Testing and analysis of a modernized freight wagon’s elements flammability

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Abstract. Paper concerns an issue of freight wagon modernization using composite materials. The goal of the project is to elongate the period between repairs (by better corrosion protection) and improve conditions of exploitation of modernized freight wagons (for example easier unloading during winter conditions – no freezes of the charge to the freight wagon body shell). Application of the composite panels to the freight wagon’s body shell was proposed as the solution that can solve mentioned problems. The composite panels composed of fiberglass and epoxy resin were proposed. They will be mounted on the body shell using rivet nuts. What is more the body shell of the modernized freight wagon will be painted using an anti-corrosion agent. In this paper the analysis of a flammability of the proposed composition (the composite plate made of fiberglass and epoxy resin mounted to the steel sheet with additional anti-corrosion agent) is presented. In the paper results of laboratory tests conducted according to international standards are presented. A series of samples of elements of modernized freight wagons was tested using the created laboratory stand. Obtained results were averaged and the proposed material was assigned to the one of the class of materials for their combustibility.

1. Introduction

Nowadays, a lot of effort is spent on development of any types of devices that are used by a human because new materials and new technologies are opening brand new possibilities before designers and engineers [1-3]. They have the opportunity to apply new materials and new methodology to design devices and systems that, for example are more effective, have better properties and lower costs of production [4-7]. The new opportunities are also results of the possibility of smart materials application, so the materials that can change one or more of their properties during operations and this change can be controlled [8-11]. On the other hand, computer aided methods of designing, manufacturing and product life cycle management are also powerful tools that helps to design and produce modern technical devices [12,13]. Modern systems include elements from different science areas, such as mechanics, electronics and informatics. Such connection brings new possibilities and new effects, so those systems can be called mechatronic systems [14-19]. In spite of all of those benefits of modern engineering it is also important to take into account that designed technical system should also has a positive influence onto realization of the principles of sustainable development by both, the method of its production, as well as the whole product life cycle. The principles of sustainable development is understood as to ensure the development of the present generation, among others in terms of economic growth and meet its needs, while maintaining opportunities for further
development and meet the needs of future generations. It is an idea that is committed to social justice through economic and environmental efficiency projects undertaken. In this light, the development of currently used technical devices that aim is to obtain their longer exploitation that will lower demand for raw materials and improve their use is the idea of the research project which results are presented in this paper as well as is the main idea of other researchers work [20-27].

This paper reports a part of works conducted in the research and development project entitled "Analytical and experimental studies and determination of the structural features of components and assemblies in innovative structure of repaired wagons". This project is realized within the Program of Applied Research by Institute of Engineering Processes Automation and Integrated Manufacturing Systems of Silesian University of Technology together with consortium partners: company DB Schenker Rail Poland SA and Germaz. The main objective of the project is to develop a technology of modernization of freight wagons for the transport of coal and aggregates, through the use of innovative materials and technologies to repair this type of wagons during periodic repairs. Actions which have been undertaken within the project are to improve the operating conditions considered types of wagons by increasing their resistance to corrosion and freezes transported cargo to the shell of the body in the winter conditions, and thus an easier unloading [28,29]. An additional objective is also verification of strength of modernized carriages and an estimation of the possibility of reducing their weight, while maintaining or increasing the permissible load. One of elements of the project is also to develop a system for diagnosing the technical condition of the modernized shell of wagon body during operation. For this purpose the use of non-destructive testing methods of technical state of constructions will be used, including methods that use the analysis of dynamic response of the object. Therefore research is conducted which examines the possibility of use of the foils with piezoelectric properties as sensors used in the system of vibration measurement of tested items [3,8,9]. These research efforts are a continuation of previous work related to the analysis of possibilities to use of composite materials as a part of the wagons boxes shell. Application of the composite panels to the freight wagon’s body shell was proposed as the solution that can solve mentioned problems during exploitation of freight wagons [13,28,29]. The composite panels composed of fiberglass and epoxy resin were proposed. They will be mounted on the body shell using rivet nuts. What is more the body shell of the modernized freight wagon will be painted using an anti-corrosion agent.

Application of the new materials in the considered freight wagons is connected with the need to conduct a series of studies of the proposed materials properties, taking into account their strength analysis, abrasion resistance, fatigue resistance, and other properties important because of the working conditions in the modernized freight wagons. Very important property that has strong influence onto the safety of the modernized freight wagons exploitation is the verification of the new elements flammability.

2. Method of testing of a modernized freight wagon’s elements flammability

In this paper the analysis of a flammability of the proposed composition (the composite plate made of fiberglass and epoxy resin mounted to the steel sheet with additional anti-corrosion agent) is presented. The composite panels mounted on the modernized freight wagon’s doors and walls are presented in Fig. 1. The flammability is also one of the very important properties taking into account all requirements for rail infrastructure. Composite materials are used not only to provide adequate mechanical properties, but also the electrical, thermal, tribological, related to work in different environments. Composites are of great interest for their excellent mechanical properties, durability and a light weight density. Fiber-reinforced composite materials are usually used to provide enhanced static and fatigue strength and rigidity, which are obtained by introducing resistant and rigid fibers to matrix. Warp transmits only the load applied to the fibers. Composite materials of this group have high mechanical properties both at room temperature and at elevated temperatures. Glass fibers are the oldest, cheapest and most commonly used fiber used for reinforcement of composites. Same fibers are widely used in the automotive, aerospace, electronics, boat building, electrical engineering, industrial engineering. Examples of products made of composite polymer matrix reinforced with fiberglass are
hulls of airplanes and gliders, coachwork car, hulls, tanks and pipes in the chemical industry, sports and recreation equipment.

Figure 1. The composite panels mounted on the modernized freight wagon’s doors and wall.

Glass-epoxy composites based on epoxy resin belong to the group of chemically hardenable materials. They are the result of fiberglass saturation and compressed into a layer. This type of composite is distinguished by the following features: very good mechanical properties and insulation, high parameter bending strength and compressive strength with low weight, wide range of applications, low water absorption.

Taking into account the proposed composite panels’ application it was important to verify their flammability. During the combustion of polymeric materials there is a series of negative physico-chemical reactions, such as weight loss of material, smoke, and further it is often harmful toxic pyrolysis products, the persistence of high temperatures and a breach of the mechanical strength of the material. These negative consequences can lead to situations that endanger human life or result in high material losses. There are many standards and methods described in them, which, when applied will allow the observation of the material and how it will behave under specific conditions during the flammability test, in order to assess the category of fire resistance material and decide whether the material used is safe to perform its function. Small thermal stability and flammability of composites is definitely not desirable feature among this group of materials, it results in changes in the physical and chemical structure of the composite which is subjected to high temperatures. These changes are evaluated by different properties depending on the acquired procedures. Flammability of composite is determined by their ability to start the combustion and then the spread of fire. For example, polymers used as the outer shell of the spacecraft must be capable of withstanding 400 hours at a temperature of 350° C or 80 hours at a temperature of 550° C or a few minutes at a temperature of 3000-8000 °C. In terms of assessing the flammability of the material and its behaviour during the smoking various types of test methods can be apply, in which different parameters are determined, such as:

- flammability, measured as the time of smoking and glowing of sample after removal of the flame of the burner and the measurement of the length of unburned section of the sample,
• oxygen index,
• content of harmful substances in the products of decomposition under the influence of temperature,
• weight loss, fast weight loss, temperature changes of physical-chemical,
• time that is necessary to start the combustion process, rate of heat release, smoke production rate, the total amount of heat and smoke generated, surface area darkened by smoke, the rate of weight loss, effective heat of combustion at a given intensity of radiation.

Important are characteristics of polymers at elevated temperature:
• thermal stability - described as upper temperature limit of their possible application under load or starting temperature of decomposition measured using thermogravimetry,
• flammability - assessed as a characteristic of a substance that is able to burn [30].

In the presented work flammability of the modernized freight wagons elements was measured based on the EN 60695-11-10 Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods [31], which describes the methods for testing the flammability of composite materials. In agreement with this standard a test stand was designed. Using the stand it was possible to carry out the study of the material in accordance with the recommendations of this standard. Described diagram of the stand is presented in Fig.2 [31]. During the realized tests the method B - an attempt of vertical burning was used to research the flammability of the analysed material.

![Diagram of the stand for flammability testing using an attempt of vertical burning method.](image)

**Figure 2.** Diagram of the stand for flammability testing using an attempt of vertical burning method.

Because of the need to prepare the samples in the form of composite panels joined with steel sheet by means of rivet nuts the dimensions were adopted as 130x20 mm. The thickness of the composite panel is 6.5 mm and the steel sheet thickness is 4 mm. Prior to testing five samples must be acclimatized with a dryer with air circulation at 70 °C for 168 hours ± 2 hours and then cool down by the extractor for at least 4 hours, taken out samples must be subjected to the test in 30 minutes. This process causes the aging of the material so that you can verify the impact on the flammability of a process operation of the material. Moreover five samples must be conditioned at 23 °C for at least 48
hours and must be tested in an hour after the preparation. In the study a composite panel which has been already used in operating conditions as the cladding of the freight wagon body was used. For the second case new composite, not subjected to the exploitation was performed and air-conditioned in room temperature. During the study the five samples of each type was performed and tested:

- composite panel which has been already used in operating conditions;
- new composite panel;
- composite panel which has been already used in operating conditions joined with the steel sheet by rivet nuts and painted using an anti-corrosion agent;
- new composite panel joined with the steel sheet by rivet nuts and painted using an anti-corrosion agent.

The composite panel which has been already used in operating conditions was made of six layers of a fiberglass fabric having a basis weight 450 g/m². As the matrix a Synolite 8388 resin was used and the composite was made by spraying moulding. In the second case eight layers of a fiberglass fabric having a basis weight 1000 g/m² were used. The epoxy resin LG700 and hardener HG700 were used and mixed in a proportion of 100 to 30. The composite was hand made.

![Composite panel](image)

**Figure 3.** An example of tested piece - composite panel joined with the steel sheet by rivet nuts painted using an anti-corrosion agent.

In agreement with the on the EN 60695-11-10 standard, during measurements the tested sample in the form of a rectangular bar is fixed vertically at one end and the other free end is subjected to a testing flame of 50 W for 10 seconds. Then, the flame is moved away to a safe distance, where it will not interact with the sample and the burning time of the tested material is measured. On the expiry of the fire the tested sample is again subjected to the flame also for 10 seconds. In the next step the torch is removed to a safe distance from the sample and time of burning and glowing is measured. Flammability of the tested sample is assessed by measuring the time of burning and glowing as well as by measurements of burned area and falling particles. The laboratory stand for testing the flammability of analysed components is presented in Fig. 4.

In order to analyse the results of each set of five tested samples it is necessary to calculate the total burning duration \( t_f \) in seconds, based on the following equation:

\[
    t_f = \sum_{i=1}^{5} (t_{1,i} + t_{2,i}),
\]  

where \( t_{1,i} \) and \( t_{2,i} \) are the burning and glowing times of the sample, respectively.
where $t_1$ denotes time of tested piece burning after it was first subjected to a testing flame and $t_2$ is the time of burning after the second application of the torch. Then the tested material can be classified to one of categories presented in Tab. 1.

![Image](image_url)

**Figure 4.** The laboratory stand for testing the flammability of analysed components.

**Table 1.** Classification of the flammability of tested components [31].

| The criteria                                | Category of flammability |
|---------------------------------------------|--------------------------|
| Burning duration of a single sample ($t_1$ and $t_2$) | V-0 ≤ 10s, V-1 ≤ 30s, V-2 ≤ 30s |
| Total duration of the set of five tested samples $t_f$ | V-0 ≤ 50s, V-1 ≤ 250s, V-2 ≤ 250s |
| Duration of burning and glowing of a single sample ($t_1$ and $t_2$) | V-0 ≤ 30s, V-1 ≤ 60s, V-2 ≤ 60s |
| Did flames or glow shift to the clamped end? | No, No, No |
| Was cotton pad inflamed by the falling particles? | No, No, Yes |

Taking into account presented method of flammability analysis the time of burning of a series of tested pieces were measured and analysed.

3. Results and conclusions

The flammability of series of five tested pieces was verified in agreement with assumed standard of measurements. At the first step five tested pieces of composite panel which has been already used in operating conditions as well as five tested pieces of new composite panel were tested. In both cases very similar results were obtained. The tested material burned totally after the first subjected to a testing flame. The tested pieces after 30 seconds from the testing torch application are presented in Fig. 5. It can be noticed that the tested composite panel which has been already used in operating conditions burned faster, what is more extraction of a large amount of particles that were thrown out from the composite panel. It was observed after about 45 seconds from the moment that the torch was removed from the sample. It is presented in Fig. 6.
Figure 5. Tested pieces after 30 seconds from the testing torch application: a) the new composite panel, b) the composite panel which has been already used in operating conditions

Figure 6. The composite panel which has been already used in operating conditions after 45 seconds from the moment that the torch was removed from the sample
In the next step the flammability of the same types of composite panels joined with the steel sheet by rivet nuts and painted using the anti-corrosion agent was verified.

In case of the panel made of new composite the results are as follows:

- The burning duration of a single sample from the first fire application \(t_1\) ranged from 1.5 to 2.5 seconds in the case of a whole set of five samples, so the material could be classified in category V - 0 but after application of a burner second time the burning duration \(t_2\) was from 47 to 54 seconds what exceeds the scope of each category.
- The total burning duration \(t_f\) of the whole set of samples was 263 seconds and it exceeds allowed time of about 13 seconds.
- The burning duration and the time of glowing of a single sample after the second application of the flame \((t_2 + t_3)\) was from 50 to 54 seconds, so the material could be classified in the category of V-1.
- Flame or glow did not achieve the clamped end of the piece.
- The cotton pad has not been set on fire by particles or molten drips.

In case of the panel which has been already used in operating conditions the results are as follows:

- The burning duration of a single sample from the first fire application \(t_1\) ranged from 45 to 70 seconds and it exceeds allowed time.
- The total burning duration \(t_f\) of the whole set of samples was 421.5 seconds and it exceeds allowed time of about 13 seconds.
- The burning duration and the time of glowing of a single sample after the second application of the flame \((t_2 + t_3)\) was from 21 to 50 seconds, so the material could be classified in the category of V-1.
- Flame or glow did not achieve the clamped end of the piece.
- The cotton pad has not been set on fire by particles or molten drips.

Taking into account the results of the carried out tests the tested materials could not be classified in any of the categories described in the EN 60695-11-10 standard. In agreement with the standard in such situation when the results are not in accordance with the specified criteria, the tested material cannot be classified by this test method. In future tests the other standards and methods of flammability verification will be carried out. As the result of the carried out tests in agreement with the EN 60695-11-10 standard: Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods, it can be concluded that the proposed composition of composite panel joined with the steel sheet by rivet nuts and painted using an anti-corrosion agent is more resistant to the flame than only a single composite panel but still it has a high flammability. Laboratory conditions may not reflect the real conditions of use of the material. It is recommended further research to accurately determine the fire hazard that needs to take into account more factors such as:

- amount of fuel,
- intensity of burning (rate of heat release),
- the products of combustion,
- the intensity of the fire,
- configuration of material on the real object,
- ventilation conditions.

In the future work also the methods for increase the fire resistance of the proposed composites must be carried out.

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