10th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2006, Barcelona-Lloret de Mar, Spain, 11-15 September, 2006

IMPACT WAVE PRESSURE MODELING IN THE EXPLOSION BASED DEEP-DRAWING PROCESS*

Stipo Buljan, Himzo Đukić,
Fakultyof Mechanical Engineering and Computing,
University of Mostar, Matice Hrvatske bb, 88000 Mostar, Bosnia and Herzegovina

Zoran Jurković,
Faculty of Engineering, University of Rijeka,
Vukovarska 58, 51000 Rijeka,
Croatia,

ABSTRACT
Almost for all methods of optimization, simulation, revitalization and control of processes, it is necessary to define the mathematical model of a process. In the examined case, the process parameters have been identified and the mathematical model of the impakt wave pressure has been defined in case of pulling out by explosion. The model correctly describes, within the examined range and with certain degree of accuracy, the process of the impact wave provoked by explosion in water being the media for power transmission.In this case, a 200-mm bottom made of Steel 4580 was being shaped. Speed of detonation was 2994 m/s and 6105 m/s. Explosive used in this case was Vitezit 20.
Keywords: modeling, high pressure, impact wave.

1. INTRODUCTION
Non conventional – high speed impulsive methods – to which shaping by explosive belongs, are characterized by the potential energy, which is needed for shaping, that is shortly transforming into the kinetic energy. Taken into consideration that at high speed the plasticity of material increases, by this way it is possible to shape materials which plasticity is very low while they are shaped by the conventional method at the speeds of deformation up to 10 m/s. Also, explosive shaping embraces wide diapason of diameters from 30 mm to 5000 mm and thickness (0,5 – 30) mm [1] .
There are very few titles issued so far, from the field of treatment tin sheet metal by explosion-based deformation. In order to perform an experimental explosive-based testing of plastic treatment, it is necessary to satisfy a number of factors, ranging from security procedures to the area of testing. That might be one of the reasons why this filed has not been fully elaborated.

2. PLAN OF EXPERIMENT
Presumably that, in the process, there are three independent changeable values x_1, x_2, and x_3 and two levels, then there will be $N=2^3=8$ experiments. This type of experiment enables us to examine changes of the factors in relation to measured value of pressure at the moment of drawing process. Independently changeable factors and their level in this case, for explosion-based drawing of dished end 1-mm thickness with chemical composition shown in given Table, are the following:

1. Factor	G – mass of explosive	2. Factor	V_E – speed of detonation of explosive
	G_1 – 0,008 kg		V_{E1} – 6105 m/s
	G_2 – 0,016 kg		V_{E2} – 2944 m/s

*This work was developed within the project “Explosion based deep-drawing process modeling, using genetic and stochastic methods”, which was financed by the Federal Ministry of Education and Science for 2005/2006, in the Federation of Bosnia and Herzegovina.

3. Factor *R* – distance between working object and explosive

R_1 – 150 mm R_2 – 180 mm

Plan of experiment is generally given in Table 1.

Table 1.

Y_{ijk}	R_1		R_2	
	V_{E1}	V_{E2}	V_{E1}	V_{E2}
G_1	$G_1V_{E1}R_1$	$G_1V_{E2}R_1$	$G_1V_{E1}R_2$	$G_1V_{E2}R_2$
G_2	$G_2V_{E1}R_1$	$G_2V_{E2}R_1$	$G_2V_{E1}R_2$	$G_2V_{E2}R_2$

3. DISPLAY OF THE RESULTS OF EXPERIMENTAL RESEARCH

We measured pressure on 24 samples in 8 different conditions by crasher. Measured values of impact wave pressure at the very beginning of drawing process are shown in Table 2 Measurement of pressure was done by crasher steam.

Table 2.

No. of experiments N_j	Physical variable of the process			Coded variable of the process			Numerical results		
	G	V_E	R	X_1	X_2	X_3	Values of impact wave pressure obtained in experiment $Y_j=P_{vj}$		
	kg	m/s	mm				bar		
1	0,008	6105	150	-1	1	-1	861	804	861
2	0,016	6105	150	1	1	-1	1063	1016	1063
3	0,008	2994	150	-1	-1	-1	682	617	617
4	0,016	2994	150	1	-1	-1	861	804	804
5	0,008	6105	180	-1	1	1	745	682	745
6	0,016	6105	180	1	1	1	966	915	966
7	0,008	2994	180	-1	-1	1	548	475	475
8	0,016	2994	180	1	-1	1	745	682	617

4. DEFINING MATHEMATICAL MODEL

Matrix, with the number of experiments $N=2^k=2^3=8$, was used for modeling the process. Equation of impact wave pressure at explosion-based deep drawing process is mathematically modeled by polynomial equation [2], which has shape for k=3:

$$Y= b_0+b_1x_1+b_2x_2+b_3x_3+b_{12}x_1x_2+b_{23}x_2x_3+b_{13}x_1x_3+b_{123}x_1x_2x_3 \qquad (1)$$

Mathematical model solution basically means defining the coefficient of mathematical model using the results of the experiment. For mathematical model (1) with three input variable x_1, x_2 and x_3 and orthogonal requirements conditions, coefficients of model can be calculated on this way:

$$b_i = \frac{1}{N}\sum_{j=1}^{N} X_{ij} Y_j^{-E}, \; i = 0, 1, 2, 3;$$

$$b_{im} = \frac{1}{N}\sum_{j=1}^{N} X_{ij} X_{mj} Y_j^{-E}, \; 1 \le i < m \le 3; \qquad (2)$$

$$b_{imk} = \frac{1}{N}\sum_{j=1}^{N} X_{ij} X_{mj} X_{kj} Y_j^{-E}, \; 1 \le i < m < k \le 3;$$

Where Y_j^{-E} - are arithmetic mean of experimental results of measurement in certain points of the plan

$Y_j^{-E} = \frac{1}{n}\sum_{i=1}^{n} Y_{ji}$;n - Number of measurement repetitions; Y_{ji} - Value of particular measurement;

N – Number of the plan points.

Based on the above data, respectively to equation (2), applying the results of experiment given in Table 2., we will calculate coefficients b_i, b_{im} *and* b_{imk}.
Mentioned coefficients have following values:
$b_0 = 775,575$; $b_1 = 99,575$; $b_2 = 114,963$; $b_3 = -62,18$; $b_{12} = 8$; $b_{13} = 2,175$; $b_{23} = 8,1$; $b_{123} = 2,788$
Therefore, mathematical model has following shape:

$$y=775,575+99,575x_1+114,96x_2-62,18x_3+8x_1x_2+2,18x_1x_3+8,1x_2x_3+2,79x_1x_2x_3 \qquad (3)$$

4.1. Testing accuracy and reliability

Testing significance of model coefficient (3) was done using following equation:

$$|\, b_i \,| \geq \Delta b_i = \pm t_{t(f_y,\alpha)} S_{b\,i} = t_{t(f_y,\alpha)} \frac{S_y}{\sqrt{N \cdot n}}, \quad \text{for } i = 0,1,2......k \qquad (4)$$

Variation of mistakes of experiment was defined by following equation:

$$S_y^{\;2} = \frac{\sum_{j=1}^{N}\sum_{i=1}^{n}(y_{ji} - \bar{y}_j)^2}{f_y} = \frac{24746,68}{16} = 1546,67 \qquad (5)$$

$$S_b^{\;2} = \frac{S_y^{\;2}}{Nn} = \frac{1546,67}{24} = 64,44 \qquad (6)$$

From equation (6) it follows: S_b=8,0277
Since S_{bt} = 8,0277·1,75 = 14,0485, significance requirements was satisfied for following coefficients:

$|b_0| = |775,575| > 14,0485$; $|b_1| = |99,575| > 14,0485$
$|b_2| = |114,96| > 14,0485$; $|b_3| = |-62,18| > 14,0485$

Where $t_{(f_1,\varepsilon)} = t_{(f_y,\alpha)} = t_{(16,0,05)} = 1,75$

f_y *=N (n-1)=8(3-1)=16* – degree of tolerance

After checking significance, coefficients b_0, b_1, b_2, and b_3 are significants**,** while coefficients b_{12}, b_{13}, b_{23}, *and* b_{123} are not, then mathematical model of impact wave pressure has shape like this:

$$Y = 775,575 + 99,575x_1 + 114,96x_2 - 62,18x_3 \qquad (7)$$

Checking adequacy of mathematical model was done using F-criteria (Fisher criteria) according to following equation:

$$S_a^{\;2} = \frac{\sum_{j=1}^{N} n(y_j^{\,-E} - y_j^{\,R})^2}{f_a} \qquad (8)$$

f_a *= N-k-1=4* -Tolerance related to dispersion of adequacy.
In order to obtain the result it is needed to calculate value from the model (7).
Decoding in accordance to equation (9) results in values for x_1, x_2 and x_3.

$$x_i = 1 + 2\frac{\ln f_i - \ln f_{i\max}}{\ln f_{i\max} - \ln f_{i\min}} \qquad (9)$$

$$x_1 = 2,885 \ln G + 12,932; \; x_2 = 2,807 \ln V_E - 23,469; \; x_3 = 10,969 \ln R + 19,81 \qquad (10)$$

When we put decoded values for x_1, x_2, and x_3 from equation (10) in equation (7),
it will result in design value of pressure or model in its real size:

$$y = -1866,4059 + 287,2739 \ln G + 322,6927 \ln V_E - 682,0897 \ln R \qquad (11)$$

Midrange of impact wave pressure obtained based on experiment [3] and values of impact wave pressure obtained from equation (11) are shown in Table 3.

Table 3.

No. of experiment N_j		1	2	3	4	5	6	7	8
Midrange of pressure $\bar{y}_j$	bar	842	1047,3	638,7	823	724	949	499,3	681,3
Calculated value of pressure $y^R{}_j$		853,42	1052,54	623,50	822,63	729,06	928,18	499,14	698,27

From equation (8) it follows:

$$S_a^{\ 2} = \frac{\sum_{j-1}^{N} n(y_j^{\ -E} - y_j^{\ R})^2}{f_a} = \frac{3 \cdot 1136{,}1325}{4} = 852{,}099$$

$S_a^{\ 2}$= 852,099; S_y^2= 1546,67; Since $S_y^2 > S_a^{\ 2}$, then

$$F_a = \frac{S_y^{\ 2}}{S_a^{\ 2}} \le F_t(f_1, f_2) = F_t(f_y, f_a) = \frac{1546{,}67}{852{,}099} = 1{,}815 \le F_t(16{,}4) = 5{,}848 \qquad (12)$$

From equation (12) it is obvious that $F_a<F_t$, therefore, criteria of adequacy of mathematical model is satisfied. Then, mathematical model (11) describes impact wave pressure at explosive-based drawing in adequate manner. Final shape of mathematical model is:

$$p_V = 287{,}2739 \ln G + 322{,}6927 \ln V_E - 682{,}0897 \ln R - 1866{,}4059 \qquad (13)$$

Where: *p_V (bar), G (kg), V_E (m/s), and R (m).*

Coefficient of multiple regression is calculated by:

$$R = \sqrt{1 - \frac{\sum_{j-1}^{N} (y_j^{\ -E} - y_j^{\ R})^2}{\sum_{j=1}^{N} (y_j^{\ -E} - y^{-E})^2}} = \sqrt{1 - \frac{1136{,}1325}{217182{,}5143}} = \sqrt{0{,}994768} = 0{,}99738 \qquad (14)$$

When coefficient of multiple regression exactly describes real state of the process, e.g. its functional dependency, then it is $R \to 1$, and that is the case in our experiment. Then, dependency of changeable x_i and impact wave pressure is great. Therefore, mathematical model (13) exactly and reliably enough (P = 0,95) describes impact wave pressure inside the area of experiment, and that can be proved if compared to the values in Table 3.

5. CONCLUSION

In this work we obtained mathematical model which greatly describes impact wave pressure for the area of the experiment at explosive-based drawing.

Based on so far knowledge, next research of explosion-based modelling can be based on modelling and simulation of mentioned process. Basic purpose of modelling of any process, this one as well, is defining mathematical model and others, which are needed for optimisation, simulation, revitalisation and management of systems aiming to increase productivity, economical quality, quality of products in general, decrees time of processing, its costs, energy, etc. Also, mentioned research can be related to multiphase explosive-based drawings and usage of another explosives in some other aggregate condition.

6. REFERENCES

[1] K.Lange:Umformtechnik Band 4, Spring-Verlag, Berlin, Heideberg, Newyork, London, Paris, Tokio, Hongkong, Barcelona, Budapest,1993

[2] M.Jurković:Matematičko modeliranje inžinjerskih procesa i sistema, Mašinski fakultet, Bihać, 1999

[3] S.Buljan: Matematičko modeliranje procesa dubokog izvlačenjapomoću eksplozije i određivanje tlaka udarnog, magistarski rad, Strojarski fakultet, Mostar, 2002