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NUMERICAL RESEARCH OF IMPACT OF TUBE WALL THICKNESS AND POLYURETHANE FOAM DENSITY ON ABSORPTION CHARACTERISTICS

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***Abstract** – Implementation of collision energy absorber in bearing structure of the current railway vehicles presents a big engineering challenge. A main challenge is to develop compact absorber suitable for installation in a very limited space at the front beam. Beside to compact dimensions, designer has a task to create absorber with required absorption power and the most acceptable deformation scenario during energy absorption. Previous investigations of the different types of collision energy absorbers have shown that shrinking tube absorber gives the best output parameters. The subject of this paper is numerical research of the impact of tube wall thickness and polyurethane (PU) foam density on energy absorption and specific energy absorption of shrinking tube absorber. Using this type of absorber, energy absorption arises: 1) elastic-plastic deformation of tube wall, 2) friction between absorption elements and 3) compression of PU foam inside the tube. The paper presents numerical simulations performed in ANSYS Workbench software using the quasi-static behavior and a plane axi-symmetric model. Analysis of empty and foam filled tube were done. Validation of developed numerical model was realized by comparison with experimental results obtained via previous quasi-static tests. Results of numerical simulations showed that increase of wall thickness leads to significant increase of mass and deformation resistance, respectively. Greater mass in comparison with purpose and benefit of absorber is absolutely acceptable, but a sharp increase of the deformation resistance may induce uncontrolled distortions of wagon structure before a fully utilization of absorber. On the other side, increase of PU density gives lower increase of deformation resistance in comparison to previous one and negligible increase of mass. Mentioned parameters were carefully analyzed and influence of them on energy absorption and specific energy absorption was discussed. Presented numerical analyses showed that it is possible precisely to set absorption characteristics without performing experimental tests, and to reduce development costs by using validated numerical model.*

Keywords – Railway Vehicles, Numerical Simulations, Energy Absorber, PU Foam

1. INTRODUCTION

Perennial work in field of passive safety of railway vehicles gave a many useful results used for development of different types of collision energy absorbers as well as numerical models that can help in design of absorption elements. Shrinking tube absorber showed the most acceptable absorption characteristics in comparison with other types. Subject of this paper is development of numerical model of shrinking foam filled tube absorber, validation of it and analyses of impact of main parameters. The aim is to form numerical model simplified as much as possible, but which must correct simulate shrinking process of the tube and compression of rigid polyurethane (PU) foam inside the tube. Base for forming of numerical model are previous experimental investigations [1-3]. Results presented in these papers show that is possible to use numerical simulations in design process to get absorption elements which can absorb requested amount of collision kinetic energy. In addition, material model used in these investigations showed as acceptable and gave realistic image of behavior of tube material during deformation process. Properties of rigid PU foam of density 175 kg/m^3 were recorded via test of

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PU foam specimen under axial load. The main parameters for a few different density of PU foam, next to previous one, were taken from experimental results presented in the papers [4-7].

Numerical simulations of axial load of empty and foam filled seamless tubes were performed. Results obtained by these calculations were used for analyses of impact of different parameters on the absorbed energy (AE) and the specific absorbed energy (SAE).

2. NUMERICAL SIMULATIONS

Quasi-static numerical simulations by using ANSYS Workbench software package on the plane axi-symmetric models were realized, Fig. 1.

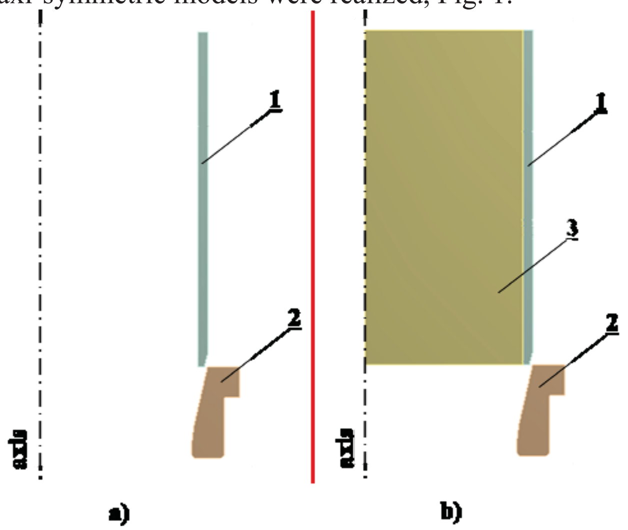

Fig.1. Numerical models: a) empty tube and b) foam filled tube (1-semaless tube, 2-cone bushing and 3-PU foam)

Axial symmetry of absorber configurations, empty tube and foam filled tubes, give possibility for using plane axisymmetric numerical model. This option allows very good simulation of material behavior and way of deformation, and significant decrease of calculation time on the other side.

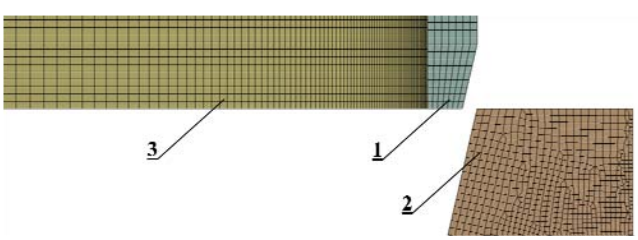

Fig.2. Meshed model: 1-semaless tube, 2-cone bushing and 3-PU foam

Fig. 2 shows meshed elements. During deformation, reaction force was measured on defined vertical stroke. Value of stroke was 210 mm (length of the seamless tube is 220 mm). Adopted value of friction coefficient, between seamless tube and cone bushing, is 0.35. This value is adopted in accordance to results [2, 8].

2.1. Material properties

Absorber were formed from semaples tube, cone bushing and PU foam filler inside the tube. Seamless tubes were made from low carbon steel in grade P235T1 with dimensions ∅219.1/δx220 mm. Parameter "δ" is a wall thickness that has different values in the numerical simulations (2.5, 4, 5.9, 6.7, 8.0 and 10.0 mm). Cone bushing were made from quench and tempered carbon steel in grade C45 with dimensions ∅220/199/13°x60 mm. Rigid PU foam was prepared by mixing liquid polyisocyanate with liquid polyol directly in the tube, what was induced bonded PU foam for the tube wall. Main material properties of tube, cone bushing and PU foam of density 175 kg/m^3 are shown in Table 1. Bilinear material model of the tube was used.

Tab. 1. Material properties

Component	Elastic modulus [MPa]	Tangent modulus [MPa]	Poisson ratio	Yield stress [MPa]
Seamless tube	2.1e5	1450	0.3	235
Cone bushing	2.1e5	-	0.3	430
PU foam 175 kg/m^3	66.1	-	0	1.4

3. RESULTS

Numerical simulations of energy absorbtion of foam filled tube absorber were performed for six different values of wall thickness and six different values of density of PU foam. First step was validation of developed numerical model using results obtained by previous research papers. After that analyses of impact of different values of tube wall thickness and foam density were performed.

3.1. Validation of developed numerical model

Fig. 3 shows force vs. stroke diagram obtained by numerical simulations and experimental investigations of empty seamless tubes with wall thickness of 5.9 and 6.7 mm. Based on this diagram can be concluded that results of experimental investigations and numerical simulations are in a good correlation. Validation of numerical model was performed for two different wall thicknesses of seamless tubes.

Fig. 4 shows samples after finished deformation process obtained by experimental investigations (a) and numerical simulations (b). At the experimental and numerical samples three characteristic zones on the tube wall show very similar shape of deformation. Very close curve of flow of force and shape of deformation between experimental and numerical model validate developed numerical model for further analyses.

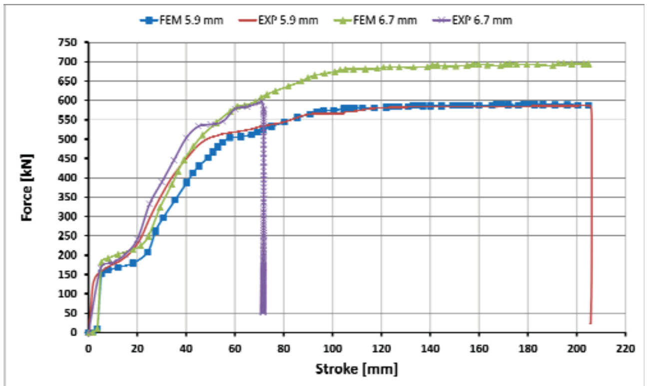

Fig. 3. Force vs. stroke diagram – validation numerical models

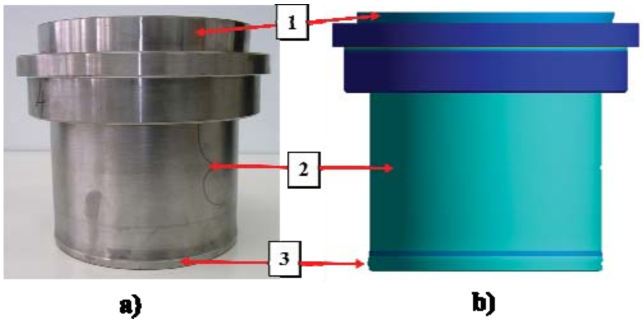

Fig. 4. Shape of deformation: a) experimental investigations and b) numerical simulations

3.2. Results of numerical simulations

After validation of developed numerical model, FEM analyses of absorption characteristics for different values of tube wall thickness and density of PU foam were done.

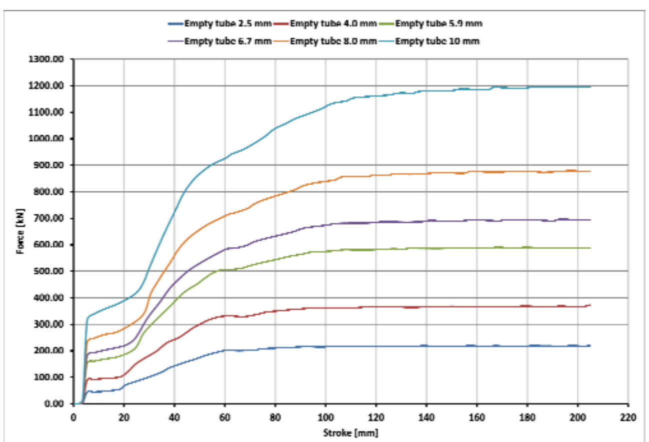

Fig. 5. Force vs. stroke diagram – empty tube

Fig. 5, 6 and 7 show force vs. stroke diagram for mentioned variation of parameters.

Using presented F(h) diagrams the main absorption parameters were calculated and formed diagrams AE/SAE vs. tube wall thickness/density of PU foam, Fig. 8-10.

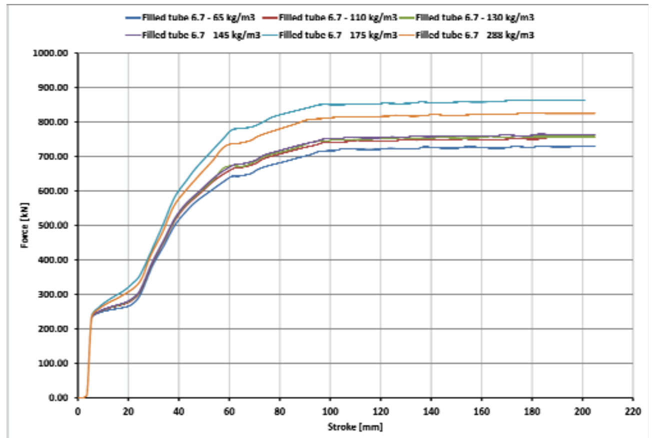

Fig. 6. Force vs. stroke diagram – foam filled tube – different density of PU foam

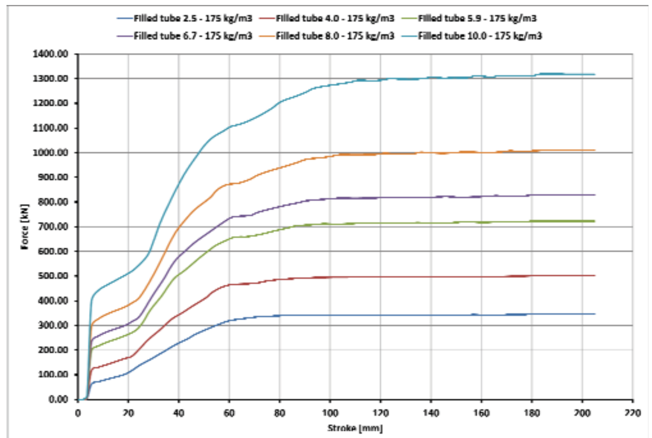

Fig. 7. Force vs. stroke diagram – foam filled tube – different density of wall thickness

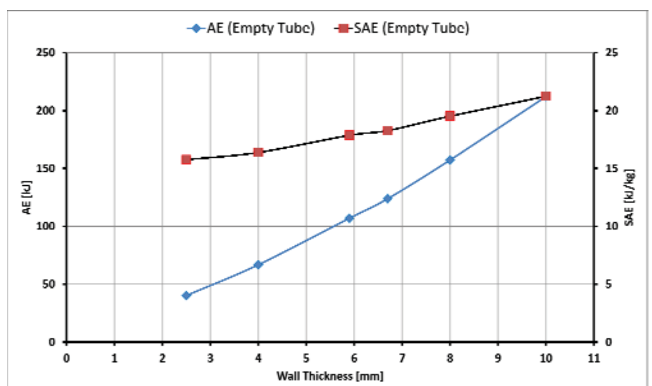

Fig. 8. AE/SAE vs. wall thickness – empty tube

In this diagram can be seen that AE significant increases with increase of wall thickness, what was expected. SAE slightly increases because increase of tube wall thickness leads to significant increase of tube mass. Fig. 9 shows similar change of AE and SAE for foam filled tube with constant density of 175 kg/m^3 and different values of wall thickness.

Fig 10. shows that increase of density leads to slightly increase of AE and decrease of SAE.

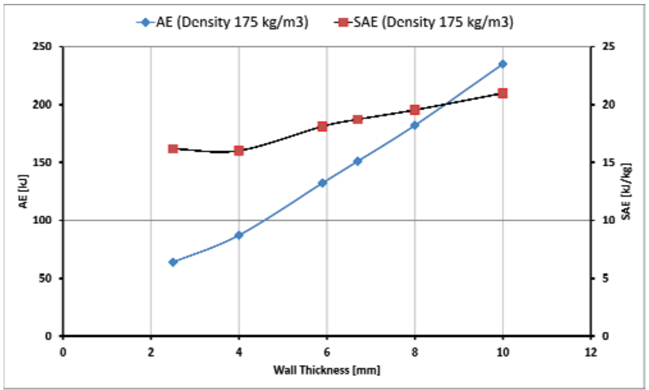

Fig. 9. AE/SAE vs. wall thickness – foam filled tube

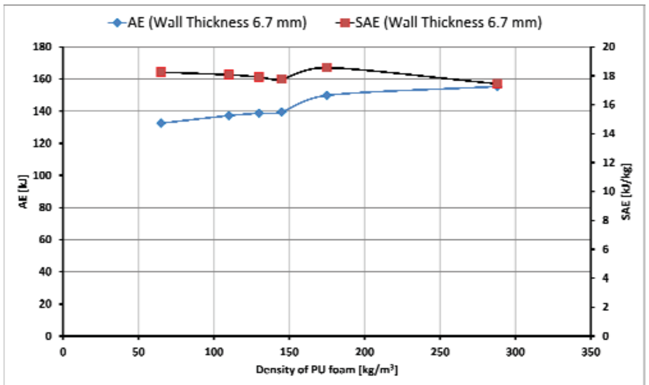

Fig. 10. AE/SAE vs. density of PU foam – foam filled tube

4. CONCLUSION

Purpose of collision energy absorber is to reduce collision consequences and to decrease injuries of passengers as well as increase safe of goods and prevent uncontrolled distortion of wagons structure. Results presented in this paper show that different parameters have lower or higher impact on absorbed energy. Change of wall thickness from 2.5 up to 10 mm can increase AE for about 5 times while change of density from 65 up to 288 kg/m^3 can increase AE for about 17%. Considering obtained results and requests for gradual introducing of force in bearing structure of wagons during collision use of rigid PU foam as a filler of tube presents very acceptable solution for fine tuning of absorption characteristic of shrinking tube energy absorber. Developed and validated numerical model in this paper can be used in design phase without need for additional experimental tests. In this way it is possible to reduce design costs in significant amount. Next step of the research of this type of absorber is to perform dynamic test of foam filled tube absorber. These results will complete the numerical model and provide opportunity for further use of it in dimensioning of foam filled absorption elements in accordance with the standard requests, without any additional experimental investigations.

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