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Role of Shape Factor in an Integrated Honeycomb Structure for Safe Drive

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Abstract: *A numerical technique has been adopted to investigate the "out of plane" strength of a honeycomb structure enclosed in a car door panel. The concept has been utilized to improve the car door strength during the car door-pole impact. The design and analysis have been done using CATIA v 5 and Ansys software respectively. The car door-pole crash test has been carried out at speeds of 60 and 80 m/sec. An attempt has been made to predict the critical damage, with and without use of a honeycomb structure in a car door panel. The results showed that deformation reduced by ~6 mm at both speeds with a honeycomb integrated car door panel. Two different types of geometrical nonlinearity was observed in the crash analysis namely round notch and diamond notch. The diamond notch was found to be critical with a high magnitude of equivalent stress at 80 m/s due to local stress concentration. The shape factor was found to play a significant role in the car door-pole crash analysis. A simulation result has been presented, that may enable design engineers to develop a robust design for a safe drive.*

Key Words: *Shape factor, Numerical analysis, Honeycomb structure, Car door panel.*

1. INTRODUCTION:

It is well known to us that honeycomb structures exhibit high strength in an "out of plane" configuration compared to an in-plane direction. Several studies have been reported on the honeycomb structure. R. D. Deshpande et al. have done three-point bending tests on the face plates and core wall of honeycomb using Hyper mesh and LS-DYNA. The effect of using different materials like copper, aluminum, titanium, and steel for faceplates was investigated. The deflection, critical load and stress were found. The finite element results like deflection and critical load were verified by theoretical calculation for a better selection of materials behavior [1]. A. Zalani et al. [2] have carried out design and analysis of the door stiffener using finite element analysis against FMVSS 214 pole impact test. Two cases were simulated based on the door stiffener. The baseline case was without door reinforcement and modified design with a door stiffener. The modified design with door stiffener was found to be very effective in case of a side impact. Similar tests have been carried out by M. Raghuveer et al. [3] on the design and impact analysis of a car door made up of steel and composite materials using a numerical technique and SOLIDWORKS. In the study, a great amount of reduction in weight and improved energy absorption were found. In other works, Shubham V. Rupani et al. [4] have done a review on the design, modelling, and manufacturing of honeycomb sandwich structures. Characteristics like high strength to weight ratio and high stiffness have been compared for different materials. Also, design and manufacturing aspects were explained briefly on the honeycomb structure. Muhsin J. Jweeg et al. [5] have done vibration analysis on the honeycomb to evaluate the natural frequency with different designs and mechanical parameters. and the analytical and theoretical results were compared. Free-vibration analysis of sandwich panels with a randomly irregular honeycomb core was analysed by T. Mukhopadhyay et al. [6]. Results have been presented for natural frequencies of low bending vibration modes considering different degrees of irregularity through a probabilistic framework. Xiaoman Liu et al. [7] have carried out research on the impact of honeycomb sandwich plates and determined their natural frequencies. Results found that the impact of sandwich plates on the natural frequency changed due to the change in geometric and physical parameters. He also deduced the free vibration equation for sandwich panels. L S Dhamande et al. [8] have done damage detection on an Aluminium honeycomb structure using vibration analysis. The motive behind conducting the test was to detect the presence of damages in the manufactured product. He prepared a laboratory specimen, created artificial damage to the structure and determined the natural frequencies. The damage detection test was based on the Fast Fourier transform (FFT) analyser and the results obtained in the experiments were compared with the finite element method. Assad Naeemet et al. [9] have worked on Steel honeycomb dampers for seismic retrofit structures. The dynamic behaviour was studied at different seismic load, the structure variation was captured, and it was found that the honeycomb dampers were effective in the enhancement of seismic load. B.Vishnu Vardhana Naidu et al. [10] have developed honeycomb structures using a 3D printing technique, additive manufacturing process and has conducted a compression and impact strength test. The results obtained in his study were found to have good technical significance in engineering practices. From the literature survey, it is understood that honeycomb structures exhibit high strength in out of plane compared to the in-plane direction, irrespective of the material type and dimensions and were found to offer many engineering advantages. In view of this, an attempt has been made to leverage the advantages offered by the honeycomb structure by integrating the same structure to a car door panel to mitigate and reduce the side damage during road accidents, using the numerical technique.

2. STRUCTURAL DESIGN AND NUMERICAL ANALYSIS:

A numerical technique has been used to understand the crashworthiness of the modified car door panel. Structural steel has been used for both the honeycomb structure and the car door panel. The elastic modulus was considered to be $E = 2\times10^5$ MPa. The material properties were directly taken from the Ansys workbench material database. A car door with and without a honeycomb structure has been tested against a rigid pillar using the explicit method. The pole-crash test was conducted at a speed of 60 m/s and 80 m/s where the pole has been treated as a rigid body. The selection of the speeds was for the sake of understanding and simplicity. The tetrahedron and trigonal shell elements have been used to mesh the model. Approximately thirty thousand nodes were created for the numerical analysis. The important dimensions and the meshed model are shown in Fig.1 & 2 respectively.

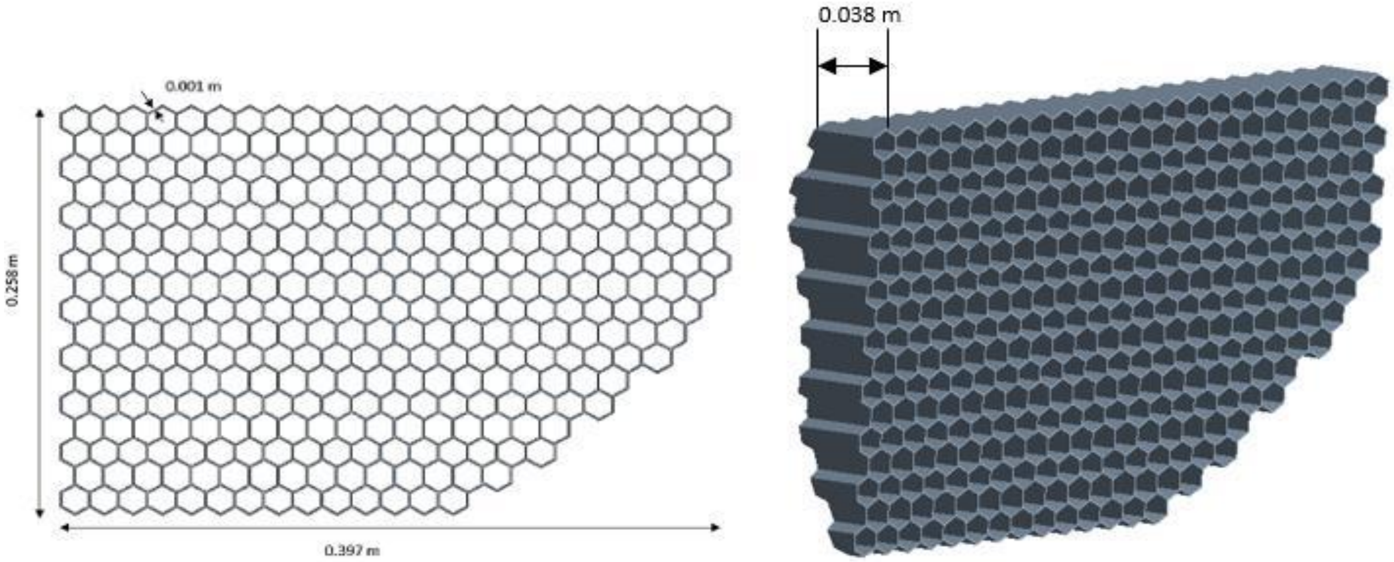


Figure 1 Important dimensions of honeycomb structure.

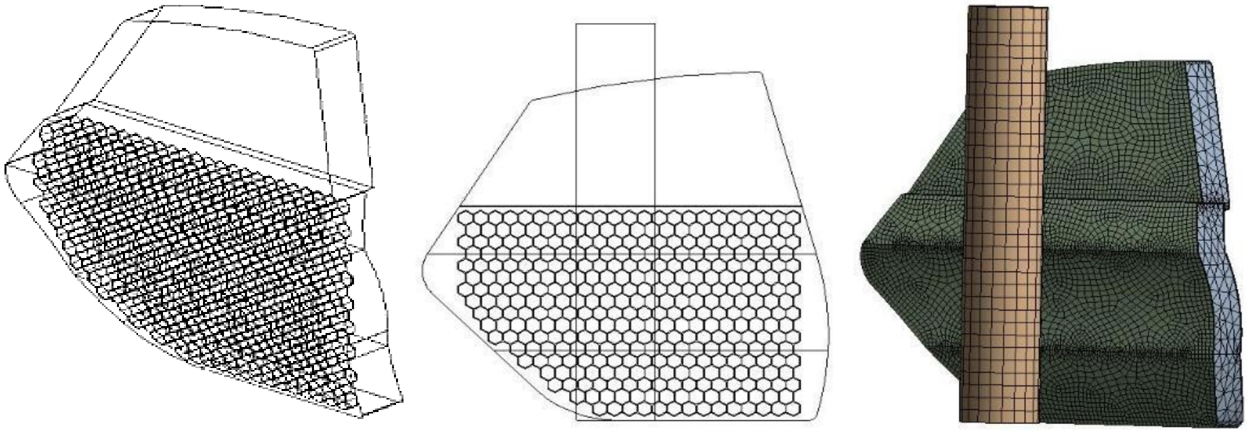


Figure 2 Wire frame car door panel and meshed model.

3. RESULT AND DISCUSSION:

Results obtained from the numerical analysis showed that deformation and residual stress did not only depend on the area of contact made between the static pillar and car door panel but also on the type of structure. In the dynamic analysis, it has been observed that the total deformation is significantly more at 80 m/s compared to 60 m/s without the integration of the honeycomb structure in a car door panel. However, a significant decrease in the magnitude of an average total deformation was found (~4 mm), at both speeds, after honeycomb integration (Fig. 4(a) and (b)) and without honeycomb structure integration (Fig. 4(c) and (d)). After honeycomb integration, at 60 m/s, the magnitude of equivalent stress was found to be reduced by 3597 MPa, refers to Fig.5(a) and (b). However, an anomaly has been observed in the magnitude of maximum equivalent stress at 80 m/s. The reason for such abnormalities can be attributed to the shape and surface irregularities, identified in the present study as a diamond-shaped notch, and round-shaped notch. The round-shaped notch was found in the case of a car door panel without the integration of the honeycomb structure. The enlarged view of the round and diamond-shaped notches are shown in Fig.3(a) and (b) respectively. It has been understood that the deformation and flow stress was mainly governed by the shape factor. The shape factor has been an important parameter and has a significant role in the study of stress concentration and niche engineering analysis [11]. The vector diagram representing the stress nucleation for both the type of geometrical nonlinearity has been shown in Fig.3. From Fig.3 it has been understood that yielding/stress flow initiated form the edge of the round notch. The compressive stress denoted σ_c, was found to gradually reduce and changed to tensile stress (σ_t), in the vector diagram. On the other hand, in the case of the diamond-shaped notch, yielding was found to be initiated from the center, identified as σ_c and gradually found to be reduced denoted as σ_t. The above two geometrical non-linearities have been in accordance with the von-mises results plot at 80 m/s with the honeycomb structure (refer to Fig 6 (b)). At 80 m/s relatively high non-linearity was observed compared to 60 m/s, identified as a more zig-zag path. At both speeds 60 & 80 m/s the deformation and von-mises stress have been found to be significantly improved after the honeycomb integration. However, at 80 m/s the residual stress found to be more attributed to the shape factor, the diamond notch effect leading to high-stress concentration. The maximum deformation and equivalent stress magnitude with and without honeycomb structure have been shown in Table1.

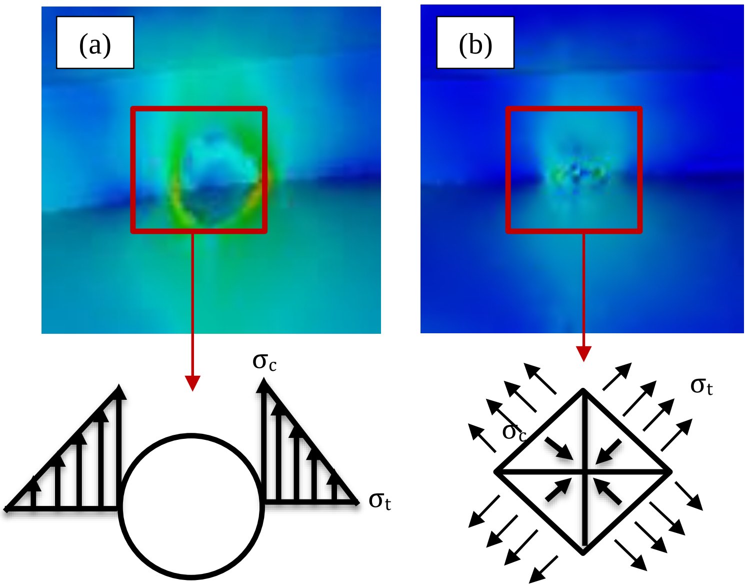
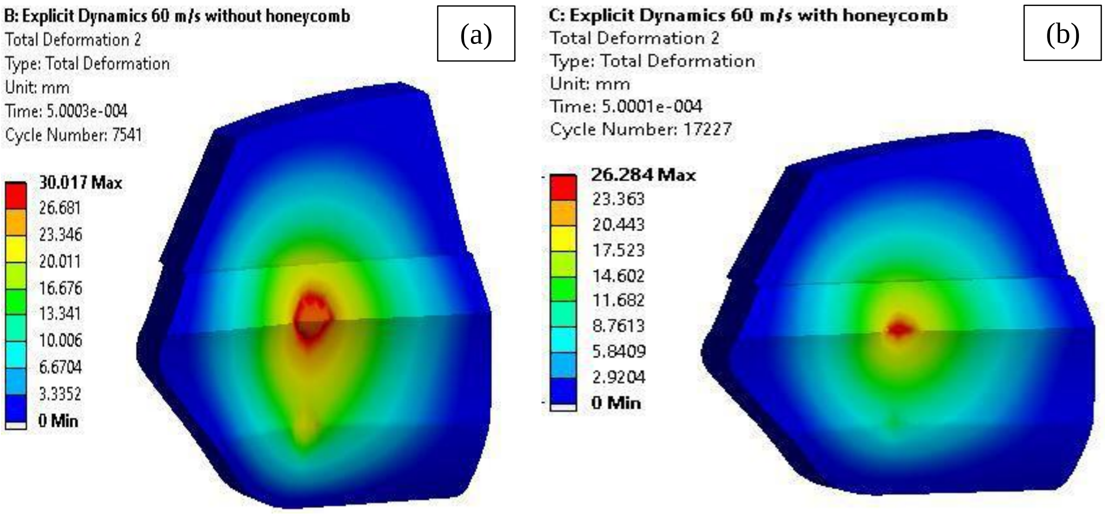


Figure 3 Enlarged view of round and diamond shaped notch stress concentration along with the direction of residual stress vector diagram where σ_c: Compressive stress & σ_t: tensile stress: (a) without honeycomb and (b) with honeycomb structure in a car door panel respectively.



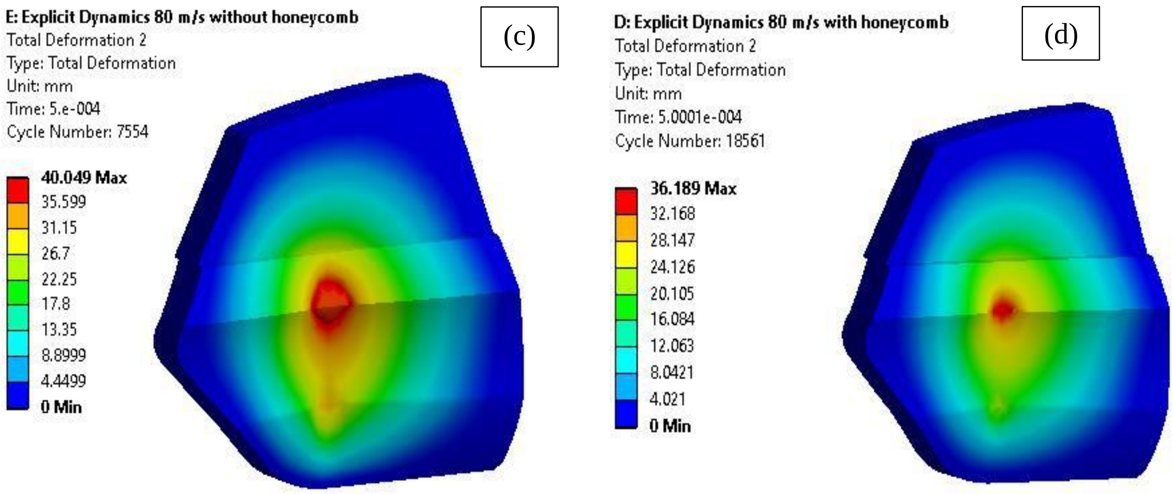


Figure 4 Photograps of total deformation at (a)(b) 60 m/s and (b)(d) 80 m/s without honeycomb and with honeycomb structure respectively.

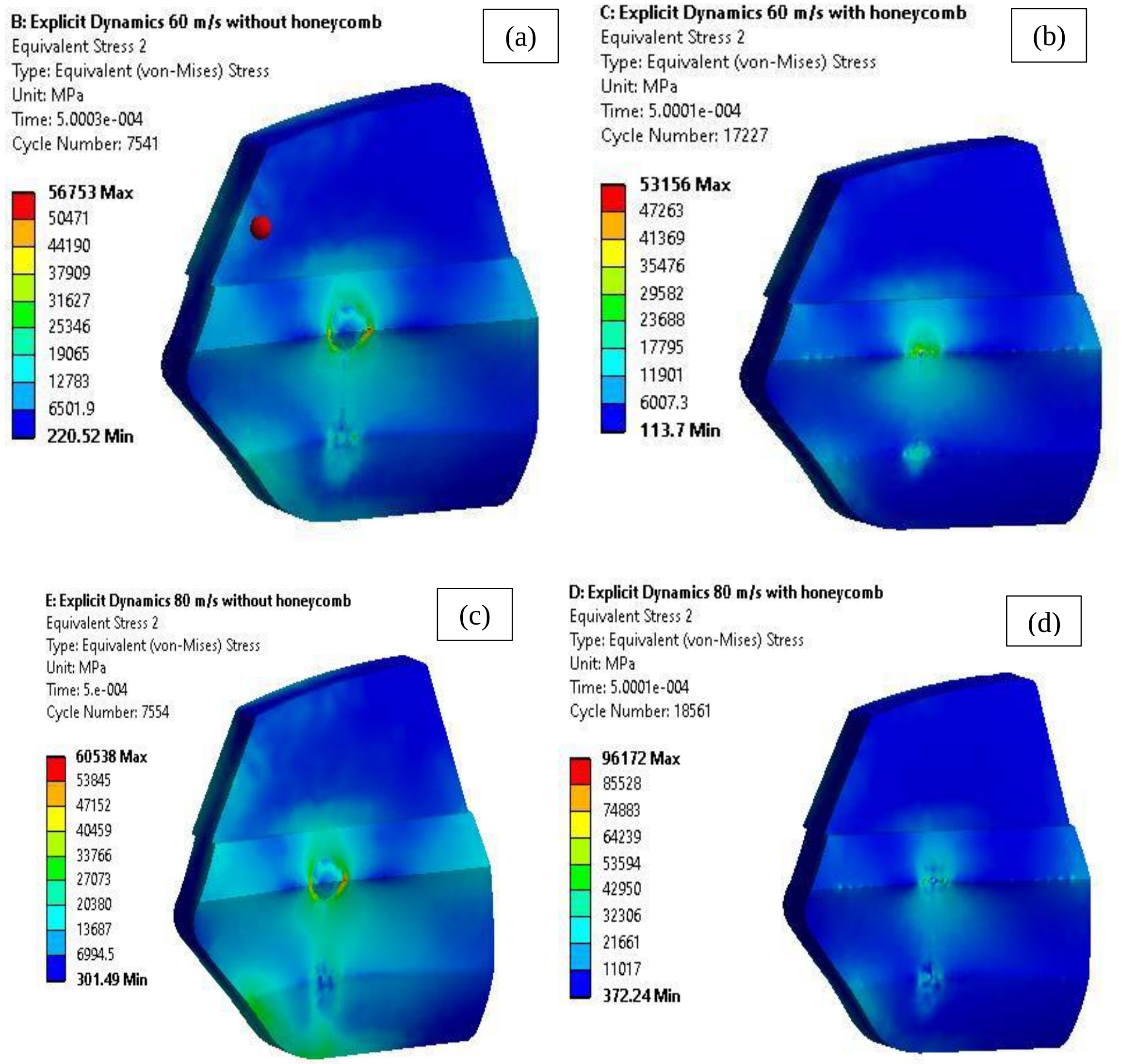
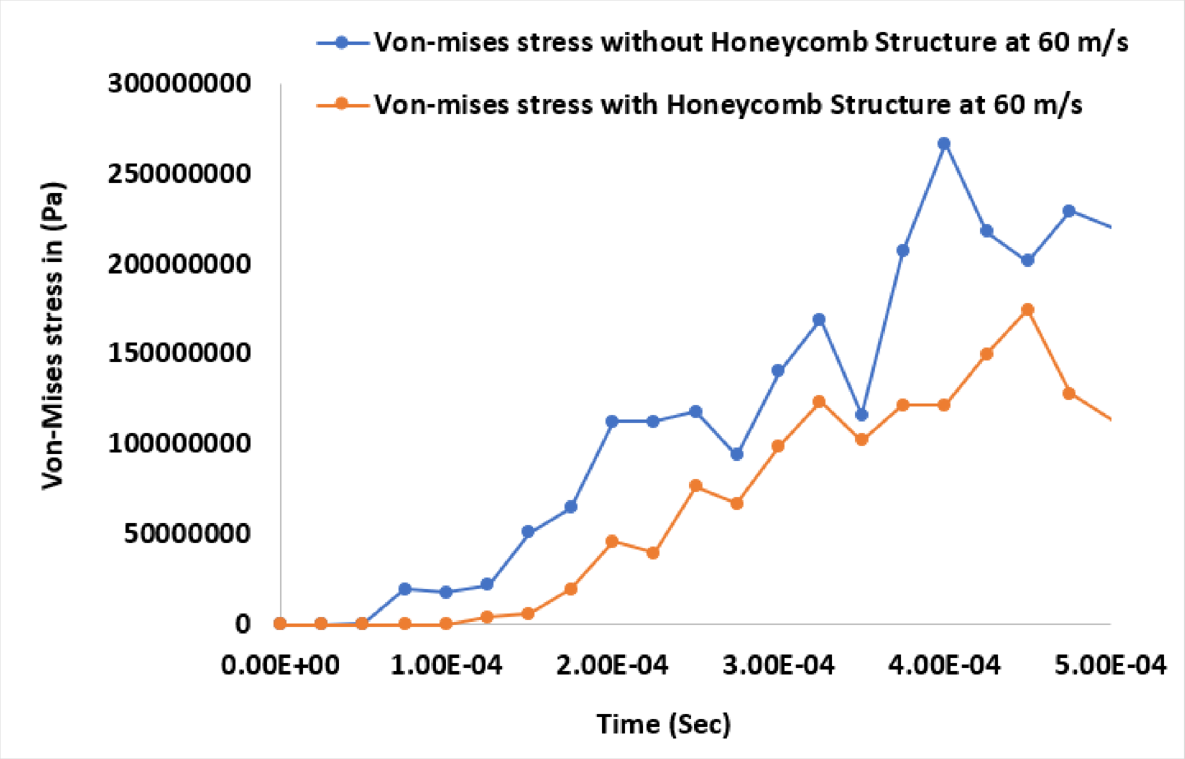


Figure 5 Photograps of of Equivalent stress at (a)(b) 60 m/s and (b)(d) 80 m/s without honeycomb and with honeycomb structure respectively.

Table 1: MAXIMUM DEFORMATION AND EQUIVALENT VON-MISES STRESS RESULTS WITHOUT AND WITH HONEYCOMB STRUCTURE

S.No.	Speed (m/s)	Without Honeycomb Structure		With Honeycomb Structure	
		Total Deformation (mm)	Von-Mises Stress (MPa)	Total Deformation (mm)	Von-Mises Stress (MPa)
1	60	30.017	56753	26.28	53156
2	80	40.049	60538	36.189	96172



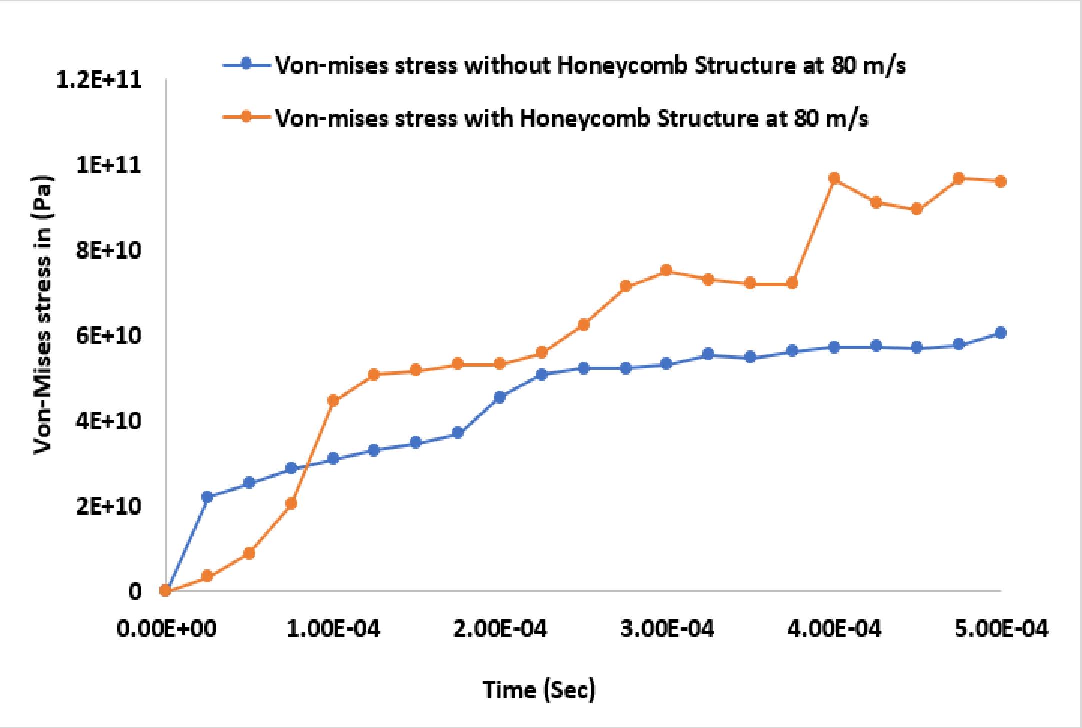


Figure 6 Residual stress/Equivalent stress plot versus time at (a) 60 m/s (b) 80 m/s

3. CONCLUSION:

From the above numerical analysis, the following important conclusions may be drawn:

- Two different types of geometrical nonlinearity were observed, namely the round-shaped notch and diamond-shaped notch. The round-shaped notch was mainly identified without the integration of the honeycomb structure and diamond-shaped notch was observed after the integration of honeycomb structure in a car door panel.
- The shape factor was found to play a significant role in the determination of critical damage and stress concentration. It has been understood that the diamond-shaped notch leads to high stress concentration, in the present investigation at 80 m/s. On the other hand, uniform stress distribution resulted from the round-shaped notch at 60 m/s.
- At the speeds of 60 and 80 m/s, there is a decrease in deformation by 4 mm, observed after the integration of honeycomb structure, which may be suggested for future design alteration after thorough investigations.

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