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OCENA PRZYDATNOŚCI MODELU ANALITYCZNEGO DO PRZEWIDYWANIA PARAMETRÓW STRUMIENIA KUMULACYJNEGO

Streszczenie: W pracy przedstawiono ocenę przydatności zaproponowanego w [6] analitycznego modelu formowania się strumienia kumulacyjnego do przewidywania parametrów strumienia. Porównano wyniki obliczeń parametrów strumienia za pomocą modelu analitycznego i kodu numerycznego z wynikami eksperymentu. Na podstawie wyników porównania, sformułowano wnioski odnośnie przydatności modelu analitycznego.

ASSESSMENT OF USEFULNESS OF ANALYTICAL MODEL FOR PREDICTING SHAPED CHARGE JET PARAMETERS

Abstract: An assessment of usefulness of the analytical model of shaped charge jet formation proposed in [6] has been presented. Results of calculations of jet parameters by the analytical model and by a hydrocode have been compared with the results of experiments. Basing on the results of the comparison, conclusions have been formulated concerning usefulness of the analytical model.

1. Introduction

Analytical models of shaped charge jet formation are based on the hydrodynamic theory, assuming incompressible liner material, stationary process and plain symmetry. None of the assumptions of the hydrodynamic theory are valid in reference to metal, conical liners and nonstationary process of jet formation. However, the analytical models are willingly used for the sake of their low computational cost in comparison with hydrocodes [1]-[5]. In [6] results of an analysis of various elements of analytical models, proposed in the literature, were reported. The analysis was performed by making comparison of the shapes of collapsing liner, jet and slug, calculated by the analytical model, determined experimentally and calculated by a hydrocode [7]. Some improvements into existing analytical models are proposed in order to achieve better agreement with the reference data. The improved model can be considered as a "state of the art" in the field of analytical models of shaped charge jet formation. In this paper results of a comparison of predicted jet parameters by the model, by the hydrocode and determined experimentally on the basis of a broad experimental material are presented. The aim of the analysis is to assess the predicting capability of the analytical model.

2. Analysis

In the paper [7] a comparison was made of experimental and calculated by the hydrocode shapes of collapsing liners. The results of [7] have been used for the assessment of the predicting capability of the analytical model. Fig.1 shows shapes of a collapsing liner and a slug calculated for a test charge by the use of the model described in [6], by the hydrocode and determined experimentally. We can conclude that shapes of the collapsing liner agree well with the hydrocode results and experimental records. There is a discrepancy between experimentally determined position of the end of the slug and the results of calculations both by the use of the hydrocode and the analytical model. This effect can be attributed to the formation of an overdriven detonation at the top of a liner. This possibility has not been taken into account in theoretical models.

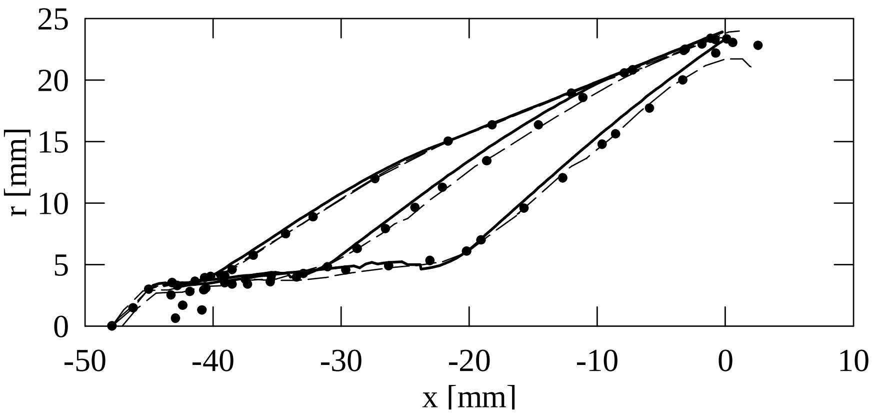

Fig.1. Collapsing liner and slug shapes for *t* = 8.7, 10.7 and 13.7 μs; solid line – analytical model, dashed line – hydrocode [7], points – experiment [7]

A comparison of velocity distributions in the jet calculated by the analytical model and the hydrocode is made in Fig.2. The agreement is satisfactory.

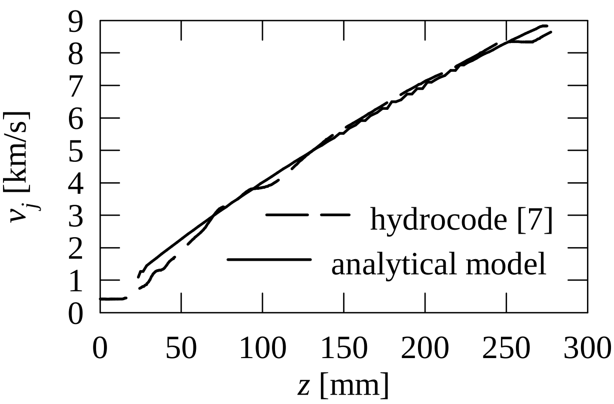

Fig.2. Calculated velocity distributions in in the jet

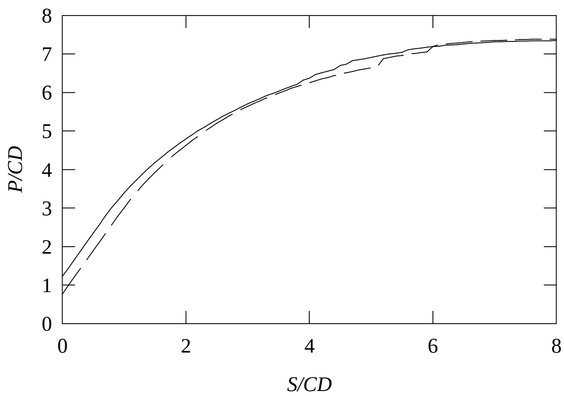

Fig.3. Ideal penetration calculated on the basis of velocity distribution shown in Fig.2

Both distributions shown in Fig.2 were used for an assessment of an "ideal penetration depth" by the DSM model [8]. The jet break-up time values were taken from the experiment. Ideal penetration depth versus stand-off distance plots are shown in Fig.3. There is a general agreement between penetration depth values predicted on the basis of jet velocity distributions, calculated by the hydrocode and by the analytical model.

The analytical model is based on the assumption of a stationary process of liner collapse, while the formation of the jet tip is a fully non stationary process. It causes that the jet tip velocity is not predicted accurately. This weak point of the analytical model can be illustrated by the predicted jet tip shapes shown in Fig.4. As one can see, the hydrocode predicts much sooner formation of the jet tip than the analytical model. However, jet shapes predicted by the hydrocode and the model behind the leading particle agree quite well.

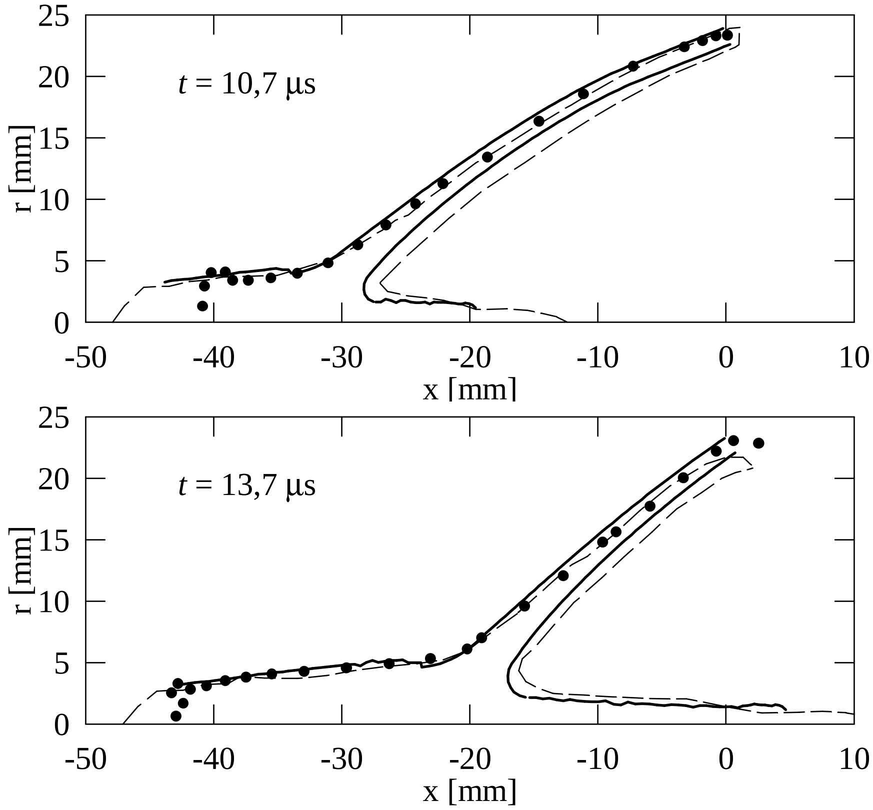

Fig.4. Collapsing liner, jet nad slug shapes for *t* = 10.7 and 13.7 μs; solid line – analytical model, dashed line – hydrocode [7], points – experiment [7]

In order to assess the level of inaccuracy of the predicted jet tip velocity, broad comparison was made between calculated and determined experimentally jet tip velocities. In experiments four types of explosives were used, three various casings, four diameters of a lens, and seven values of density of the liner material. The test charges and details of experimental techniques were described in [9].

Table 1 summarizes results of determining jet tip velocities experimentally and by the use of the analytical model and the hydrocode. Differences of jet tip velocity values between experimental and determined by the analytical model reach 10%. However, the hydrocode produces in some cases even greater discrepancy between calculations and experiment than the analytical model. Because jet penetrates the target with velocities from the tip velocity to approx. 3 km/s, we can expect that inaccuracy in predicting jet tip velocity may result in no more than 20% inaccuracy of predicted depth of penetration.

Possible reasons of observed discrepancies between calculated and experimental values of jet tip velocity can be discussed on the basis of plots shown in Figs. 5 and 6. Fig.5 shows predicted and determined experimentally dependence of the jet tip velocity on the lens diameter. In real process, increasing of the lens diameter causes, on one side, an increase of the incidence angle of detonation front but on the other side it makes stronger the influence of the rarefaction waves arising at the lateral surface of the charge. The analytical model takes into account only the first effect. Therefore, it predicts too strong dependence of the jet tip velocity on the lens diameter.

As in the case of the influence of the lens diameter, the influence of the liner density is also shaped by two opposite tendencies. On one side, lighter porous liners (in the experiments sizes of the liners were kept constant) can be launched to a higher velocity values than monolithic liners. As a result the jet tip velocity should increase. But on the other side, in the process of launching porous liners, part of the explosion energy is consumed for the compression of pores and resulting increase of the temperature of liner material. Therefore, the part of energy used for launching is lower than in the case of denser liners. That is why, we observe in experiments non monotonic dependence of the jet tip velocity on the liner material density – Fig.6. The analytical model does not take into account the loss of energy for compression of porous liners.

Table 1. Comparison of measured and calculated jet tip velocities for changing characteristics of shaped charges (in parenthesis deviations from the experimental values)

Characteristics	v_j^0 [m/s](%) (hydrocode)	v_j^0 [m/s] (experiment)	v_j^0 [m/s](%) (analytical)
explosive			
RDX	8543 (9)	7870	8053 (2)
HMX	8648 (2)	8510	8795 (3)
CompB (cold pressed)	7163 (-2)	7290	7984 (10)
CompB (hot pressed)	7793 (4)	7520	8276 (10)
Casing material			
paper	7990 (-7)	8600	8915 (4)
aluminum	8510 (-2)	8700	8891 (2)
steel	8520 (-3)	8770	8964 (2)
lens diameter [mm]			
0	7502 (-8)	8169	7699 (-6)
20	6992 (-19)	8631	8206 (-5)
31	8648 (-1)	8703	8827 (1)
40	8365 (-8)	9078	9447 (4)
density of liner material (sintered liners) [kg/m^3]			
7980	8351	-	8930
8070	-	8170	8901 (9)
8170	8648 (-1)	8703	8871 (2)
8350	6006 (-31)	8761	8812 (1)
8490	-	8428	8764 (4)
8520	-	8617	8758 (2)
8590	-	8508	8737 (3)
8620	-	8297	8728 (5)

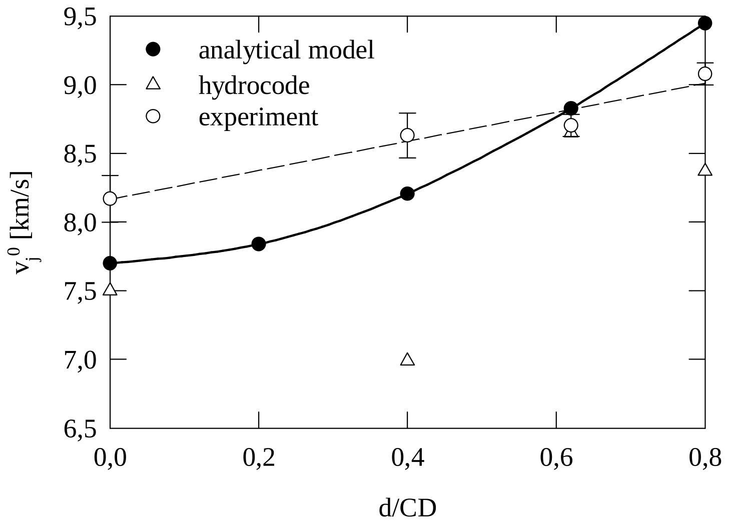

Fig.5. Comparison of calculated and measured jet tip velocities in the function of a ratio of lens diameter to charge diameter

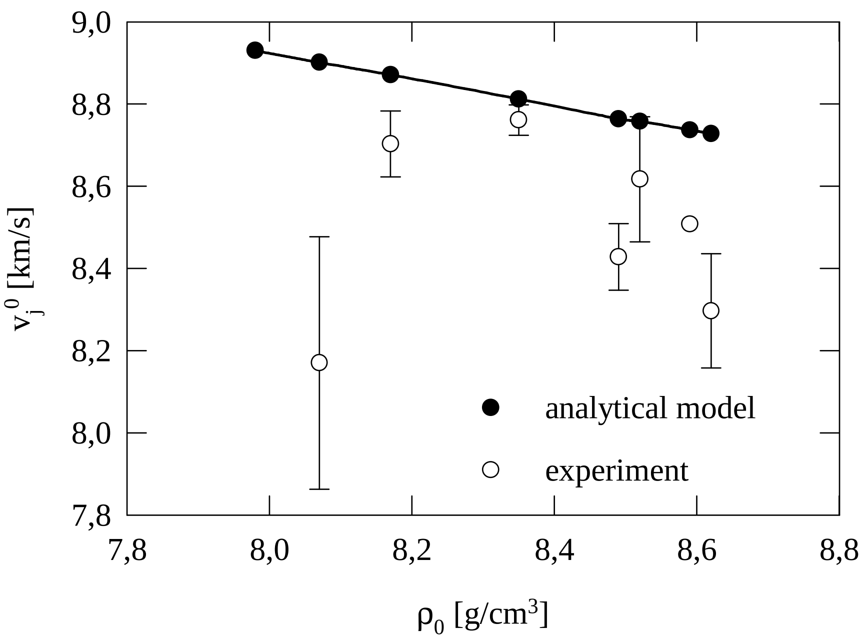

Fig.6. Comparison of calculated and measured jet tip velocities in the function of liner material density

3. Conclusions

1. The analytical model proposed in [6] predicts the collapse of the liner and the distribution of the jet velocity with the accuracy comparable to the accuracy of the hydrocode calculations.
2. The model does not predict correctly jet tip velocities. Differences of jet tip velocity values between experimental and determined by the analytical model reach 10%.
3. The hydrocode [7] did not show its distinct supremacy over the analytical model. Therefore, it is rational to use the analytical model for predicting jet parameters.
4. The search of improvements in the analytical model should be concentrated on the non stationary phase of jet tip formation, on taking into account effects of rarefaction from

the lateral surface of the shaped charge and loss of energy due to compression of porous liners.

5. Further work will be directed into creating a set of models including a model of jet formation (the discussed model can be the basis), a model of jet break-up time and a model of jet penetration. The set of models could be a useful tool in designing process of shaped charges.

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