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Finite Element Analysis of the Impact Behavior of Sandwich Panels with Nanocomposite Face sheet (Epoxy/ Fiberglass/Nanosilica)

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Abstract*:* In this research, the impact behavior of nanocomposite sandwich panels with epoxy/fiberglass/nanosilica face sheet were assessed by the finite element method. In the first step, the mechanical properties of the nanoparticle-containing composite should be obtained. A unit cell of fabric was designed in Catia software and placed within the designed polymeric matrix. The mechanical properties of this unit cell were defined as a new matrix and the nanoparticles were randomly dispersed in the new matrix using a Python code. The elastic properties of the modeled nanocomposite were obtained using Abaqus software via applying periodic boundary conditions based on the mean volumetric stress. In the next step, the sandwich structure was subjected to impact loads at various speeds and contact force-time diagrams were plotted using Abaqus software. The modeled results were compared with the known experimental data which showed a high accuracy in predicting the mechanical properties and impact behavior of the nanocomposite sandwich structures.

Keywords: Finite Element Method (FEM), Impact Test, Nanocomposite, Nanosilica, Sandwich Panel

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Research paper

1 INTRODUCTION

Sandwich structures consist of two face sheets (skins) and a core structure. Face sheets are separated by the core structure which provides support for them. Composite sandwich structures have gained increasing attention due to their low weight and proper mechanical properties. The application of the foam core in the sandwich panels can dramatically decline the weight of the structure while increasing its energy absorption capacity.

In recent years, the use of composite face sheet has attracted a lot of attention with the aim of improving mechanical properties and light weight [1-3]. The susceptibility of foam-core sandwich panels toward the impact load is one of the main concerns. The core of these sandwich panels is susceptible to sudden loads such as impacts. Such impact loads can be applied to the sandwich panel at any stage of production and installation. Numerous studies have addressed the mechanical properties of sandwich panels under impact loads. Accordingly, the mechanical properties of the composite face sheets are decisive factors in the susceptibility of the sandwich structures. In this regard, the production of composite face sheets with desirable mechanical properties is one of of crucial significance [4]. Rizo and Maldenski [5] assessed the response of composite sandwich panels under low-velocity impact. They also utilized a 2D finite element method to predict the mechanical behavior of the sandwich structure under impact load at micro-scale. Feng and Emerich [4] evaluated the influence of the foam core density and alignment of the composite face sheet on the mechanical response of the sandwich panel under impact load. They found that the fiber alignment plays a decisive role in the final properties of the sandwich panel. Feli and Mehdipour [6] assessed a three-dimensional solution based on Fourier's series and the generalized differential quadrature method to model the low-velocity impact on sandwich panels with hybrid nanocomposite face sheets and found that the impact damage resistance of the sandwich panels with hybrid nanocomposite face sheets is enhanced.

To the author's knowledge, there is no finite element solution available in the open literatures for impact behavior of nanocomposite sandwich panels with epoxy/fiberglass/nano silica face sheet. The present work deals with the impact behavior of nanocomposite sandwich panels with epoxy/fiberglass/nano silica face sheet by the finite element method. A unit cell of fabric was designed in Catia software and placed within the designed polymeric matrix. The mechanical properties of this unit cell were defined as a new matrix and the nanoparticles were randomly dispersed in the new matrix using a Python code. The elastic properties of the modeled nanocomposite were obtained by using Abaqus software via applying periodic boundary conditions based on the mean volumetric stress. The sandwich structure was subjected to impact loads at various speeds and contact force-time diagrams were plotted by using Abaqus software. The modeled results were compared with the known experimental data which showed a high accuracy in predicting the mechanical properties and impact behavior of the nanocomposite sandwich structures.

2 FINITE ELEMENT MODELLING

Fig. 1 shows the studied sample which comprised a foam core and two nanocomposite sheets on both sides.

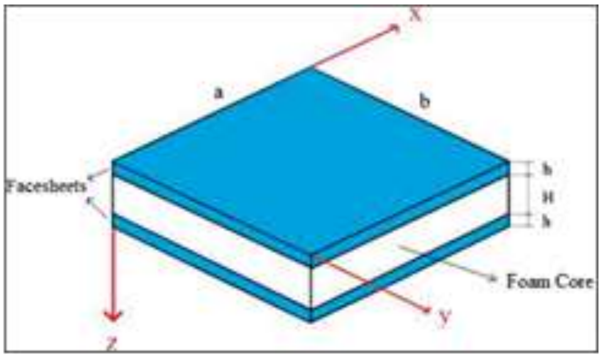


Fig. 1 A schematic view of the experimental sample [6].

In the experimental section, the produced composite was prepared in three groups of nanoparticle-free, containing 3 Wt.% and 5 Wt.% nano silica. The samples were then exposed to impact loads with initial velocities of 1.88 and 2.22 m/s. The produced sandwich samples encompassed two nanocomposite sheets at the top and bottom of the foam core [6]. To model the sandwich panel under the impact load, the mechanical properties of the nanoparticle-containing composite should be obtained. For this purpose, a unit cell of fabric was designed in Catia software as depicted in "Fig. 2".

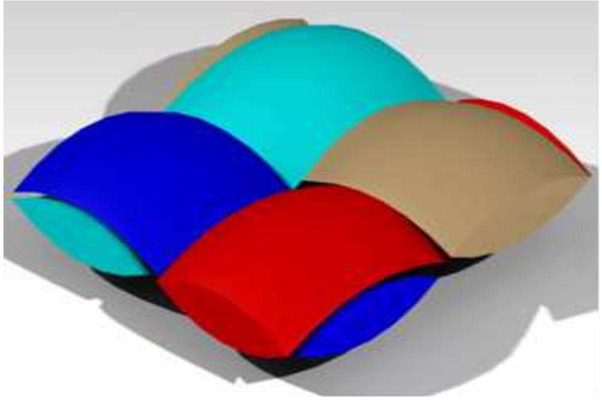


Fig. 2 Unit cell of the designed fabric.

In the next step, the unit cell of the fabric was placed within the designed polymeric matric and the nanoparticles were randomly dispersed in the matrix using a Python code (“Fig. 3”).

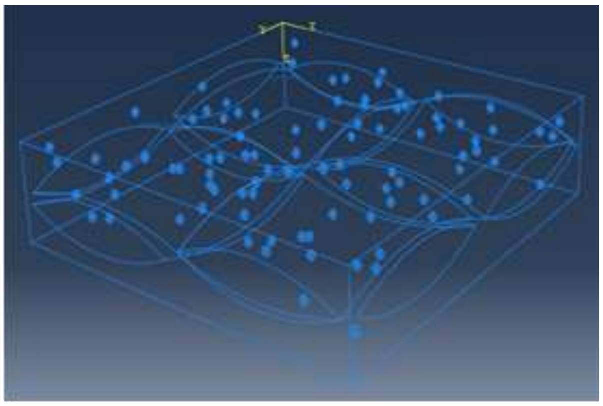


Fig. 3 Composite unit cell along with nanoparticles.

The elastic properties of the modeled composite were obtained by applying periodic boundary conditions based on the mean volumetric stress [7]. Mesh independence of the results and elasticity modulus values are listed for various mesh sizes in “Table 1”.

Table 1 Mesh independence of the results

Model	Mesh size	Elasticity modulus (GPa)
1	0.5	11.23
2	0.2	12.91
3	0.1	12.21

Regarding the negligible difference between models 2 and 3, the mesh size of model 2 was selected for the analysis.

In the next step, the model was designed in the test dimensions including composite face sheets, foam core, and impactor (“Fig. 4”).

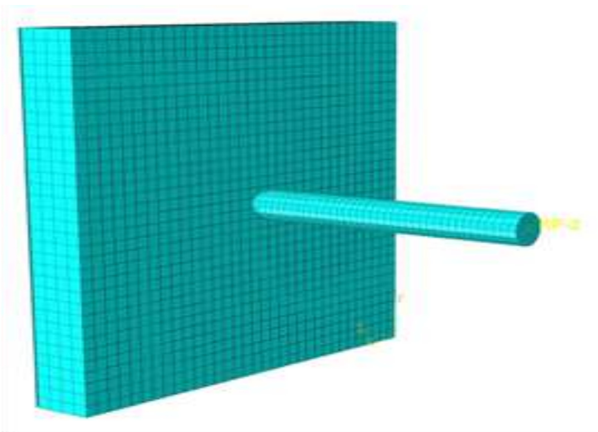


Fig. 4 Mesh system of the nanocomposite sheet and impactor.

In this model, the degrees of freedom of the lateral sheets of the sandwich panel were determined depending on the initial velocity of the impact. Noteworthy, complete adhesion was considered for the face sheet-core contact.

3 RESULTS AND DISCUSSION

3.1. 5%wt-v1880 Sample

Based on “Fig. 5”, the highest Von Mises stress at the collision time was for the 5%wt-v1880 sample. Maximum Von Mises stress at the collision site was 303 and 15.55 MPa for the composite sheet and foam, respectively. Moreover, stress was significantly declined along the perpendicular direction due to the presence of the foam in the force transfer path. This dramatically decremented the Von Mises stress in the back face sheet.

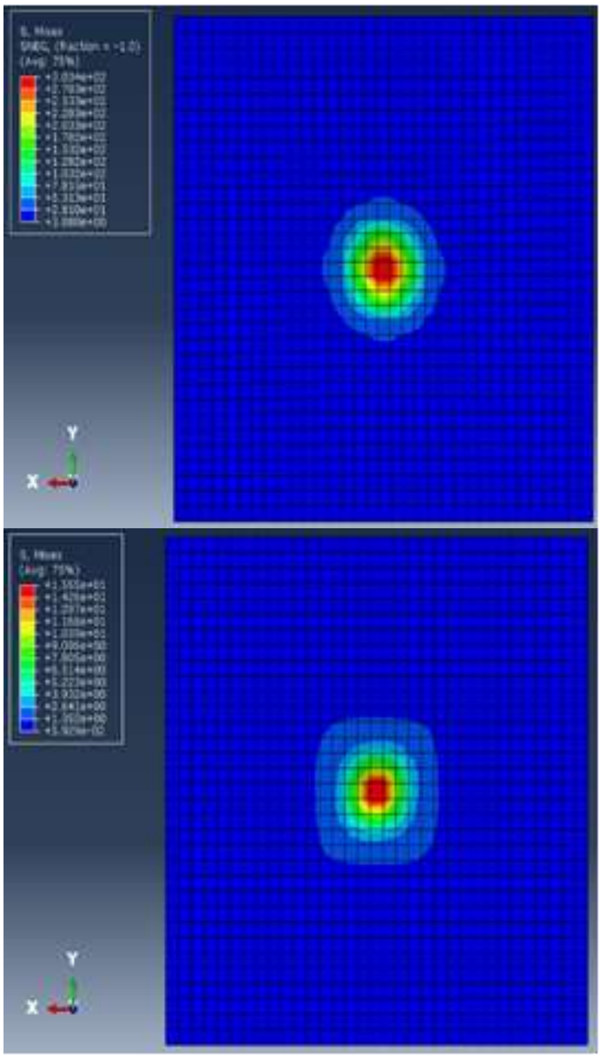


Fig. 5 Von Mises stress in the sheet and foam.

According to “Fig. 6”, the highest strain of the composite sheet was 0.0076. The normal displacement of the beam was also 2.08 mm.

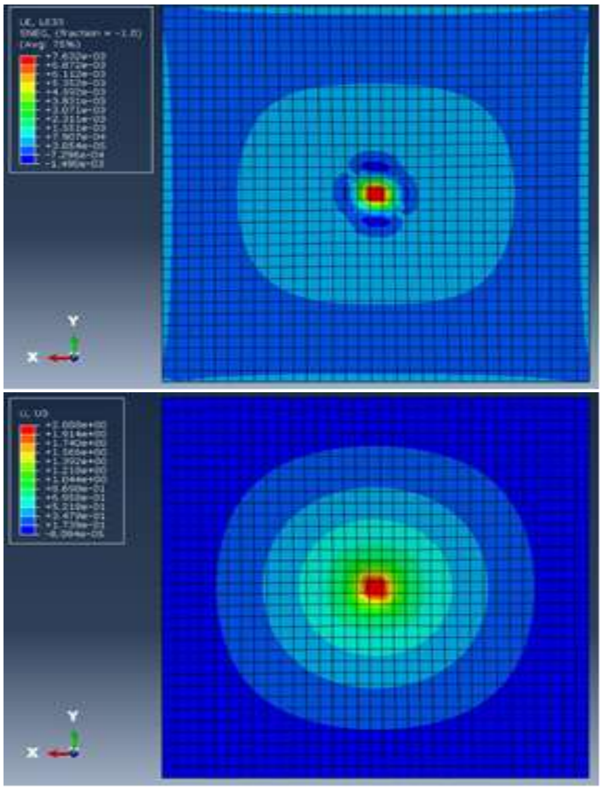
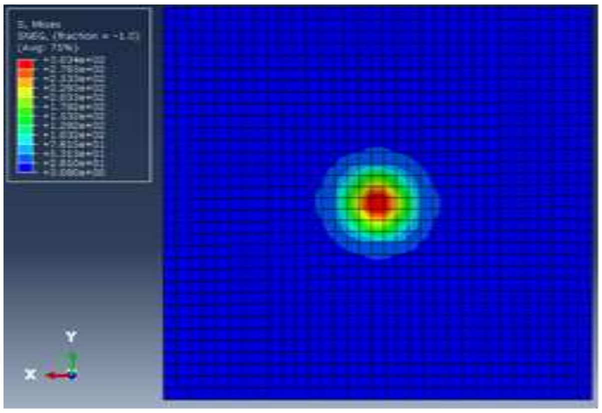


Fig. 6 Strain and displacement of the sandwich structure.

3.2. 3%wt-v1880

As suggested by “Fig. 7”, the highest Von Mises stress occurred at the collision time of the impactor with 3%wt-v1880. The highest Von Mises stress at the collision time was 325 and 16.29 MPa for the composite sheets and foam, respectively. The stress dramatically decreased along the perpendicular direction due to the presence of the foam in the path of force transfer. This dramatically declined the Von Mises stress in the back face sheet.



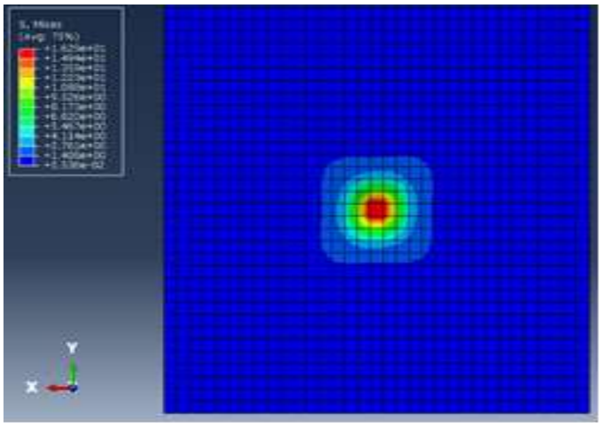


Fig. 7 Von Mises stress of the composite sheet and foam.

According to “Fig. 8”, the highest strain of the composite face sheet was 0.026. the normal displacement of 2.15 mm was also observed in the beam of the sample.

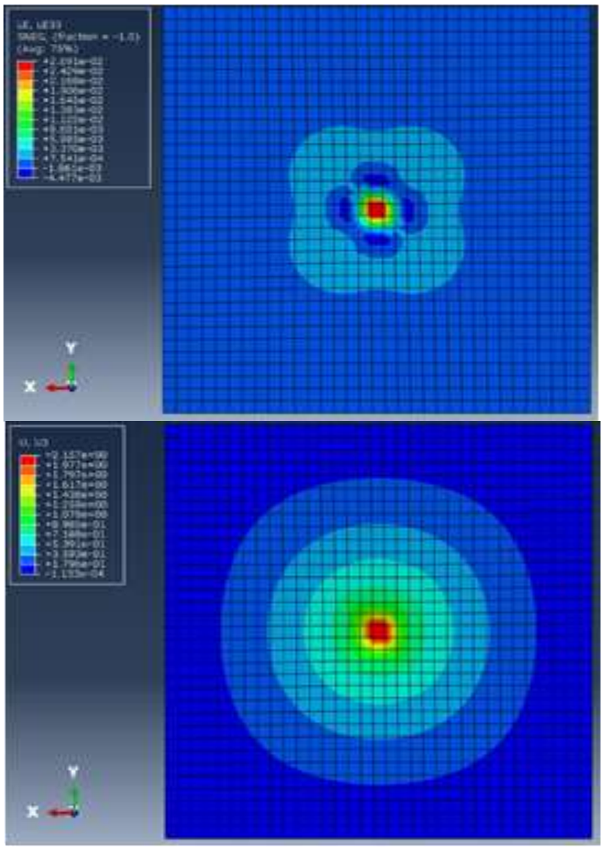


Fig. 8 Strain and displacement of the sandwich structure.

3.3. 0%wt-v1880

Based on “Fig. 9”, the highest Von Mises stress at the collision time was for the 0%wt-v1880 sample. Maximum Von Mises stress at the collision site was 345 and 16.29 MPa for the composite sheet and foam, respectively. Moreover, stress was significantly declined along the perpendicular direction due to the presence of the foam in the force transfer path. This dramatically decremented the Von Mises stress in the back face sheet.

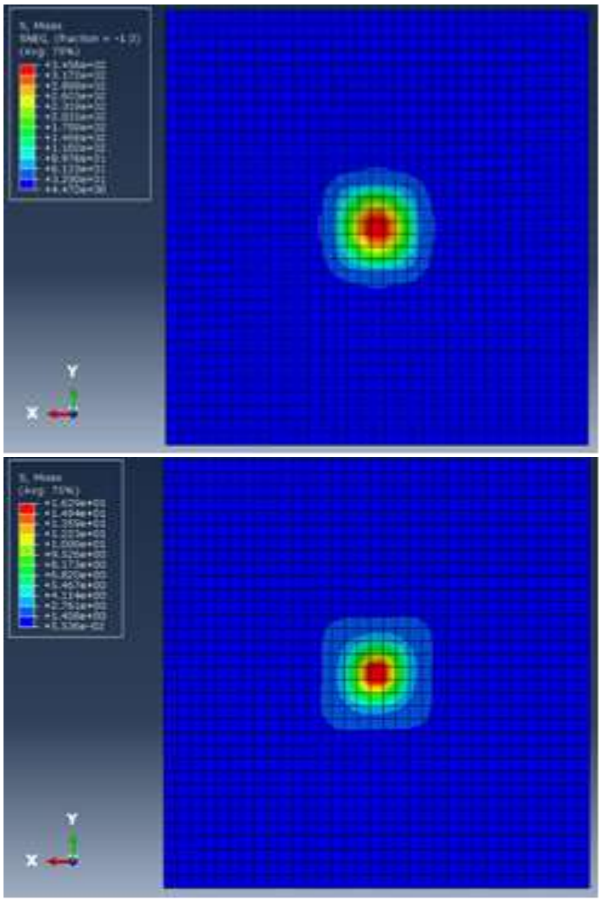
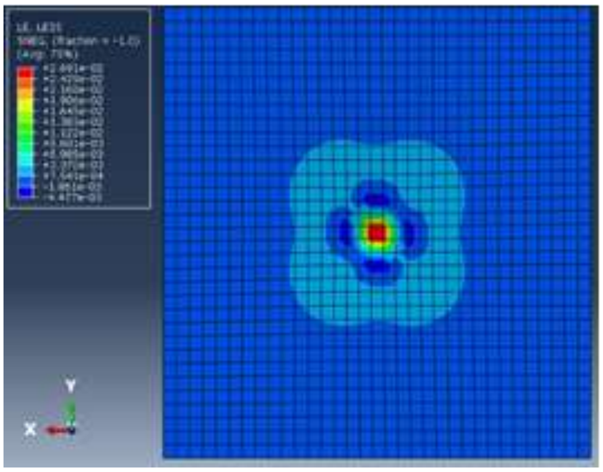


Fig. 9 Von Mises stress in the sheet and foam.

According to “Fig. 10”, the highest strain of the composite sheet was 0.027. The normal displacement of the beam was also 2.16mm.



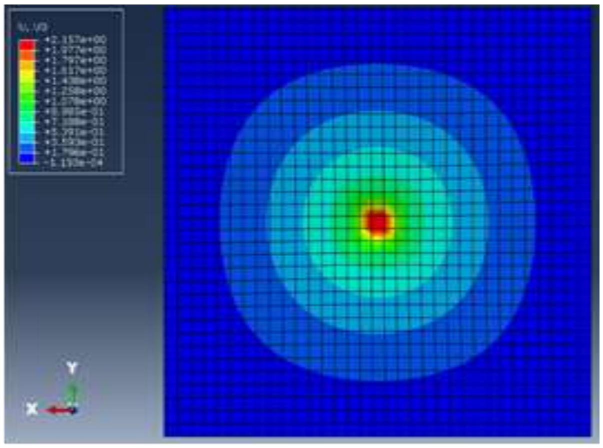


Fig. 10 Strain and displacement of the sandwich structure.

3.4. 5%wt-v2220

Based on “Fig. 11”, the highest Von Mises stress at the collision time was for the 5%wt-v2220 sample. Maximum Von Mises stress at the collision site was 342 and 18.85 MPa for the composite sheet and foam, respectively. Moreover, stress was significantly declined along the perpendicular direction due to the presence of the foam in the force transfer path. This dramatically decremented the Von Mises stress in the back face sheet.

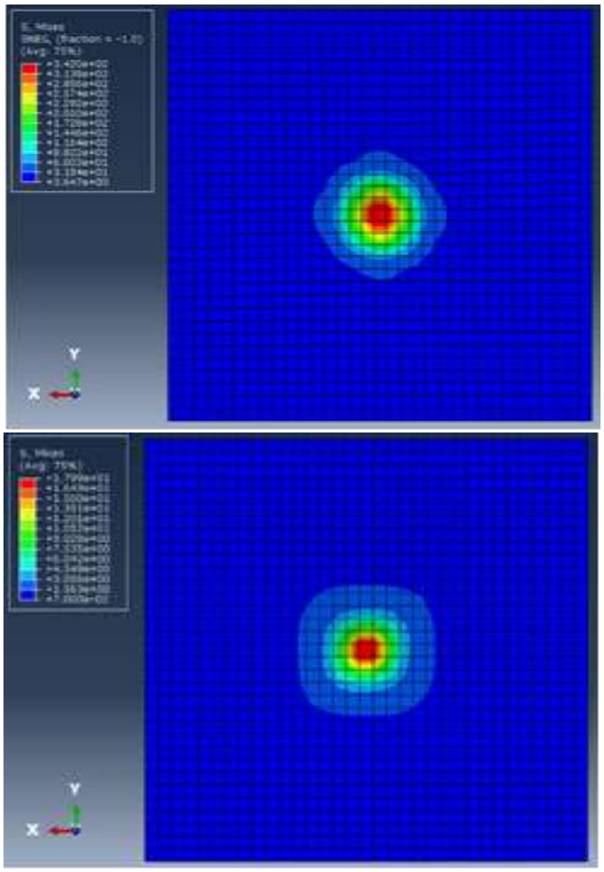


Fig. 11 Von Mises stress in the sheet and foam.

According to “Fig. 12”, the highest strain of the composite sheet was 0.029. The normal displacement of the beam was also 2.52 mm.

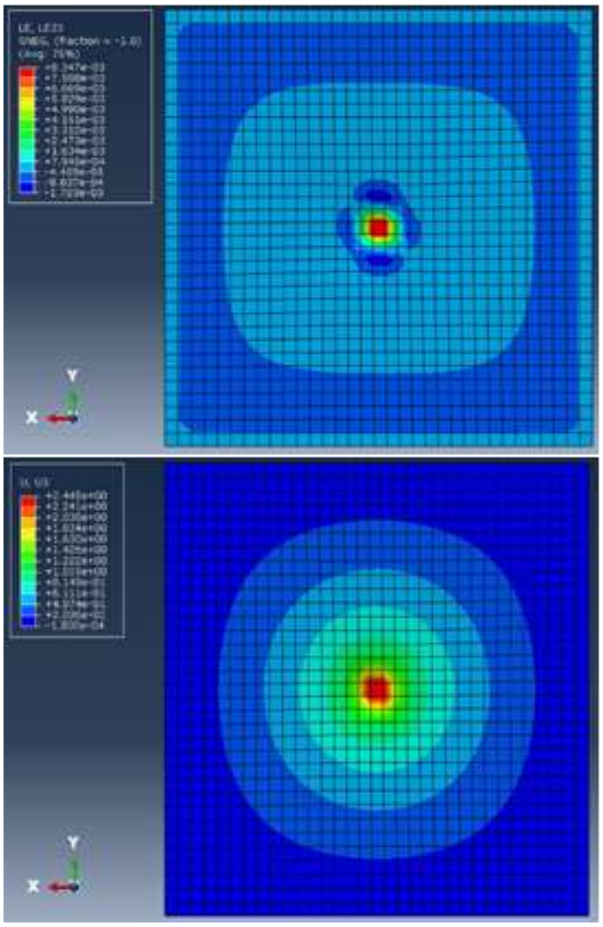
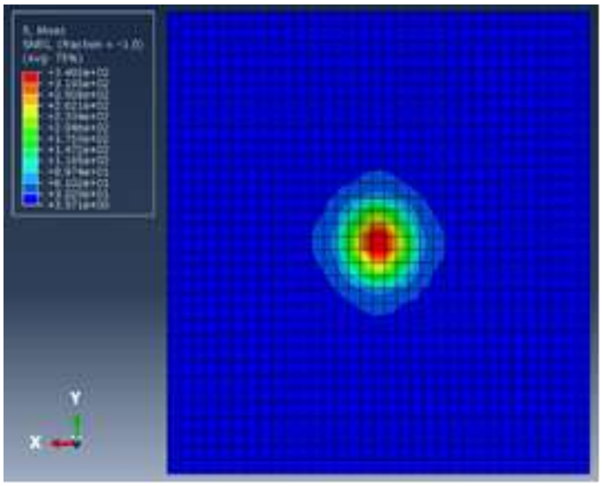


Fig. 12 Strain and displacement of the sandwich structure.

3.5. 3%wt-v2220

According to “Fig. 13”, the highest Von Mises stress at the collision site was 348 and 18.77 MPa for the composite sheet and foam, respectively.



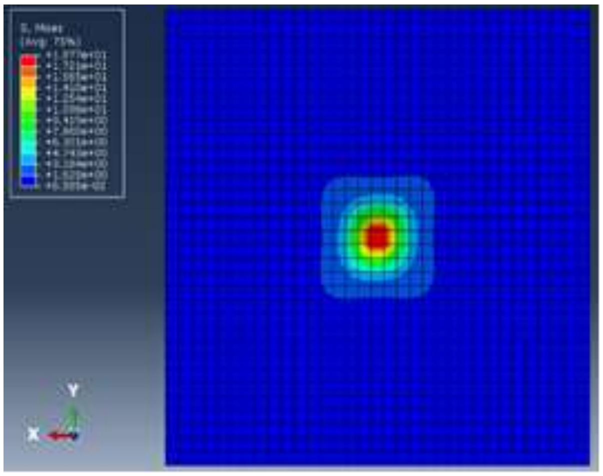


Fig. 13 Von Mises stress of the nanocomposite sheet and foam.

Fig. 14 also indicates that the highest strain in the composite sheet was 0.029 with the beam normal displacement of 2.52 mm.

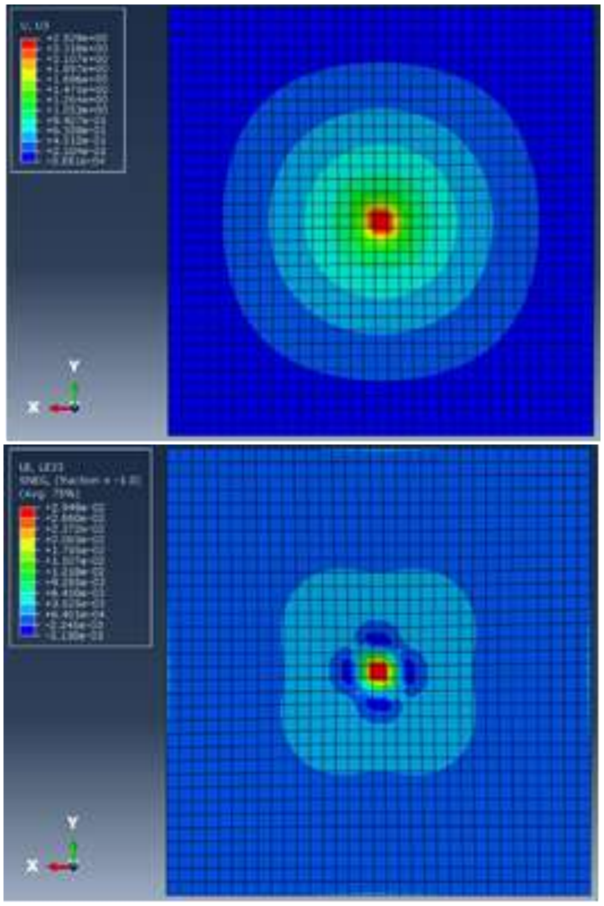


Fig. 14 Displacement and strain of the sandwich panel.

3.6. 0%wt-v2220

As “Fig.15” shows, the maximum Von Mises stress at the collision site was 388 and 18.85 MPa for the composite sheet and foam, respectively. Furthermore, the stress was drastically decremented along the perpendicular direction due to the presence of the foam in the path of force transfer, hence declining the Von Mises stress in the back face sheet.

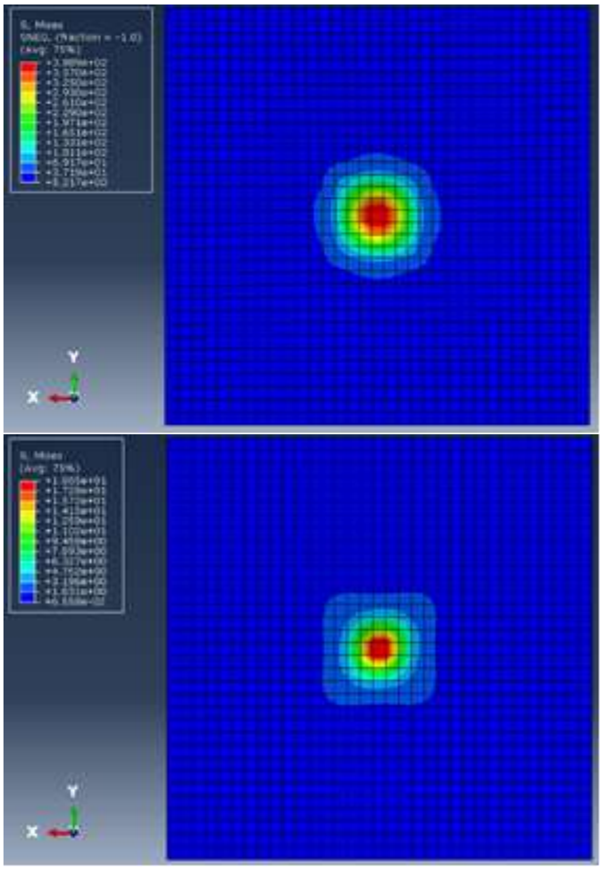
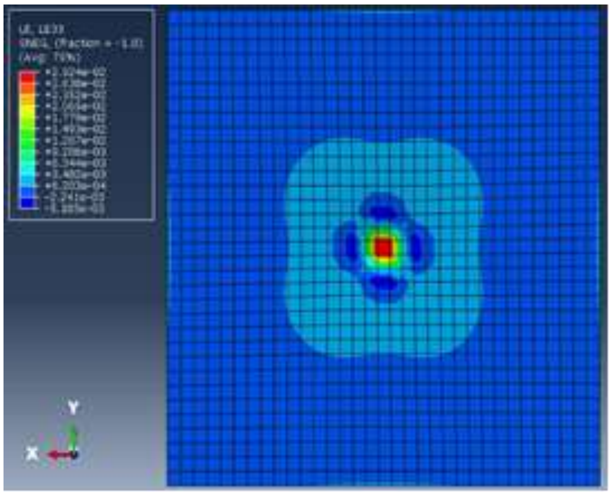


Fig. 15 Von Mises stress in the composite sheet and foam.

The highest strain of the composite sheet was 0.029 with the beam vertical displacement of 2.52 mm, see “Fig. 16”.



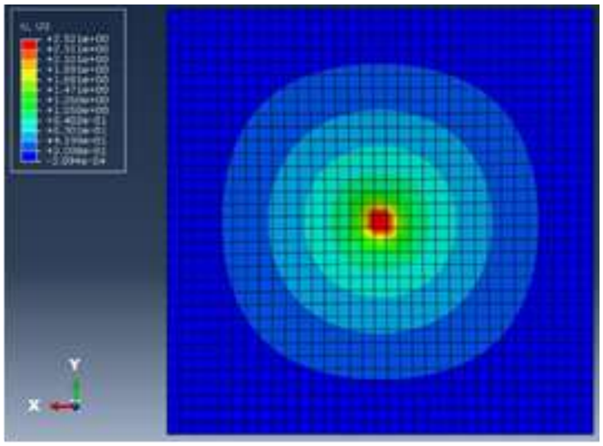
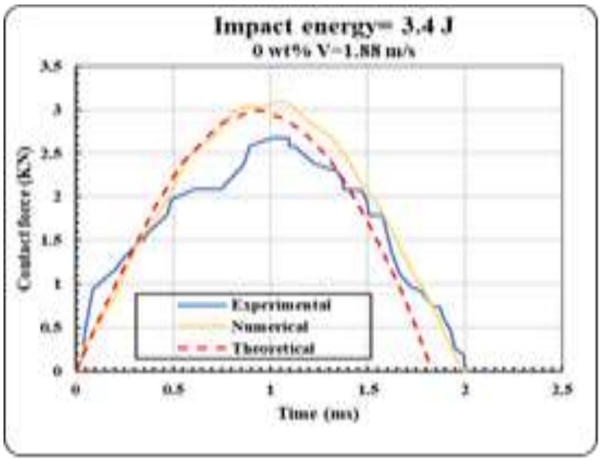
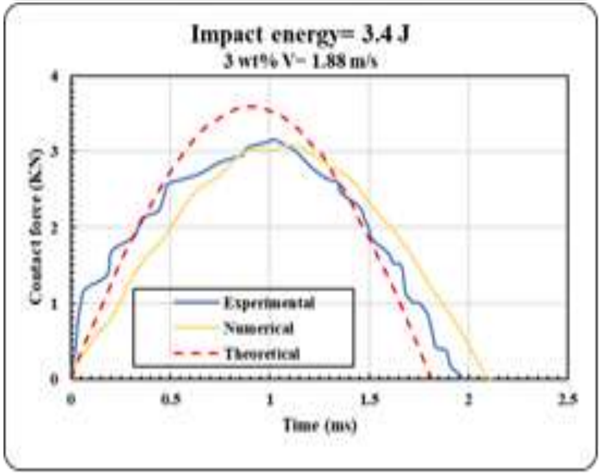


Fig. 16 Strain and displacement of the sandwich structure.

4 CONCLUSION

Fig. 17 and 18 indicate the contact force at different velocities for various nano silica contents.





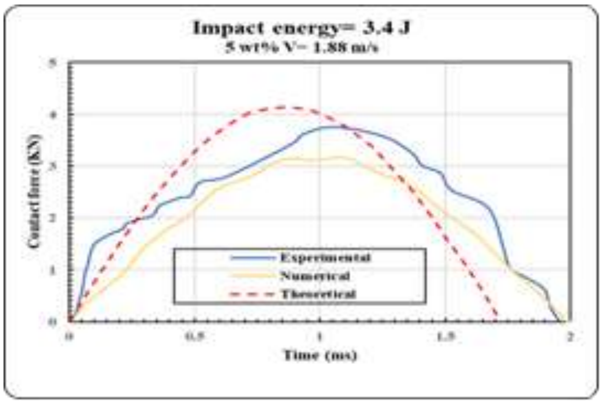


Fig. 17 Contact force for different nano silica contents at the impact velocity of 1.88 m/s.

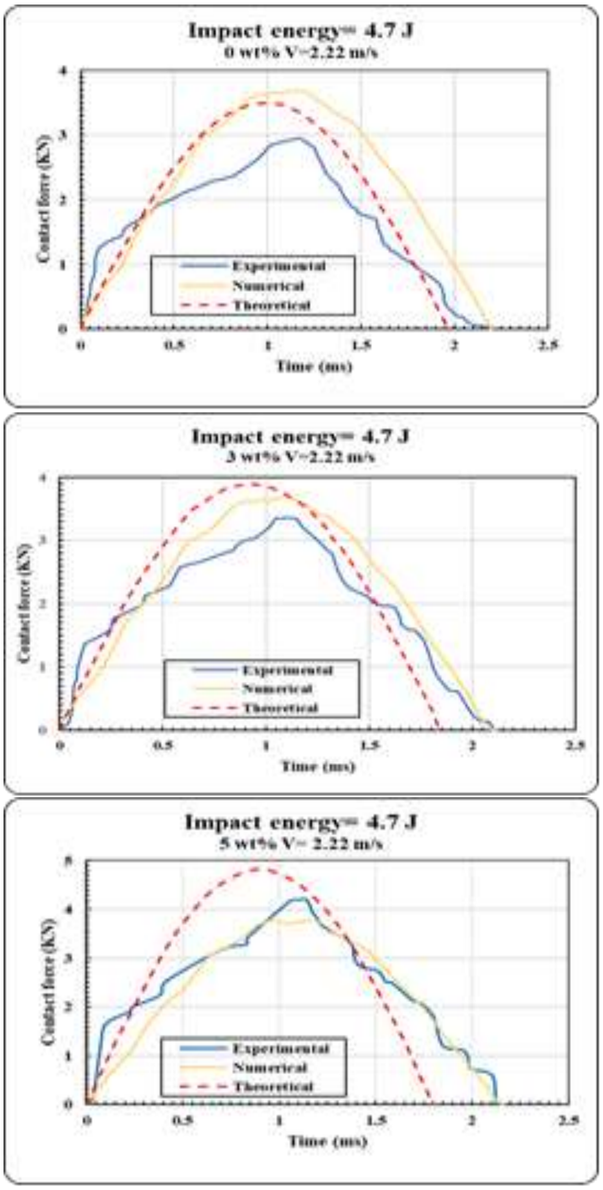


Fig. 18 Contact force for different nano silica contents at the impact velocity of 2.22 m/s.

Based on “Figs. 17 and 18”, FEM well predicted the mechanical properties of sandwich panels and impact force during the tests for various nano silica contents and velocities. At high nano silica contents, the difference between the experimental and numerical results showed an enhancement which can be assigned to the assumption of ideal composite. Some bubbles may be formed during the production stages in the composite which can decrement its strength. This issue was not considered in the modeling process. On the other hand, a rise in nano silica content can increase the chance of nanoparticle accumulation while the modeling considered random distribution of the nanoparticles. According to “Figs. 17 and 18”, FEM offered a higher accuracy in the prediction of the mechanical behavior of the sandwich panels under impact load as compared with theoretical approaches, suggesting the superiority of this method over theoretical techniques. Despite some errors, the proposed model properly predicted the impact force and contact time. So, this method can be utilized for optimization of the composite properties by varying the production parameters such as the geometry of the fabric, or weight percentage of the nanoparticles, hence declining the production costs.

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