

Response of fully backed sandwich beams to low velocity transverse impact

M. SADIGHI, H. POURIAYEVALI, M. SAADATI

Abstract— This paper describes analysis of low velocity transverse impact on fully backed sandwich beams with composite faces from Eglass/epoxy and cores from Polyurethane or PVC. Indentation on sandwich beams has been analyzed with the existing theories and modeled with the FE code ABAQUS, also loadings have been done experimentally to verify theoretical results. Impact on fully backed has been modeled in two cases of impactor energy with SDOF model (single-degree-of-freedom) and indentation stiffness: lower energy for elastic indentation of sandwich beams and higher energy for plastic area in indentation. Impacts have been modeled by ABAQUS. Impact results can describe response of beam in terms of core and faces thicknesses, core material, indenter energy and energy absorbed. The foam core is modeled using the crushable foam material model and response of the foam core is experimentally characterized in uniaxial compression with higher velocity loading to define quasi impact behaviour.

Keywords— Low velocity impact, Fully backed, Indentation, Sandwich beams, Foams, Finite element

I. INTRODUCTION

SANDWICH structures are composed of composite laminates as skins and low density foam as core that present suitable properties for flexural stiffness and absorbing energy without weight penalty. These characteristics exhibit important role in impact loading. Impact response of sandwich structures are affected generally from two kinds of stiffnesses, flexural and contact stiffnesses of structures. Indentation loading can describe contact stiffness between indenter and beam and flexural stiffness is dependent to structure boundary conditions so can obtain it by three point loading.

In indentation of sandwich structures, foam has a weak resistance. Much research effort has been given to this problem in order to model a response of sandwich structures to local load. An excellent review article by Abrate [1] provides a through overview of research work on subject. Soden [2] also presented an analytical model for indentation of sandwich beam assuming plastic

behaviour for core. Zenkert, et al [3] have recently studied indentation of sandwich beams. They presented an elastic-perfectly plastic compressive behaviour of foam core that elastic part of indentation is described by Winkler foundation model. Indentations on sandwich beams have been done experimentally and have been simulated with FE codes.

Extensive applications of sandwich structures have been caused that researchers attend to their response of dynamic loadings

A complete review of Low velocity impact of sandwich structures has been presented by Abrate[4]. found et al [5] and Aymerich et al [6] modeled impact with mass-spring model and Abrate[7]. olsson [8] suggested more complete analytical model, also Todd[9] modeled large mass impact with SDOF model. Yang and Qiao [10] presented impact of fully backed composite sandwich structures. Hazizzian and Cantwell [11] have investigated low velocity impact of sandwich structures and attended to absorbed energy in structures.

In this paper impact of fully backed sandwich beams have been modeled with SDOF model with contact stiffness, impactor energies have been chosen in two stages of lower and higher for elastic and plastic indentation on sandwich beams. Impact loadings have been modeled by ABAQUS. Results have been presented in terms of core and faces thicknesses, core material, indenter energies, absorbed energy and their effects on force and time of loading and impactor and beam displacement. Behaviour of core affects a principal influence in response of sandwich structures so cores have been loaded experimentally and accurately modeled in ABAQUS.

II. PROPERTIES OF BEAM COMPONENTS

A. FOAMS

In this research, PVC and Polyurethane foam were used in sandwich beams. These foams show a special behavior in uniaxial compression in according of Fig 1. The foam properties were obtained from uniaxial compression tests according to that given in ASTM D5308 standard [12]. Loading velocities were selected in two cases of 2mm/min and 100mm/min.

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2mm/min is used for quasi static tests and 100mm/min is used for quasi impact tests. Experimentally foam properties are displayed in Table I.

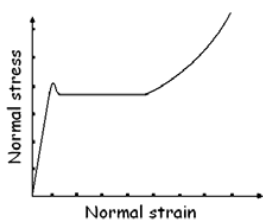


Fig1. Foam behavior in uniaxial compression

TABLE I Mechanical Properties of Foams

Foam	ν	2 mm / min		100 mm / min	
		E Mpa	σ _y Mpa	E Mpa	σ _y Mpa
PU	0.42	6.15	0.274	6.9	0.315
PVC	0.32	20.4	1.11	25.1	1.25

B. Composite Laminate Properties

Composite laminates were fabricated from Woven Eglass / epoxy in hand layup style. They were prepared in two forms of 2layers and 4layers and their properties were obtained from tests according to that given in ASTM D3039 standard [12]. Composite laminate properties are presented in Table II

TABLE II Mechanical Properties of composite laminate

Layers	Thickness mm	E ₁ Mpa	σ _y Mpa	G ₁₂ Mpa	G ₃₂ Mpa	G ₁₃ Mpa	E ₂ Mpa
2	0.92	11e3	62	8	8	15	19
4	0.52	14e3	130	12	12	20	30

III. INDENTATION OF SANDWICH BEAM

In this section, Abrate’s suggestion [1] and Zenkert’s approach [2] were chosen to introduce indentation of sandwich beams.

A. Indentation Theory

The model assumes an elastic Winkler foundation for the elastic core, and a perfectly plastic foundation for part of core that undergoes crushing, as schematically is shown in Fig2, [2].

A.1 Elastic Solution

When the load *P* is small, the entire foundation is elastic and governing equation is

$$D_f \frac{d^4 w_{el}}{dx_e^4} + K w_{el} = 0 \tag{1}$$

Where:

w_{el}: face sheet deflection *k*: foundation modulus

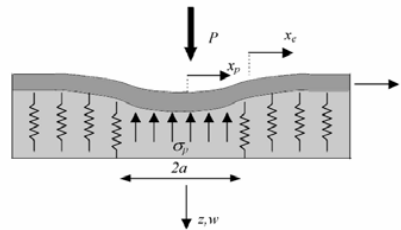


Fig 2 Indentation model of sandwich beams [2]

$$k = \frac{E_c}{t_c} \tag{2}$$

t_c: core thickness *E_c*: core elastic modulus

And boundary conditions are

$$w'_{el}(0) = 0 \quad w_{el}(0) = \alpha \quad w'_{el}(\infty) = 0$$

$$w'_{el}(\infty) = 0$$

A.2 Perfectly Plastic Solution

As the load increases, a part of core with length of 2a undergoes plastic deformation and core shows a uniform constant reaction *σ_p* on the face sheet.

Thus, governing equation is

$$D_f \frac{d^4 w_{pl}}{dx_p^4} + \sigma_p = 0 \tag{3}$$

Where:

σ_p: plateau compressive yield stress

And boundary conditions are

$$w'_{pl}(0) = 0 \quad w_{pl}(0) = \alpha$$

$$\left(\frac{d^3 w_{pl}}{dx_p^3} \right)_{x_p=0} = \frac{P}{2D_f}$$

General equation for face deflection is obtained by combining the elastic and plastic of Eqs. (1) and (3)

B. Indentation Test in Sandwich Beams

The properties of manufactured sandwich beams have been presented in Table III. Foam materials, skins thicknesses and foam thickness are varied between samples.

Indentation has done experimentally with 20mm diameter indenter. Loading velocity was chosen 2mm/min. Sandwich beams have been supported on a rigid plate (Fig 3). Also indentation was modeled in Abaqus (Fig 4). Contact stiffness of beams was presented in table III.

Indentations curves are displayed in Fig’s 5 and 6 for several samples of sandwich beams introducing in Table 3. Results show suitable convergences.

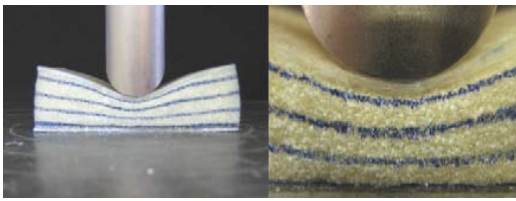


Fig 3 indentation in sandwich beam with PU core

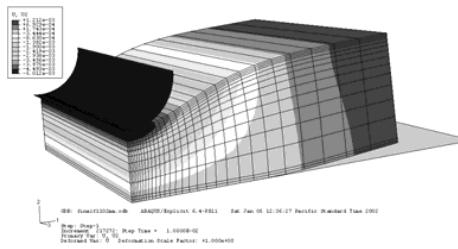


Fig 4 indentation modeling of sandwich beam in Abaqus

IV. IMPACT ON FULLY BACKED SANDWICH BEAMS

In this loading, a rigid plate has been chosen for boundary condition that sandwich beams place on it and are loaded with a low velocity cylindrical indenter. In this state we can only use contact stiffness and eliminate flexural stiffness of sandwich beams. Impact loadings include indentation on sandwich beam so we used indenter in two states of energy loading: Lower energy for elastic indentation without residual indent after loading and higher indenter energy for plastic indentation. Mass and velocity of indentors with their energies have been presented in table IV.

A. Elastic indentation

In according to fig 7. Impact loading have been modeled with a SDOF model with Eq (4) and contact stiffnesses of table III for elastic indentation also it simulated in ABAQUS. Impact results was presented in fig 8 and a complete comparison between results of manufactured beams has been presented in Fig's 9 and 10

B. Plastic indentation

There isn't any accurate and suitable model for describing of unloading on sandwich beams so we used elastic contact stiffness for unloading to reach specified residual indent. In according to fig.11 [13], an experimental result of indentation and unloading have been presented that shows mentioned assumption isn't inaccurate. In loading stage, equations (III) are used for indentation and in total time of impact, contact stiffness has been eliminated when there isn't any indentation or any contact between indenter and beam. Plastic Impact results have been presented in fig's 12, 13

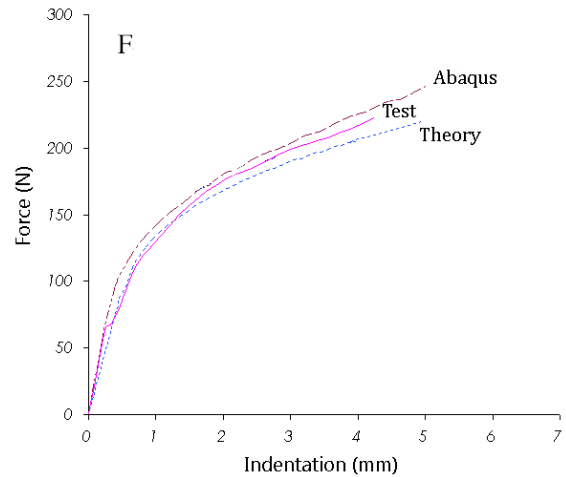
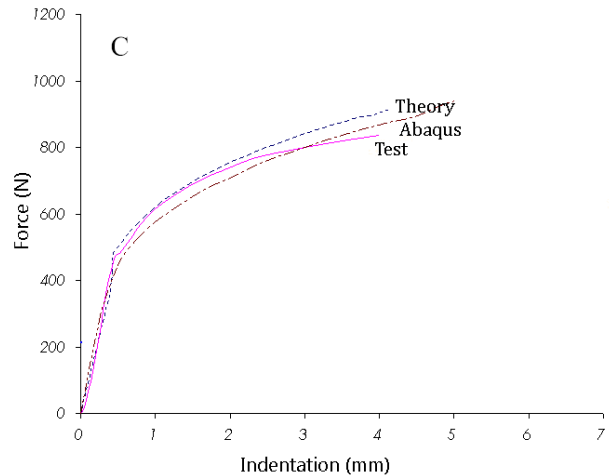


Fig 5 Indentation in sandwich beams of C, F

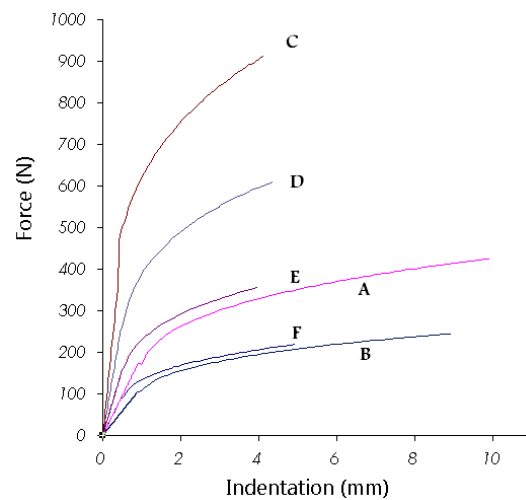


Fig 6 Results of theory part (III) for sandwich beams from Table III

TABLE III .Properties of used sandwich beams

A	B	C	D	E	F	Sandwich beams	
50	50	30.5	30.5	30.05	30.5	Wide	mm
60	60	60	60	60	60	Length	mm
21.6	20.5	10.2	9.7	11.9	11.6	Thickness	mm
PU	PU	PVC	PVC	PU	PU	Core	
40	40	70	70	40	40	Core density	Kg/m ³
19.76	19.46	8.36	8.66	10.06	10.56	Core thickness	mm
4layer	2layer	4layer	2layer	4layer	2layer	Composite skins	
0.92	0.52	0.92	0.52	0.92	0.52	Skins thickness	mm
400	244	1076	643	392	235	Elastic contact stiffness	N/mm

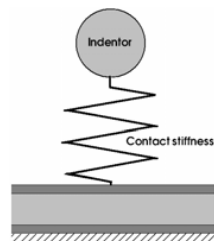


Fig 7 SDOF model for low velocity impact

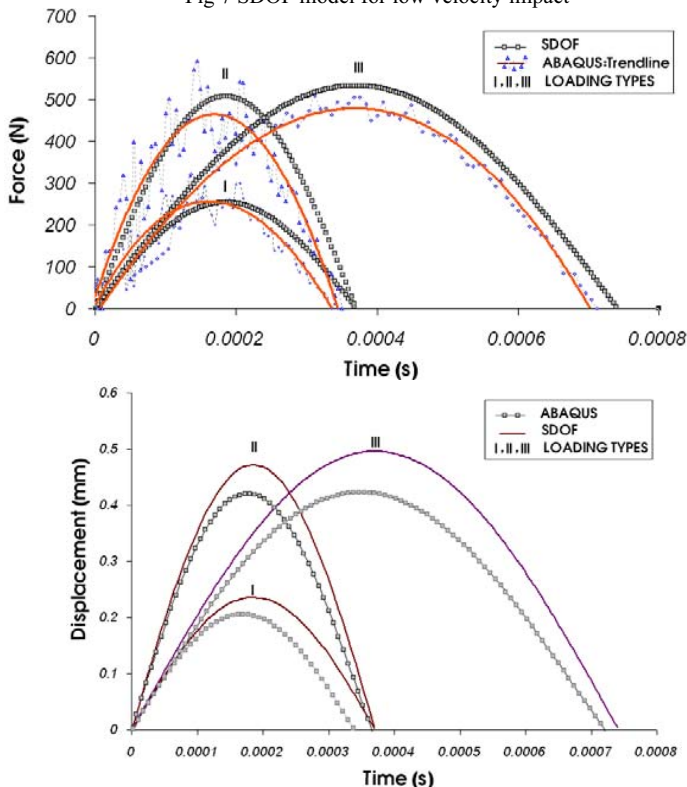


Fig 8 Response of fully backed beam of C to elastic impact loadings

TABLE IV indenter characteristic for elastic & plastic indentation

Loading types	Energy (J)	Velocity (m/s)	Mass (gr)
Elastic impact			
I	0.03	2	15
II	0.12	4	15
III	0.12	2	60
IV	0.01	2	5 (gr / cm wide)
Plastic impact			
V	1.2	2	600

$$M_1 \cdot \ddot{X}_1 + K_c X_1 = 0 \tag{4}$$

V. RESULTS

Assuming elastic indentation for impact loading and according to fig 8, It can be calculated that SDOF theory shows higher values than Abaqus results for impact force and loading time, that it are resulted from approximation in calculating contact equations and mass-spring model assumption. However results present suitable following to each other in impact time. Fig 8 present that indenter displacement is larger for SDOF results.

Comparison between indenter energies show that: Increasing in indenter mass is caused increasing for force and time of impact and indenter displacement increasing but increasing in velocity of indenter results increasing in impact force and displacement but don't show any important change in loading time. For loadings with similar indenter energies like state II, III (in table IV), results show a little difference in maximum impact force that they are very close to each other. Fig 9 shows response of beams that have been presented in table III, they have been modeled with SDOF and similar indenter energies of IV from table IV for all of them. Also this comparison have been done in ABAQUS and indenter velocities presented in fig 10

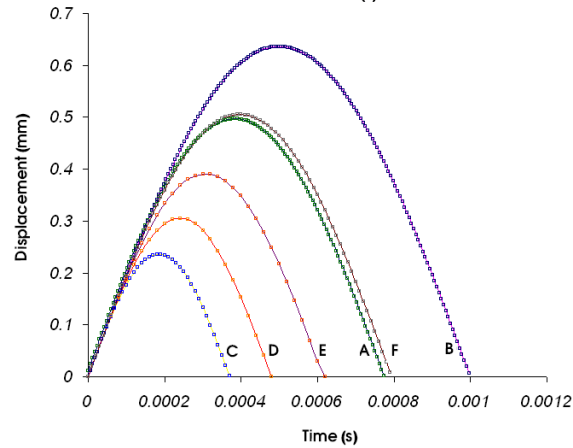
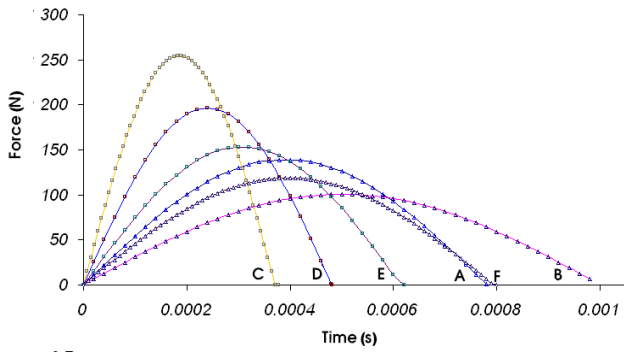


Fig 9 Response of beams using SDOF for IV loading type

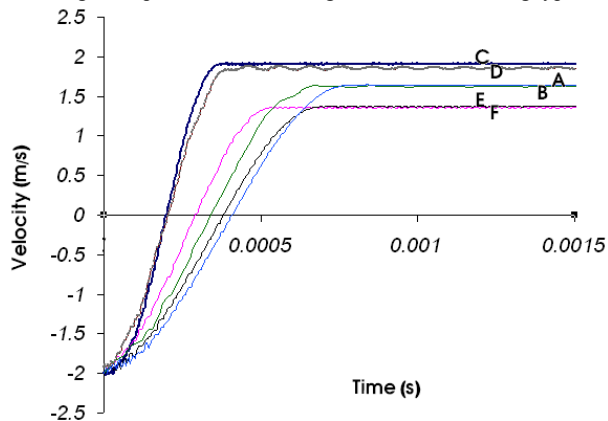


Fig 10 Response of beams using ABAQUS for IV loading type

Results show that increasing of foam thickness is caused increasing in loading time and indenter displacement but it involves decreasing in impact force and indenter velocity changing. Lower change in indenter velocity shows decreasing in absorbed energy of indenter.

Increasing of foam stiffness shows decreasing in loading time, indenter displacement and absorbed energy but it cause increasing in impact force. Increasing of skin stiffness shows decreasing in loading time and indenter displacement but presents increasing in impact force.

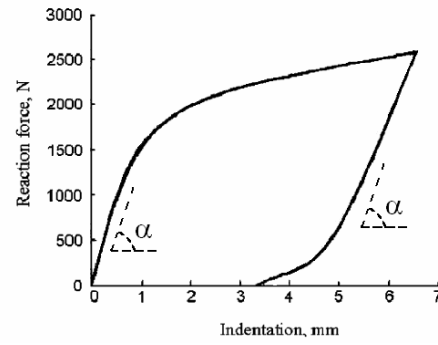


Fig 11 experimentally loading & unloading for indentation on sandwich beam [13]

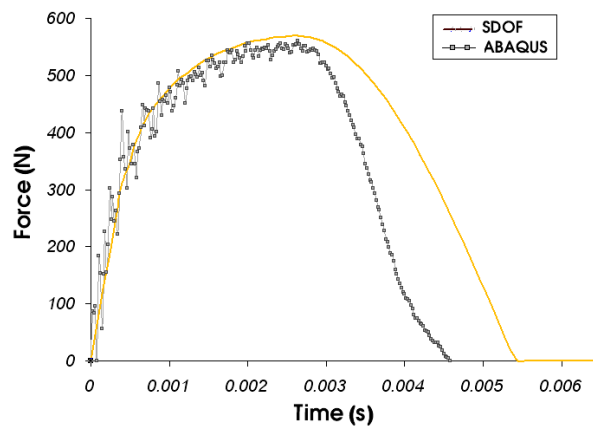
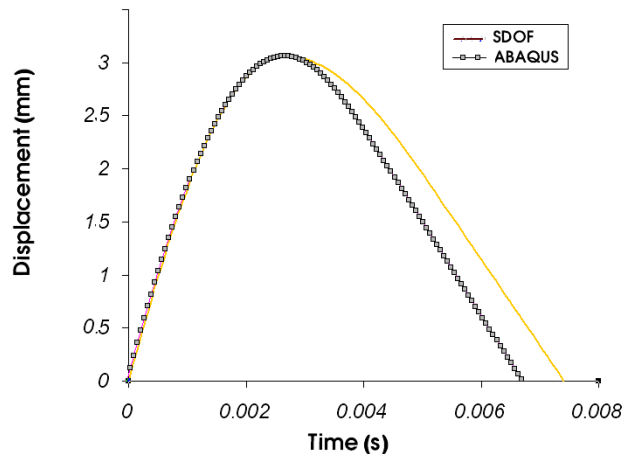


Fig 12 Response of fully back beam of A to Plastic impact with V loading type

But don't have any effect on absorbed energy for elastic impact. Fig 12 shows that for V loading type, indentation goes to plastic area on sandwich and certainly residual indent will happen. In this state beam doesn't go to initial position, so contact between indenter and beam will be cut earlier in return indenter stage. In plastic indentation SDOF theory behave in a very good following with FE results in loading step but in return, assumption of elastic contact and residual indent make some differences between results.

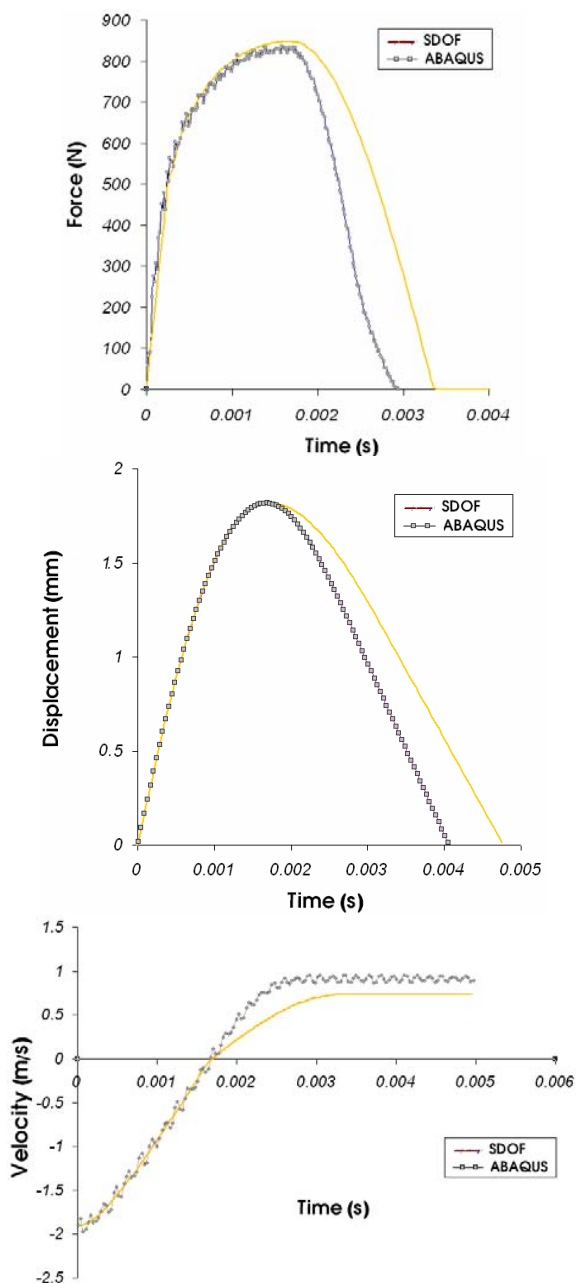


Fig 13 Response of fully back beam of C to Plastic impact with V loading type

VI. CONCLUSION

Knowing and modeling of foams behavior have an important role in prediction of sandwich structure responses.

In indentation on sandwich beams, presented theory shows proper behavior comparing with test and FE results that present a suitable model for contact stiffness defining.

For modeling of impact SDOF model shows structure behavior in a good approximation with FE results. Contact stiffness is only source of resistance in impact, so using of single-degree-of-freedom model is acceptable and

satisfactory. Indentation of impact can be divided in two stage of elastic and plastic area.

In elastic impact loading, changing in foam and skins thickness, stiffness have an important effect in behavior of sandwich structure for time, force, displacement and absorbed energy in impact loading.

In plastic impact loading, SDOF results converge greatly with FE in loading area but in unloading, mentioned assumption make differences between results, so results behave similar and with each other in this area.

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