Chapter 16
Designing Principles for High Energy Absorbing Materials

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Abstract The focus target of our century and even of all centuries in the history is the security. Every state wants to guard their own functionality and citizens. The treasure of the nations are firstly peoples (soft target) and after all, buildings and assets.

The construction engineering used the traditional materials and designing a long time ago. In our century, the useful materials are changed and the building operations technologies are developed and changed. Great example is the new idea of 3D printed houses. In case of the new buildings many special loads have to be considered (earthquake, blast load, flood, etc.), and also this knowledge has to be taken into account in design of buildings, and there is a need to use resistant materials for such loads. Lot of innovated materials (metal foams, special composites) have appeared in the last decade. Polymer composites with new segments, like the reinforcing fibers (glass fiber, carbon fiber, aramid fiber) and the special property acrylates can be used. The functional innovation for special loads and high energy absorbing is supported on the basic theories of the designing principles by material selection and the combination with their realisation. The base of this innovation is the knowledge of the design principles of the requirements of these loads.

This work it can try to introduce the designing principles and the designing for high-energy absorbing materials what can be the base of the material science innovations.

Keywords High energy absorbing · Composite designing · Blast protection

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16.1 Introduction

The use of explosives worldwide in terror campaigns has rekindled international interest in the blast research. The knowledge of the blast effects is important to protect people and the way to prevent or mitigate damage [1]. The modelling of the complex load of the explosion with mathematical models and computational methodologies are very difficult because of the wide variety of explosives and blasting types. It can find some antiterrorism standards and design guides in the US and Canada for buildings [2, 3]. The application of the protocol can be useful during the new buildings designing and can be also suitable in case of the reinforcing of the old buildings. In this article, we wanted to review the basic knowledge of buildings protection and to describe principles for the innovation of the useful high energy absorbing composite materials. The chapters of this article contain the short review of the blast load, the defence materials required properties and the innovation possibilities. The designing method is shown in Fig. 16.1, using Ashby model [4].

16.2 Stress Analysis

A first step of the new material design process is a stress analysis based on the understanding of blast load and the effect of the explosion (see Fig. 16.2.) [5, 6]. The air-blast establishes high-intensity pressures what is the reason on the exterior walls, windows, roof systems, floor system and columns damage [5]. The Fig. 16.3. shown the pressure impulse diagram for a single degree of freedom elastic system with an ideal blast wave [6].

The nascent pressure and the effect of the blasting depend on the distance between the wall and the explosion centre, the quantity of the explosive, the TNT equivalent of the explosive and the position of the explosion (air-blast, floor-blast, etc.).

The building coating can increase the blast resistance of the walls in case of lower damage level, lower quantity of explosive, lower TNT equivalent range of explosive or higher distance between the burst center and the attacked wall. The analysed dynamic load is a special complex load. In a few seconds the pressure increase, the gas volume expand quickly and cause positive and negative phase. The shock wave becomes negative, followed by a vacuum. The positive phase duration is much longer than the negative phase [7–9]. The Fig. 16.4. shows one type of the blast attack, the shock wave is almost hemispherical on this case [5].

The blast load is determinable by numerical techniques (Lagrangien, Eulerian, Euler-FCT, ALE, FEM) [10].

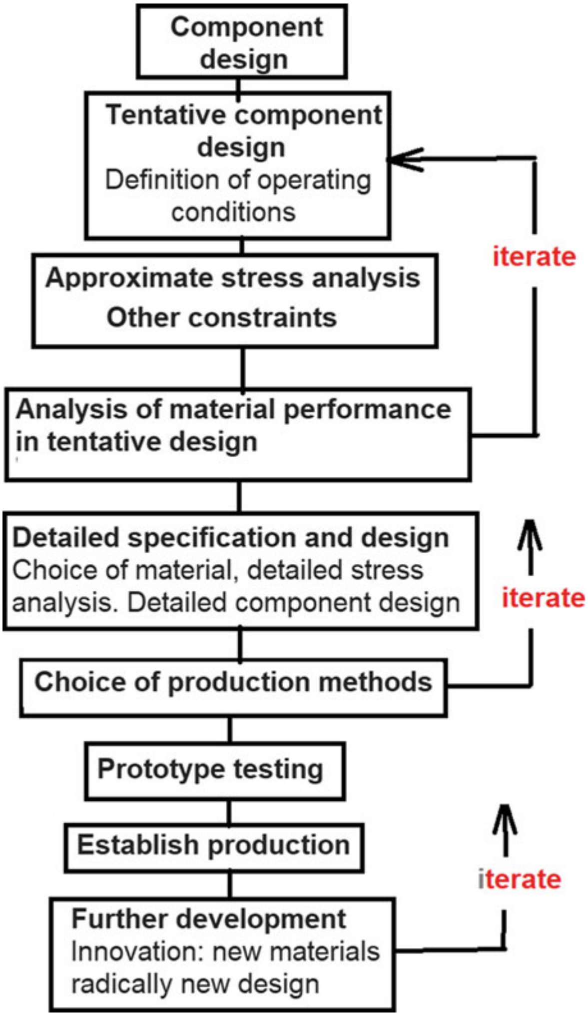

Fig. 16.1 Design methodology [4]

The theory is base of the determination of the rigid-body dynamics model (Brach 1991), has a serious limitation, needs to use a better approximation model like stress wave propagation in perfectly elastic media. The contact stress model base on Hertz theory (Johnson 1985) has been used to obtain a force-deformation relationship [12]. The elastic model can be extended to stress wave propagation in solids that are not perfectly elastic. By the way of modelling, it can use finite element methods (FEM). Some useful commercial software to determine the impact, like ABAQUS, LS-DYNA, [11, 12] etc.

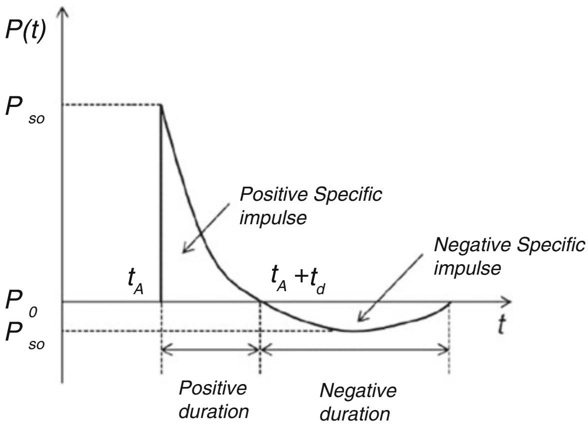

Fig. 16.2 Air-blast pressure time history [6]

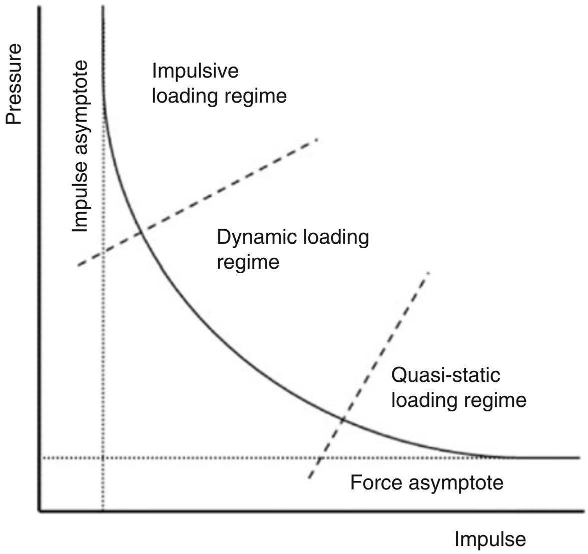

Fig. 16.3 Pressure impulse diagram [6]

16.3 High Energy Absorbing Materials

Materials show elastic-plastic behaviour under the load. Cellular materials have high energy-absorption characteristics (honeycomb, foams, woods, cellular textile, etc.) [11].

When a blast load is applied, the foam has to absorb more energy than the excessive energy input due to applying the cladding [13]. The next eq. (16.1) shows the energy input difference:

$$E_1 - E_2 \leq \sigma_{pl} \cdot A \cdot \Delta h \tag{16.1}$$

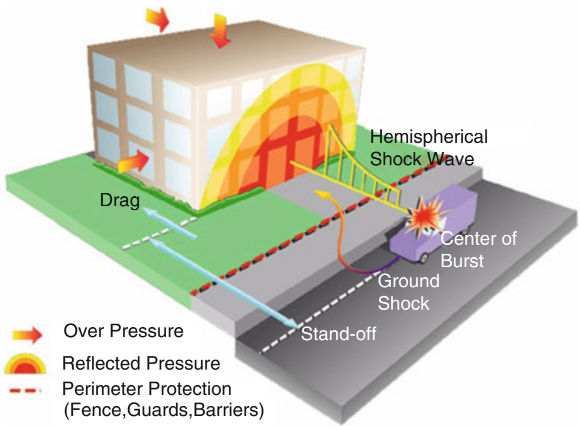

Fig. 16.4 One example of an explosion [5]

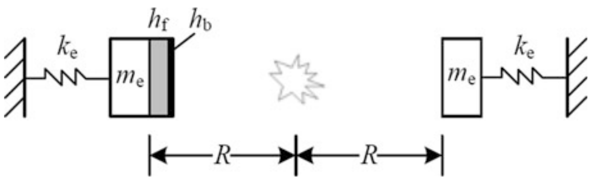

Fig. 16.5 Example for airburst: with and without foam cladding [13]

where E_1 and E_2 are energy input in situations with and without the lightweight cladding, respectively; A is an area of the structural member, fully covered by the foam cladding; Δh is the crushed distance of foam core; σ_{pl} is the plastic crushing stress limit of the foam [13]. In the Fig. 16.5. the foam layer of the sample shows effectiveness for blast mitigation.

On the base previous researches, it can conclude that the introduced structured materials have well energy absorption capability. Also, determinable that this structure energy absorption capability depends on the honeycomb or foam structure (isotropy, porosity, texture) in accordance with (Ashby et al.) [4].

16.4 Composites Design Principles for Blast Protection

On the base of the stress analysis [14, 15] can select material for the blast protective application. The base of designing is the knowledge of the material properties and the determined loads. It can find different FEM program to predict the blast load.

The composite materials compound mechanical and chemical properties, are well known. These data are the base of the designing. The plastic energy absorption capability of these materials is important. The useful materials are foams, fiber reinforced polymers and advanced composites.

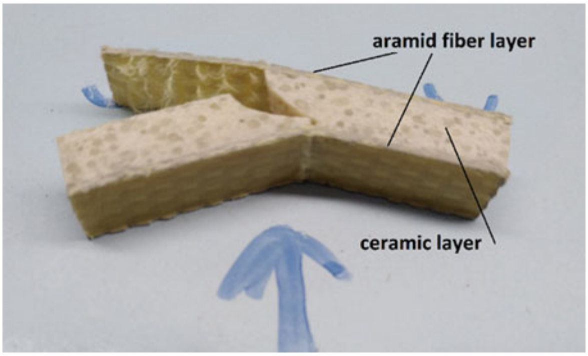

Fig. 16.6 Test sample composite after impact load

Fig. 16.7 Multilayer test sample composite after impact load [16]

The designed material needs to test by laboratory testing and analysed by numerical simulation. Simulation needs to create a model evaluated by the results of the laboratory testing.

On the base of our test result in accordance with the previous researches, we found a suitable way for blast protection material designing is the multilayer or sandwich structure materials. The Fig. 16.6. shows an aramid fiber layer adhesive joined by the ceramic layer. Under the impact test, the aramid showed good resistance and flexibility. Composite with ceramic showed high strengths. The Fig. 16.7. shows a multilayer composite - a composite reinforced by glass fibers and ceramic hollows. The ceramics hollows are hard but in this composite, shows a high energy absorption. The glass fibers task to increase the flexibility and the acrylic join all together. This special multilayer composite shows good resistance again impact load and this structure is a good example and basic experience of our research.

16.5 Conclusion

The results of the test are with the previous researches [4, 7, 10, 15, 16] showed that the bulk materials are not suitable for the blast protection, but the blast load designed composites materials (multilayer, sandwich, etc.) can unite numerous different mechanical, physical and chemical properties and can be suitable. We concluded that the multilayer composite showed better dynamic load resistance than the bulk materials.

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