all on one curve, thus making the dimensioning procedures much easier.The greater spreading of data obtained with high impact materials is presumably due to the difficulty in detecting crazes, in view of their extremely small dimensions.

Effect of H_2O absorption. Figure 3 shows the results obtained by Pioltini et al (11) on extruded PMMA specimens either conditioned in stove to complete drying, or in water to reach the maximum absorption at the equilibrium (2.2%).

It appears that the water-saturated material resistance resulted comparable with that of the material conditioned at 50% relative humidity and 23°C, while the resistence of the dry material resulted higher in accordance with data reported by Brueller (12).

<u>Effect of molecular weight.</u> Figure 4 shows the influence of molecular weight on the resistance to crazing. A high molecular weight offers a higher resistance to crazing than a low molecular weight ; this can be quantified in terms of 15% of the asymptotic value for prolonged test times.

<u>Effect of amount and type of graft contents.</u> Figure 5 shows the influence of graft contents. As graft contents increases, resistance to crazing increases significantly in terms of total deformation, but not in terms of applied stress. In the structure dimensioning phase , it is therefore useful to employ a high impact material if during the project phase the maximum admissible deformations are applied, as for instance in the case of cold curved sheets. Conversely, in the case of roofings which are subjected to the weight of snow, the high impact effect does not seem to be decisive.

Figure 6 shows the dependence of crazing time on the type of graft material (at equivalent graft contents), for a "core shell" type (type A) and for other two types indicated as grafted B and C. At test times of up to 10^4 s and for high values of applied stress, types A and B show the best resistance.

Since the creep behaviour is comparable for the three materials, these differences can be ascribed to a different contribution of shear deformations that are higher for type A and B grafted materials.

For test times longer than 10^4 s and low applied stresses the resistence to crazing results comparable for the three materials.

<u>Additional symbols.</u>

σ adm = Stress admissible by the structure (MPa)

σ f = Craze formation stress measured in prolonged tensile creep test (MPa)

σ max = Maximum stress in the structure (MPa)

η = Safety coefficient number

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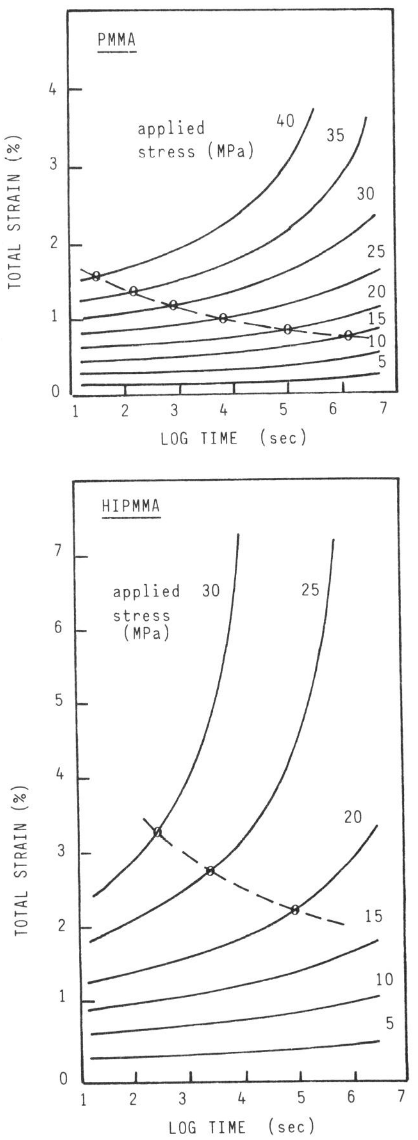

Figure 1 Tensile creep strain vs. log time,(o) onset crazing time.

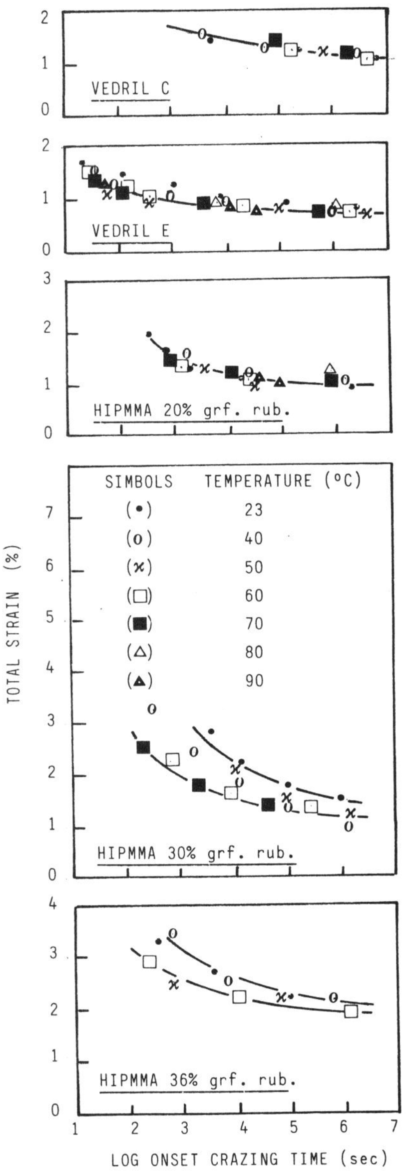

Figure 2 Influence of the temperature.

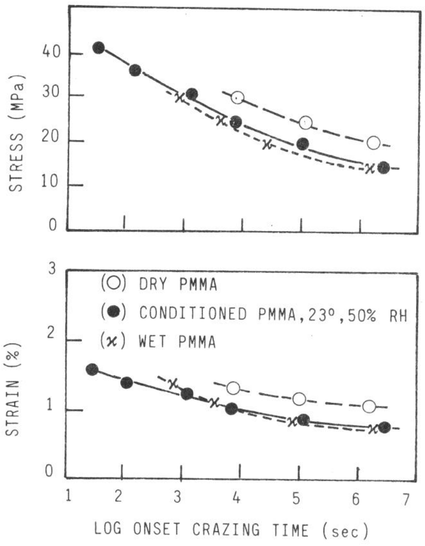

Figure 3 Influence of moisture.

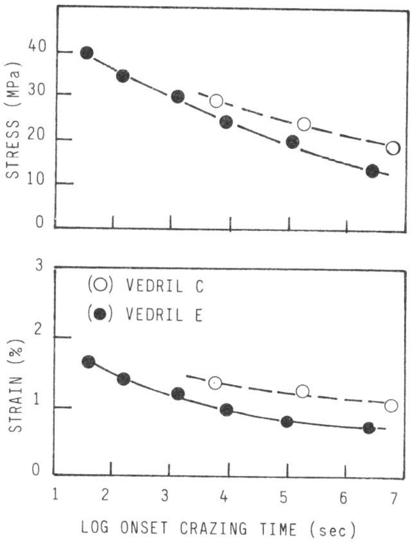

Figure 4 Influence of the molecular weight.

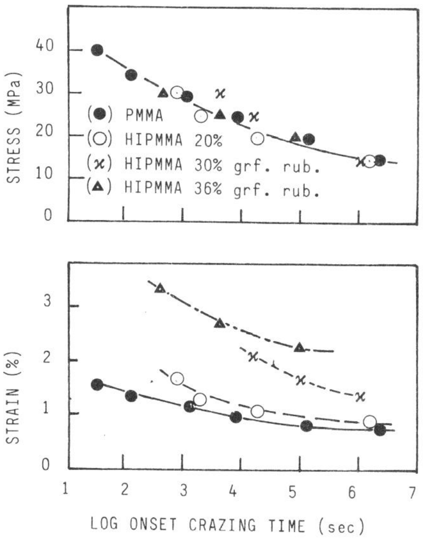

Figure 5 Influence of the grafted rubber contain.

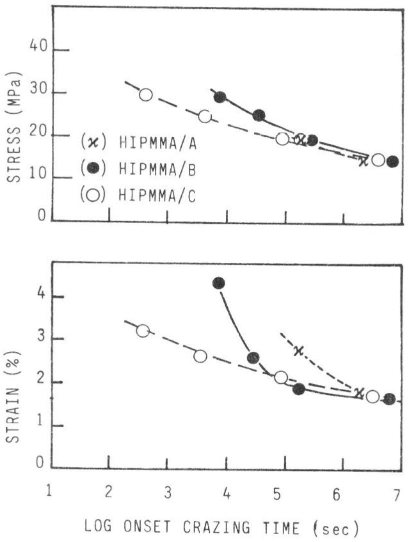

Figure 6 Influence of the grafted rubber type.