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Abstract

The experimental result of empty hexagonal tube subjected to dynamic loading is reported and compared with the previous reseachers. The type and final mode of deformation is also studied and compared with FEA. Good agreement is obtained between FEA and experiments for both mean load and plastic fold length. The dynamic mean load is about 1.5 times that of the quasi-static value.

Keywords — **dynamic, axial crushing, energy absorbers, hexagonal tubes.**

I. INTRODUCTION

Collisions between objects always happen in our life, ranging from a small impact such as striking a golf ball to the collision of aircraft with land buildings or other aircraft, some more frequent then others. Of greater concern are the accidents, which involve collisions of transportation vehicles, mainly due to the frequency of occurrence and the resulting damage of the collisions. The development and design of impact energy absorber systems, which dissipate kinetic energy of unwanted collision in a controlled manner has received much attention in recent years, particularly in relation to the safety of vehicles. The advancement of technology has led to higher speeds of vehicles. Impact energy absorbing systems in the structures are normally 'one-shot' devices.

The active absorbing element of energy absorption system can be divided many shape such as circular tube[1-3], square tubes[4-5], beam[6] and multi corners[7]. However, less attention has been given to the study of hexagonal tubes to be used as energy absorber.

In this paper, some experimental results were reported for dynamic impact loading of empty hexagonal tubes made of mild steel in as-received material. The experimental energy absorbed is compared with numerical analysis. Typical modes of deformation in dynamic loading is compared with quasi-static[8-10].

II EXPERIMENTAL DEVELOPMENT

A.Drop hammer and loadcell

The drop weight apparatus shown in Figure 1 consisted of a hardened steel plate fronted mass (consisting of a number of steel disks separated by disk springs) two guide plates at the top and bottom.

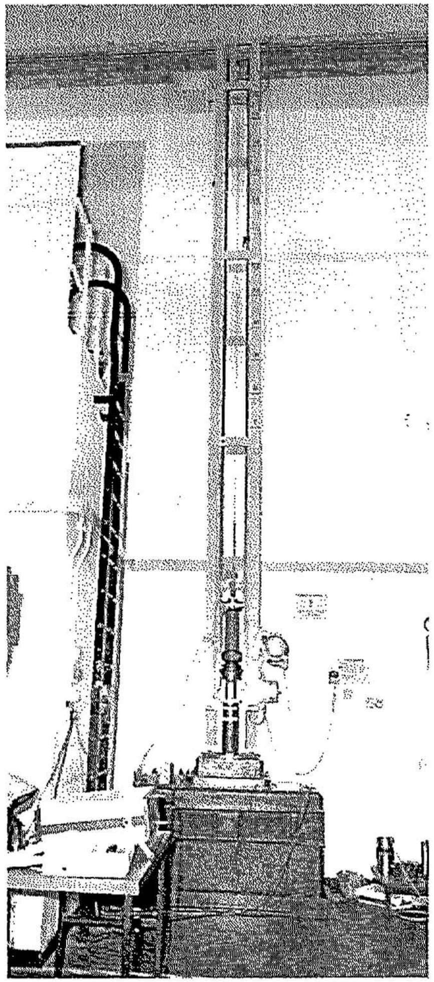

Figure 1 Photograph of the the drop hammer apparatus

required mass. The close-up view of the mass is shown in Figure 2.

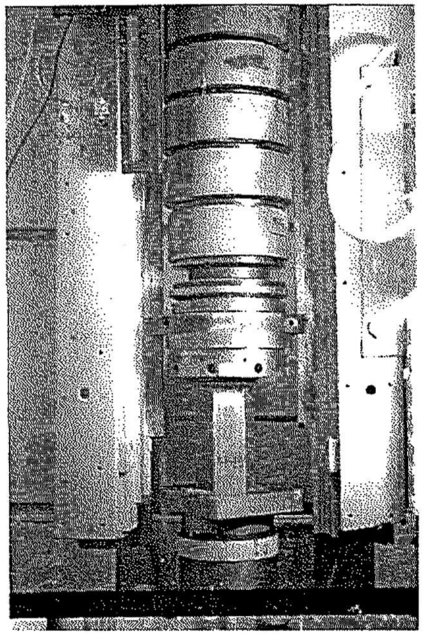

Figure 2 The close-up view of a mass

The mass could be pulled up along two vertical guides and released from a predetermined height. The minimum mass, *m* that could be fitted was 47 kg and the maximum was about 100 kg. Lateral loading on hexagonal rings and honeycombs was not implemented as the energy absorbed by these specimens was too small compared with the initial kinetic energy, that could be obtained even with a few tens of centimetres of drop height.

A Kistler piezoelectric loadcell (Type 9091) was used to record the force-time history during the test. The load washer was placed underneath a solid steel anvil, which was mounted on to the solid base. The specimens rested on the anvil fixed on to the base, which precompressed the load washer. Top and bottom surfaces of load washer were separated from the steel components with 3 mm thick rubber gaskets to reduce the signal noise due to vibrations.

B.Charge amplifier and Nicolet 490-storage oscilloscope.

A Kistler charge amplifier (type 5009) was used to transform the charge output from the loadcell to voltage and suitably amplify the signals. The signal was then transmitted them to a Nicolet 490 digital storage oscilloscope. The traces thus stored were saved on to a

traces displayed in Nicolet's screen was also obtained.

C.Optical positional and velocity sensor.

An optical system was used to measure the velocity of drop hammer, starting from just before its impact on the specimen throughout the period of compression. It consisted of an Light Emitting Diode (LED) light source aligned with two fibre optic sensors on opposite faces of a bracket. The light output through the optic fibres was incident on a photocell connected to an electronic circuit. The light was converted to an electrical (voltage) signal. The optical connection was affected by an opaque-transparent grating (of pitch 2.54 mm) that was fixed in a rigid frame, which in turn was rigidly connected to the drop weight. The interruption of the light caused by the grating created electrical pulses with a frequency directly proportional to the velocity of the grid through the optic station. A summing amplifier in the circuit created a signal proportional to the number of pulses, which provided a measure of displacement. The voltage pulses and summed up voltage from the electrical circuit was also transmitted to the digital storage oscilloscope. The velocity-displacement measuring set up was tested prior to the experiment to ensure the calibration parameters were correct.

D. Specimen

Four 200 mm long of single hexagonal tubes were tested. Due to constraint of drop hammer apparatus, three impacted were performed.

E. Test procedure

The sensitivities of the charge amplifier was adjusted to the setting required by the loadcell and the expected peak load (from a knowledge of the corresponding quasi-static test data) and the voltage and time settings of the oscilloscope were adjusted to the required levels. During the tests, the oscilloscope was triggered by a predetermined level of the signal from the loadcell, set at about 55% of the peak signal level expected from the data available from the corresponding quasi-static tests.

The specimen was located centrally and mounted on the anvil. The base of the specimen, particularly in case of hexagonal tubes was restrained by providing minimal fixtures around the circumference of the specimen. This was to prevent any lateral movement of the specimen that sometimes caused it to tip over and sometimes fall off the anvil during rebound of the hammer after the first impact. In the case of hexagonal tube specimens, the tube dimensions, the drop mass and height were such that the only one fold was caused due to a drop. Hence, after recording the load and displacement traces as well as the deformations of the specimen after the first drop, the same specimen was subjected to further drop tests. Tables 1 shows the summary of dynamic result, which include the plastic fold length, mean load, impact velocity and energy absorbed are recorded for each test.

Table 1: A summary of dynamic results for a single hexagonal tubes

Spec no.	λ_p (mm) for impact loading	Peak load (kN)	Impact velociy v_i (m/s)	mean load, F_m (kN)	Energy absorbed (Nm)	note
h3-ia	34	358	9.47	153	4598	1st drop
h3-ib	34	330	9.47	124	3951	2nd drop
h3-ic	36	281	9.47	114	3635	3rd drop
h3-id	34	312	9.47	164	4100	1st drop
h3-ie	34	220	9.47	113	3386	2nd drop
h3-if	36	220	9.47	107	2129	3rd drop

III RESULTS AND DISCUSSION

Figures 3 show the typical load-time, and displacement-time traces as well as the voltage pulse recording for specimen h3-i under dynamic loading. Only one fold had formed in the specimen. Further drop tests were carried out on this same specimen. Each drop produced 4900 Nm

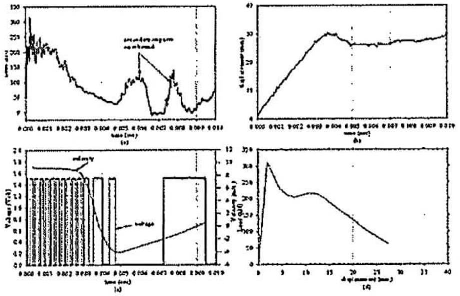

Figure 3 Typical experimental result of a hexagonal tube under dynamic loading.Only first impact shown. (a)load against time (b) displacement against time (c) voltage/velocity against time (d) load against displacement

In Figure 4, the three load-displacement traces for this specimen obtained during repeated (three) impacts are shown. The quasi-static curve also included for comparison[10]. The peak load that initiates buckling in the first drop is about twice that seen under quasi-static conditions. The second and third drops cause buckles in the deformed specimen also cause approximately twice the load at the corresponding peaks in the quasi-static tests. The loads at the second and third peaks are about the same but are about 30% lower than the first peak load.

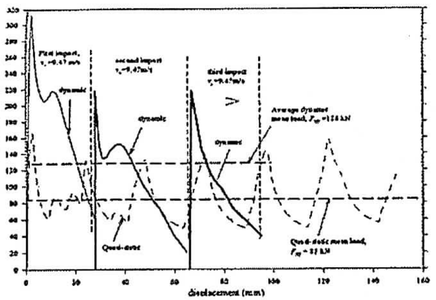

Figure 4 Load against displacement of hexagonal tube under dynamic condition (m = 98 kg, v_i = 9.47 m/s) compared with quasi-static(solid line – dynamic and dashed-dot line – quasi-static

The corresponding deformations are also shown in Figure 5a-d. Figure 5a is the undeformed specimen for comparison. The specimen deformed by the first drop is shown in Figure 5b. The shapes of the deformed specimen after second and third drops are shown in Figure 5c and 5d, respectively. The FEA deformed mode is also compared in Figure 6[11].

The plastic fold length was derived by counting the number of folds in the deformed length of tubes. The average values of λ_p were found between 34 to 36 mm for all specimens, which is shown in Table 1.

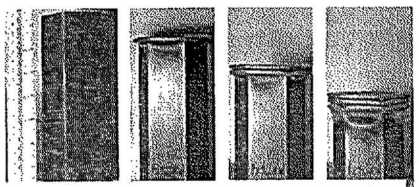
(a) (b) (c) (d)

Figure 5 The deformed specimens under dynamic loading with undeformed specimen (a) undeformed (b) first drop (c) second drop (d) third drop

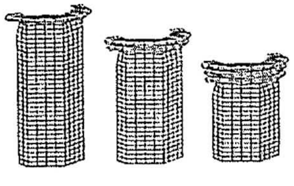
(a) (b) (c)

Figure 6 The deformed mesh under dynamic loading (strain-rate dependent material) after (a) first impact (b) second impact (c) third drop[11]

All specimens exhibited the concentina mode, even though no trigger was provided. This mode continued in second and third impacts. Figure 4 shows that the peak load is approximately 312 kN, 220 kN and 220 kN for first, second and third drops. Overall mean load is 128 kN. This is approximately 50% higher than that of the quasi-static trace and this increase is due to the effects of inertia and strain rate[11]. However, the plastic fold length, λ_p is approximately the same for both quasi-static and dynamic loading cases (Table 1)

Figure 7 shows the experimental energy-absorption curves for single hexagonal tubes, compared with the FEA predictions under quasi-static as well as under dynamic loading conditions. In the experiment dynamic loading, the first and second impact terminates respectively at $\delta =$ 28 mm and 60 mm, which is shown in Figure 6. The experimental energy absorbed at displacement of 80 mm were about 11000 Nm, and agree will with FEA. Dynamic loading cases (Figure 7) differs with quasi-static due to strain rate, inertia, and elastic strain energy stored in each drop.

It is worth noting here, the dynamic mean load is about 1.5 times that of the quasi-static value . This is also noticed in FEA. The FEA plastic wavelength and experiment is identical (i.e. $\lambda_p = 34$ mm)[11].

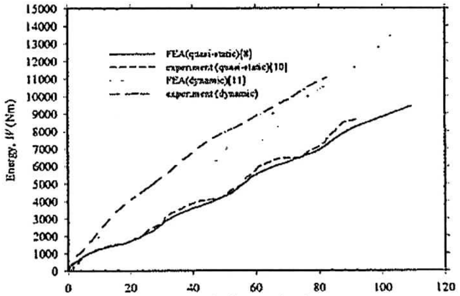

Figure 7 Energy-absorption curve of hexagonal tube under quasi-static and dynamic loading

IV CONCLUSIONS

The experimentally observed and numerically predicted load-displacement characteristics of a single hexagonal tube under dynamic loading at about 10 m/s are compared. The predicted mean loads and energy absorbed agreed with the observation, which was also about 50% higher than the quasi-static mean load. This is equivalent to an increase in energy absorption by a factor of 1.5 under dynamic loading. The modes of deformation under quasi-static and dynamic loads were similar and compared well with predictions .

The plastic fold length, λ_p did not change noticeably under dynamic loading.

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