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Some Results on the Crazing of Perspex Including the Effect of Humidity

by

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Some results on the crazing of Perspex including the effect of humidity

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SUMMARY

The effect of humidity on the stress crazing of Perspex by four crazing agents has been investigated. A quantitative value for the change in threshold crazing stress with change in relative humidity has been derived.

A table of threshold crazing stresses for Perspex with a range of liquids has been compiled.

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1 Introduction

It has been shown[1] that the effect of absorbed water is to lower the threshold crazing stress of Perspex by approximately 1,000 lb/sq in. for each per cent of water absorbed. Only one crazing agent, ethyl alcohol, which is miscible with water, was used in the investigation. The threshold crazing stress was apparently a non-continuous function of the amount of water absorbed and this was attributed to the accelerated humidity conditioning procedure used. It was decided to extend these experiments to other crazing agents, both miscible and immiscible with water, and to condition the specimens to different relative humidities rather than to immerse them in water for varying times to obtain the desired moisture content.

In conjunction with this work, the threshold crazing stresses for Perspex with a large variety of liquids has also been determined. This information serves to bring the table of Report Chem 447[2] (list of liquids known to cause crazing) up to date and to make it more quantitative in nature.

2 Experimental

2.1 Method of test

Perspex specimens (10 in. × 1¼ in.) were machined from both plasticised and unplasticised sheets of thickness ¼ in. The specimens were heat treated and annealed by the method defined in Specification D.T.D.925A. They were placed immediately above saturated solutions of various salts contained in closed vessels. The saturated solutions had been chosen to give different controlled humidities at room temperature[3], and are listed in Table I. The specimens were exposed to these conditions for six months, this time period having been shown by subsidiary experiments to be necessary for the practical attainment of moisture equilibrium in ¼ in. thick Perspex.

To determine the threshold crazing stress a specimen was clamped as a 4 in. cantilever. A known weight was suspended from the end and the crazing agent was applied continuously with a small camel hair brush to the whole of the upper stressed surface of the specimen for a period of five minutes. In all, four crazing agents were used, two of which were miscible with water (ethyl alcohol and acetone) and two immiscible with water (trichloroethylene and benzene). The crazed specimen was examined in a "crazing viewer" similar to that described in reference 1. A parallel beam of light is incident on the lower surface of the specimen at an angle of 30°. Transmitted light is absorbed at a black surface while light impinging on crazing marks is reflected and viewed through a magnifying lens. The distance of the first crazing mark from the point of application of the load was measured and also the exact width and thickness of the specimen at that crazing position. The threshold crazing stress (S) is given by the expression

$$S = \frac{6\ Wx}{bt^2}$$

where W = load including weight carrier (lb)

x = distance of first crazing mark from point of application of load (in.)

b = width of specimen at first crazing mark (in.)

t = thickness of specimen at first crazing mark (in.).

2.2 Water absorption of specimens

Four specimens from each group exposed at the various humidities were weighed after the six months exposure. They were then placed in an oven at 120°C for 60 hours, removed, allowed to cool in a desiccator over phosphorus pentoxide and reweighed.

2.3 Threshold crazing stress for various liquids

The apparatus and procedure used were the same as the those used in the study of the effect of relative humidity on crazing. Plasticised Perspex was first heat treated and annealed and stored in desiccators over phosphorus pentoxide for the short period before use.

3 Results

3.1 Threshold crazing stress change with humidity

The threshold crazing stresses of plasticised and unplasticised Perspex after conditioning at various humidities are listed in Tables II and III. Each value quoted is the mean of four determinations. The results have been plotted for each crazing agent and are shown in Figures 1 to 4. The results for plasticised and unplasticised Perspex were the same within the limits of experimental error. Reasonable straight lines could be drawn for each set of results. The slopes of the lines were calculated by the method of least squares and are given in Table IV. The slope was practically the same for each crazing agent.

3.2 Absorption of water at different humidities

The amount of water absorbed by plasticised and unplasticised Perspex during six months conditioning at different humidities is given in Table V and the results are plotted in Figure 5. A direct proportionality between relative humidity and amount of water absorbed was not obtained. This may indicate that moisture equilibrium had not quite been reached at the end of the six month period. The absorption of the unplasticised Perspex was slightly higher than that of the plasticised variety over the whole range of humidities.

Using the values for water absorption obtained, graphs of threshold crazing stress against per cent water absorption were also plotted. (Figures 6 to 9). Reasonable straight lines could be drawn for the data on the water-miscible liquids, acetone and ethyl alcohol, but the data for the liquids immiscible with water, trichloroethylene and benzene, lay on a curve, the threshold crazing stress falling off less rapidly at the higher amounts of water absorption. The lowering of the crazing stress is in the range 900 - 1,000 lb/sq in. for each per cent of absorbed water for each crazing agent. This confirms the results reported[1] on ethyl alcohol. The closer approach to a linear relationship between crazing stress and amount of water absorbed obtained in this investigation confirms the supposition that the apparent point of inflection in the Imperial Chemical Industries results was due to the accelerated conditioning procedure used.

3.3 Threshold crazing stress for various liquids

The results obtained on nominally dry Perspex are listed in Table VI which serves to rate crazing agents according to their activity. In general, increase in the length of the hydrocarbon chain in the molecule results in an increase in the crazing stress; aromatic derivatives tend to cause crazing at lower stress levels than their aliphatic analogues. It will be noted that in spite of the conditioning procedure used, the threshold crazing stresses obtained were those to be expected from a moisture content of 0.4 - 0.6%.

4 Conclusions

The threshold crazing stress of plasticised and unplasticised Perspex at room temperature is lowered by approximately 16 lb/sq in. for every one per cent increase in the relative humidity, provided equilibrium is attained. Alternatively, the threshold crazing stress decreases by 900 - 1,000 lb/sq in. for every one per cent of absorbed water. This is true of a variety of crazing agents. The results for plasticised and unplasticised Perspex are the same within the limits of experimental error, despite a slightly greater water uptake by the unplasticised material.

REFERENCES

No.		
1	Imperial Chemical Industries Ltd. Plastics Division.	"Perspex Acrylic sheet - a crazing test". I.S. Note 352, 1953.
2	E. W. Russell	"Studies of polymethyl methacrylate Part III. Crazing effects". R.A.E. Report Chem 447. 1948. Unpublished M.O.S. Report.
3	-	International Critical Tables Vol. I p. 67. McGraw-Hill 1927.

TABLE I

Relative humidities and their sources

Condition	Source	Relative humidity % at 20°C
1	Solid phosphorus pentoxide	0
2	Saturated solution of potassium acetate	20
3	Saturated solution of potassium thiocyanate	47
4	Saturated solution of sodium nitrite	66
5	Saturated solution of ammonium sulphate	81
6	Water	100

TABLE II

Threshold crazing stress of plasticised Perspex in lb/sq in. at different humidities

Crazing Agent	Relative humidity %					
	0	20	47	66	81	100
Acetone	1,940±50	1,570±120	1,360±30	910±10	800±80	340±80
Benzene	2,680±140	2,420±90	1,820±130	1,540±150	1,390±80	1,060±130
Ethyl alcohol	2,610±90	2,440±100	1,740±130	1,570±110	1,400±60	890±40
Trichloroethylene	1,890±100	1,480±80	1,080±90	880±20	670±120	280±30

TABLE III

Threshold crazing stress of unplasticised Perspex in lb/sq in. at different humidities

Crazing Agent	Relative humidity %					
	0	20	47	66	81	100
Acetone	1,780±170	1,580±170	1,230±110	930±30	660±90	320±20
Benzene	2,780±80	2,470±50	1,860±130	1,450±50	1,270±70	950±70
Ethyl alcohol	2,650±110	2,270±140	1,690±40	1,580±80	1,270±20	790±80
Trichloroethylene	1,770±140	1,430±160	1,030±80	800±80	610±80	240±70

TABLE IV

Slopes of the graphs of threshold crazing stress against relative humidity expressed as lb/sq in. for every one per cent r.h.

Crazing Agent	Plasticised Perspex	Unplasticised Perspex
Acetone	-15	-15
Benzene	-16	-17
Ethyl alcohol	-17	-18
Trichloroethylene	-15	-15

TABLE V

Absorption of water by Perspex at different humidities
(Specimens 10 in. × $1\frac{1}{4}$ in. × $\frac{1}{4}$ in. Conditioned for 6 months)

Relative Humidity %	Water absorption % by weight	
	Plasticised Perspex	Unplasticised Perspex
0	0.09	0.095
20	0.36	0.41
47	0.69	0.75
66	1.04	1.06
81	1.24	1.36
100	1.65	1.75

TABLE VI

Threshold crazing stresses for nominally dry plasticised Perspex with a range of liquids

Liquid	Threshold crazing stress lb/sq in.
Hydrocarbons	
n-hexane	4,350
n-heptane	4,600
iso-octane	> 5,000
*cyclo*hexane	> 5,000
benzene	1,940
toluene	1,460
xylene	2,060
styrene	1,250
tetralin	3,370
decalin	4,540
pinene	> 5,000
Alcohols and phenols	
methyl alcohol	1,990
ethyl alcohol	2,210
*iso*propyl alcohol	2,980
n-butyl alcohol	3,260
t-butyl alcohol	3,410
n-amyl alcohol	3,690
ethylene glycol	> 5,000
benzyl alcohol	1,710
m-cresol	1,810
Aldehydes	
acetaldehyde	2,380
furfural	900
benzaldehyde	1,250
Ketones	
acetone	1,320
ethyl methyl ketone	1,220
diacetone alcohol	1,390
*cyclo*hexanone	2,800
acetophenone	1,640
Carboxylic acids	
acetic acid	1,740
butyric acid	1,590
lauric acid	4,520
Ethers	
Cellosolve	1,700
diethyl ether	2,580
*iso*propyl ether	3,740
Nitro compound	
nitrobenzene	1,700

TABLE VI (Contd)

Liquid	Threshold crazing stress lb/sq in.
Amines	
diethylamine	2,160
triethanolamine	> 5,000
aniline	1,830
benzylamine	1,220
pyridine	1,600
quinoline	2,650
Chlorinated compounds	
chloroform	1,500
carbon tetrachloride	4,240
ethylene dichloride	1,490
trichloroethylene	1,300
benzyl chloride	1,340
Esters	
methyl formate	1,390
ethyl formate	1,140
methyl acetate	1,760
ethyl acetate	1,100
Cellosolve acetate	1,520
butyl acetate	1,970
amyl acetate	2,430
monoacetin	3,690
methyl methacrylate	1,940
dimethyl sbacate	3,380
butyl stearate	> 5,000
tributyl phosphate	3,850
tricresyl phosphate	> 5,000
benzyl benzoate	3,470
dimethyl phthalate	4,170
diethyl phthalate	> 5,000
butyl phthalate	> 5,000
dibutyl phthalate	> 5,000

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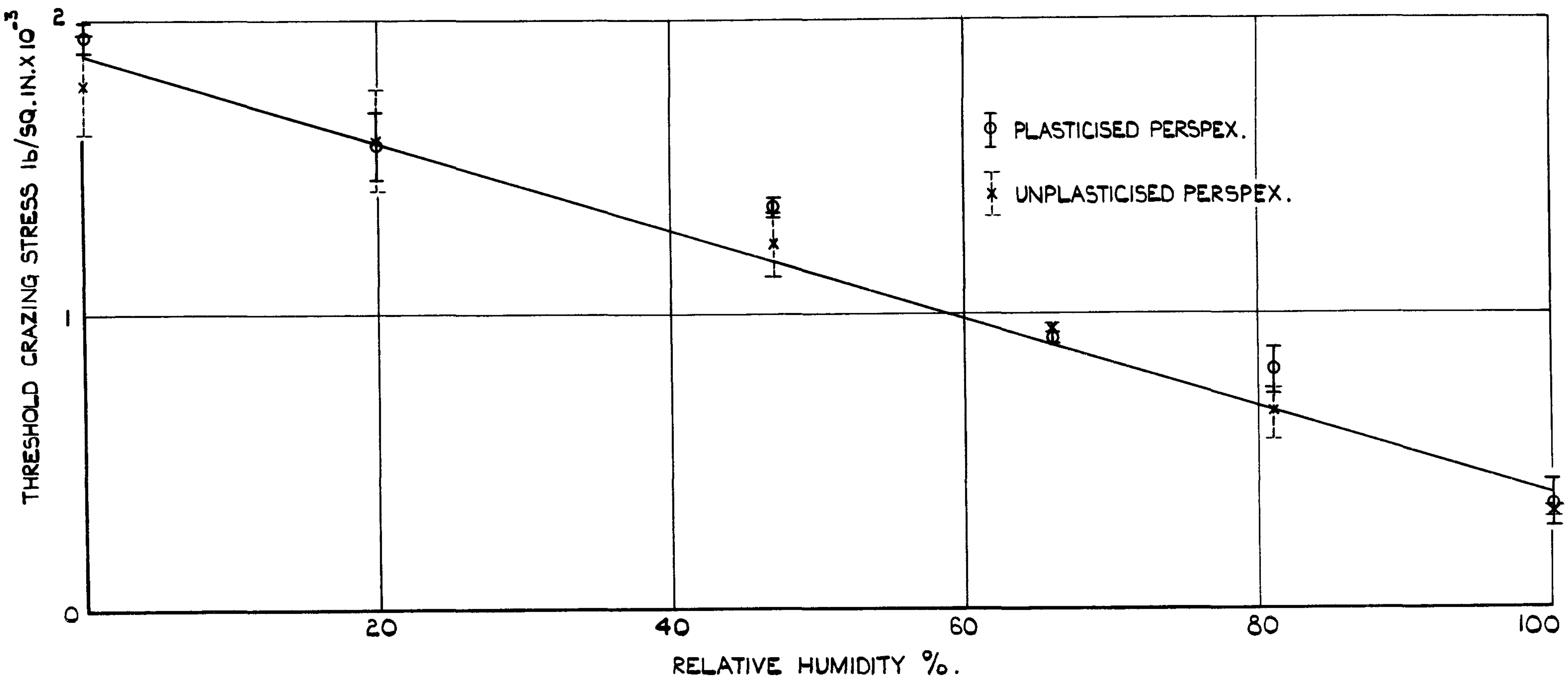

FIG.1. THE EFFECT OF HUMIDITY ON THE CRAZING OF PERSPEX BY ACETONE.

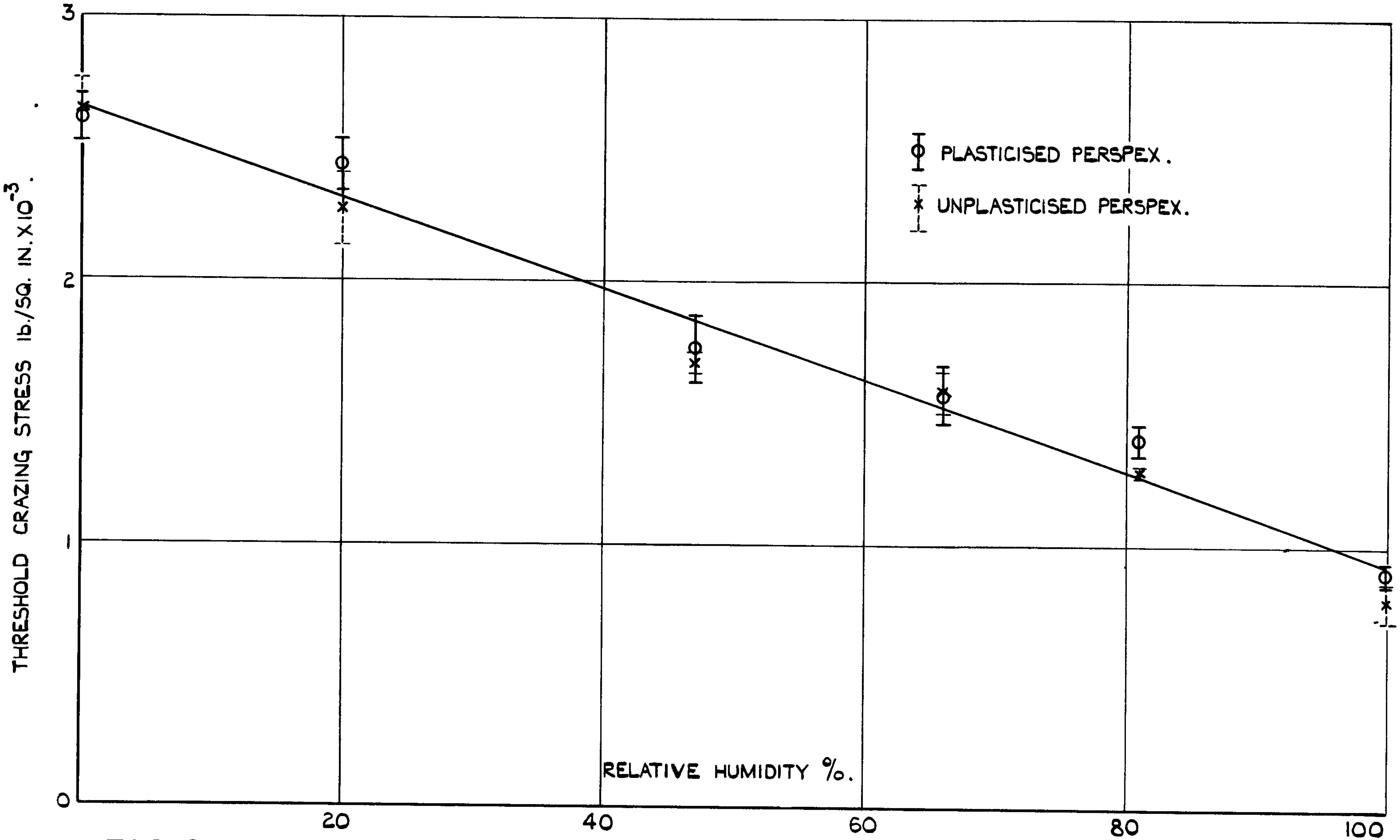

FIG.2. THE EFFECT OF HUMIDITY ON THE CRAZING OF PERSPEX BY ETHYL ALCOHOL.

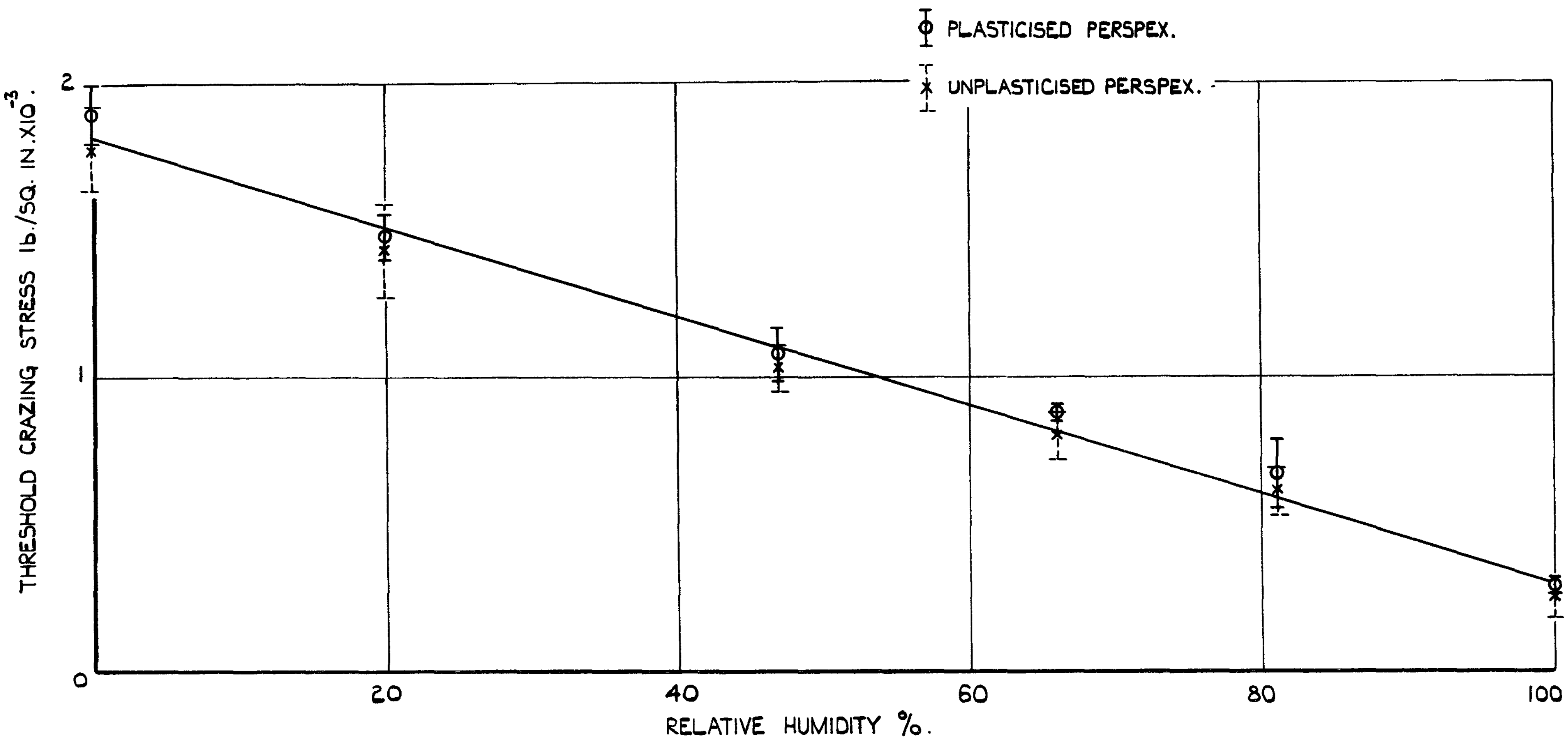

FIG. 3. THE EFFECT OF HUMIDITY ON THE CRAZING OF PERSPEX BY TRICHLOROETHYLENE.

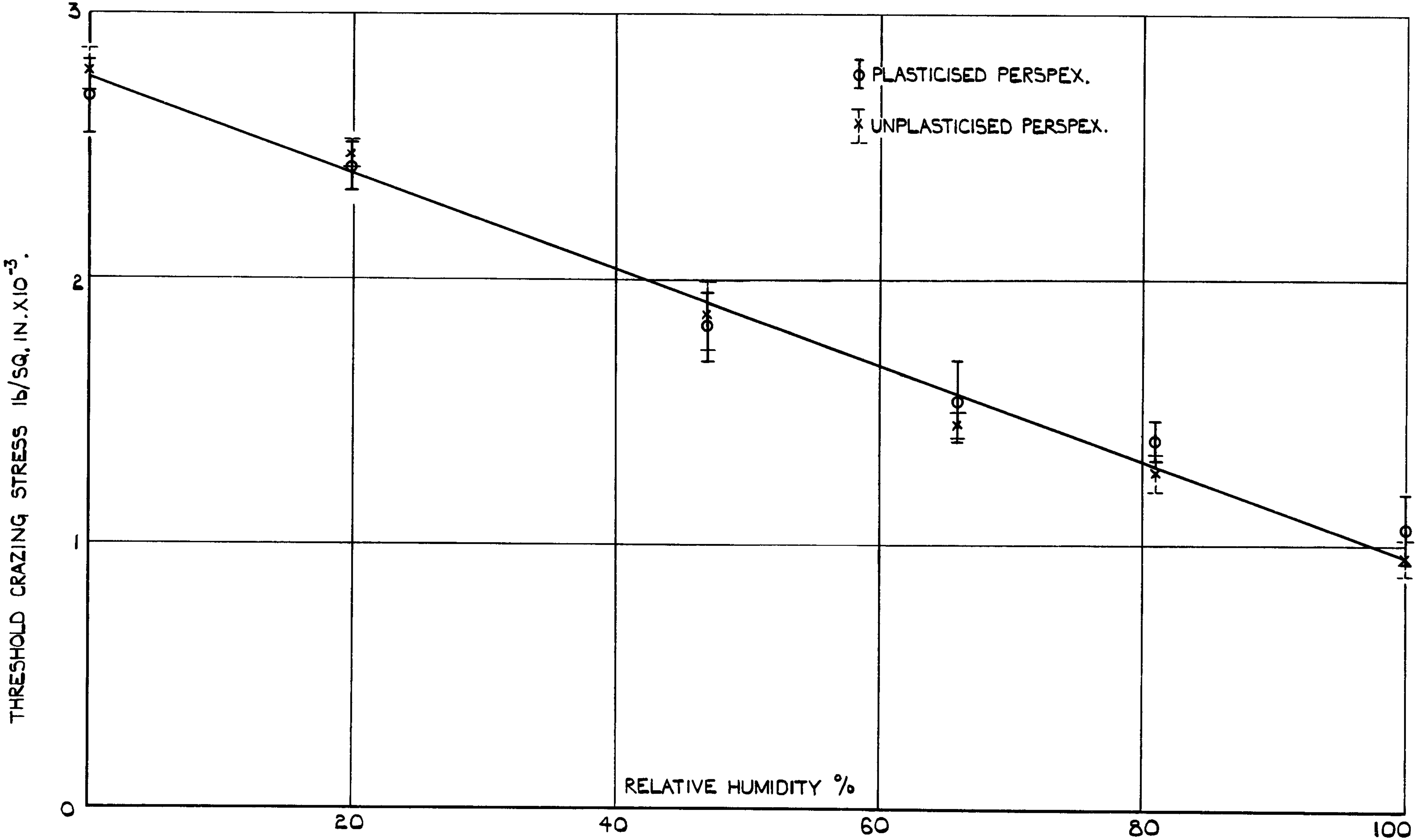

FIG. 4. THE EFFECT OF HUMIDITY ON THE CRAZING OF PERSPEX BY BENZENE.

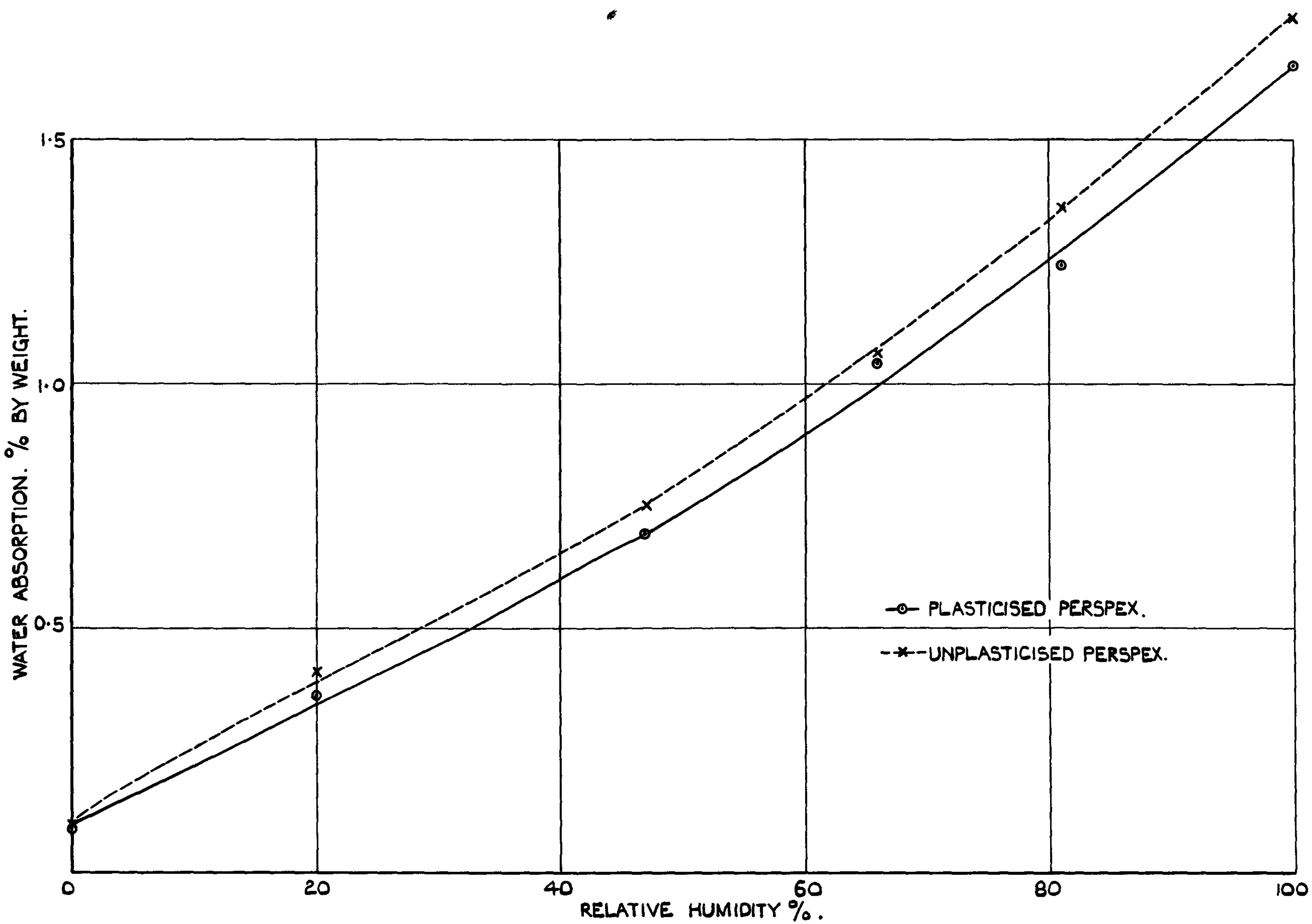

FIG. 5. WATER ABSORPTION OF PERSPEX AT DIFFERENT HUMIDITIES (SPECIMENS 10 in. X $1\frac{1}{4}$ in. X $\frac{1}{4}$ in. CONDITIONED FOR SIX MONTHS.)

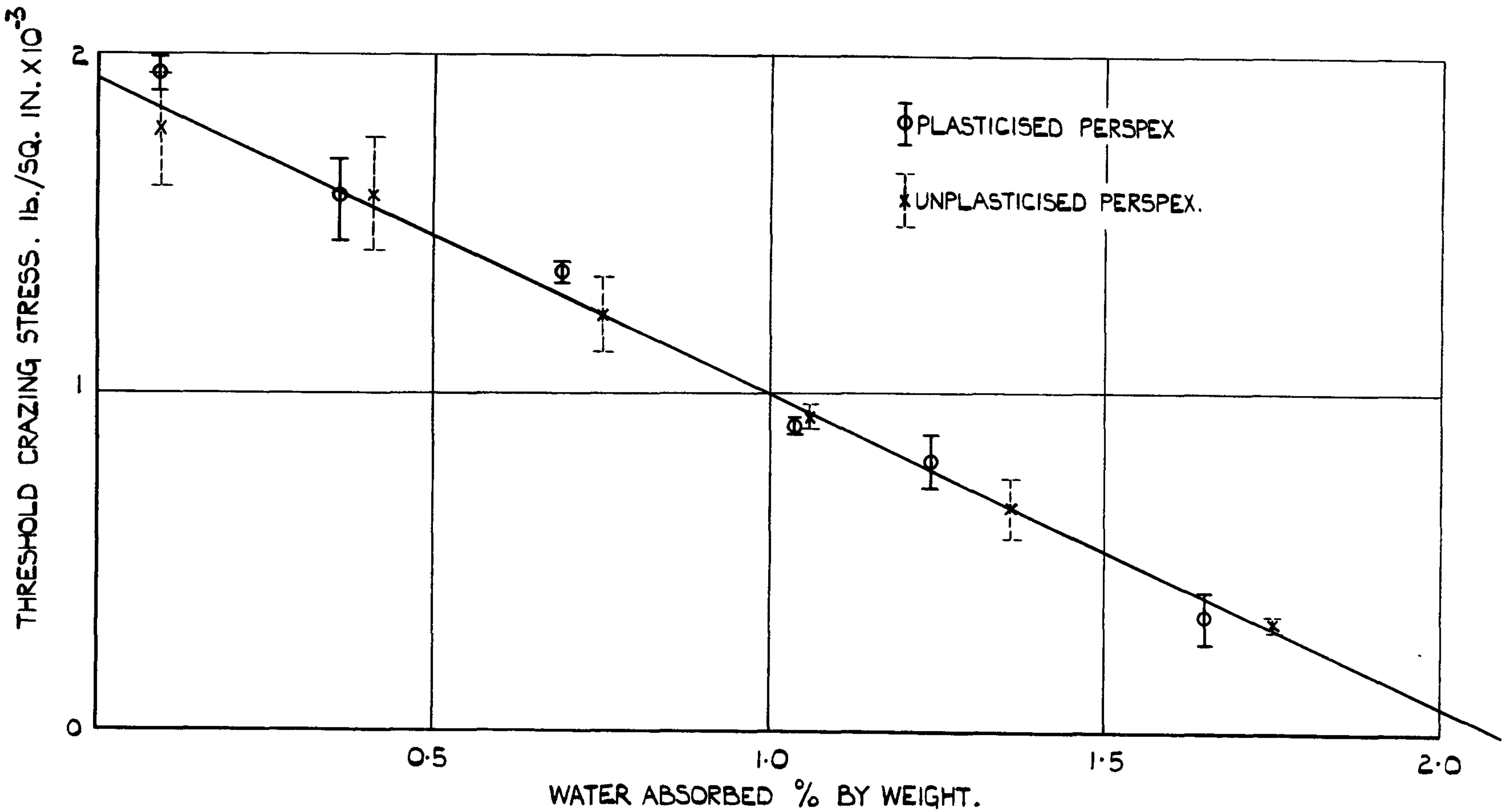

FIG.6. THE EFFECT OF ABSORBED WATER ON THE CRAZING OF PERSPEX BY ACETONE.

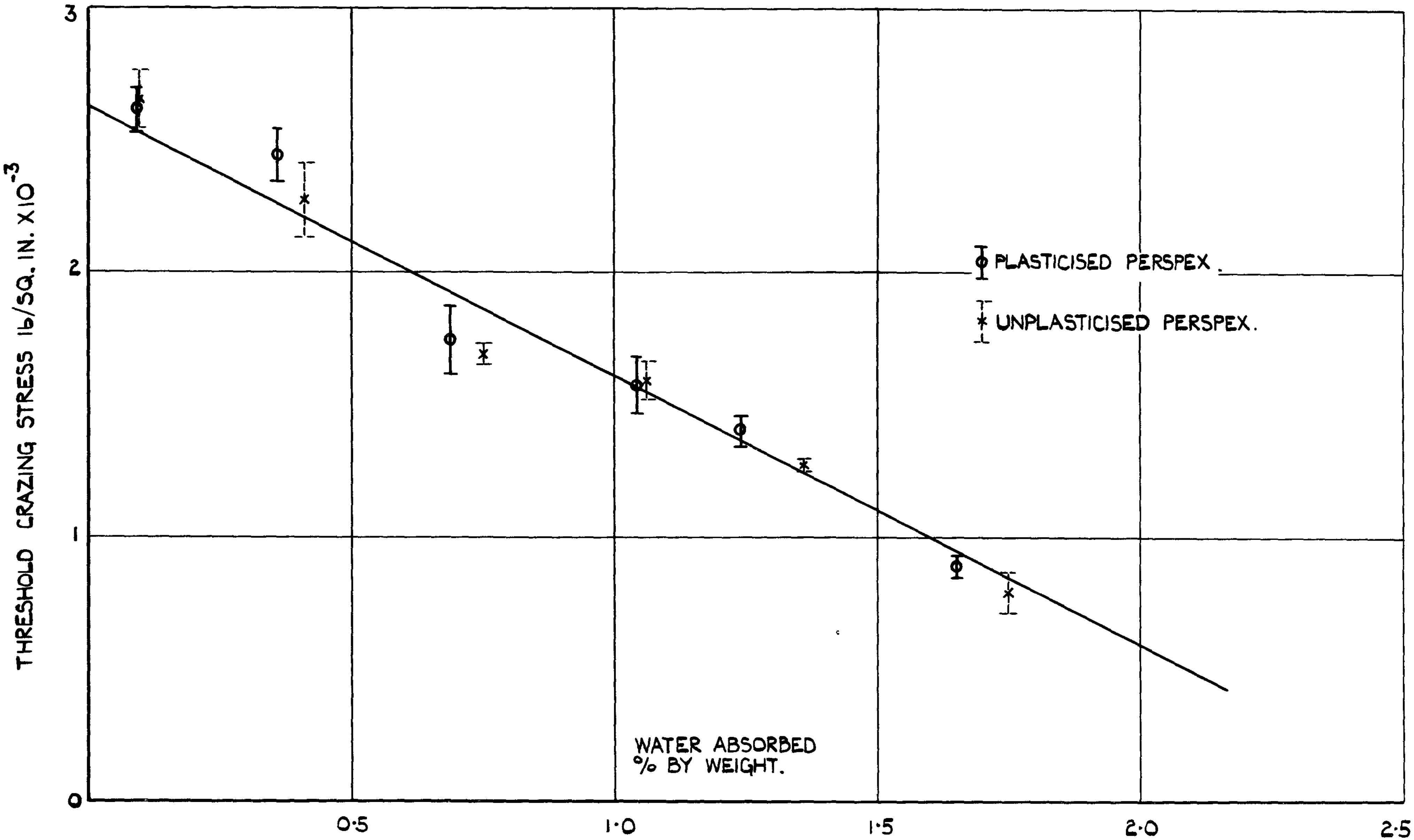

FIG.7. THE EFFECT OF ABSORBED WATER ON THE CRAZING OF PERSPEX BY ETHYL ALCOHOL.

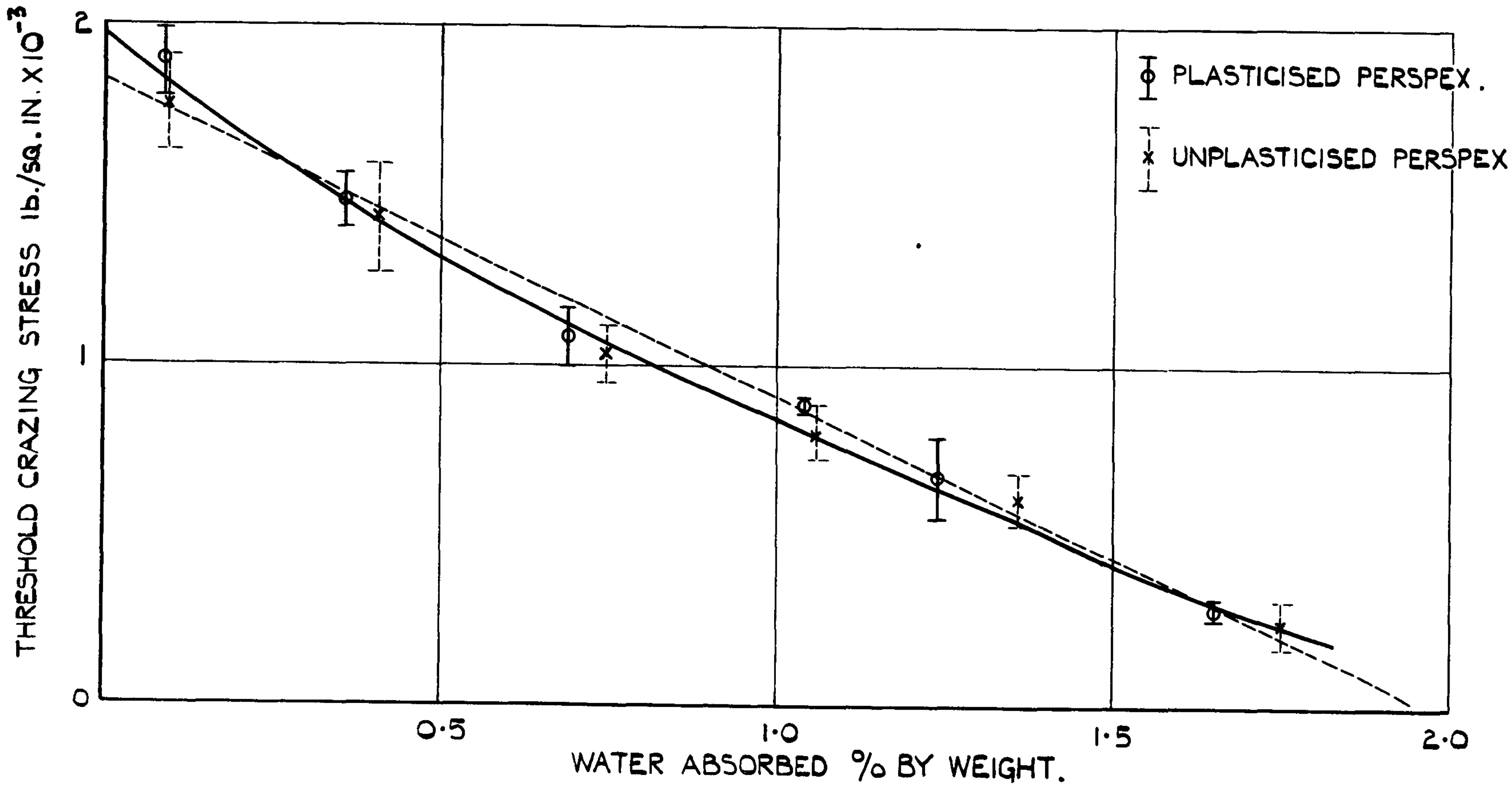

FIG. 8. THE EFFECT OF ABSORBED WATER ON THE CRAZING OF PERSPEX BY TRICHLOROETHYLENE.

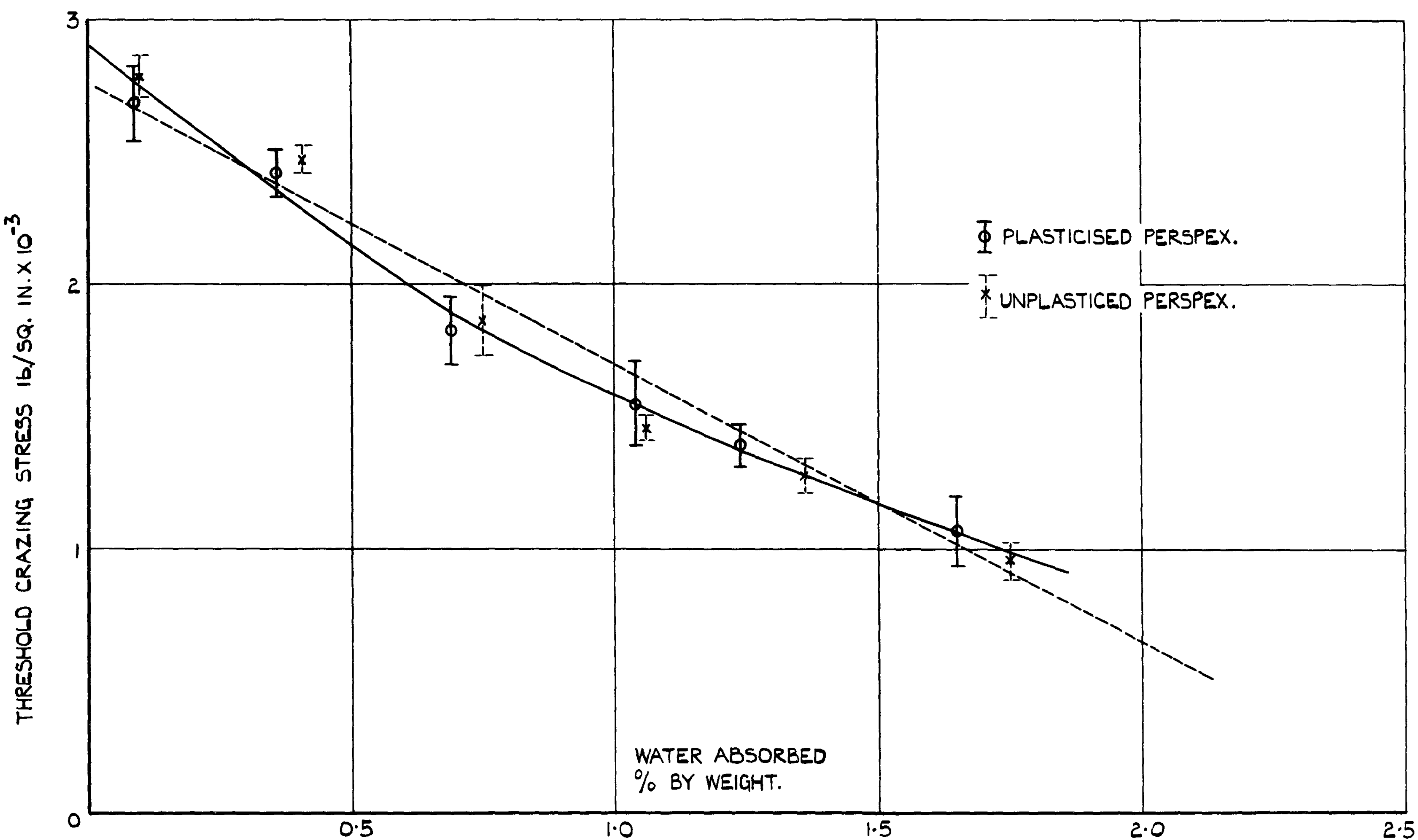

FIG. 9. THE EFFECT OF ABSORBED WATER ON THE CRAZING OF PERSPEX BY BENZENE.

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