A Finite Element Analysis Based Study on Effects of Polyurea Coating for Blast Mitigation

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Abstract. One of main threats for Armoured fighting vehicles (AFVs) is anti-tank mines. Future war scenario insists on light tanks that can withstand land mines with higher order destruction. Hence a non-classical approach for blast mitigating structures has dealt with. In this sequence, there are two kinds of approach, one is to redesign the bottom plate structure and second is using special materials for coating. This work investigates the effect of special material Viz., Polyurea coating on the bottom structure of the AFV hull. Polyurea coating added to the Steel plate (considered as localized AFV vehicle hull structure) in such a way that the coating thickness is lesser than the thickness of base material. Explicit dynamic Finite Element (FE) based numerical simulations were performed using ANSYS AUTODYN. In this setup, coating is introduced to the Steel plate in two variations, namely, on non-blast face (opposite to the blast load) and blast face. The simulation is carried out with varying coating thickness (6mm, 8mm, 10mm 14mm) and with varying blast charges of TNT (2kg, 5kg, 7kg, and 12kg) in the stand-off distance (distance from the center of the explosive to the plate) of 450mm. The peak deformation of the plate caused by the blast load on the coated and uncoated homogenous plate is compared for their relative performances.

1. Introduction
Landmines can be defined as an explosive or other material, normally encased, designed to destroy or damage vehicles, boats or aircraft, or designed to wound, kill, or otherwise incapacitate personnel. It may be denoted by the action of its target, the passage of time or by controlled means [1]. Although the history of mines can be traced back to Roman times, the first modern mines were developed during first world war [2]. Based on the weight of explosives, mines can be categorized into anti-personnel mine and anti-tank mine. Anti-personnel mines are designed to harm humans, their quantity of explosive amount ranges from 0.003 to 0.25 kg [3]. Anti-tank(AT) mines are specifically designed for armoured vehicles, their explosive content ranges from 1.5kg to 12kg or more. Because of high explosive content AT mines possess a greater threat to vehicle and its crews. This work will focus only on the effects of AT mines to the AFV hull structure.
1. Blast Phenomena

An explosion is an extremely rapid release of energy in the form of light, heat, sound, and a shock wave. A shock wave consists of highly compressed air traveling radially outward from the source at supersonic velocities. The intensity of the wave fades with distance. Blast wave travels through the atmosphere at the speed of sound, which is approximately 1126 feet per second at 68°F in dry air, and at about 1100 fps at 45°F. In an ideal blast wave as seen in Figure 1, when the blast occurs, the pressure increases to a maximum value called as incident and reflected peak overpressure for incident and reflected blast waves, respectively. After this phase, the pressure starts decreasing gradually and reaches atmospheric pressure level, this phase is called as positive phase duration. After this phase, the pressure decreases further, dropping below the atmospheric level called as negative phase [4][5].

Figure 1. Blast phenomena

The decaying of pressure that occurs during a blast event can be characterized by Friedlander equation.

\[
P(t) = P_{so} \left[1 - \frac{t - T_a}{T_0}\right] \exp\left[\frac{-A(t - T_a)}{T_0}\right]
\]

Here \(P(t)\) is pressure at time \(t\), \(P_{so}\) is the peak overpressure, \(T_0\) is the positive phase duration, \(A\) is the decay coefficient, and \(T_a\) is arrival time [6].

1.1.2. Scaled distance The important parameter for blast loading computation is scaled distance. The peak pressure value of the blast wave, decrease rapidly by increasing the distance between the blast source and the target surface. The pressure is high when the distance from detonation point is less and the duration are longer whenever the distance from the detonation point increases. The variation of blast characteristics can be taken into account with the help of scaled distance or scaled laws. Scaled distance helps to scale parameters, which were defined through experiments. The experimental results are, in this way, generalized to include cases that are different from initial experimental setup. The most commonly used scaling law is introduced by Hopkinson-Cranz [7] and it is defined by

\[
Z = \frac{R}{\sqrt{W}}
\]
Where R is the stand-off (m) distance (distance from the center of the mine to the target body), W is the TNT equivalent charge mass (kg).

1.3. Polyurea overview
Polyurea is a cross-linked amorphous isocyanate monomer or prepolymer and polyamine curative. Polyurea should contain up to 80% of polyamine. It is an elastomeric-thermoset polymer with high elongation property, in most cases they are capable of elongate up to 100%. Polyurea is often used as coating materials because it can be applied just by spraying. Also, it has good ductile behavior and able to reduce fragmentation during blast and impact situations. Polyurea is most commonly used to coat composite laminates, building structures because of their potential in resisting blast and impacts. Research indicates that adding polyurea to concrete structures are capable reducing the displacement caused by blast up to 40%. In Middle East countries where the terrorist activities are high, buildings and houses are reinforced with polyurea coating to protect from bomb blasts [8][9].

2. Literature Survey
Many research studies have been carried out to understand the effects of mine blast on various structures. Some of the most significant works are discussed below

Hrvoje Draganic et al (2012) studied the process of determination of blast load on structures, this paper reviews the analytical formulations to determine blast load. The peak over pressure has been calculated analytically and simulated on building model using SAP2000 software package. Loading was defined change of pressure over time. The determined blast load is used to find deformation at certain point of interest using the software. This paper provides a detailed description of blast wave. It shows how the TNT blast wave pressure varies with time, which is helpful in understanding the blast phenomena. [10].

T. Ngo et al (2011) express the nature of explosion and blast phenomenon. Here the classification of explosives and the material used for explosives has been studied. And also, the temperature rise during the detonation has been given. The blast wave propagation graph has been plotted by using the graphical technique. The next significant part of this paper is blast wave-structure interaction. The structural behaviour of an object or structure exposed to such blast wave may be analysed by dealing with two main issues. Firstly, blast-loading effects. Secondly, the structural response, or the expected damage criteria associated with such loading effects. The remaining part deals with material behaviours at high strain rate. Here the dynamic properties of Concrete and reinforcing steel have been studied under high-strain rates and stress-strain rate graphs have been plotted [11].

Jong Yil Park et al (2017) studied the dynamic behaviour of steel plate subjected to blast load. Steel plate was subjected to 50kg TNT at different stand-off distance. The study has been done both numerically and experimentally and studied for strain variable. Numerically it was modelled using AUTODYN software package in ALE method. A good agreement was observed between numerical and experimental value [12].

D.K Sahoo et al (2017) investigated blast resistance of layered plates using CONWEP method. Layered plate with different material combinations with varying thickness for the layers. This paper gives an idea about CONWEP method and method to use it in numerical simulation [13].

S N. Raman et al (2011) This paper provides a review on the status of research in using polyurea coating to enhance blast and impact resistance of structures. Application of coating on masonry, composite as well as RC structures have been discussed. This paper helps to understand the application and effectiveness of polyurea coating around various fields [14].
Ackland et al (2011) studied blast mitigation of mild steel plates subjected to blast load of 0.5 Pentolite at close range blast with polyurea coating. Mile steel plates is applied with polyurea of thickness 350% and 575% more than the steel thickness. It was observed that the deformation reduction of steel plate coated with polyurea on non-blast face reduced deformation effectively than at the blast face [15].

Kathryn Ackland et al (2013) studied the effect of polyurea coating on the blast resistance of mild steel. Plates with and without polyurea coating applied to non-blast face is subjected to blast load of 0.5 pentolite at close range distance. Coating were applied in a way such that the bare plate density suits the polyurea applied plate by reducing the thickness of the steel plate. Bare steel plate of 6mm, 5mm steel plate of thin coating thickness and 4mm plate of thick coating were considered for investigation. It has been observed that bare plate dissipated more energy that polyurea coating plate with same aerial density. Also, residual deformation is low is bare plate in comparison to coated plate with same aerial density [16].

Ashan samiee et al (2013) performed numerical simulation of steel plates with polyurea bilayers, subject to blast like loads. Different cases of coating were investigated such as coating of front face and back face of 10mm steel with same thickness (10mm, 20mm, 30mm and 40mm), Bare steel and coated steel maintained with same aerial thickness in four configurations (11.4mm, 12.8mm, 14.2mm and 15.6mm). Pressure is applied in two types, direct application on bilayer system and application of pressure through a fluid medium such as polyurethane or water. It is observed that polyurea coated on non-blast face had less average plastic strain on central region of steel plate. It is concluded that in steel plate applying thin layer of coating when applied on either side, change in performance is negligible. As thickness is increased the advantages becomes clear. Regarding the effect of loading between direct and indirect pressure application to the bilayer system has same response but in indirect application of pressure plastic strain is lower. Overall cases it is identified that when polyurea is coated on non-blast face, the blast mitigation is more effective [17].

Li-hui Dai et al (2018) investigated the effect of polyurea coated steel plates subjected to underwater explosive load. Experimental and numerical investigation were conducted with thin steel plate of 2mm. Coating was applied at two configurations, thickness same as base plate and thickness double the base plate on blast and non-blast face. Blast load of 0.1kg charge of RDX at different standoff distance in close range, experiment was conducted underwater. It is observed that for thin steel plate, coating on front face provided significant blast resistant which contradicts other research works. Also, it is noted that increase in thickness provide better deformation resistance [18].

From the literature study, it is clear that the polyurea coating enhances blast resistance to building and concrete structures [14]. In the case of ductile materials like steel the coating is added equal to the thickness or more than the thickness of the base material [16] [17] [18], but not lesser than the thickness of base plate. This work investigates the effect blast mitigation of polyurea coating added to steel plate whose thickness is lesser than the base material.

3. Methods To Predict Mine blast
In numerical simulations, effect of mine blast can be predicted into two different methods Arbitrary Lagrange Euler (ALE), Conventional Weapon (CONWEP).

3.1. ALE method
ALE method involves geometric modeling of all the elements that involves in the mine blast numerical simulation. The structural elements are modeled using Lagrange elements. Lagrange is used to model the materials which have less distortion as Lagrange keeps the material in its initial element as there is no transport of material from element to element. The material with high distortion such as
Air, Explosives are modeled using Eulerian element as it allows the material from flow to cell to cell [2]. The Lagrange and Eulerian are given a coupling to interact with each other. The advantage of ALE method is that it allows visualization of blast phenomena.

3.2. CONWEP method

CONWEP is well accepted method for predicting mine blast. It is based on the experimental parameters from air burst and hemispherical surface blast done by Kingery and Bulmash for US army [19]. It contains over explosive charge data from 1kg to over 40,000kg. The experimental values are categorized based on scaled distance in graphical form by curve fitting technique. CONWEP is pure Lagrange model where in only the structure is modeled. It is valid for over a scaled distance range of 0.147 m/kg$^{1/3}$ to 40 m/kg$^{1/3}$. Since CONWEP method eliminates the need for modeling Air and explosives, it saves computational time.

3.3. Problem description

The AFV vehicle hull has been localized as a dimensioned 1000mm x 1000mm x 15mm steel plate. The plate is kept at over 450mm stand-off distance (distance from the center of the explosive to the plate. The explosive charge is TNT. The explosive buried 100mm inside the sand as show in Figure 2. The TNT charge is varied (2kg, 5kg, 7kg, 10kg, 12kg). Then Polyurea coating of various thicknesses is applied to the steel plate on two cases, on non-blast face and blast face with varying coating thickness (6mm, 8mm, 10mm, and 14mm) and studied for the response under same blast load conditions.

![Figure 2. Visual representation of Problem description in ANSYS AUTODYN](image)

3.4. Material Parameters

The material parameters involved in this study are as follows

3.4.1. AISI Steel 4340. AISI Steel 4340 is a medium carbon (carbon content is in between 0.3% to 0.6%), low alloy steel containing chromium, nickel and molybdenum. It is known for its toughness, strength and good fatigue resistance. The chemical composition of Steel 4340 can be seen in Table 1.
Table 1. The chemical composition of Steel 4340.

| Element                  | Percentage [%] |
|--------------------------|----------------|
| Iron, Fe                 | 95.195 - 96.33 |
| Nickel, Ni               | 1.65 - 2.00    |
| Chromium, Cr             | 0.70 - 0.90    |
| Manganese, Mn            | 0.60 - 0.80    |
| Carbon, C                | 0.37 - 0.43    |
| Molybdenum, Mo           | 0.20 - 0.30    |
| Silicon                  | 0.15 - 0.30    |
| Sulfur                   | 0.04           |
| Phosphorous              | 0.035          |

The behavior of Steel 4340 is defined by Johnson-Cook strength and failure model. Johnson-Cook model was used to define strength of the material Steel 4340. This constitutive model defines the strength behavior of materials subjected to large strains, high strain rates and high temperatures [20].

\[ Y = [A + Be_p^n] \left[1 + C \log e_p^n \right] \left[1 - T_H^m \right] \]  (3)

Where
- \( e_p \) = effective plastic strain
- \( e_p^* \) = normalized effective plastic strain rate
- \( T_H \) = homologous temperature = \((T - T_{room})/(T_{melt} - T_{room})\)

The five material constants are A, B, C, n and m. The first set of brackets in above equation gives the stress as a function of strain, which can be found by quasi-static tensile testing (\( e_p = 1.0 sec^{-1} \) and \( T_H = 0 \)). A is the basic yield stress at low strains whereas B and n define strain hardening. The second and third set of brackets represents the effects of strain rate hardening and temperature softening. With the thermal softening, the yield strength drops to zero at the melting temperature \( T_{melt} \). The material constants can be obtained empirically via dynamic Split Hopkinson Bar tensile tests over a range of temperatures and strain rates. The obtained model constants were checked by calculations of Taylor tests of impacting metal cylinders on rigid metal targets which provided strain rates in excess of \( 10^5 sec^{-1} \) and strains in excess of 2.0.

Table 2. The Johnson-Cook parameters for AISI 4340 Steel.

| Material     | A [Mpa] | B [Mpa] | n  | c   | m   | T_{melt} [K] | T_{room} [K] |
|--------------|---------|---------|----|-----|-----|-------------|--------------|
| Steel 4340   | 792     | 510     | 0.26 | 0.014 | 1.02 | 1793.15     | 293.15       |

3.4.2. Air. The material model of air used in this simulation is loaded from AUTODYN material library. Ideal equation of state (EOS) is used to describe air [9], which is described the form of

\[ P = (\gamma - 1)pe + P_{shift} \]  (4)

Where \( p \) is pressure, \( \gamma \) is adiabatic constant (for air behaving as an ideal gas \( \gamma = 1.4 \)). \( e \) is the density, shift is a small pressure defined to dive zero starting pressure in order to avoid complications in problems with multiple material where initial small pressure in the gas would generate small unwanted velocities. \( e \) is the specific internal energy and can be defined by

\[ e = c_v T \]  (5)
Where the constant $C_v$ is the specific heat at constant volume.

The values for the variables in for ideal gas equation for air model in AUTODYN are listed in the Table 3.

**Table 3. Air – Ideal Gas parameters.**

| $\gamma$ | $\rho$ [kg/m$^3$] | $C_v$ [/kg/k] | $T$ [K] |
|----------|-----------------|---------------|---------|
| 1.4      | 1.225           | 0.000718      | 288.2   |

3.4.3. *TNT (Explosive).* The TNT is defined using Jones-Wilkins-Lee (JWL) form of equation of state

$$P = A \left[ 1 - \frac{\omega}{R_1 V} \right] e^{-R_1 V} + B \left[ 1 - \frac{\omega}{R_2 V} \right] e^{-R_2 V} + \frac{\omega E}{V}$$

Where $A$, $B$, $R_1$, $R_2$, are empirically derived constants varies with each explosive, $V$ is the relative volume of expansion of explosive product and $E$ is the detonation energy per initial unit volume [3][9]. The material property of TNT and variable for JWL equations listed in Table 4.

**Table 4. TNT – JWL parameters.**

| Variable                  | Value  |
|---------------------------|--------|
| kgm3                      | 1.225  |
| $A$                       | 373.77 |
| $B$                       | 374.71 |
| $R_1$                     | 4.15   |
| $R_2$                     | 0.9    |
| $\omega$                 | 0.35   |
| C-J Detonation velocity (m/ms) | 6.93 |
| C-J Energy/unit volume (MJ/m$^3$) | 6000 |
| C-J Pressure (Mpa)        | 21000  |

3.4.4. *Polyurea.* Material model for polyurea in most cases is defined using Mooney-Rivlin model [21]. Polyurea is observed to have higher elongation[22]. As the deformation in the present study is within this elastic limit, linear elastic model is used to define the Polyurea material. Table 5 shows the material parameters for polyurea.

**Table 5. Material parameters of Polyurea.**

| Material | $\rho$ [kg/m$^3$] | $E$ [N/m$^2$] | $\nu$ |
|----------|-----------------|---------------|-------|
| Polyurea | 1500            | $7 \times 10^7$ | 0.3   |

3.5. *Numerical Simulation Of Bare Plate Subjected To 2KG TNT Blast Load*

The plate of 1000mm x 1000mm x 18mm is subjected to 2kg blast load of TNT is to be studied with both ALE and CONWEP method using ANSYS AUTODYN solver.
3.5.1 ALE method. The plate is designed using Axisymmetric modeling using Lagrange elements. The air, sand and TNT are modeled by Eulerian element. Since 3D ALE method is time consuming, this study is made in 2d axisymmetric method. The plate is modeled with dimension 18mm x 500mm. Air is modeled with dimension 1000mm x 500mm, sand is modeled with dimension 383mm x 500mm and TNT is designed with semi-circular geometry with radius 66.42mm. The TNT is of 2kg using the relation \( m = \rho V \). The axisymmetric model is shown in Figure 3. Boundary condition, the plate is fixed at one end, and flow out condition is given at three edges for the air and sand. Gauge points are fixed at the edge of the plate. The mesh size for plate is 3mm and for Eulerian domains are 2.5mm, to allow interaction between Euler and Lagrange domain. The aim of this simulation is to capture the peak deformation of the plate.

![Figure 3. ALE setup – symmetric model before TNT explosion](image1)

![Figure 4. ALE setup – symmetric model after TNT explosion](image2)

3.5.2 CONWEP method. The same case is modeled in COWNEP method. A 3D plate with symmetric condition, the dimension of plate is 500mm x 500mm x 18mm. Since CONWEP is a pure Lagrange method there is no need to model Air, Sand and TNT. The CONWEP option should be given as boundary condition in AUODYN. Under analytical blast boundary condition, the weight of the TNT is entered as 2kg, stand-off distance is of 450mm and the type of blast is set to surface blast. And the pressure clearing is kept off because in symmetric method clearing does not work properly. The two edges of the plates are fixed, the CONWEP condition is given at the bottom face of the plate, and mesh size is 3 mm. Gauge point is kept at corner of the plate. The case setup in CONWEP method for steel plate is shown in Figure 5.
The peak deformation for both the methods gives close values. The value obtained in both methods is shown in Table 6.

**Table 5. ALE and CONWEP deformation result comparison**

|                  | Peak deformation in ALE method | Peak deformation in CONWEP method |
|------------------|--------------------------------|----------------------------------|
|                  | 33.60 mm                       | 32.676 mm                        |

Since both the values are almost similar, the rest of the simulations are to be carried out in CONWEP method as it simplifies the model and saves computational time.

The same methodology is applied for blast charges of 5kg, 7kg, 10kg and 12kg. Only by altering the charge weight in the CONWEP boundary condition, the simulation is done.

### 3.6. Polyurea coated to plate

**3.6.1 Numerical simulation of coated plate.** In AUTODYN software the polyurea coating is modelled without any external gap between the plate and the polyurea coating. Based on experimental work done by Amini et al [23]. On steel plate with polyurea coating, it is found that while analyzing in numerical software, the bond strength of 100 Mpa gave most close agreement with experimental value. Hence a bonding strength of 100 Mpa is takes in this study.
3.7. Numerical simulation of concrete with and without coating

Since it is clear from the research that polyurea has significant role along with concrete [14] for comparative study, concrete plate with same dimension as that of steel plate. Three cases are to be studied bare concrete, 6mm coating on blast face and non-blast face. The deformation resistance is studied with comparative to steel plate.

4. Results

4.1. Deformation observed on coated plate

The peak deformations of plate with coating on non-blast side and blast side subjected to mine blast of various masses of TNT are tabulated and compared.

4.1.1. Deformation results for 2kg TNT. The deformation obtained for bare (homogenous) and coated plate subjected to 2kg TNT blast is listed in Table 6.

| Coating thickness | Deformation (mm) |
|-------------------|------------------|
|                   | Homogenous | 32.188 |
| 6mm coating       |            | 31.464 |
| 8mm coating       |            | 31.229 |
| 10mm coating      |            | 30.969 |
| 14mm coating      |            | 30.262 |
| 8mm coating (non-blaster) | 31.375 |
| 8mm coating (blast)  |            | 31.283 |
| 10mm coating (non-blaster) | 30.982 |
| 10mm coating (blast)  |            | 30.458 |

Figure 6. CONWEP model – case setup of 6mm coated plate
4.1.2. **Deformation results for 5kg TNT.** The deformation obtained for bare and coated plate subjected to 5kg TNT blast is listed in Table 7.

| Coating thickness | Deformation (mm) |
|-------------------|------------------|
| Homogenous        | 55.735           |
| 6mm coating       | 54.504           | 54.940 |
| 8mm coating       | 54.112           | 54.642 |
| 10mm coating      | 53.787           | 54.428 |
| 14mm coating      | 52.811           | 53.841 |

**Figure 6.** Deformation output of 2kg TNT load
4.1.3. Deformation results for 7kg TNT. The deformation obtained for bare and coated plate subjected to 7kg TNT blast is listed in Table 9.

| Table 8. Deformation outputs comparison for 7kg TNT blast load. |
|---------------------------------------------------------------|
| Coating | Deformation (mm) |
| Homogenous | 69.619 |
| 6mm coating | 68.004 | 68.176 |
| 8mm coating | 67.483 | 67.782 |
| 10mm coating | 66.966 | 67.628 |
| 14mm coating | 65.690 | 65.69 |

Figure 7. Deformation output of 5kg TNT load

Figure 8. Deformation output of 7kg TNT load
The deformation obtained for bare and coated plate subjected to 10kg TNT blast is listed in Table 9.

**Table 9.** Deformation outputs comparison for 10kg TNT blast load.

| Coating                        | Deformation (mm) |
|--------------------------------|------------------|
| Homogenous                     | 90.156           |
| Coating on non-blast side      |                  |
| 6mm coating                    | 87.833           |
| 8mm coating                    | 87.081           |
| 10mm coating                   | 86.359           |
| 14mm coating                   | 84.582           |
| Coating on blast side          |                  |
| 6mm coating                    | 88.315           |
| 8mm coating                    | 87.328           |
| 10mm coating                   | 86.727           |
| 14mm coating                   | 85.786           |

![10kg TNT load](image)

**Figure 9.** Deformation output of 10kg TNT load

4.1.5. Deformation results for 12kg TNT.

The deformation obtained for bare and coated plate subjected to 12kg TNT blast is listed in Table 10.

**Table 10.** Deformation outputs comparison for 12kg TNT blast load.

| Coating                        | Deformation (mm) |
|--------------------------------|------------------|
| Homogenous                     | 104.16           |
| Coating on non-blast side      |                  |
| 6mm coating                    | 101.36           |
| 8mm coating                    | 100.47           |
| 10mm coating                   | 99.602           |
| 14mm coating                   | 97.508           |
| Coating on blast side          |                  |
| 6mm coating                    | 101.27           |
| 8mm coating                    | 100.39           |
| 10mm coating                   | 99.746           |
| 14mm coating                   | 98.870           |
4.2. Acceleration observed on coated plate

The acceleration obtained from plate bare plate and coated plate subjected to mine blast of various masses of TNT are tabulated and compared.

4.2.1. Acceleration results for 2kg TNT load. The acceleration obtained for bare (homogenous) and coated plate subjected to 2kg TNT blast is listed in Table 11.

![Deformation output of 12kg TNT load](image)

Table 11. Acceleration outputs comparison for 2kg TNT blast load.

| Coating               | Acceleration (mm/ms²) |
|-----------------------|-----------------------|
| Homogenous            | 115.36                |
|                       | Coating on non-blast side | Coating on blast side |
| 6mm coating           | 106.84                | 108.34                |
| 8mm coating           | 106.19                | 104.73                |
| 10mm coating          | 104.15                | 102.71                |
| 14mm coating          | 99.353                | 97.991                |
4.2.2. Acceleration results for 5kg TNT load. The acceleration obtained for bare and coated plate subjected to 5kg TNT blast is listed in Table 12.

Table 12. Acceleration outputs comparison for 5kg TNT blast load.

| Coating                        | Acceleration (in mm/ms²) |
|--------------------------------|--------------------------|
| Homogenous                     | 242.82                   |
|                                | Coating on non-blast side| Coating on blast side |
| 6mm coating                    | 227.77                   | 228.22                 |
| 8mm coating                    | 223.74                   | 223.34                 |
| 10mm coating                   | 219.44                   | 219.02                 |
| 14mm coating                   | 209.36                   | 208.96                 |
4.2.3. Acceleration results for 7kg TNT load. The acceleration obtained for bare and coated plate subjected to 7kg TNT blast is listed in Table 13.

| Coating | Acceleration (in mm/ms$^2$) |
|---------|-----------------------------|
| Homogenous | 311.03 |
| Coating on non-blast side | 292.74 | 292.37 |
| Coating on blast side | 286.63 | 287.04 |
| 6mm coating | 281.12 | 281.56 |
| 8mm coating | 268.22 | 268.62 |

Figure 13. Acceleration output of 7kg TNT load

4.2.4. Acceleration results for 10kg TNT load. The acceleration obtained for bare and coated plate subjected to 10kg TNT blast is listed in Table 14.

| Coating | Acceleration (in mm/ms$^2$) |
|---------|-----------------------------|
| Homogenous | 399.07 |
| Coating on non-blast side | 377.40 | 378.13 |
| Coating on blast side | 367.77 | 370.09 |
| 6mm coating | 360.70 | 360.30 |
| 8mm coating | 344.15 | 346.32 |
4.2.4. Acceleration results for 10kg TNT load. The acceleration obtained for bare and coated plate subjected to 12kg TNT blast is listed in Table 15.

**Table 15.** Acceleration outputs comparison for 10kg TNT blast load.

| Coating                      | Acceleration (in mm/ms²) |
|------------------------------|--------------------------|
| Homogenous                   | 450.94                   |
| Coating on non-blast side    |                          |
| 6mm coating                  | 426.84                   |
| 8mm coating                  | 415.57                   |
| 10mm coating                 | 407.57                   |
| 14mm coating                 | 388.67                   |
| Coating on blast side        |                          |
| 6mm coating                  | 423.88                   |
| 8mm coating                  | 419.07                   |
| 10mm coating                 | 419.01                   |
| 14mm coating                 | 392.80                   |

![Figure 14. Acceleration output of 10kg TNT load](image)
4.3. Concrete Results

The results obtained for concrete with 6mm coating, subjected to 2kg TNT explosion is listed in Table 16 and Table 17.
Table 16. Deformation outputs comparison for 2kg TNT blast load on Concrete.

| Coating                        | Displacement (mm) |
|-------------------------------|-------------------|
| Homogenous                    | 202.13            |
| Coating on non-blast side     | 167.46            |
| Coating on blast side         | 169.79            |
| 6mm coating                   |                   |

Table 17. Acceleration outputs comparison for 2kg TNT blast load on Concrete.

| Coating                        | Acceleration (mm/ms²) |
|-------------------------------|-----------------------|
| Homogenous                    | 354.80                |
| Coating on non-blast side     | 295.86                |
| Coating on blast side         | 294.65                |
| 6mm coating                   |                       |

4.4. De-bonding observation

De-bonding is observed in coating side facing on blast side in all coating thickness, for all charge masses. No de-bonding occurred in coating facing non-blast side. This is clear from the fact that in case on blast side there is excess energy available so as to shear the bonding between the two phases. In case of non-blast side coating, the excess energy is absorbed by the steel structure and hence there is no shear between the two materials. Fig 4.14 shows the debonding of polyurea of 14mm thickness subjected to 2kg TNT explosion.

Figure 10. Debonding of polyurea coating

5. Conclusion

In all the case studied, it is clearly seen that there is decrease in the peak deformation and acceleration value. This is reduction is not significant when compared to the elastomeric properties of the material. In fact, the meager reduction can be attributed to the additional thickness that is added on to the structure. Further, it is noted from that there is significant reduction in peak deformation and acceleration on concrete structures coated just 6mm Polyurea. From these simulations, it is clear that the Polyurea coating has a significant role in case of blast mitigation where the base material. Whereas, in case of ductile materials like steel, the base material also has enough blast resistance and hence the elastomeric properties of the Polyurea coating becomes insignificant.
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