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ESTIMATING THE CHARGE SIZE IN EXPLOSIVE FORMING OF SHEET METAL

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SUMMARY

A method is given for estimating the charge size for the explosive forming of sheet metal components. The method is applied to a number of relatively simple shapes and good agreement is shown with experimental results.

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1. Introduction

In this paper we consider the explosive forming process in which sheet metal is formed (stretch-formed) by the energy obtained from the detonation of a chemical explosive. This process is being used on an increasing scale in industry and has a number of advantages including low cost of capital equipment and the possibility of forming large components which would be impracticable using more conventional forming techniques.

In what follows a method is presented for calculating the amount of explosive (charge size) needed to form a given component. A simple energy method is used in which the charge size is calculated by equating the plastic work needed to form the component to the amount of explosive energy available for doing work on the component.

Rigorous solutions for the plastic work done in forming a component, even for relatively simple shapes, are complex and if the method is to have general application some approximate, more easily applied method of calculating the plastic work is needed. In this connection two features of the process are helpful. In the first place the stress through the thickness of the sheet will be small and can be neglected and the sheet is deformed by either simple uniaxial tension or biaxial tension. Second, the sheet is in many applications formed into a shaped die and the final shape is therefore known.

Consider the small element of sheet shown in figure 1, of original side lengths x and y. Let the element increase its side lengths by Δx and Δy, under the action of the equal tensions Y (where Y is the yield stress in uniaxial tension). The plastic work done is then given by

$$\begin{aligned} \text{W.D.} &= \text{original volume} \times \text{strain energy per unit volume} \\ &= t\,x\,y\left\{Y\frac{\Delta x}{x} + Y\frac{\Delta y}{y}\right\} \\ &= t\,Y\,\Delta A \qquad (1) \end{aligned}$$

where t is the initial thickness of the sheet and ΔA is the <u>imposed</u> change in surface area. ΔA is defined as the imposed change in surface area in order to make equation (1) applicable to the uniaxial case. That is, for uniaxial tension ΔA is taken as the product of the extension in the direction of the load and the initial width of the sheet, and the change in area resulting from the drawing-in at right angles to the load is neglected. For biaxial states of stress in which one stress is equal to Y and the other between 0 and Y, equation (1) is in error, but for most practical cases this error will be small. The use of engineering strain (change in length/original length) instead of natural strain in equation (1) should not lead to large errors as in most applications the strain is small.

In equation (1), the yield stress Y has been assumed constant. If the material work-hardens then the work-done is given by

$$W.D. = t\,\Delta A\left\{Y + \frac{1}{2}\frac{\Delta A}{A}H\right\} \qquad (2)$$

where H is the slope of the idealized plastic stress-strain curve.

In considering the explosive energy we will assume that the total explosive energy can be represented by a sphere with the charge at the centre. The proportion of energy available for deforming the blank (from which the component is to be formed) is then taken to be given by the surface area of the spherical sector acting on the blank divided by the surface area of the corresponding sphere.

Let us now consider the application of the method to some relatively simple shapes.

2. Clamped Circular Diaphragms

Let us assume that a clamped circular diaphragm of free radius 'a' (see Fig. 2) deforms to a spherical cap of radius 'r' and central height 'h'. Then

$$\text{spherical surface area} = \pi\left\{\frac{a^2}{4} + h^2\right\}$$

$$\text{original surface area} = \frac{\pi a^2}{4}$$

and the change in surface area

$$\Delta A = \pi h^2$$

from equation (1)

$$W.D. = t\,Y\,\pi\,h^2 \qquad (3)$$

The explosive charge is placed relative to the diaphragm as shown in Fig. 2, where S is the distance of the charge from the diaphragm, i.e. the stand-off. By considering the ratio of the area of the spherical sector acting on the diaphragm to the surface area of the sphere representing the total energy, it can be shown that the energy available for doing work on the diaphragm is given by

$$\text{energy} = \frac{W\,\eta\,\theta^2}{4} \qquad (4)$$

where 2θ is the solid angle subtended by the blank at the charge (θ assumed small), W is the chemical energy released on detonation and η is the efficiency of energy transfer which will depend, for example, upon the transfer medium. Equating equations (3) and (4) we obtain

$$t\ Y\ \pi\ h^2 = \frac{W\ \eta\ \theta^2}{4}$$

$$\text{or} \quad h^2 \propto \frac{W\theta^2}{tY} \qquad (5)$$

Experimental results obtained at Cranfield[1] and R.A.R.D.E.[2] are given in Figs. 3 and 4. In spite of the scatter of experimental results equation (5) is seen to give good agreement with experiment. When W is the only variable then equation (5) reduces to

$$h \propto W^{0.50}$$

which compares well with the empirical relation of Travis and Johnson[3]

$$h \propto W^{0.55}$$

The efficiency of energy transfer η has been calculated from the slopes of Figs. 3 and 4 and was found to be 38.6% and 38.3% respectively.

3. Thin Walled Tubes

Fig. 5 shows the experimental arrangement for bulging thin walled tubes. The explosive charge was set at the centre of the tube and the tube was free to draw in along its length.

Let us assume that after forming the tube wall follows a circular arc (shown dotted in Fig. 5). Then we find that

$$\Delta A = \frac{4}{3}\pi \ell h$$

where ℓ is the length of the tube and h is the maximum radial deflection (Fig. 5), and substituting in equation (1)

$$W.D. = \frac{4}{3}\pi \ell h t Y \qquad (6)$$

If 2θ is the angle subtended by the tube at the centrally positioned charge then the energy available for doing work on the tube is given by

$$\text{energy} = W\ \eta\ \sin\theta \qquad (7)$$

Equating equations (6) and (7) gives

$$\frac{4}{3}\pi \ell h t Y = W \eta \sin\theta$$

$$= W\eta \frac{\ell}{(\ell^2 + D^2)^{\frac{1}{2}}}$$

(where D is the original tube diameter) and therefore

$$h \propto \frac{W}{t\,Y(\ell^2 + D^2)^{\frac{1}{2}}} \qquad (8)$$

Experimental results obtained at Cranfield[1] are given in Fig. 6, (material and thickness constant) and equation (8) can be seen to give good agreement. From the slope of Fig. 6, η was found to be 29.2%.

4. Forming into a shaped die

In the examples considered in the previous two sections assumptions regarding the final shape had to be made. In the case of forming into a die the final shape is known and the change in surface area ΔA can readily be found.

Consider the expansion of the frustum of a cone into a spherical die as shown in Fig. 7. If there is no axial restraint then it can be shown that

$$\Delta A = \frac{4}{3}\pi h \ell \cos\theta$$

where h, ℓ and θ are as shown in Fig. 8. Substituting for ΔA in equation (1) gives

$$\text{W.D.} = \frac{4}{3}\pi h \ell \cos\theta \; t\, Y \qquad (9)$$

For a change at O (Fig. 8) the energy available for doing work is given by

$$\text{energy} = W \eta \sin\theta \qquad (10)$$

Combining equations (9) and (10)

$$W = \frac{4 \pi h \ell t Y}{3 \eta \tan\theta} \qquad (11)$$

Equation (11) was used to calculate the charge size for a particular component the details of which were:

Work material DTD 571 stainless steel, yield stress 21 tons/in^2, Sheet thickness .020 in., remaining dimensions as shown in Fig. 8.

As the experimental arrangement was similar to that for the tubes, i.e. enclosed charge, η was taken as 29.2% (the value calculated from Fig. 6). Substituting in equation (11) gives

$$W = 302 \times 10^5 \text{ in lb}$$

or using 1 in cordtex = 13500 in lb

$$W = 22.4 \text{ in of cordtex.}$$

In carrying out the forming it was found advantageous to use two explosions, with explosive charges of roughly the same size, the total amount of cordtex used being 23 inches. The final component is shown in Fig. 9. Although in forming into a die it is difficult to judge if the charge size was larger than needed it did appear that the value given by equation (11) was approximately correct.

5. Discussion

In the analysis presented in this paper a number of simplifying assumptions have been made, let us now consider these. To represent the total explosive energy by a sphere is only an approximation. We have assumed a point source for the charge when in practice the size of the charge can be significant. In this connection, if a complicated component is being produced with the charge split up and placed at different positions then the interaction of the various charges on different parts of the component must be considered. In addition this method takes no account of reflected energy, which under certain (sometimes specially designed) conditions can be large.

In the experiments described the charge was placed well below the water surface. If this distance (the hydrostatic head) is small compared with the stand-off, then as Johnson[4] has shown, the efficiency η is highly dependent on the actual value of the hydrostatic head.

In calculating the plastic work done in forming the diaphragms and tubes it was assumed that the final shape was a circular arc. Measurements made after forming showed that this was a good approximation for the tubes but that for the diaphragms the shape fell between a circular arc and a parabola. However, unless the central height is large ($h \rightarrow a$) the use of a circular arc is sufficiently accurate. The method used for calculating the plastic work from the change in surface area is itself only approximate and tests are to be made to measure its accuracy over a range of conditions.

In conclusion it can be said that in spite of the approximate nature of the method given the agreement with experiment is encouraging. The method could prove of particular value in estimating the charge size for components which are formed into a shaped die. To the best of our knowledge no other method is available for doing this.

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7. References

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