THE EFFECT OF SURFACE FINISH ON THE STRENGTH AND CRAZE RESISTANCE OF POLYMETHYLMETHACRYLATE IN SOME FLUIDS

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INTRODUCTION

A serious constraint on the use of polymers in engineering situations is that imposed by the detrimental effect that some fluid environments have on the mechanical properties of the polymer when it is exposed to the fluids under stress. This can manifest itself as increased rates of diffusion and softening or, in the case of glassy polymers, the nucleation and growth of crazes. Crazes are similar to small cracks except that they contain orientated fibrous material which can support tensile loads. They occur in areas of local tri-axial tensile stress and will not form under compression or pure shear. The craze structure resembles an open cell foam with a high internal specific area and a void content of up to 60%.

Considerable attention has been focused on attempts to relate the stress (or strain) that will produce crazing with the physical properties of the environmental fluid. Bernier and Kambour [1] have shown that the strain required to produce visible crazes in polyphenylene oxide correlated well with the solubility parameter of the fluid, having a minimum at the value of the solubility parameter of the solid. Subsequent works [2] suggest that the hydrogen bonding parameter and fractional polarity also play a role.

Gotham [3,4] has published results showing that the static fatigue strength of polyethylene is reduced on exposure to silicone oil and Stolki [5] has shown that both ductility and strength are decreased with increasing exposure time to some environments. McCammond and Ward [6] found that the strength of notched polymethylmethacrylate (PMMA) tensile specimens doubled relative to that in air when tested to failure at a constant straining rate in n-propanol. Preliminary tests on unnotched specimens showed no such dramatic increase in strength and prompted this investigation.

EXPERIMENTAL

Test specimens were manufactured from 3.2 mm thick PMMA sheet and had the profile shown in Figure 1. A "waisted" shape was chosen to ensure that the site of craze initiation and failure could be closely controlled to facilitate ease of observation. The surfaces of the two edges of the specimen were prepared by sanding or polishing in a direction perpendicular to the specimen length using the media listed in Table 1. In addition, two groups of specimens were manufactured with 60° "V" notches 0.625 mm and 0.25 mm deep and having a notch tip radius of 1/4 of the depth. All specimens were subsequently washed, annealed and stored in

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the climate controlled test laboratory.

Before testing, the surface roughness of each specimen (except those with notches) was measured using a Taylor Hobson Talysurf 10. One pass was made on each edge of the specimens and two roughness readings were obtained per pass. The output from the stylus was recorded on magnetic tape using a Hewlett Packard 3960 recorder and was simultaneously viewed on an oscilliscope. Improperly prepared specimens were discarded at this point. The recorded profiles were digitized and stored for subsequent computer surface roughness analysis. A high pass digital filter was used to remove any low frequency "waviness" of the specimen surface. Statistical methods were used to check the uniformity of the surface preparations and Chauvenet's criterion used to remove any outliner specimens. The notched specimens were photographed using a Leitz Wetzlar microscope; the photographs enlarged and digitized using a PDP 11 mini computer system with digitizing tablet. The average surface roughnesses obtained with the various media are listed in Table 1.

Constant strain rate tests were performed using an Instron testing machine with the specimens housed in a stainless steel cell with 2 glass windows. After preliminary tests, a cross-head speed of 20mm/min was selected as being one at which the sensitivity of strength to testing speed was minimized. The early detection of craze nucleation was effected by means of the reflection of an infra-red light beam, incident at an angle of 15° to the normal to the surface, onto a photo-cell. The output from the photocell together with the output from the testing machine load cell was displayed on a Hewlett Packard chart recorder.

Tests were conducted in air, water, methanol and hexane for each of the surface roughnesses. The procedure adopted for testing was to fit the specimen into the test machine with the cell filled with fluid and lowered clear of the specimen. The cell was raised, immersing the specimen, just before the test was commenced thus giving a standardized, short, pre-soak time. Tests have indicated that pre-soak time can affect the time required for nucleation of crazes during creep tests and also the resulting craze density [7]. The stress at which craze nucleation was detected, together with the ultimate strength, was noted. The area used to calculate stress was the minimum cross-sectional area as measured by a microscope.

RESULTS AND DISCUSSION

The data for the variation of strength with surface roughness is shown in Figure 2 for the four fluids. A minimum of 3 specimens were tested to obtain each data point, the error bars represent the maximum and minimum strengths obtained while the dot represents the average of the specimens tested. Data points for water, methanol and hexane have been omitted for clarity, but those for air included to give an indication of the scatter recorded. The results show that at low surface roughnesses the strength in the liquid environments is less than that in air, whereas for the notched specimens (large surface roughness), the strength in the active environments (methanol and hexane) is greater than that in air or water. The stresses at which craze nucleations were detected are shown in Figure 3. Again the plot for hexane indicates the maximum, minimum and average values of the craze nucleation stress. It is clear that while a small reduction with increasing surface roughness is apparent, no dramatic changes similar to those noted for ultimate strengths exist.

It might be expected that the ultimate strengths would be related to the craze nucleation stress since the existence of crazes would provide a preferential crack path for failure to occur. This is supported by the data at low surface roughnesses where the strengths are ordered similar to the nucleation stresses. At large surface roughnesses, however, the high, localized, stresses at the root of the surface indentations would encourage diffusion of the fluid into the polymer and the resulting softening could inhibit crack growth (reducing the polymer's notch sensitivity) and increase the ultimate strength relative to that in air.

CONCLUSIONS

The ultimate strength of PMMA was found to vary significantly with the specimen surface roughness and fluid environment. At low surface roughnesses the variation in craze nucleation stress with fluid environment played a dominant role in determining the ultimate strength whereas at large surface roughnesses the diffusion and softening effect of the active fluids reduced the notch sensitivity of the material and increased the strength relative to that in air.

ACKNOWLEDGMENTS

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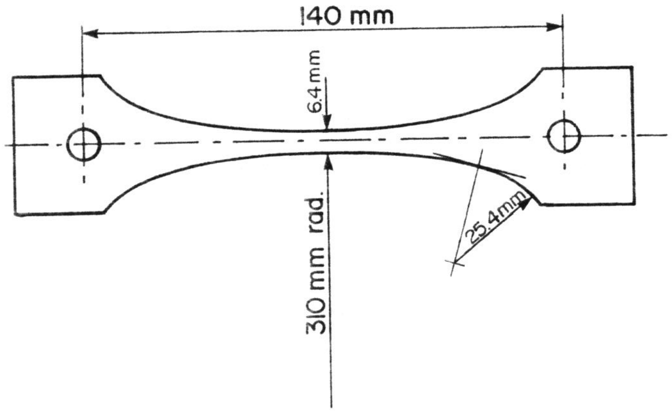

Figure 1 Tensile Specimen

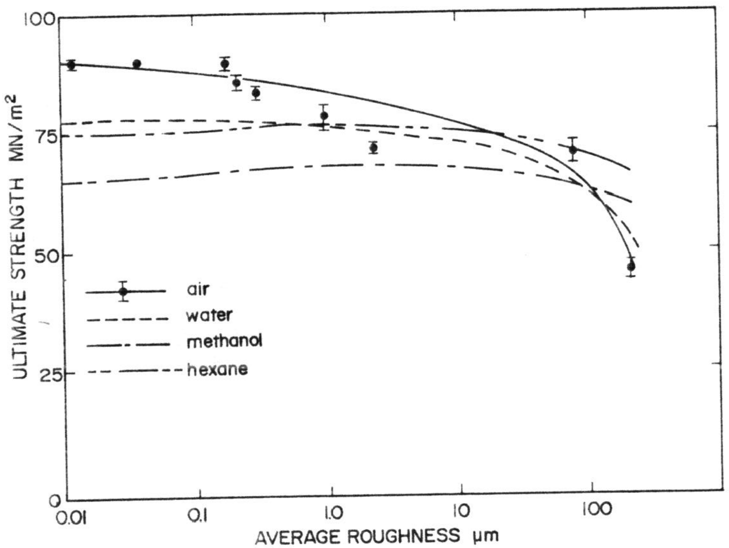

Figure 2 Variation of Ultimate Strength with Surface Roughness

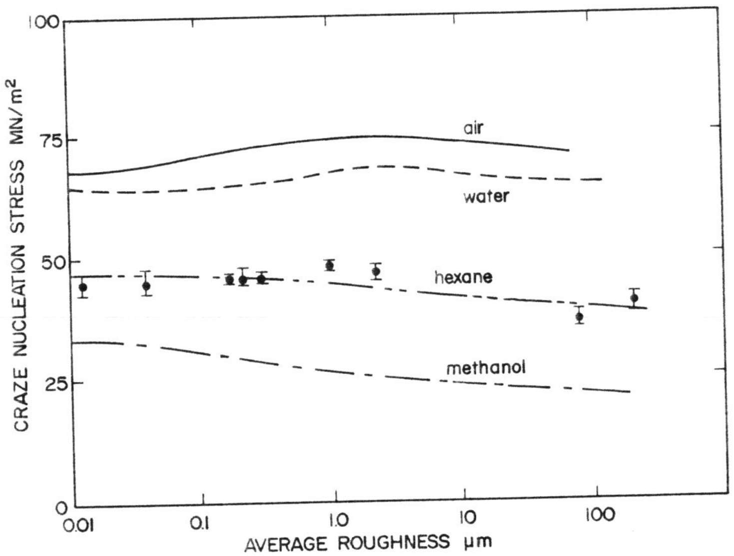

Figure 3 Variation of Craze Nucleation Stress with Surface Roughness

Table 1

Preparation Medium	Surface Roughness μm
Jewellers Rouge	0.013
Tripoli Polish	0.040
600 Grit Sand Paper	0.18
As Machined	0.21
400 Grit Sand Paper	0.30
240 Grit Sand Paper	0.99
80 Grit Sand Paper	2.33
0.25 mm notches	76.2
0.625 mm notches	294.0