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PERFORMANCES AND BEHAVIOUR OF WCu-PSEUDO-ALLOY SHAPED CHARGES WITH A SIMPLE MODEL FOR CALCULATING THE STAND-OFF CURVE

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Performances and behaviour of shaped charges with tungsten/copper pseudo-alloy liners are presented. After a first series of test with different liner thicknesses, the almost optimal charge has been analysed more in detail. The penetration power is significantly greater than those obtained with the copper reference charge up to stand-offs of 25 calibres and top values of 11 calibres have been measured against RHA targets. The observed stand-off behaviour of the WCu-charge cannot be explained by the classical penetration model. By substitut-ing modified and yet very rough hypotheses it was possible to obtain a much better agreement with the measured penetrations

INTRODUCTION

Shaped charges with a penetration capability of 10 calibres or more offer a great interest for upgrading existing antitank systems and represent a real threat for actual armours. After the publication of informations claiming that such performances had been realised with tungsten/copper pseudo-alloy liners [1–4], we decided to verify these affirmations because they were in contradiction with previous results obtained with high temperature isostatically pressed (HIP) liners of WCu- and WNiFe-alloys [5,6]. The poor penetration power of these 40 mm charges was due to strongly curved or divergent jets.

CHARACTERISTICS OF THE SHAPED CHARGE

Having found a supplier for the WCu-liners, we started a first series of experiments to confirm the potential of such charges and to optimise the one selected for the tests. We chose a very simple 100 mm shaped charge (Fig. 1) with a conical liner of constant thickness, a precision initiation and a quasi-isostatically pressed explosive body of Octastit 8 (PBX with 95% HMX).

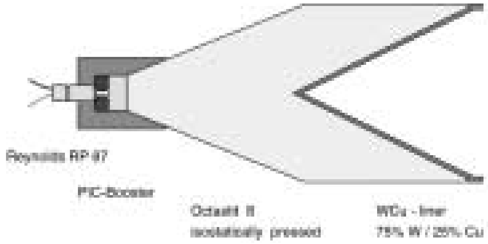


Figure 1: Design of the simple 100 mm shaped charge used for the tests.

Three types of liners with different thicknesses have been manufactured from preforms of the WCu-pseudo-alloy K25C with a density of 14.8 g/cm^3 supplied from Plansee: a 2.5 mm liner having the same dimensions as the liner of the copper reference charge, a 1.5 mm liner having about the same surface density as the copper one and an intermediate 2.0 mm liner.

PRELIMINARY TESTS

The first series of tests against homogeneous steel targets (hardness of 239 HB) at stand-offs between 2.5 and 25 calibres showed that most of the results obtained with the WCu-charges and the three liner thicknesses laid over the corresponding values of the reference copper charge and that the maximum of the stand-off curve was shifted to 10–12.5 calibres. The best penetration results (10–11 calibres) were obtained with the 1.5 mm liners at stand-offs of 7.5 and 10 calibres (Figs. 2 and 3).

Three complementary tests made with a reduced liner thickness of 1.0 mm presented a decrease of performance due to higher jet divergence and instabilities.

A second series of experiments was therefore realised with the almost optimal 1.5 mm charge to get more information on the penetration capability and on the jet fragmentation dynamics.

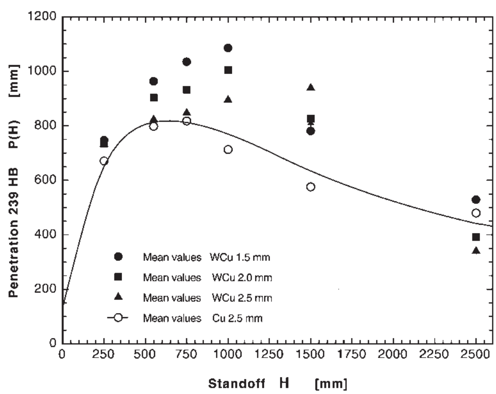


Figure 2: Mean values of the penetration of the WCu-charge with three different liner thicknesses (1.5, 2.0 and 2.5 mm) compared with the stand-off curve of the reference charge with a copper liner of 2.5 mm.

RESULTS WITH THE 1.5 mm WCu-LINER

Stand-off curve

The results obtained against hardened steel (239 HB) and RHA (302 HB) targets confirmed the previous results with further shots over 10 calibres and even one over 12 calibres. The mean penetration increases as the stand-off increases from 2.5 to 10 calibres, where a value of about 11 calibres has been obtained. For greater stand-offs the reduction of the penetration is accompanied with a significant increase of the dispersion. All measured values with one exception are nevertheless greater than the corresponding mean penetration measured with the copper reference charge. These results show that good performances can be obtained with tungsten pseudo-alloy shaped charges at stand-offs up to 25 calibres.

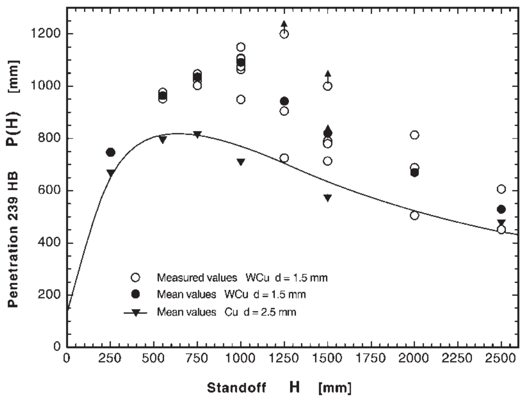


Figure 3: Measured penetration of WCu-charges with the 1.5 mm liner compared with the stand-off curve of the reference charge with a copper liner of 2.5 mm having about the same surface density as the WCu liner.

Jet characteristics

Morphology, dynamics and fragmentation of the WCu-jet have been analysed and measured from X-ray pictures taken at different time intervals after initiation (Fig. 4). The fragmentation of the WCu-jet is very different and occurs very early in comparison to that of copper jets. Fine shear cracks can be observed over the entire jet section short time

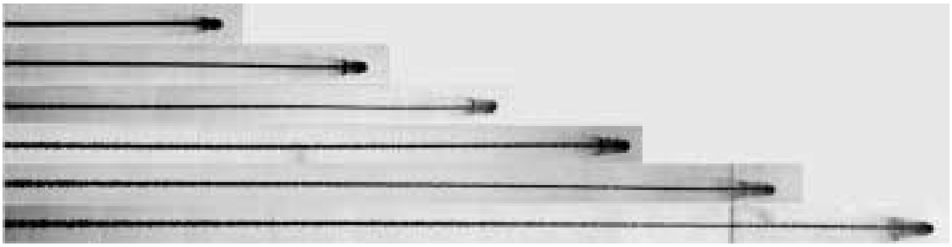
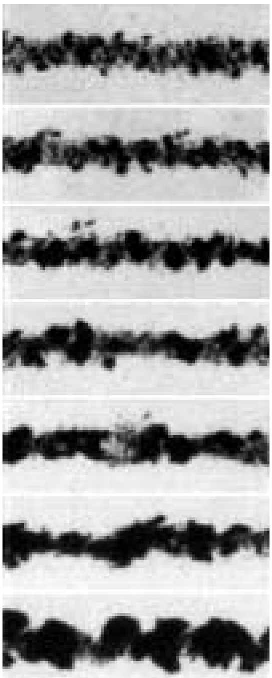


Figure 4: X-ray pictures of the jet of the WCu-charge with the 1.5 mm thick liner. The time interval between the pictures is about 20 µs.

after the jet formation indicating that the conventional stretching phase must be very short (Fig. 5). The fragments resulting from these shear fractures are small at jet tip and greater at the tail (Fig. 6). Most of the greatest fragments are not stable and subject to further divisions resulting in great number of smaller particles. The spatial distribution of these particles is homogenous without formation of gaps or long and massive fragments as observed on copper jets. During the break-up and stretching phases no radial instabilities were observed with the charges having a liner thickness equal or greater than 1.5 mm. The strong fragmented jet is not spreading out, so that the diameters of the jet elements can be considered as constant.



The measured jet tip and jet tail velocities are constant over the observable distance of 2 meters and the velocity of the jet elements varies linearly along the jet.

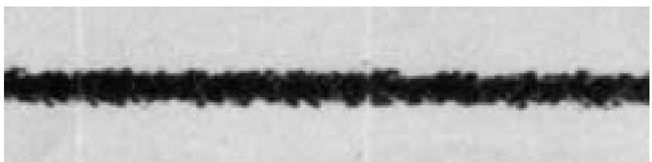


Figure 5: Detail picture of the middle part of a moderately stretched WCu-jet showing the initial shear fractures.

Figure 6 left: Structure of the rear part of a stretched jet having a total length of 1.8 m. The top picture corresponds about to the middle of the jet and the bottom picture to the jet tail. Each picture is 5 cm long and the distance between the pictures is 10 cm.

Results against composite targets

Despite these good performances and the very regular quasi-cylindrical craters bored in the homogeneous steel targets, catastrophic results were obtained against triple composite targets due to very strong interaction between the highly fragmented WCu-jet and the walls of the small crater in the composite elements. The previously observed jet coherence (Fig. 4) was destroyed causing spreading and strong erosion of the jet particles, resulting in very poor penetration efficiency (Fig. 7).

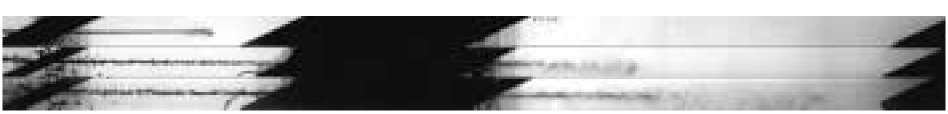


Figure 7: X-ray pictures of the jet before (top) and after the penetration in the composite element showing the very strong erosion of the jet.

CALCULATION OF THE STAND-OFF CURVE

Classical penetration model

With experimental parameters of the jet dynamics measured on X-ray pictures, we tried to calculate the stand-off curve of the 1.5 mm WCu-charge with a classical penetration model giving satisfactory results for copper and molybdenum charges (Fig. 8). This model postulates a constant stretching of the jet elements until break-up occurs. During this stretching phase the initial length ΔL of a jet element is multiplied by a time dependant factor λ, whilst the density practically remains equal to the initial liner density ρj, the diameter decreasing to ensure the conservation of mass. After break-up and particle formation the stretching stops and the elongation factor $\lambda = \lambda_B$, the length of the element $\lambda_B \Delta L$ as well as the maximal potential penetration capability ΔP_B remain constant.

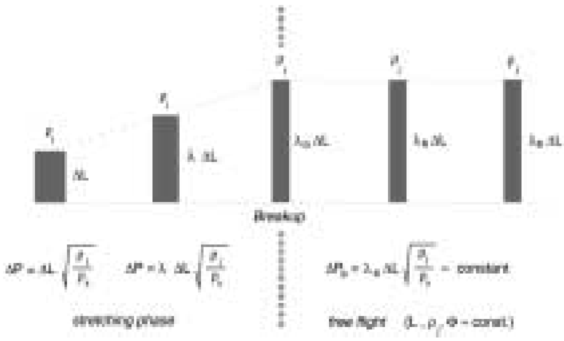


Figure 8: Calculation hypotheses of the classical penetration model.

None of the stand-off curves calculated with the classical model and with different sets of parameters for the jet break-up and divergence could be fitted on the measured stand-off curves of the WCu shaped charge with the 1.5 mm thick liner (Fig. 9).

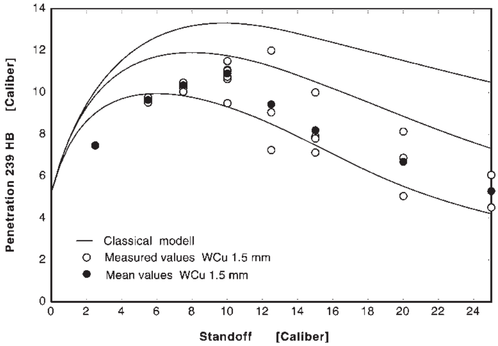


Figure 9: The classical penetration model valid for copper or molybdenum charges is not adequate to describe the stand-off behaviour of WCu-charges.

The initial slope of the calculated stand-off curve is to steep in comparison with the observed one. As a consequence of the rapid increase of the penetration at low stand-offs the position of the maximum of the curve cannot be fitted on the observed optimum stand-off of 10–12 calibres.

These results indicate that the postulated stretching and penetration processes of the classical model are not valid for WCu-jets.

Modified penetration model for WCu-jets

By substituting modified and yet very rough hypotheses it is possible to obtain a much better agreement with the measured penetrations up to a stand-off of about 13 calibres. The new model is based on the observations of the specific behaviour of the WCu-jets characterised by an early break-up and a very strong jet fragmentation. After break-up, the jet elements can be considered as an accumulation of numerous unbounded little particles. In opposition to the copper jet elements, the length of these elements continues to grow with a corresponding reduction of the mean density. This density is equal to ρ_j/λ_k if the diameter Φ of the element is supposed to be constant. Introducing this density value and $\lambda_k \Delta L$ for the length in the simple penetration formula, we found that the potential penetration capability of the element is proportional to $(\lambda_k)^{1/2}$. This penetration is less than the penetration obtained in the case of a conventional stretching until $(\lambda)^{1/2}$ becomes equal to the maximal stretching factor λ_B that could be reached with a solid, homogeneous jet element having a density ρ_j (Figs. 8 and 10). If the stretching factor is further increased the penetration of the WCu-jet element becomes greater than the maximal penetration ΔP_B of a conventionally stretched solid element (fig. 8).

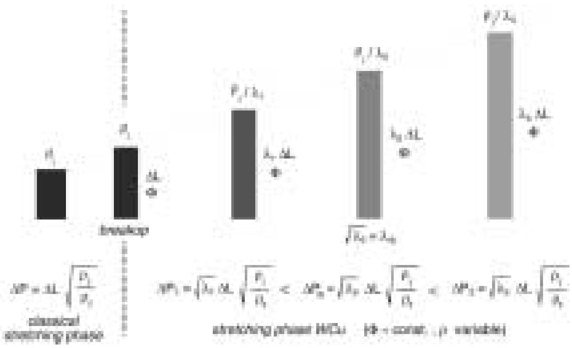


Figure 10: Calculation hypotheses for the modified penetration model.

After introduction of these very simple and rough hypotheses in the calculation model, it was possible to obtain a much better agreement with the measured penetrations of the WCu-charge up to a stand-off of about 13 calibres (Fig. 11) where a non implemented additional disturbance of the penetration process takes place.

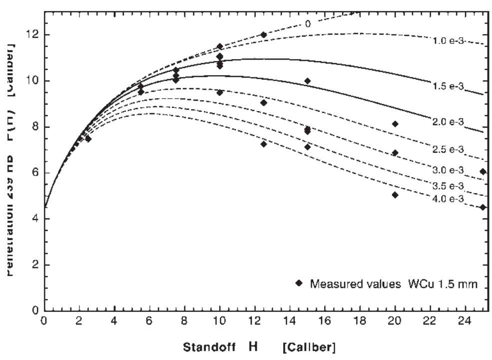


Figure 11: The modified model allows a much better agreement with the measured values up to stand-offs of about 12.5 calibres if the parameter for jet divergence is set between 1.5 10-3 and 2.0 10-3.

CONCLUSIONS

This study demonstrates that excellent penetrations up to stand-offs of 25 calibres can be obtained with tungsten/copper pseudo-alloy shaped charges having a sufficient liner thickness. The tests done against composite armour confirm once more that a penetration capability of over 1meter in RHA-targets is not a sufficient condition to defeat them. The initial part of the stand-off curve of the WCu-charge cannot be fitted correctly with the conventional penetration model conceived for copper charges. By introducing new and simple calculation hypotheses better agreement with the measurement could be obtained up to a standoff of about 13 calibres. This model should also be valid for other highly particulated or powder jets.

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