Structural Engineering and Mechanics, *Vol. 56, No. 4 (2015) 535-548*
DOI: http://dx.doi.org/10.12989/sem.2015.56.4.535

Effect of gas detonation on response of circular plate-experimental and theoretical

Hashem Babaei*, Tohid Mirzababaie Mostofi[a] and Seyed Hamidreza Sadraei[b]

Department of Mechanical Engineering, University of Guilan, 3756-41635 Rasht, Iran

(Received May 10, 2015, Revised October 30, 2015, Accepted November 3, 2015)

Abstract. A series of experimental results on thin mild steel plates clamped at the boundary subjected to gas detonation shock loading are presented. Detonation occurred by mixing Acetylene (C2H2)-Oxygen (O2) in various volume ratio and different initial pressure. The applied impulse is varied to give deformation in the range from 6 mm to 35 mm. Analytical modeling using energy method was also performed. Dependent material properties, as well as strain rate sensitivity, are included in the theoretical modeling. Prediction values for midpoint deflections are compared with experimental data. The analytical predictions have good agreement with experimental values. Moreover, it has been shown that the obtained model has much less error compared with those previously proposed in the literature.

Keywords: circular plate; large deformation; gas detonation forming; shock loading; theoretical modeling

1. Introduction

Different high velocity forming processes, like gas detonation forming (Honda and Suzuki 1999, Cezary and Bojar 2008, Shepherd 2009), hydrodynamic impact forming (Skews *et al*. 2004, Li and Jiang 2011, Babaei *et al*. 2015a, Babaei *et al*. 2015b), explosive forming (Bisadi and Meybodi 2011, Mynors and Zhang 2002, Hadavi *et al*. 2012, Wielage and Vollertsen 2011) and electro-magnetic forming (Li *et al*. 2013, Psyk *et al*. 2011, Meng *et al*. 2011) are used in industry these days, but in metal forming process, the significant subject is providing high rate energy sources with minimize cost. These methods have advantages such as low cost, forming of complex products, easily short production period, less wrinkles and best results which these processes are found to be attractive by the manufacturers.

Generally, gas detonation forming is easy, useful and safe in comparison to other methods of forming of plates. This forming processes works with detonation of two or more gases which are combined together. During the detonation process, the combustion pressure leads to shock wave. This results in a shock wave pressure profile similar to that of a blast wave. The pressure energy of gas detonation is used to form the sample plate to the desired die or free shape. The possible automation due to an easy mixing and a clean combustion is the main advantage of using gases.

*Corresponding author, Assistant Professor, E-mail: ghbabaei@guilan.ac.ir, hghbabaei@gmail.com
[a]Ph.D. Student, E-mail: t.m.mostofi@gmail.com, tmostofi@phd.guilan.ac.ir
[b]M.Sc. Student, E-mail: shamidrezas@yahoo.com

http://www.techno-press.org/?journal=sem&subpage=8 ISSN: 1225-4568 (Print), 1598-6217 (Online)

Gas detonation generates the high pressure equivalent to that achieved by explosives is obtained using a relatively simple set-up. Amount of pressure released can be controlled by mix ratio and volume of gases.

Many researches have been done on sheet metals to observe detonation of mixed gases procedure in combustion chamber and determine the shock pressure (Honda and Suzuki 1999).The maximum ultimate pressure at central point of plate and imploding are varied from 12Gpa to 27 Gpa and 200 Mpa to 650 Mpa, respectively. It was proven that gas detonation forming is a better procedure in comparison to traditional process such as bulging and pressing formability for high tensile strength of aluminum and steel plates. In another investigation, the experiments done by detonation of Hydrogen (H_2) and Oxygen (O_2) in different volume ratio (Meybodi and Bisadi 2009). The obtained results shown that the optimum and best percent of gas mixture was 32% O_2 with 68% H_2. Also, comparing the experimental results and finite element model such as thickness strain distributions and deformed geometry are done which was obtained that 75% to 90% resemblance in formability of desired shape. In aluminum cylindrical cups forming by gas detonation method, the effect of die design and pressure due to gas detonation are investigated (Yasar *et al*. 2006, Yasar 2004). The results are simulated by the 2D and 3D computational modelling. The deformed geometry, predictions of spring back and thickness distribution obtained from simulation results are compared with the experimental ones, however the thickness strain distributions did not fit with experimental values.

Almost all investigations which have been done by gas detonation forming and have been reviewed, were validated by finite element models. So, there is not a significant theoretical validation in these works. In previous years, many theoretical models have been presented to investigate central response of fully clamped circular plates subjected to dynamic loading with various conditions. For example, an analytical model presented by Perrone and Bhadra (1984) to predict maximum deflection by equating initial kinetic energy of system to inner plastic energy absorbed during large deformation. The presented model is appropriate when membrane strain energy is much more than bending. Symonds and Wierzbicki (1979) used wave form solution to predict response and deflection of circular plates subjected to impulsive loading which were compared with experimental values. In another study, Shen and Jones (1993) investigated different modes of failure and dynamic response of clamped circular plates under impulsive loads. Moreover Batra and Dubey (1971), Ghosh and Weber (1976), Jones (1989), Nurick and Martin (1989a, 1989b), Duffey (1967), Hudson (1951) and Lippman (1974) presented analytical models to predict midpoint deflection of circular clamped plates subjected to dynamic loading.

The main purpose of experimental study in this paper is to developing optimum set-up of combustion chamber gas and controlling of shock loads. Steel plates are used to obtain more understanding of metal plate behaviour subjected to detonation of mixed gases in this experimental study. This paper also presents a theoretical model to predict the central deflection of circular plates by energy method based on upper bound solution. The main purpose of theoretical study in this paper is prediction of plastic deformation of circular plate subjected to transvers shock loading for clamped boundary condition. For validation of theoretical model, the other reported models in literature are compared with the present model.

2. Experimental study

2.1 Set-up of combustion chamber gas and forming method

The experiments are carried out in an explosion chamber, which is made of special stainless-steel tube with an outside diameter of 210 mm, an inner diameter of 120 mm length of 53cm. The combustion chamber consists of pressure measurement system, gas control valve, and ignition system. At the end of chamber the test specimen is situated. Thin metal plates are clamped between tube and a frame which made from 20mm thick mild steel plating and has a 120 mm diameter hole. So, each specimen has a circular exposed area with a diameter of 120 mm. Pictures and schematic of the experimental set-up is demonstrated in Figs. 1 and 2.

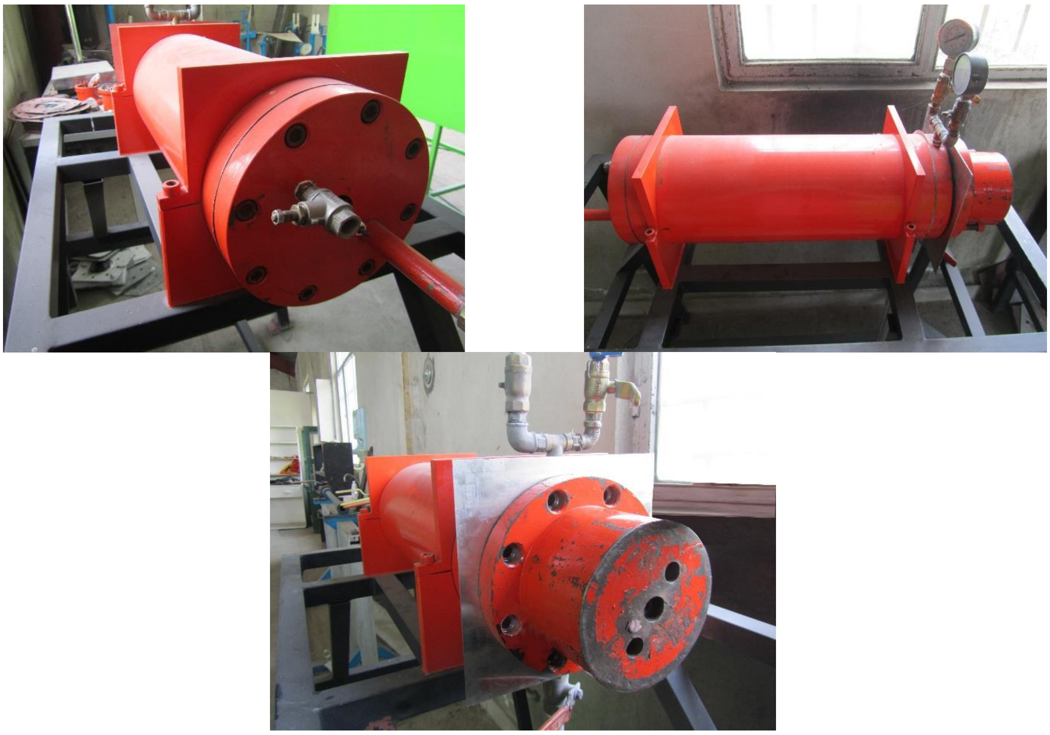

Fig. 1 Photographs of experimental arrangement

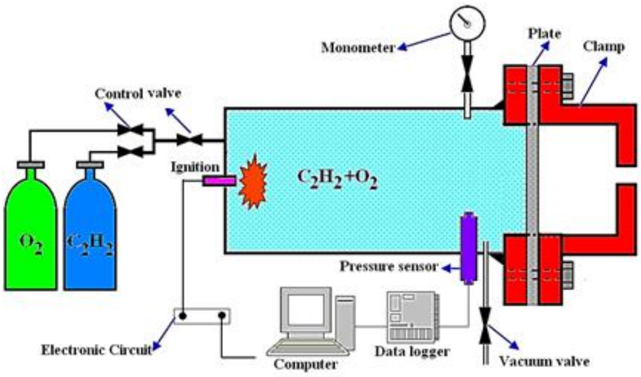

Fig. 2 Schematic of experimental arrangement containing control valves, monometer, pressure sensor, vacuum valve, data logger, and electronic circuit

Table 1 Physical characteristic and performance of pressure transducer

Model	Company	Sensitivity	Measurement range	Weight	Sensing element	Temperature range	Natural resonance
CY-YD-214	SINOCERA	4 PC/105Pa	0-200 MPa	20 g	Quartz	-40C° to 150C°	100kHz>

Table 2 Physical characteristic and performance of dynamic data acquisition and analysis system

Model	Company	Channels	Max sampling rate	Weight	Operating temperature	Storage temperature
YE-6233	SINOCERA	4 per unit (16-bit resolution)	3MHz with one channel 1.5MHz with two channels 750kHz with four channels	0.5 kg	0℃ to 60℃	-55℃ to 85℃

Table 3 Physical characteristic and performance of charge amplifier

Model	Company	Input Range	Output Range	Weight	Noise	Operating temperature	Storage temperature
YE-5858	SINOCERA	Voltage: ±5VP(Max) Charge: ±0.5×105 PC (Max)	±5VP/5mA(Max)	1.5 kg	$\leq 5\mu$V	0℃ to +40℃	-55℃ to 85℃

(a) (b) (c)

Fig. 3 Photographs of (a) dynamic data acquisition and analysis system, (b) piezoelectric type pressure transducer, and (c) charge amplifier

Table 4 Synopsis of uniaxial tensile test results on aluminum and steel

Material	Thickness of Plate (mm)	Yield stress (MPa)	Ultimate stress (MPa)	Density (Kg/m^3)
Steel	1.0, 2.0, 3.0	289.2	474.5	7850

In this series of tests, the shock loading was generated by detonation of mixed gases of Acetylene and Oxygen allowing the resulting shock wave to travel down the combustion tube and impinge upon the target plate. It is assumed that input energy generated by detonation of gas is converted into plastic work and kinetic energy during high rate deformation process. The mixed gas is ignited by using electronic circuit a spark plug. Before of detonation, initial pressure of mixed gas is measured by monometer and after of detonation, pressure is measured by piezoelectric type pressure transducers and computer logging system. The technical and physical information about pressure transducer, dynamic data acquisition system and charge amplifier is summarized in Table 1-3. Also, the photographs of these accessories are shown in Fig. 3.

2.2 Mechanical properties

The mechanical properties which has been used in experimental studies is obtained from uniaxial tensile tests of mild steel with various thicknesses. For this reason, three specimens were cut in horizontal, vertical and diagonal directions for efficiency of anisotropy on yield stress values. The uniaxial tensile test results do not show important difference between these directions, values of ultimate tensile stress and yield stress are calculated. It is necessary to mention that these tests which are used to draw the stress-strain curve are conducted in accordance with ASTM-E8 standard. The results are presented in Table 4.

2.3 Experimental results

Tested samples plates with mild steel material have different thicknesses consist of 1.0, 2.0 and 3.0 mm. Initially, the plates have been cut into 250 mm×250 mm square shapes. In series of test, Acetylene and Oxygen gases are mixed with two ratio 1/1 and 1/2, respectively.

After detonation of mixed gases, pressure is measured by using a piezoelectric sensor and data logger system with high frequency. Sensitivity of the system is 1.0 MHz, and the pressure data are acquired with a sampling period of 0.3 micro second. So, pressure wave measured in period-time of a micro second. The detonation pressure graph obtained from the set of precision system during detonation and forming process has been shown in Fig. 4.

All tests were performed at room temperature (20°C). Immediately after each test, by direct observation it was found that temperature change of detonation gas wave specimen was not significant. This may be due to very fast expansion of gaseous products generated by explosion and very short duration of interaction between pressure pulse and target plate. It is a common practice to assume that input energy provided by explosive pressure is converted into plastic work and kinetic energy during high rate deformation of the plate.

In this series of test, for steel plate with different thickness, the effect of gases mixed ratio on deformation of plate has been investigated. Each mixed ratio generates special pressure distribution respect to time. Thus impulsive load (I) depends to mixed ratio and its can be calculated by using the following equation (Kosing and Skews 1998).

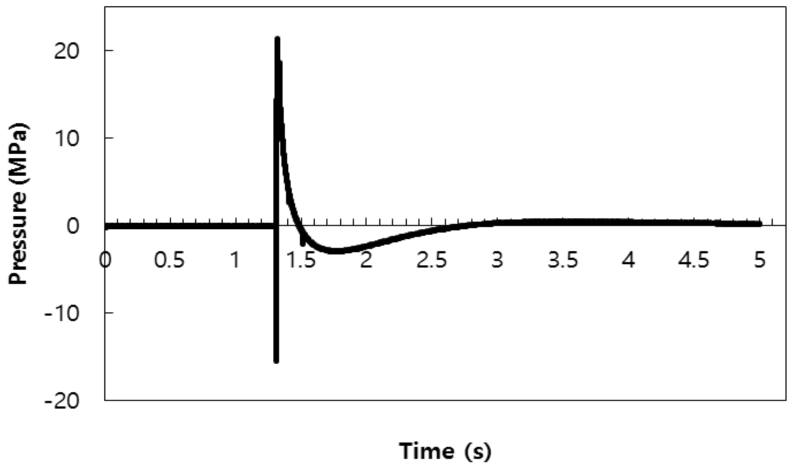

Fig. 4 The graph of detonation pressure measurement.

Table 5 Results of gas detonation forming tests

Test No.	Material	Thickness of plate (mm)	Oxygen pressure (psi)	Acetylene pressure (psi)	Impulse (kgm/s)	Midpoint Deflection (mm)
1	Steel	1	3	6	4.12	6.14
2	Steel	1	5	2.5	8.32	13.15
3	Steel	1	35	17.5	45.09	35.84
4	Steel	2	10	5	25.6	19.09
5	Steel	2	20	10	27.84	21.5
6	Steel	2	30	15	43.17	31.7
7	Steel	2	15	15	31.23	25.75
8	Steel	2	20	20	45.13	33.54
9	Steel	2	20	20	35.76	17.76
10	Steel	3	30	30	51.63	25.72
11	Steel	3	20	10	22	13.58
12	Steel	3	30	15	37.56	19.09
13	Steel	3	40	20	47.31	22.19
14	Steel	3	35	20	42.35	22.83
15	Steel	3	35	17.5	32.65	19.38

$$I = A\int_{t_1}^{\infty} p(t)dt \quad (1)$$

Where, A is area of plate, $p(t)$ and I are pressure distribution respect to time and impulse of shock wave, respectively

The experimental details and photograph corresponding to deformed plate are given in Table 5 and Fig. 5, respectively.

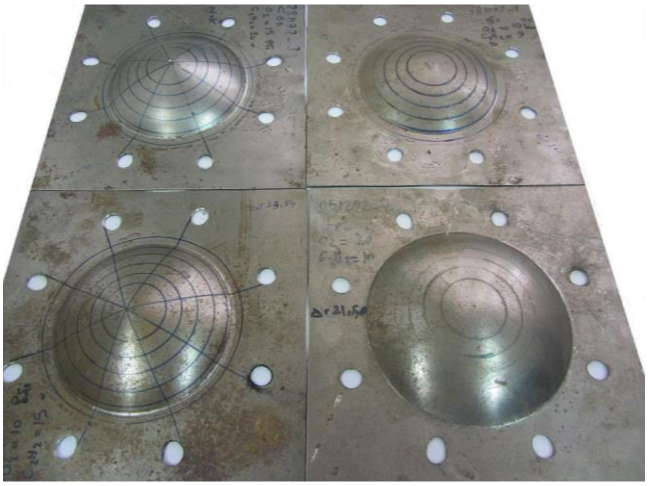

Fig. 5 Photograph of deformed steel plates using gas detonation device

3. Theoretical investigation

A theoretical model is presented by energy method based on upper bound solution in this section, which is used for predicting the maximum deflection of circular plates subjected to detonation of gases mixed. Because of using gases mixture detonation and based on results of experiments of this paper, the deflection profile have domical form. So, parabolic formula is selected to explain the displacement distribution of the plate in transverse direction.

$$w(r) = W_0\left(1 - \left(\frac{r}{R}\right)^{\alpha}\right) \tag{2}$$

Where $w(r)$ is the transverse displacement distribution and W_0 is deflection of late at center. R and r are the outer radius of the plate and radial coordinate, respectively. In this equation, α is the order of the deflection profile function. According to experimental results, the value of α can be supposed 2 for steel plates.

During deformation of plate, the plastic work done is

$$W_p = \int_V (\sigma_r d\varepsilon_r + \sigma_\theta d\varepsilon_\theta)dV \tag{3}$$

It is supposed that thickness strain ε_t is negligible, however strain distributions in radial and circumferential directions are considerable, which are reported in reference (Wen 1998). By using Eq. (2), the strain distributions can be obtained

$$\varepsilon_r = W_0\alpha\frac{r^{\alpha-2}}{R^{\alpha}}\left(W_0\alpha\frac{r^{\alpha}}{2R^{\alpha}} + z(\alpha-1)\right) \tag{4}$$

$$\varepsilon_\theta = W_0 z\alpha\frac{r^{\alpha-2}}{R^{\alpha}} \tag{5}$$

The hydrostatic part of stress tensor does not have an important effect on plastic and yielding in a hydrostatic pressure insensible material as metal. As a result, these parts are subtractable from the stress tensor and it is prevalent to employ the Tresca or Von Mises yield criterion and Von Mises flow rules. Then, equations as bellow are obtained for a circular plate by Tresca yield criterion and Von Mises flow relation for rigid plastic materials (Babaei and Darvizeh 2012).

$$\sigma_r = \sigma_\theta = \sigma_d \tag{6}$$

In the above equation, σ_r and σ_r are radial and circumferential strees. It should be noted that σ_d is considered to be the mean dynamic flow stress. Thus, Eq. (3) can be changed to Eq. (7)

$$W_p = \int_V \sigma_d (\varepsilon_r + \varepsilon_\theta) dV = \int_0^R \int_{-\frac{H}{2}}^{\frac{H}{2}} \sigma_d (\varepsilon_r + \varepsilon_\theta)\, 2\pi r dz dr \tag{7}$$

Substituting the values of radial and circumferential strain into Eq. (7) and integrating with respect to r and z directions gives

$$W_p = \frac{1}{2}\pi\sigma_d \alpha (HW_0^2 + H^2 W_0) \tag{8}$$

For computing the midpoint deflection, the initial kinetic energy E_K is equal to the plastic work done W_p. Given that the impulsive load is applied uniformly to the circular plates, the initial velocity profile of those are considered monotonic

$$V_0 = \frac{1}{m} \tag{9}$$

$$E_K = \frac{1}{2} m V_0^2 = \frac{I^2}{2m} \tag{1}$$

Where

$$m = \rho \pi R^2 H \tag{11}$$

Where ρ and m are the density and mass of a plate, respectively.

By equating Eqs. (10) and (8)

$$\frac{1}{2}\pi\sigma_d \alpha (HW_0^2 + H^2 W_0) = \frac{1}{2\rho\pi R^2 H} \tag{12}$$

For derivation of maximum deflection W_0 from above equation, it is assumed that the mean dynamic flow stress σ_d can be expressed as a scalar multiple of the quasi static yield stress σ_y.

$$\sigma_d = \lambda \sigma_y \tag{13}$$

The Cowper-Symonds equation is used for computing value of the ratio λ between dynamic and quasi static yield stresses. Thus, Eq. (13) can be rewritten in the form of Eq. (14) (Babaei and Darvizeh 2012, Gharababaei and Darvizeh 2010)

$$\frac{\sigma_d}{\sigma_y} = \lambda = 1 + \left(\frac{\dot{\varepsilon}_m}{D}\right)^{\frac{1}{q}} \tag{14}$$

In above equation, $\dot{\varepsilon}_m$ is the mean strain rate. Also, D and q are material constants, respectively. Usual values of mild steel are given as q=5 and D=40.4 s^{-1} in references (Babaei and Darvizeh 2012, Gharababaei and Darvizeh 2010, Babaei and Darvizeh 2011).

The strain rate $\dot{\varepsilon}_m$ is calculated by Eq. (15) (Babaei and Darvizeh 2011)

$$\dot{\varepsilon}_m = \frac{I}{3\sqrt{2}\pi\rho R^4}\left(\frac{W_0}{H}\right) \tag{15}$$

Eventually, Eq. (14) can be rewritten as

$$\frac{\sigma_d}{\sigma_y} = \lambda = 1 + \left(\frac{I}{3\sqrt{2}\pi\rho R^4 D}\left(\frac{W_0}{H}\right)\right)^{\frac{1}{q}} \tag{16}$$

By using experimental results and Eq. (16), the values of λ is calculated for each test. Substituting Eq. (13) into Eq. (12) gives

$$\left(\frac{W_0}{H}\right)^2 + \frac{W_0}{H} = \frac{I^2}{\rho\sigma_y\pi^2 R^2 H^4}\left(\frac{1}{\lambda\alpha}\right) \tag{17}$$

To simplify the above equation, a dimensionless impulsive parameter ϕ is introduced

$$\phi = \frac{I}{\pi R H^2\sqrt{\rho\sigma_y}} \tag{18}$$

Eventually, Eq. (17) is converted to following equation

$$\left(\frac{W_0}{H}\right)^2 + \frac{W_0}{H} = \frac{\phi^2}{\lambda\alpha} \tag{19}$$

Finally, by solving Eq. (19), the relationship between dimensionless parameters of deflection W_0/H and impulse is obtained.

$$\frac{W_0}{H} = \frac{1}{2}\left(\sqrt{1 + \frac{4}{\lambda\alpha}\phi^2} - 1\right) \tag{20}$$

4. Validation of theoretical model

In this section, the validity of theoretical model is assessed by comparing the results of presented model with experimental values in Figs. 6 and 7. It should be noted that these figures demonstrate comparison between the theoretical values of dimensionless deflection and the experimental values for various series of experiment which have been carried out by detonation of mixed gases. As shown in these figures, the results of theoretical model has acceptable accuracy in comparison with experimental ones. Also, it is obvious that 93% of points are in ±1 dimensionless deflection range which is a reliable confine. It is noteworthy to say that this subject is the strength point of the presented theoretical model for prediction of the maximum midpoint deflection of a

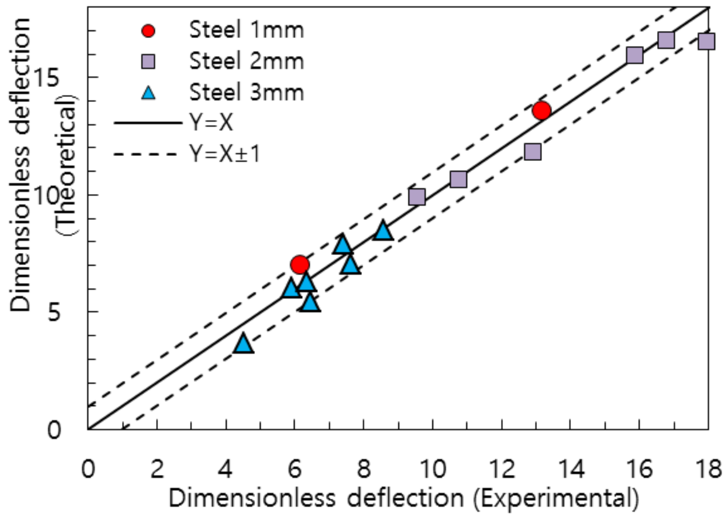

Fig. 6 Comparison between theoretical and experimental values of dimensionless deflection

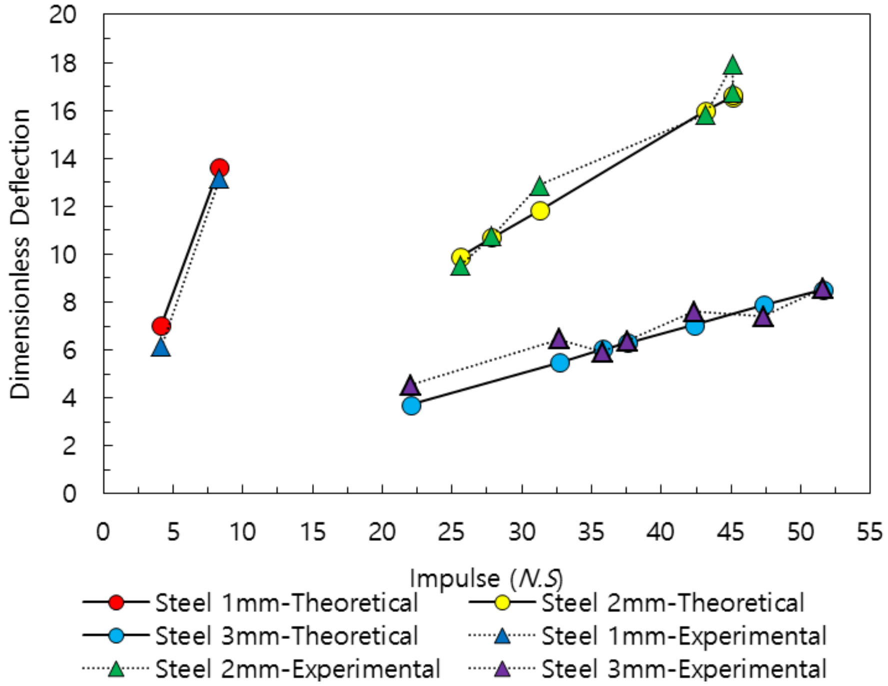

Fig. 7 Variation of dimensionless deflection values versus impulse ones

thin circular plate subjected to impulsive loading. Hence, utilizing the mentioned theoretical model for predicting the deformation profile and also the midpoint deflection of circular plates is appropriate.

There have been reported lots of investigations for theoretical modelling of deformation and dynamic response of circular plates subject to impulsive loading to predict the relation of

Table 6 Relations of reported models

References	Model
Symonds & Wierzbicki (1979)	$\frac{W_0}{H}=\frac{0.212I}{H^2R\sqrt{\rho\sigma_y}}$
Lippman (1974)	$\frac{W_0}{H}=\frac{0.132I}{H^2R\sqrt{\rho\sigma_y}}$
Calladine (1989a)	$\frac{W_0}{H}=\frac{0.225I}{H^2R\sqrt{\rho\sigma_y}}$
Duffey (1967)	$\frac{W_0}{H}=\frac{0.242I(1-\nu+\nu^2)^{0.5}}{H^2R\sqrt{\rho\sigma_y}}$
Perrone & Bhadra (1984)	$\frac{W_0}{H}=\frac{0.117I}{H^2R\sqrt{\rho\sigma_y}}$

Table 7 RMSE of different reported theoretical models

References	RMSE
Calladine (1989a)	6.72
Duffey (1967)	5.95
Symonds & Wierzbicki (1979)	5.71
Perrone & Bhadra (1984)	1.79
Lippman (1974)	0.76
Present Model in Eq. (20)	0.65

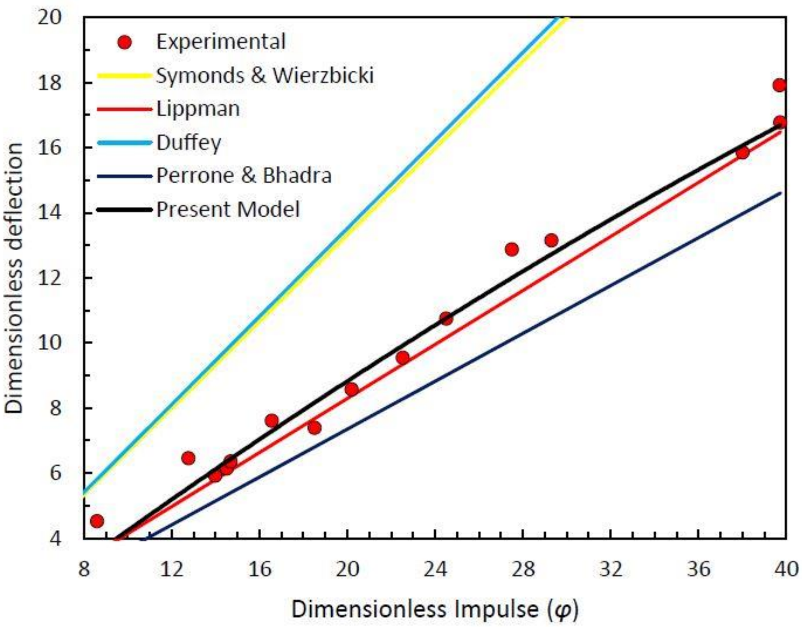

Fig. 8 Comparison between experimental and theoretical value of dimensionless deflection in present model and reported ones in Table 6

dimensionless deflection as a function of material properties, geometry of plate and impulse. These theoretical models predict maximum central deflection of thin circular plate for uniformly impulsive loads which are briefed in Tables 6.

The results of dimensionless deflection versus dimensionless impulse are demonstrated in Fig. 8. It is clear that all of the experimental data are closer to the present model than other ones which can be successfully used to predict maximum central deflection of thin circular plate subjected to detonation of mixed gases. It is obvious from Fig. 8 that Lippman model can predicts maximum central deflection well but for better comparison, Root Mean Square Deviation (RMSE) of the present model in Eq. (20) and the reported ones are calculated in Table 7. Finally, it can be seen that the theoretical model of this paper have much less RMSE compared to other models that are reported in Table 6. The other theoretical models which were not mentioned in Table 6, have much more RMSE than those. It should be noted that in the present model because of using parabolic function for displacement distribution of the plate in transverse direction which indicates nonlinear relation between dimensionless deflection and impulse, value of RMSE is less than other reported models in references. This nonlinearity causes that the theoretical results are closer to experimental data.

5. Conclusions

In this paper, the high speed forming of circular plate subjected to detonation of mixed gases is investigated experimentally and theoretically. Also, the obtained experimental results show the behavior of thin circular plates subjected to impulsive loading. The theoretical model which presented in this research, account for the energy dissipation through plastic work. The solution is specified by geometrical parameter and material completely.

A numerical simulation procedure for predicting directional typhoon wind fields over complex terrain has been proposed in this study.

• Acetylene (C_2H_2)-Oxygen (O_2) in different mixing ratio and variation of initial pressure of the gases, provide strong shock loading for forming of plates. The impulse resultant gas detonation and deformations of the steel plates have been measured.

• The results delivers a good perception of relationship between midpoint deflections and applied impulsive load, while plate thickness and volume ratio of gases vary.

• Predictions of present model for dimensionless deflection of thin circular plate subjected to impulsive loading have an excellent accuracy with experimental data.

• The result of comparing the obtained theoretical results with the other investigations is that the error value in present model is less than the others reported in references.

• The precision of quantities such as midpoint deflection is very susceptible to the mathematical function explaining accurate shape of deflection profile. Therefore, it is intended that this theoretical model will be supplementary to available ones.

References

Babaei, H. and Darvizeh, A. (2011), “Investigation into the response of fully clamped circular steel, copper, and aluminum plates subjected to shock loading”, *Mech. Bas. Des. Struct.*, **39**(4), 507-526.

Babaei, H. and Darvizeh, A. (2012), “Analytical study of plastic deformation of clamped circular plates

subjected to impulsive loading", *J. Mech. Mater. Struct*., **7**(4), 309-322.
Babaei, H., Mirzababaie Mostofi, T. and Alitavoli, M. (2015a), "Study on the response of circular thin plate under low velocity impact", *Geomech. Eng.*, **9**(2), 207-218.
Babaei, H., Mirzababaie Mostofi, T. and Alitavoli, M. (2015b), "Experimental and theoretical study of large deformation of rectangular plates subjected to water hammer shock loading", *Proc. IMechE., PartE: J. Mech. Eng. Sci*., DOI: 10.1177/0954408915611055.
Batra, R.C. and Dubey, R.N. (1971), "Impulsively loaded circular plates", *Int. J. Solids. Struct*., **7**(8), 965-978.
Bisadi, H. and Meybodi, M.K. (2011), "Experimental, numerical, and theoretical analyses of simultaneous forming-welding of inhomogeneous plates", *Proc. IMechE., PartC: J. Mech. Eng. Sci*., **225**(11), 2552-2564.
Cezary, S. and Bojar, Z. (2008), "Gas detonation spray forming of Fe–Al coatings in the presence of interlayer", *Surf. Coat. Tech*., **202**(15), 3538-3548.
Duffey, T.A. (1967), "The large deflection dynamic response of clamped circular plates subjected to explosive loading", Sandia Laboratory Research Report No. SC-RR-67-532.
Gharababaei, H. and Darvizeh, A. (2010), "Experimental and analytical investigation of large deformation of thin circular plates subjected to localized and uniform impulsive loading", *Mech. Bas. Des. Struct.*, **38**(2), 171-189.
Ghosh, S.K. and Weber, H. (1976), "Experimental-theoretical corrections of impulsively loaded axisymmetric rigid-plastic membrane", *Mech. Res. Commun*., **3**, 423-428.
Hadavi, V., Ashani, J.Z. and Mozaffari, A. (2012), "Theoretical calculation of the maximum radial deformation of a cylindrical shell under explosive forming by a new energy approach", *Proc. IMechE., PartC: J. Mech. Eng. Sci*., **226**(3), 576-584.
Honda, A. and Suzuki, M. (1999), "Sheet metal forming by using gas imploding detonation", *J. Mater. Proc. Tech*., **85**(1), 198-203.
Hudson, G.E. (1951), "A theory of the dynamic plastic deformation of a thin diaphragm", *J. Appl. Phys.*, **22**, 1-11.
Jones, N. (1989), *Structural impact*, Cambridge University Press, Cambridge.
Li, F., Mo, J., Zhou, H. and Fang, Y. (2013), "3D Numerical simulation method of electromagnetic forming for low conductive metals with a driver", *Int. J. Adv. Manuf. Tech*., **64**(9-12), 1575-1585.
Li, L.J. and Jiang, W.K. (2011), "A new effective method to predict the permanent deformation of plane plates subjected to underwater shock loading", *Proc. IMechE., PartC: J. Mech. Eng. Sci*., **225**(5), 1069-1075.
Lippman, H. (1974), "Kinetics of the axisymmetric rigid-plastic membrane supplied to initial impact", *Int. J. Mech. Sci*., **16**, 297-303.
Meng, Z., Huang, S., Hu, J., Huang, W. and Xia, Z. (2011), "Effects of process parameters on warm and electromagnetic hybrid forming of magnesium alloy sheets", *J. Mater. Proc. Tech*., **211**(5), 863-867.
Meybodi, M.K. and Bisadi, H. (2009), "Gas detonation forming by a mixture of H_2+ O_2 detonation", *World Acad. Sci. Eng. Tech*., **33**, 55-58.
Mynors, D.J. and Zhang, B. (2002), "Applications and capabilities of explosive forming", *J. Mater. Proc. Tech.*, **125**, 1-25.
Nurick, G.N. and Martin, J.B. (1989a), "Deformation of thin plates subjected to impulsive loading-a review (partII)", *Int. J. Impact. Eng*., **8**, 171-186.
Nurick, G.N. and Martin, J.B. (1989b), "Deformation of thin plates subjected to impulsive loading-a review (partI)", *Int. J. Impact. Eng*., **8**, 159-170.
Perrone, N. and Bhadra, P. (1984), "Simplified large deflection mode solutions for impulsively loaded viscoplastic circular membranes", *J. Appl. Mech.*, **51**, 505-509.
Psyk, V., Risch, D., Kinsey, B.L., Tekkaya, A.E. and Kleiner, M. (2011), "Electromagnetic forming-a review", *J. Mater. Proc. Tech*., **211**(5), 787-829.
Shen, W.Q. and Jones, N. (1993), "Dynamic response and failure of fully clamped circular plates under impulsive loading", *Int. J. Impact. Eng*., **13**(2), 259-278.

Shepherd, J.E. (2009), "Structural response of piping to internal gas detonation", *J. Press. Vess-T,* ASME, **131**(3), 031204.

Skews, B.W., Kosing, O.E. and Hattingh, R.J. (2004), "Use of a liquid shock tube as a device for the study of material deformation under impulsive loading conditions", *Proc. IMechE. PartC: J. Mech. Eng. Sci*., **218**(1), 39-51.

Symonds, P.S. and Wierzbicki, T. (1979), "Membrane mode solution for impulsively loaded circular plates", *J. Appl. Mech*., **46**, 58-64.

Wen, H.M. (1998), "Deformation and tearing of clamped circular work-hardening plates under impulsive loading", *Int. J. Pres. Ves. Pip*., **75**, 67-73.

Wielage, H. and Vollertsen, F. (2011), "Classification of laser shock forming within the field of high speed forming processes", *J. Mater. Proc. Tech.*, **211**(5), 953-957.

Yasar, M. (2004), "Gas detonation forming process and modeling for efficient spring-back prediction", *J. Mater. Proc. Tech*., **150**(3), 270-279.

Yasar, M., Demirci, H.I. and Kadi, I. (2006), "Detonation forming of aluminium cylindrical cups experimental and theoretical modelling", *Mater. Des*., **27**(5), 397-404.

CC