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SHOCK REDUCTION POWER OF DIFFERENT MATERIALS IN PLATE TARGETS

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Presenting aspects of the specific deformation behavior of steel and aluminium alloys under blast load this paper contributes new data to the discussion about efficient protection measures. For this purpose two newly developed observation methods for highly dynamic movements have been applied. Firstly, acceleration data have been measured by Piezoresistive Accelerometry and secondly displacement data have been measured by Laser Assisted Reflectometry.

INTRODUCTION

The vulnerability of the operation staff in vehicles under detonation threat is strongly dependent on the shock reduction power of the chassis. Since the human body bears only relatively smooth momentum alterations [1], protection measures against blast mine detonations must reduce the momentum transfer into the crew compartment tremendously [2,3]. This can be achieved if the kinetic energy of the detonation gases is transferred into other energy forms. With respect to operation boundary conditions the most efficient way is to change kinetic energy into deformation work and dissipation heat. Further, practical protection devices against bottom mines have to be thin in order to guaranty the necessary clearance. Consequently, the protection device must be based on materials with a potential for maximum dynamic deformation work. The aim of this research activity is therefore to

- find those materials which consume maximum energy at minimum dynamic deformation.
- measure the surface acceleration of plates for vulnerability investigations
- develop fieldable methods for the analysis of dynamic deformations in prototypes

Going for the first aim we observe the dent formation in plates of the same areal density during explosive charge detonation. Due to the different densities of the chosen materials the test specimen will have different thickness. We prefer constant areal density to constant thickness since blast protection primarily deals with inelastic collision. And there the mass is a crucial parameter. We reduce the examination zone to the centre where

Home
Table of Contents

the dent forms. Measuring its one-dimensional movement perpendicular to the original plane we then calculate its deformation work per area unit normal to the plate surface (Figure 1).

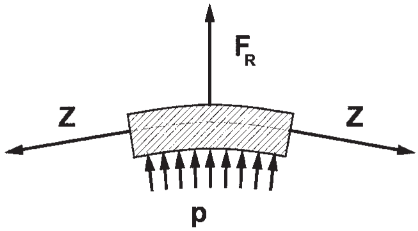


Figure 1: Cross-sectional view of the strain in the dent of a dynamically deformed plate.

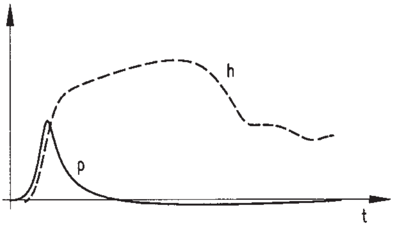


Figure 2: Pressure and dent height evolution versus time.

This is a dimension figure for the detonation energy fraction which causes the deformation of the plate. And its inverse value is a dimension figure for the shock reduction power of the plate. The calculation of the deformation work W is based on the following approach. Measuring the one-dimensional movement of the dent top surface in function of time, we know its path, speed and acceleration. Consequently the deformation power at a certain time can be written as

$$\dot{W} = F_R \cdot \dot{x} \tag{1}$$

with F_R resulting from the surface acceleration and the areal density m in the dent.

$$F_R = m \cdot \ddot{x} \tag{2}$$

For the deformation work performed up to an interesting state the deformation power has to be integrated numerically up to the corresponding time.

$$W_{S,D} = \int_0^{t_S,t_D} F_R \cdot \dot{x} \cdot dt = m \int_0^{t_S,t_D} \dot{x} \cdot \ddot{x} \cdot dt \tag{3}$$

In this study the integration was done up to two important points. Once up to the time of maximum surface speed (t_S) and twice up to the time of the dynamic dent height (t_D, minimum dent height). These two extremes cover the terminal ballistically mostly affecting states of the plate (Figure 2, [2], [3], [4], [5]).

For the second goal we need precise acceleration data of the different plates. Based on the statistically confirmed interrelationship with the endurance time [1] they will serve for vulnerability considerations of personal in vehicles. Summing up, we need accurate and repeatable methods for the observation of highly dynamic movements. For this purpose we use the following two new methods. The first method, the Piezo Resistive Accelerometry (PRA) is directly registering the acceleration of the plate centre. The second method, the Laser Assisted Reflectometry (LARY) is registering the path length between the plate centre and the beam source. We use PRA to get precise acceleration data during the

Home
Table of Contents

detonation phase and to confirm the calculated acceleration data from LARY. Subsequently the deformation work W_S and W_D is calculated based on LARY data. Being very robust these two methods also accomplish the third goal allowing the scientist to collect data under fieldconditions.

EXPERIMENTS

During this test series, executed in the Detonics Laboratory Hondrich [6], specimen of 5 different metals are investigated. 3 steel qualities, Standard steel (StS), General purpose construction steel (GPCS) and high hardness armour steel (HHA) plus 2 aluminium qualities, standard aluminium (StA) and high-tensile aluminium (HTA).

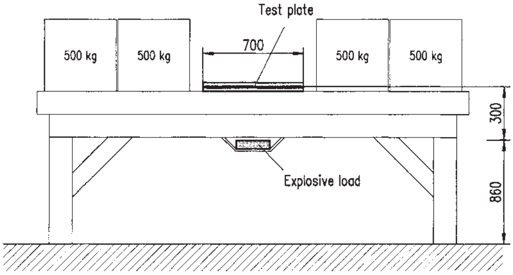


Figure 3: Schematic diagram of the test arrangement.

The specimen are square plates of 700 mm extension. Whereas the steel plates have a thickness of 10 mm the one of aluminium is 30 mm. The specimen are fixed between two rectangular steel frames with a circular opening of 500 mm (Figure 1 and 9). The steelframe is fixed to a steel construction and the whole arrangement is loaded with four concrete cuboids of 500 kg each. A plastit load of 500 g (explosive gelatine) is placed under the plate having a distance of 300 mm between its top and the specimen.

The charge is hold with a wooden frame 860 mm above the concrete basement. The plastit mass has a cylindrical shape with a height/diameter ratio of 1/3 and is electrically ignited in the centre of its bottom surface. The two selected measurement methods are applied separately for each material in order to avoid interactions.

Piezeresistive Accelerometry (PRA)

There exist a broad range of different sensors to measure accelerations. But the accelerations occuring on a protection plate during an explosion are mostly much too high to measure with commercially available sensors [2], [7]. These have to be modified to measure the enormous accelerations without any damage. In our method we use a 60000 g piezoresistive accelerometer (Endevco 7270A). The signal of this sensor is amplified by a miniature amplifier that together with the sensor and a steel protecting case form the measurement unit (s. Fig. 1). The measured signals are visualized and stored with an oscilloscope (LeCroy).

Home
Table of Contents

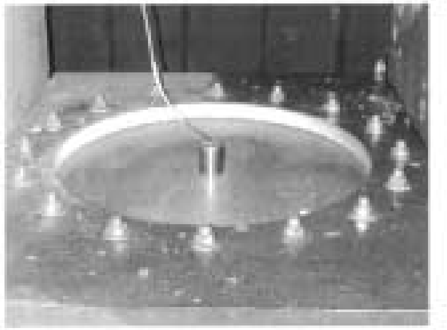


Figure 4: Measurement unit mounted on a test plate.

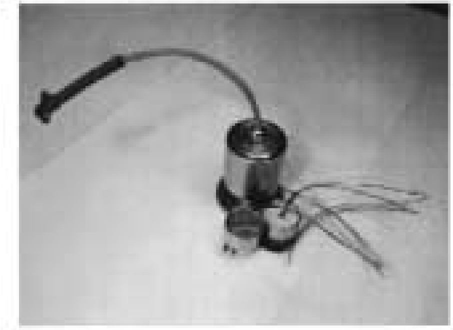
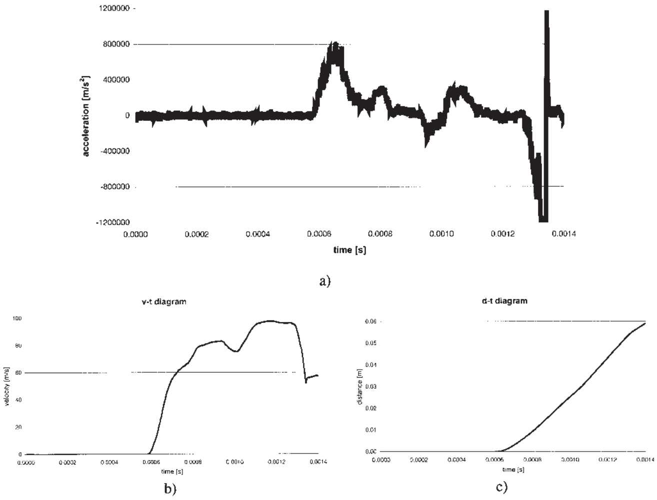


Figure 5: Complete measurement unit (above) and interior parts-embedded amplifier and fitting rings (below).
With its steel casings the whole unit weighs about 330 g and has a dimension of 40 mm x 40 mm.

Similar to the technique in [8] undesired high frequencies which could destroy the accelerometer are mechanical damped by different layers of special rubber and synthetic material. The sensitive electronic parts are additionally embedded in a three-component epoxy resin. In first experiments different loads (65 up to 1000 g) of plastit are ignited at different distances (100–400 mm) beneath an 8 mm steel plate. In this configuration maximum accelerations up to about 2 Mio m/s2 are recorded without damaging the measurement unit. To get information about the velocity the mathematically filtred acceleration data is integrated, second integration 1eads to the distance. Fig. 2 shows typically obtained results.



a)

b)

c)

Figure 6: Detected and calculated results caused by the detonation of 1 kg plastit at 500 mm distance below an 8 mm standard steel plate. a) measured acceleration, b) velocity in function of time and c) resulting distance.

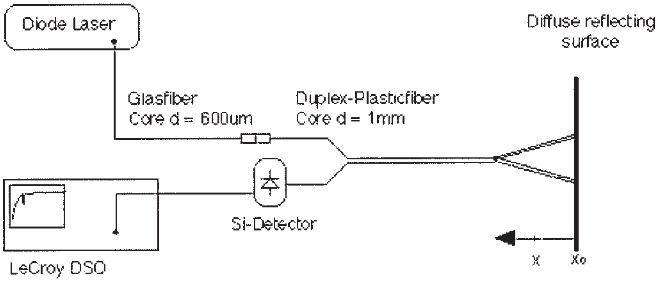


Figure 7: Schematic diagramm of the LARY method

Figure 8: Glass fibers of the LARY-method mounted on a steel yoke.

FIGURE 9: Wooden cage for the exclusion of disturbing gases and detonation flash.

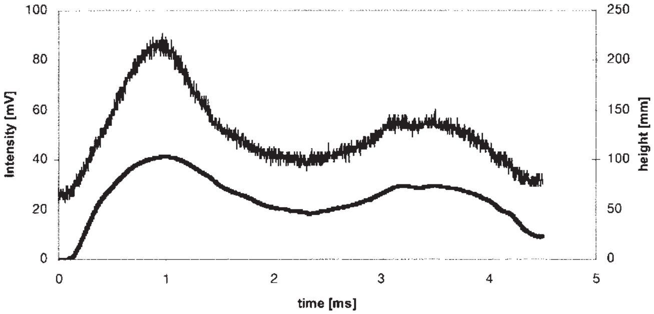


Figure 10: Detected Intensity (upper curve) and calculated dent height (lower curve) caused by 500 g plastit at 300 mm distance below a GPCS plate.

Laser Assisted Reflectometry (LARY)

One main disadvantage of measurement methods which are applied directly coupled to the moving part is their limited mechanical stability under load. Indirect measurement methods on the other hand often demand a stable and clean environment. To prevent this boundary conditions we have developed an indirect method called Laser Assisted Reflectometry (LARY) for outdoor experiments [9]. LARY determines the one-dimensional displacement of moving surfaces. This is based on the on-line analysis of the intensity of a laser beam reflected on the examined surface. For this purpose the light emission and light reception must be located as close as possible to each other. The emitted laser beam must be directed perpendicularly to the examined surface (Fig. 7). The displacement of the surface is calculated based on the well known fact that the reflected radiation intensity is inversely proportional to the second power of the distance from the reflector. The laser light has a wavelength of 820 nm and is emitted by a diode Laser of 15 W output. The emitting and receiving glass fibers are parallely mounted on a steel yoke at a distance of 65 mm over the plate center (Fig. 8). We exclude the detonation flash and afterflaming by means of a wooden cage (Fig. 9). Exemplary, Figure 10 shows the intensity signal detected over a GPCS plate (upper curve) and the calculated height of the dent.

RESULTS

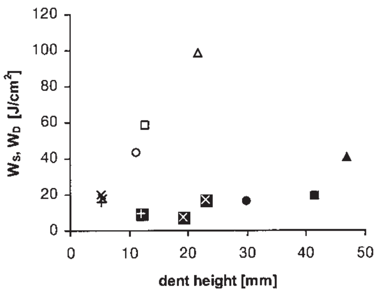


Figure 11:
Deformation work of the dent top at max. surface speed (upper values) and at dynamic dent height.

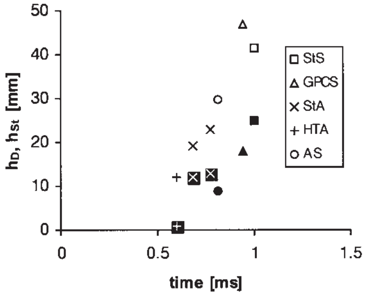


Figure 12:
Dynamic dent height versus observation time. Below, the remaining static dent height is indicated.

Data collected by both, the LARY and the PRA method result in a similar evolution of acceleration, speed and path. They properly registrated data during the detonation process and up to 1 ms. Above 1 ms data suffer in some cases from artefacts of the test arrangement. In case of PRA the sensor is limited to lower accelerations than appearing in case of HHA, StA and HTA after 1 ms. Most probably this is going back on the loosening of the fixing. Equivalently, LARY suffers from the same effect. The strong movement of the arrangement is e.g. displacing the glass fibre from the detector after 3–4 ms. The deformation work per area unit W_S and W_D shown in Figure 11 clearly increases with increasing dent height. Interestingly, the aluminium qualities have the lowest deformation work at lowest dent height of all materials. As already mentioned, the materials with low dynamic deformation work cause a dramatic increase of the stress in the fixing of the specimen. This is quite consistent with the fact, that the detonation energy below the plate remains constant. Another important effect is the trend for increasing deformation time with

Home
Table of Contents

increasing dynamic dent height (Fig. 12). Typical peak values of the dent acceleration are 200 000 g and –150 000 g during intervals of the order of magnitude of microseconds. The acceleration dala collected with PRA method will be used for vulnerability considerations.

CONCLUSION

The tested metals do not accomplish maximum deformation work at minimum deformation. The dynamic deformation work and the time consumed obviously increase with decreasing hardness.

The aluminium experiments prove the shock reducing effect of increasing thickness. This is simply due to the fact that the bending height f_{max} is inversely proportional to the plate thickness t to the second. That’s why, the weakening effect of the lower Youngs Modulus E is clearly exceeded by the threefold thickness compared to steel.

$$f_{max} \approx \frac{\rho \cdot l^4}{E} \cdot \frac{1}{t^2} \qquad (4)$$

For the investigated metals high shock reduction power is obviously coupled to high stiffness. And this causes higher stress of the whole chassis.

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Home

Table of Contents