Recommendation for the Design of Composite Covers which Protect the Chassis of a Rail Vehicle

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Abstract

Fragments of research to formulate criteria allowing for the rational design of covers to protect against the destructive impact effects of small, sharp elements, are discussed. The motivation for this research was the result of the analysis of damage to composite covers which protect the chassis of a modern traction vehicle, moving at high speed on Polish railway routes. Such covers must have appropriate strength properties and high surface resistance to external damage, while limiting the influence of the impact of foreign elements on the cover, and the impact of external sources of noise and vibrations on the interior of the vehicle. They have a sandwich structure and are made of a polymer composite. General guidelines for the design of covers having the required properties are not known.

A method of analyzing the resistance of the cover to damage associated with the impact of elements with sharp edges and irregular shapes, using the LS-Dyna software, has been proposed. For the needs of the proposed method, a general model of the cover structure has been introduced. The assumptions adopted in determining the field of possible solutions are discussed. Particular attention is paid to the required structure of the cover, allowing for the differentiation of its properties observed in the longitudinal and transverse directions of the vehicle. Selected conclusions resulting from the research carried out so far, are presented.

Keywords: composite covers, vibroacoustic insulation of composite covers, impact resistance

1. Introduction

Railway vehicles which move on ballasted lines during operations, are exposed to the impacts of stones which constitute the mentioned ballast. Their high speed, very often above 200 km/h, causes air to lift the stones and to throw them against the equipment and structural parts located on the underframe. The impact of the ballast may cause damage to the impacted area and in some particular cases, may cause a serious incident. The next indicated inconvenience is noise caused by the air and the impacts. Because of these points, many manufactures equip their product with additional protective covers which are fixed to the underframe to isolate them from the destructive external factors. [1]

This protection may be realized in a few different ways, but mostly by using special steel plate or a polymer composite sandwich. Composites present some advantages compared to steel because of their better noise reduction, as well being lighter. That’s why modern trains are often protected by this material. On the other hand, using polymer composite materials to protect the chassis from the aggressive environment makes it necessary to be precisely sure of their properties because they are anisotropic. Hence there is a need to conduct simulations and real tests to confirm the efficiency and impact resistance of the designed cover.

According to this specific use of the composite, there is a lack of clear requirements and specifications which could be used by designers to increase the reliability of the mentioned covers. To study the damage features, one of the covers was unmounted from the train after a few months in service. This enabled the types and dimensions of the damages to be observed, and detailed microscopic observations were conducted. A few different types of damages were indicated, but during this investigation, smooth “cracks” were considered (Figure 1a) because of their overwhelming amount. This kind of damage is caused by lifting ballast, as indicated earlier, with impact speeds of about 70 m/s. To ensure safety of the underframe’s equipment, covers must present an adequate level of strength, which is described in detail as the stiffness, coefficient of friction, and direction of the fibers.

As well as high impact resistance, there are also other requirements that should be met by the composite cover. According to European Regulations, all combustible parts which are attached to trains need to meet requirements for the material’s fire behavior. One example of these requirements, which trains need to fulfil, is the European Standard - EN45545: Railway applications – Fire protection on railway vehicles. The objectives are to minimize the probability of a fire starting, to control the rate and extent of fire development, and to minimize the impact of the products of a fire on passengers. [2, 3] The materials must also meet the standards based on existing Fire Safety regulations for railway vehicles from the International Union of Railways (UIC).

Last but not least, another advantage of using a composite cover instead of a steel one, are the acoustic properties – the absorption and reflection of acoustic waves, which increases the comfort of the passengers. Many of the above presented requirements were analysed during different simulations and analyses performed to try to define a set of universal requirements for new designed composite covers.

2. Methods and materials

As a first step, a detailed analysis of the real existing cover was performed. One example of the typical damage is presented in Figure 1a.

a) b)

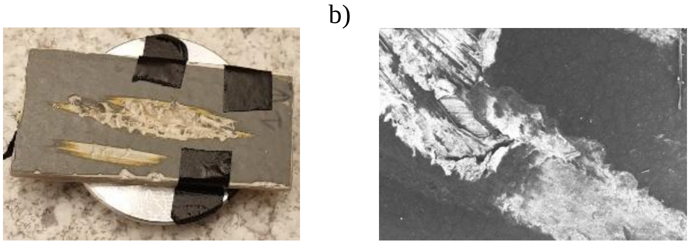


Figure 1. a) Specimen, example of longitudinal damage. Sample prepared for SEM observations. b) Detailed view of the damaged area

This was chosen and taken for further analysis. For the selected specimen, an SEM observation was carried out and an example view is presented in Figure 1b. It was noticed that all of the scratches are turned towards the vehicle's axis of movement. Taking this into account, it was proposed that the degree of damage depends on the directionality of the fibers in the outer layer. After a detailed analysis of the composite cover's structural damages, it was observed that the damaged edges looked ragged (Figure 1b). This means that during the scratch, the fibers were pulled out of the composite which increased the damaged area. This is because that in existing composites, the external plies are made from chopped strand mat with a chaotic strand orientation. To decrease the area of damages, unidirectional external plies could be used. In this configuration, a scratch will occur, but it will only produce a small area of damage.

2.1. *Influence of Coefficient of Friction*

As the next factor, the friction accompanied with the impact against the external surface was studied. To check the influence of the Coefficient of Friction (CoF) on the damage scope on the external surface of the composite, simulations using LS-Dyna software were performed. The main goal of using FEA methods is to replace a continuous system, which is applicable for real constructions, by a discrete system to allow for calculations [4]. At the first stage, the impactor was considered as a sharp edged wedge which is a meshed rigid part. As representative of the impacted reference surface, a newly created laminate was used. The details of the specimen are:

- Overall dimensions: 50 x 15 x 2.5 mm.
- Mechanical properties: Young's Modulus - X direction: 45 GPa, Y direction: 10 GPa , Z direction: 10 GPa,
- Poisson's Ratio XY: 0.3, YZ : 0.4, XZ: 0.3.
- The final laminate was built from 14 plies, which structure follows the order: $[0_2/90_2/45/\text{-}45_2/\text{-}45_2/45/90_2/0_2]_T$.

A series of simulations were performed, with varying impact angles (30°, 60°) and an impact velocity equal to 70 m/s. The impact velocity corresponds to the real condition of moving railway vehicles during normal operational service. The specimen was fixed on the whole area of the bottom surface, to ensure that no global elastic deformation occurs. In fact, the analysis is focused on local damages which is the reason why this simplification was implemented. Analyses were performed with different Coefficient of Friction values, which varied from 0.1 up to 0.9, by every 0.1. Values close to 0.9 means contact with a sticky rubberized coating, while 0.1 imitates a smooth surface. Both types of external surface can theoretically exist on a cover – a polished topcoat, or additionally, a painted layer to protect the composite from the external environment. For a pair of materials which are used to make the real considered cover and the impactor, CoF value is in the range of 0.35-0.55, which depends on surface condition.

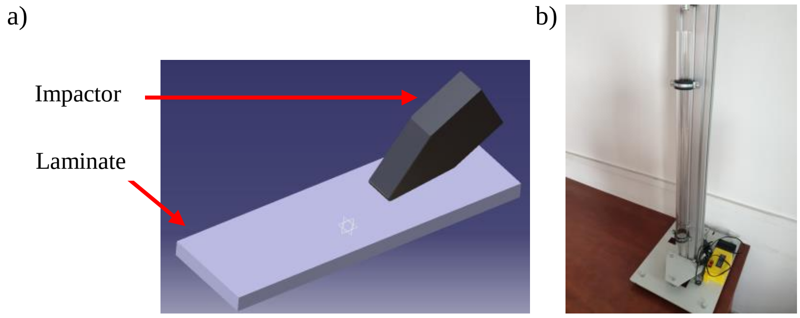


Figure 2. a) Simplified model representing the composite specimen and impactor.
b) Apparatus for determining the value of Coefficient of Restitution

The results of performed analysis are presented to show the dependency of the composite damage range on the value of the CoF and the angle of impact.

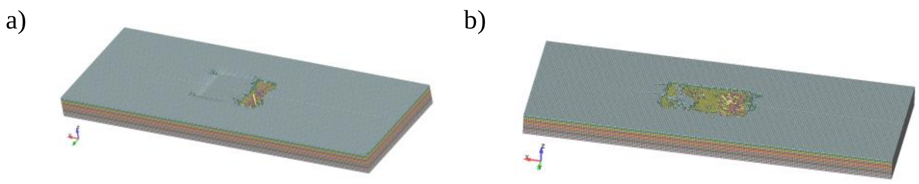


Figure 3. Differences in area of damage, impact angle 30 deg,
Coefficient of Friction: a) CoR = 0, b) CoR = 0.5 [5]

As seen in Figure 3, by increasing the CoF value, the area of damage increases. Furthermore, it was observed that with an increasing impact angle, the influence of the CoF on the damage scope reduces, because instead of a scratch, a puncture occurs.

2.2. *Influence of material elasticity*

A cover which protects the underframe of modern railway vehicles may have large overall dimensions, therefore, the rigidity of the cover in relation to the impact strength is not without significance. Because of that, studies on the relationship between the stiffness of the material and its impact resistance, were performed. For this purpose, relevant simulations of the impact for two different variants of the composite material were done. Both structures were sandwich ones, with the same cross-sectional order. The only differences were the coefficients for the foam between the external laminates. The elastic core has a density equal to 330 kg/m^3, and Young modulus E = 122 MPa, while those of the rigid core are 630 kg/m^3 and E = 286 MPa, respectively. [6]

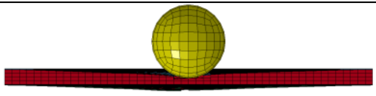
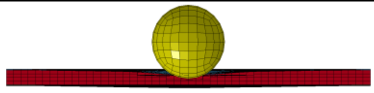
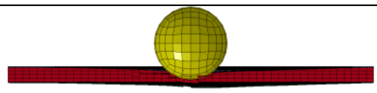
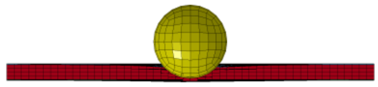
Time [ms]	Elastic foam inside	Rigid foam inside
5.65		
8.48		
21.92		

Figure 4. Differences in results of impact
with different rigidities of thesandwich's core at the same time

According to the comparison between the results in these two cases (Figure 4), it was observed that in the variant with the elastic foam, in first impact phase, because of the large deformation of the sandwich material, the top and bottom external layers were damaged, based on the idea that full penetration occurs faster than in the variant with the rigid core. In the rigid composite in the first phase of impact, a smaller deformation was observed, and thanks to that, the bottom external laminate wasn't damaged. In the next phase, when the core layer was fully penetrated, the ball deformed the bottom layer elastically, without penetration. In this case, the area of the damaged core is much larger than in the previous variant because of the elastic deformation of bottom layer. A large area of debonding between the core and external laminate is easily visible

To verify the elasticity properties of the materials, a dedicated apparatus was created according to standard EN ISO 10545-5 (Figure 2b). This allowed the determination of the value of Coefficient of Restitution (CoR) of the composite material. The CoR's value corresponds to the height of rebound of dropping a steel ball from a fixed height onto the test specimen. A value of CoR close to 0 means a perfectly inelastic collision, where the kinetic energy of the ball is converted into heat or deformation of the object. On the other hand, a value of CoR close to 1 means that the collision is perfectly elastic where no kinetic energy is dissipated. In the real world, the values of CoR are between $0 < e < 1$, depending on the type of material.

2.3. *Fire & Smoke requirements*

As covers designed for being use on trains need to meet the Fire &Smoke requirements, analysis based on European standards was performed. In the first step, to determine the appropriate level of fire protection requirements, the hazard level needs to be specified for the designed train. It must be determined based on a product of the relation between the running time for vehicles in the event of fire (operational category), and the type of the vehicle, for example, a double decked vehicle or a sleeping vehicle (design category). If the vehicle category is correctly defined, the hazard level can be designated. For a considered vehicle, determined as an Electric Multiple Unit, the operational category equals OC2 –which means the running time in the event of a fire shall be 4

minutes, a value which depends on the time needed to stop the movement and start the evacuation process. [7] The design category was specified as N – standard vehicles, according to Table 1, so this means a HL2 level of Material Safety requirement [3]
The designed parts reaction to fire depends on their intrinsic nature and also[2]:

- on the location of the materials within the design,
- on the shape and the layout of the materials,
- on the surface exposed and the relative mass.

Based on that, requirement R7 is finally dedicated for the considered external covers, because of the requirement list provided by the standards, which specifies:

- Location: External part – EX3, under the frame of external body shell,
- Specific use: External surfaces of the underframe structure of the body shell (floor) including paint and coating systems (thermal, design, and acoustic coating) and the protective floor panelling.

As a result, requirement R7, which needs to be met by the underframe's covering must pass the following standards:

- T02 based on ISO 5658-2 – Lateral flame spread,
- T03.01 based on ISO 5660-1 – Reaction to fire tests,
- T10.04 based on EN ISO 5659-2 – Plastics – Smoke generation,
- T11.01 based on EN45545-2 Annex C – Gas analysis in the smoke chamber.

For the above listed standards, more detailed requirements are described in the particular standards themselves. If a new composite material for the cover is to be created, then the tests presented above need to be performed and the relevant certificates should be sent to customer.

2.4. *Acoustic requirements and properties*

Noise requirements in the railway industry are determined by the Commission Decision, "*concerning the technical specification for interoperability relating to the subsystem "rolling stock – noise*" *of the trans-European conventional rail system*" (2006/66/EC). Based on that, in relation to noise inside the vehicle, the interior noise level of the passenger vehicles is not considered to be a basic parameter, but the noise level in the driver's cab is an issue. [7] Noise levels need to be kept at the lowest possible level by limiting the noise generated at source, as well as by additional insulation and sound absorbers.

The main sources of the noise and vibrations which come from the rail vehicle may be classified as: rolling noise, curve squeal, aerodynamic noise, ground noise, and bridge noise. [8, 9] One of the methods of rolling noise reduction is the use of shielding, for example, wheel mounted, bogie mounted, or vehicle mounted covers. Creating underframe protection covers as noise absorbing, enables the requirements to be met, and additional shields may be not required.

Noise absorption and insulation depends on the frequency, and the loss is higher for higher frequencies. In the case of considering a single-layer construction, such as a steel cover, transmission occurs according to the mass law, the more massive the structure is, the smaller the amount of sound passing through. For lightweight structures, the use of a filler in the form of an absorbent material results in better sound insulation. This points out the advantage of polymer composite sandwiches in comparison with steel metal covers.

3. Conclusions

The resistance of the cover to impacts by sharp stone edges may be investigated by means of LS-Dyna software. For the investigations, a steel bullet shape, representing the sharp edged and irregular stones, may be used as the impacting element. Simulations shall be done with different specimen angles of inclination, where all the angles should be lower than 45°. It has been assumed that chaotically moving stones before impact of train's underframe, mainly have a vertical velocity, with a low horizontal velocity value in relation to the ground. In this case, the component of horizontal speed during an impact is derived from the speed of the moving train. Since the train speed is much higher than the vertical speed of the stones, the resultant impact force is directed at an acute angle of a rage 0-45° relative to the surface of the underframe, and the value of the impact speed is close to the value of the speed of the moving train. In the case of the underframe cover, where the train speed reaches a maximum 70 m/s, the considered estimated impact energy value for the stones should not exceed 320 J. This value is calculated as kinetic energy taking into account the mentioned speed of the train and the mass of the impactor - 130g. As the impactor shape and its weight during the simulations are constant, the energy may be adjusted by variable velocity – lower operation speed, means lower impact energy.

By using LS Dyna analysis, it is possible to define the required stiffness and strength for each layer of material. As we considered a composite material, the layers are represented by plies and the stiffness value by the plies and foam between the external laminates. The proposed order of the directional composite layers in the external laminate is presented in Figure 5. The number of plies, their direction, and the density of the foam are the points of investigation. For external plies which are mostly exposed to impacts, it is recommended to use unidirectional plies with the direction related to vehicle movement axis. This facilitates a decrease in the damaged area once it occurs.

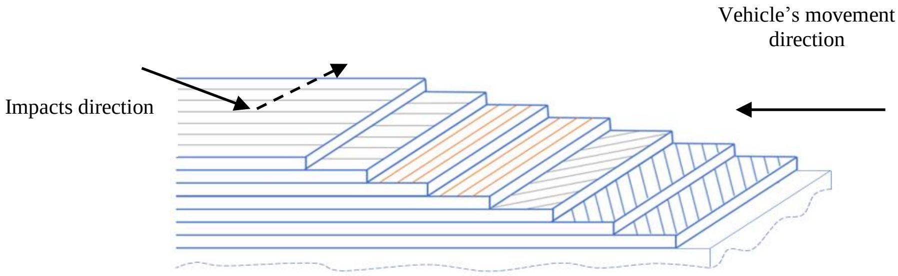


Figure 5. Proposal of external plies order

After the simulations, a real specimen should be created and then validation tests should be carried out to check and confirm the accuracy of the simulations. For this purpose, a test-bench dedicated to impact research should be used. An example of the work principles is presented in Figure 6.

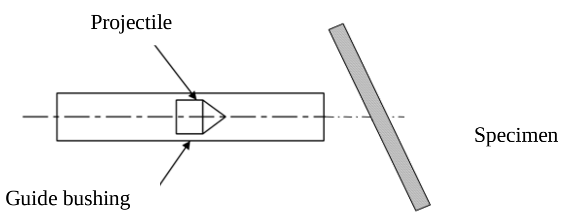


Figure 6. Scheme of impacting machine

After the real test, results, such as penetration depth, will be compared to validate the correctness of the assumptions made during the numerical simualtions.

Acknowledgment

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