Geometrical structure analysis of combustible and non-combustible foams by computed tomography

B Gapiński¹, M Wieczorowski¹, N. Swojak¹, M Szymański²
¹ Poznan University of Technology, Faculty of Mechanical Engineering and Management, Institute of Mechanical Technology, Division of Metrology and Measurement Systems, pl. M. Skłodowskiej-Curie 5, PL60965 Poznań, Poland
² STER Sp. z o.o. Człuchowska 12, PL60434 Poznań, Poland

E-mail: bartosz.gapinski@put.poznan.pl

Abstract. Materials of spongy structure are commonly used in public transport vehicles. In the case of seats, they enable passengers to improve their comfort. However, one of the biggest problems is the combustibility of foams made of synthetic materials. On the occasion of fire, a high temperature may arise, accompanied by the emission of health- and life-threatening gases. Therefore, special non-combustible foams are used in order to increase the travellers’ safety during a possible fire. In this paper, we presented the comparison of geometrical structure between combustible and non-combustible foams. The study was conducted using computed tomography (CT). This method enables scientists to make a 3D evaluation of an examined material internal structure. Moreover, the lack of measurement pressure allows for making the assessments without any deformations to the tested material. Our findings were based on the observation of differences between geometrical structures of combustible and non-combustible foams, originating from differences in their production processes. CT is a novel tool to get more information on the inspected foams. Still and all, it will not replace combustibility, resistance and exploitation tests.

1. Introduction

Public transport vehicles may be divided into road and rail ones. The former covers two basic groups, i.e. buses and coaches. In turn, the latter is described by three groups, namely trams, trains and tubes. Each of the above-mentioned groups of vehicles is characterized by a set of individual demands regarding travellers’ safety and comfort. These requirements are contained in the EU Directives and national regulations. In a number of cases, they are also defined directly by the users [1].

One of the factors that affect the travellers’ comfort, particularly during long-distance routes, is an appropriate configuration and shape of seats and the use of foams characterized by an adequately selected hardness. This aspect is of utmost importance with reference to seats designed for railway carriages, in which it quite often takes several hours for passengers to reach their destinations. For travellers’ safety reasons, a strong concern is focused on the passengers’ prevention from the effects of possible fire. This approach regards all the used materials. More specifically, due to a considerable number of seats in a railway carriage, seat foams are applied to an extremely detailed inspection, which forces the manufacturers to supply high technology non-combustible foams [2, 3, 4].

¹ Bartosz Gapiński; bartosz.gapinski@put.poznan.pl
2. Computed tomography
Computed tomography (CT) has been known since the 70s of the 20th century. However, no earlier than in the first decade of the 21st century, results in terms of qualitative and quantitative analysis met the requirements for measurement devices used in a broadly understood mechanical engineering. Computed tomography has a wide range of good points, from which the paramount is a possibility to observe and measure the internal structure of an examined object with no need to destroy it [5, 6, 7]. It is used both to examine the internal structure of materials, check the imperfections in their manufacture (e.g. porosity in castings), or evaluate the quality and reliability of the assembly. In the above-mentioned areas, this is a method irreplaceable by any others [8, 9, 10].

3. Measurements of combustible and non-combustible foams
The examination covered two types of polyurethane foams, namely combustive and non-combustive. Protection against combustibility is provided by the addition of foamed graphite. This results in changing the foam colour from light milk-white into grey (Fig 1).

![Figure 1. The images of combustible (left) and non-combustible foams (right)](image1)

The combustible foam is characterized by a homogenous distribution of cells. Yet, the addition of foamed graphite modifies its structure – its particles are left inside its walls in the form of dark inclusions (Fig. 2), and single large-sized cells arise (Fig. 3).

![Figure 2. X-ray image of combustible foam (left) and non-combustible foam (right)](image2)

![Figure 3. A 3D image acquired from CT: combustible foam (left) and non-combustible foam (right)](image3)
A CT scan of foam portion is visualized in Figure 3. For each single sample, 2000 capture measurements were taken using a directional X-ray source. Each capture is a mean value out of 5 images registered within 500 ms; voltage 70 kV and current 250 µA. Based on a spacious image of the examined objects, the calculation of porosity distribution was made. The results were presented in a plot (Fig. 4). In order to achieve a better comparison, the upper limit of the plot Y axis was adjusted to 4 mm$^3$. In the case of combustible and non-combustible foams, the largest cell volumes were 3.811 mm$^3$ and 14.242 mm$^3$, respectively. Based on measured values presented in Fig. 4, I have asserted that air cells making up the non-combustible foam are larger and more prolific than the ones of the combustible foam. Air pockets of such an origin form an effective barrier against fire spreading.

![Figure 4. Cell count plotted against cell volume for combustible and non-combustible foams.](image)

A 3D image obtained from under a computed tomograph also allows for the analysis and visualization of cell distribution inside the foam spongy structure. Selected sections of combustible and non-combustible foams were illustrated in Fig. 5. My findings fully reflect data presented in Fig. 4.

![Figure 5. Cell distribution and the analysis of cell volume: combustible foam (left) and non-combustible foam (right).](image)

Similarly to the cell size and distribution, wall thickness of the sponge-forming polyurethane is as much important. Strut thickness is visualized in Fig. 6. Most of the walls are very thin and do not exceed several micrometres. Apart from those tiny ones, an inconsiderable number of walls of greater thicknesses can be distinguished. In the case of combustible foams, the wall thickness ranges between 0.04 and 0.13 mm. For non-combustible foams, this parameter displays values from the following...
interval: 0.03-0.24 mm. Higher thickness values for the non-combustible foams stem from the addition of foamed graphite to the structure of the discussed material.

Figure 6. Strut thickness distribution: combustible foam (left) and non-combustible foam (right).

4. Conclusion
The paper compares the geometrical structures of combustible and non-combustible foams. An admixture of foamed graphite to polyurethane foam modifies the foam geometrical structure. It induces the formation of thicker walls and air cells of greater volume. Graphite particles distributed inside the foam structure makes it flame retardant. In the event of fire contact, they give rise to dieseling areas that prevent from fire spreading. Unattainable by means of different techniques, my study fully confirms the usefulness of computed tomography in the assessment of foam geometrical structures.

5. Acknowledgments
The part of presented research results were funded with grants for education allocated by the Ministry of Science and Higher Education in Poland No. 02/22/DSPB/1432 and part of this work was supported by the Polish National Centre of Research and Development (project contract No. Innotech In-Tech K2/IN2/58/182896/NCBR/12; “Elaboration of manufacturing technology of new generation ultralight seats for public transportation fulfilling requirements of UE directives, UN regulations and American White Book”).

6. References
[1] Grundlagen für die Konstruktion und Prüfung von Fahrgastsitzen in Schienenfahrzeugen; Deutsche Bahn AG, Leipzig
[2] Standard CSN EN 45545-1: Railway applications - Fire protection on railway vehicles 2013 International Organization for Standardization, Geneva
[3] Standard UIC564-2: Regulations relating to fire protection and firefighting measures in passenger carrying railway vehicles or assimilated vehicles used on international services 2xxx International union of railways, Paris
[4] Hirschler M M 2008 Polym. Adv. Technol.19: 521–529
[5] Weißenborn O, Geller S, Gude M, Post F, Praetorius S, Voigt A and Aland S 2016 ECCM17 17th European Conference on Composite Materials Munich, Germany
[6] Chen Y, Das R and Battley M 2017 Composite Structures 159 784–799
[7] Maszybrocka J, Stwora A, Gapinski B, Skrabalak G and Karolus M 2017 Bull. Pol. Ac.: Tech. 65(1) 85-92
[8] Lorettz M, Maire E and Baillis D 2008 Advanced Engineering Materials 10(4) 352-360
[9] Rajak D K, Kumaraswamidhas L A and Das S 2017 Rev. Adv. Mater. Sci. 48 68-86
[10] Montminy M D, Tannenbaum A R and Macosko C W 2004 Journal of Colloid and Interface Science 280 202–211