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MASS EFFICIENCY OF ARAMID COMPOSITES DEPENDING ON MASS AND IMPACT VELOCITY OF CYLINDRICAL STEEL FRAGMENTS

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In the present study Aluminum plates and plates of Pressed Laminate of Rubber coated Aramid Fabric (LRAF) were impacted by cylindrical projectiles of steel in order to determine the corresponding ballistic limit velocities. For both materials Aluminum and LRAF the mass efficiency factor E_M influenced by projectile mass and impact velocity was calculated using the reference material rolled homogeneous armor (RHA) steel. The E_M factor for Aluminum is independent of projectile mass and increase quasi linearly with increasing impact velocity. The E_M factor for LRAF is influenced by both projectile mass and impact velocity. The values of the E_M factor within the investigated range of velocity lie for Aluminum between 1.3 and 1.8 and for LRAF between 1.7 and 3.2.

INTRODUCTION

Fiber Reinforced Plastic (FRP) showing good ballistic protection behavior and low density is used as tissue in body armor systems, as spall liner or as structural components in armored vehicles. The protection efficacy of Pressed Laminate of Rubber coated Aramid Fabric (LRAF) applied to spall liner on the rear side of Rolled Homogeneous Armor (RHA) plates with high hardness was described in a study by Strassburger et al. [1] and in another study by Lampert and Jeanquartier [2].

In terminal ballistic literature describing ballistic performance of textile fabrics often there is only mentioned the mass efficiency factor (E_m) for the special threat Fragment Simulating Projectile (FSP). An eventual dependency by a different threat or the influence of impact velocity, impact conditions, mass and shape of fragment is not taken into consideration. The E_m factor often is also assumed to be a constant and therefore the influence of mass and impact velocity of projectile is neglected. But caution is advisable just at the determination of the E_m factor for textile fiber fabrics. Determining the E_m factor perforation limit of target and reference material depending on mass and impact velocity of projectile needs to be known. In the present study it is exemplary pointed out how the E_m factor of LRAF is influenced by mass and impact velocity of cylindrical projectiles. The protection efficacy of LRAF, Aluminum and RHA is compared with special focus on the influence of projectile mass and impact velocity. For that purpose several plates of LRAF, Aluminum and RHA were impacted without obliquity by cylindrical projectiles of steel varying mass and impact velocity of projectiles and varying thickness of plates.

EXPERIMENTAL SET-UP

The cylindrical projectiles of steel C45 (Brinell-Hardness 240BH) with a length to diameter ratio L/D=0.8 launched by sabots of plastic were fired with a 23 mm caliber smooth barrel laboratory gun. The range of impact velocity was between 500 m/s and 1800 m/s, the mass of projectile varied between 4.95 g and 31.5 g and the obliquity was 0° NATO. The distance between muzzle and target was 6m and the projectile flied quite stable without tumbling. Two laser light barriers positioned 2 m in front of the target measured the projectile velocity.

The effective impact velocity was calculated taking the velocity drop of the projectile into account. The Yaw angle α of projectile was so small that perforation performance of projectile did not show any influence. Figure 1 illustrates the fixation technique of target material especially how the LRAF plate is stretched in a special frame. The three investigated target materials are listed in Table 1.

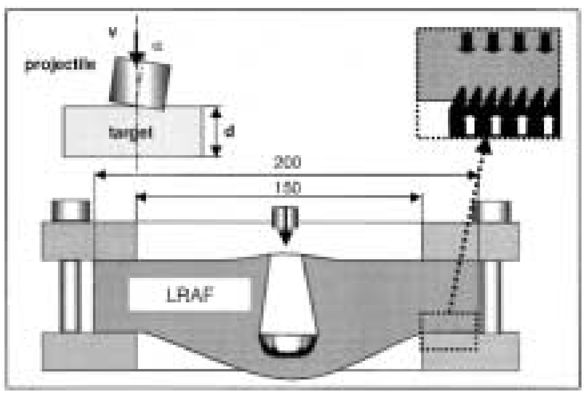

Figure 1.

Table 1: Properties of investigated target materials

Properties/ Material	**RHA**	**Aluminum**	**Pressed Laminate of Rubber coated Aramid Fabric (LRAF)**
Structure	Homogenous	Homogenous	Layered Aramid fabrics are vulcanized by rubber (d=10.5 mm corresponds to 21 layer fabrics)
Density ρ	7.85g/cm^3	2.8g/cm^3	1.2 g/cm^3
Brinell-Hardness	470 – 510HB	125HB	-
Thickness d	7 – 14 mm	20 – 30 mm	15 – 53 mm

RESULTS

Residual Mass of Projectile

Loss of projectile mass after perforating Aluminum or LRAF plates yields less than 4%, whereas the C45 steel projectile shows an enormous loss of mass perforating the RHA plate.

Deformation of Projectile

With help of the deformation condition defined by the ratio A_A/A_0 (with A_A : Maximum cross-section area of deformed projectile after perforation, A_0: cross-section area of projectile before impact) the deformation behavior of projectile without mass loss was investigated (Fig. 2). Penetrating Aluminum maximum state of deformation is already reached at an impact velocity of v=1200 m/s. At this velocity the deformation of projectile penetrating LRAF is still low. At v=1760 m/s the deformation of projectile in LRAF is smaller than in Aluminum. Projectiles are slowed down relatively mild in LRAF.

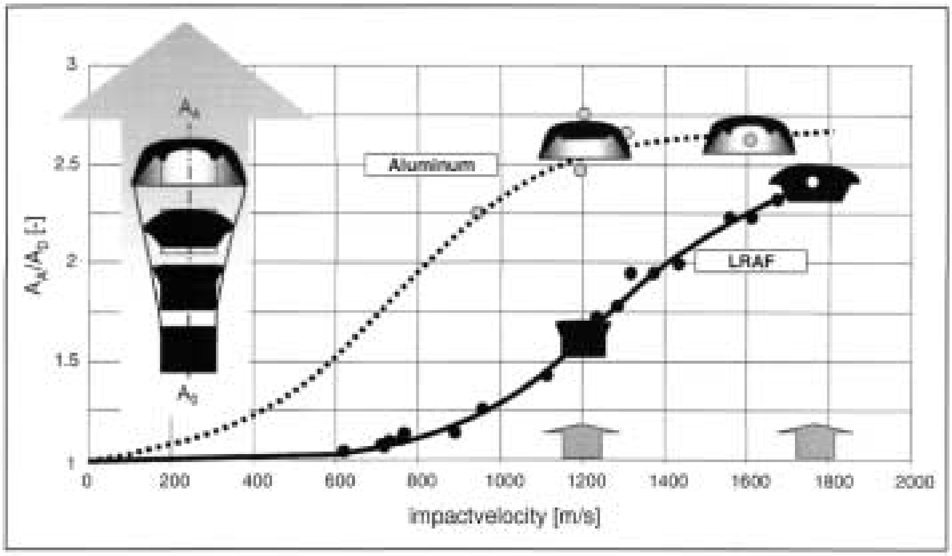

Figure 2.

Deformation of Target Material

At the example of trials with 4.95 g projectiles the deformation of target and the deformation of a retained projectile is analyzed (Fig. 3).

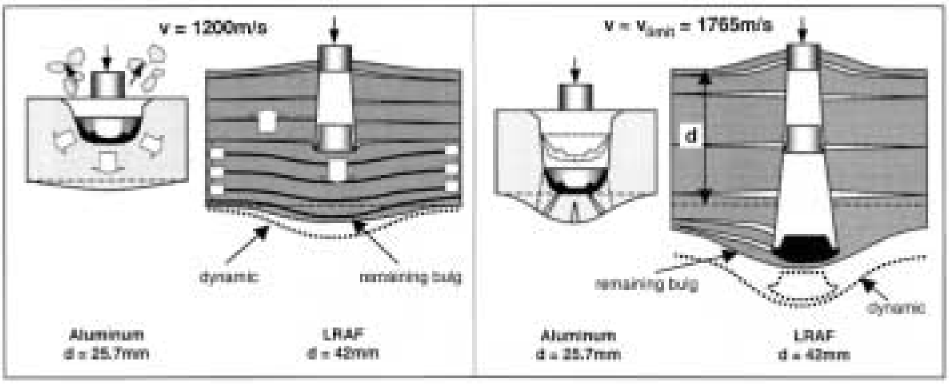

Figure 3.

Impact Velocity v=1200 m/s

Aluminum: Deformation of projectile has reached a maximum. Target material is replaced and rejected forming a crater. There's only a slight bulging on the rear side of target material.

LRAF: The diameter of impact crater corresponds to the diameter of projectile. Only the upper part of the textile tissues is perforated, whereas the lower part is delaminated showing bulging effects.

Impact Velocity v=1765 m/s

Aluminum: The diameter along the perforation channel stays constant. On the rear side of target cracks occur and a thick plug with diameter equal to that of projectile breaks out.

LRAF: The dynamic bulging is significant higher than the remaining.

Perforation Limit

Between the normalized perforation limit $d/m^{1/3}$ versus the ballistic limit velocity v_{limit} exists a linear relationship presented in a study by Strassburger et al. [1]. The two Parameter function (1) describing this linear relationship is accurate for metallic target material such as Aluminum and RHA in a range of v_{limit}=600 m/s–2000 m/s for projectiles with aspect ratio L/D≈1.

$$d/m^{1/3} = k_1 + k_2 \cdot v_{limit} \quad (1)$$

With d : Perforation limit (m)
m : Mass of projectile (kg)
v_{limit} : Ballistic limit velocity (m/s)

For Aluminum and RHA the ratio $d/m^{1/3}$ remains constant holding limit velocity constant but varying mass of projectile. For LRAF such a behavior could not be observed (Fig. 4). For each mass of projectile an own Fit-function has to be adapted. The utilized Fit-functions with accuracy of velocity range are listed in Table 2.

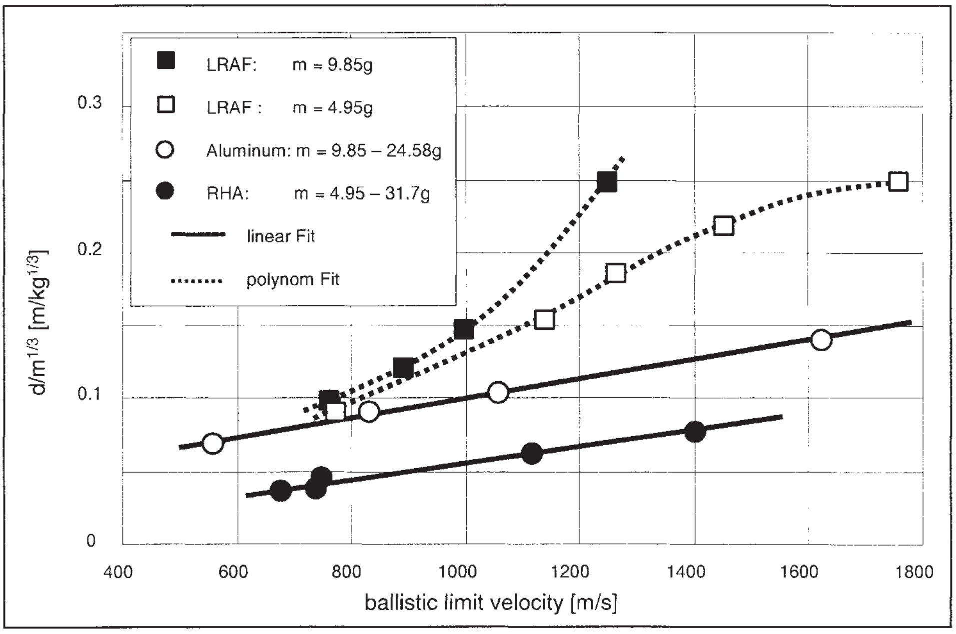

Figure 4.

Target Material	Mass of projectile Accuracy of velocity range	Fit-Function
RHA	Arbitrary Mass 700< v <2000m/s	$d/m^{1/3} = -2.097 \cdot 10^{-3} + 5.727 \cdot 10^{-5} \cdot v$
Aluminum		$d/m^{1/3} = 3.416 \cdot 10^{-2} + 6.609 \cdot 10^{-5} \cdot v$
LRAF	m = 4.95g=0.00495kg 700< v <1800m/s	$d/m^{1/3} = 3.024 \cdot 10^{-1} - 7.867 \cdot 10^{-4} \cdot v + 8.483 \cdot 10^{-7} \cdot v^2 - 2.383 \cdot 10^{-10} \cdot v^3$
	m = 9.85g=0.00985kg 700< v <1300m/s	$d/m^{1/3} = 2.273 \cdot 10^{-1} - 4.636 \cdot 10^{-4} \cdot v + 3.836 \cdot 10^{-7} \cdot v^2$

Table 2: Fit-Functions

MASS EFFICIENCY FACTOR E_M

Mass efficiency factor for the materials LRAF and Aluminum using RHA as reference material (Table 1) was calculated according to formula (2).

$$E_M = (\rho_{ref} \cdot d_{ref})/(\rho_i \cdot d_i) \qquad (2)$$

The two parameters d_{ref} and d_i were calculated by empirical functions listed in Table 2. The maximum thickness of the investigated LRAF plates was 53 mm having v=1250 m/s ballistic limit velocity for the 9.85 g projectile. The prediction of performance of the 9.85 g projectiles could therefore only be done in the velocity range of 700 m/s to 1300 m/s.

Range of Velocity 700 m/s–1300 m/s

In contrast to metallic target materials the E_M-factor of LRAF is dependent on mass of projectile (Fig. 5). With increasing impact velocity the E_M-factor increase for Aluminum and decrease for LRAF. At 700 m/s there's a maximum difference between the E_M-factors of the two materials. At equal perforation resistance the areal density of LRAF plate is approximately 2.1–2.5 times lower than that of Aluminum. At 1300 m/s and using the 9.85 g projectiles there's no difference between the two E_M-factors, thus the two materials have the same areal density.

Range of Velocity 1300 m/s–1800 m/s

In the range of v>1300 m/s the E_M-factor of LRAF for the 4.95 g projectile is only slightly influenced by velocity, whereas for the 9.85 g projectile the E_M-factor of LRAF is lower than that of Aluminum (Fig. 6). In that case the areal density of an Aluminum plate is smaller than the areal density of a LRAF plate.

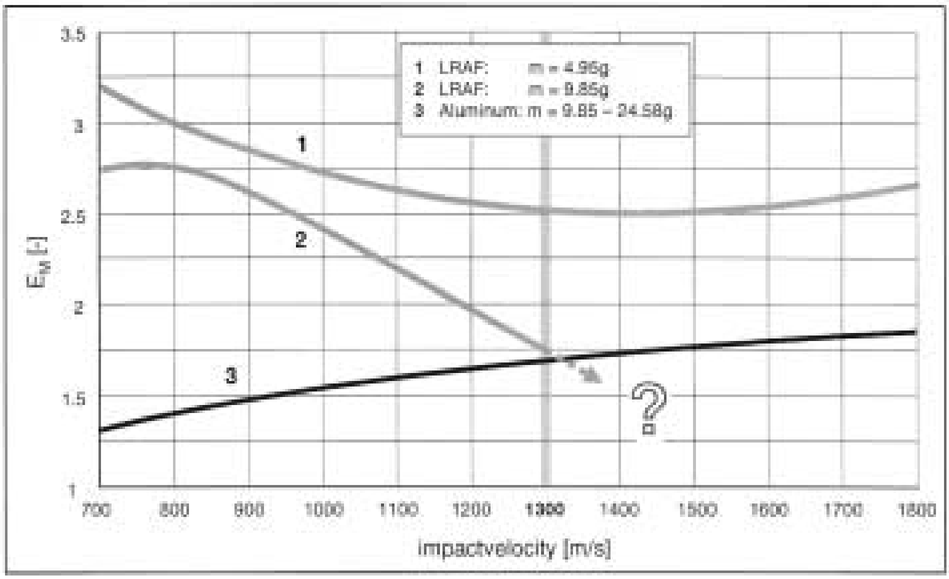

Figure 5.

CONCLUSION

The E_M factor of Aluminum is independent of projectile mass and by increasing velocity Aluminum plates become lighter in comparison with steel plates showing an equal protection. The E_M factor of LRAF is dependent on projectile mass. Unlike Aluminum the E_M factor of LRAF is steadily reduced increasing impact velocity. A further effect was also observed. At equal impact velocity deformation of projectile within LRAF is clearly lower than within Aluminum or within RHA and there's only a loss of projectile mass perforating RHA plates.

Only at knowledge of all-important factors of influence protection arrangements can be optimized mass efficiently.

ACKNOWLEDGEMENTS

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