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Numerical simulation of concrete slabs strengthened with PTFE sheets subjected to blast load

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Abstract. Due to the noticeable increase in bombing activities, the understanding of the structures response against blast loads has become one of the major concerns in structural engineering. This present study investigates the blast loading hazards that can take place in concrete slabs. Concrete slabs strengthened using PolyTetraFluoroEthylene (PTFE) are used to investigate the control of the hazards. The thickness of the slabs is 200 mm. The models are exposed to a blast load equivalent to 20 Kg of TNT explosives with a standoff distance equals to 500 mm. The concrete slabs are strengthened using different thicknesses and different number of sheets. In order to investigate the effect of PTFE sheets, AUTODYN software is used to create the numerical models. Concrete is modelled using Lagrange solver while the air and TNT explosives are modelled using Euler solver. The results of the study show that PTFE sheets control concrete fragmentation and debris propagation. The use of PTFE can improve concrete resistance to one of the blast components because of its stability at high temperatures, thermal insulation, and resistance to weathering. PTFE has a wide working temperature range from -100°F to +400°F (-73°C to 204°C) in which its properties remain functional.

1 Introduction

An explosion can lead to many hazards that can jeopardize human safety. Some of those hazards are blast pressure, heat, structural collision, vibration, and fragments. Human tolerance to those hazards can vary widely [1]. Von Ramin et al. [2] studied the fragments distribution and energy from debris of a one way span masonry wall to predict the minimum safety ranges. Lin et al. [3] conducted a parametric study to investigate the responses of FRP-strengthened RC panels under blast loads. They found that increasing the thickness of the GFRP sheet decreases the maximum and residual deflections of RC panels. Tai et al. [4] studied the effect of meshing and steel reinforcement in concrete slabs. The study of the dynamic response of RC slabs showed that the mesh size is very sensitive to the shock wave propagation and should be as fine as possible. Also, the reinforcement ratio

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in the concrete slab affects damage location. Weerheijm et al. [5] studied the failure of a one way concrete slab under internal explosion.

The objective of this research is to study the control of hazards in concrete slabs using PTFE sheets. A parametric study is conducted using AUTODYN to compare the behaviour of the slabs with different number and thickness of PTFE sheets.

PTFE $(C_2F_4)_n$ is an artificial highly crystalline fluoropolymer consisting of carbon and fluorine, it is best known commercially as Teflon. PTFE is chemically inert and resistant to attacks from corrosive chemicals. PTFE is highly dense and has a high melting temperature which makes it highly stable at high temperatures and has high impact strength [6, 7].

1.1 Blast wave and debris propagation

Figure 1 illustrates the idealization of a blast wave pressure-time history. The curve can be divided into two phases: positive and negative phases. At time t_A, detonation takes place. A sudden increase in pressure occurs, it is equal to (P_P - P_O) and called overpressure. From t_A to t_B, the positive phase represents the instantaneous rise of pressure and decrease of pressure to ambient condition. The negative phase starts at time t_B and ends with the decay of the wave. The negative phase is longer than the positive phase and the pressure turns into a very small value of suction [8].

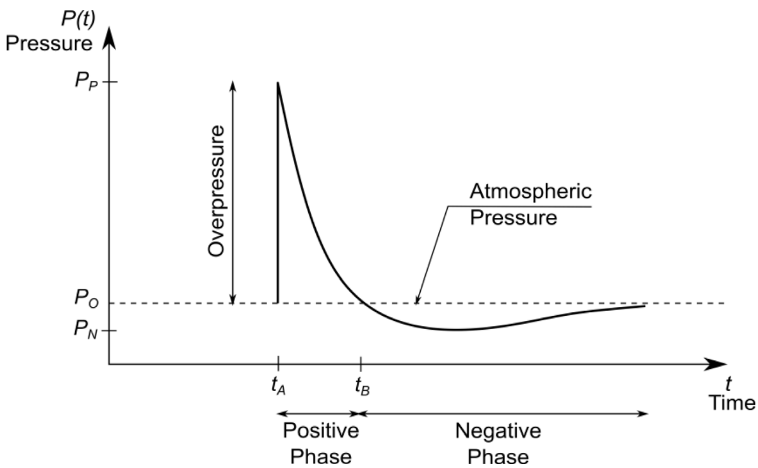

Fig. 1. Blast wave pressure-time history [8].

During an explosion, fragments may be formed from any object in the path of the blast wave. Fragments can travel for long distances thus increasing the blast radius and human injuries. The distance travelled by a fragment is affected by initial direction, size, shape, and explosion yield [8].

1.2 Structural response to shock waves

Analysis of structures under blast loads can be a complex process. In order to simplify this process, it is widely accepted to model the structure as a single degree of freedom SDOF.

Figure 2 illustrates the SDOF system for analysis. The structure is idealized as a lumped mass *M* having a weightless spring with stiffness *K* and an idealized triangular pulse as shown in Equation (1). Equation of motion for the un-damped SDOF is shown in Equation (2). Design for blast loads is affected mainly by the first cycle response, thus damping is neglected. [1, 9]

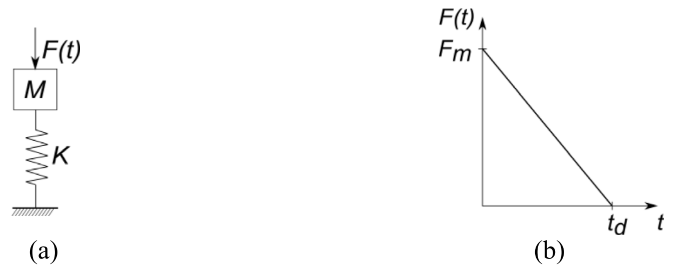

Fig. 2. (a) Un-damped SDOF system, (b) Blast load

$$F(t) = F_m\left(1 - \frac{t}{t_d}\right) \quad (1)$$

$$Ma + Ky = F_m\left(1 - \frac{t}{t_d}\right) \quad (2)$$

Due to the dynamic analysis simplification, transformation factors for load, mass, and resistance are used to convert the required system for analysis into a SDOF.

1.3 Concrete behaviour at high strain rates

Concrete behaviour is different under dynamic and static loading. In dynamic loading, for the same strain value concrete reaches a higher value of stress. Strain rates for blast loads are 10^{11} times the static strain rates. According to Bischoff et al. the relative increase in concrete ultimate strength in uniaxial compression can reach a value of 2 [10] and according to Malvar et al. ultimate tensile strength can increase up to 7 times [11]. To account for this behaviour, codes of practice introduced the dynamic increase factor DIF which is defined as the ratio of the dynamic to static strength [1].

2 Numerical simulation

In order to conduct this study, accurate modelling of materials, loading, boundaries, meshing, and gauges are carried out. Approaches and techniques developed by AUTODYN software are used [12]. Setup for the analysis is 20Kg of TNT explosives placed at a standoff distance of 500mm from the concrete slab as shown in Figure 3.

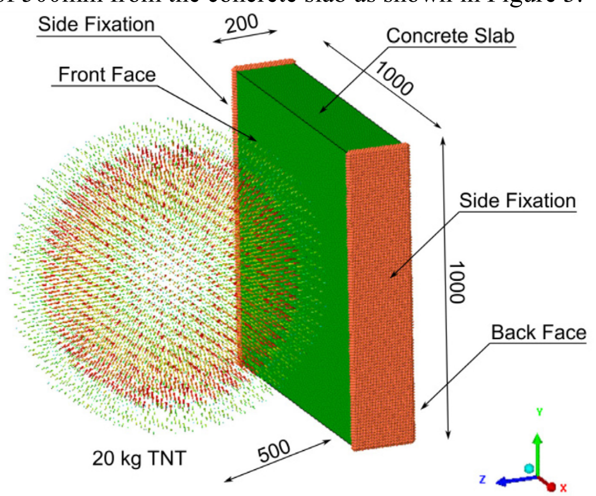

Fig. 3. Models setup. (dimensions in mm)

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2.1 Material description

The materials used to simulate the concrete slab, PTFE sheets, and the surrounding medium are CONC-25MPA, TEFLON, and AIR respectively. The materials are taken from the AUTODYN materials library and adjusted to the conditions of the study. Equation of state, strength model, failure model, and properties for concrete, Teflon, and air are shown in Table 1.

Table 1. Materials models and properties.

Material	Equation of State	Strength Model	Failure Model	Erosion Control	Erosion Strain	Reference Density (g/cm^3)	Shear Modulus (kPa)
CONC-25MPA	P alpha	RHT concrete	RHT concrete	Instantaneous geometric strain	0.7	2.5	$1.67\text{x}10^7$
TEFLON	Shock	Von Mises	Hydro (Pmin)	Instantaneous geometric strain	0.5	2.16	$2.33\text{x}10^6$
AIR	Ideal Gas	-	-	-	-	$1.225\text{x}10^{-3}$	-

2.2 Geometry and mesh description

For this study 24 models are carried out, all test specimens are 1000x1000x200 mm concrete slabs defined using Lagrange solver with mesh size 10x10x5 mm. PTFE sheets are modelled by filling the concrete slab part using the TEFLON material. The air and explosives are defined using Euler solver with mesh size 40x40x60 mm. All slabs are modelled as one way slabs using side fixation as boundary condition. Geometric details for models are illustrated in Figure 4 and Table 2. Figure 5 shows a sample from the models.

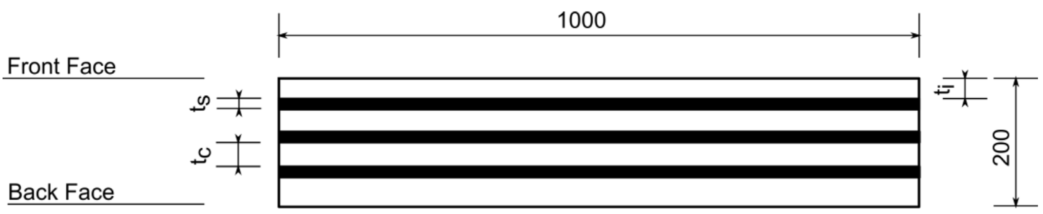

Fig. 4. Models schematic. (dimensions in mm)

Table 2. Sheets configurations.

#	*ts* mm	*ns*	*tc* mm	*ti* mm	#	*ts* mm	*ns*	*tc* mm	*ti* mm
S1	-	-	-	-	S13	30	3	50	10
S2	5	1	-	10	S14	5	1	-	195
S3	10	1	-	10	S15	10	1	-	190
S4	20	1	-	10	S16	20	1	-	180
S5	30	1	-	10	S17	30	1	-	170
S6	5	2	50	10	S18	5	2	50	140
S7	10	2	50	10	S19	10	2	50	130
S8	20	2	50	10	S20	20	2	50	110
S9	30	2	50	10	S21	30	2	50	90
S10	5	3	50	10	S22	5	3	50	85
S11	10	3	50	10	S23	10	3	50	70
S12	20	3	50	10	S24	20	3	50	40

ts	is the PTFE sheet thickness in mm.
ns	is the number of PTFE sheets.
tc	is the concrete thickness between PTFE sheets in mm.
ti	is the initial concrete thickness at the front face in mm.

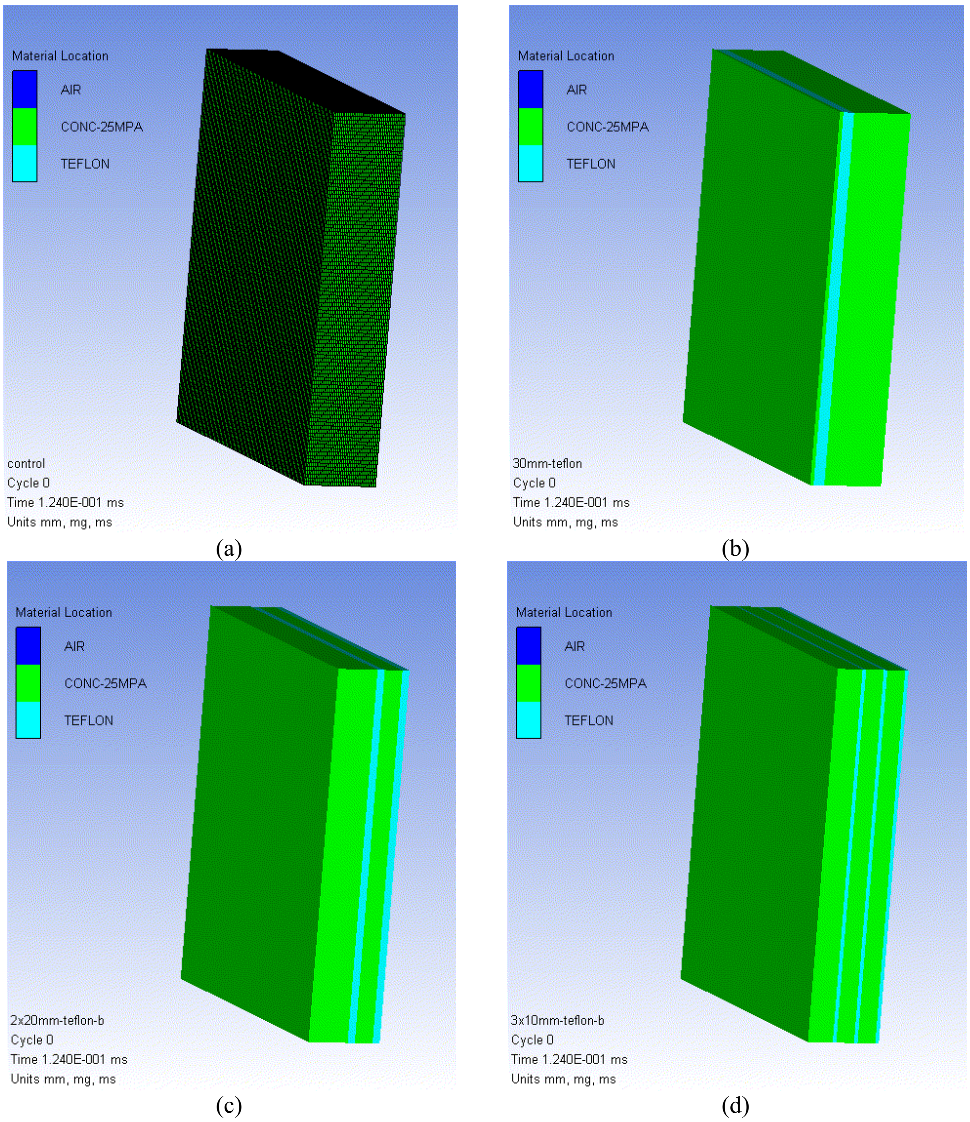

Fig. 5. Sample of models (a) S1 model, no PTFE sheets and showing the mesh grid, (b) S5 model, 30mm sheet at the front face, (c) S20 model, two 20mm sheets at the back face, and (d) S23 model, three 10 mm sheets at the back face.

2.3 Explosion Simulation Validation

In order to validate the TNT charge used in the simulation, overpressure from manual calculations and the simulation are compared. Overpressure is calculated manually from Kinney and Graham [8] overpressure formulation described in Equation (3) and UFC 3-

340-02 technical manual [1]. Scaled distance of the equivalent TNT explosives is calculated using Equation (4).

$$P_{SO} = P_o \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{\left[1+\left(\frac{Z}{0.048}\right)^2\right]\left[1+\left(\frac{Z}{0.32}\right)^2\right]\left[1+\left(\frac{Z}{1.35}\right)^2\right]}} \quad (3)$$

$$Z = \frac{R}{\sqrt[3]{W}} \quad (4)$$

R is the distance between the centre of the explosion and the gauge in m
W is the weight of the TNT explosives in kg.
Z is the scaled distance in m.
P_{SO} is the overpressure in kPa.
P_O is the ambient pressure equal to 101.325 kPa.

Pressure-time history for the 20 kg explosives in the AUTODYN simulation is illustrated in Figure 6. Overpressure is taken as the peak value from the pressure-time history and compared with manual calculations in Table 3. Comparison shows that AUTODYN overpressure value is relatively close to the overpressure values manually calculated.

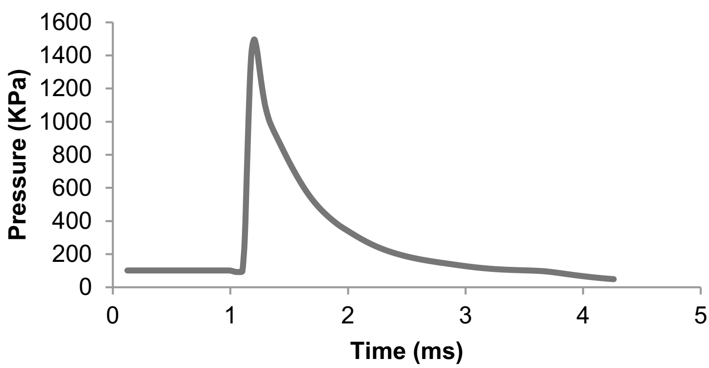

Fig. 6. Pressure-time history from the AUTODYN Model for R = 2.5m and W = 20kg.

Table 3. Overpressure Calculations.

R	***W***	***Z***	***Pso* (kPa)**		
m	**kg**	**m/kg$^{1/3}$**	**Kinney & Graham**	**UFC 3-340-02**	**AUTODYN Model**
2.5	20	0.921	1204	1380	1497

3 Results

From this study, we can notice that the maximum deflection is found in slabs at midspan. Concrete experiences mostly flexural failure at midspan and a combination of flexural and shear failure at the side fixation. The use of PTFE sheets reduces the debris and fragmentation up to 90%, thus decreasing the blast radius and human injuries. Table 4 shows results for maximum fragment propagation (*FP*), approximate fragmentation percentage (*F*), and pressure behind the slabs (*P*). Figures 7 to 13 show the numerical models.

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Table 4. Numerical simulation results.

#	*FP* mm	*F* %	*P* kPa	#	*FP* mm	*F* %	*P* kPa
S1	768.35	100	106.69	S13	143.22	1	105.83
S2	838.37	100	106.43	S14	604.48	75	106.71
S3	844.84	100	106.44	S15	686.92	65	106.65
S4	785.5	100	106.65	S16	552.8	60	106.42
S5	873.58	100	106.85	S17	569.46	50	106.24
S6	757.04	65	106.51	S18	667.2	80	106.62
S7	911.03	60	106.41	S19	576.49	70	106.39
S8	685.73	45.5	106.47	S20	296.81	10	106.04
S9	705.5	40	106.22	S21	168.39	5	105.94
S10	694.46	37.5	106.43	S22	635.32	60	106.53
S11	920.69	30	106.34	S23	378.18	5	106.28
S12	957.92	15	106.22	S24	175.3	1	106.07

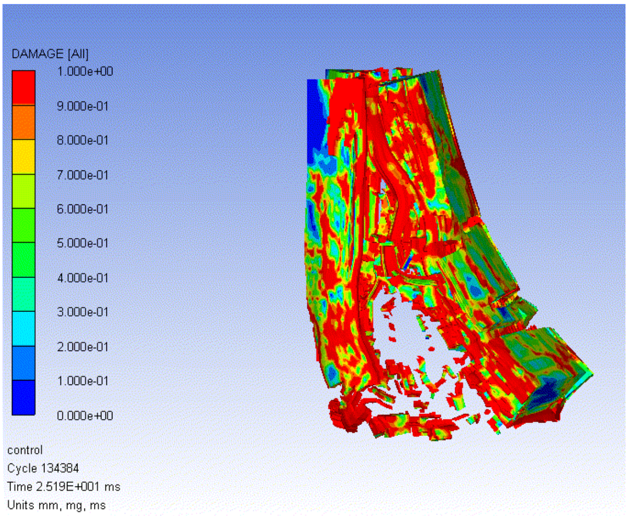


Fig. 7. S1 model, no PTFE sheets and showing the damage.

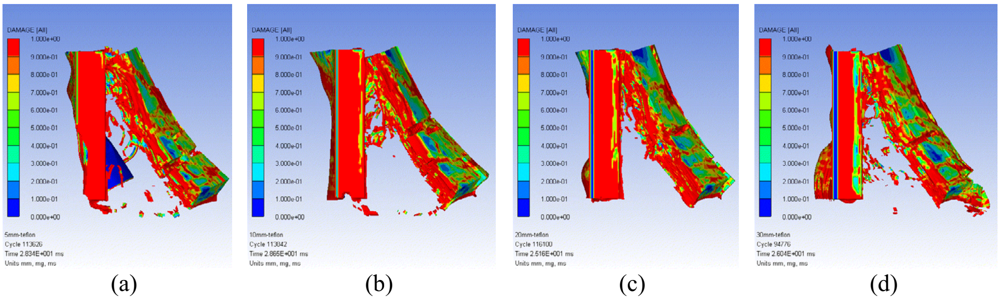
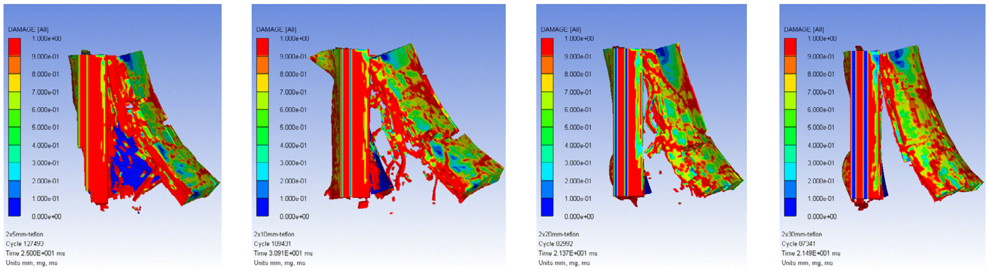
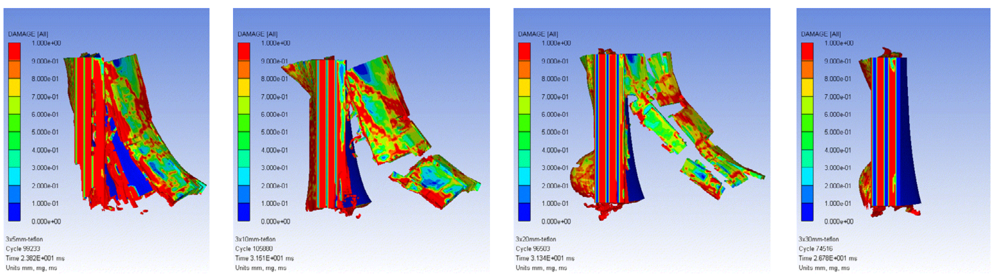


Fig. 8. One PTFE sheet at the front face models showing the damage, (a) S2 model, (b) S3 model, (c) S4 model, (d) S5 model.



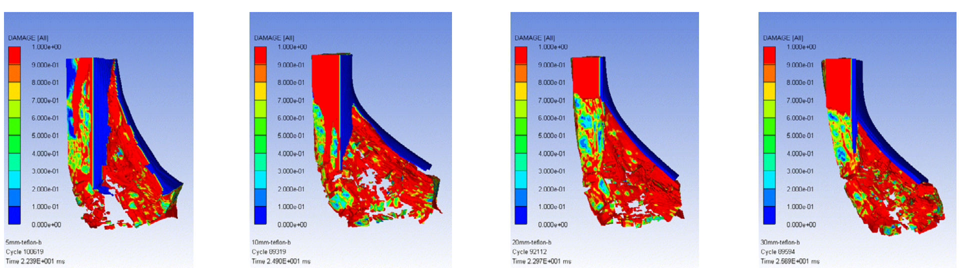
(a) (b) (c) (d)

Fig. 9. Two PTFE sheets at the front face models showing the damage, (a) S6 model, (b) S7 model, (c) S8 model, (d) S9 model.



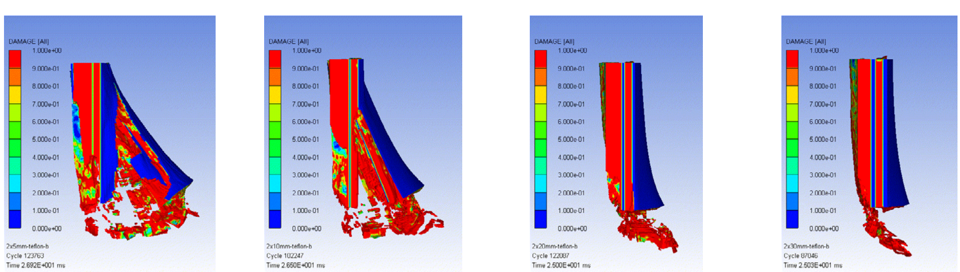
(a) (b) (c) (d)

Fig. 10. Three PTFE sheets at the front face models showing the damage, (a) S10 model, (b) S11 model, (c) S12 model, (d) S13 model.



(a) (b) (c) (d)

Fig. 11. One PTFE sheet at the back face models showing the damage, (a) S14 model, (b) S15 model, (c) S16 model, (d) S17 model.



(a) (b) (c) (d)

Fig. 12. Two PTFE sheets at the back face models showing the damage, (a) S18 model, (b) S19 model, (c) S20 model, (d) S21 model.

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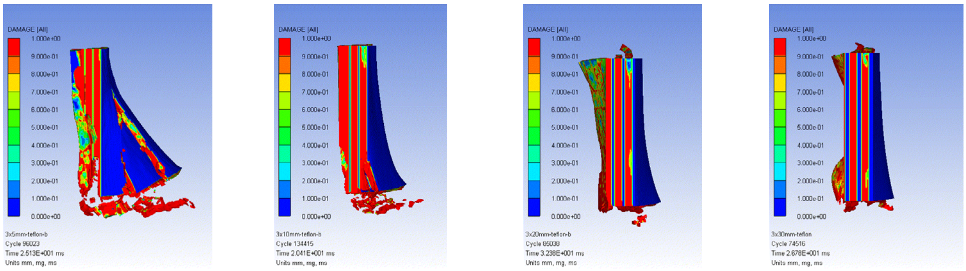

(a) (b) (c) (d)

Fig. 13. Three PTFE sheets at the back face models showing the damage, (a) S22 model, (b) S23 model, (c) S24 model, (d) S13 model.

4 Conclusion

From this study, we can conclude the following:

- Numerical simulation of the blast wave propagation in ANSYS AUTODYN is satisfactory.
- Optimum placement of PTFE sheets is at the back face of the slab using the sandwich configuration.
- Increasing thickness and number of PTFE sheets decreases fragmentation by up to 90%.
- PTFE sheets placed at the front face did not diminish the blast wave pressure.
- PTFE should be used for blast fragmentation protection purposes only and not in the structural design.
- PTFE sheets can be added to new structures or used to protect existing structures.
- Experimental testing should be conducted to verify the results.

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