A New and Simple Method of Determination of the Parameters of Explosive Welding and Latest Results

by R. Prümmer*

Introduction : The method of explosive welding has been known for many years as a good means for welding especially dissimilar metals. Growing demands of the industry for explosively plated metal sheet enhanced more fundamental research. In order to describe the process the welding parameters are of great importance. As they solely determine the bonding strength, their knowledge is desired.

There exist several theoretical and semi-empirical methods[1)-4)] which describe the relationship between type and amount of explosive and the parameters for explosive welding. Several attempts have been made in order to measure these parameters. High speed photography[3)4)], X-ray radiographic flash method[5)] or electrical methods are limited with respect to the amount of explosive used in the experiment. The electrical method only allowes the determination of just one parameter of explosive welding. The purpose of this paper is to describe a simple method which allows the determination of all parameters for explosive welding simultaneously. The method is cheap in application.

The Explosive Welding Configuration

The arrangement for explosive welding is shown in Fig. 1 shematially. Three parameters are describing the welding process:

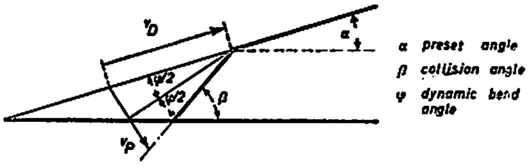

Fig. 1 Geometry of explosive welding

In case of an initial standoff-angle $\alpha \neq 0$ the following geometrical relationships exist:

Plate velocity:

$$v_P=2v_D\cdot\sin\frac{\varphi}{2}=2v_D\sin\left(\frac{\beta-\alpha}{2}\right) \qquad (1)$$

Collision point velocity:

$$v_K=v_D\cdot\frac{\sin\varphi}{\sin\beta}=v_D\frac{\sin\varphi}{\sin(\alpha+\varphi)} \qquad (2)$$

where v_D is the detonation velocity of the used explosive. φ is the dynamic bend angle.

In the case of a parallel set-up of the upper and lower plate for explosive welding equation 1 and 2 reduce to

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Fourth Internationl Conference of the Center for High Energy Forming July 9-13, 1973, Vail, Calorado.

$$v_P = 2v_D \sin\frac{\varphi}{2} \qquad (1\,a)$$

$$v_K = v_D \qquad (2\,a)$$

with $\beta = \varphi$ (3)

in most cases the collision angle β is less than 200, so that in a parallel set-up eq. (1) can be written

$$v_P = v_D \cdot \sin\varphi = v_D \cdot \sin\beta \qquad (4)$$

Electronic Method of Measuring the Parameters

The method is based on a slanted resistance wire, which is hidden by the fast moving fiyer plate. A shortening of the circuit occurs continuously and can be registered by an oscilloscope. Fig. 2 shows the arrangement which is known as a good means for measuring free surface velocities in shock wave propagation experiments[7]. The smaller the angle η, the better is the resolution. This method is applicable, when the direction of the velocity-vector is known.

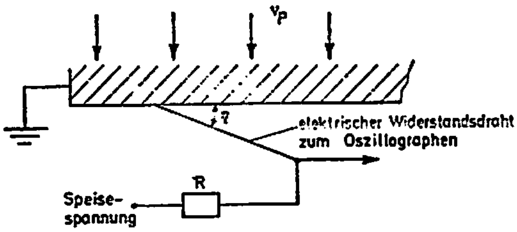


Fig. 2 Slanted resistance wire technique for measuring free surface velocities

In case of explosive welding at least two unknown parameters have to be determined, that is the velocity of the flyer plate itself and the angle β under which the flyer plate is striking the base plate.

The simultaneous measurement of both these parameters is enabled by a two fold slanted resistance wire. In the case of a roofshaped wire, as shown in Fig. 3 with the inclination-angle $+\eta$ and $-\eta$ the collision velocity along the wire is different on each side. In the case of a fiat wire, $h=0$, the following collision velocity is measured

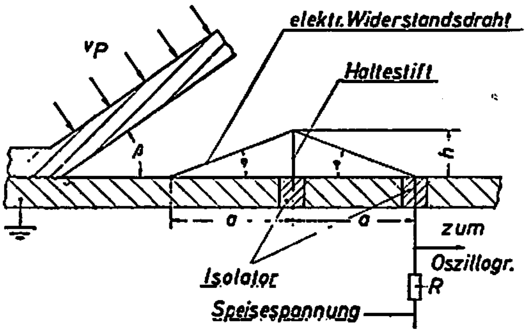


Fig. 3 Roof-shaped resistent wire for measurement of explosive welding parameters

$$v_K = \frac{v_P}{\sin\beta} \qquad (5)$$

The collision velocity at the ascending part (from left to right) of the wire is measured to be

$$v_1 = \frac{v_P}{\sin(\beta-\eta)} \qquad (6)$$

and at the descending part of the wire

$$v_2 = \frac{v_P}{\sin(\beta+\eta)} \qquad (7)$$

Out of this it follows:

$$\beta = \text{arc ctg}\left(\text{ctg}\,\eta \frac{v_1 - v_2}{v_1 + v_2}\right) \qquad (8)$$

It the times of duration of collision along the ascending and decending part of the wire are t_1 and t_2 respectively the following equations are obtained

$$\beta = \text{arc tg}\frac{h(t_1+t_2)}{a(t_2-t_1)} \qquad (9)$$

$$v_K = \frac{2a}{t_1+t_2} \qquad (10)$$

$$v_P = \frac{2a\cdot h}{\sqrt{h^2(t_1+t_2)^2 + a^2(t_2-t_1)^2}} \qquad (11)$$

If the height h of the roof-shaped wire is small compared to its length $2a$ then eq.

(11) con be written

$$v_P=\frac{2h}{(t_2-t_1)} \qquad (11\text{ a})$$

where only an error of about 3 % has to be taken into account.

The measurement is performed by an oscilloscope with polaroidcamera. The circuit diagram is shown in Fig. 4. During the measurement the resistor R_a is shortened continuously, when hidden by the flyer plate.

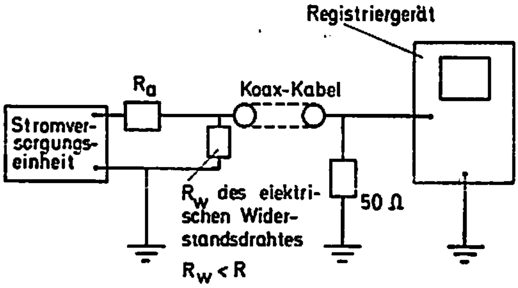


Fig. 4 Circuit diagram for measurement of explosive welding parameters

During collision a crater is formed in the flyer plate and explosive welding occurs. The diameter of the resistant wire originally was 0.4mm, Fig.5.

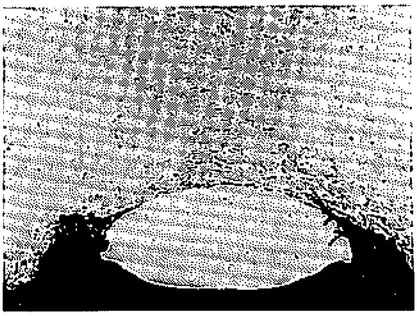
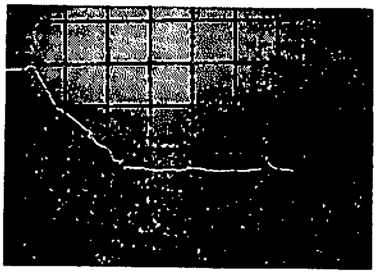
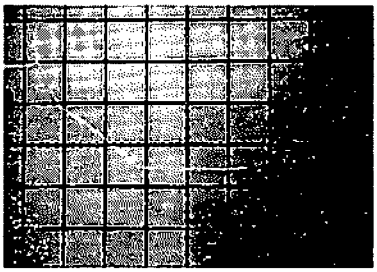


Fig. 5 Resistant wire after collision with flyer plate

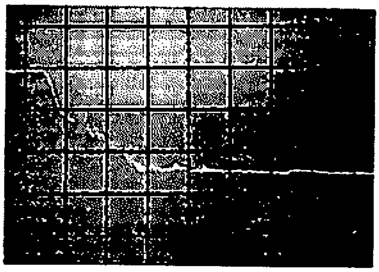
Typical Oscillographs are shown in Fig. 6 a-c. A steel plate, 5mm in thickness was accelerated by different kinds and amounts of explosive. From the points of intersections of straight lines in the diagrams the times t_1 and t_2 were taken and the parameters calculated using equations9)-11).



a) explosive: Ammonit 1, 19 mm thick
20 μsec/cm



b) explosive: Ammonit 1, 13 mm thick
20 μsec/cm



c) explosive: RDX, 10 mm thick
10 μsec/cm

Fig. 6 Examples of determination of welding parameters: flyer plate: steel, 5 mm thick

The results are summarised in Fig. 7. The values of dynamic bend angle β are drafted vs. the ratio v_P/v_D. The solid line represents theoretical-empirical investigations of Deribas et. al.4), which obey the formula

$$\sin\frac{\beta}{2}=0.6\frac{\sqrt{1+\frac{32e}{27m}}-1}{\sqrt{1+\frac{32e}{27m}}+1} \qquad (12)$$

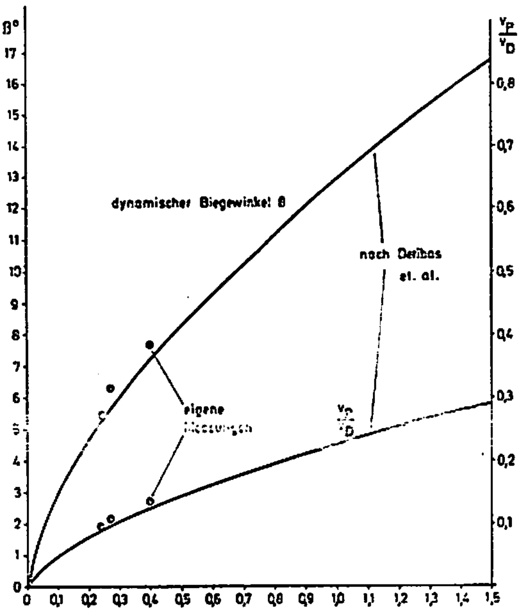


Fig. 7 Dynamic bend angle vs. ratio of mass of explosive/mass of flyer plate. Explosive: Am 1, $v_D \approx 3,500$ m/sec

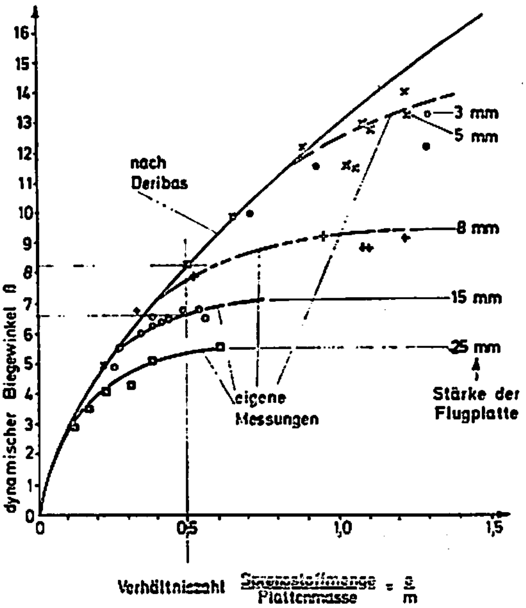


Fig. 8 Dynamic bend angle vs. ratio of mass of explosive/mass of flyer plate. Explosive: Am 1, $v_D \approx 3,500$ m/sec

where e is the mass of explosive and m the mass of the flyer plate. There exists good agreement between predicted and experimental values.

Influence of material of flyer plate

In the course of further investigations, especially when the parameters due to high values of e/m were investigated systematic deviations were observed. The dynamic bend angle and the ratio of v_P/v_D was observed to be smaller than the expected values.

Fig. 8 summarises results of investigations performed with an aluminium alloy AlZnMg 1 as a flyer plate material. Different thicknesses of this material were investigated. As long the flyer plate is thin (< 5mm) there exists good agreement between the obtained values of the dynamic bend angle β with predicted values up to a e/m-ratio of about 1,2. A deviation to smaller values, however, is obtained, the greater the thickness of the aluminium flyer plate is chosen.

A further series of investigations was performed in order to resolve the influence of the strength of the material of the flyer plate on the welding parameters. The mechanical properties of the investigated steels are given in Table 1:

Table 1 Mechanical Properties of Steels used as flyer plates.

Material	thickness of plate	UTS	Vickers hardness
St 37	6mm	35kp/mm^2	100kp/mm^2
N-A-XTRA	5mm	72kp/mm^2	210kp/mm^2
HY 100	7mm	97kp/mm^2	286kp/mm^2

The size of the plates was 400mm in length and 200mm in breadth, the same as in the previous experiments with aluminium plates. As Fig. 9 shows for a given ratio e/m there exists a decrease of the dynamic bend angle with increasing strength of the flyer plate material.

Conclusions

When thin plates are explosively accelerated

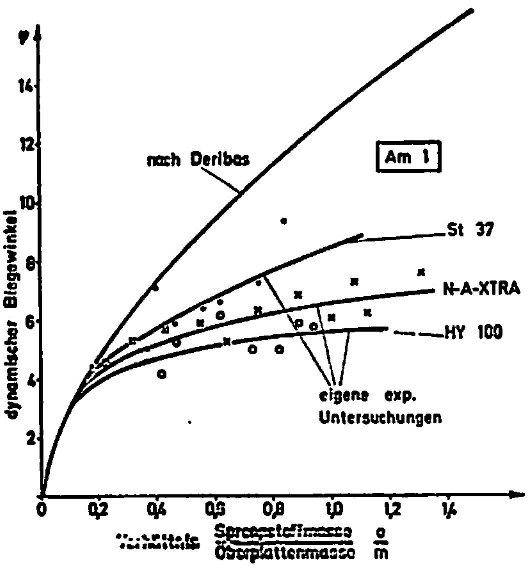


Fig. 9 Dynamic bend angle vs. ratio of mass of explosive/mass of flyer plate. Explosive: Am 1, $v_D \approx 3,500$ m/sec

by a tangential detonation wave the terminal velocity is given by the amount of explosive and the detonation velocity of the explosive. In a nondimensional diagram, represented by the dynamic bend angle and the ratio of mass of explosive and mass of flyer plate a good agreement between a semi-theoretical curve[4] and experimental values is obtained.

This result is also confirmed by other investigators[1)-4),8)].

When thick plates or such of high strength materials are put into investigation, the dynamic bend angle at a given explosive-flyer mass ratio is smaller than expected.

It becomes smaller with

1) increasing thickness of the flyer plate and
2) increasing strength of the material of the flyer plate.

Qualitatively the same deviation from theoretical values was observed by Enright & Sharp[9]. These investigations were performed with flyer plates of different aluminium alloys. The explosive was a mixture of 80% Ammoniumnitrate and 20% TNT, mixted with up to 55% sodiumchloride, revealing detonation velocities between 2,500 and 3,300m/sec.

Fig. 10 illustrates these measurements in the same type of graph like in Fig. 9.

It also was observed that the initial velocities of fragments from exploding tubes

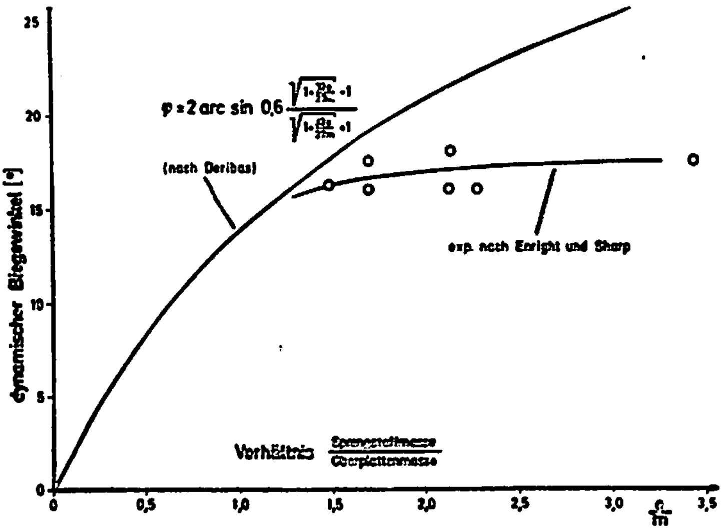


Fig. 10 Dynamic bend angle vs. ratio of mass of explosive and mass of flyer plate. Material of flyer plate: different Al-alloys. explosive: 80% Ammoniumnitrate + 20% TNT, containing sodiumchloride.

are decreasing when at constant geometrical arrangement the toughness of the tube material is increasing[10]. This effect was attributed to the plastic work consumed during explosive acceleration.

The described results on the deviations of the dynamic bend angle to smaller values suggests the existence of a relation of the amount of deviation with the flexural strength of the flyer plate. During the acceleration of the flyer plate a shock wave is reflected several times back and forth and then acceleration occurs. Plastic work has to be performed to enable bending.

As the detonation wave is travelling across the surface of the flyer plate tangentially, the total volume of the flyer plate is plastically deformed, (Fig. 11).

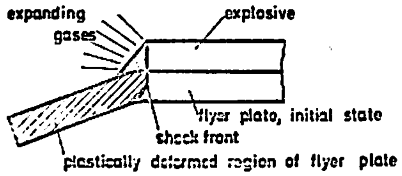


Fig. 11 Plastic deformation of flyer plate

In order to calculate the amount of plastic work the stress-strain relationship of the materials of the flyer plate at the implied fast strain rates has to be taken into account. A quantitative calculation presently can't be performed, as the strain rate behavior and the dynamic yield point of the materials investigated isn't known jet.

For the practise of explosive welding these results are of great importance, when thick plates and high strength materials are welded. If a certain dynamic bend angle is desired in explosive welding both the explosive-flyer ratio and the thickness and shrength of the flyer plate material has to be considered. This aspect bounds the development of model laws in explosive welding to thin plates.

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