Acta Materialia Transylvanica 1/2. (2018) 93–96.
https://doi.org/10.2478/amt-2018-0034
Hungarian: https://doi.org/10.2478/amt-2018-0033
https://eda.eme.ro/handle/10598/30466

Application of High Energy Absorbing Materials for Blast Protection

Tünde KOVÁCS,[1] Zoltán NYIKES,[2] Lucia FIGULI[3]

[1] *Óbuda University, Donát Bánki Faculty of Mechanical and Safety Engineering, Institute of Materials and Manufacturing Sciences, Department of Materials Technology, Budapest, Hungary, kovacs.tunde@bgk.uni-obuda.hu*

[2] *Óbuda University, Doctoral School on Safety and Security Sciences, Budapest, Hungary, nyikes.zoltan@phd.uni-obuda.hu*

[3] *University of Zilina, Faculty of Security Engineering, Department of Technical Science and Informatics, Zilina, Slovakia, lucia.figuli@fbi.uniza.sk*

Abstract

In the current century, building protection is very important in the face of terrorist attacks. The old buildings in Europe are not sufficiently resilient to the loads produced by blasts. We still do not fully understand the effects of different explosives on buildings and human bodies. [1–3] Computing blast loads are different from that of traditional loads and the material selection rules for this type of impact load are diverse. Historical and old buildings cannot be protected simply by new walls and fences. New ways need to be found to improve a building's resistance to the effects of a blast. It requires sufficiently thin yet strong retrofitted materials in order to reinforce a building's walls [4–6].

Keywords: *metal foam, energy absorbing, building protection, reinforced composite.*

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1. Introduction

In Europe, many terrorist attacks have caused notable damage. The NATO and V4 countries are currently working to secure the safety of citizens, critical infrastructure and buildings [6–8]. The challenge of our age is to innovate and invent new materials for these special loads: loads that didn't have to be considered previously. Extraordinary loads, such as those produced by blasts, are combined load because they involve various parameters, including shock waves and scatters. Blast effects from a detonation produce building damage and fragmentation effects. The initial explosion produces secondary damage, caused by fragments of brick and other materials striking other buildings and human bodies [1–3].

Compared to static loads, the blast effect of such high-speed plastic deformation can produce different behaviour in the materials.

The properties of traditional materials under static loads are well understood and tested. This knowledge forms the basis of the design of these constructions.

However, the material selection and design for dynamic and extreme loads are not yet well defined, from the testing method point of view, or the material properties point of view.

2. TNT equivalent determination

The wave and heat energy caused by a blast depending on the blast range and chemical composition. Determining the TNT equivalent is useful for designing the load *(1)* [3, 8]:

$$W_{TNT} = \left(\frac{\Delta H_{EXP}}{\Delta H_{TNT}}\right) W_{EXP}(kg) \qquad (1)$$

where:

W_{TNT} (kg)) is the TNT volume equivalent mass,
ΔH_{EXP} (MJ/kg) is the blasting heat,
ΔH_{TNT} (MJ/kg) s the TNT blast heat,
W_{EXP} (kg) is the calculated explosive mass.

Table 1. shows the performance of some explosives.

Table 1. *Performance of some common explosives [8, 9]*

Name of the explosive	The energy of the blast (MJ/kg)
TNT	4.1–4.55
C4	5.86
RDX	5.13–6.19
PETN	6.69
Pentolite 50/50	5.86
Nitro-glycerine	6.30
Nitrocellulose	10.60
Amon/Nitrate	1.59

3. Determination of the blast pressure

We already know some equations for determining the blast load. The most useful for load design is the Hopkinson-Cranz law *(2)* [8, 9].

$$Z = \frac{R}{\sqrt[3]{W}} \quad \left(m \cdot kg^{-\left(\frac{1}{3}\right)} \right) \tag{2}$$

where the distance of the blast determination of the object is Z (mkg$^{-(1/3)}$) from the W (kg) explosive mass volume for TNT equivalent.

The Mills equation for nascent gas pressure determination *(3)*, where W is the explosive mass in the TNT equivalent (kg), R is the explosive distance from the object (m):

$$P_{SO} = \frac{R}{Z^3} - \frac{R}{Z^2} + \frac{R}{Z} \quad (kPa) \tag{3}$$

The blast establishes a short pressure load followed by a longer duration of a vacuum effect. The design load is calculated from the pressure. The blast load parameters can be obtained from the literature **[8].** fThe maximal pressure shows the pressure and vacuum loads in the case of the blast, shown in **Figure 1.** láthatóak. A nyomó és húzó igénybevételek egy robbanás esetén kerülnek bemutatásra.

4. Classical Lamination Theory (CLT)

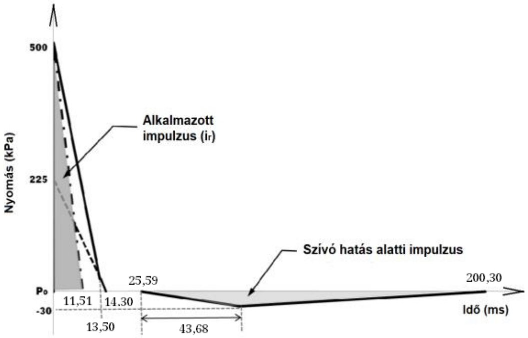

Figure 1. *Front wall pressure and time curve [8]*

For designing composite materials classical lamination theory knowledge is required. Based on this theory and design rules we can manufacture a new composite for static and dynamic loads but for blast load we cannot identify design rules. In our research, the classical design rules are the basis of the blast resisting materials design. Based on the practical impact test results we are able to develop the design rules for blast resistant composites.

Design method steps are as follows [4]:

1. Calculation of the stiff parts of the matrix (Q) for all layers,
2. Determination of the loads,
3. Calculation of the layer plane deformation (ε_{xx}, ε_{yy}, γ_{xy}),
4. Determination of the stress in all layers (σ_{xx}, σ_{yy}, τ_{xy})
5. Calculation of the layer's elastic constant (E_{xx}, E_{yy}, ν_{xy}, ν_{yx}, G_{xy})
6. Determination of the average effective strength base on the damage parameters.

In our case of the next special material, this theory was applied (CLT). The load is combined including high pressure and high energy impact.

5. Testing of specific composite for blast protection

For the protection of buildings, a new retrofit technique is required. The new materials innovated by material science can provide a good solution for this project task. These materials are usually composite, such as syntactic foams, spherical shells or carbon field reinforced composites [4–6]. Some common retrofit techniques have been introduced in previous work which focused on the practical aspects of retrofit techniques used for the blast protection of buildings. It presents the summary of various retrofit techniques [12, 14]. In the case of the introduced extraordinary dynamic loads, we needed to select or innovate a high kinetic energy absorbing material. The metal foams and the composites can be useful for absorbing these loads.

In the following innovation, we introduce a polymer sandwich composite, reinforced by ceramic spherical shells with a glass woven structure.

One of the steps of manufacturing the sandwich structured polymer is shown in **Figure 2.**

Figure 3. shows a prepared sample for testing. The introduced composite has layers of ceramic spherical shells combined with a gas woven structure. Ceramic spherical shells are 0.8 mm (average) diameter, the glass fibre woven structure is 390 g/m2 and the matrix material is epoxy resin (Araldite LY 1564). There were 15 unidirectional and isotropic layers. The dynamic effect was simulated by the Charpy impact test.

The result of the Charpy impact test is shown in **Figure 4.** It is obvious that the tested sample didn't break under the applied load. The test method used can give us information about the dynamic load effect of such materials.

6. Conclusion

Based on the practical impact test results and the experimented test samples we detected that the ceramic spherical shell diameter was important for kinetic energy absorption. We tested three different ceramic spherical shell diameters of reinforced composites (diameters: 0.15 mm, 0.8 mm, 1.5 mm). The kinetic absorption depended on the ceramic spherical shell diameter, the smallest caused a reduced kinetic absorption level. In the case of the larger diameter spherical shells this property improved but in the case of the open spherical shells, stuffed with acrylic, the kinetic absorption level was reduced. This effect caused a moderate improvement in the kinetic energy absorption level. Finally, we can conclude that the middle sized spherical shell diameter improved the kinetic absorption level.

The introduced composite material shows the method to follow for blast resistant material innovation. Furthermore, the implemented composite design rules can be a basis of new material designs.

Moreover, the recycling possibility of these materials is an important aspect, as is shown in **[13]**. In the case of the introduced material, this prerequisite wasn't attainable.

Based on these practical and theoretical results, we are planning to continue with the innovation in new blast-resistant composite materials.

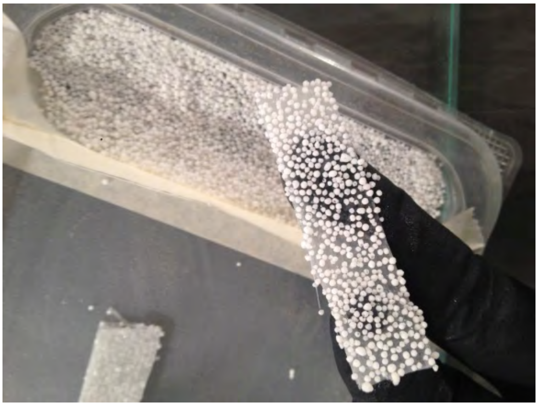

Figure 2. *One of the manufacturing steps of the ceramic spherical shells and glass woven structure reinforced composite [10]*

Figure 3. *Ceramic spherical shells and glass woven structure reinforced composite [10].*

Figure 4. *Picture of the sample after dynamic impact load [11]*

Acknowledgement

The authors would like to thank András Bezzeg and Ákos Végh KANDSI Kft. (AKOBEZ) for the composite manufacturing and also thank Ágoston Balázs for the Charpy test investigation.

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