Comparison of Lagrange Method& SPH Method of Numerical Simulation of KFRP Plate Impact by 9mm Projectile

[a]Arunesh Kumar Srivastava,[b]K.N.Pandey,
[a]Research Scholar, [b] Professor,
[a,b]Mechanical Engineering Department, Motilal Nehru National Institute of Technology,Allahabad-211004, U.P. (INDIA)
Corresponding Authors: arunesh_srivastava15@yahoo.com
Contact Number: +91 9415637008

ABSTRACT- Present paper deals with theComparison ofLagrange Method& SPH Method of Numerical Simulation impact of 9mm round nose steel projectile on KFRP (Kevlar fiber reinforced plastic)armour plate using explicit finite element analysis as implemented in ansysautodyn 14.0. This numerical simulation evaluates finite element modeling using both Lagrange and SPH method for representing 6 mm thick KFRP target plate. The impact on KFRP plate has been subjected to a high velocity range of 400- 700m/s. The result concludes that residual velocity and reduction in kinetic energy of Lagrange method is better than SPH method in the contact of projectile impact on KFRP Plate.

Keywords:SPH(Smooth Particle hydrodynamics),KFRP(Kevlar fiber reinforced plastic) Projectile.

1. INRODUCTION

Ballistic material plays a vital role in defense application for providing protection against specified projectile. They are used as a primary material in the manufacturing of bullet proof waist and armored fighting vehicle. Hence failure analysis of this material under impact load condition has become an important study to qualify them for defense application. Impact phenomenon is a very complicated process in which the performance depends on many parameters like duration of the impact, kinetic energy, velocity of projectile and the properties of target and projectile material [1].Corran et al.[2] investigated the effect of projectile mass, nose shaped and hardness on penetration of steel and aluminum alloy plates of varying thickness. By using blunt cylendro- conical projectiles it was observed that the ballistic limit of the plate changes with the change of projectile mass and nose shape.

Composite materials are used increasingly in many military, civil and spacecraft applications. Spacecraft encounter various impacts phenomena in space, among which orbital debris impacts are of most concern. These impacts occur at a wide range of velocities. Impact velocities from a few hundred m/s to more the one km/s are common in geostationary orbit and even occur in low Earth orbit. Composites materials that are used in aerospace and land based structural components are often subjected to high velocity impact threats, such asbroken engine parts, pebbles, fragments from bombs, shells and mortars. These applications have excellent mechanical properties as high specific strength, specific stiffness, resistance to corrosion and increased fatigue life. [3]. R. Vaziri et al. [4] analysed impact analysis of laminated composite plates and shells by super finite elements. A super finite element method that exhibits coarse-mesh accuracy is used to predict the transient response of laminated composite plates and cylindrical shells subjected to non-penetrating impact by projectiles. The current computational model offers a relatively simple and efficient means of predicting the structural impact response of laminated composite plates and shells.C Navarro [5] studied simplified modelling of the ballistic behaviour of fabrics and fibre reinforce polymeric matrix composite. The study presents recent advances and development of the dynamic behaviour and the simplified engineering modelling of fabrics and fibre reinforced polymeric matrix composite when subjected to the impact of low calibre ballistic projectile travelling at medium and high velocities.

Richard Clegg et al. [6] studied application of a coupled anisotropic material model to high velocity impact response of composite textile armour. The new material model specially designed for the shock response of an isotropic material was developed and implemented in the hydro codeautodyn. The model couples non-linear and isotropic constitutive relation with a Mie - Gruneisen equation of state. Colin Hayhurst et al. [7] studied a methodology for deriving material models for the ballistic impact response of composite plate was shown. Anautodyn-2d model was derived which matches the V_{50} for fragment simulating projectile impacts on dyneema UD- HB-25 plates. The model also reproduces the deformation and delamination extent of the target plate.

S. S. Morye et al. [8] studied modelling of the energy absorption by polymer composites upon ballistic impact. The development of a simple model for calculating the energy absorption by polymer composites upon ballistic impact. Three major components were identified as contributing to the energy lost by the projectile during ballistic impact, namely the energy absorbed in tensile failure of the composite, the energy converted into elastic deformation of the composite and the energy converted into the kinetic energy of the moving portion of the composite. These three contributions are combined in the model to determine a value for the ballistic limit of the composite, $V_{0.}$

Darren M. White et al. [9] studied numerical simulation and experimental characterization of direct hyper velocity impact on a spacecraft hybrid carbon fibre/Kevlar composite structure. This syudy reports the development of numerical material model and associated data that successfully captures the behaviour of a CFRP structure subject to direct hyper velocity impact with and without the addition of Kevlar- epoxy layers bonded to the CFRP. The reported simulation have been carried out using autodyn- 2d hydroaodes software in which it is possible to couple the orthotropic constitutive behaviour with a nonlinear equation of state.

Z. Fawaz et al. [10] studied numerical simulation of normal and oblique ballistic impact on ceramic composite armours. This study presents three-dimensional finite element models that investigate the performance of ceramic–composite armours when subjected to normal and oblique impacts by 7.62 AP rounds. The finite element results are compared both for normal and oblique impact, respectively. Simulation of the penetration processes as well as the evaluation of energy and stresses distributions within the impact zones highlight the difference between normal and oblique ballistic impact phenomena. The findings show that the distributions of global kinetic, internal and total energy versus time are similar for normal and oblique impact.

TarinVanichayangkuranont et al. [11] studied Numerical Simulations of Level 3A Ballistic Impact on Ceramic/Steel Armour. When the energy absorption between the ceramic and steel plates are compared, most of the energy that the armour absorbs are stored in the ceramics, accounting for 73.3, 86.5, 92.0 and 90.8% of the total energy that the armour absorbed from the bullet impacts from cases I to IV respectively. This leaves only 26.8, 13.5, 8.1 and 9.3% of the total strain energy in the steel plates. The simulations use the impact model of 9-mm bullets upon ceramic and steel plates. The results show that ceramic absorbs most of the impact energy from the bullets, accounting for more than 80% of the total energy. The most severe damages to the armour occur at the back sides of the ceramic plates due to the superposition of reflecting stress waves. Ricardo L. Azevedo [12] studied numerical simulation of soft-body impact on GFRP laminate composites: mixed SPH-FE and pure SPH approaches. Impact events involving a laminate composite had been largely studied through computational approaches; due mainly to the technical difficulties and high costs associated with experimental tests, and the availability of highly sophisticated computational codes. In this study, medium-to-high velocities impact events of ‘dummy birds’ against balanced S2-Glass/Epoxy laminate composites are simulated through LS-Dynaexplicit finite element package. Pure and mixed formulation coupling finite elements (FE) and smoothed particle hydrodynamics (SPH) techniques is adopted to describe the motion of the impacted composite plate and the soft body projectile, respectively.

Wicklein et al. [13] studied hypervelocity impact on CFRP: testing, material modelling andnumerical simulation. This study was described the derivation and validation of a numerical material model that predicts the highly dynamic behaviour of CFRP (carbon fibre reinforced plastic) under hypervelocity impact. CFRP is widely used in satellites as a face sheet material in CFRP- AL/ HC sandwich structure (HC / honeycomb), that can be exposed to space debris. The test result from the CFRP of the current study allow for the derivation of an experimentally based orthotropic continuum material model.

2. COMPUTATIONAL PROCEDURE

2.1 **Non-linear Dynamics Modeling of High strain –rate**All the calculations carried out in the present work are done using autodyn, ageneral purpose non-linear dynamics modeling and simulation software.autodynfalls into a group of computer programs known as “hydrocodes”, which are particularly suited for modeling explosion, blast, impact and penetration events. Within the code, the appropriate mass, momentum and energy conservation equations coupled with the materials modeling equations and subjected to the appropriate initial and boundary conditions are solved. These equations are solved using different numerical methods and the choice of the method (“processor”) is driven by the physical nature of the problem. Lagrange processor is typically used for solid continuum and structures) and the Euler processor is commonly used for modeling gases, liquids or solids subject to large deformations. Solid continuum and structures are also analyzed using the griddles SPH (Smooth Particle hydrodynamics) processor which does not suffer from a grid tangling problem (typically encountered in Lagrange processor) and does not entail the use of an unphysical erosion algorithm (removal of highly distorted grids to help the numerical procedure) [14].

2.2 **Description of the Numerical Model**In this numerical simulation the Kevlar fiber reinforced composite (KFRP) is used for making the plate and projectile is steel (4340).Plate diameter 100mm^2, Plate Thickness 6mm, Projectile diameter 9 mm,Projectile length 13.6mm, and Projectile weight 9gm. One element per thickness, fixed boundary condition was used for making plate by Lagrange method. While for making the plate by SPH method 0.5 particle size was used.

The orthotropic strength model of KFRP plateandJohnson- Cook strength model for Steel 4340 projectile is used in this simulation at room temperature condition shown in Table 1 and 2. Fig. 1(a) and 1 (b) shows the systematic arrangement of projectile and target plate impact with initial and boundary condition. Fig 2 (a), (b)to fig 5 (a), (b) shows damaged occurring in Lagrange and SPH method and Fig 6 (a), (b) to fig. 13 (a), (b) shows residual projectile velocity verses time and reduction in kinetic energy verses time for Lagrange and SPH method at 400 m/s, 500 m/s, 600 m/s and 700 m/s respectively. Fig. 14 (a), to fig. 14(d) shows residual projectile velocity verses timefor Lagrange and SPH method at 400 m/s, 500 m/s, 600 m/s and 700 m/s respectively.

Table 1: Orthotropic Strength Model of KFRP Plate

E_{11} (KPa)	E_{22} (KPa)	E_{33} (KPa)	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY(Pa)	Shear Modulus YZ(Pa)	Shear Modulus XZ(Pa)
$1.95*10^{+6}$	$1.80*10^{+7}$	$1.80*10^{+7}$	0.0756	0.08	0.698	$2.24*10^{+5}$	$1.86*10^{+6}$	$2.24*10^{+5}$

Table 2: Johnson- Cook Strength Model for Steel (4340) Projectile

Initial Yield Stress (Pa)	Density (Kg/m^3)	Bulk Modulus (Pa)	Strain Rate Constant	Thermal Softening Exponent	Melting Temperature (^{0}C)	Reference Strain Rate (/sec)
$7.92*10^{+005}$	7830	$1.59*10^{+08}$	$1.4*10^{-002}$	1.03	1520	1

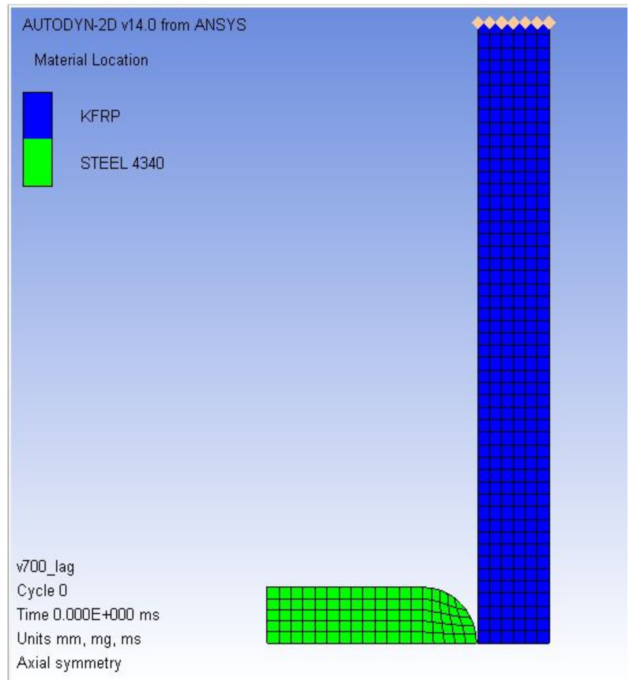

Fig 1 (a)

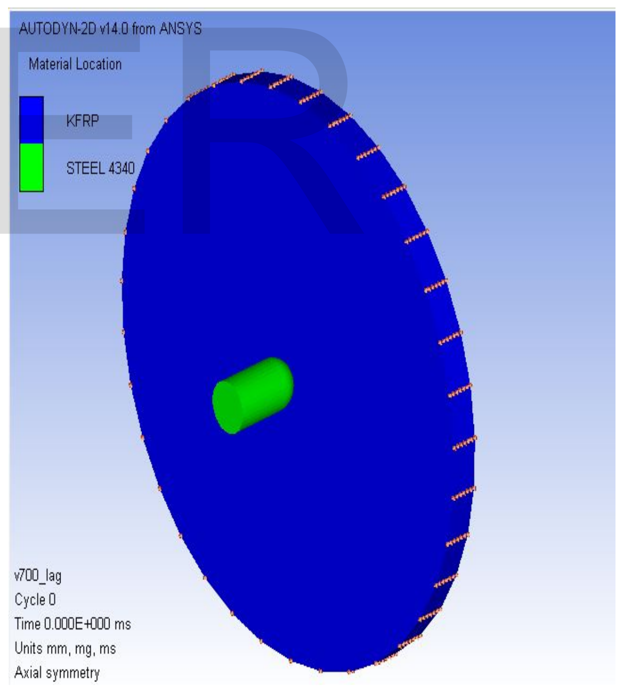

Fig 2 (b)

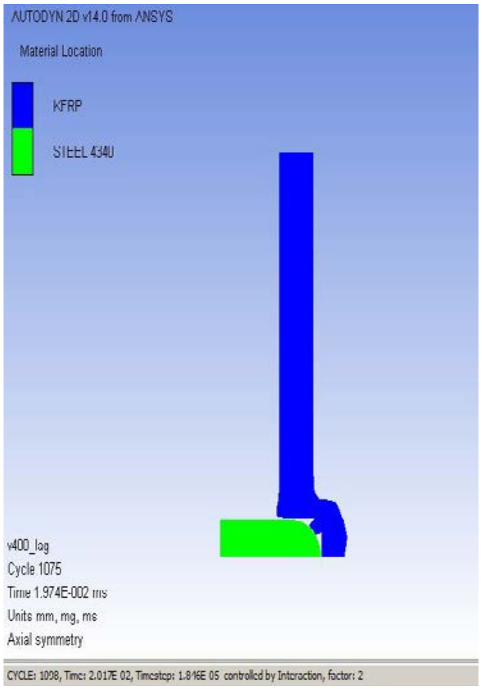

Fig. 2a (400m/s) Lagrange

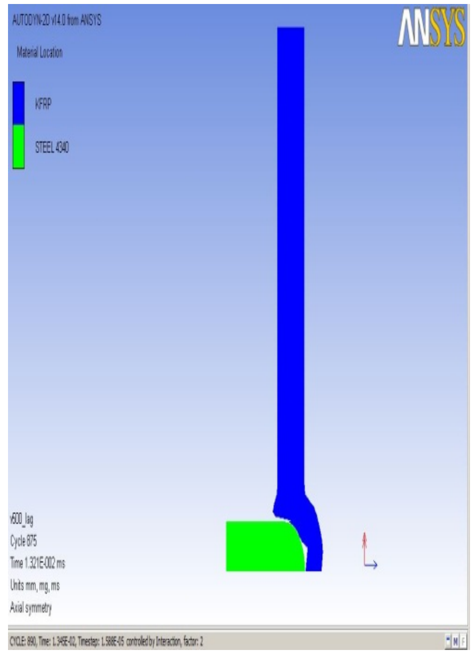

Fig. 3a (500m/s) Lagrange

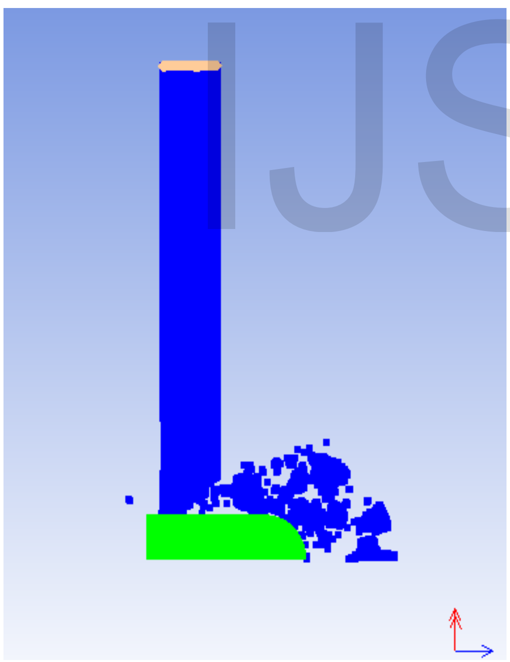

Fig.2b(400m/s) SPH

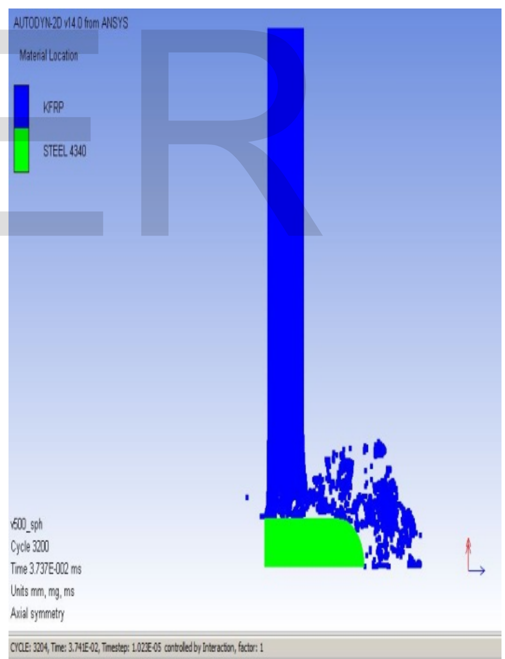

Fig.3b(500m/s) SPH

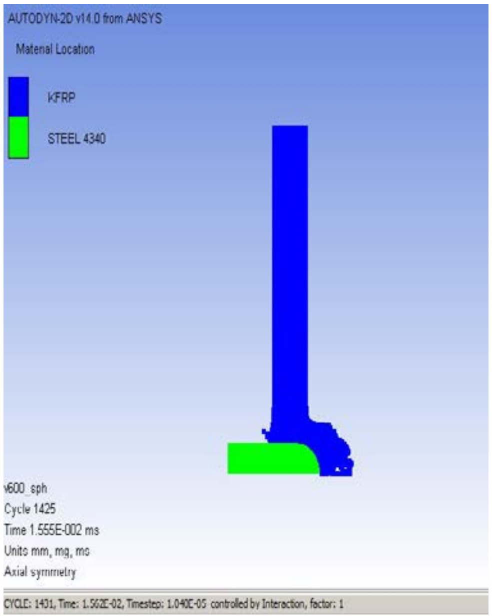

Fig. 4a (600m/s) Lagrange

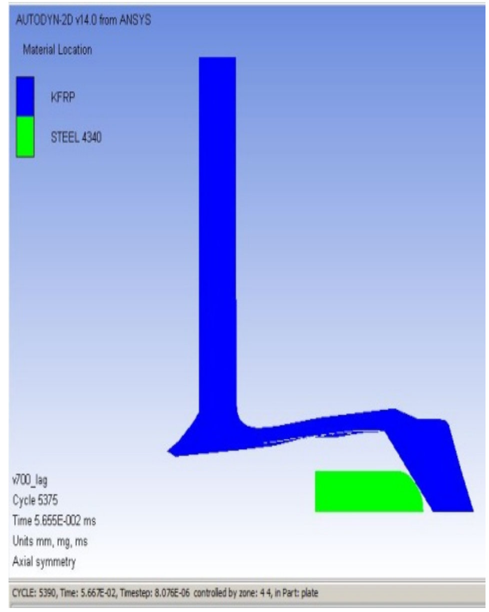

Fig. 5a (700m/s) Lagrange

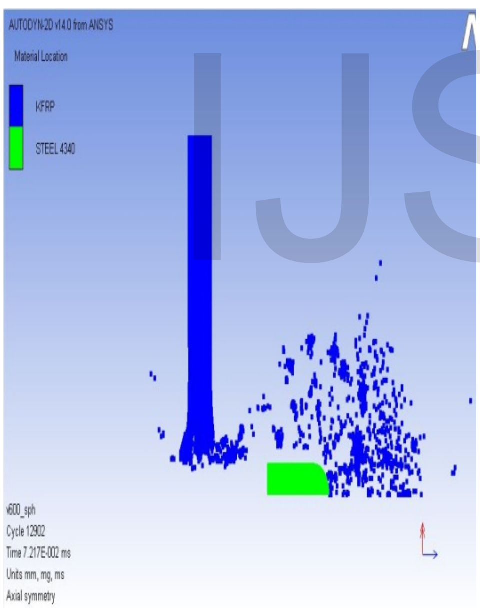

Fig.4b (600m/s) SPH

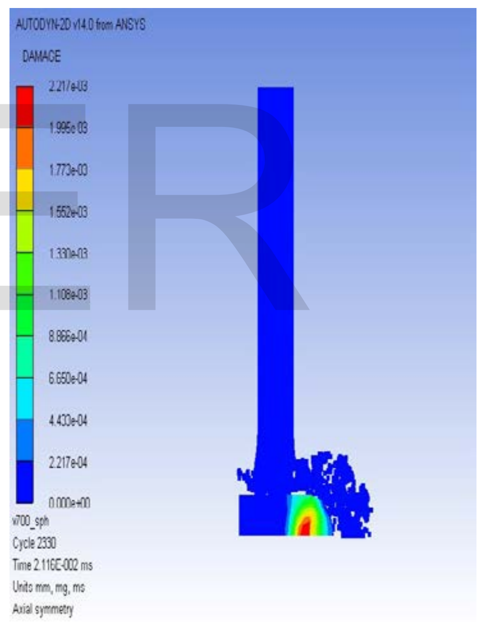

Fig.5b (700m/s) SPH

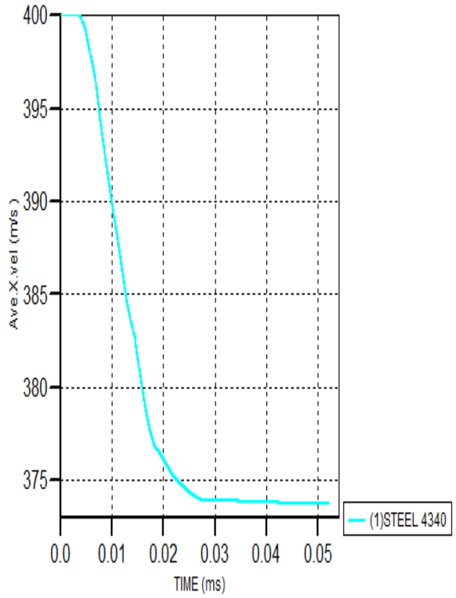

Fig.6a (400m/s) Lagrange

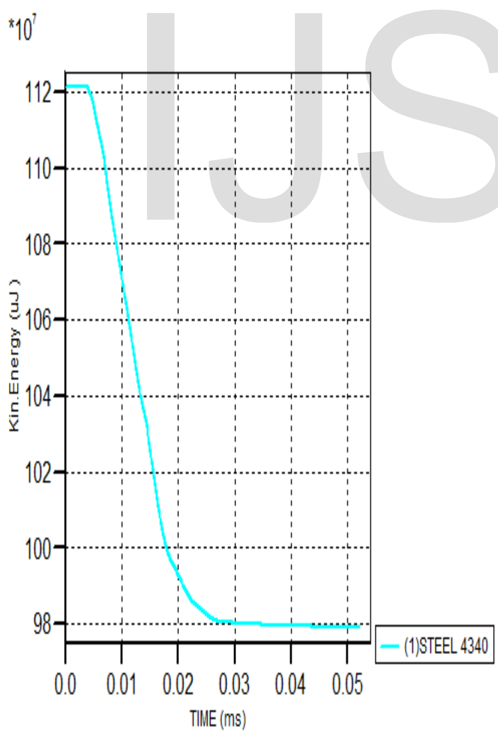

Fig. 6b (400m/s) Lagrange

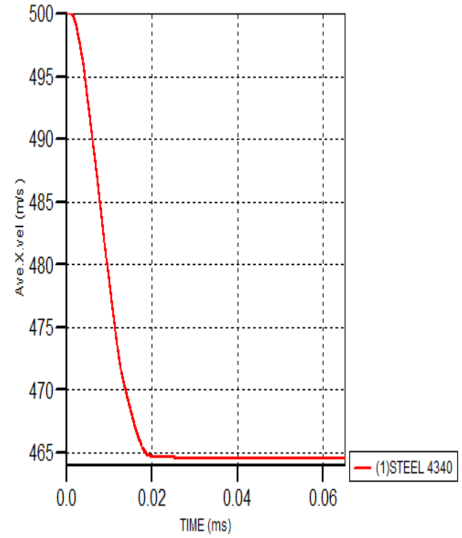

Fig. 7a (500m/s)) Lagrange

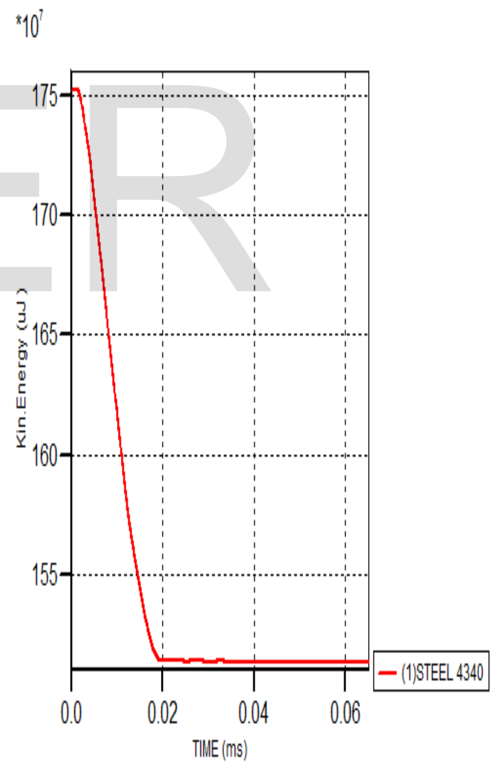

Fig.7b (500m/s)) Lagrange

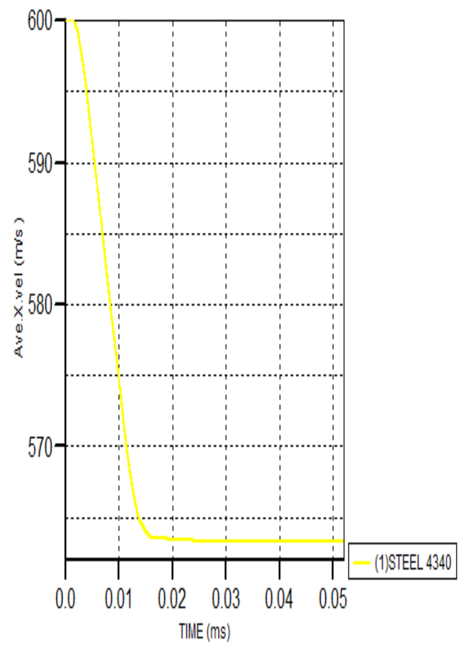

Fig. 8a (600m/s)) Lagrange

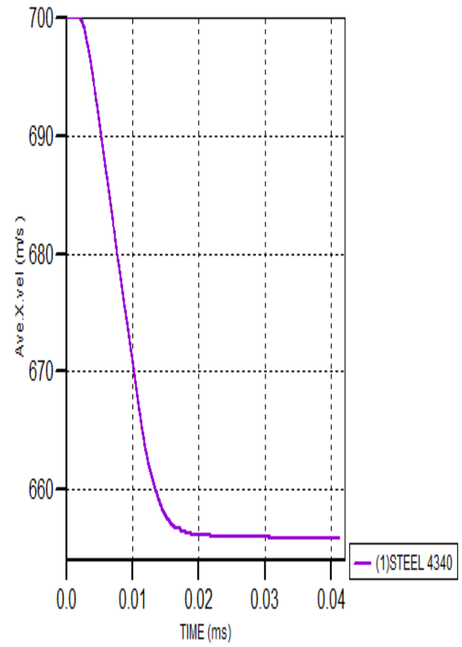

Fig. 9a (700m/s)) Lagrange

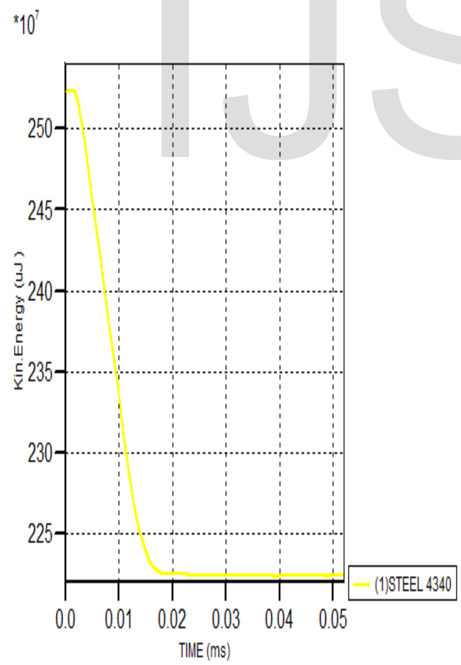

Fig. 8b (600m/s)) Lagrange

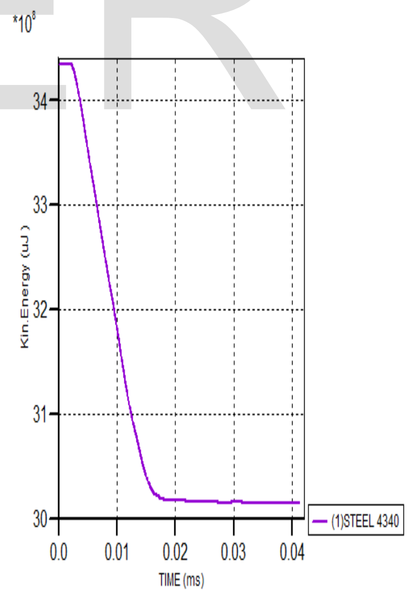

Fig. 9b (700m/s)) Lagrange

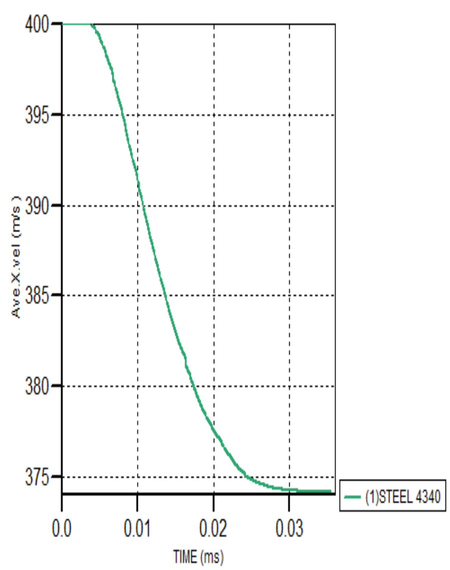

Fig. 10a (400m/s) SPH

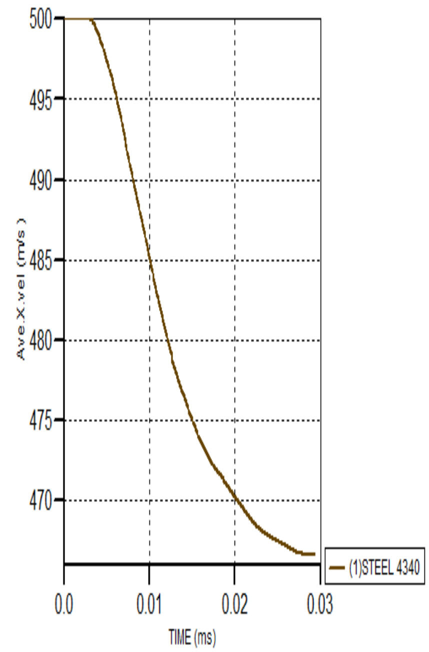

Fig. 11a (500m/s) SPH

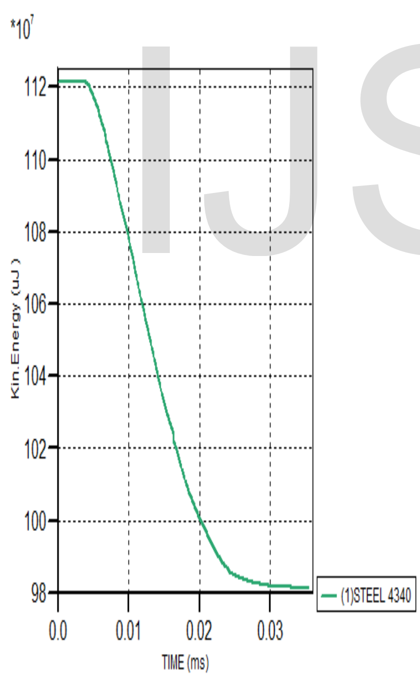

Fig. 10b (400m/s) SPH

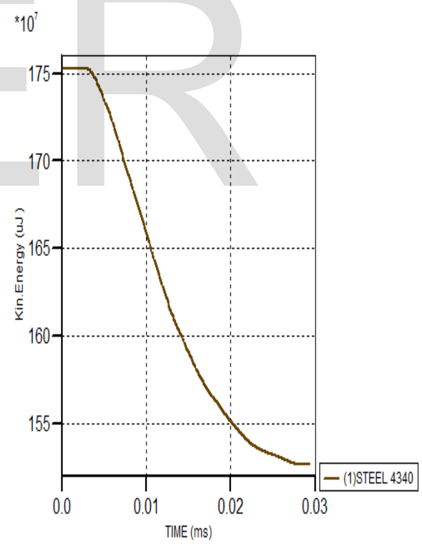

Fig. 11b (500m/s) SPH

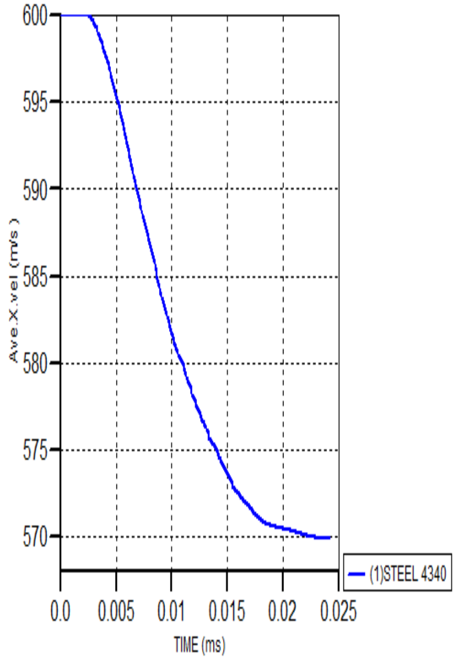

Fig. 12a (600m/s) SPH

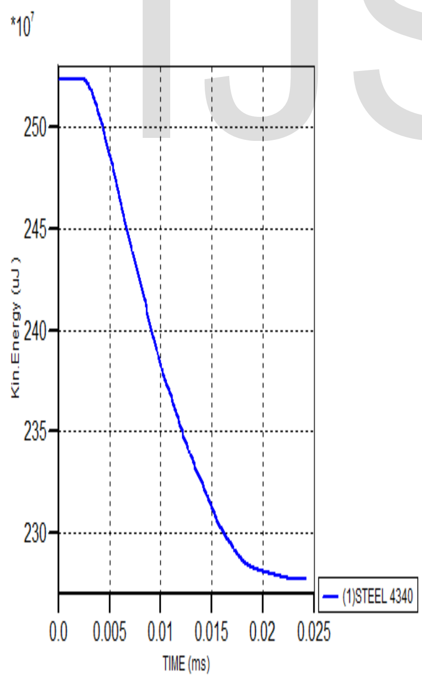

Fig. 12b (600m/s) SPH

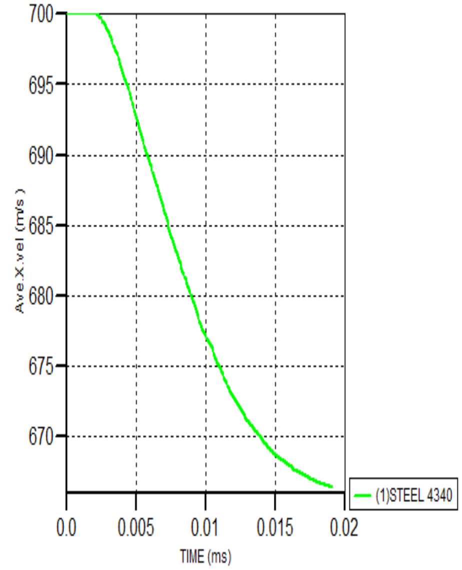

Fig. 13b (700m/s) SPH

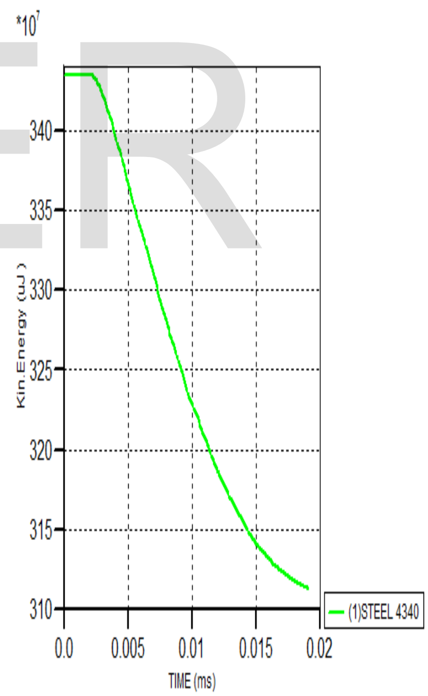

Fig. 13b (700m/s) SPH

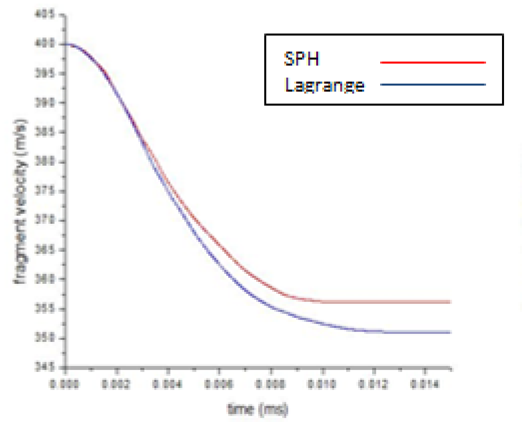

Fig. 14a (400m/s)

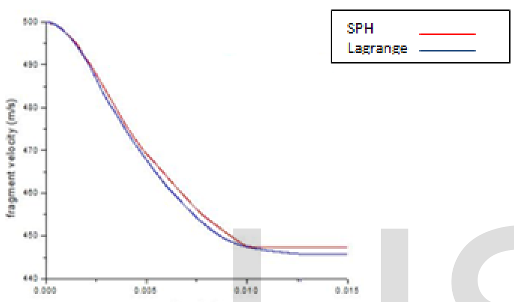

Fig. 14 b (500m/s)

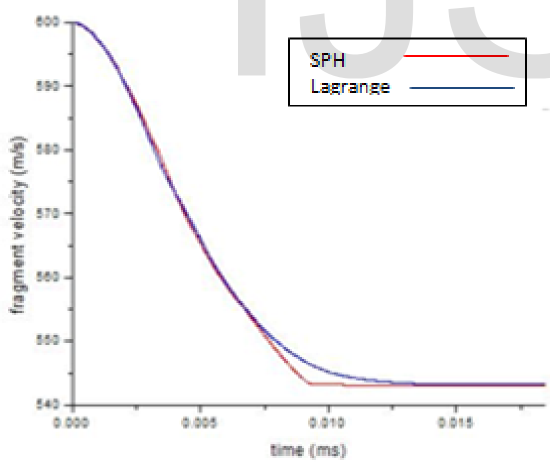

Fig. 14c (600m/s)

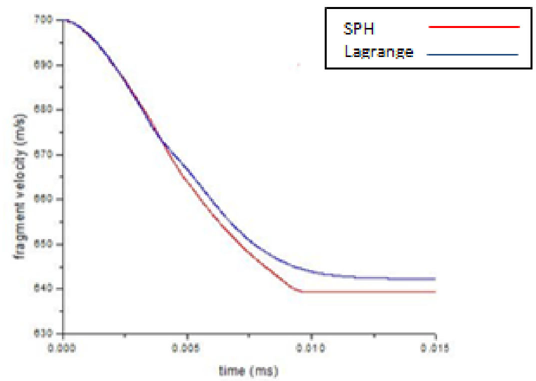

Fig. 14d (700m/s)

3. RESULTS AND DISCUSSION

I. The graph plotted on Projectile residual velocity verses time and kinetic energy verses time on both Lagrange and SPH method showed variation of projectile residual velocity and kinetic energy reduction in projectile in the range of 2- 4 %.

II. During penetration and perforation of KFRP target plate, the delamination is important failure damage mode that affects the structural behavior of the damage initiate.

III. In this comparison SPH method didn't show any damage due to delamination. Hence it concludes that impact on laminated composite plate Lagrange method is better option than SPH method.

REFERENCES

[1] SrikanthGopalkrishnana, Senthil.V, Failure analysis of ballistic material, International conference on advanced materials engineering, IPCSIT vol. 15, 2011

[2] R. S. J. Corran, P. J. Shadbolt, C. Ruiz, Impact loading of plates an experimental investigation, International Journal of Impact Engineering,1(1),(1983),3- 22.

[3] A Ramadhan, A. R. Abu Talib, A. S. MohdRafie, R. Zahari, Experimental and numerical simulation of energy absorption on composite Kevlar 29/ polyster under high velocity impact, Journal of advanced science and engineering research,2,(2012), 52-67.

[4] R Vaziri,Impact analysis of laminated composite plates and shells by super finite element, international journal of impact engineering,18,(1996),765-782.

[5] C Navarro, Simplified modeling of the ballistic behavior of fabrics and fiber reinforce polymeric matrix composite, key engg. Materials,141,(1998),308-402.

[6] Richardclegg, Application of a coupled anisotropic material model to high velocity impact of composite textile armor,18 international symposium, san Antonio, texas, USA, November 15-19, 1999.

[7] Colin J. Hayhrust, John Leahy, Development of Material Model for Nextal and Kevlar- Apoxy for High Pressure and Strain Rates, Personal Armour System Symposium, 5- 8 September, 2008, Colchester, UK.

[8] S.S. Morye, modeling of the energy absorption by polymer composite upon ballistic impact, composite science & technology,60,(2000),2631-2642.

[9] Darren M. White, Numerical simulation and experimental characterization of direct hyper velocity impact on a space craft hybrid carbon fiber/kevelar composite structure, international journal of impact engineering,(2003),779-790.

[10] Z. Fawaz, Numerical simulation of normal and oblique ballistic impact on ceramic composite armours, composite structure,63,(2004),387-395.

[11] TarinVanichayangkuranont, KuntineeManeeratana , NuwongChollacoop, Numerical Simulations of Level 3A Ballistic Impact on Ceramic/Steel Armor, 20th Conference of Mechanical Engineering Network of Thailand 18-20 October 2006, NakhonRatchasima, Thailand.

[12] Ricardo L. Azevedo, Numerical simulation of soft-body impact on GFRP laminate composites: mixed SPH-FE and pure SPH approaches, Mechanics of Solids in Brazil 2009, Brazilian Society of Mechanical Sciences and Engineering

[13] M. Wicklein, S. Ryan, D.M. White, R.A. Clegg, Hypervelocity impact on CFRP: testing, materialmodeling, and numerical simulation,International journal of impact engineering,18,(1996),765-782.

[14] AUTODYN-2D and 3D, Version 5.0, User Documentation, Century Dynamics Inc., 2004.