Advanced Materials Research
ISSN: 1662-8985, Vol. 845, pp 803-808
doi:10.4028/www.scientific.net/AMR.845.803

Online: 2013-12-04

Estimation of Charge Mass for High Speed Forming of Circular Plates Using Energy Method

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Keywords: High speed forming; energy method; cone forming; stand-off distance; strain energy

Abstract. In this paper the explosive mass for forming a circular plate to a cone is determined using the energy method. To achieve this goal, the strain energy which is necessary to form a circular plate to a cone is calculated at first. Later the transmitted energy due to the detonation of an explosive material which is placed in a constant stand-off distance to a circular plate is specified. Equaling the strain energy and the transmitted energy, the explosive mass is figured out. Comparing the obtained results with the experiments shows the relatively acceptable compatibility.

Introduction

Explosive forming is a process which has been developed about 50 years ago. After 1970's, It has been used to produce different parts for aerospace industries [1]. First of all the United States was the most important use of this technology. But later it has been utilized by Japan and European countries much more [2]. In couple recent decades a lot of researches have been carried out about explosive forming due to the mentioned factors. [3-5]

Cone forming is one of the sophisticated and arduous areas in sheet-metal forming processes. In conventional drawing methods, failure is too likely to come to pass on the specimens because of low-contact area of the sheet with a punch in the first steps of forming. Besides, since most of the sheet surface in the area between the punch tips and blank holder is given free rein to form, wrinkles may occur on the flange or product wall [6, 7]. Therefore, conical parts are normally made by spinning [8, 9], explosive forming [1, 10, 11], or multi-stage deep drawing processes[12].

Tardif [11] was the first person who used underwater explosion to produce cones by circular blanks. But except for trailblazer and novelty, his work has not clasped a precise experimental or analytical investigation. The only relatively comprehensive experimental investigation about explosive forming of cones is Johnson and Travis's research [13].

Charge mass plays an important role in the explosive forming process. Therefore, the main objective of this study is to estimate the explosive mass for a completed shaping and prevent failure and rupture. In order to attain the mentioned goal, the energy method has been used to determine the explosive mass. First of all the required strain energy for a perfect forming has been calculated and in the next step the received energy to a circular plate due to an explosion has been found. At last, equaling the explosion energy and strain energy lead to specify the charge mass. The results have been compared with the experimental outcomes of Johnson and Travis [13].

Determining Strain Energy to Form a Cone

The first step to determine the charge mass is to calculate the strain energy for forming a circular blank to a cone. The relationship between stress and strain is so important to find the strain energy. The incremental strain energy per volume unit is defined as equation 1 [14].

$$dU = \sigma_{eff} d\varepsilon_{eff} \tag{1}$$

Where σ_{eff} and ε_{eff} are effective stress and effective strain respectively. dU is the incremental strain energy or the strain energy. The value of effective stress and effective strain is expressed by equations 2 and 3 [14].

$$\sigma_{eff} = \sqrt{(1/2)\left[(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2+(\sigma_1-\sigma_2)^2\right]} \tag{2}$$

$$\varepsilon_{eff} = \sqrt{(2/3)\left(\varepsilon_1^{\,2}+\varepsilon_2^{\,2}+\varepsilon_3^{\,2}\right)} \tag{3}$$

Where σ_1, σ_2 and σ_3 are principle stresses and ε_1, ε_2 and ε_3 are principle strains. The integration of the equation 1 gives

$$U = \int_0^{\varepsilon_{eff}} \sigma_{eff}\, d\varepsilon_{eff} \tag{4}$$

Where U is the strain energy per unit volume. The total strain energy is the volume integral of the equation 4 as the equation 5.

$$U_T = \int_V U dV \tag{5}$$

Where U_T is the total energy of deformation and V is the volume of material. According to equations 1 to 5, determining the effective stress and effective strain is the first step to survey the total strain energy for perfect forming of a cone.

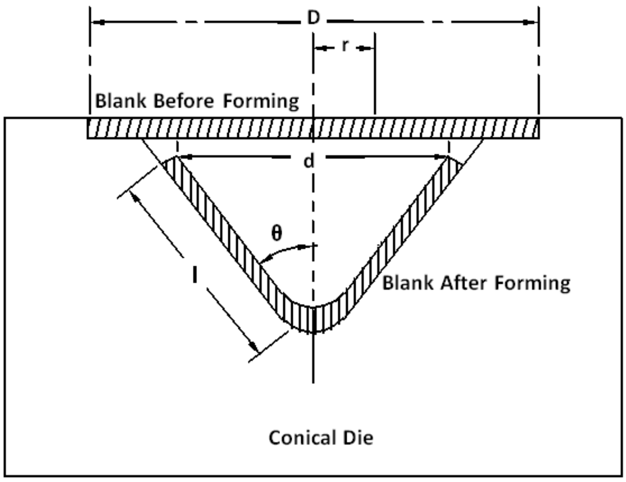


Figure 1. The schematic of forming process

Figure 1, shows a schematic of forming a blank to cone. In developing an estimation, it is necessary to take into account a number of idealizations at the outset. It is assumed that the thickness of the blank remains without changing during the deformation process and also the effect of work-hardening is neglected. According to figure 1 and considering that The volume remains constant during plastic deformation [14, 15] and paying attention to constant thickness assumption the equation 7 is defined as

$$\frac{\pi D^2}{4} = \frac{\pi d l}{2} \tag{6}$$

Where D, d and l are the primary diameter of blank, cone base diameter and cone slant length respectively. Considering the geometry in figure 1 and equation 6, the equation 7 can be defined as

$$d = D\sqrt{\sin\theta} \tag{7}$$

The circumferential strain in the edge of cone base is equal to

$$\varepsilon_h = \ln\left(d / D\right) \tag{8}$$

Incorporating equation 7 and equation 8, the equation 9 is generated as

$$\varepsilon_h = (1/2)\ln\left(\sin\theta\right) \tag{9}$$

Considering no changing in volume during plastic deformation, the equation 10 is expressed as

$$\varepsilon_h + \varepsilon_l + \varepsilon_t = 0 \tag{10}$$

Where ε_t and ε_l are thickness and slant height strain. According to the no changing in thickness assumption the value of ε_t is equal to zero. Therefore the equation 10 is converted to equation 11.

$$\varepsilon_h = -\varepsilon_l \tag{11}$$

According to equations 9 and 11, the effective strain given by equation 4 can be rewritten then in term of ε_h as shown in equation 12.

$$\varepsilon_{eff} = (-\sqrt{3}/3)\ln(\sin\theta) \tag{12}$$

Neglecting the work-hardening effect, the value of σ_{eff} is equal to yield stress of the material. Using the recent assumption and inserting equation 13 in equation 5, the strain energy per unit volume can be expressed as follows

$$U = (-\sqrt{3}/3)Y_s \ln(\sin\theta) \tag{13}$$

Where Ys is the yield stress of the material. Finally the total strain energy is the volume integral of the equation 13 which is written as the equation 14.

$$U_T = -(\sqrt{3}/12)\pi D^2 t Y_S \ln(\sin\theta) \tag{14}$$

Calculating of Energy Transmitted to a Circular Plate Due to Explosion

The energy density due to underwater explosion shock wave can expressed as follows [1].

$$T_E = k(W^{\frac{\xi+1}{3}} / Z^{\xi}) \tag{15}$$

Where T_E is the energy density in terms of pound per square inch. W is the charge mass and Z is the distance of each point from the center of the charge. K and ζ are constants depended on explosive material. It is worth mentioning that the equation 17 is exclusively operational for underwater explosion [1].

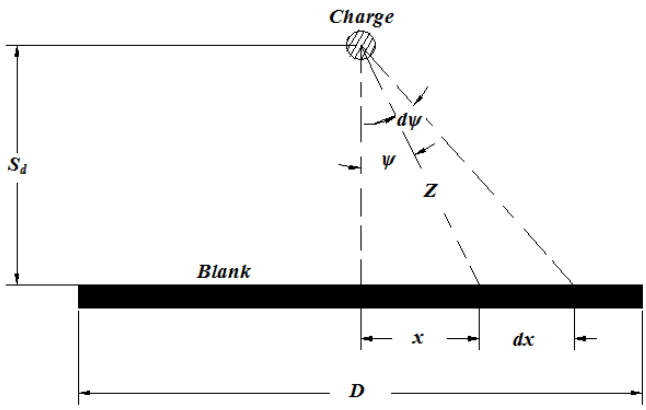


Figure 2. Circumstance of energy transmission to a circular blank due to the explosion

Figure 2, shows a charge which has been fixed at a distance S_d to the blank. The mentioned distance is so-called stand-off. According to the equation 15 and figure 2, the energy in a part of shockwave with the angle of $d\psi$ is transmitted to a circular element of blank with the radius of x and the width of dx. The mentioned value of energy (dT_E') can be obtained via equation 16 [1].

$$dT_{E'} = k(W^{\frac{\xi+1}{3}} / Z^{\xi})\left(2\pi xzd\psi\right) \tag{16}$$

According to the figure 2, the energy of a Shockwave element with the surface area of $2\pi xzd\psi$ is transferred to the homolog element on the blank with a surface area of $2\pi xdx$. Therefore, the intensity of transmitting energy is decreasing by $\cos\psi$. Thus, the transferred energy to the circular element of blank with the width of dx can be expressed as equation 17.

$$dT_{E'} = k(W^{\frac{\xi+1}{3}} / Z^{\xi})\left(\cos\psi 2\pi xdx\right) \tag{17}$$

The total transmitted energy to the blank is the integral of the equation 17 which is written as the equation 18.

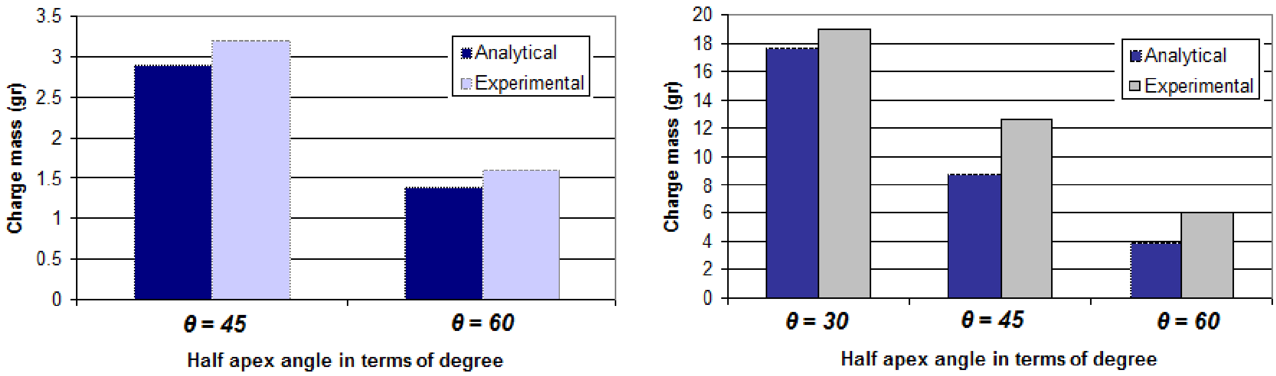
$$T_{E'} = \frac{2\pi kW^{\frac{\xi+1}{3}}}{S_d^{\ \xi-2}(\xi-1)}\left(1-(1/\left[1+\left(\frac{D}{2S_d}\right)^2\right]^{\frac{\xi-1}{2}}\right) \tag{18}$$

Equaling the equations 14 and 18, the charge mass is calculated as equation 19.

$$W = \left[\frac{-\sqrt{3}D^2tY_S S_d^{\ \xi-2}(\xi-1)}{24k}\ln(\sin\theta)\left\{1-\left[1+\left(\frac{D}{2S_d}\right)^2\right]^{\frac{2}{\xi-1}}\right\}^{-1}\right]^{\frac{3}{\xi+1}} \tag{19}$$

Comparing the Analytical Results with the Experimental Outcomes

The analytical results of this investigation have been compared with Johnson and Travis 's outcomes [13]. In all experiments the blank is placed on the die without blank-holder. All the facilities is located in a water vessel. The explosive material is TNT located in the S_d = *150mm* with the constants K = *52000* and ζ = *2.12*. Materials used in the experiments are aluminum and steel with the yield strength 115Mpa and 250Mpa respectively. Figures 3 shows the comparison between analytical and experimental results which demonstrate appropriate accordance. Although the results seem more precise about aluminum blanks.



a b

Figure 3. Analytical and experimental results for Aluminum blanks (a) and steel blanks (b)

Results and Discussion

In this paper, the charge mass for converting a circular plate to a cone estimated employing energy method. Results indicated that the charge mass has a direct relationship with yield strength and an inverse relationship with conical angle. The observed results are confirmed by Johnson and Travis's experimental outcomes [13]. The analytical outcomes were compared with experimental results which are in reference number [13]. Considering figures 3, the analytical results are more in close accord with the experimental results for aluminum blank in comparison with steel. The mentioned difference could have originated from several factors such as friction, work-hardening effect and the behavioral response of material to strain rate. The recent factors are great extent dependent on material type. The geometrical assumptions, ideal usage of energy method and some assumptions correlated to mechanical properties of material can lead to error occurrence in calculations. As it is indicated in figure 3, the charge mass which is estimated by analytical method is less than experimental results. It could have occurred because of disregarding friction and the losses of transmitted energy from charge to specimen.

Conclusions

In the present paper, an equation was acquired considering the mechanical properties and geometrical condition of the specimen and die. The equation presented in this paper can be used to estimate the approximate charge mass for manufacturing metal cones. The mentioned equation is only usable for underwater explosion. However, comparing with experimental results shows that analytical prediction includes reasonable error.

Acknowledgement

Financial support from the Ministry of Higher Education, Malaysia and Universiti Teknologi Malaysia through Research University Grant (No. 05H27) is gratefully acknowledged.

References

[1] A.A. Ezra, Principles and practice of explosive metalworking, Industrial Newspapers, 1973.

[2] H. Otto, A. Dowling, R. Sullivan, A comparison of the effects of explosive forming and static deformation on the mechanical properties of pressure vessel steels, Metallurgical Transactions, 4 (1973) 657-661.

[3] V. Hadavi, J. Zamani, R. Hosseini, The empirical survey on the effect of using media in explosive forming of tubular shells, World Academy of Science, Engineering and Technology, 60 (2009) 574-579.

[4] R. Alipour, Finite element analysis of elongation in free explosive forming of aluminum alloy blanks using CEL method, International Review of Mechanical Engineering, 5 (2011) 1039-1042.

[5] E. Kowsarinia, Y. Alizadeh, H.S. Pour, Theoretical and experimental study on the effects of explosive forming parameters on plastic wrinkling of annular plates, The International Journal of Advanced Manufacturing Technology, (2012) 1-9.

[6] M. Kawka, L. Olejnik, A. Rosochowski, H. Sunaga, A. Makinouchi, Simulation of wrinkling in sheet metal forming, Journal of Materials Processing Technology, 109 (2001) 283-289.

[7] Metal Forming Handbook, Springer Berlin Heidelberg, 1998.

[8] A. Sekiguchi, H. Arai, Control of wall thickness distribution by oblique shear spinning methods, Journal of Materials Processing Technology, 212 (2012) 786-793.

[9] C.C. Wong, T.A. Dean, J. Lin, A review of spinning, shear forming and flow forming processes, International Journal of Machine Tools and Manufacture, 43 (2003) 1419-1435.

[10] A.A. Ezra, F.A. Penning, Development of scaling laws for explosive forming, Experimental Mechanics, 2 (1962) 234-239.

[11] H.P. Tardif, in: Other Information: Orig. Receipt Date: 31-DEC-62, 1958, pp. Medium: X; Size: Pages: 8.

[12] Z. Liuru, in: Mechanic Automation and Control Engineering (MACE), 2011 Second International Conference on, 2011, pp. 7704-7706.

[13] F.W. Travis, W. Johnson, The Explosive Forming of Cones, The 3rd International Conference of Machine Tool Design, (1962) 341-364.

[14] W.F. Hosford, R.M. Caddell, Metal Forming: Mechanics and Metallurgy, Cambridge University Press, 2011.

[15] P.M. Dixit, U.S. Dixit, Modeling of Metal Forming and Machining Processes, in: Modeling of Metal Forming and Machining Processes, Springer London, 2008.