NUMERICAL INVESTIGATION OF DROP WEIGHT IMPACT ON PEEK BASE LAMINATED COMPOSITE MATERIAL

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ABSTRACT

The present work describes a numerical investigation of the damage in a laminated composite material subjected to impact load. The study conducts on polyetheretherketone (PEEK) base laminated composite material reinforced by two types of fibers (glass and Kevlar) in order to studying the number of factors that may affect on the absorbed energy behavior of the composite material such as fibers, and velocity of impactor. The investigation was done by using finite element analysis software ANSYS 14. Results indicated that peak force in general increase when increase the velocity of impactor and the carbon reinforcing composite showed better resistance, on other hand the energy peaks also increase with increasing velocity.

Key words: numerical modeling, laminated composite, impact load, drop weight, ANSYS.

دراسة عددية للصدمة الناتجة عن الثقل الساقط على مادة مركبة طبقية ذات أساس من البولي ايثر ايثر كيتون

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الخلاصة

البحث الحالي يصف طريقة النمذجة العددية للتنبؤ بالضرر الحاصل في المادة المركبة متعددة الطبقات نتيجة تعرضها لأحمال صدمية. أجريت الدراسة على مادة مركبة متعددة الطبقات ذات أساس من البولي ايثر ايثر كيتون المقوى بنوعين من الالياف (زجاج وكافلر) لدراسة تأثير عدد من العوامل التي قد تؤثر على سلوك امتصاص الطاقة في المادة المركبة مثل نوع الليف وسرعة الجسم الصادم، الدراسة أجريت بطريقة العناصر المحددة باستخدام برنامج (ANSYS) وقد بينت النتائج زيادة منحنيات القوة والطاقة مع زيادة سرعة الصدم والمادة المقواة بألياف الكربون أبدت مقاومة أفضل.

1- INTRODUCTION:

Composites materials with fiber reinforcing have wide scope of engineering applications in areas such as automobile, aerospace, defense also marine, because of their high strength to weight ratio, stiffness, high strength, and resistance to elevated temperature [Tijani *et.al* 2014 and Arun *et.al* 2010]. Regardless of these advantageous of their characteristics, they are still, liable to damages due to various factors through manufacture and in service [Arun *et.al* 2010]. The damage mode due to low impacting velocity loadings on composites materials consists of matrix cracking, delamination, and fiber failure [Tijani *et.al* 2014 and Sohn M.S. *et.al* 2000]. The damage mode in high impacting velocity loading is basically the same for low impacting velocity, but with further damage mechanisms such as shear plugging [Shahkarami *et.al* 2006]. For increasing the impact strength of composites materials by various ways has been shown out of several papers. Fiber treatment [Kim J.K. *et.al* 2001], interleaving [Park and Jang 1998], hybridization of fibers [Arun *et.al* 2010, Sohn M.S. *et.al* 2000 and Park and Jang 1998] and matrix modification [Shyr and Pan 2004] are outstanding among the methods reported. Finite element analysis (FEA) has been earning in a large portion of past investigating on modeling and expect the response of fiber reinforcing composite. Numerous research papers on modelling of impacting damage in laminated composite materials have been carried out [Ardakani *et.al* 2014].

Muhammed Tijani *et.al* investigated the low velocity impacting tests on modifying unsaturated polyester reinforcing with four various woven fabrics by use hand-layup method. The time versus load curves are analysed and (SEM) was used to observing the surface that impacted composite laminates. The results fixed that all the samples have ductility index of above 2 for the test conducting at impacting energy of 27J for the monolithic composites of Kevlar having regard to the highest ductility index. M.Alemi *et.al* [8]conducts impact modeling for fiber reinforcing polymeric composites material, two simplified methods are presented of fast simulation of out-of-plane impacting response of this materials. As a result a berserk estimation of the dynamic load response of the composite material can be attained.

Chan and In-Gul examined the monitoring of impacting forces on an aircraft composite material wing using impact response function (IRF). The IRF be derived depend on the finite element analysis (FEA), the results of impact position identifications and impacting load reconstructions are verify by numerical simulate using finite element analysis

Gouda *et.al* investigated of Mode-I fracture behavior of glass fiber and carbon fiber reinforced hybrid polymeric composite based on experimental study and finite element analysis, results indicated that the cracked specimens are tougher along the fiber orientations as compared with across the fiber orientations

Umar Farooq and Karl Gregory developed a finite element mathematical model to simulation impact behavior and to portend the failure response for carbon fiber reinforcing composite plate subjected for low velocity dropping weight impact on a partitioned area where an impactor of flat tip hits the sample. They found this method is simple and active to predict equivalent transverse shear stresses from a model. These predicting and calculated stresses are used in failure theory to predict possible failure mode.

S.N.A. Safri *et.al* studying the velocity impact force and absorbed energy conforming to the incident impacting level of type glass/Epoxy composites material. Results showed, the peak impact force and peak of absorbed energy increase with the increasing in happening impact energy

H. KU *et.al* investigated the difference in impact strength between microwave curing vinyl ester particulate composites material and those cured under natural conditions. The results show that the difference in the impact strength is minimal.

In the present study an attempt is made to determine the damage of continuous carbon, Kevlar and hybrid fibers composite material systems based on PEEK as matrix as laminated composite materials with different layers sequences and different velocities of impactor weight numerically by using finite element program code called [ANSYS 14].

2- MATERIALS

Hybrid laminated composite materials reinforcing with Kevlar-Carbon fiber are the laminated composites material, which are become increasingly popular for different structural applications in aerospace, automotive, and other industrial sectors. The current research has been carried out with PEEK resin and unidirectional Kevlar and carbon fiber with difference layers sequence. **Table 1** show the typical elastic properties for materials used in the study. [Techatron® 2013 and Sika® 2011] The rectangular plate of fiber reinforced composite plies with dimensions (350×350×4) mm were considered. Quasi-isotropic configurations of eight layers [45/0/-45/90] symmetric with volume fraction of (50%), each layer have (0.5) mm thickness for three types of reinforcement (carbon fibers, Kevlar fibers and hybrid carbon with Kevlar), as shown in the **Fig. 1**.

3- MODEL DEVELOPMENT

A drop-weight model to portend the composites behavior was incorporated into ANSYS program (Explicit Dynamics) for simulation the model and create the results as follows:

3-1- Definition of the Problem

The drop weight impact problem can be described as shown in **Fig. 2**. An impactor that has a mass of *m* kg and a diameter of *d* mm with the velocity of *V* m/s drops on the composite plate which is fixed from the edges of below surface In this study, the stacking sequence of the composite plate is chosen as [45/0/-45/90] s.

3-2- Geometry:

The model consists of two parts, are the laminated composite plate with dimensions (350×350×4) mm as describe above in section (2) and centrally located impactor made up from steel as the ball with diameter (5) cm was selected to impacting the target as the dropping weight as shown in **Fig. 3**.

3-3- Type of element and meshing:

The element (**SHELL 93 element**) may be used for layered applications for structural modeling of laminated composite.

The mesh of the model is SHELL 93 (isoparametric 8-node structural shell) with element size of default size (No. of elements are 3928, No. of nods are 2404), and using the free meshing type to mesh all the model is shown in **Fig. 4**.

3-4- Boundary Conditions:

The model (plate) is constrained in all degrees of freedom at lower edges as fixed support while the impactor was modelled as a rigid body with a defined velocity (*V*) at the moment of impact according to Newton's second law of motion that related the free downfall height (*h*) and acceleration (*g*) as: [6]

$$V = \sqrt{2}gh \quad (1)$$

Where the value of (*h*) used in the study is (50 cm)

In addition, the time between the fall of the impactor and striking the specimen is required in analysis setting which can be calculate as follows:[6]

$y(t) = \frac{1}{2}gt^2 + \mathrm{V}t$ (2)

Where,

V= the initial velocity (m/s).

$y(t)$= the high with respect to time (m).

t = time elapsed (s).

g = local gravitational acceleration (m/s^2).

The maximum energy E in the impactor before to impact is given by:[6]

$E = 0.5\, Em^2$ (3)

Where m is mass of impactor.

The absorbed energy *(E_a)* is function of time that can be determined by:

$E_a = 0.5mv^2 - 0.5m[v^2 - (\frac{1}{m}) \int_0^t Fdt]^2$ (4)

Multiple velocities were applied to the impactor as shown in **Fig. 5** were used to study its effects of their on impacting behavior of composite laminated plate.

4- RESULTS AND DISCUSSION:

Numerical simulation results are presented in the form of graphs and contours plot. These results give an information about the behavior of the laminated composite plate subjected to impacts load with different velocity impactors. The ply out of 8-ply model were selected for presented herein.

The peak force and the peak of energy absorbed were the main results obtained from the drop weight impacted a composite laminated plate. Peak force is the maximum force of the impactor impacted on the laminated plate over the entire impact time, whereas the absorbed energy is the energy at the maximum impact load. The absorbed energy is obtained by integration the load-displacement curve.

Figs. 6, 7 and 8 show the force peaks against time for carbon, Kevlar and hybrid reinforced composite materials respectively at different velocities.

The figures of the force-time curves' indicated that increasing in the velocity of impactor body leads to increasing in contact forces where the maximum contact force can be obtained at maximum impact velocity (10 m/s) for all type of composite materials and we noted that the peak of force is stable at zero N until the impactor is strike the composite plate and at moment of striking, the peak of the force begin to changing (oscillations) upwardly and downward this is due to starting contact between the specimen and the impactor, after these a drop in the impact force indicates the unloading of impactor because the presence of damage and finally fading oncoming to zero.

For the same figures, it is clear that the contact force is maximum for Kevlar reinforced laminated composite in the first consideration and the moderate values for hybrid composite (this is due to the hybridisation effect with the carbon fibers introduce into the component subscribe to the load sustain effect) while lower values of contact force produced in carbon reinforced laminated composite, due to the higher strength of carbon fibers.
Figs. 9, 10 and 11 shows the absorbed energy against time for carbon, Kevlar and hybrid reinforced composite materials respectively at different velocities.

Where observation that the results of energy contrary the peaks of force where noted the maximum absorbed energy is appear for carbon reinforced laminated composite for all velocities while the lower one for Kevlar reinforced laminated composite and the increase in velocity caused the increasing in the energy value and these observation indicated that increasing in absorbed energy results into more fiber breakages and matrix cracking.
Figs. 12, 13 and 14 show the contours plot of total deformation occurring in laminated composite materials due to impact load in carbon, Kevlar and hybrid reinforced composite materials respectively at different velocities.
It can be observed that higher velocity can caused maximum damage in composite plate for all types of reinforcement. It can also be shown from the figures that carbon reinforcing laminated appear more resist to impact load from other materials in this study.
Figs. 15, 16 and 17 shows the contours plot of Von-Mises stress resulting in laminated composite plate due to impacting the carbon, Kevlar and hybrid reinforced composite materials respectively at different velocities.
The figures display the overall distribution of Von Mises stress throughout the composite material. The approximate location and value of maximum Von Mises stress can also determine from these figures.
The minimum value of Von Mises stress, means the maximum structural strength is obtained. From these figures can it noted be the lower value of Von Mises stress obtained in carbon reinforcing laminated plates and this means that it has higher strength to impact damage.

5- CONCLUSIONS:

A numerical simulation of drop-weight impacting on laminated composite was accomplish in the commercially obtainable software ANSYS 14. The peaks of force and energy were analysed, peak force in general increase when increase the velocity of impactor and the carbon reinforcing composite showed better resistance, on other hand the energy peaks also increase with increasing velocity. Total deformation and Von-Mises stress exhibits variation with variation of velocity and type of fibers.

Table (1), Typical Elastic Properties for Materials Used in the Study.

Material	E (GPa)	*v*	G (GPa)
PEEK	4.4	0.44	1.54
Carbon fiber	220	0.3	84.6
Kevlar 49 fiber	112.4	0.36	41.32

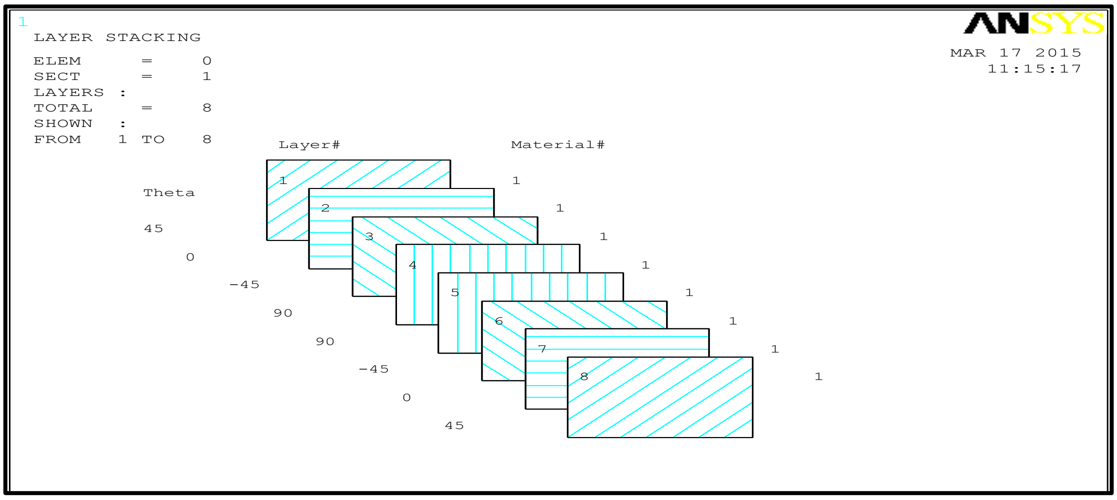

Fig. (1), layers sequence in laminated composite materials.

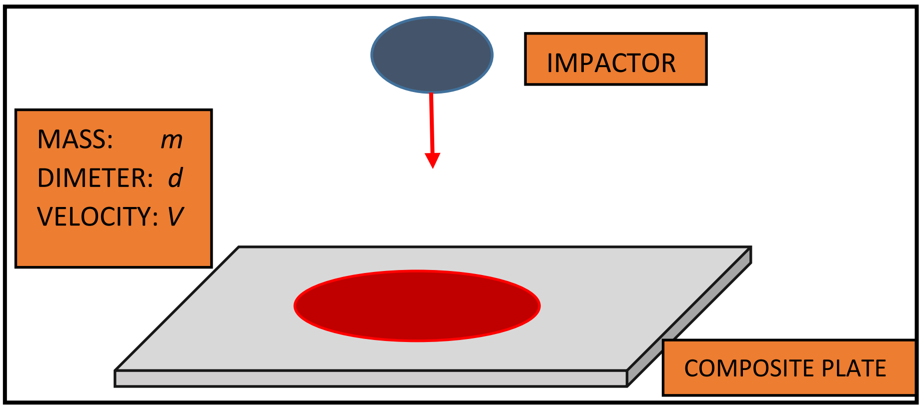

Fig. (2), description of the problem.

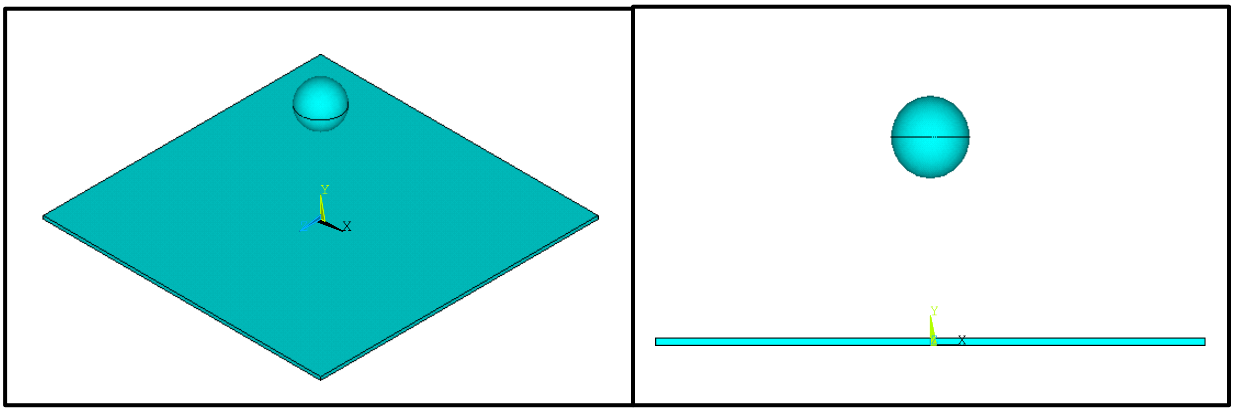

Fig. (3), contents of 3D modeling of the problem.

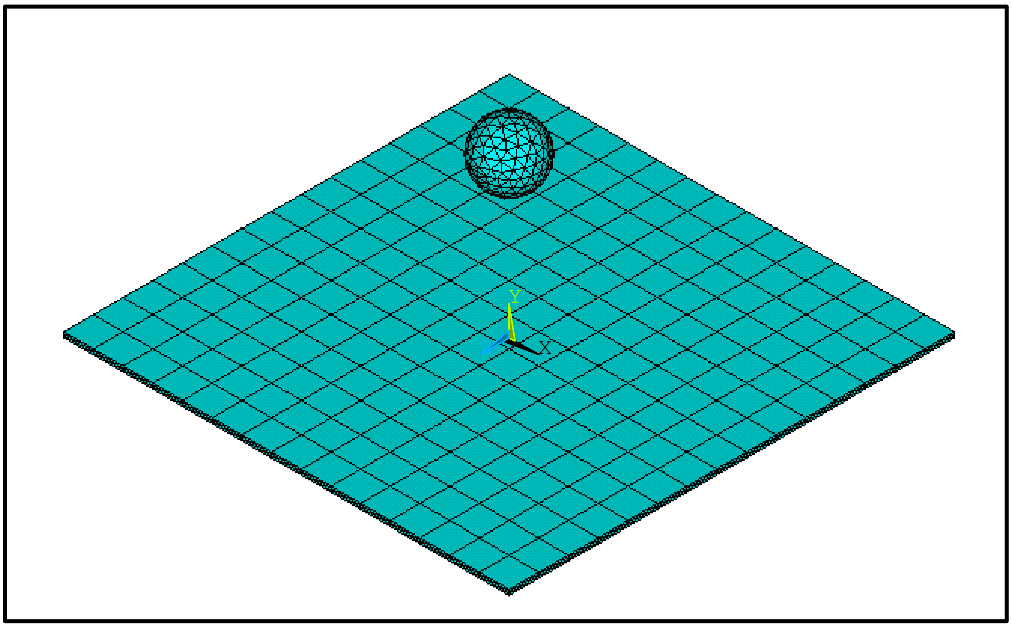

Fig. (4), finite element model of the problem.

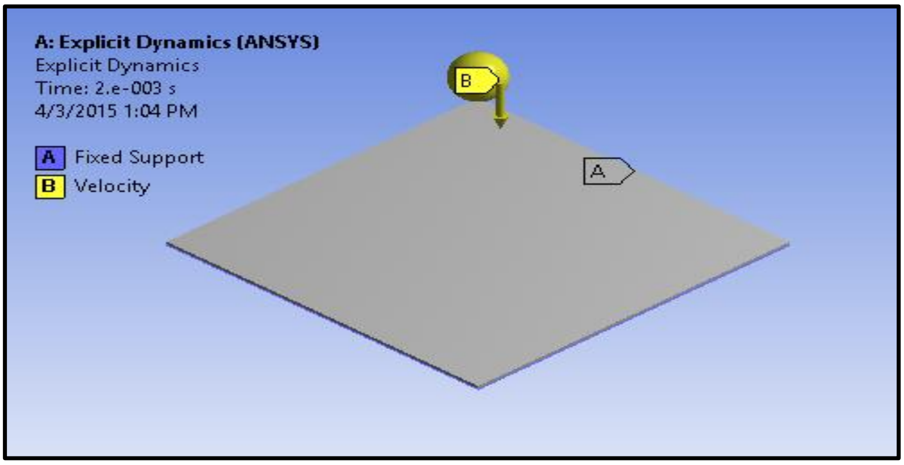

Fig. (5), apply boundary conditions.

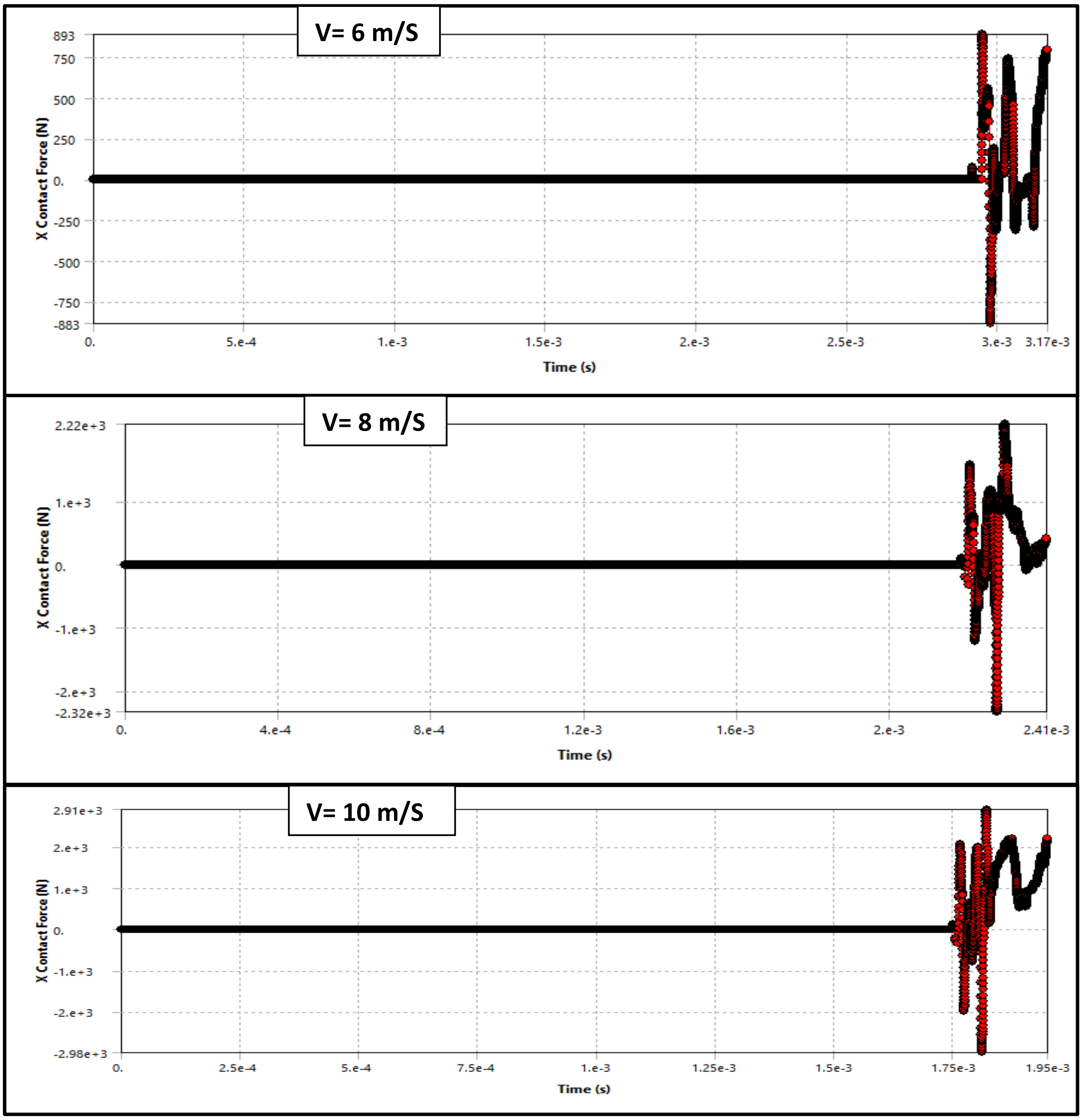

Fig. (6), force against time for carbon reinforced composite

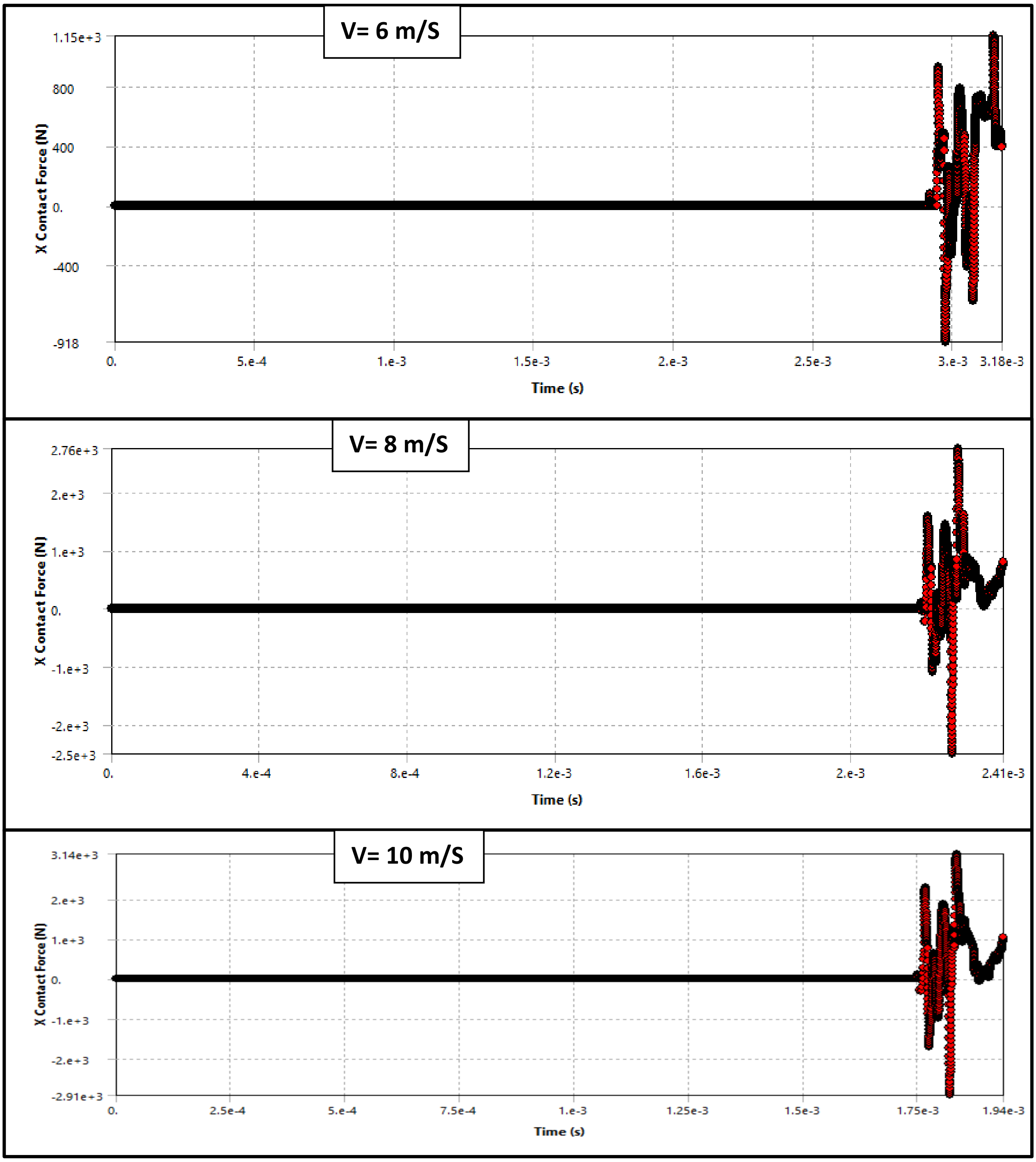

Fig. (7), force against time for Kevlar reinforced composite

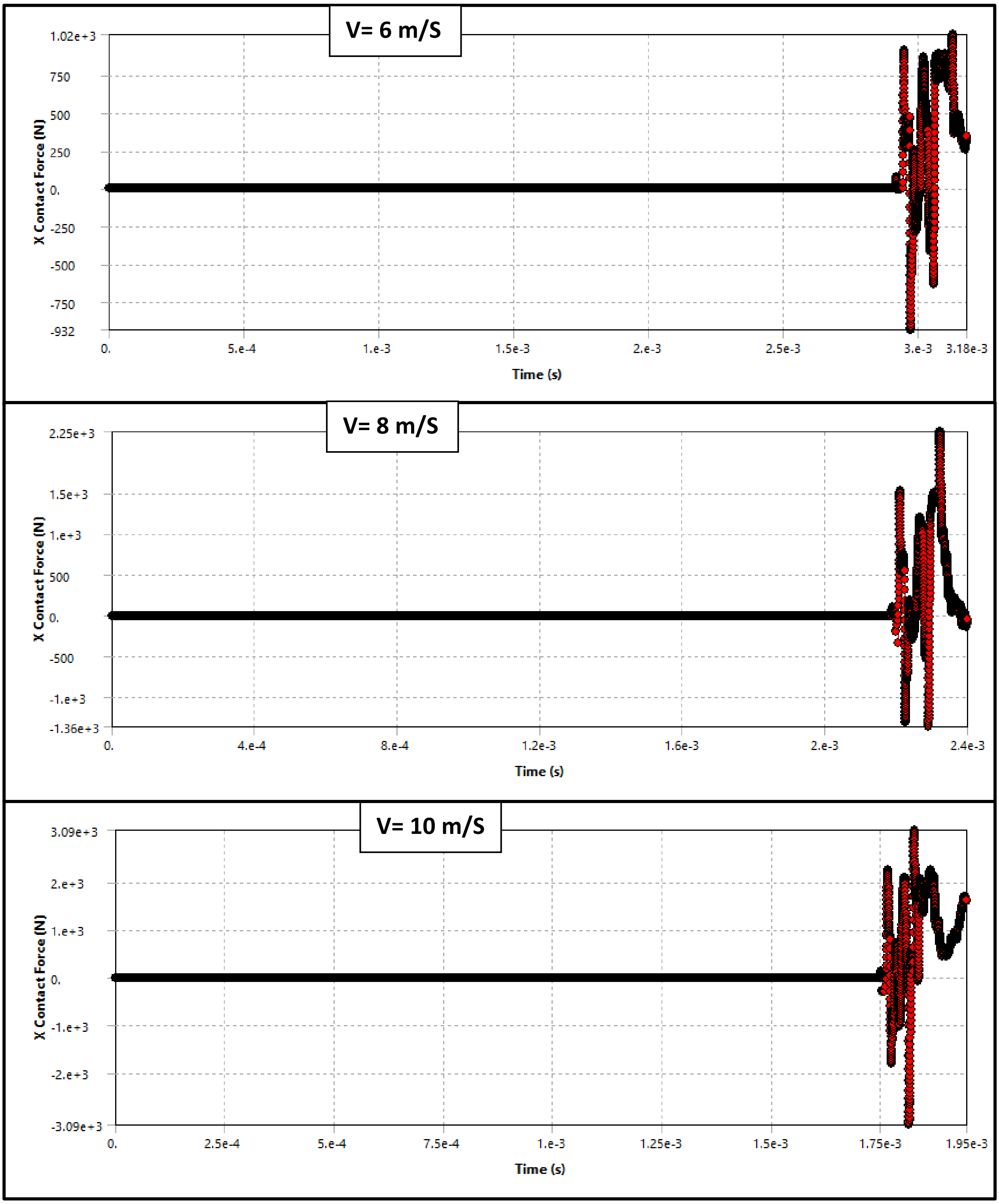

Fig. (8), force against time for hybrid reinforced composite

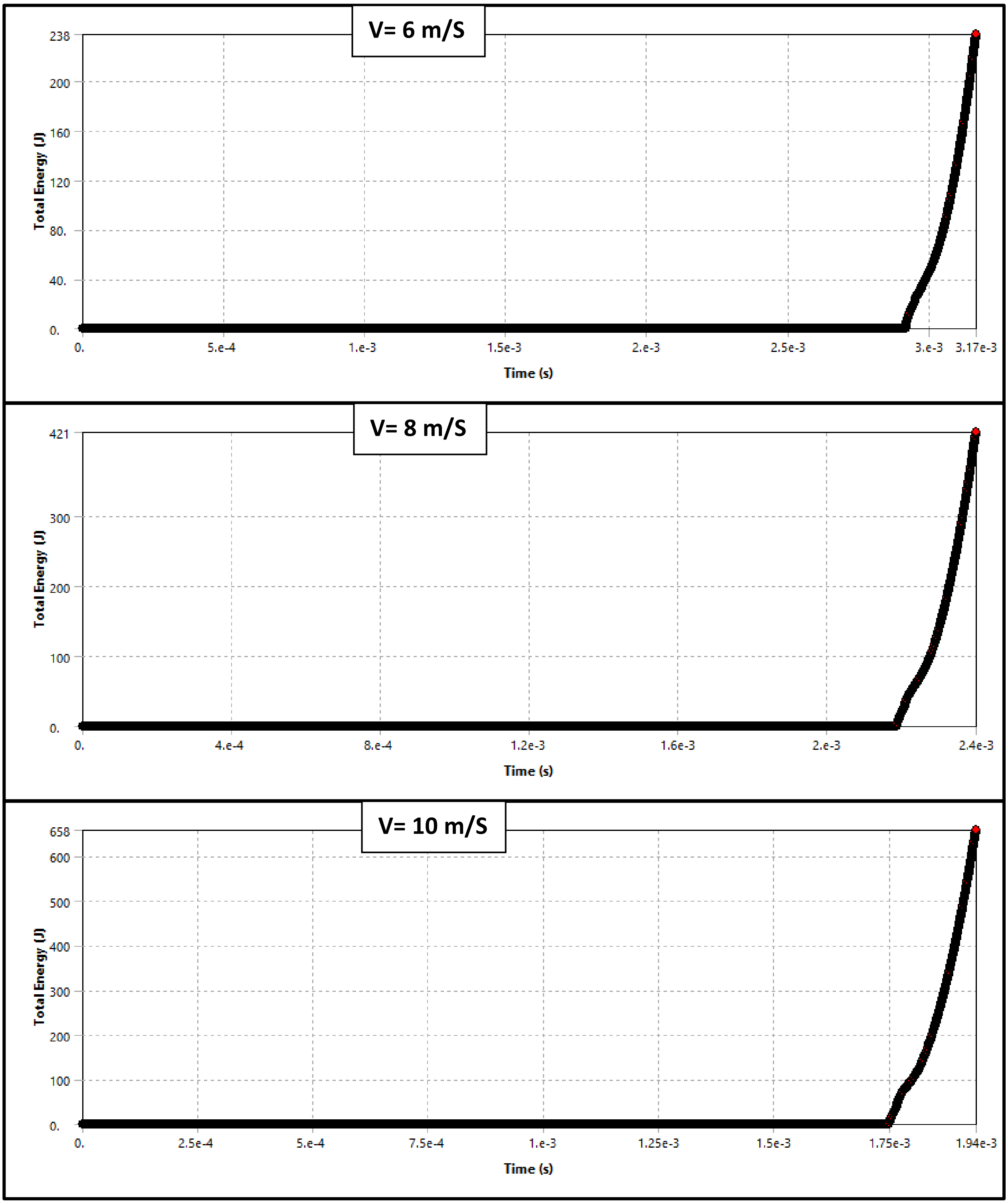

Fig. (9), total absorbed energy against time for carbon reinforced composite

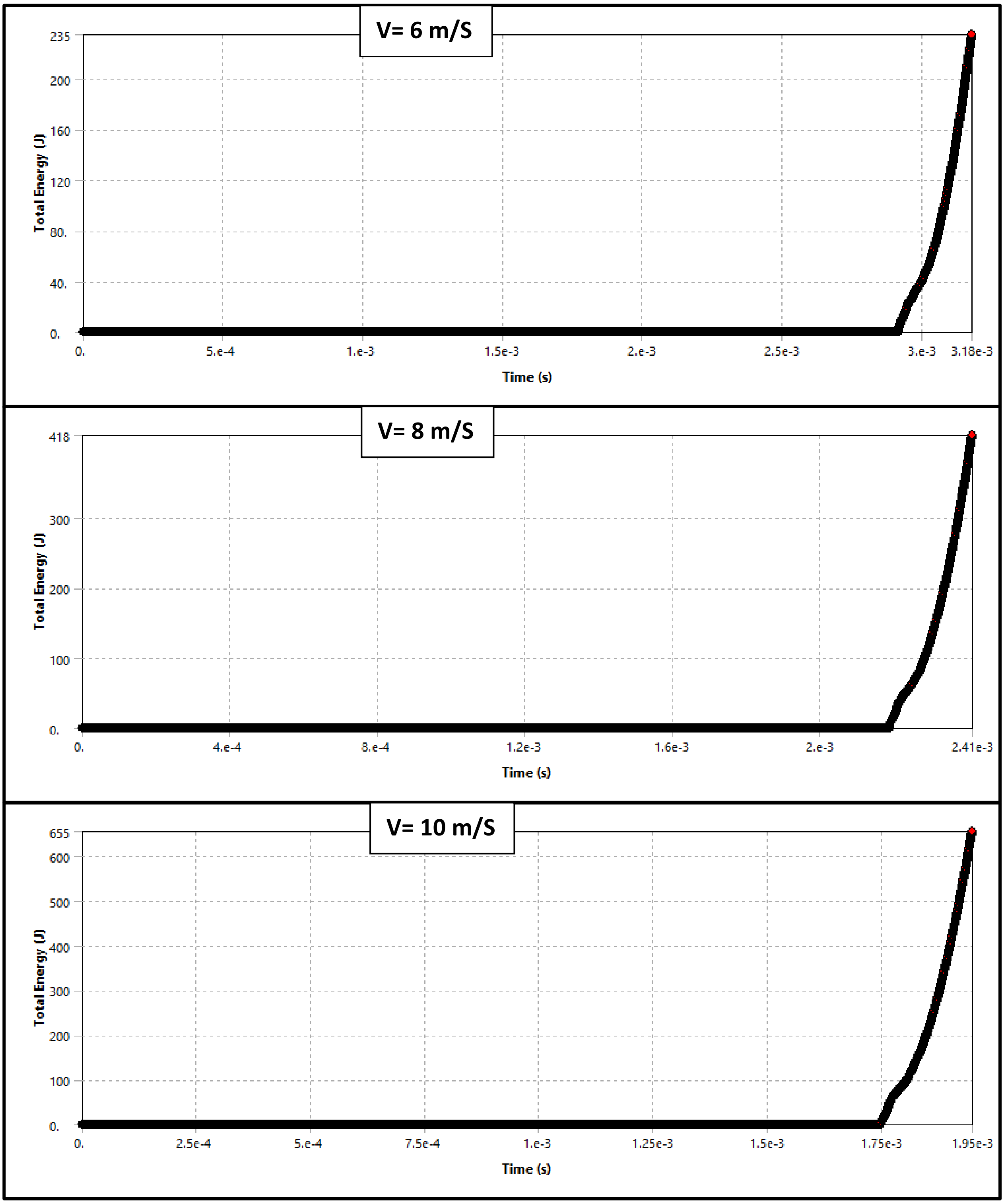

Fig. (10), total absorbed energy against time for Kevlar reinforced composite

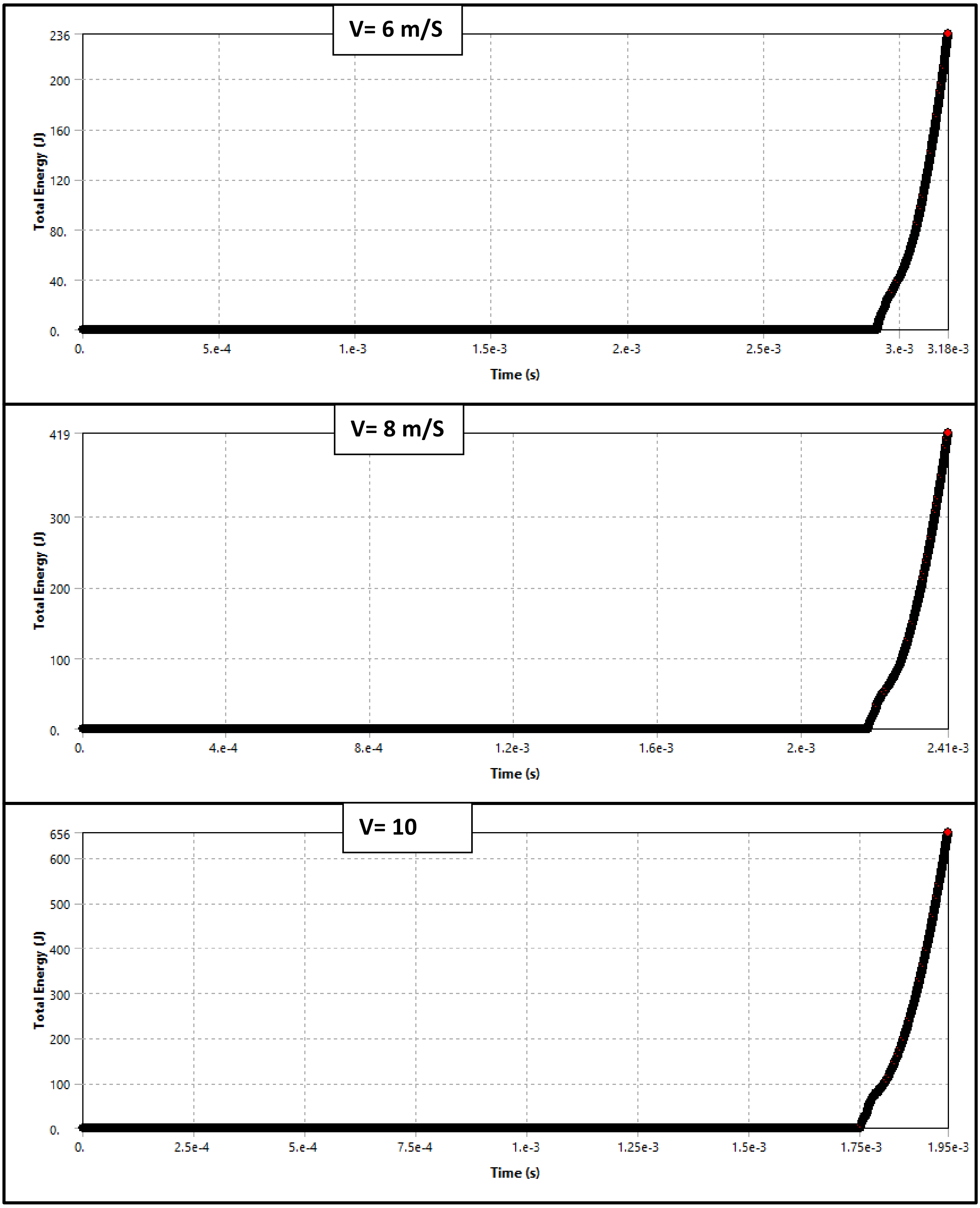

Fig. (11), total absorbed energy against time for hybrid reinforced composite

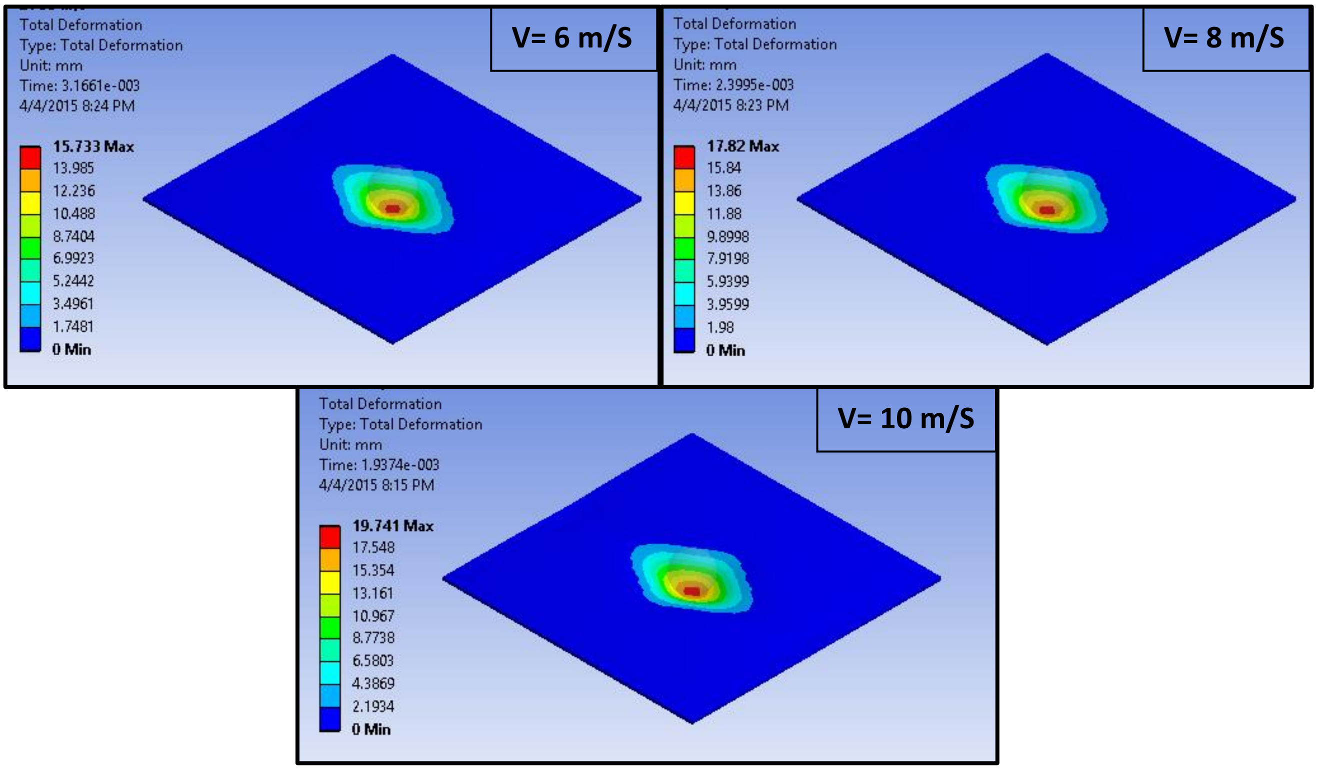

Fig. (12), total deformation for carbon reinforced composite

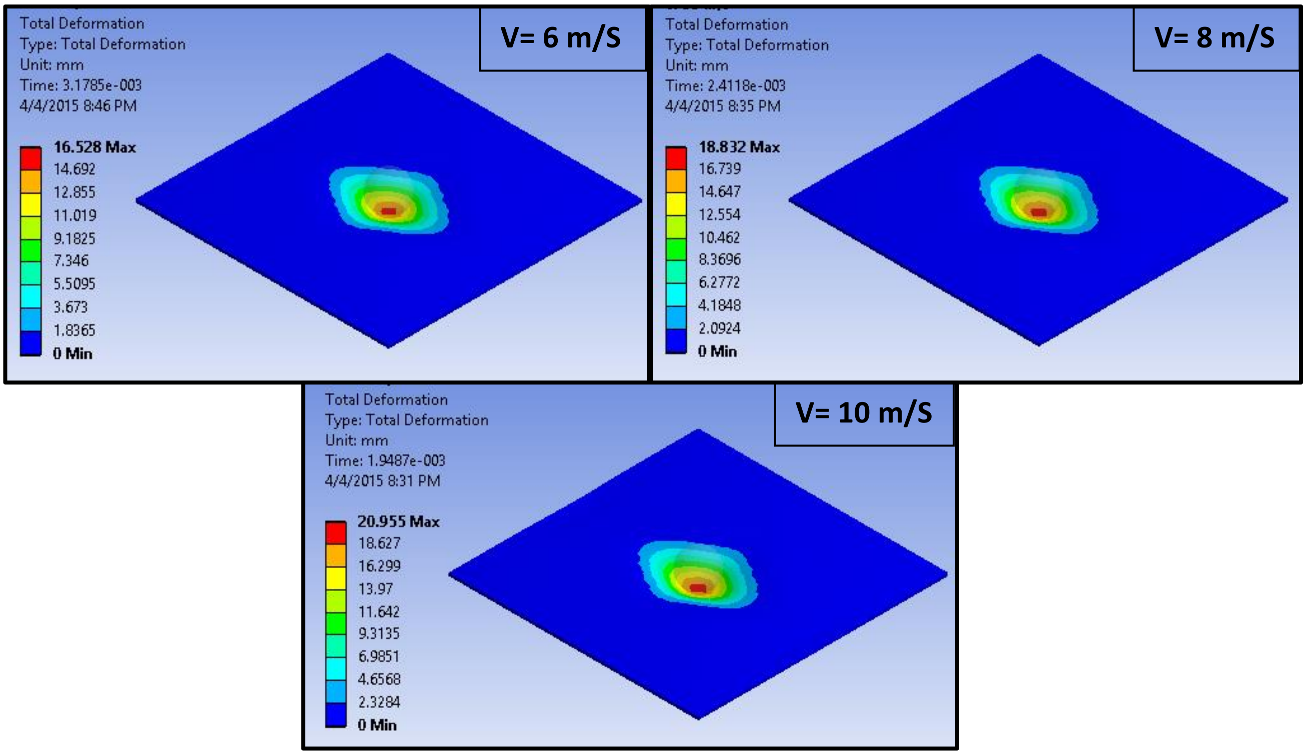

Fig. (13), total deformation for Kevlar reinforced composite

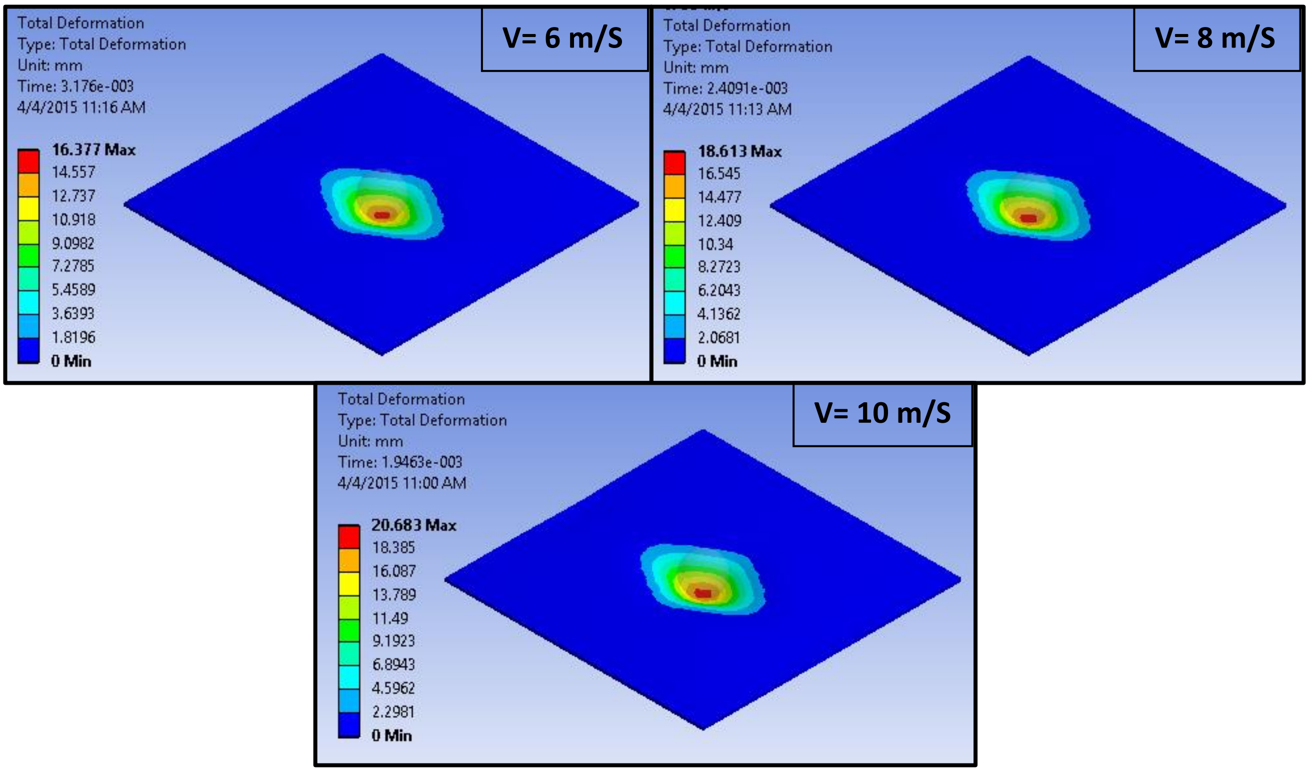

Fig. (14), total deformation for hybrid reinforced composite

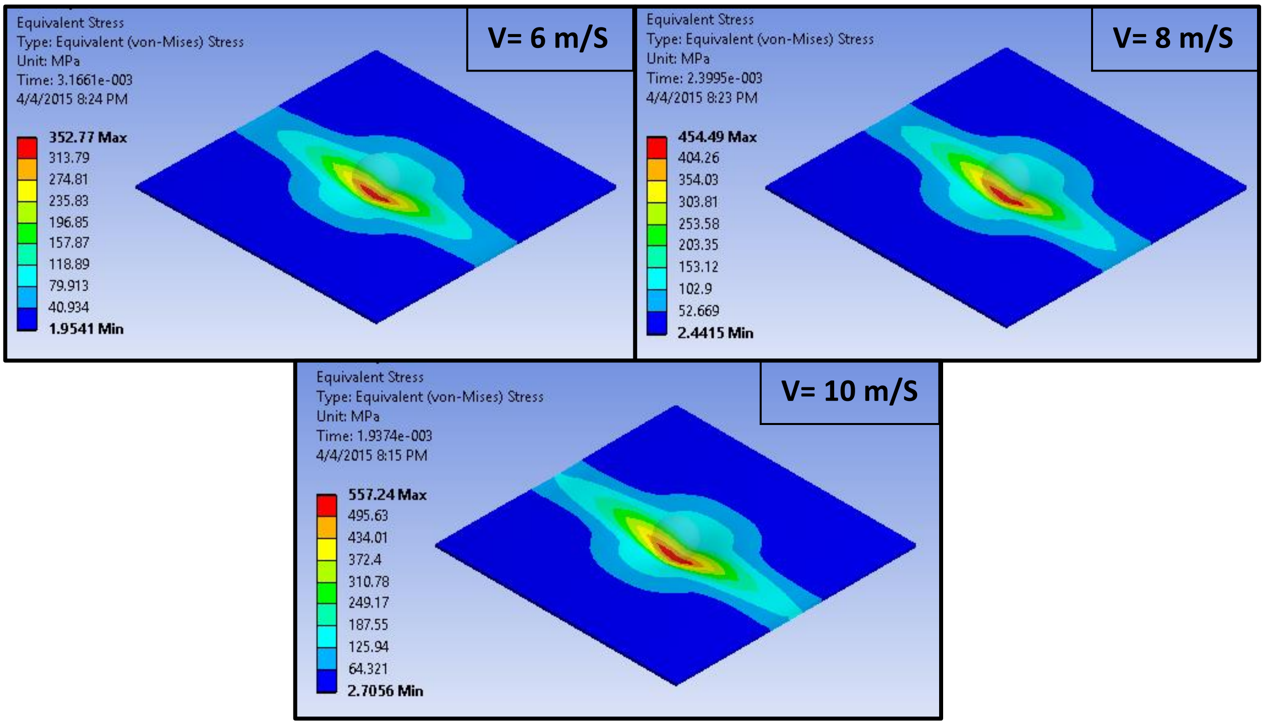

Fig. (15), Von-Mises stress for carbon reinforced composite

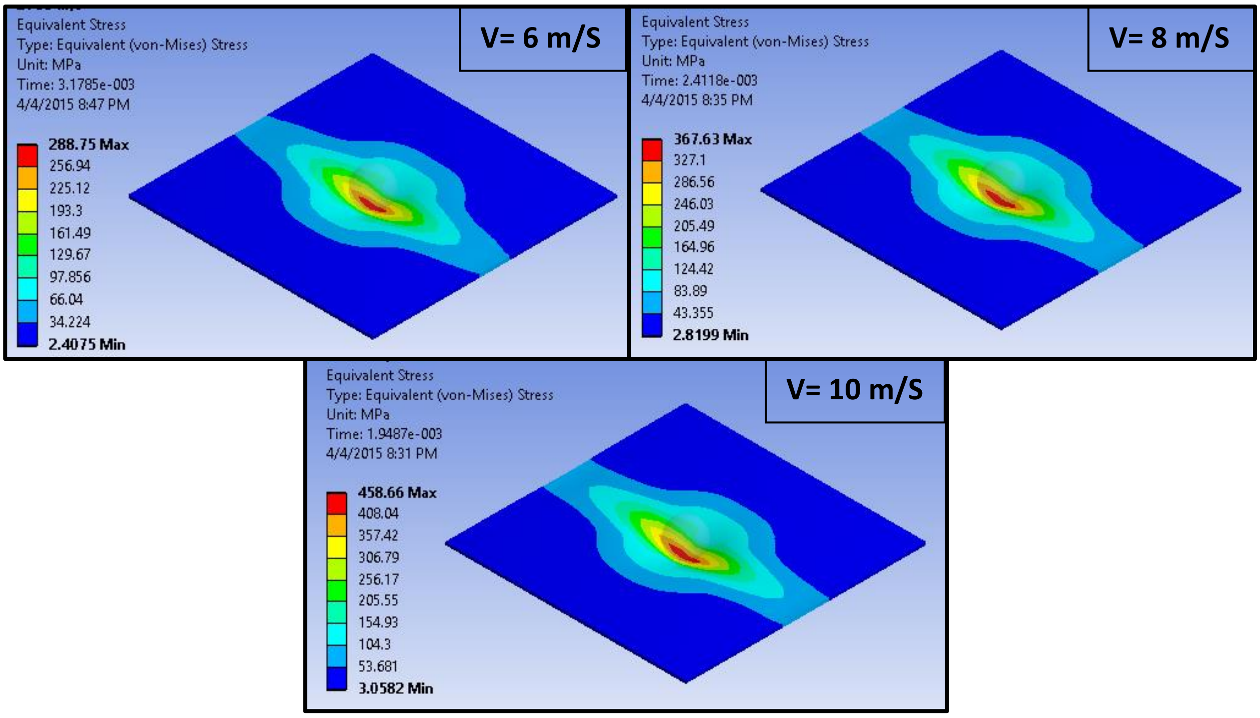

Fig. (16), Von-Mises stress for Kevlar reinforced composite

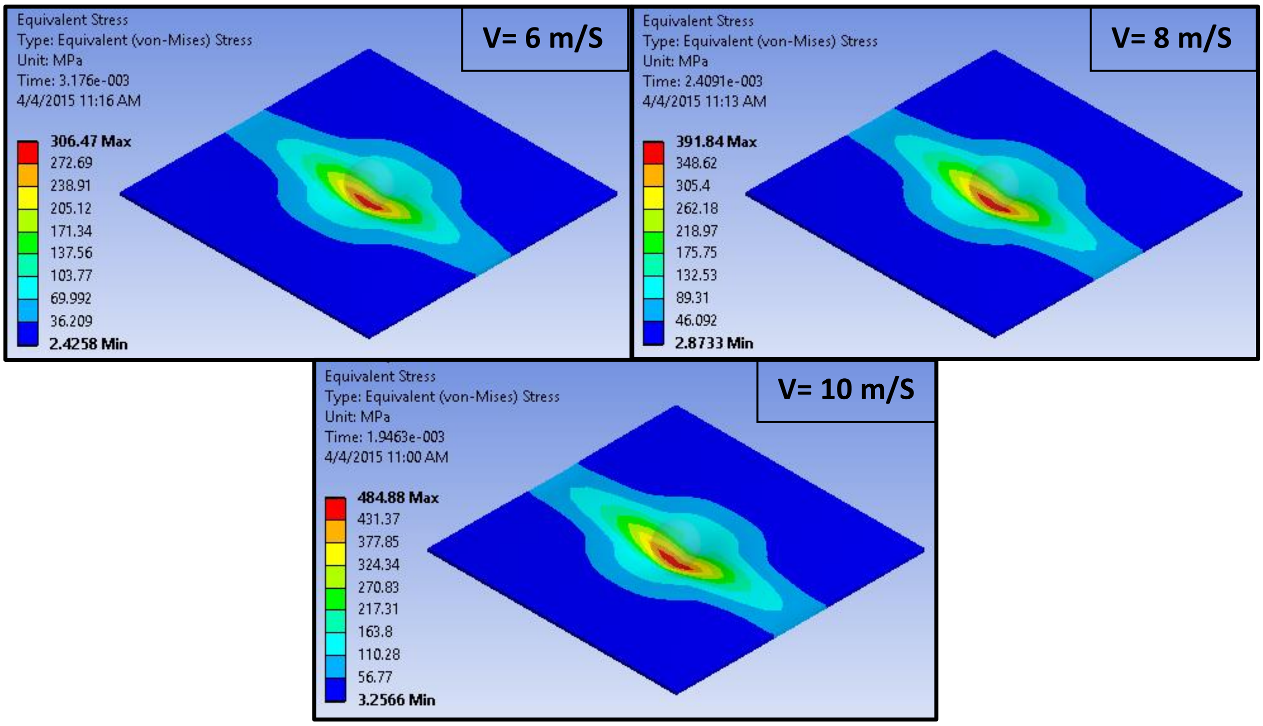

Fig. (17), Von-Mises stress for hybrid reinforced composite

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