

EXPERIMENTAL SET-UP FOR DYNAMIC FRACTURE OF
MATERIALS AT HIGH TEMPERATURE

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The purpose of this paper is to introduce an original experimental set-up to study the dynamic response of materials from room temperature to high temperature (~1600°C). This study is organised in two parts. The first discusses the prototype experimental-set-up where heated specimens are dynamically loaded in three point bending configuration. The second part deals with some experimental results to calculate the dynamic stress intensity factor in using the Kishimoto and co-workers 's method.

INTRODUCTION

The purpose of this paper is to introduce an original experimental set-up to study the dynamic response of materials from room temperature to high temperature (~1600°C). A wide range of materials have been investigated such as glasses (Research group 972 report (1)), ceramics, a sintered tungsten (Lamaison (2)) and a carbon-carbon composite (Guillaumat et al (3)). This study is organised in two parts. The first discusses the experimental-set-up where heated specimens are dynamically loaded in three point bending configuration (figure 1). The second part deals with the experimental results to calculate the dynamic stress intensity factor in using the Kishimoto and co-workers 's method (Kishimoto (4)).

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EXPERIMENTAL SET-UP

The specimens are dynamically loaded in three point bending configuration by means of an instrumented ceramic bar which is impacted by a projectile.

The instrumented ceramic bar goes through the gate of the furnace with a dynamic gasket. This configuration allows both the confinement of the furnace and the freely displacement of the ceramic bar. This bar is placed in contact with the specimen before test. Projectile and bar are guided during test by respectively two compressed air shaft bearings. The specimen is located for heating in the centre of the graphite susceptor of the furnace which is submitted to an induced current to reach high temperature up to 1600°C. The heating is performed first under vacuum and second under argon. The temperature is controlled by a thermocouple and is checked by an optical pyrometer which provides a measurement closed to the specimen.

Due to the impact of the projectile, bar waves propagate along the ceramic bar instrumented by two full semi-conductive gage bridges to eliminate bending conditions. In using the Split Hopkinson Pressure Bar technique, normal force and displacement of the extremity of the ceramic bar in contact with specimen are calculated versus time from the recorded signals measured by the gage bridges. Rupture Mechanics analysis must be performed to calculate the dynamic stress intensity factor of the studied materials.

SPLIT HOPKINSON PRESSURE BAR TECHNIQUE

The Split Hopkinson Pressure Bar method provides an estimation of normal resultant force and displacement versus time at the cross section of the bar in contact with the specimen. The striker impacts the extremity of the instrumented bar and generates an elastic compressive wave, propagating towards the specimen. A part of the incident wave is then reflected on the bar, the other part is transmitted to the specimen. The bar is instrumented with semi-conductive gauge bridges to measure longitudinal strains at two given sections S_1 and S_2 . Let us notice these two sections S_1 and S_2 are considered to carry out after test the calculation of force and displacement versus time at any cross section of the bar and particularly at the contact cross section between bar and bending specimen.

BENDING SPECIMEN

The studied specimens are parallelepipeds with 10 mm thickness (B), 10 mm width (W) and 60 mm length. They are supported by a graphite cylinder placed in the susceptor of the furnace. To conduct a fracture toughness test a edge crack is introduced with 5 mm deep (a).

THE TESTING PROCEDURE FOR DETERMINATION OF PLANE STRAIN FRACTURE TOUGHNESS K_{Ic}

Three-point bend specimens are widely used for determination of static fracture toughness K_{Ic} as well as dynamic fracture toughness K_{Id} . (Bacon et al (5)) The dynamic fracture toughness K_{Id} is a material property, which depends on both the temperature and the rate of loading. It is equal to the value of the dynamic stress intensity factor $K_I(t)$ at the time t_i of initiation of crack growth. Since the time derivative $\dot{K}_I(t)$ is used to represent the rate of loading, the full time history $K_I(t)$ and the time t_i are needed.

The static stress intensity factor was expressed by (Tada et al. (6)) for the chosen specimen geometry as :

$$K_I = \frac{3.P.S.\sqrt{a}}{2.B.W^2} \cdot Y\left(\frac{a}{W}\right) \quad (1)$$

with P is the applied force, Y is a calibration function; B, W and S respectively are the thickness, the width and the span length of the specimen (40 mm).

According to (Srawley (7)) the calibration function Y is given for specimens with S/W = 4 as following :

$$Y = \frac{1.99 - \frac{a}{W} \left(1 - \frac{a}{W}\right) \left(2.15 - 3.93 \frac{a}{W} + 2.7 \left(\frac{a}{W}\right)^2\right)}{\left(1 + 2 \frac{a}{W}\right) \left(1 - \frac{a}{W}\right)^{\frac{3}{2}}} \cdot Y\left(\frac{a}{W}\right) \quad (2)$$

To take into account dynamic effect (KISHIMOTO (4)) suggests the following expression of the dynamic stress intensity factor :

$$K_I = \frac{3.S.\sqrt{a}}{2.B.W^2} \cdot Y\left(\frac{a}{W}\right) \cdot K \cdot D(t) \quad (3)$$

where K is the specimen stiffness and $\delta(t)$ is the load point displacement measured during the test. K is obtained in using a model of one-degree-of-freedom with stiffness K and a mass M :

$$\frac{\int_0^t F(\tau).d\tau}{v(\tau)} = M + K \cdot \frac{\int_0^t D(\tau).d(\tau)}{v(\tau)} \quad (4)$$

Due to inertia effect, M does not exactly correspond to the mass of the specimen. K is given by the slope of the curve of equation (4) and the Y axis at the zero point provides M .

Then K_I versus time is determined in approximate form with (3). At the time t_i of initiation of crack growth the dynamic stress intensity factor $K_{I_d}(t_i)$ is calculated.

EXPERIMENTAL RESULTS

The results shown in Figures 2 and 3 illustrate the evolution of the fracture toughness of two materials (floated glass and carbon-carbon composite) versus the temperature for a velocity of the extremity of the ceramic bar of about 0.2 ms^{-1} . Figure 2 illustrates a location of the transient temperature for float glass about 300°C where $K_{I_d}(T)$ begins to decrease. As regards carbon-carbon composite we observe on Figure 3 a strong decreasing of $K_{I_d}(T)$ until 1000°C . For higher temperatures, a plateau appears which illustrates a low sensitivity of the dynamic rupture mechanisms of the studied carbon-carbon composite to the temperature.

CONCLUSION

Thanks to this experimental set-up to study dynamic rupture properties for high temperatures. The measurements by means of Split hopkinson Pressure Bar technique represent the interaction versus time of the projectile-specimen system. With them for a wide range of temperatures, it is possible to perform models to obtain dynamic rupture characteristics of a wide range of materials.

REFERENCES

- (1) Research group 972, « Impact - matériaux » C.N.R.S. - D.R.E.T. Activities report 1992-1997.
- (2) Lamaison M., « Contribution à la compréhension des phénomènes de rupture sous sollicitations dynamiques d'un diborure de titane et d'un tungstène. » In french, PhD thesis, E.N.S.A.M., 1997, Order n° 1997-05.
- (3) Guillaumat L, Garcia-Quirros L., Abbe F., Richard J.P., Societe Europeenne de Propulsion. -LAMEF ENSAM, confidential report. 1996.
- (4) Kishimoto K., Aoki S., Sakata M., Engineering Fracture Mechanics 13, 1980, pp. 501-508.
- (5) Bacon C., Int. J. Impact Ingng, Vol 13, 1993, n°4, pp 527-539.
- (6) Tada H., Paris P. C., and Irwin G.R., "The stress analysis of cracks handbook." Del research Corp. Hellertown, PA, 1973;
- (7) Srawley J.E., Int J. of Fracture 12, 1976, 475-476.

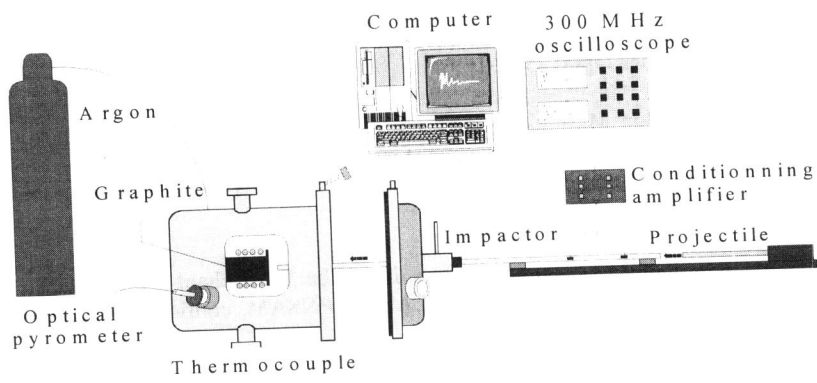


Figure 1 : Experimental set-up to study dynamic fracture of materials at high temperature.

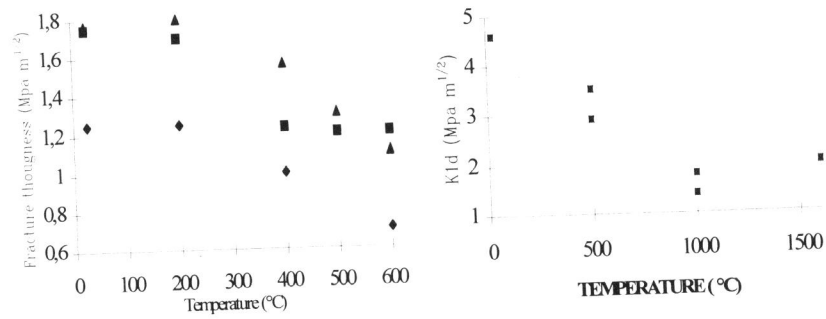


Figure.2 : Fracture toughness of a floated glass versus temperature.

Figure.3 : Evolution of K_{Id} versus temperature for Carbon-Carbon material.