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Experimental investigation into response of circular plates subjected to hydrodynamic shock

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Abstract: In this paper, plastic deformation of the clamped mild steel and aluminum circular plates subjected to different hydrodynamic impact loading conditions are investigated. Extensive experimental tests were carried out by using a drop hammer. The experimental results presented in terms of central deflection of the plates, deflection profiles, and strain distributions. The effect of different parameters such as material properties, plate thickness, stand off distance of hammer or the transferred energy were also investigated on behavior of deformation of plate.

Keywords: Deformation, Circular Plate, Hydrodynamic, Drop Hammer, Shock

1. Introduction

Solid phase-based forming has attracted a great amount of interest as a new technology of forming since it can compensate for the disadvantages of the conventional forming processes. However, it still has difficulties in industrial production due to problems such as the reheating of the billet, high manufacturing costs, and an inability to produce large parts [1].

For example, one of the new technologies and expensive method in metal forming is High-power laser irradiation. Through this method, sheet metal can be formed by a laser-generated temperature gradient between the laser irradiation heating the local area and the neighboring materials [2]. In sheet metal forming, the amount of deformation has always attracted immensely experimental and analytical research efforts. The amount of deformation is limited by the occurrence of plastic instability in the form of localized necking or wrinkling. The localized neck is a very important phenomenon in determining the optimum deformation that can be imposed on a work piece [3]. The prediction of fractures in metal forming is very useful for evaluating the feasibility of a forming process. Many ductile fracture criteria have been proposed over the past years for the prediction of fractures, particularly in cases where the fracture occurs without the formation and development of necking [4].

High rate metal forming processes were fairly well developed. These techniques had some advantages over conventional metal forming. These include the ability to use single-sided dies, reduced spring back, and improved formability [5].

In various engineering application, mechanical elements may be subjected to dynamic load of foreign object or to pressure pulses caused by impact. These involve inertial effect, finite deformation and non-linear behaviour of the materials. The available analytical models concern solids of simple geometric shape, boundary condition and applied load in which simplifying hypotheses of the problem are also commonly used to allow the analytical treatment [6].

One of the structural problems which have widely been considered is that of a fully-clamped metallic circular plate subjected to transverse impact loads.

High-speed metal forming was invented at the end of last century and finds implementation in explosive, electro-hydraulic and electro-magnetic forming. The most common technique is explosive forming with chemical charges. The advantage of forming with liquid shock waves in a shock tube in comparison to explosive forming is better control of the process and increased safety [7].

The purpose of the present study is to gain further understanding of the metal plate behaviour subjected to hydrodynamic impact loading by testing ferrous and nonferrous metal plates, including the effect of plate thickness and the transfer energy.

2. Experimental Procedure

The test specimens were 250mm by 250mm and varied in thickness from 1.0 mm to 3.0 mm. plate specimens were not subjected to heat treatment before being used in impact loading condition. The specimens were clamped in a frame, comprising of two (250mm×250 mm) frames made from 20mm thick mild steel plating. The frames had a 100 mm diameter hole. Each specimen had a circular exposed area with a diameter of 100 mm. the front clamp is connected to a vertical water shock tube, which has a total length of 0.4 m. The shock tube consists of a stainless-steel tube with an outside diameter of 116 mm and an inner diameter of 100 mm. The inside of the tube is honed smooth. The experimental arrangement is shown in Figure 1.

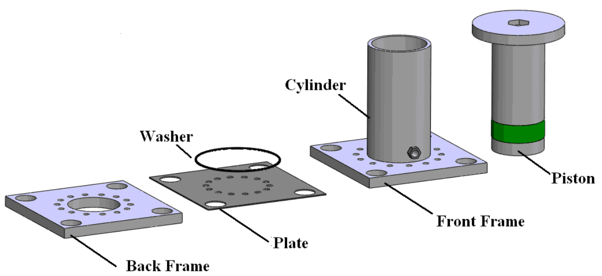


Figure 1. *Schematic of the experimental test rig*

For the high-speed metal forming in a liquid shock tube, the potential energy of drop-weight testing system is used [7]. After dropping of a hammer with weight of 74.8 Kg, the potential energy stored is converted into kinetic energy of hammer and after incidence hammer to piston, piston rapidly moving and caused to compressed water and then the high-pressure leads to deformation of plate. Photograph and schematic corresponding to experimental set-up are given in figure 2.

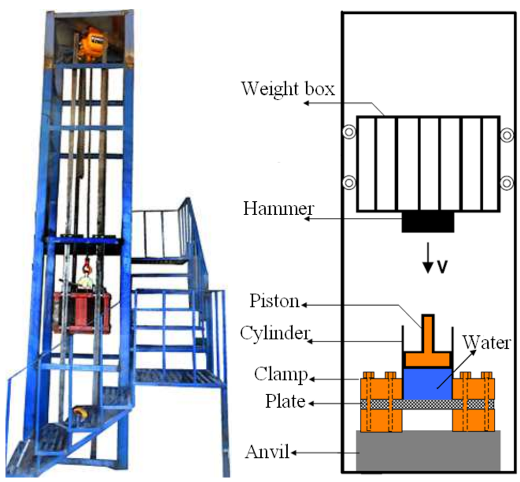


Figure 2. *Photograph and Schematic of experimental arrangement*

3. Mechanical Properties of the Plate Materials

Table 1. *Summary of tensile test results on steel, aluminium and copper*

Material	Nominal Thickness (mm)	Mean average Yield Stress (MPa)	Mean average Ultimate Tensile Stress (MPa)
Steel	1.0, 2.0	320	370
Aluminium Alloy 1100	1.0, 2.0,3.0	120	150

Tensile test specimens were prepared from commercially aluminium alloy 1100 and mild steel St1300 with different thicknesses. To include the effect of anisotropy on the values of yield stress, from each sheet two specimens were cut in longitudinal and transverse directions. The results of tensile test on specimens cut longitudinally show no significant difference of those cut transversely. The mean average values of yield stress and ultimate tensile stress are calculated for each material for different thickness. A summary of the properties of the different plate materials is given in Table 1.

4. Experimental Results and Discussion

Table 2. *Results of hydrodynamic loading tests*

Test No.	*Material*	*Plate thickness(mm)*	*stand off distance of hammer (Cm)*	*Mid-Point Deflection(mm)*
1	Steel-1300	1	100	16
2	Steel-1300	1	125	17.8
3	Steel-1300	1	150	19.8
4	Steel-1300	2	100	11.9
5	Steel-1300	2	200	14.4
6	Steel-1300	2	300	18.7
7	Al-1100	1	10	8.2
8	Al-1100	1	20	11.5
9	Al-1100	1	30	14.4
10	Al-1100	2	30	5.8
11	Al-1100	2	50	11.3
12	Al-1100	2	65	15.0
13	Al-1100	3	50	8.5
14	Al-1100	3	65	9.3
15	Al-1100	3	100	15.3

For the first set of tests, stand off distance of hammer was held variation from 1.0m to 3m for steel plates and 0.1m to 1.0m for aluminium plates, for each material and different thickness, the effect of stand off distance of hammer or the transferred energy was investigated. The experimental details are given in Table 2.

By comparison of the profile of the plates tested at higher stand-off distance of hammer was observed to be more dome than those plates tested at lower stand-off distance. The effect of the hydrodynamic pressure upon the central portion of the plate will become increasingly greater, relative to the distance of outer edges and increasingly, smaller to the angle of incident between the hydrodynamic pressure and the plate at the outer edges. Photograph corresponding to deformed plate are given in figure 3.

(a)

(b)

Figure 3. *Photographs of typical plates (a) Aluminium alloy plate, (b) Steel plate*

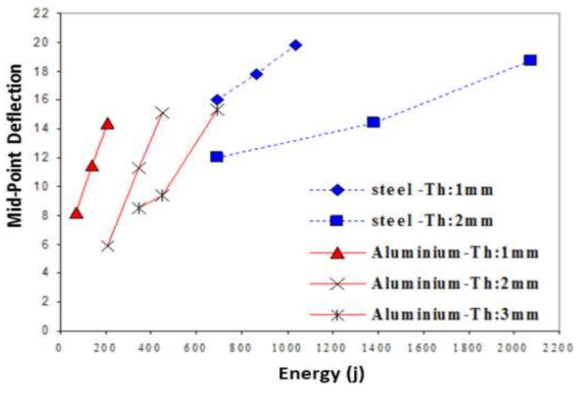


Figure 4. *Graph of measured mid-point deflection versus energy*

The graphical representation of mid-point deflection versus transferred energy for steel and aluminium plates is shown in figure 4. In this graphs, effect of thickness is included. The mid-point deflection increases with increasing transferred energy for each material and plate thickness.

5. Strain Distributions of Deformed Plates

The strains of deformed plates could be determined by measuring the deformation of the formed plates. Strain components were determined by measuring the displacement of a circular grid and thickness variation after deformation process. Five concentric circular grids of diameters (20, 40, 60, 80 and 100mm) were plotted with template on to the specimens before blast loading. The values of circle diameters and thicknesses at the each intercept of concentric circle and inscribed diameter were measured. The thicknesses at the centre of original and deformed plate were also measured. In fact these measurements were made across an inscribed diameter. By subtracting reading at each station from that at the corresponding diametrically opposite station on the same concentric circle, the current diameter D was determined. By substituting the value of D into the equation, [8]

$$\varepsilon_\theta = Ln\frac{D}{D_\circ} \qquad (1)$$

values of ε_θ are calculated.

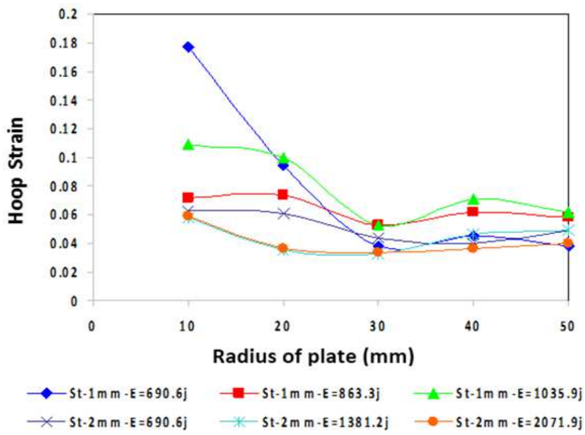
In equation (1), $D_\circ$ is initial diameter of the same inscribed circle. The value of hoop strain for a given value of transferred energy at the point of concern was calculated. To determine thickness strain, initial thickness $T_\circ$ at each intercept and for the deformed plate was measured. The values of thickness T for the diametrically opposed stations of each circle were averaged and substituted into equation, [8]

$$\varepsilon_t = Ln\frac{T}{T_\circ} \qquad (2)$$

and values of ε_t are calculated. To obtain value of ε_r, the equation representing constancy of volume,

$$\varepsilon_\theta + \varepsilon_t + \varepsilon_r = 0 \qquad (3)$$

is employed. The variation of ε_θ and ε_t for different metal plates (steel, aluminium) and two are plotted in figures 5 and 6, respectively.



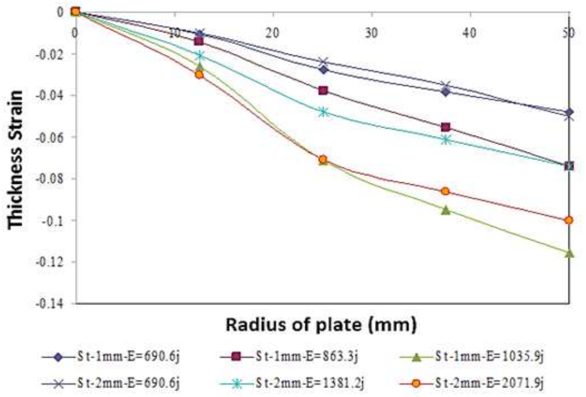


Figure 5. *Distribution of hoop and thickness strain for steel plates*

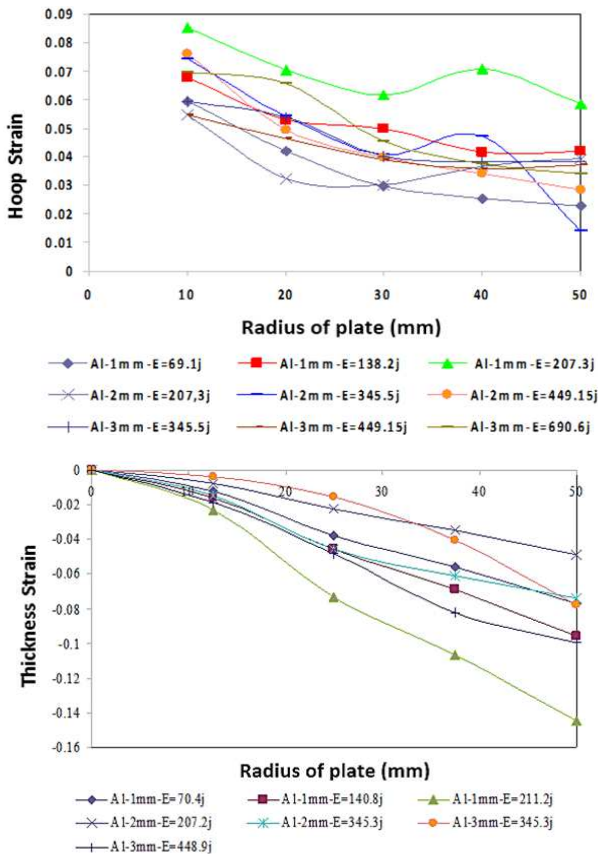


Figure 6. *Distribution of hoop and thickness strain for Aluminium plates*

Comparing these figures It could be deducted that values of ε_θ and ε_t are significantly affected by material properties, plate thickness, stand-off distance of hammer or the value of energy imparted on the plate. But the distributions of strains versus radius for different Material and plates thicknesses are almost similar for constant energy. The highest values of hoop and thickness strains occur at the centre of the deformed plate and it reduces to minimum values at the outer edge.

6. Conclusion

The experimental results in this paper represent the behaviour of ferrous and non-ferrous plates subjected to hydrodynamic impact loading. The results can provide an insight to predict the relationship between mil-point deflections and applied potential energy. The obtained results show the importance of material properties, and plate thickness on the deformation profiles. The effects of material and geometrical properties on the natural strain distribution have been reported. The influence of transverse energy values on distribution of hoop strain is more remarkable than of thickness strain.

Nomenclature

R	Radius of plate
T_o	initial thickness of plate
T	Plate thickness
D_o	initial diameter
D	current diameter
ε_r	Radial strain
ε_θ	Circumferential strain
ε_t	Thickness strain

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