Toughness Characterization of Large Thickness Components Subjected to Drop Loads: Application for Ductile Cast Iron

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ABSTRACT

Transportation or storage packages that contain radioactive material may be subjected to drop loading in case of error during handling for example. In order to design these components against brittle fracture, it is necessary to characterize the crack sensitivity of the material used to fabricate them. This aspect is of large importance in the case of ductile cast iron.

An experimental/theoretical program has been launched in CEA within an IPSN program in order to define a criterion and the corresponding material characteristic to analyze crack behavior in packages of large thickness (> 200 mm) subjected to drop tests conditions.

1 INTRODUCTION

Transportation and storage packages are components designed to protect environment when radioactive materials are handled. Geometry and thickness of such components are chosen essentially according radioprotective considerations and they are depending largely on the size and the state of contents. However, it is important also to check the mechanical behavior in order to be sure that structural integrity (and leaktightness) is maintained in case of impact events possible during handling and transportation. In fact, criteria are given by (I.A.E.A., 1973) to verify that the mechanical behavior is correct. These criteria are based on the experimental verification of behavior of actual scale-one package under drops conditions (drops on vertical rigid pin and on rigid non absorbing foundation); see (Moulin, 1990) for a verification case.

It is proposed to use ductile cast iron for the fabrication of package. Large thickness components are conveniently obtained by casting (Helms, 1987). However, this material is not allowed for transport of lethal material by the ASME Code Section VIII (ASME, 1983). It was decided to gather complementary basic data on this material in order to quantify its ductility and toughness under transportation or storage conditions (Tanguy, 1987). In particular, this implies to study the influence of temperature from -40°C to +50°C and strain rate from static loading to velocity corresponding to drop conditions.

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2 MATERIAL CHARACTERISTIC CHARACTERIZATION

2.1 Material identification

The material used for the various experiments is extracted from one particular component shown in figure 1. It is worth to note the rather large thickness 0.018 m and large weight (5320 kg) of this cask. The ductile cast iron material corresponds to the general GGG40 material for which conventional identifications are:

Table 1. Material identifications

Composition	carbon (weight %)		2.6	3.6
	silicon (weight %)		1.7	3.2
	nickel (weight %)		0	1.4
Microstructure	graphite nodule size	(mm)	0.01	0.10
	graphite nodule spacing	(mm)	0.1	1.0
	ferrite grain size	(mm)	0.03	0.06
	volume % graphite		8.0	24.0
Mechanical	fracture toughness	(MPa.m$^{\frac{1}{2}}$)	60	120
	yield strength	(MPa)	100	430
	ultimate tensile str.	(MPa)	130	530
	tensile along 5 cm gage	(%)	1	22
	reduction in area	(%)	1	30

2.2 Tensile tests

Tensile tests are performed on a conventional testing machine with small circular section specimen (outside diameter = 5 mm, calibrated length 30 mm). During the test, the strength and the displacement of the mobile end of the specimen are continuously recorded. The tests were designed to be conducted at constant strain rate. However, for the highest velocity, constant strain rate was obtained only after the achievement of yield stress.

Figure 2 gives the evolution of yield strength and ultimate tensile strength as a function of temperature and strain rate. At the point of final rupture, the corresponding conventional strain (A%) is almost independent of temperature and strain rate. The minimal value measured is equal to 20%.

The results indicate that, as far as strain rate is concerned, the yield strength is increased by 25% at most, the ultimate tensile strength is increased by 13%. The effect of temperature reduction is to increase yield strength and ultimate tensile strength by 30% and 15% respectively.

It was also noticed that the effect of specimen orientation and location is very low in the component tested. However, in one case the presence of a "chunky" nodule produces a reduction of 70% in the A% ductility value.

2.3 Charpy energy

The energy of rupture was measured on Charpy V specimens (55x10x10 in mm) with 2 mm V machined notch. These specimens were extracted from the same material components. The figure 3 gives the evolution of the Charpy energy as a function of temperature. The initial energy is 300 J. The experimental results suggest that the end of brittle behavior is at about -40°C and that the beginning of ductile behavior is at about -10°C. The two different behaviors results in quite different aspects in ruptured sections (large clear grains for brittle behavior - fine grey grains for ductile behavior).

Toughness characterization:

The toughness characterization was carried out according to the general procedure given by the ASTM E 813 (ASTM, 1986) documents. These characterizations are made from CT side grooved specimens of different nominal thickness (B_4 = 24, 50 and 125 mm) at static loading. The effect of temperature and of the radious at the end of the initial crack tip is studied on two CT 25 only. The specimen are generally fatigue precracked.

Figure 5 gives an illustration of a CT 125 geometry.

Figure 4 gives the evolution of strength as a function crack opening on the load line for some CT 24 specimens. It is worth noting that non linear behavior is important even before initiation for this material. For low temperature (-40°C), the curve is close to the one obtained with blunt notch at room temperature.

Electric potential drop method is used to detect initiation and to measure propagation. The experimental curve giving the evolution of electric potential drop as a function of crack opening shows a minimum. It was checked by comparison with compliance measurements and interrupted tests that the minimum of this curve can be used for the experimental definition of initiation.

Table 2. Toughness tests results

	Initiation		Max. Load	
Specimen CT	Crack opening mm	J kN/m	Crack opening mm	J kN/m
125-1	-	-	-	-
125-2	1.51	68	2.11	117
125-3	1.47	67	1.82	96
50-1	0.746	39	1.08	70
50-4	0.742	40	-	-
50-2	0.750	41	-	-
24-6	0.47	31	-	-
24-7*	0.547	41	0.763	65
24-4	0.486	33	0.716	57
24-2	0.49	32	0.604	44
24-3(-40°C)	0.469	33	0.666	55

* blunted notch.

Table 2 summarizes the results obtained for the different specimens at the point of initiation and at the point of maximal load. The different J values were calculated according to the "one specimen procedure" which relies on scale function given by the limit load analysis of CT specimen geometries.

This table shows that for one geometry, initiation and maximal load are obtained at almost equal crack opening values. These critical crack opening values increase as a function of specimen thickness. The J values also increase as a function of thickness and are almost constant for one test geometry. The J values measured at the instant of maximal load is equal to two times the values measured at initiation.

For CT 24.7 specimen tested with electro-erosion crack tip (r = 0.1 mm) the apparent J value at initiation is increased by 30% by comparison with fatigue precracked specimens. The specimen tested at -40°C gives the same J value than specimens tested at room temperature. This could suggest that for static loading the brittle behavior temperature is lower than -40°C for these specimens.

3 CONCLUSIONS

Material tests were carried out in order to verify that a ductile cast iron, used in the construction of a particular package, has sufficient ductility and toughness in case of drop events.

These tests concern tensile properties, toughness and Charpy energy.

The reduction of temperature and the increment in strain rate result in an increase in tensile properties. The ductility is almost independent of these factors.

Charpy tests would give a complete brittle behavior at about -40°C.

Toughness increases considerably with thickness. J is therefore not a convenient parameter to characterize the materiel toughness although crack initiation takes place with large plasticity. Untill -40°C, first results indicate that the behavior is still ductile.

With further experiments, it is intended to study more precisely the effect of strain rate and thus apparent contradiction between static tests and Charpy results concerning the temperature of transition in brittle behavior.

REFERENCES

I.A.E.A. Safety series n°6 (1973). ISSUE.

Helms, R., Ziebs, J. (1987). Ergebnisse der Werkstoffprüfung aus Behältern aus GGG 40 in den Jahren 1981 bis 1987. Seminar of B.A.M on June 9 and 10 (1987) in collaboration with Deutscher Verband fur Material Prüfung e.V. Edition D.V.M.

ASME Code Section VIII, Division 1 (1983) SI Edition - Part UCI - Requirements for Pressure Vessels Constructed of Cast Iron.

Tanguy, L. (1987). "Revalidation of Nodular Cast Iron in France". Seminar of B.A.M., Berlin, R.F.A., June 9 and 10; 1987. Edition D.V.M.

ASTM (1986). E813 Standard Test for J_{IC} a Measure of Fracture Toughness. Annual ASTM Standards. Philadelphia, USA.

Moulin, D., Tanguy, L., Aufaure, B. (1990). Puncture Test of a Package. Comparison between Experimental Test and Dynamic Analysis. PVP - Vol.195, MPC Vol.30, Fatigue, Degradation and Fracture 1990. ASME New York, USA.

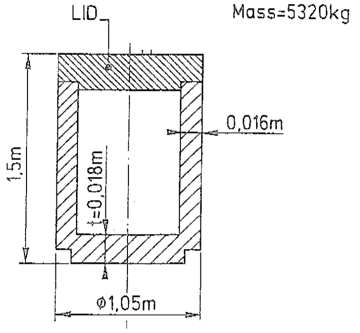

Fig. 1 - GEOMETRY OF A PARTICULAR PACKAGE MADE OF DUCTILE CAST IRON

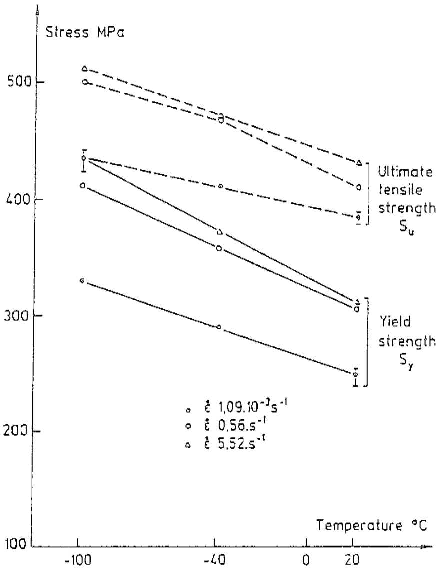

Fig. 2 - EVOLUTION OF TENSILE PROPERTIES WITH TEMPERATURE AND STRAIN RATE

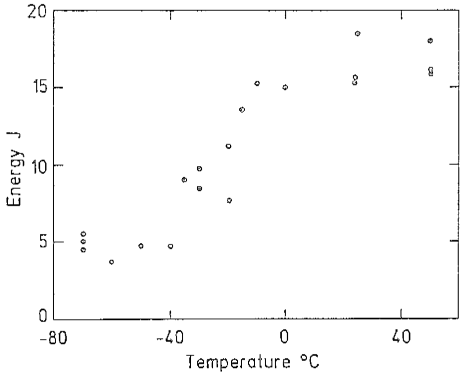

Fig. 3 - EVOLUTION OF CHARPY ENERGY

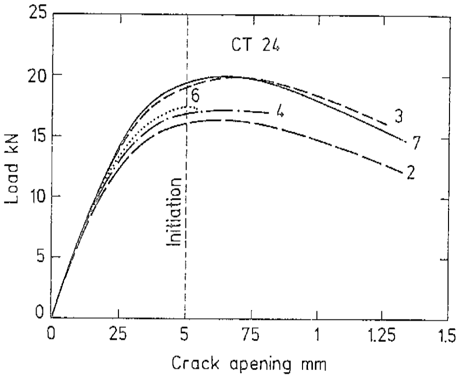

Fig. 4 - EVOLUTION OF LOAD WITH CRACK OPENING (LOAD LINE) FOR 5 CT 24 SPECIMENS

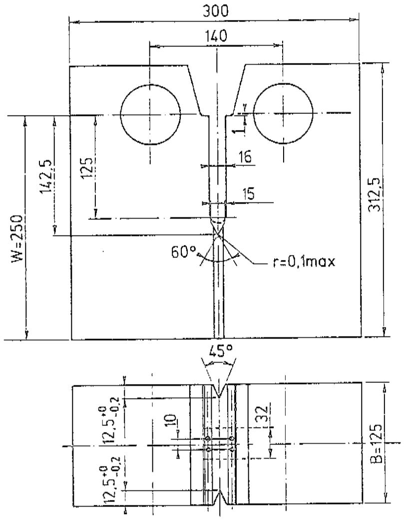

Fig. 5 - CT 125 GEOMETRY