# EFFECTS OF TEMPERATURE, STRAIN RATE AND GEOMETRY ON THE FRACTURE TOUGHNESS OF POLYURETHANE.

A. GHOUL *, A. BOUABDALLAH*, A. BENGUEDIAB*
N. RANGANATHAN**, J. PETIT**.

The temperature and the solicitation speed present an effect duality on the fracture of materials. This behaviour is particularly present in the polymers, because of their viscoelastic characteristics. The material chosen for this study is the polymeric component which constitute the matrix of many explosives and propergols. Essentially this material is a polyurethane whose the rate of reticulation depends on the product specificity to make.

## INTRODUCTION

The aim of our study is to show the effects of the temperature, the solicitation speed and the geometry of sample on the fracture toughness of the polyurethane.

Our basic hypothesis will be that the parameter dU/dA characterise the property of the strength to the material fracture which we are going to study and the evaluation methods of this parameter are equivalents. We limited the study to the conditions of initiation of crack, because since during the propagation the phenomenon of relaxation appears in the regions to be unloaded. This phenomenon for the viscoelastic materials bring up to a variation of the toughness with the speed of crack initiation. We will show also that the experimental determination of dU/dA is possible from a unique sample. This last particularity is obviously important for the industry.

*Institut de Mécanique, BP.151, Université de Chlef- 02000 Chlef(ALGERIE).
**LMPM-ENSMA, Site du Futuroscope, BP.109 -86960 Futuroscope Cedex- FRANCE.

## MATERIALS AND EXPERIMENTAL DEVICES

The tests have been performed on a traction machine of Instron type Whose 10 KN capacity is piloted by a computer(Fig.1). The three types of specimen which used are DENT, CC, AXI. The different lengths chosen of cracks are given in the table below.

| Geometry | Lengths of cracks "a (mm) " | | | | |
|---|---|---|---|---|---|
| AXI | 0 | 2 | 3 | 4.5 | 7 |
| DENT | 0 | 7 | 10 | 12 | 14 |
| CC | 0 | 15 | 20 | 28 | - |

The specimen is sticked on the mounting of the machine. A loading cell of 1 KN is placed on a cross-bar to allow the measure of the stress made by the specimen. The displacements are measured by a captor fixed to the ends of the specimen. The speed of solicitation is given between 1 and 100 mm/mn. The different temperatures are obtained by the circulation of the nitrogen in a climatic housing installed around the sample. The measure of different points of the housing shows the existence of a temperature gradient about ± 2.5°C. The circulation of the nitrogen is obtained by the evaporation and pressure of the liquid nitrogen contained in a proof bottle.

The measures of load and displacements are directly available on the output of the machine(Fig.1). These signals given in function of time are transmitted, than taken by a numerical linking of parallel type(IEE) by a HP computer whose soft ware package allows their storing for a future exploitation.

## RESULTS AND DISCUSSIONS

To show the effects of temperature and the speed of solicitation on the fracture toughness, we have used the energetic parameter method. This approach is very interesting because it allows the determination of a materiel fracture toughness from one test of failure of cracked specimen. The samples used in this case are the AXI type. In this configuration of geometry, RICE, PARIS, MERKLE[1] and NAIT[2] have shown that the J integral can be given by the relation :

$$J = \frac{1}{2\pi r^2}\left(3\cdot\left(\int_0^{d_c} P\cdot dd_f\right) - P\cdot d_c\right) \quad (1) \quad \text{with } r = R-a \;;\; d_f = d_t - d_{el}$$

$r$ : radius of ligament , R radius of specimen,

$d_c$ : displacement of the application points,

$d_t$ : total displacement,

$d_{el}$ : elastic displacement.

The values of JIC are defined by the maximal values of dc. The medium values of the fracture toughness for each speed of solicitation and each temperature are shown on the Figure 2.

First we note that there is an effect duality between the temperature and the speed of solicitation. The fracture toughness of polyurethane rises of 8% when the speed of solicitation becomes 10 times higher. It rises of 40% when the speed of solicitation becomes 100 times higher. However the effect of the temperature seems to be less marked relatively to the one of the speed of solicitation. The fracture toughness reduces of 4% when the temperature rises of 20%(Fig.3).

To analyse the effect of temperature and the speed of solicitation on the fracture toughness of polyurethane, a major curve takes into account these two parameters on the same time, was established(Fig.4). We have used the equation of WLF[3] to determine the sliding factor $a_T$ :

$$a_T = -C_1 (T-T_0) / C_2 + (T-T_0) \qquad (2)$$

$C_1$ and $C_2$ are universal constants which are equal respectively 8,86 and 101,6. T is the test temperature, Tg the transition temperature and $T_0$ references temperature. $T_0$ = Tg +50°C. The domain of validity of this formula is Tg<T<Tg+ 100°C.

To show the effect of specimen geometry on the fracture toughness value, we have made a comparative study on three different geometry : DENT, CC, and AXI. In the same time, we used different methods to calculate the fracture toughness. The tests are realised for T = 20°C and V=0.5 mm/mn. The results are presented on the table.2 below.

| Evaluation Method | Geometry of specimen | | |
|---|---|---|---|
| | DENT | CC | AXI |
| Method of Energetic Parameter Jc ($J/m^2$) | 196 | 187 | 189 |
| Method of BEGLEY-LANDES Jc ($J/m^2$) | 189 | 191 | 182 |
| Method of ANDREWS Ic ($J/m^2$) | 201 | 215 | 330 |

It is clear that the effect of geometry is not negligible on the fracture toughness evaluation(Table.2). We can indicate also, that the energetic parameter method is very interesting because it uses only one sample by test and gives a good result. Another point, it seems that the Andrews method is not practical to be used for the AXI geometry(Table.2).

## CONCLUSION

In the range of temperature explored -50 to +50 °C and in the interval of solicitation speed 0.5 to 100 mm/mn, the fracture toughness of polyurethane is a linear function characterised by a dual effect of these two parameters.

The experimental energetic parameter method used to evaluate the fracture toughness seems very interesting in our case because it is economic and gives acceptable results.

It is interesting that a reflective subject will be accorded to explain quantitatively the results obtained on the AXI geometry. A numerical analysis of the stress field in the ligament seems necessary to this problem type.

## BIBLIOGRAPHY

[1] J.C .RICE , P.C.PARIS , J.G. MERKLE
"some futher results on J-integral analysis and estimates" ASTM STP 536, PP. 231-244.

[2] M. A. NAIT
"Ténacité dynamique d'un propergol solide composite: Aspects expérimentaux et théoriques". Thèse de docteur de l'INPL, Déc 1985. Metz.

[3] R.G. NEVIERE
"Experimental method for JIc computation on fracture of solid propellant". Eng. Fract. Mech. Vol.28, N°4, 425-434, 1987.

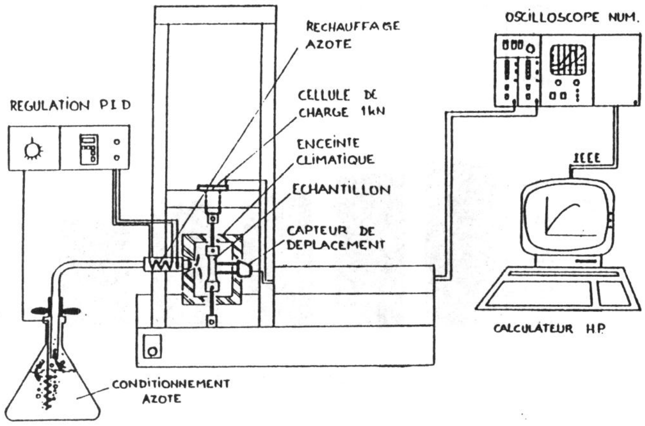


**Fig. 1.** - **Instron Machine with acquisition system.**

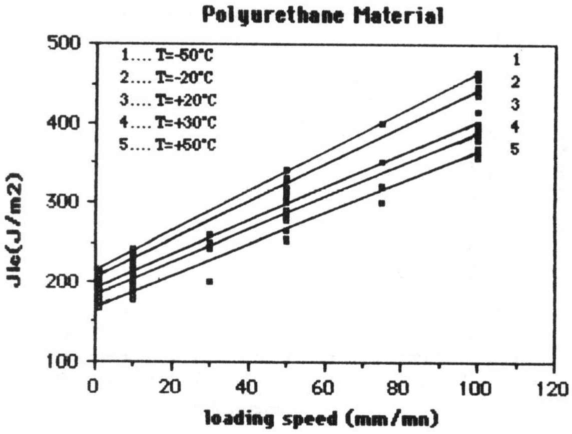


**Fig. 2.** - **JIc versus Temperature and Loading speed.**

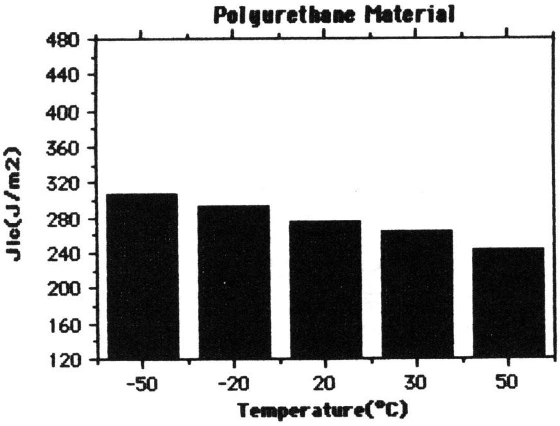


Fig. 3. - Histogram : Fracture tougness versus temperature.

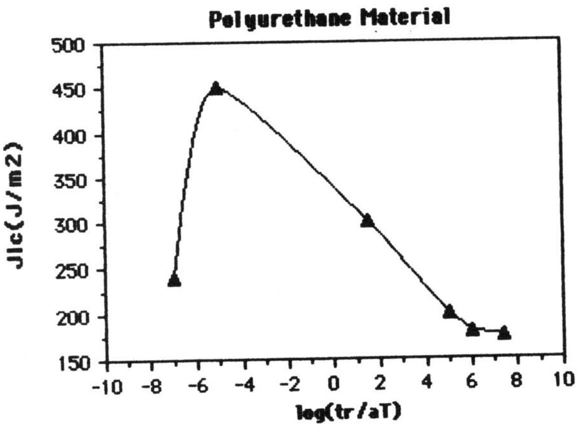


Fig. 4. - JIc versus temperature and loading speed.