Estudo numérico e experimental do impacto lateral em componentes feitos de material composto

English title

Numerical and experimental study of the lateral impact on composite components

Abstract

The present project plan is an extension of the ongoing research project 2020-366. Besides the lateral impact on metallic and composite flat plates, that is the stem of project 2020-366, two relevant studies are included in the project plan; (I) static and dynamic material characterization of polymeric composite with application in railway sleepers manufacturing and (II) numerical and experimental study of impact safety of Brazilian motorcycle helmets. All these three studies will consider safety and material response under dynamic loading.

Keywords: Dynamic response, Material characterization, Composite railroad sleeper, Motorcycle helmet, Lateral impact; Impact safety.

Introduction

The present research plan being proposed for 12 months and it includes three different studies in the field of dynamic response and material characterization. The present proposal is divided into three parts; (a) Lateral impact on flat plates (the original theme of research project 2020-366); (b) Static and dynamic material characterization of composite material for manufacturing railroad sleeper and (c) Impact safety study of Brazilian motorcycle helmets. These three projects are assigned to the GMSIE laboratory.

Part A: Lateral impact on flat specimens

This study is aimed to investigate the dynamic response of flat plates, made of Aluminum and sandwich composite, impacted by cubical projectiles. The effect of cube orientation on the impact behavior and failure modes will be considered in detail. The general overview of impact test configuration is presented in Fig. 1. Three different cube orientations will be considered against the flat plates, see Fig. 2. The number of valid tests for each orientation is presented in Table.1. A tolerance of ±5° is acceptable for the debris orientation.

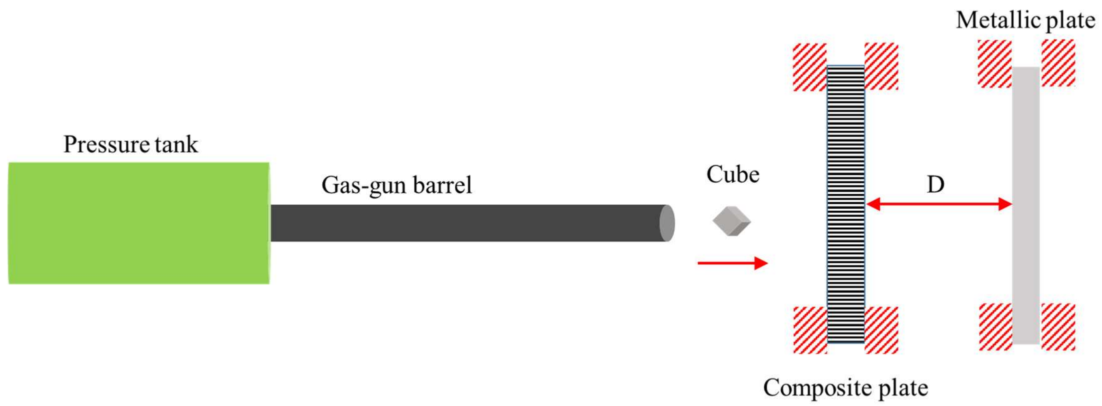
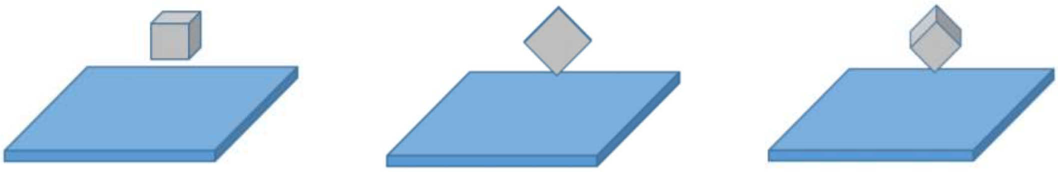


Fig.1. Overview of lateral impact test on plates.



(a) (b) (c)

Fig. 2. Cubical impactor orientation; (a) Side-on, (b) Edge-on and (c) Corner-on (Jordan and Naito 2014).

Table. 1. Required valid tests for each cube orientation.

Test Specimen Configurations	Debris Orientation		
	Side-on	Edge-on	Corner-on
01	07	07	07
02	07	07	07
03	07	07	07

This test is relevant to impact the airplane structure due to engine failure. The client has proposed two types of square plates to the GMSIE laboratory to be tested. One to represent the wing-fuselage fairing (sandwich composite) and another to represent the wing stub lower skin (Aluminum) of the airplane. For both plates, a free impact area of 130 mm x 130 mm should be provided by the test fixture, Fig. 3. The plates and cube will be provided by the client. Details of material and thickness are confidential.

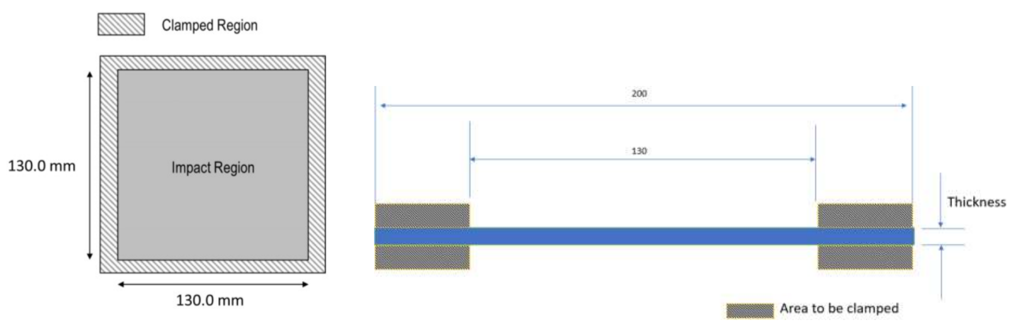


Fig. 3. General overview of the test sample and clamped area.

To clamp the plates a new fixture is designed during the last year, Fig 4. This fixture design has been sent to the client for approval and fabrication.

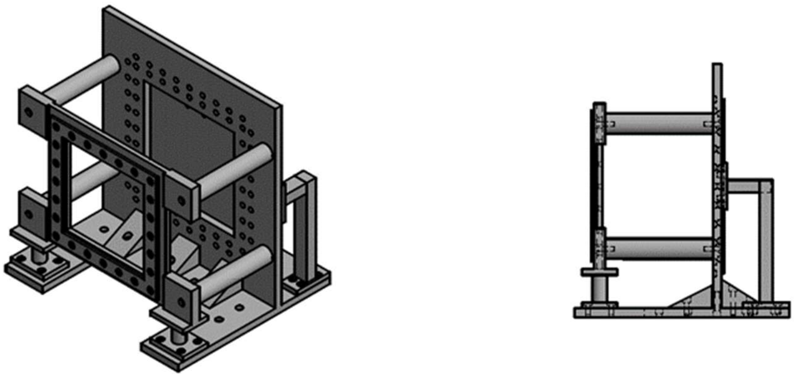
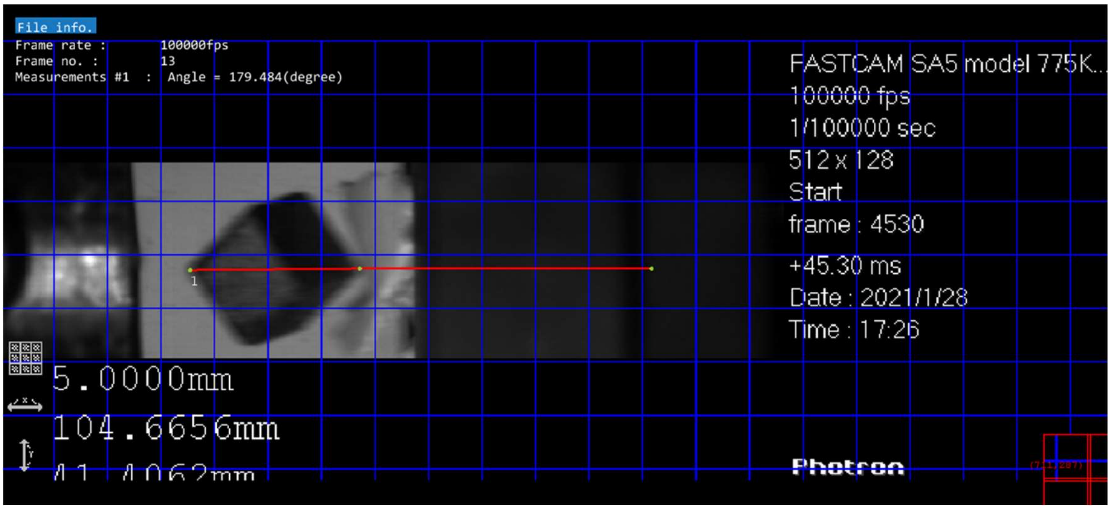


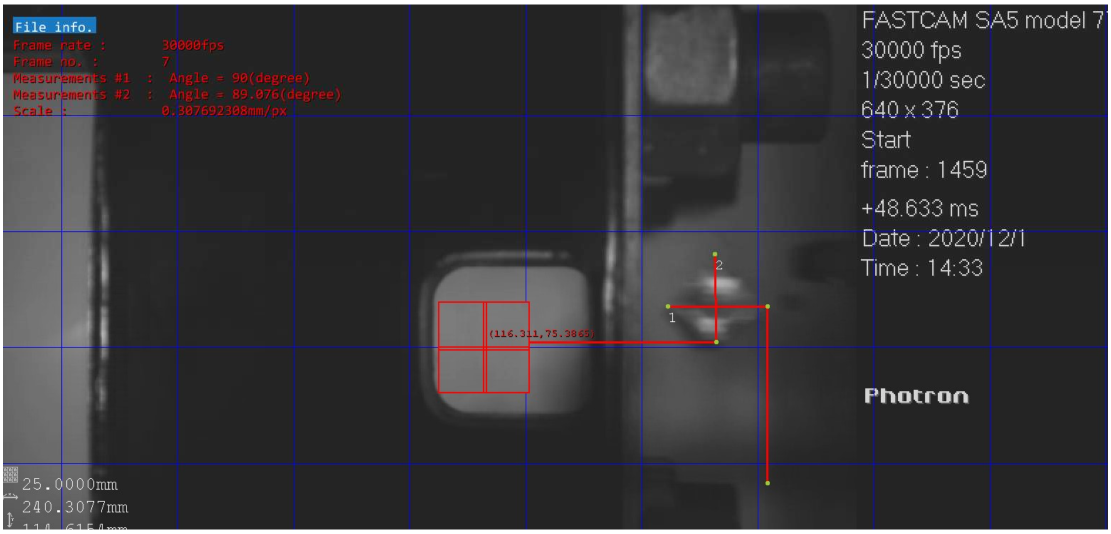
Fig. 4. New plate fixture (design needs to be approved).

The main challenging part of this study is launching cubical projectiles in an accurate orientation with 214 m/s velocity. To launch the cube using Sabot is necessary. During last year several models of Sabot were designed and printed with a 3D printer. The Sabot and projectiles were launched by using an old gas-gun facility (Fig. 5) available in the GMSIE laboratory. Accurate orientations were captured and analyzed from high-speed imaging, two examples of Edge-on and Corner-on orientations are presented in Fig, 6. High-speed cameras were used to measure the velocity of the impactor and check the orientation (side-on, edge-on, and corner-on).

Fig. 5. Available gas-gun in the GMSIE laboratory.



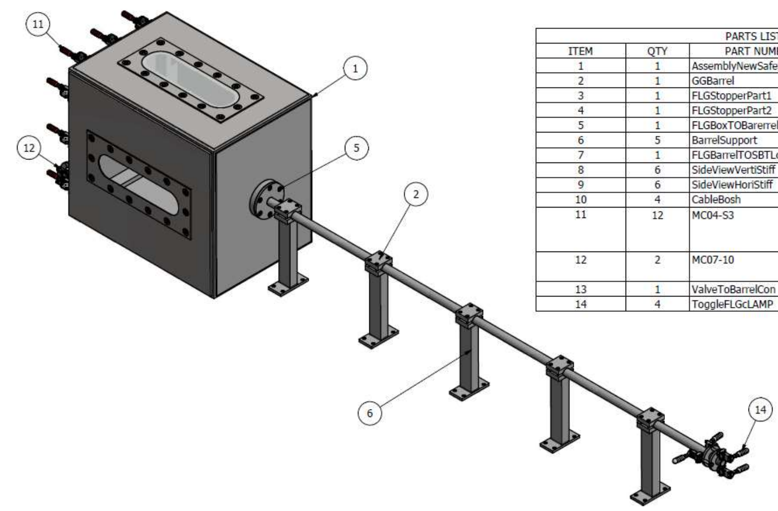
(a)



(b)

Fig. 6. Pretest analysis to check the cube orientation and velocity; (a) Corner-on test and (b) Edge-on test.

Since the maximum achievable projectile velocity with using the old gas-gun (at GMSIE laboratory) was lower than 214 m/s, a new gas-gun system with a longer barrel tube and safety vacuum box was designed (Fig. 7). The design is shared with the client for modification and manufacturing.



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	AssemblyNewSafetBox	
2	1	GGBarrel	
3	1	FLGStopperPart1	
4	1	FLGStopperPart2	
5	1	FLGBoxTOBarerrel	
6	5	BarrelSupport	
7	1	FLGBarrelTOSBTLoc	
8	6	SideViewVertiStiff	
9	6	SideViewHoriStiff	
10	4	CableBosh	
11	12	MC04-S3	MC04-3, MC04-S3-Toggle Clamps - Bottom Holder, Vertical Handle Type
12	2	MC07-10	MC07-10-Toggle Clamps Side Push (Flange Base)
13	1	ValveToBarrelCon	
14	4	ToggleFLGcLAMP	Description

Fig. 7. Proposed new gas-gun for lateral impact test (to be approved by the client).

The following results should be prepared at the final of the project and delivered to the client.

- Test setup (gas-gun) and test devices detailed description,
- Test procedure detailed description,
- Equipment calibration sheet,
- Speed and debris angle of impact,
- Mass of the debris,
- Data acquisition files, and
- Inspection reports including photos and damages dimension and description

The preparation of this experimental study has been completed; the project is waiting for the client (Embraer) to approve the fixture, gas-gun, equipment, and providing the plates. The GMSIE laboratory is ready to start the tests after receiving approval and samples.

The numerical study of the lateral impact on plates has not been requested by the client, however, a numerical model will be developed to analyze progressive damaging in composite and metal plates due to lateral impact. A user-defined material model was developed last year for composite material. This material model was used to simulate the axial impact on composite tubes. The results have been submitted as an academic paper '*Finite element modeling of crushing of CFRP cylindrical tubes under low-velocity axial impact*'. The user-defined material model will be used to model the skin of sandwich composite panels in the present research project in ABAQUS/Explicit.

Activities that should be completed

- Conducting lateral impact tests (after receiving the fixture and specimens from the client)
- Image analysis and data reduction
- Conducting leak test on the metallic plates after impact

Part B: Static and dynamic characterization of composite railroad sleeper

Several composite railway sleeper (Fig. 8) technologies are being developed; however, their applications are still limited. While recycled plastic sleepers are low-cost, the main challenges are their limited strength, stiffness, and dynamic properties rather than traditional sleepers made of timber, concrete, or steel(Ferdous et al. 2015; Remennikov and Kaewunruen 2014).

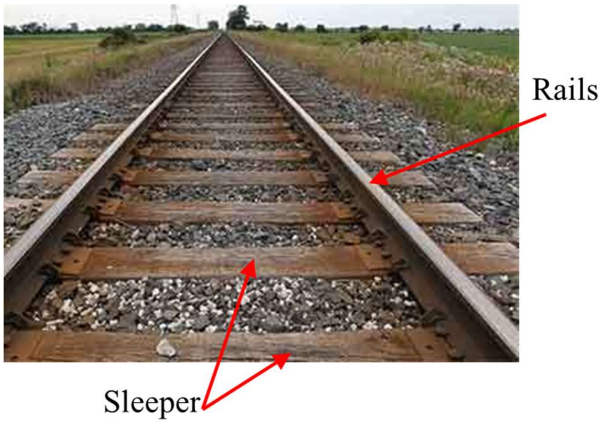
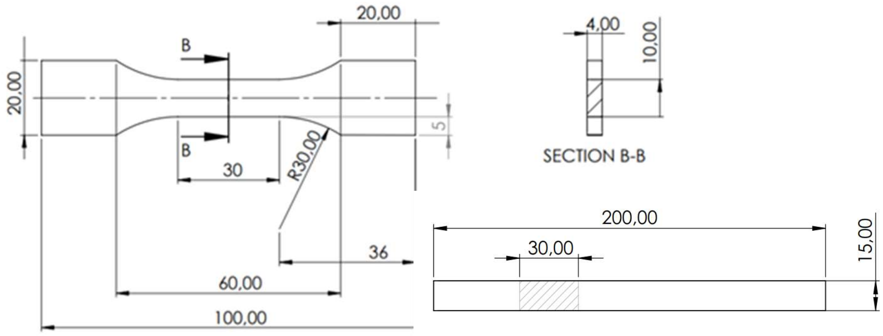


Fig. 8. Sleeper and railroad.

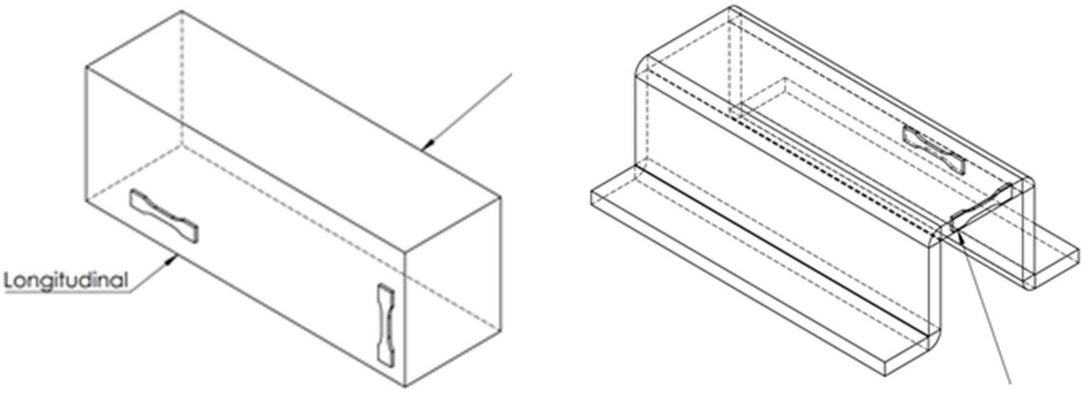
The main objective of this experimental study is to characterize the static and dynamic mechanical properties of composite material (reinforced plastic material) for manufacturing a new railroad sleeper in Brazil.

Different specimens will be cut from the manufactured parts (Provided by the client) in two orthogonal directions. Fig. 9 shows an example of required specimens and cutting the specimens in different directions from fabricated components.

Both dynamic and static tests will be used in two orthogonal directions in order to characterize the mechanical properties of the material. Tensile test (quasi-static with Instron machine at GMSIE laboratory) and dynamic tensile tests with low-energy drop tower test (or Split-Hopkinson pressure bar) are considered to be done. The Digital Image Correlation technique (DIC) with the high-speed camera will be used widely to do data reduction. Table 2 lists the experimental tests and required test samples.



(a)



(b)

Fig. 9. Example of required specimens; (a) Tensile test sample and (b) cutting specimens from the components.

The current progress of Part B is as follows

- Some specimens have been designed and ordered to be manufactured.
- Ongoing literature review to find more possible test conditions.

Table 2. List of tests and required specimens for railroad sleeper.

Material	White	Black
Direction 0°	3	3
Direction 90°	0	3
Number of temperature	2	2
Total	6	12
Tension level	3	3

Direction 0°	3	3	
Direction 90°	0	3	
Number of temperature	2	2	
total	18	36	
Deformation rate levels	3	3	
Direction 0°	0	3	
Number of temperature	2	2	
total	6	18	
Direction 0°	3	3	
Direction 90°	0	3	
Number of temperature	1	1	
total	3	6	
Total number of tests	**33**	**72**	105
	3	**6**	9
	24	**48**	72

Activities that should be completed

- Dynamic tensile test
- Static tensile tests
- Flexural test
- Search for the other possible tests

Part C: Helmet impact safety study- numerical and experimental procedure

This study is going to assess the impact safety performance of commercial motorcycle helmets in the Brazilian market, by considering the current standard experimental procedures and numerical study. The Finite Element numerical framework will be validated against different sets of experimental test results. The main test rig was designed (Fig. 10) and used for a previous helmet study at the GMSIE laboratory.

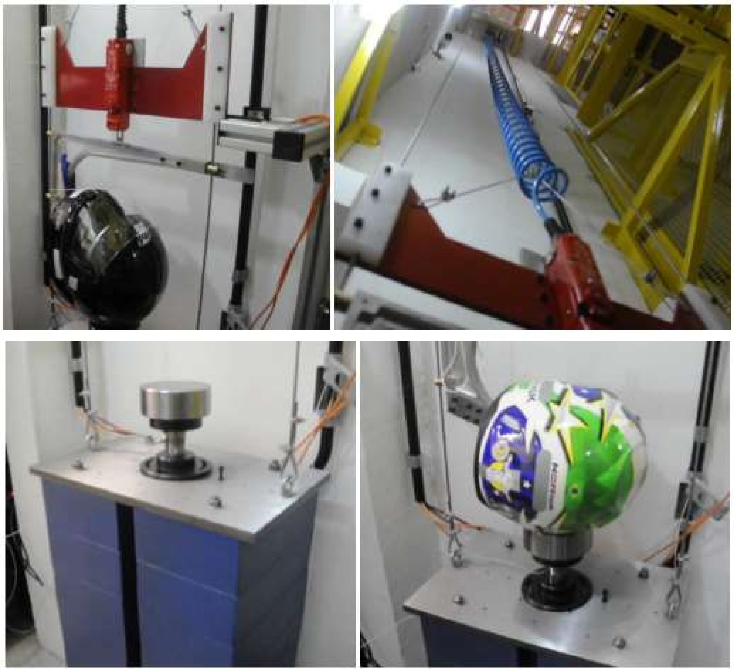


Fig. 10. Helmet test rig at GMSIE laboratory.

The main objective of this part of the study is to investigate the impact behavior of motorcycle helmets in the Brazilian market. Several new experimental tests will be done in the present study (part C) considering rotational headform and brian during the impact that is reported to be responsible for brain injury during an accident. Besides, numerical finite elements and 3D modeling of helmets will be conducted here. The three-dimensional model will consist of headform, brain, helmet exterior shell, and protective foam of the helmets. Some detailed objectives of the present study are listed below.

- Developing 3D scanning of helmet (photo metrology)
- Developing finite element model of helmets and simulating impact scenarios.

- Minor modification of the present helmet test rig (at GMSIE laboratory).

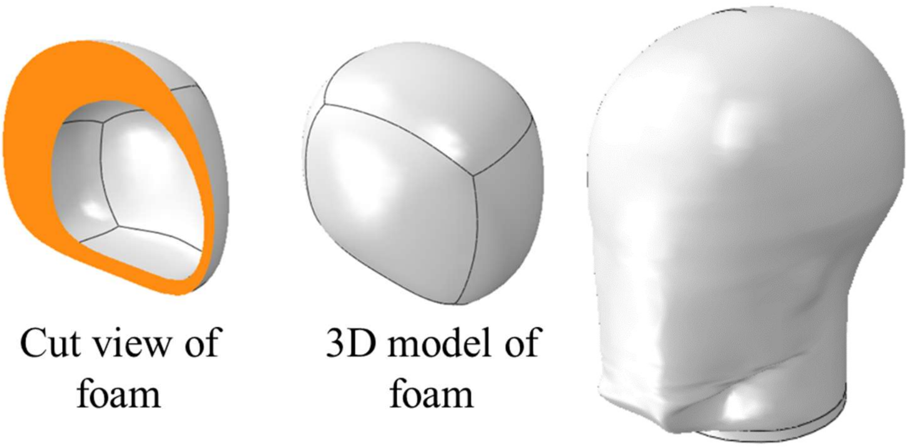
Two main parts of the helmet, (1) helmet exterior shell, (2) protective foam (lining) that providing significant impact head protection will be modeled in the FE model (Fig.11).

Fig. 11. Available Helmet in the Brazilian market.

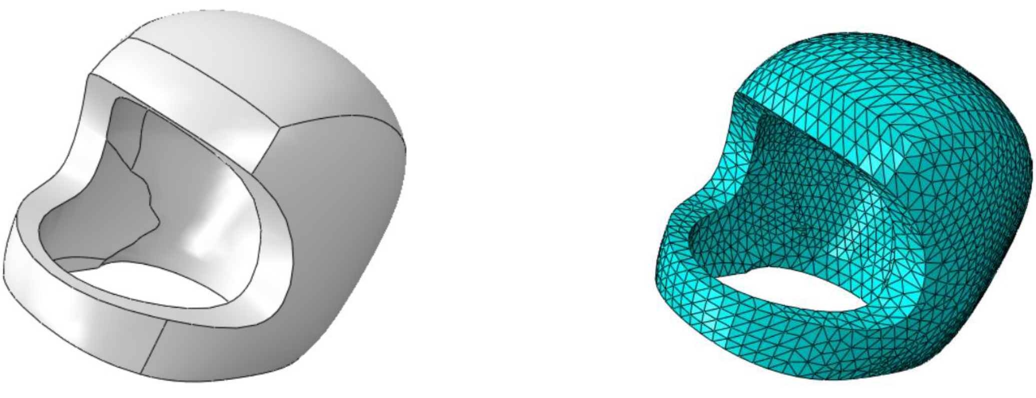
Several photos will be captured from the helmet in the perpendicular planes. These scaled photos were imported to AUTODESK FUSION 360 to create a three-dimensional model of the helmet. Then body lines on an initial ball shape were fitted onto the body lines on the helmet photos to generate a rough model of the helmet. Then details such as the visor port and holes on the exterior shell were subtracted from the rough model by using 2D sketches. the generated surface was imported to ABAQUS as a part and can be meshed by using conventional shell elements (S4), see Fig. 12. The same procedure will be used to model the solid form of protective foam, however, some modifications on the solid form will be done in ABAQUS CAE such as subtracting the head form of the solid foam. A Solid model of foam was generated in the FUSION 360 as illustrated in Fig. 13. Then this rough 3D model was imported into ABAQUS CAE as a part. A 3D model of headfrom including head and neck areas was used to modify the protective foam part. The FE model of protective foam part was generated by using 4-node linear tetrahedron solid elements (C3D4).

(a) (b)

Fig. 12. 3D model of the helmet exterior shell; (a) Three-dimensional model of helmet exterior surface, (b) FE model of the exterior shell.



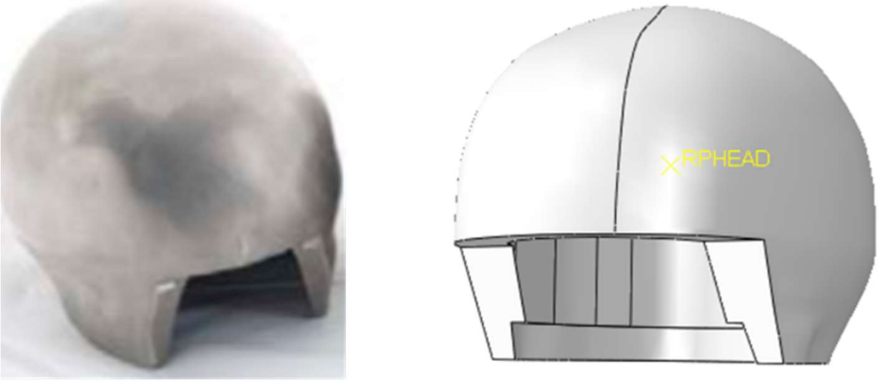
(a) (b)



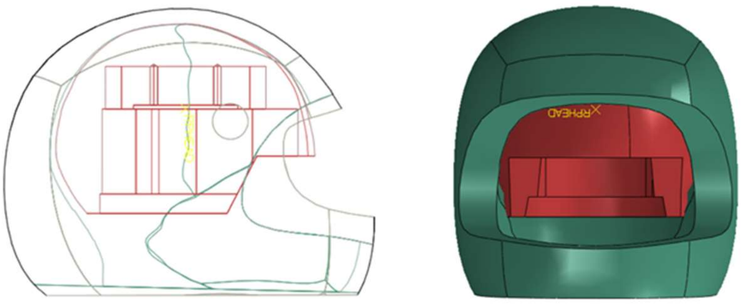
(c) (d)

Fig. 13. Protective foam model; (a) Rough 3D model imported into ABAQUS; (b) Head form used for modifying foam part, (c) 3D model of the protective foam, (d) FE model of protective foam.

To comply with the experimental tests, instead of the full head form (Fig. 13(b)) a part of the headform (head without neck area) is model in the numerical study, Fig. 14. The Fe model of the head is generated as a rigid part by using the R3D4 element. The head form fitted in the foam part with a 50 N preload, Fig 5(b). Hard contact and tangential interaction with frictional coefficient 0.35 were considered between the head form and foam. The position of the headfrom in the helmet is based on Ref.(Mills et al. 2009; Zou, Kleiven, and Schmiedeler 2007).



(a) Experimental head for is available at the GMSIE laboratory.



Green: Foam Red: Head from

(b)

Fig. 14. Headfrom assembled in the helmet.

In the following, an example of finite element simulation of impact on the helmet with results is presented. The brain was not modeled in this simulation. A list of elements for each part is presented in Table 3.

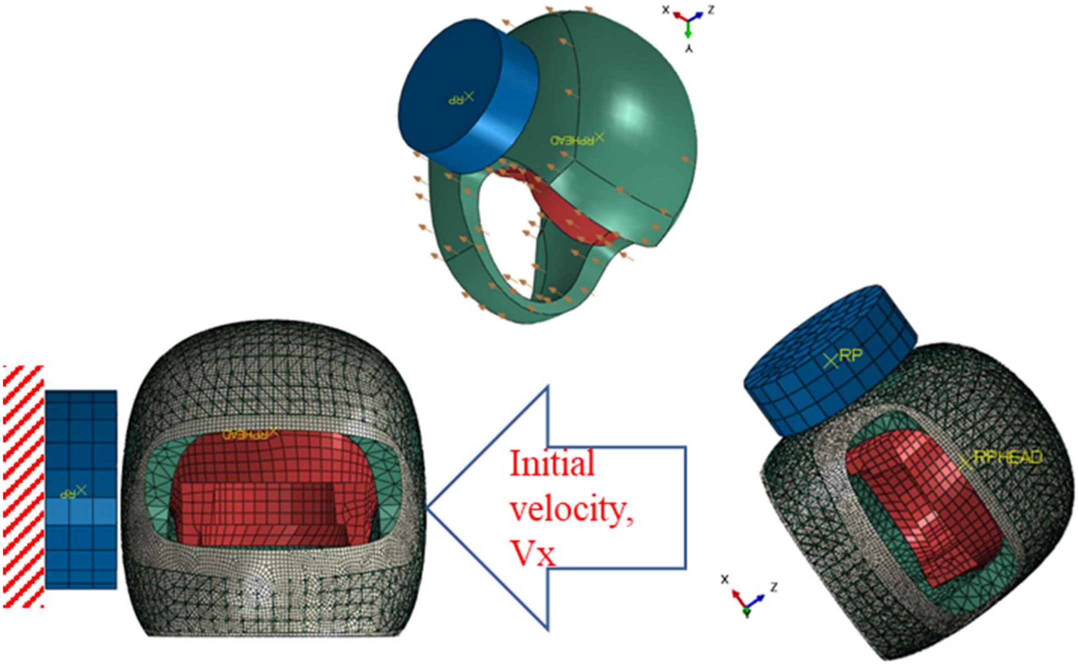


Fig. 15. Lateral impact.

Table 3. Elements in the simulation.

Part	Element type	Description
Helmet exterior shell	Conventional shell (S4R)	A 4-node doubly curved thin or thick shell, reduced integration, hourglass control, finite membrane strains element
Helmet protective foam	3D stress solid element (C3D4)	A 4-node linear tetrahedron element
Head form	Discrete rigid element (R3D4)	A 4-node 3-D bilinear rigid quadrilateral element
Curbstone	Discrete rigid element (R3D4)	A 4-node 3-D bilinear rigid quadrilateral element

The acceleration results and deformation of the helmet and headform are presented in Figs. 16 and 17.

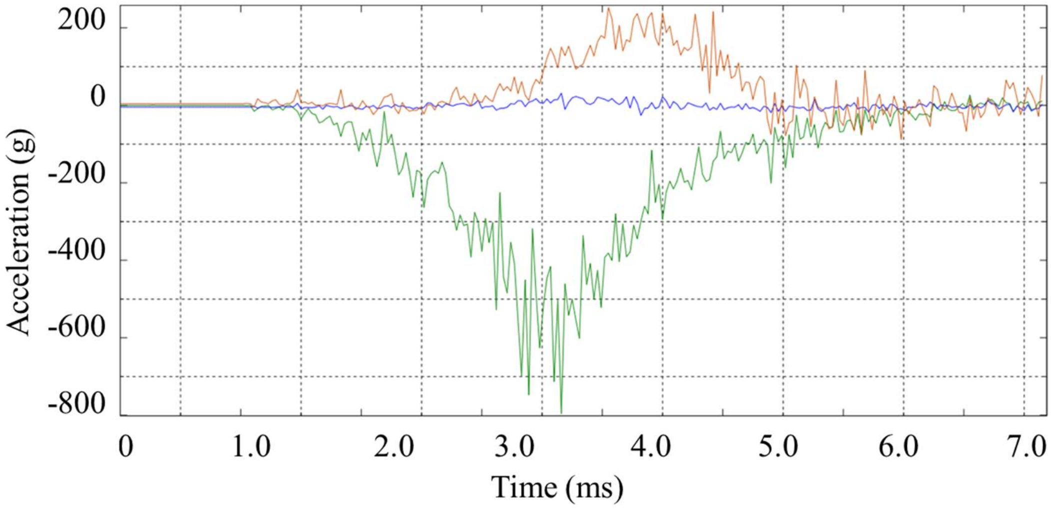


Fig. 16. Acceleration time history of impact test on the helmet; Green Acceleration in the x-direction, Blue Acceleration in the y-direction; Red acceleration in the z-direction

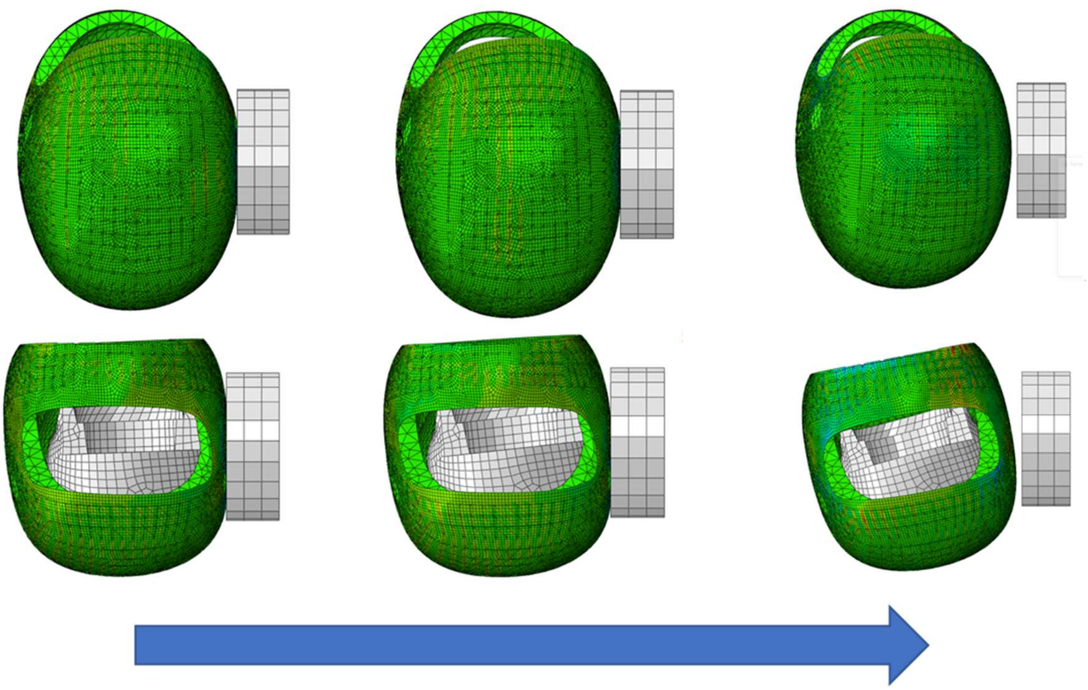


Fig. 17. Helmet and head deformation during the impact test.

The tasks that will be done are as below.

- Improving the numerical simulation of impact on the helmet, including rotational and transitional displacement of head and brain.
- Modifying the helmet test rig and conducting new helmet experimental tests.

Activities plan and timetable

A journal paper has been submitted until now related to part A. The research duration is divided into four three-month periods Q1, Q2, Q3, and Q4 as listed in the following timetable.

Part	Activity	Q1	Q2	Q3	Q4
Part A	After providing plate sample (70) lateral impact test				
Part B	Experimental tests (dynamic and static tests)				
Part C	Experimental tests on the helmet and numerical simulation				
Publications	One academic journal paper and a conference paper will be published				

References

Ferdous, Wahid, Allan Manalo, Gerard Van Erp, Thiru Aravinthan, Sakdirat Kaewunruen, and Alex Remennikov. 2015. “Composite Railway Sleepers – Recent Developments, Challenges and Future Prospects.” *Composite Structures* 134:158–68.

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Remennikov, Alex M. and Sakdirat Kaewunruen. 2014. “Experimental Load Rating of Aged Railway Concrete Sleepers.” *Engineering Structures* 76:147–62.

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Universidade de São Paulo
Escola Politécnica
Programa de Pós-Doutorado

Plano de trabalho

I - Dados gerais

Nome do pós-graduando:	Pouria Bahrami Ataabadi
Área de concentração:	Engenharia Mecânica de Projeto e Fabricação
Linha de pesquisa:	Impacto nos componentes compostos
Nome do supervisor:	Prof. Dr. Marcílio Alves
Nível:	Pós-Doutorado em Engenharia Mecânica

II - Atividades a serem desenvolvidas

1) Desenvolvimento do projeto de pesquisa intitulado “Numerical and experimental study of the lateral impact on curved and flat composite components”, cujo detalhamento encontra-se na descrição do respectivo projeto;
2) Participação em atividades didáticas da disciplina de graduação **PMR5026 – Elementos Finitos nonLinear: Teoria, Programação E Experimentos**;
3) Realização de testes dinamicos de materiais e apoio a testes gerais no Laboratório do Grupo de Mecânica dos Sólidos e Impacto em Estruturas (GMSIE).

III - Cronograma

O período do projeto é dividido em 4 etapas, cada uma com três meses. O detalhamento das atividades para periodo do projeto encontra-se na Tabela 1.

Tabela 1 – Cronograma das atividades de pós-doutoramento.

período	Período do projeto de pós-doutoramento			
Etapa	Etapa I	Etapa II	Etapa III	Etapa IV
Desenvolvimento do projeto de pesquisa				
Atividades didáticas da PMR5026				
Apoio a testes no Laboratório (GMSIE)				

As atividades didáticas das disciplinas de graduação e de pós-graduação serão desenvolvidas entre os meses de fevereiro e agosto desse ano e do próximo ano. Por fim, as atividades da linha de pesquisa serão executadas até o final do programa de pós-doutorado, e compreendem a revisão e aprofundamento da teoria de falha dos materiais, dos modelos constitutivos e da caracterização dos materiais poliméricos e aços, de eletrônica e de controle, testes em laboratório, modelagens e simulações numéricas.

São Paulo, 20 de abril de 2021

Pouria Bahrami Ataabadi

Prof. Dr. Marcílio Alves