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DEFINITION AND USES OF RHA EQUIVALENCES FOR MEDIUM CALIBER TARGETS

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The armor protection levels and specific armor designs being projected for future threat vehicles drive the selection of the main armaments for next generation medium caliber platforms. The designs of these armors are usually based on the estimated protection level of the threat vehicle. This process is complicated by the fact that the level of equivalent armor protection, as expressed in terms of millimeters of rolled homogeneous armor, is a function of the projectile material, its geometry, impact velocity, and the method by which it is determined. Hence, the armor protection level assigned to an armor package is by no means a unique number. The means by which the RHA equivalence is defined and how it will be used should be clearly understood before it is released as a protection level.

BACKGROUND

The armor protection levels and specific armor designs being projected for future threat vehicles drive the selection of the main armaments for next generation medium caliber platforms. The designs of these types of armor are usually based on the estimated protection level of the threat vehicle, as expressed in terms of millimeters of rolled homogeneous armor (RHA) or RHA equivalence (RHA-e). RHA-e is used to describe the protection level of the entire vehicle, which is obviously an over simplification. RHA-e can also be used for just one particular target design that represents one aspect of the threat vehicle.

RHA-e is a convenient criterion by which to measure a weapon's defeat range of a threat vehicle or its lethality at closer ranges. Often, both of these measures are calculated with one RHA-e value that is assigned to the threat armor. The range at which a projectile can penetrate that thickness of RHA determines the defeat range. The lethality inside the vehicle is estimated by a level of residual penetration, after the armor is perforated, which is expected to be equivalent to a given probability of damage or loss of function. For example, a residual penetration (P_R) of 25 mm may be estimated to achieve a probability of kill (P_K) of 0.5. The range at which a projectile can penetrate that total thickness of

RHA (RHA-e of the armor plus the additional penetration) is the lethal range (range to achieve a P_K of 0.5).

It has been shown that the armor protection level assigned to an armor package, RHA-e, is by no means a unique number for all projectiles [1]. Therefore, to accurately portray the protection level of the threat vehicle, the way that the RHA-e value is determined and how it is to be used must be clearly understood for each application. Several basic experiments were conducted to examine the methods used to determine the RHA-e and the variances that can be expected. Also, a systematic evaluation of a finite RHA plate further explores the RHA-e methodology.

METHODS OF DETERMINING RHA-E

Two methods are typically used to determine the RHA-e of armor: the limit velocity (V_L) and the RHA P_R. Both methods require the use of a baseline RHA performance curve as a function of velocity for the projectile. Ideally, if there were one RHA-e for each target, these methods would result in the same value.

Establishing the Baseline RHA Performance Curve

A baseline curve can be either a penetration curve or a perforation curve. The penetration RHA curve is established by the firing of several shots at different impact velocities into semi-infinite armor. Semi-infinite armor is defined as armor in which no free surfaces (side or rear) affect the depth of penetration. The depth of penetration is then plotted as a function of impact velocity. This establishes the baseline RHA depth of penetration curve. A similar curve is established for the perforation of RHA. Perforation is the complete penetration of a finite thickness RHA plate. The velocity at which the finite thickness RHA is barely perforated is the V_L. Several shots are used to determine the V_L against a given target. These consist of shots at impact velocities near the apparent V_L, with some partial penetrations and some complete perforations. The Lambert-Jonas model [2] is then fit to the impact and residual velocity data pairs, from these shots and several shots at higher over-match, to determine the V_L. The thickness of the RHA is plotted as a function of the V_Ls to establish the perforation baseline curve. A minimum of two VLS is required to estimate the curve.

A typical long rod penetrator can completely perforate a greater thickness of armor than it can penetrate. This is attributed to the break out phase of a finite thickness plate. As the penetration approaches the rear free surface of the finite plate, the target fails, either by ductile failure or shear failure, which requires less energy for the penetrator than if it were to continue in a steady state penetration mode. Also, as the obliquity of the finite RHA is increased, the line-of-sight (LoS) thickness that can be perforated at the same velocity also increases. The rear free surface of the plate is reached earlier in the penetration process for higher obliquity plates [3]. These trends in performance are illustrated in Fig. 1, a plot of LoS thickness of the armor as a function of impact velocity. As can be seen, the penetration curve lies lowest on the plot. The finite thickness data, perforation data, lies

Home
Table of Contents

higher on the plot and increase with increases in obliquity. This graphically shows that for one velocity, a typical long rod penetrator will perforate more than it can penetrate and also will perforate more at obliquity than it does at normal impact (0° obliquity). Because of these factors, it is desired to have the baseline RHA perforation curve for the same obliquity as the armor being evaluated. Obviously, from the differences in these curves, the RHA-e is going to be highly dependent on the baseline curve used.

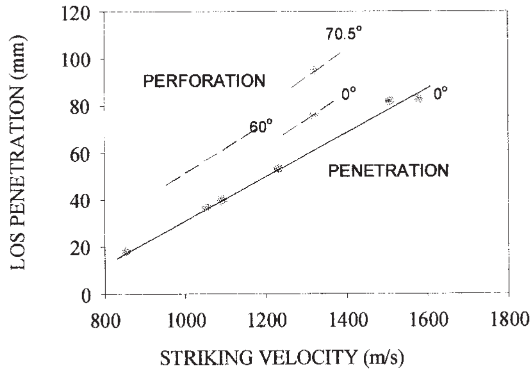

Figure 1. Sample baseline RHA performance.

Limit Velocity Method

The first method used for the RHA-e of a target is the V_L method. A V_L is determined for the target of interest as described earlier. The V_L is then plotted on the RHA baseline curves. The RHA-e is determined at the intersection of the V_L and the baseline curve. This results in two values for the RHA-e, one for the penetration curve and one for the perforation curve. The RHA value determined with the perforation baseline curve will typically be slightly higher than the value determined with the penetration baseline, as described earlier. Regardless of the baseline used, this method clearly reveals the velocity required to perforate the armor (by defmition, the V_L). At this velocity, the armor will just be perforated, and there will not be any residual energy and no behind-armor effects or lethality. Therefore, the V_L method can be used to give the range where the target is barely perforated.

Residual RHA Method

The second method uses a residual RHA plate placed behind the target of interest, the P_R method. The target being evaluated is then shot at impact velocities above the V_L, ensuring impacts on the residual RHA plate. The measured P_R is then subtracted from the baseline RHA curve, either perforation or penetration, at the impact velocity evaluated. Again, there will be two values for each shot, depending on whether the P_R is subtracted from the penetration or perforation baseline curve. Whereas RHA-e for the V_L method is only determined at one velocity, the P_R method can use several shots at different over-match conditions. The P_R can be related to the over-match (impact velocity), giving the degree of lethality for different engagement ranges. The V_L method will give the actual protection level of the target, and the P_R RHA method gives the potential of the projectile to inflict damage behind the armor at different over-matches.

EXPERIMENTAL ANALYSIS

Experimental Arrangement

Since actual armor is not constructed of monolithic RHA, the RHA-e of a typical dual element spaced array range target was calculated. Several types of penetrators were used: an Armor-Piercing, Discarding Sabot (APDS) penetrator and two Armor-Piercing, Fin-Stabilized, Discarding Sabot (APFSDS) penetrators, one made from depleted uranium (DU) and one of a tungsten heavy alloy (WHA). The penetrator cores were push launched in a fully instrumented laboratory system [3].

Both methods, VL and PR, were used for each of the penetrators against this range target. Previously established baselines, both penetration and perforation, for each penetrator were then used to determine the RHA-es for the target for each of the penetrators.

Discussion

The RHA-e determined via the penetration baseline is shown in Fig. 2, which shows RHA-e as a function of velocity. The data are shown on the plot by different symbols for the different penetrators. The two methods are distinguished by open symbols for the V_L method (one data point each) and solid symbols for the P_R method. As can be seen, there is not one value for all penetrators against the target, independent of the method used. There is a strong dependence on velocity; increase in velocity gives an increase in RHA-e. Also notable is how the two WHA rods lie on the same curve, even though they are of completely different geometries. The DU, however, lies higher on the plot. DU and WHA have very different modes of penetration in RHA steel [4]. These different modes are probably reflected in the two different curves, one for DU and one for WHA. Fig. 3 shows the same data, V_L and P_R, when the perforation ability is used as the baseline. Again, there are different values for each penetrator and for

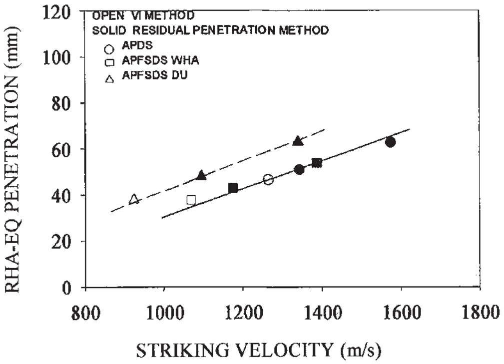

Figure 2. RHA Equivalence (penetration baseline).

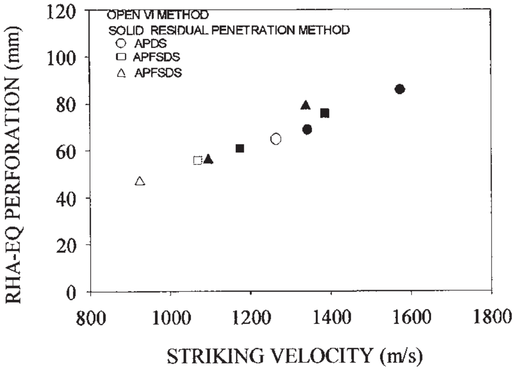

Figure 3. RHA Equivalences (perforation baseline).

the different methods. However, these data, regardless of the penetrator core or material, all lie on approximately the same curve. DU penetrates RHA much more efficiently than WHA; however, WHA will produce a larger breakout effect. Therefore, the two processes may cancel each other, depending on the predominant failure mechanism of the target evaluated, narrowing the gap between the RHA-e values. These data still have the same trend with velocity as observed in Fig. 2.

All the data were combined in Fig. 4. The wide discrepancies for the RHA-e are obvious from this plot. First, there are different values for the two methods, V_L or P_R. Second, there is strong velocity dependence, which is even more evident with the P_R method. Instead of having one value for all over-match conditions, there is a different value for each shot. The higher the impact velocity or the greater the over-match, the tougher the target appears to the penetrator or a higher RHA-e is computed. Finally, the baseline used, penetration or perforation, gives a different value across the gamut of variables. The relative differences in RHA-e calculated for the projectiles with the two baselines are similar. However, they are not exactly the same because the different penetrators will behave differently against semi-infinite and finite plates, because of the geometry or material of the penetrator.

Systematic Study of RHA-e

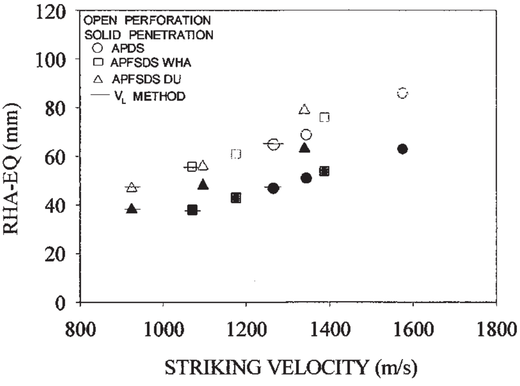

Figure 4. RHA Equivalences for both baselines.

These results may be expected for different penetrators there are different modes of failure for the penetrators and target than for the RHA baseline. Therefore, a systematic study of a simple RHA plate impacted with a typical long rod penetrator was completed. This study was devised to better clarify the differences in the two methods (V_L and P_R) and the two baseline curves (penetration and perforation). A typical long rod penetrator, 130 mm long by 9.7 mm in diameter made from WHA, was evaluated against a standard 31.75-mm RHA steel target at 60 degrees obliquity.

The V_L against this target was determined, along with several shots above the V_L to measure the P_R. Previously established penetration and perforation baseline curves were used. The V_L for the experimental target was added to the perforation baseline curve, because this is a RHA perforation data point. The data are shown in Fig. 5, the V_L and the P_R for the target and the RHA baseline penetration and perforation curves. Fig. 6 shows the RHA-e as determined for both baseline corves. Depending on the method and baseline, a 31.75-mm RHA target at 60 degrees (LoS of 63.5 mm) can have a LoS RHA-e from 50 mm (V_L and a penetration baseline) to a maximum of 120 mm (highest impact velocity with the P_R method and the perforation baseline). The RHA-e of a RHA plate should be the thickness of that plate (in this case, 63.5 mm LoS). This is the value that is determined with the V_L method and the perforation baseline curve. However, if the residual capability after the RHA plate is perforated is desired, the V_L should not be used to gauge the performance because the P_R will decrease as the over-match is increased. In this case, the P_R method should be used.

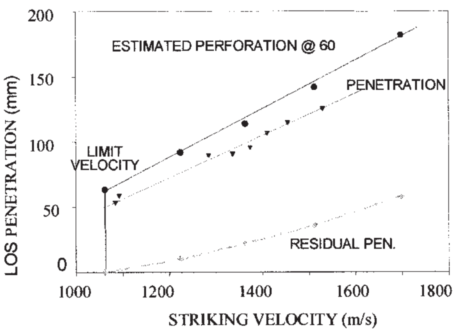

Figure 5. WHA rod data & RHA baselines.

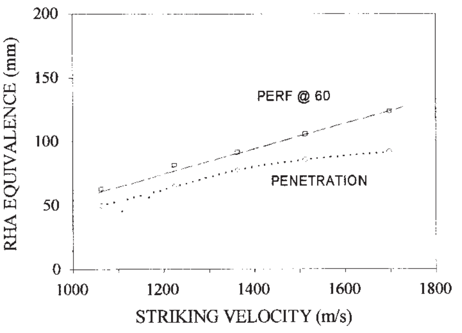

Figure 6. RHA equivalences of RHA plate.

Summary

These examples illustrate how a standard method needs to be clarified for each application of the RHA-e. The V_L method will give the actual defeat range of the target when this projectile will just perforate this level of protection. The P_R RHA method will give the potential for behind armor lethality. A penetrator impacting the target at this velocity will have a certain amount of residual capability; this value will depend on impact velocity. However, equating the level of residual penetration to an equivalent level of probability of kill is also very ambiguous. The P_K value is highly dependent on what is located behind the armor (personnel, ammunition, weapons, engines, etc). Each of these will have a different P_K for a similar residual penetration. So one residual penetration value for every condition is not adequate. Even if this ambiguous criterion is used, the V_L method is not applicable to determine the residual penetration, i.e., subtracting the computed RHA equivalent determined via the V_L method from the amonnt of RHA that the penetrator can perforate at the given impact velocity. This procedure will over-estimate the residual penetration for this over-match. As noted, in reality (via the P_R method) the residual penetration decreases relative to the baseline as the impact velocity is increased.

CONCLUSIONS

The protection level of a threat vehicle cannot be defined by one RHA-e value; it depends on several factors: penetrator material, penetrator geometry, target configuration, RHA penetration, and the method and RHA baseline used. It has been shown that the RHA-e for one medium caliber target evaluated with several projectiles can vary by more than 100%. Even for an RHA target evaluated with one penetrator, the RHA-e can also vary by more than 100%, depending on the method, the velocity, and the baseline used.

If only one value for the protection level is used, penetrators are designed to perforate the maximum amount of RHA. Most actual armor is not monolithic RHA and consists of many different materials and configurations. Therefore, the defeat mechanism is often drastically different to perforate this armor than the deformation process for RHA penetration. A penetrator designed to penetrate the maximum amount of RHA may not be the optimum design for more complex armor designs.

The final use of the RHA-e should dictate which method is used to define the protection level. If the final use is the perforation range, the range at which the target is just perforated, the V_L and the perforation baseline should be used. If a protection level and a desired lethality are being computed, then the P_R method and the penetration baseline should probably be used. In this case, a baseline RHA-e must be established as a function of velocity to clearly show how the projectiles are affected at different levels of overmatch.

Finally, whenever possible, the actual range targets and standard behind-armor lethality methods should be used to accurately estimate the performance of a projectile against a threat vehicle. Obviously, this is too expensive and time consuming for most applications. Therefore, all the points presented in this paper must be considered when RHA-e is used as the threat protection level when future armaments for medium caliber platforms are selected.

REFERENCES

1. K. Frank, “Armor-Penetrator Performance Measures”, BRL-MR-3097, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, March 1981
2. J.P. Lambert and G.H. Jonas. “Towards Standardization in Terminal Ballistics Testing: Velocity Representation.” BRL-R-1852, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1976.
3. J.A. Zook, K. Frank and G.F. Silsby. “Terminal Ballistics Test and Analysis Guidelines for the Penetration Mechanics Branch.” BRL-MR-3960, U.S. Army Ballistic Rescarch Laboratory, Aberdeen Proving Ground, MD, January 1992.
4. L.S. Magness and T.G. Farrand. “Deformation Behavior and its Relationship to the Penetration Performance of High Density KE Penetrator Materials.” Proceedings From the 1990 Army Science Conference, Durham, NC, May 1990.