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PROTECTION PERFORMANCE OF THE SINGLE WALLED BUMPER STRUCTURE AGAINST LARGE SIZE DEBRIS AT COMPARATIVELY LOW SPEED

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ABSTRACT

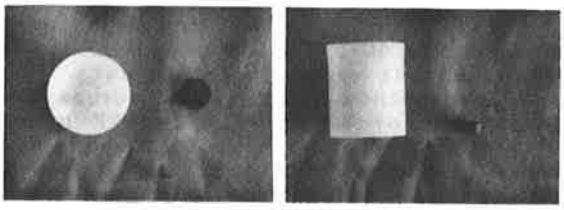
This paper describes the impact experiment results of single walled Aluminum and CFRP bumper structures by a comparatively large projectile with the speed of about 2km/s. The data are compared with various kinds of empirical formulae proposed so far and show experimentally that bumper thickness has its optimal design value from the viewpoint of total penetration thickness. Some results of numerical simulation by a hydrocode are also presented.

1. INTRODUCTION

Due to the lack of observation and protection capabilities, it has been considered as a critical problem that debris in size 1 several cm in diameter can be neither identified for collision avoidance maneuver nor shielded against using the so-called "Whipple Bumper" in acceptable size and configuration. Recent discussion in NASA suggested that debris in 2 cm diameter would be set as the target of the R&D activities for observation and protection capabilities. As to the debris impact speed, it has been pointed out that, from the view point of ballistic limit, there is a critical region in the comparatively low speed range (2 3km/s) due to the transition from the purely mechanical failure mode to that involving melting phenomena. Recognizing the importance and criticality of large and comparatively low speed debris impacts as mentioned above, the authors insist that systematic design database in that parameter range should be established as soon as possible.

2. EXPERIMENT SETUP AND SPECIMENS

A single stage gunpowder launcher was used to accelerate a 14 gram high molecular weight polyethylene projectile up to about 2km/s. The acceleration tube and setup chamber where bumper and main wall plates were installed were vacuumed to 20 mmHg to reduce the damage by the blast wave of gunpowder explosion. Distance between the back face of a bumper plate and the front face of a main wall plate was 106mm. Test configuration is shown in Fig. 1 and properties of targets and projectiles are summarized in Table 1. A small piece of magnet was attached to the end of each projectile (Fig. 2) and impact velocity data were obtained by measuring the peak time difference of electric current in the two coil circuits induced by magnet passing through them.



(a) Top view (b) Side view

Fig. 2 Projectile and magnet for velocity measurement

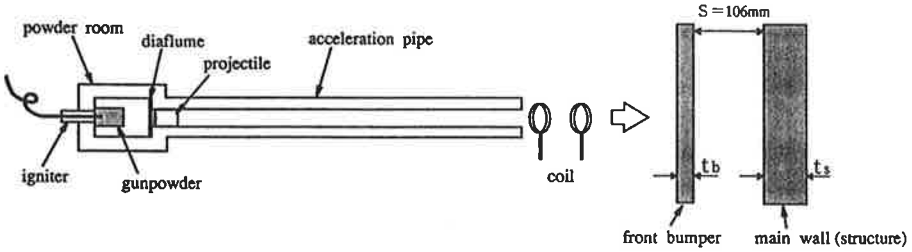


Fig. 1 Test Configuration

Tab. 1 Properties of target and projectile

Projectile	Mass	:	14g
	Diameter	:	25mm
	Length	:	30mm
	Material	:	High-molecular weight polyethylene
	Density	:	1.05g/cm^3
Target	Front bumper		
	2024-T3 Thickness	:	2.5, 4.8, 22.2, 38.1 (mm)
	IM6/R6376 Thickness	:	2.7, 2.7 (mm)
	Main wall (Structure)		
	2024-T3 Thickness	:	38.1 (mm)

3. RESULTS AND DISCUSSION

3. 1 Experiment results

Fig. 3, 4 shows the impact damage in case of 2. 5 mm bumper and it is observed that there still exists the spread of many small craters generated by solid type fragments of the projectile and the bumper plate, which indicates that the transition to the melting dominant failure mode has not been realized yet.

In Fig. 5 two experiment data of non-bumper cases are compared with the empirical formulae of penetration depth on semi-infinite plates cited bellow.

$$P=0.383\ \rho_p^{\ 0.148}\ m_p^{\ 0.352}\ V^{\ 2/3} \qquad \text{(JSC)} \qquad (1)$$

$$P=0.427\ \rho_p^{\ 0.133}\ m_p^{\ 0.367}\ V^{\ 2/3} \qquad \text{(Rockwell)} \qquad (2)$$

$$P=0.340\ \rho_p^{\ 1/3}\ m_p^{\ 1/3}\ V^{\ 2/3} \qquad \text{(GM-DRL)} \qquad (3)$$

$$P=1.09\ \rho_p^{\ 1/3}\ m_p^{\ 1/3}\ V^{\ 1/3} \qquad \text{(Bjork)} \qquad (4)$$

In the parameter range of authors' experiment JSC and GM-DRL formulae show excellent agreement with those two data. Four other data points bellow these curves show the effects of aluminum and CFRP bumper structures. Unfortunately, in case of CFRP bumper, impact velocities could not be measured due to breakup of magnets and data are plotted using the estimated velocity value. Quite different failure mode of the CFRP bumper can be observed in Fig. 6, 7.

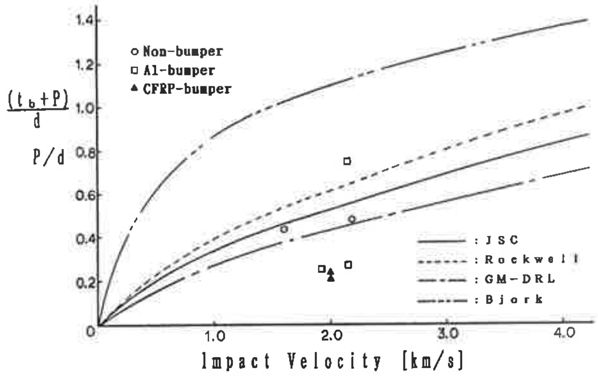


Fig. 5 Test results and various experimental formulae

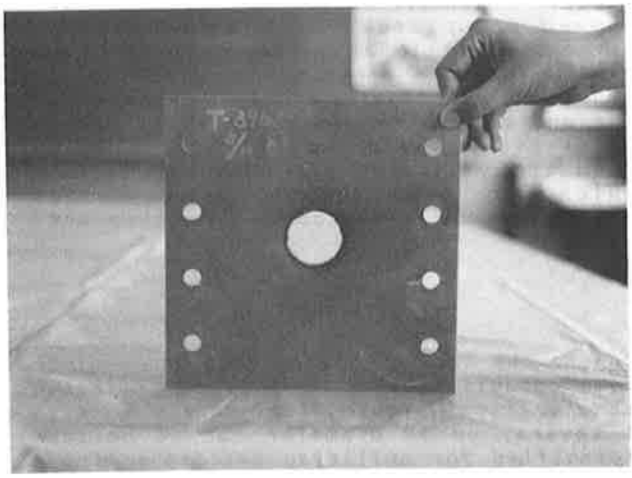


Fig. 3 Penetration hole of bumper plate (Bumper thickness: 2. 5mm)

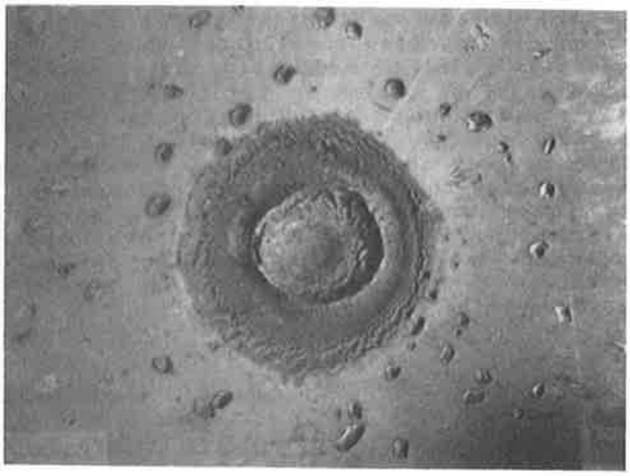


Fig. 4 Craters in main wall (Bumper thickness: 2. 5mm)

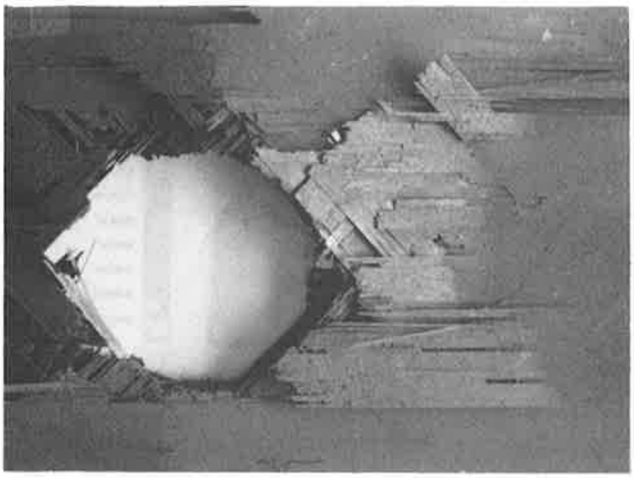


Fig. 6 Penetration hole of CFRP bumper

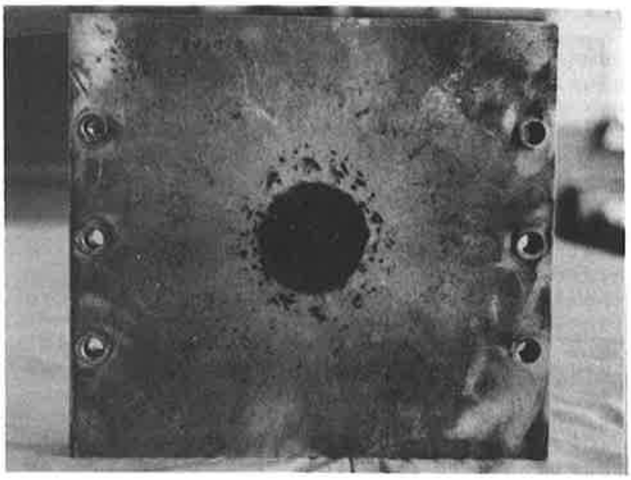


Fig. 7 Craters in main wall (CFRP Bumper)

In Fig. 8 the total penetration depth and the main wall penetration depth are plotted in various Aluminum bumper thickness cases. It seems obvious or matter of course that the penetration depth of the main wall would decrease monotonously according to increase of the bumper thickness. But the total penetration depth shows another behavior that it has the minimum/optimum value and that increase of bumper thickness beyond the optimum point causes increase of the total penetration depth which can be larger than the crater depth of the non-bumper wall case. This experimental fact insists the necessity of build-up of a systematic experiment database in these parameter range and the optimization process in bumper structure design utilizing it.

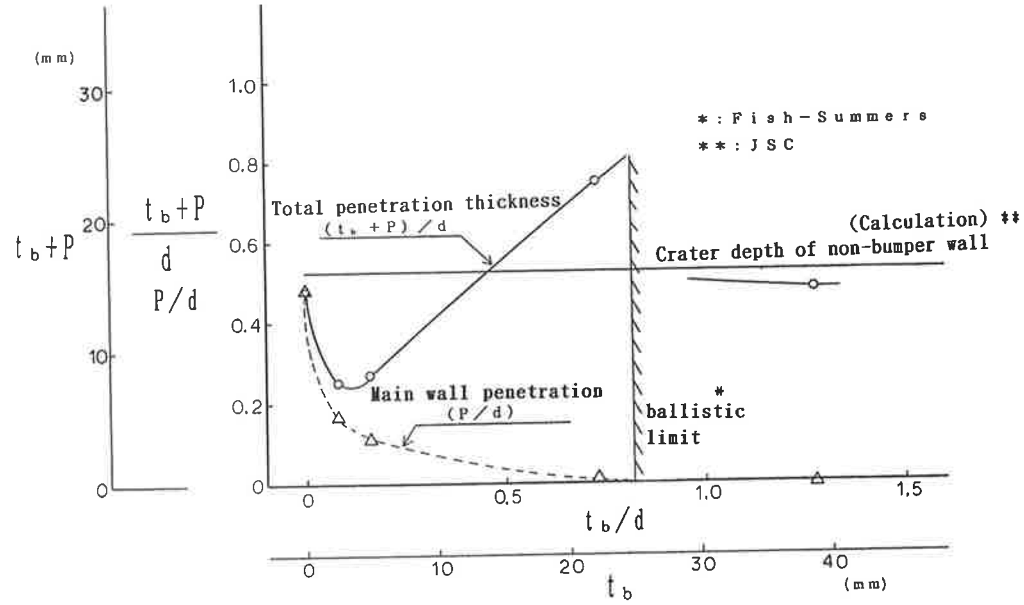


Fig. 8 Relation between total penetration depth and bumper thickness

3.2 Numerical simulation by a hydrocode

Numerical simulation in case of 2.5mm aluminum bumper was trially carried out using a hydrocode, AUTODYN-2D installed in SUN4 EWS. The problem was modeled axisymmerically and so-called Lagrange processor was applied to the projectile and the target. Considering the experimental impact velocity, the shock equation of state was adopted for both elements and hydro for the projectile , von-Mises for the target as strength models. The hydro tensile stress was assumed to be 10 Mbar. Some of the results are shown in Fig.9, 10. Taking it into account that optimization for material parameters, mesh size, processor types has not been conducted, predicted hole radius(23mm) and main wall crater depth(1-2mm) seem to be agreed fairly well with the experimental data(hole radius:20mm and main wall crater depth:4mm). But further study efforts will be needed to discuss the applicability and the precision of this kind of numerical simulation codes.

4. REFERENCES

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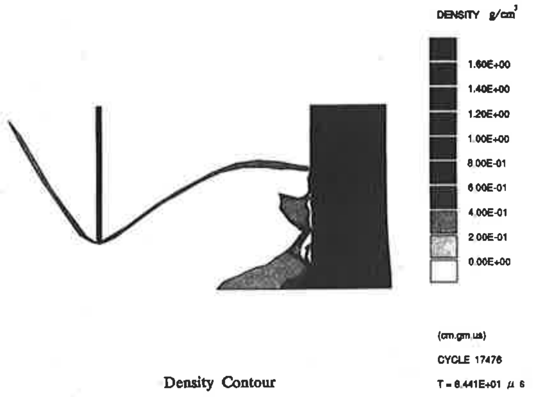

Fig.9 Material density contour

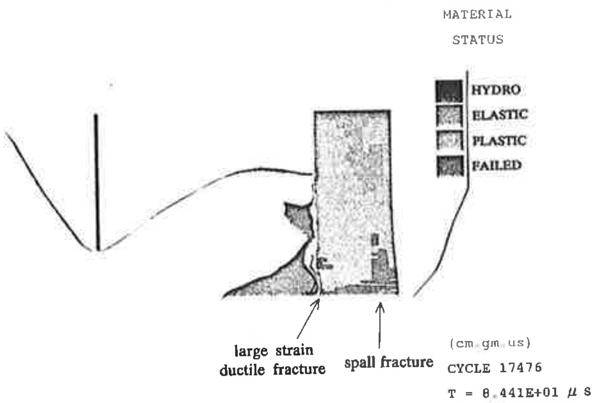

Fig.10 Material status