Fabrication of Protective Composite Structures by Infusion Technology to Resist the Blast Wave

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Abstract

The paper presents the results of experiments on the use of infusion of polymer binders into a pre-constructed skeleton of reinforcing structures. Currently, three-layer structures with an average layer of aluminum honeycombs are considered to be one of the effective structural elements that ensure the damping of the blast wave. As an alternative middle layer, it is possible to offer elements of various shapes (cylinders, cubes, etc.) and geometries made of modern composites that are well-proven under the impact of a shock wave. These are, as is known, metal-polymer composites, i.e. materials containing, in addition to polymer binder and fabric filler, thin layers of metal. In order to form a solid structure that perceives an explosive load, an attempt was made to use RFI technology to obtain individual elements with which two steel sheets are connected. Aramid, glass fabrics and aluminum thin (0.5, 0.15, 0.05 mm) plates were used in the experiments. For the implementation of the infusion process, an epoxy resin was used, suitable in its technological parameters for this process. The use of this resin leads to the minimization of non-nourished areas and pores. In this case, the uniformity of the product obtained from the composite material is achieved. It should be added that RFI technology differs from other polymer processing technologies in the following significant advantages: the possibility of abandoning expensive equipment, reducing energy costs for equipment and its maintenance, and complete rejection of the use of prepregs. However, there are a number of difficulties that are associated with the technological process of infusion, these primarily include the rheological requirements of the binder: at room temperature, the resin should have a low viscosity, and in the practice of fillers, the viscosity should have rather low values. Below are some preliminary plans for the development of this technology in order to obtain a product that provides attenuation of the blast wave.

Keywords: fabrication, protective composite structures, infusion technology, blast wave

Introduction

Currently, sandwich structures are widely applied to reduce the negative impact of the blast wave on the protective object. To protect steel sheets from explosion (reducing their deformation, ensuring integrity), for example, it is considered effective to use aluminum honeycombs as the middle layer of three-layer panels (steel sheet - aluminum honeycombs - steel sheet). The review of the development of sandwich structures is considered by Quanjin Ma and co-authors [1]. Recently, a number of experimental [2–8] and theoretical investigations by numerical simulation [9–11], has been carried out on the sandwich structures with a middle layer of polyurethane. However, experience shows, that during the explosion loading, polyurethane may be subjected by large thermal shock with the release of toxic gases. It should be noted that, the space between the steel sheets is completely filled in the considered cases. In our research, to connect two steel sheets, using structural elements of different shapes (cubes, cylinders, etc.) and sizes located in the space between the sheets according to a pre-calculated scheme is proposed. As structural elements, metal-polymer composites based on the textile form of aramid (Kevlar), glass and thin layers of aluminum alloy are proposed. Aluminum layers prevent the formation of cracks in the structure during explosive impact. For the formation of structural elements, the technology of impregnation of a package of layers of fabrics and aluminum plates under vacuum - RFI technology (Resin Film Infusion) has been developed. During the Elaboration of technology of three-layer sample fabrication for explosion resistance experiments, we were able to obtain “Know-How” knowledge.

Methodology

The main task of the research was to obtain a sample in dimensions 60x60 cm, to test it under explosion impact and determine the shock resistivity. The structure of sample consists of two steel sheets with a thickness of 1 and 2 mm and structural elements between the sheets space, Structural elements are metal-polymer composite located in a certain, pre-calculated coordinates

(**Figure 1**). Structural elements represent cubes (or elements of a different geometric shape). They are obtained by vacuum infusion. The essence of the technology lies in molding followed by impregnation with a binder due to the creation of a rarefaction arising from the pressure difference with the environment. During the process, voids in the material are filled with resin, which is supplied in liquid form. The principal request is to ensure that the air is removed from all microscopic spaces so that resin can take it's place.

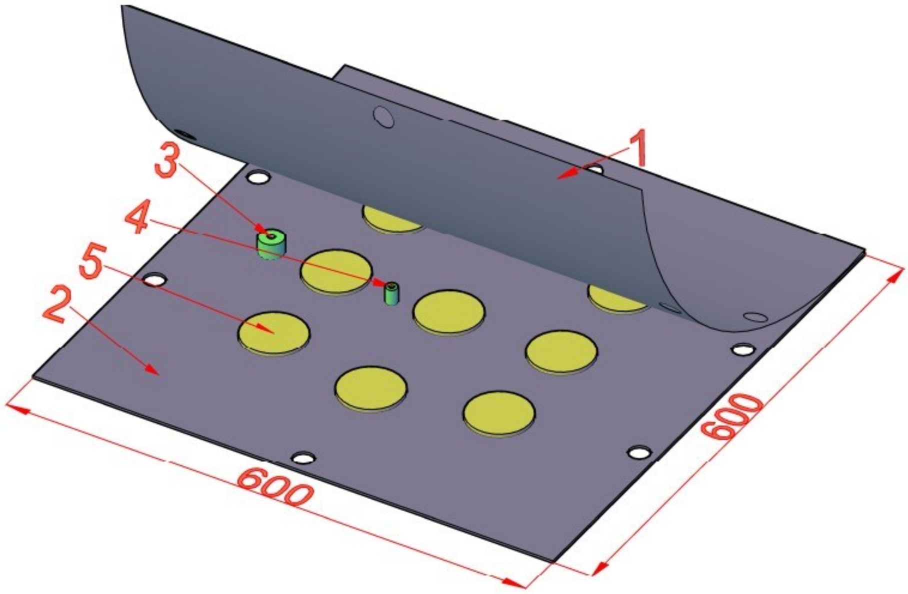

Fig. 1. Metal-Polymer composite Structure: (1) steel sheet δ=1mm; (2) Steel Sheet, δ=2mm; (3) Pressure sensor; (4) Accelerator sensor; (5) metal-polymer composite d=70 mm, δ=4.2mm.

The main stages of the process are:

- The optimal choice of materials, equipment (tubes, fittings, clamps, etc.), the layout of the materials used (fabrics, aluminum plates);
- Preparation of chemical-resistant forms capable of withstanding the required process temperatures (100...150°C), cleaning of surfaces with a separating layer (if necessary, applying a gel coating);
- Laying of reinforcing components. Pre-cut parts were laid in layers.
- During laying, the direction of the fiber is controlled in order to ensure the rigidity and strength of the product;
- Creation of a technological layer, providing for the laying of a drainage grid for air removal and resin distribution, laying of vacuum lines;
- Mould sealing. For this purpose, a special multilayer composite film was used
- Resin impregnation. The choice of resin is a decisive factor for the successful implementation of vacuum infusion. Currently, the market offers the following two-component epoxy resins developed for this purpose: XR150, XR100, Biresin CR80, Epolam 2031. Their viscosity at 25℃ ranges from 350 to 700 mPa/s, gelation time - from 80 to 420 minutes. In addition to epoxy resins, epoxy vinyl ester and polyester resins are also used.

RFI has its advantages and disadvantages, as an any technological process. The advantages are: the possibility of obtaining large-sized products without the need to divide them into component parts; ensuring high quality and uniformity of the material; reducing the required volumes of the binder. The product has an optimal ratio of fiber/metal plates - binder, which makes it possible to obtain a product with a minimum density with increased strength. Safety for human health is achieved by minimal interaction with harmful chemicals. The disadvantage of the process is the complexity of developing an infusion strategy and a large range of required materials, which leads to an increase in cost. In addition, high requirements are imposed on the personnel for the implementation of individual stages of technology.

Results and Discussion

Considering, that there are special requirements for the implementation of infusion technology, for the implementation of individual processes, the work started with the development of elementary infusion processes. The scheme was created for the practical use of the technology (**Figure 2**). The technology was tested to obtain the composite (the disk with a diameter of 70 mm and a thickness of 4.1 ... 4.2 mm). Assemblies of fabrics and aluminum plates are located in a pre-prepared chamber. They are located on a glass base and are bounded on top by a plastic coating reinforced with double-sided adhesive tape.

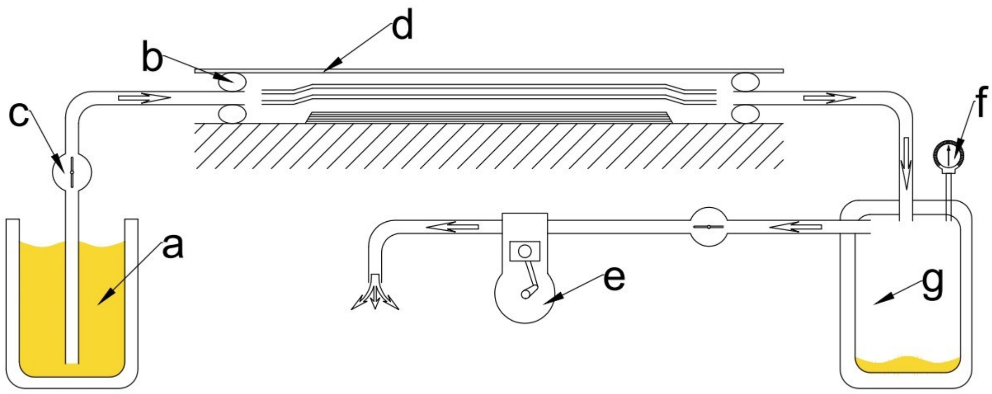

Fig. 2. RFI Technology (vacuum Infusion) Scheme. captions: a) resin; b) adhesive tape; c) starting valve; d) plastic coating; e) vacuum pump; f) barometer; g) vacuum chamber.

The gases are removed from the pre-prepared resin gas mixture with the hardener by vacuum pump. A technical vacuum (≈10^{-3} tor) is created in the chamber, preloading the assembly of fabrics and aluminum plates. The technical process of maintaining pressure in the chamber is controlled for 0.5 hours. After reaching a stable vacuum environment, resin is supplied in liquid form with the help of a special pipe with notches located in the chamber, the pipe wraps around the assembly of fabrics and plates (**Figure 3**).

Fig. 3. The process of making a sample for testing

Figure 4 shows the process of manufacturing structural elements using above-described technology. In the experiments, layers of aramid / glass; basalt; high molecular polyethylene fabrics and thin plates (0.5; 0.15; 0.05 mm) of aluminum alloys were used. The total thickness of the resulting composite was 4.1 ... 4.2 mm.

Fig. 4. Sample made using RFI technology

As for the choice of the binder component, as a rule, low viscosity resins (100-250 mPa/s) are used. Because this is a necessary condition for the full impregnation of fabric fibers. Moreover, during the diffusion process, it should not increase. If this is the case, we will get a change in the rate of resin infusion, which will attract an incomplete impregnation of the fibers. The tests were carried out using PREMIUM Epoxy Resin AB Glue (manufactured in Turkey). Figure 5 shows the obtained samples in the form of disks.

Some properties of samples are presented in **Table 1**.

Tab. 1. Some properties of polymer composite

#	specific gravity, g/cm^3	mass fraction of resin, %	note
1	1.45	9.3	glass fabric treated on both sides, 6 layers
2	1.46	33.1	9 layers of fiberglass, pre-treated on one side
3	1.36	11.4	Aluminum 0.5 mm 1 layer; aramid A350 11 layer
4	1.39	8.4	Aramid A350 – 4, A200 - 12 layers; aluminum 0.5 mm - 1, 0.15 mm - 1, 0.05 mm - 1 layer
5	1.45	19.7	Aramid A350 – 4, A200 - 8 layers; aluminum 0.5 mm - 1, 0.15 mm - 1, 0.05 mm - 1 layer
6	1.09	2.6	Aramid A350 - 17 layer
7	1.34	12.2	Aramid A350 - 10 layer; aluminum 0.5 mm - 1, 0.15 mm - 1, 0.05 mm - 1 layer

Based on the obtained results, composition #4 (Table 1) was selected for next stage of development of experiments. The structure of the metal-polymer composite in this case consists of: four layers of aramid (surface density 350 g/m^2); one layer of aluminum sheet 0.5 mm thick; four layers of aramid (surface density 200 g/m^2); one layer of aluminum sheet 0.15 mm thick; four layers of aramid (surface density 200 g/m^2); one layer of aluminum sheet 0.05 mm thick, and four layers of aramid (surface density 200 g/m^2).

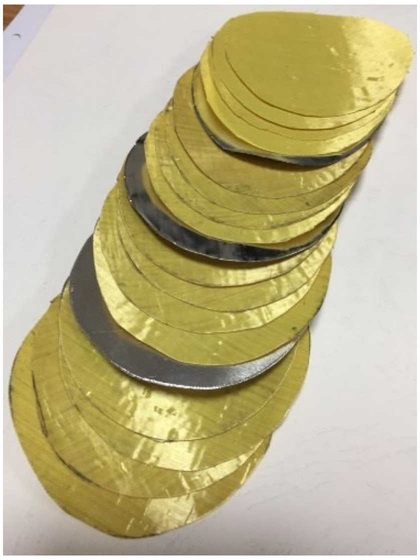

Fig. 5. Distribution of aluminum and amide layers in a metal-polymer composite

Figure 5 shows the distribution of aramid and aluminum alloys layers in the composite.

Conclusion

1. RFI technology has been developed in relation to the production of sandwich structures designed to protect against an explosive wave.
2. A metal-polymer composite consisting of aramid and glass fabrics and thin (0.05 ... 0.5 mm) layers of aluminum alloys is proposed to fabricate based RFI technology. An alternative, less scarce epoxy composition has been selected, analogous in its technological parameters (viscosity, gelation time, temperature peak of the polymerization process) to the compositions offered by the modern market.
3. According to RFI technology, structural elements for the middle layer of the sandwich structure are prepared. With their use, a sandwich panel was designed for subsequent testing for the effects of an explosion wave loading.

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