Study on effect of impact loading on sandwich plate with corrugated cores

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Abstract—Application of aluminium alloys are increased in lightweight protective structures subjected to impact loading due to its low density and other useful properties. Extruded aluminium panels extend their application in many fields, with impacts and other types of high-speed loading conditions, like offshore platforms, bridge decks, train and ship components and lightweight protection systems. The present study reveals that the mechanisms of hardened steel projectile penetration of aluminum alloy sandwich panels with empty, triangular corrugated cores have been analytically investigated. A mathematical model developed based on cavity expansion theory for sandwich plate with triangular corrugated core and the results were compared with the published data values. The results showed close values with the numerical results. For highest penetration resistance with reduced areal density, variations of different geometrical parameters of corrugated structures on residual velocity parameters were analyzed. The penetration resistance increases with increase in parameters of web thickness, web angle, core thickness and plate thickness.
***Keywords —Corrugation,Perforation, Ballistic resistance,* high-speed loading conditions, velocity**

I. INTRODUCTION

Sandwich panels are extensively and increasingly used due to its lightweight properties. A sandwichplate is usually having a three-layer structure, comprised of a thick core between two thin, flat face sheets. The core of the sandwich construction keeps the faces apart and stabilizes them by resisting vertical deformations due to its outstanding strength and also enables the whole structure to act as a single thick plate by virtue of its improved shear strength. Development of core materials has drawn attention to many researchers since 1940s in an effort to reduce the weight of sandwich panels [1].The application of sandwich panels can also be further extended in many fields such as acoustic insulation, thermal insulation and fire safety. Sandwich structures are being widely used in a number of critical engineering applications, such as vehicles, ships, aircrafts, andspacecraft, due to their excellent comprehensive characteristics. (Vasanthy and Jeganathan 2007, Vasanthy et.al., 2008, Raajasubramanian et.al., 2011, Jeganathan et.al., 2012, 2014, 2020 & 2021 , Sridhar et.al., 2012, Gunaselvi et.al., 2014 & 2020, Premalatha et.al., 2015, Seshadri et.al., 2015, Shakila et.al., 2015, Ashok et.al., 2016, Satheesh Kumar et.al., 2016 & 2019).Recent study of application of the laser-welded corrugated-core sandwich constructions has been done to extend its application towards defense protective system [2]. Sandwich cores were classified into four types as ascertained by Figure 1:

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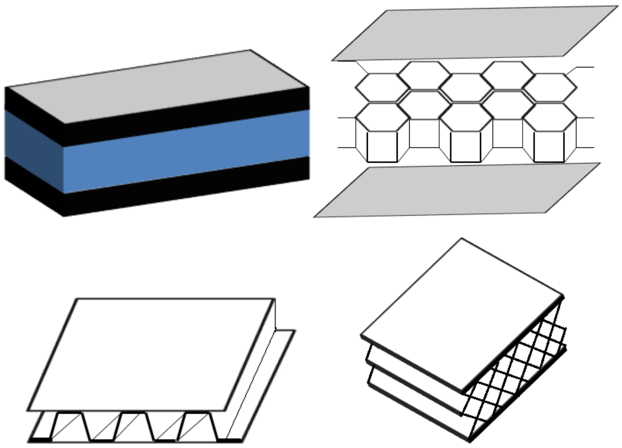

(a) (b)

(c) (d)

Fig 1. Types of core (a) Solid (b) Honeycomb (c) Web (d) Corrugated

II. DESCRIPTION OF SANDWICH PLATE WITH CORRUGATED CORES

Corrugated core sandwich structures have low density and improved physical and mechanical properties, which can offer a wide range of design concepts for lightweight. The mechanical properties of corrugated composite sandwich structures with sinusoidal plate core were studied where the compressive strengths and dynamic response of corrugated metal sandwich plates with unfilled and foam-filled sinusoidal plate cores were investigated analytically and numerically both[3]. The corrugated core panel for prismatic core has its best performance in the longitudinal orientation, attributable to the greater buckling resistance while honeycomb core panels are more weight efficient than the best prismatic core panels at low load capacity but the benefit diminishes with the increment in load requirement. The larger the yield strain of the material used to manufacture the panel, the greater the performance, and the larger the benefits of the prismatic core. [4].The continuous corrugated core shape needs to bedescribed by a finite set of discrete variables, by means of numeric interpolation [5].

Metallic sandwich panels with unfilled cellular cores can exhibit superior bending stiffness and strength compared to solid (monolithic) plates of the same alloy and mass per unit area (areal density)[6]. Aluminum sandwich plates with corrugated aluminum core and glued bonds are used extensively in industry and construction, both as structural elements as well as cover plate elements and interior walls. (Manikandan et.al., 2016, Sethuraman et.al., 2016, Senthil Thambi et.al., 2016, Ashok et.al., 2018, Senthilkumar et.al., 2018, Sundar and Jeganathan 2019 & 2020, Anandan et.al., 2019, Murugavel et.al., 2019, Arokiaswamy et.al., 2019 & 2020, Ganesh Babu et.al., 2020, Gomathi et.al., 2019 & 2020, Manju et.al., 2020, Leema Rose et.al., 2020).

III. IMPACT RESPONSE OF SANDWICH PLATE

Lightweight materials and structures utilized in transportation systems are sometimes subjected to dynamic loads due to impact events or the impingement of shock waves created by nearby explosions. The development of multifunctional materials and structures that provide dynamic load mitigation capabilities in addition to their normal structural requirements are therefore important to a number of fields such as crash protection, petro-chemical safety, infrastructure protection and many military applications.A smaller fraction of the shock impulse is transmitted into sandwich panels compared with monolithic plates of equal mass per unit area (areal density)[7]**.**

D.W. Zhou et al,[8] perform ballistic limit for oblique impact of thin sandwich panels and spaced plates and concluded that sandwich panels are more resistant to perforation during hypervelocity impact than monolithic structures with the same thickness as the face sheets. The layered beams without spacing were more efficient than separated beams of equal areal density because maintenance of contact between layered plates and increased bending stiffness increased the impact force acting on the projectile and thus led to greater deceleration and flattening.

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Recent experimental studies indicate that metallic sandwich panels with low relative density cellular cores (optimized for structural load support and shock resistance) have approximately the same ballistic performance as monolithic structures of equal areal mass.The ballistic impact resistance of a simple metallic plate of fixed thickness depends upon its density, strength, ductility, and its strain and strain rate hardening characteristics. Experimental impact tests were carried out to validate the numerical model byBrenda L. Buitrago[9]. Good agreement was found between numerical and experimental results; in particular, the numerical simulation was able to predict the ballistic limit of the sandwich panel with a difference of 2%. The influence of both skins and the core in the energy-absorption capabilities of the sandwich panel was studied in a broad range of impact velocities. Most of the impact energy was absorbed by the skins. For impact velocities above 250 m/s, approximately 45% of the impact energy was absorbed by the front skin and 40%by the back skin. For impact velocities close to ballistic limit, the front skin absorbed almost the 60% of the energy[10].

Most studies on high-velocity impact behavior of sandwich structures are based on experimental tests. Although experimental studies provide information on the sandwich structure tested, since impact phenomena depend on numerous parameters, knowledge of its influence on ballistic behavior requires a broad test programme, which is time consuming and expensive. The models most widely used to analyze the perforation of sandwich structures are analytical models and numerical ones. In order to develop an optimized corrugated core structure, study of response of various design parameter involved is required which is not feasible with the experimental procedure. Numerical and analytical methods offer easy, cost effective and time-saving with an acceptable accuracy.Dahiwale and Panigrahi[11] studied the effect of different parameter in impact analysis of triangular corrugated core sandwich panel using finite element analysis (FEA). The analysis was carried out by varying the design parameter of corrugated structure such as:-

a) Web thickness
b) Core thickness
c) Web angle
d) Front plate thickness
e) Back plate thickness

Residual velocity varies significantly with the variation of all these parameters and the best improvement in ballistic performance was studied for both base and web impact. This numerical model is found to be promising in optimizing the design parameter for triangular corrugated core sandwich panel. Similar kind of analytical model is being developed in this study to analyze analytically and validate the numerical result.
A mathematical model has been developed to calculate the residual velocities by taking the input various parameter. Very few literatures are available on analytical model of ballistic performance of sandwich panel with corrugated core. A well-defined mathematical formulation has been stated by Recht andIpson in ballistic perforation dynamics for monolithic solid plate based on Cavity Expansion Theory[12].

Borvik et al[13] had carried out a comparison of analytical calculations based on cavity-expansion theory with results obtained through non-linear finite element (FE) simulations and experimental results for aluminium plates with conical-nose steel projectiles. But the analysis is done on a solid aluminum plate. Taking the help of that cavity expansion theory, the analytical model has been developed for sandwich plate with corrugated core. The results are then compared with the result of numerical solution developed byDahiwale and Panigrahi for optimization of design parameter of triangular corrugated core.

IV. ANALYTICAL MODEL

The cavity-expansion theory has received much attention over the years for developing mathematical model for impact analysis. The major approximations used to develop the perforation equations are:-

a) The projectiles are rigid bodies.
b) The analysis is simplified to 1D motion in the radial plate direction.

c) The target behaves as thin which suggests independent layers that are compressed are normal to the penetration direction.
d) Ductile hole growth mechanism is assumed where the plate perforation process could be approximated with cylindrical cavity expansion.

To formulate, let us consider a rigid ogive-nose projectile mass "m", shank length "L", nose length "l" and radius "a", impacting on a solid metallic plate of size $x^x b^x h$ as shown in Fig 2 where x,b,h repersents length, width and thickness of the solid target plate respectively.

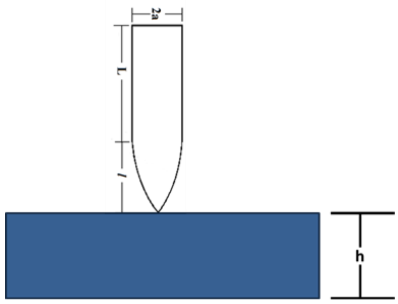

Fig 2. Dimensions of a solid plate with ogive nose projectile

The perforation models take the projectile as a rigid body and only include forces from cylindrical cavity-expansion. From the kinetic energy–work balance, we have

$$\frac{m}{2}[V_s^2 - V_r^2] = \pi a^2 h \sigma_r \qquad (1)$$

Where, m is the projectile mass, V_s is striking velocity, V_r is residual velocity, a is the projectile shank radius, h is the plate thickness,σ_r is the true radial compressive stress on the projectile nose from dynamic elastic–plastic cylindrical cavity-expansion analysis.

The ballistic limit velocity V_{bl} is the striking velocity below which the projectile fails to perforate the target, thus V_{bl} is obtained from Eq. (1) with V_r =0 and V_s =V_{bl}. In addition, the radial stress on the projectile nose from the cavity-expansion analysis is approximated as the quasi-static value σ_s; that is, σ_s is the value of σ_r as the cavity-expansion velocity V approaches zero. Thus,

$$V_{bl} = \left[\frac{2\pi a^2 h \sigma_s}{m}\right]^{\frac{1}{2}} \qquad (2)$$

σ_s is the quasi-static true radial compressive stress required to open a cylindrical cavity from zero initial radius in an elastic–plastic material. An accurate equation for residual velocity in terms of the ballistic limit velocity can be obtained from Eqs. (1) and (2), and is given by

$$V_r = V_{bl}\left[\left(\frac{V_s}{V_{bl}}\right)^2 - 1\right]^{\frac{1}{2}} \qquad (3)$$

Eq. (3) was first proposed by Recht and Ipson [12].They found V_{bl} from ballistic tests and were then able to predict V_r.
For the elastic–perfectly plastic material, the 1D, compressive response is $\sigma= E\epsilon$ in the elastic region and $\sigma= Y$ in the incompressible, plastic region. For the von Mises yield criterion, $\sigma_s$are given as:-

$$\sigma_s = \frac{Y}{\sqrt{3}}\left\{1 + ln\left[\frac{1}{\sqrt{3}}\left(\frac{E}{Y}\right)\right]\right\} \qquad (4)$$

Where Y is the yield stress and E is Young's modulus.
For an elastic power- law, strain hardening material, von Mises yield criterion [14], σ_s becomes

$$\sigma_s = \frac{Y}{\sqrt{3}}\left\{1 + \left[\left(\frac{E}{\sqrt{3}Y}\right)\right]^n \int_0^b f(x)dx\right\}, b = 1 - \frac{\sqrt{3}Y}{E} \qquad (5)$$

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$$f(x)dx = \frac{[-lnx]^n}{1-x}, \qquad 0 < n < 1 \qquad (6)$$

To calculate V_{bl} and $V_r$fromEqs. (2) and (3) we need the mass m of the projectiles.
For conical-nose rod projectiles with shank length L, nose length l, shank diameter 2a, and density ρ_p, the mass is given by:-

$$m = \pi\rho_p a^2\left(L + \frac{l}{3}\right) \qquad (7)$$

While for ogive-nose rod projectiles, the mass is calculated from

$$m = \pi\rho_p a^2(L + k_1 l) \qquad (8)$$

Where

$$k_1 = \left(4\varphi^2 - \frac{4\varphi}{3} + \frac{1}{3}\right) - \frac{4\varphi^2(2\varphi-1)}{(4\varphi-1)^{\frac{1}{2}}}.sin^{-1}\left[\frac{(4\varphi-1)^{\frac{1}{2}}}{2\varphi}\right] \qquad (9)$$

and

$$\varphi = \frac{1}{4}\left[\left(\frac{l}{a}\right)^2 + 1\right] \qquad (10)$$

Here, φ is the caliber-radius-head for the ogive-nose. Usually the caliber-radius-head j is selected and the ogive-nose length is calculated from Eq. (10). From Eqs. (2),(5) & (8) or (9), the ballistic limit velocity can be written as

$$V_{bl} = \sqrt{\left[2\left(\frac{h}{L + k_1 l}\right)\left(\frac{\sigma_s}{\rho_p}\right)\right]} \qquad (11)$$

The above equations from Equations (1)-(11) are for the solid plate of thickness "h". In order to apply the above analytical model in metal sandwich plate with corrugated cores, the sandwich plate must be of same areal density (mass per unit area) with that of solid plate as the projectile have to penetrate more than one resistance as shown in Fig3.

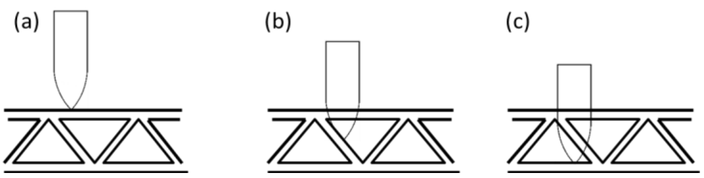

Fig3. Representation of penetration of projectile through corrugated core sandwich plate; (a) 1st impact on face plate, (b) 2nd impact on web plate and (c) 3rd impact on back face plate.

Geometrical parameter of corrugated core of triangular type are depicted in the following Fig. 4 and represented in Table.1

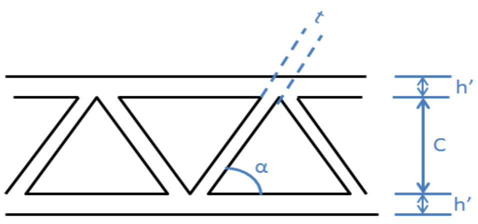

Fig4. Geometrical representation of Triangular corrugated core sandwich plate

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Table1. Geometrical parameter of Triangular corrugated core sandwich plate.

Serial No.	**Corrugated core sandwich plate**	
	Parameters	***Representation***
1	h'	Thickness of front/back plate
2	c	Core thickness
3	t	Web thickness
4	α	Web angle

For triangular corrugated core plates as shown above, the areal density is given as:

$$\rho_a = (2h' + c\rho')\rho (12)$$

Where ρ' is the relative density of corrugated core and ρ is the density of solid plate. The core relative density ρ' is the ratio of density of the core to the density of the solid metal (in other words, volume fraction of the metal in a unit cell of the core). From the geometry of the unit cell, a relation between ρ' and geometrical parameter can be obtained. For triangular core, the relation for core relative density is given by:-

$$\rho' = \frac{t}{t + cos\alpha} \qquad (13)$$

But for a solid plate of length x, breadth b and thickness h, ρ_a is mass per unit area, so

$$\rho_a = \frac{mass}{area} = \frac{m}{x.b} \qquad (14)$$

$$\rho_a = \frac{mass}{area} = \frac{m.h}{x.b.h} = \frac{m}{v}.h = \rho.h \qquad (15)$$

From Eqs (12),(13) and (15), we can derive a relation between thickness of solid plate "h" and design parameter of triangular core corrugated plate and which is expressed as:-

$$h = 2h + \frac{c.t}{t + c.cos\alpha} \qquad (16)$$

Using the above analytical formulation, a mathematical model program is being developed using MATLAB where striking velocity V_s, various material properties and design parameter of triangular corrugated core plate are provided as input to the program and residual velocity V_r is determined as the output of the program. Further, the effects of various design parameters on residual velocity are analyzed and the results are validated with the results of numerical simulation carried out byDahiwale and Panigrahi.

V. RESULTS AND DISCUSSION

Impact analysis has been computed analytically to investigate the effect of geometrical parameters of the triangular corrugated panel on residual velocities. The parameters are:

a) thickness of front and back plate
b) thickness of core
c) thickness of web
d) web angle

The analysis was carried out on target of metallic sandwich plate with triangular corrugated core made up of aluminum and rigid ogive-nose projectile made up of steel. The striking velocities used for the analysis is 508m/s and material properties which are constant throughout the analysis are given in Table 2.

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Table2. Inputs for the analytical analysis.

Serial No.	Inputs		
	Parameters	***Representation***	***Values***
1	Y	Yield stress	262MPa
2	E	Young's Modulus	69GPa
3	n	Elastic exponent	0.085
4	a	Shank Radius	6.45mm
5	ρ_p	Projectile Density	$7.83*10^3$ Kg/m^3
6	L	Shank length	67.5mm
7	l	Nose Length	21.4mm

A comparative study of the effect is done with that of numerical result to check the validity of the model which is done by plotting residual velocities versus each geometric parameter of triangular corrugated core plate. Results obtained are depicted in the following sections:

A. *Effect of web thickness(t)*

Web thickness is varied from 5 to 12.5 mm, the residual velocities of the projectile decreases with increase of web thickness which closely matches the pattern with that of numerical results. The decrease in velocity attributes two factors, one which increases the projectile deflection with increase of thickness and secondly, elastic bending of web offers resistance to projectile motion through the web. The effect of residual velocity with variation of web thickness is depicted in following Fig 5. The difference of value for analytical solution and numerical solution is calculated and error percentage is found to be lying between 2-6% which justifies the analytical model to be used for corrugated plate. The error is mainly due to various assumptions made during formulation and the core geometry is converted to equivalent solid plate thickness. But the error is minimal and the model shows promising to be applied for impact analysis problem of metallic sandwich plate.

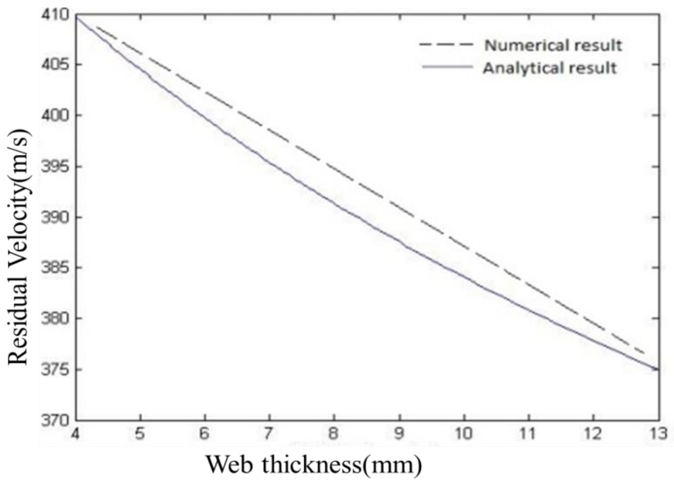

Fig. 5 Effect of Web thickness on Residual Velocity of the projectile

B. *Effect of Web angle (α)*

Increasing the web angle from 40 to 80 degree, the residual velocity decrease as it does in above case. As seen in Fig 6, the residual velocity decrease in similar fashion with that of numerical result with error which varies from 2% to 5% in different angle of web. The decrease in velocity suggest that with the increase of

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inclination, the projectile experience larger deflection which increases the resistance to the motion speed, thus reducing the residual velocity to an appreciable amount.

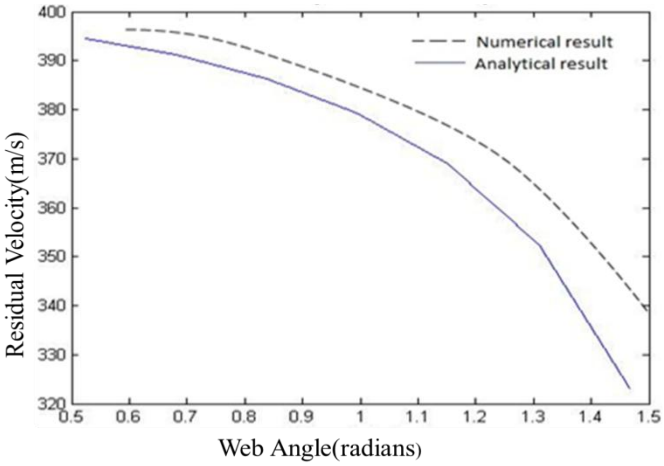

Fig6. Effect of Web angle on Residual Velocity of the projectile

C. Effect of core thickness (c)

The residual velocity shows the same decreasing pattern with the increase of core thickness and it is similar to the pattern obtained in numerical analysis which justifies the analytical model application to the impact analysis. The decrement pattern of residual velocity shown in Fig 7 is due to the fact that at higher core thickness, the projectile spends greater amount of time passing through the structure resulting in energy dissipation thus reducing the velocity.

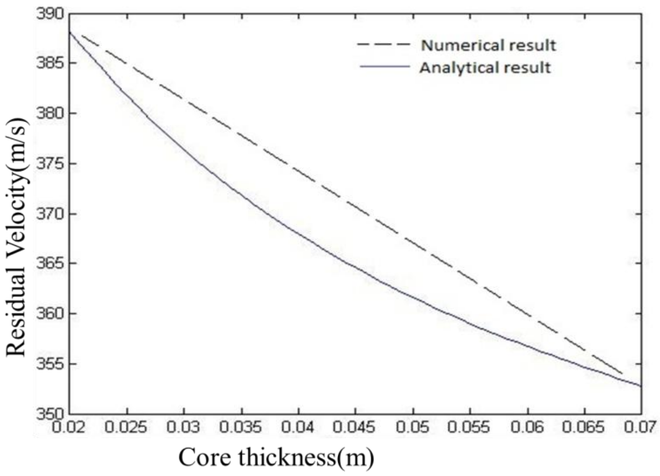

Fig.7 Effect of Core Thickness on Residual Velocity of the projectile

D. Effect of plate thickness (h')

Increasing the plate thickness of front as well as back plate affects the residual velocity in a linear fashion. The plates of sandwich structure acts as solid plate of their respective thickness, and based on cavity-expansion theory as explained in above analytical modelling section, the residual velocity decreases linearly with increase of plate thickness. As seen from the Fig 8, the residual velocity decreases linearly with increase of plate thickness.

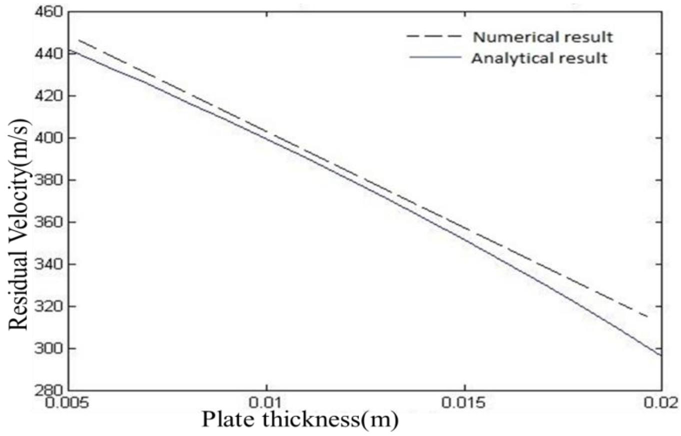

Fig.8 Effect of Plate Thickness on Residual Velocity of the projectile

Varying the geometric parameter of corrugated plate significantly increases the areal density of the sandwich structure with corrugated core which in turn affect the density and mass of the structure. So, the geometric parameters of the triangular corrugated core structure should be optimized in order to maintain the lightness of structure with the optimized result to resist the penetration of impact of a projectile. The optimization is done through the sensitivity analysis as carried out in numerical analysis by Dahiwale and Panigrahi. The sensitivity analysis suggests that the geometric parameter which has the most negative slope should be considered as the optimum choice to improve the perforation resistance and compensate with the increase of areal density.

VI. CONCLUSION

In current prospect, an analytical model based on cavity-expansion theory (CCET) has been reformulated in MATLAB and used to calculate the ballistic perforation resistance of sandwich plate with triangular corrugated core when impacted by steel projectiles. The effect of various geometrical parameters of the corrugated structure such as plate thickness, web thickness, web angle and core thickness etc. on residual velocity is examined. The results obtained are compared with the experimental results and the analytical model providing promising results with numerical one with error variation from 2% to 6% on different parameters. The difference in results between experimental and analytical model is mainly due to the assumptions made in formulation of mathematical model. The geometrical parameters of corrugated structure is converted to equivalent solid plate thickness of same areal density which results in varying results between analytical and numerical results but the pattern of response of residual velocity to geometrical parameters of corrugated structures are approximately similar. This justifies the validation of the analytical model developed for impact analysis of sandwich plate with corrugated structures. In the analysis, it is found that the residual velocity decreases with increase of geometrical parameters. The analytical model is found to be very promising in carrying out impact analysis for metal sandwich plate with corrugated cores to develop the optimized structure for effective perforation resistance.

VII. REFERENCES

1. Chang,Wan-Shu, " *Elasto-plastic analysis of corrugated sandwich Steel panels*",Phd thesis, The Pennsylvania State University, 2004.
2. Marsico, T. A., Denney, P. E., and Furio, A. "*Laser welding of lightweight structural steel panels*." Proceedings of the laser materials processing conference,ICALEO, Olrando 1993.
3. Wiernicki, J. C., Liem, F., Woods, G. D., and Furio, A. J. "*Structural analysis method for lightweight metallic corrugated-core sandwich panels subjected to blast loads.*" Naval Engineers Journal, May 1991.
4. JianxunZhang ,Qinghua Qin , T. J. Wang, "*Compressive strengths and dynamic response of corrugated metal sandwich plates with unfilled and foam-filled sinusoidal plate cores*",ActaMechanica, vol 224, pp.759–775, 2013.

ISSN:0975-3583,0976-2833 VOL8,ISSUE04,2017

5. L. Valdevit, J.W. Hutchinson , A.G. Evans, "*Structurally optimized sandwich panels with prismatic cores*". International Journal of Solids and Structures, vol41 , pp. 5105–5124, 2004.
6. DamirVu~ina, ZeljanLozina,FraneVlak, "*Optimization of metal sandwich plates with corrugated core*".Engineering modelling, vol 18(1-2), pp. 23-32, 2005.
7. Benjamin p. Russell, Adam Malcom, Haydn N, G. Wadley and Vikram S. Deshpande, "*Dynamic compressive response of composite corrugated cores*". Journal of mechanics of materials and structures vol. 5(3), 2010.
8. D.W. Zhou, W.J. Stronge, "*Ballistic limit for oblique impact of thin sandwich panels and spaced plates*". International Journal of Impact Engineering, vol35, pp. 1339–1354, 2008.
9. Christian J. Yungwirth, John O'Connor, Alan Zakraysek, Vikram S. Deshpande, and Haydn N. G. Wadley, "*Explorations of Hybrid Sandwich Panel Concepts for Projectile Impact Mitigation*". Journal of American Ceramic Society,vol 94, pp. S62–S75, 2011.
10. Brenda L. Buitrago, Carlos Santiuste, Sonia Sánchez-Sáez, Enrique Barbero, Carlos Navarro, "*Modelling of composite sandwich structures with honeycomb core subjected to high-velocity impact*". Composite Structures, vol92,pp. 2090–2096, 2010.
11. Naveen Dahiwale, S.K.Panigrahi, "*Impact analysis of Sandwich Panel with triangular corrugated core"*, M.Tech thesis, DIAT(DU), 2014.
12. Recht RF, Ipson TW. "*Ballistic perforation dynamics"* Journal of Applied Mechanic, vol 30, pp. 384–90, 1963.
13. T. Børvik, M.J. Forrestal, O.S. Hopperstad, T.L. Warren, M. Langseth, "*Perforation of AA5083-H116 aluminium plates with conical-nose steel projectiles – Calculations*". International Journal of Impact Engineering, vol.36,pp.426–437, 2009.
14. Hill R. *The mathematical theory of plasticity*. London: Oxford University Press, 1950.
15. Vasanthy M and M. Jeganathan. 2007. Ambient air quality in terms of NOx in and around Ariyalur, Perambalur DT, Tamil Nadu. Jr. of Industrial pollution Control., 23(1):141-144.
16. Vasanthy. M ,A.Geetha, M. Jeganathan,and A.Anitha. 2007. A study on drinking water quality in Ariyalur area. J.Nature Environment and Pollution Technology. 8(1):253-256.
17. Ramanathan R ,M. Jeganathan, and T. Jeyakavitha. 2006. Impact of cement dust on azadirachtain dicaleaves – ameasure of air pollution in and Around Ariyalur. J. Industrial Pollution Control. 22 (2): 273-276.
18. Vasanthy M and M. Jeganathan. 2007. Ambient air quality in terms of NOx in and around Ariyalur, Perambalur DT, Tamil Nadu. Pollution Research., 27(1):165-167.
19. Vasanthy M and M. Jeganathan. 2008.Monitoring of air quality in terms of respirable particulate matter – A case study. Jr. of Industrial pollution Control.,24(1):53 - 55.
20. Vasanthy M, A.Geetha, M. Jeganathan, and M. Buvaneswari. 2008. Phytoremediation of aqueous dye solution using blue devil (Eichhornia crassipes). J. Current Science. 9 (2): 903-906.
21. Raajasubramanian D, P. Sundaramoorthy, L. Baskaran, K. Sankar Ganesh, AL.A. Chidambaram and M. Jeganathan. 2011. Effect of cement dust pollution on germination and growth of groundnut (*Arachis hypogaea* L.). IRMJ-Ecology. International Multidisciplinary Research Journal 2011, 1/1:25-30 : ISSN: 2231-6302: Available Online: http://irjs.info/.
22. Raajasubramanian D, P. Sundaramoorthy, L. Baskaran, K. Sankar Ganesh, AL.A. Chidambaram and M. Jeganathan. 2011. Cement dust pollution on growth and yield attributes of groundnut. (*Arachis hypogaea* L.). IRMJ-Ecology. International Multidisciplinary Research Journal 2011, 1/1:31-36.ISSN: 2231-6302. Available Online: http://irjs.info/
23. Jeganathan M, K. Sridhar and J.Abbas Mohaideen. 2012. Analysis of meterological conditions of Ariyalur and construction of wind roses for the period of 5 years from January 2002. J.Ecotoxicol.Environ.Monit., 22(4): 375-384.
24. Sridhar K, J.Abbas Mohaideen M. Jeganathan and P Jayakumar. 2012. Monitoring of air quality in terms of respirable particulate matter at Ariyalur, Tamilnadu. J.Ecotoxicol.Environ.Monit., 22(5): 401-406.

25. Jeganathan M, K Maharajan C Sivasubramaniyan and A Manisekar. 2014. Impact of cement dust pollution on floral morphology and chlorophyll of *healianthus annus* plant – a case study. J.Ecotoxicol.Environ.Monit., 24(1): 29-34.
26. Jeganathan M, C Sivasubramaniyan A Manisekar and M Vasanthy. 2014. Determination of cement kiln exhaust on air quality of ariyalur in terms of suspended particulate matter – a case study. IJPBA. 5(3): 1235-1243. ISSN:0976-3333.
27. Jeganathan M, S Gunaselvi K C Pazhani and M Vasanthy. 2014. Impact of cement dust pollution on floral morphology and chlorophyll of *healianthus annus.*plant a case study. IJPBA. 5(3): 1231-1234. ISSN:0976-3333.
28. Gunaselvi S, K C Pazhani and M. Jeganathan. 2014. Energy conservation and environmental management on uncertainty reduction in pollution by combustion of swirl burners. J. Ecotoxicol. Environ.Monit., 24(1): 1-11.
29. Jeganathan M, G Nageswari and M Vasanthy. 2014. A Survey of traditional medicinal plant of Ariyalur District in Tamilnadu. IJPBA. 5(3): 1244-1248. ISSN:0976-3333.
30. Premalatha P, C. Sivasubramanian, P Satheeshkumar, M. Jeganathan and M. Balakumari.2015. Effect of cement dust pollution on certain physical and biochemical parameters of castor plant (*ricinus communis*). IAJMR.1(2): 181-185.ISSN: 2454-1370.
31. Premalatha P, C. Sivasubramanian, P Satheeshkumar, M. Jeganathan and M. Balakumari.2015. Estimation of physico-chemical parameters on silver beach marine water of cuddalore district. Life Science Archives. 1(2): 196-199.ISSN: 2454-1354.
32. Seshadri V, C. Sivasubramanian P. Satheeshkumar M. Jeganathan and Balakumari.2015. Comparative macronutrient, micronutrient and biochemical constituents analysis of *arachis hypogaea*. IAJMR.1(2): 186-190.ISSN: 2454-1370.
33. Seshadri V, C. Sivasubramanian P. Satheeshkumar M. Jeganathan and Balakumari.2015. A detailed study on the effect of air pollution on certain physical and bio chemical parameters of *mangifera indica*plant.Life Science Archives. 1(2): 200-203.ISSN: 2454-1354.
34. Shakila N, C. Sivasubramanian, P. Satheeshkumar, M. Jeganathan and Balakumari.2015. Effect of municipal sewage water on soil chemical composition- A executive summary. IAJMR.1(2): 191-195.ISSN: 2454-1370.
35. Shakila N, C. Sivasubramanian, P. Satheeshkumar, M. Jeganathan and Balakumari.2015. Bacterial enumeration in surface and bottom waters of two different fresh water aquatic eco systems in Ariyalur, Tamillnadu. Life Science Archives. 1(2): 204-207.ISSN: 2454-1354.
36. Ashok J, S. Senthamil kumar, P. Satheesh kumar and M. Jeganathan. 2016. Analysis of meteorological conditions of ariyalur district. Life Science Archives. 2(3): 579-585.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
37. Ashok J, S. Senthamil Kumar, P. Satheesh Kumar and M. Jeganathan. 2016. Analysis of meteorological conditions of cuddalore district. IAJMR.2 (3): 603-608.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.
38. Satheesh Kumar P, C. Sivasubramanian, M. Jeganathan and J. Ashok. 2016. South Indian vernacular architecture -A executive summary. IAJMR.2 (4): 655-661.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.
39. Satheesh Kumar P, C. Sivasubramanian, M. Jeganathan and J. Ashok. 2016. Green buildings - A review. Life Science Archives. 2(3): 586-590.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
40. Satheesh Kumar P, C. Sivasubramanian, M. Jeganathan and J. Ashok. 2016. Indoor outdoor green plantation in buildings - A case study. IAJMR.2 (3): 649-654.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.
41. Manikandan R, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. Assessment of ground water quality in Cuddalore district, Tamilnadu, India. Life Science Archives. 2(4): 628-636.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
42. Manikandan R, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. A study on water quality assessment of Ariyalur district, Tamilnadu, India. IAJMR.2 (4): 687-692.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.

43. Sethuraman G, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. Assessment of air quality in Ariyalur, Tamilnadu, India. Life Science Archives. 2(4): 637-640.ISSN: 2454-1354. DOI: 10.21276/lsa.2016.2.3.9.
44. Sethuraman G, M. Jeganathan, P. Satheesh Kumar and J. Ashok. 2016. A study on air quality assessment of Neyveli, Tamilnadu, India. IAJMR.2 (4): 693-697.ISSN: 2454-1370. DOI: 10.21276/iajmr.2016.2.3.3.