

The Empirical Survey on the Effect of Using Media in Explosive Forming of Tubular Shells

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Abstract—The special and unique advantages of explosive forming, has developed its use in different industries. Considering the important influence of improving the current explosive forming techniques on increasing the efficiency and control over the explosive forming procedure, the effects of air and water as the energy-conveying medium, and also their differences will be illustrated in this paper. Hence, a large number of explosive forming tests have been conducted on two sizes of thin walled cylindrical shells by using air and water as the working medium. Comparative diagrams of the maximum radial deflection of work-pieces of the same size, as a function of the scaled distance, show that for the points with the same values of scaled distance, the maximum radial deformation caused by the under water explosive loading is 4 to 5 times more than the deflection of the shells under explosive forming, while using air. Results of this experimental research have also been compared with other studies which show that using water as the energy conveying media increases the efficiency up to 4.8 times. The effect of the media on failure modes of the shells, and the necking mechanism of the walls of the specimens, while being explosively loaded, are also discussed in this issue. Measuring the tested specimens shows that, the increase in the internal volume has been accompanied by necking of the walls, which finally results in the radial rupture of the structure.

Keywords—Explosive Forming, Energy Conveying Medium, Tubular Shell

I. INTRODUCTION

THE explosive forming of metals has been known for about 100 years. In fact, while using explosive forming method as a practical method of metal forming, the energy needed for shaping the work-piece is directly obtained from the detonation of an explosive charge.

Some suggestions to apply explosives were made at end of the 18th century, but they were not implemented as industrial applications [1]. Extended industrial application of explosive forming, like any other production technology, requires a precise knowledge of effective parameters and material behavior under specific conditions.

Practical research on explosive forming of pipe-shaped specimens has been conducted since 1970, in the G. D. R., at the Ludwigsfelde truck company and at the Magdeburg Technical University. The objective of the survey has been to determine the process parameters in order to plan the production processes, including explosive forming of larger structures in industrial scale [1].

Considering the important influence of the shock wave while internal explosive loading of thin walled shells, and also

the significant effect of the medium (in which the explosion happens) on transition of the shock wave to the work-piece during explosive forming, the analysis of shock wave transition and its effective parameters such as characteristics of the conveying media, have a crucial role in understanding the explosive forming process and help us have more control over it.

In this paper, the detonation phenomena and the relevant formulations will be illustrated and then the experimental tests which have been conducted in this study will be reported. After wards the result of the tests which have been done with water as the energy conveying medium will be compared with the result of the test which were conducted by using the under water explosion. Also the analogies between the investigation in this study and the experimental results of the other researchers will be drawn. For instance the present research shows that the energetic efficiency in explosive forming by using water as conveying medium is 4 to 5 times more than the energy efficiency of the same process while using air, which is proved by the other experimental studies [1].

II. EXPLOSION

A. Explosion in Air

Explosion is a phenomenon which results from the sudden release of energy from an explosive charge as a sort of environmental source of energy. The explosive charge is in fact defined to be an unstable compound that the sudden release of energy causes several chemical changes in it and so becomes a more stable product. The very first mechanical effect of explosive blast is a forceful blow from the instantaneous pressure jump, in its shock front. The sudden change of the condition in the surrounding environment is in fact the first step of the complicated explosion phenomena. The explosive blast travels faster than the speed of sound and hence an explosion does not give its target any advance warning of impending destruction [2]. Analyzing the pressure of a definite point, right after the explosion in air shows that it suddenly increases in some micro seconds and reaches its maximum value and then starts decreasing (the positive phase) and goes under the pressure of the environment (the negative phase).

Impulse is an important aspect of damage – causing ability of the blast [3]. The impulse of unit area of the shock wave front up to the time t after the arrival is given by [4]:

$$I = \int_0^t P(t)dt \quad (1)$$

There are several equations in different references to calculate the impulse of an explosion. For example Goodman presented the below expression to calculate the impulse of unit area for "in air explosion" [8]:

$$\frac{I_0}{w^{1/3}} = 6895 \times \left(\frac{0.06067}{z} + \frac{0.02770}{z^2} + \frac{0.0002945}{z^3} \right), \quad (2)$$

$$0.04337 \leq z \leq 9.1020$$

In which the scaled distance Z is defined as equation no.(3)

$$Z = \frac{R}{W^{1/3}} \quad (3)$$

In the above expression, R is the stand-off in meter and W is the equivalent TNT mass of the used explosive charge in Kg.

B. Under Water Explosion

Under water explosion, is called UNDEX1. The pressure – time diagram regarding to a specific target which has a definite stand-off from the centre of the explosive charge in under water explosion is exactly the same as the diagram of normal explosion in the air, although, since water is assumed to be an incompressible fluid, no negative phase would be observed.

Regarding the under water explosion, the propagation velocity is many time more than the speed of sound but within the distance of 10 times of the charge radius from the centre of the explosion, it rapidly drops to the sound velocity (approximately 1440 m/s for sea water) [6].

The sudden energy release associated with the explosion of a high explosive leads to the formation of a superheated, highly compressed gas bubble and the generation of a shock wave in the surrounding water [3]. The underwater shock wave generated by the explosion is superimposed on the hydrostatic pressure. The pressure time history, P(t), at a fixed location starts with an instantaneous pressure increase to a peak pressure, P_m, (in less than 10-7 sec) followed by a decay which in its initial portion is usually approximated by an exponential function as [4]:

$$P(t) = P_m e^{-t/\theta} \quad (4)$$

$$P_m = 52.16 \left(\frac{W^{1/3}}{R} \right)^{1.13} \quad (5)$$

$$\theta = 96.5 \left(\frac{W^{1/3}}{R} \right)^{-0.22} \quad (6)$$

Where P_m is in MPa, θ is decay constant in micro seconds, W is expressed in kg of TNT and the stand off, R, is measured in meter. The impulse integrated to time $t = 6.7\theta$ is given by [7]:

$$I(N.Sec/m^2) = 5760 \left(W^{1/3} \right) \left(\frac{W^{1/3}}{R} \right)^{0.891} \quad (7)$$

Since water is assumed to be incompressible, the impulse of an under water explosion is much greater than the impulse, produced by the explosion in air. But the pressure decay happens more quickly in under water explosion. In fact the major difference between under water and in air explosion is due to the dynamic of the gas core produced by the detonation of high explosives. As the pressure of the gas core is much greater than the pressure of the surrounding environment, it expands rapidly in both cases. In normal explosions (in air) the pressure of the gas core decreases as it expands and finally it equals the atmosphere pressure. As the fumes of the explosion and the surrounding air are both gaseous and their densities at the atmosphere pressure are almost the same, so after an explosion in air, they mix together and finally the heated gaseous products of the detonation become a part of the surrounding air. But the case is different in underwater explosion because water can control the gaseous products of explosion. The mound of gas, made by an explosion is called the bubble. When an under water detonation happens, because of the expanding-contacting motion of the bubble, a portion of the produced energy is periodically transmitted between the bubble and the surrounding water. That is in fact one of the most obvious differences between under water and in air blast [8]. A large portion of investigations that concern underwater explosion are those, which account water as a completely incompressible fluid.

When a cylindrical structure is exposed to an internal explosive loading, a large strain rate will be caused. This strain rate can be calculated by equation no (8).

$$\dot{\epsilon}_i = \frac{I_0}{\rho.h.R} \quad (8)$$

Where h is the thickness and R is the radius of the shell that both are measured in meter, the density of the structure (ρ), is expressed in Kg/m^3 and, I₀, the impulse per unit of area is expressed in (Pa.Sec) [9].

III. EXPLOSIVE FORMING

The needed energy for explosive forming is gained from detonation, and produces a shock wave that propagates with supersonic speed. This shock wave is influenced by the energy-conveying medium. Transferred energy WW, pressure PW, and speed UW are of the most important factors which affect the explosive forming method of production. They also influence the life of dies and machines, and cause some changes in the environment. While using the explosive

¹Under water Explosion

forming method, the physical propelling force for the energetic metal forming processes is achieved from the internal explosion in the work-piece which produces very hot fumes. The temperature of the fumes, right after their formation, is almost 2000 to 3000 °C. The thermal energy of the explosion is transformed into mechanical working energy by an adiabatic gas expansion. A large amount of energy is lost during this procedure. The energy-conveying medium, also called working medium, constitutes a carrier for this working energy. The amount of the thermal energy which is transformed into mechanical working energy, directly depends on the temperature of the expanding fumes when they reach their ultimate pressure.

Like any other energy transferring process, a portion of the initial working energy transforms to the target work, but on the other hand a large portion of it, is wasted in different ways. The energetic efficiency of an explosive forming process is defined as below [1]:

$$\eta_{Total} = \frac{\text{Required forming work}}{\text{Energy set free by the explosion}} \quad (9)$$

The energetic efficiency increases if we lose less energy during the energy conversion which is practical by using a proper working medium.

Choices for the working media are limited because only water, amorphous substances, and air can be reasonably considered as practically suitable materials for this purpose. For example while using water as the energy conveying medium, the waste energy during the transformation through the working medium, results in heating and evaporating of water, but when sand is used as the medium, the above mentioned term of energy makes it crushed and heated. On the other hand, while using air as medium there are particularly high losses in energy conversion due to a small degree of cooling-off of fumes and the compressibility of air [1].

The experimental researches show that the Energetic efficiency η with air as the transfer medium has been determined to be approximately 5%, and with sand as the medium, the energetic efficiency is about 12% and finally the energetic efficiency of the explosive loading process when water is used as the working medium is about 24%.

With Increasing the distance from the centre of the explosion the pressure of the shock wave forehead decreases because the increase of shock wave surface causes all quantities inherent in energy transfer to be diminished. The minimum speed of the shock wave is equal to the speed of sound in that medium. A portion of the shock wave energy passes to the work-piece when it hits the work-piece. The pressure of the shock or mass wave conveying the working energy at the moment of hitting the work-piece is called forming or working pressure P_w . The magnitude of the working pressure P_w depends on different parameters, that the mass of the explosive, stand-off, characteristics of the energy

conveying medium and the shape of the explosive charge are some of these parameters.

Based on the general theory of explosive forming, the working energy is carried by the shock wave caused by the explosion. This statement is theoretically and practically correct when water, air or any other gas or liquid conveying media is used. But while using sand or any other amorphous medium, working energy is carried by the mass wave of the medium. Therefore, the charging speed U_w , as one of the most effective factors in the explosive forming process is defined as the speed of the carrier of working energy while hitting the work-piece. The shock wave speed is generally more than the speed of sound in the working medium [1].

IV. EXPERIMENTAL TESTS

The working medium plays an important role while using the explosive forming method. Hence, a set of experimental tests has been conducted on extruded aluminium cylindrical shells in order to study the differences between underwater and in air explosions. The general specifications of the specimens are mentioned in the table 1.

TABLE I THE GENERAL INFORMATION OF THE SPECIMENS

Production Method	Material	External Diameter (mm)	Length (mm)	Thickness (mm)
Extrusion	Al6063 T6	150	100	3
	Al6063 T5	120	80	

Since the main objective of these tests was to notice the effect of the medium, so the explosive forming was performed without using any dies. But considering the necessity of fixing the work piece in the explosive loading process, all the work-pieces were fastened to a fixture which was designed and manufactured for these tests and is shown in fig. 1.

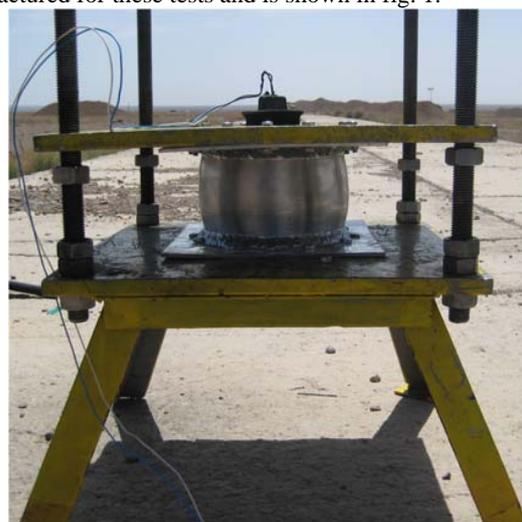


Fig. 1 the set-up used for explosion experiments

The explosive loading in all tests was initiated by using the spherical shaped C4 explosive charge, which was exactly put at the centre of cylindrical specimen. Before the performance of the tests with water as the energy conveying medium, each work piece was also filled with water.

The influence of the working medium on the mode of collapse is one of the significant points which can be evaluated by the visual examination of the tested shells. As is shown in fig. 2, the collapse of the structure under explosive loading with air as medium, has been accompanied by the fragmentation phenomena, but due to the more uniform distribution of the shock wave in water, the tensile radial rupture is being seen for the shell which was tested with water as medium (fig. 2b). Examining the rupture mode of the shells which were tested by the means of underwater explosive loading, and after counting the number of the cracks on the wall of these specimens, it is obvious that if the mass of the explosive increases, the fragmentation of the shells are unavoidable in under water explosive loading. But the uniform distribution of the cracks on the walls of specimens shows that internal explosive loading of shell structures while using water as the energy conveying medium will result in the increase of the number of more uniformly shaped fragments.

Unlike the explosive loading of cylindrical shells with air as medium, the initial cracks on the walls of specimens were seen when water was substituted for air.



(a)



(b)

Fig. 2 (a) the failure of the work-piece caused by explosive in air

(b) the rupture of the work-piece due to under water explosive loading

V. RESULT AND DISCUSSION

The difference between air and water as the working media

can be investigated by analyzing the above experimental and theoretical data. For instance, considering the data in table 2, we see that the impulse of unit area of a cylinder with the diameter of 150 (mm), caused by the explosion of 8.7 gr of C4, in air, is almost 768 (Pa.Sec). But this value for the under water explosion of 2.7 gr C4 in the same shell is approximately 1715 (Pa.Sec). In other words, although, while using water, the amount of the explosive is one third of its mass for the explosion in air, the magnitude of the impulse per unit area has become 2.23 times more. Which shows that the shock wave, resulted from the UNDEX is much greater than the shock wave caused by the "in air blast".

The experimental results of some of the tests are presented in table no 2.

TABLE II DEVIATION OF THE THEORETICAL METHOD FROM EXPERIMENTAL RESULTS

Diameter (mm)	Length (mm)	Wc4 (gr)	Z (m/Kg ^{0.33})	Medium	I/A (pa.sec)	W_f Experimental 1
150	100	5.7	0.371	Air	534.4	5.5
		6.7	0.351		613.4	7.5
		7.7	0.335		691.2	13.92
		8.7	0.322		767.8	---
		2.7	0.476	Water	1714.8	17.5
		3.4	0.440		1983.0	20.5
4.7	0.395	2432.0	27.5			
120	80	3.7	0.334	Air	547.5	6.9
		4.7	0.309		673.2	8.47
		4.7	0.309		673.2	9.26
		5.7	0.289		796.3	14.04
		6.7	0.274		917.4	---
		1.7	0.433	Water	1597.0	14.8
		2.7	0.371		2137.8	20.7

The comparative diagrams of the maximum radial deflection W_f as a function of the scaled distance Z , are plotted in fig. 3. Since the magnitude of the blast shock wave in air or water depends on the value of Z , which is itself a function of the mass of explosive and the stand-off, so, paying attention to the following diagrams, we see that for the points with almost the same values of Z , although the magnitude of the explosive and stand-off are the same, but the maximum radial deformation caused by the under water explosive loading is 4 to 5 times more than the deflection of the shells which have been tested, using explosion in air. It means that the energetic efficiency of the explosive forming process with water is 4 to 5 times more than corresponding value of the same process with air as medium. As other researches show, the energetic efficiency of the explosive loading while using water as medium is 24% and with air is approximately 5%, so using water as the energy conveying media increases the efficiency up to 4.8 times [1]. Comparing the results of the present investigation with the other researches shows a good

accuracy between the results. It is to be mentioned that, as there were no points with exactly the same value of Z, so the

comparison has been made between the points with approximately the same values of Z.

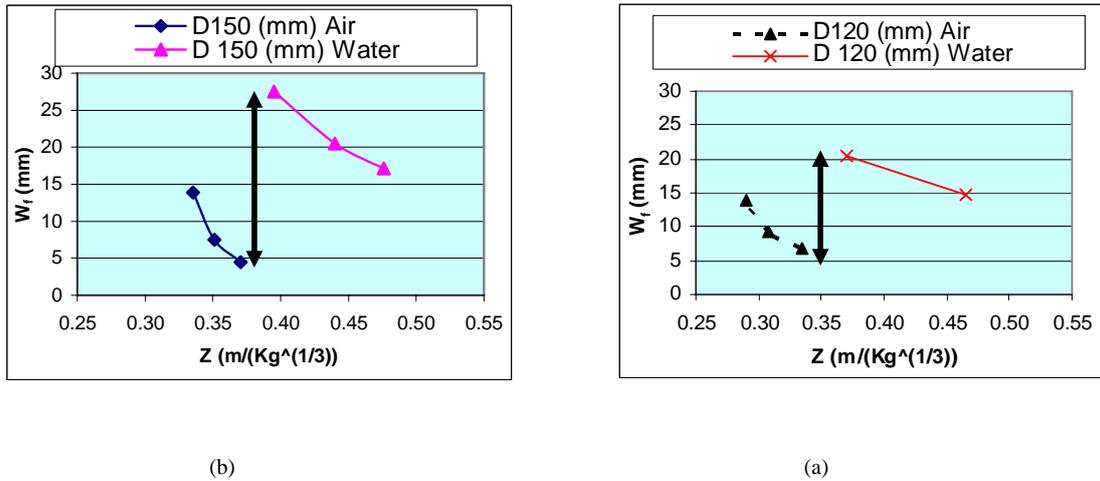


Fig. 3 comparative diagrams of maximum radial deflection of explosively loaded cylindrical shells as a function of scaled distance, using air and water as media
 (a). regarding to the cylinders with 120 mm diameter
 (b). regarding to the cylinders with 150 mm diameter

Considering the equation (8) and also fig. 4 which is drawn to show the change in strain rate as a function of the scaled distance, we see that, as a direct effect of the working media, the strain rate caused by the under water explosive loading is much greater than the strain rate caused by the blast loading in air. Measuring the length of the work-pieces after the explosive forming process shows that, although the fixture did

not confine the longitudinal motion of the shells, their length did not change significantly. Also the increase in the volume of the specimens has been accompanied with the decrease of their thickness, or necking of the walls. In fact, the more increase of the strain rate will result in more necking of the shells, that finally will result in the radial rupture of the structure.

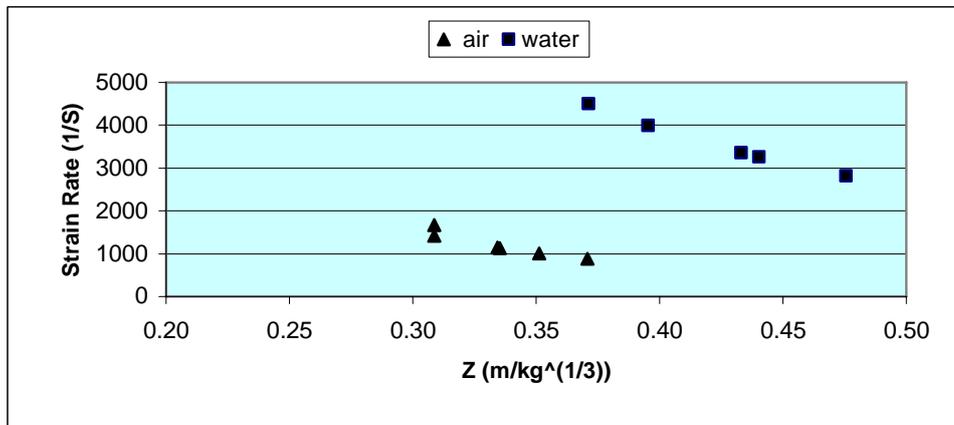


Fig. 4 comparison between strain rate of under water and in air explosive loading as function of the scaled distance.

Comparing the deflection profiles in fig. 5, which are drawn for the mid span of the shells of a same size, shows the crucial influence of the working medium on the value of deformation. As is shown, the deflection caused by the under water explosive loading is more than the corresponding value, regarding the explosive loading with air as medium, although the mass of the explosive has been less while using water.

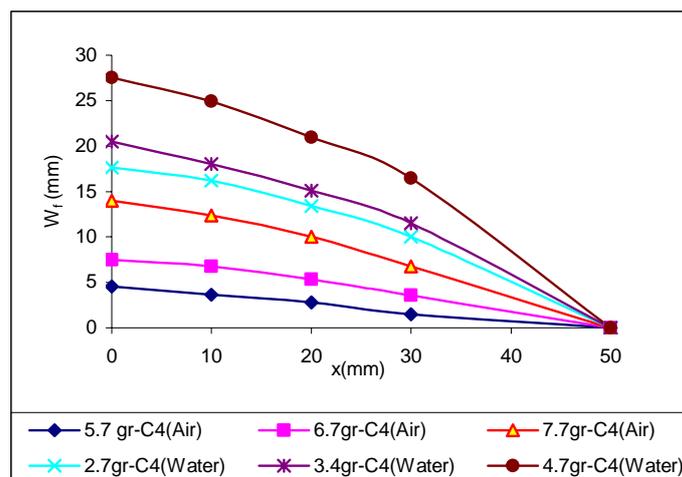


Fig. 5 Deflection profiles of some of explosively loaded shells 150 mm in diameter, using air and water as energy conveying media

VI. CONCLUSION

Paying attention to the fig. 3, and also verifying and comparing the deflections of the shells which have been tested with air and water as the energy conveying media of the explosive forming process, we can find it out that, the impulse, caused by the UNDEX is much greater than the impulse of the blast loading in air. Also comparing to the case of "in air explosive loading", using water as the working medium will significantly increase the energetic efficiency of the explosive forming process.

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