Numerical Simulation of Normal and Oblique Impact of 7.62 API Projectiles on Mild Steel Protective Plates

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Abstract - *Numerical simulations using the ABAQUS/Explicit finite element code were used to investigate the ballistic resistance of 12 mm thick mild steel plates against 7.62 API projectiles. The incidence angle was varied as 0°, 15°, 30°, 45°, 50°, 57° and 59°.The normal impact for different targets thicknesses (4.7,6,10,12,16,20,25mm)was investigated. The J. and C. model's content parameters were derived from published sources. The numerical results were compared to those obtained in previous studies, in which the projectile's incidence velocities were estimated to be around 820 m/s. The experimental and computational findings have been compared in terms of failure mechanism, residual projectile velocity, and ricochet critical angle. There is a clear connection between the experimental results and the expected outcomes. The target's resistance has been shown to increase as the target's obliquity and thicknesses increases.*

Key Words: *Numerical simulations*, Mild steel, 7.62 AP projectile, Oblique impact, Layered targets.

1. Introduction

From both a civilian and military perspective, there is a great need for defense against small arms and light weapons. Despite this, there are few studies in the open literature that have extensively examined the threat posed by such weapons. The majority of ballistic studies also consider the worst-case situation, namely the normal impact state, in which the angle between the projectile's velocity vector and the target's normal vector is zero. In most real-world situations, though, the bullet will hit the target with a degree of obliquity [1-4].

Numerical models of ballistic impact that are accurate are difficult to come by, particularly where deformable bullets are involved. Several critical components are vulnerable to ballistic impacts, and the ability to run rigorous and validated simulations is critical for predicting the phenomenon and, ultimately, improving the component's strength[5]. Material behavior, target thickness, angle of incidence, nose shape and size of projectile, as well as target configuration, are all factors that can affect the ballistic resistance of metallic plates. For predicting the material behavior of the projectile and mild steel targets, the J. and C. constitutive model was used[6, 7]. The ballistic results thus obtained have been compared with the experiments carried out Gupta and Madhu [1, 8, 9]. The use of realistic material behavior within numerical models (constitutive laws and harm criterion) is needed to obtain reliable results from numerical simulations of extreme loading conditions such as ballistic effect, both in terms of strength model and ductile fracture.

Steels have high absolute strength and stiffness along with high ductility, are less expensive than most other armour materials, and have superior load bearing capacity and formability. As a result, thin plates of ultra-high-strength steels are commonly used in both civil and military ballistic amours, where the alloy chosen is based on the use, ballistic capacity, weight, and price[10].

When impacted by 65-mm long hemi-spherical nosed rods with a diameter of 13 mm and an initial velocity of 1164 m/s, 31.8 mm thick monolithic steel targets experience greater resistance than multi-layered targets of similar thickness, according to a numerical analysis[11]. They found that the weakening of the multi-layered configuration is due to the reduction of bending stiffness in the structure. They also found that the reduction of resistance in multi-layered targets becomes more apparent when the number of plates is increased while keeping the total thickness constant, which has also been observed experimentally in [12] which reported that monolithic steel plates are more effective than multi-layered plates of the same total thickness when impacted by a 7.62-mm projectile with an initial velocity of 826 m/s.

Ballistic tests using high-strength steels against small-arms missiles are generally more costly. As a result, using Abaqus/Explicit numerical simulations, the finite element approach was used to predict the ballistic reaction of a material.

1.1 *Finite Element Modeling*

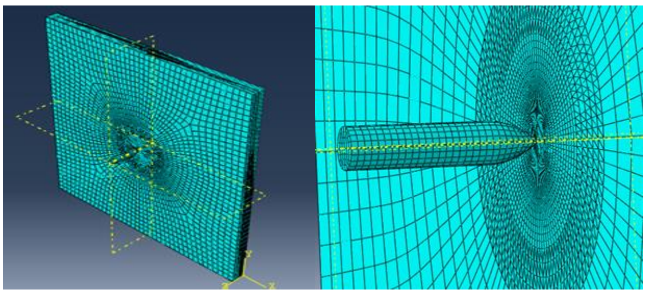
ABAQUS' three-dimensional simulation technique was used to build a finite element representation of the target and projectile. Fig.1 depicts the target and projectile finite element model. The projectile's brass jacket is thought to have stripped away, leaving only the steel core to strike the target. Therefore only the steel core has been modeled for simulating the perforation phenomenon. The J. and C. model calibrated by Niezgoda and Morka [9, 13, 14]for the hardened steel core of 7.62 AP projectile was employed in the present study, see Table 1.

The projectile had a shank diameter of 6.06 mm and a total length of 28.4 mm. The shank and ogival parts were 20.75 and 7.65 mm in weight, respectively. The goal was rendered square, 200 mm x 200 mm, with fixed boundary conditions around the edges. Table 1 shows the material parameters used in the J. and C. constitutive model to predict the ballistic performance of mild steel target properties[6, 7]. The projectile was assigned initial velocities equivalent to those obtained by Gupta and Madhu [1, 8, 9].

The Kinematic contact algorithm was used to model the contact between the projectile and the target. The projectile was regarded as the master, while the target's contact surface was regarded as the slave. In the normal direction, hard contact was established, and friction was considered to be negligible in the tangential direction. The projectile was computed using hexahedral elements of constant size of 1 mm3.

The effect of the projectile's mesh sensitivity is not discussed in this article. The mesh sensitivity in the target was investigated by changing the element size in the impact area to 0.8, 0.6, 0.2, and 0.1 mm3, corresponding to 15, 20, 60, and 120 items at the target thickness. The projectile was impacted normally at an incidence velocity 818 m/s on 12 mm thick target and the residual velocity was found to be 672, 670, 664.8 and 661.1 m/s respectively.

The size of element was therefore considered to be 0.2 mm3 and the aspect ratio unity in all the simulations. Away from the impact region, however, the size of element was slightly increased keeping the aspect ratio unity. Three planar zones were identified with diameter 10, 30 and 50 mm. The element size was kept 0.2, 1.0 and 2.0 mm3 respectively. The compatibility between the varying sizes of elements was maintained using the tetrahedral elements in the transition zones. In order to vary the angle of incidence, the target was rotated about its central axis keeping the axis of projectile horizontal.



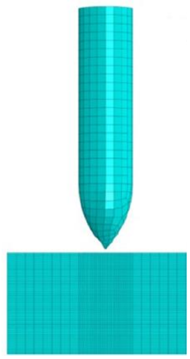


Fig -1: Proj. And target mesh

Table-1: Material parameters of mild steel target and projectile.

Description	Notations	Target Material	Projectile Material
Modulus of elasticity	E (N/m2)	203e9	202e9
Poisson's ratio	ν	0.33	0.32
Density	ρ (Kg/m3)	7850	7850
Yield stress constant	A (N/m2)	304.33e6	2700e6
Strain hardening constant	B (N/m2)	422.007e6	211e6
	n	0.345	0.065
Viscous effect	C	0.0156	0.005
Thermal softening constant	m	0.87	1.17
Reference strain rate	$\dot{\varepsilon}_0$	0.0001 s^{-1}	0.0001 s^{-1}
Melting temperature	θ_{melt} (K)	1800	1800
Transition temperature	$\theta_{transition}$ (K)	293	293
Fracture strain constant	D_1	0.1152	0.4
	D_2	1.0116	0
	D_3	-1.7684	0
	D_4	-0.05279	0
	D_5	0.5262	0

2. *Results and Discussion*

Finite element simulations using the ABAQUS/Explicit finite element code were used to investigate the ballistic efficiency of 12 mm thick mild steel targets against 7.62 AP projectiles at various angles of incidence. For predicting the target's material behavior, the J. and C. constitutive model was used[6, 7].

The ballistic results obtained so far have been similar to those obtained by Gupta and Madhu [1, 8, 9]. The projectile's occurrence velocities is estimated to be between 800 and 850 m/s. The projectile's residual velocity reduced as the angle of incidence increased. Table-2 shows that the expected residual velocities are very similar to their actual values. At a 30° angle of incidence, the maximum difference between the actual and predicted residual velocity was found to be 1.8%. The true residual velocity was 598.0 m/s, vs 587.6 m/s expected. The 7.62 AP projectile failed to enlarge the target fully.

Experiments have also shown the presence of petals on the front surface and a bulge on the back surface as shown in Figs- 2 and 3. The failure mode, including the size of the hole, petalling at the front, and the bulge at the back surface, was correctly predicted by computational simulations. The hole that was created in the objective was significantly larger on the front surface than it was on the back. The front and back surfaces of the target's hole measured 9.6 and 9.0 mm, respectively.

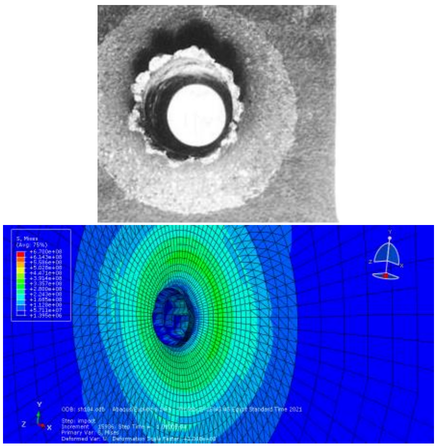


Fig-2: Front side for angle (0)

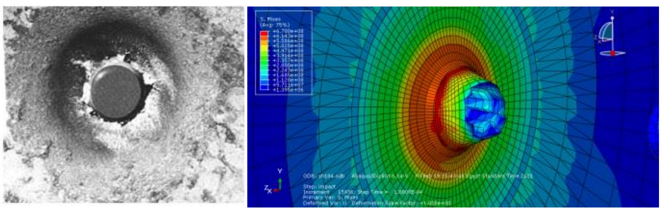
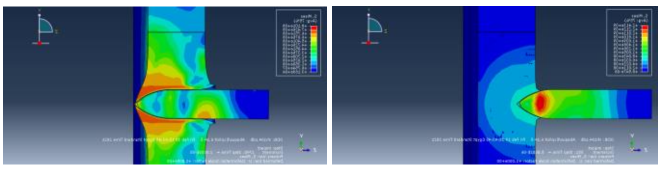


Fig-3: Rear side for angle (0)



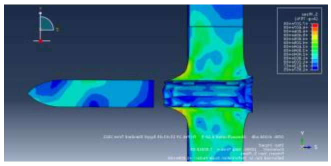


Fig -4: Steps of penetration for angle (0)

Using numerical simulations, a similar difference in hole size was predicted. The hole's estimated diameters at the front and back surfaces for gubta were 9.32 and 7.66 mm, respectively and for simulation were 9.3 and 8.5mm, respectively. The experimental findings indicated perforation of a 12 mm thick target with a residual velocity of 368.9m/s at 57° obliquity. The numerical findings, however, predicted that the projectile would ricochet in the target at the same angle of obliquity.

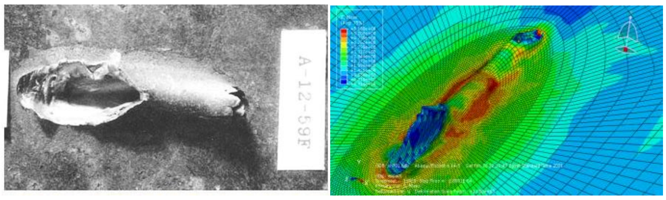


Fig-5: Ricochet at angle (59)

The projectile penetrated the target and at the same time deviated from its central axis due to the component of resisting force normal to target surface. Because of the high obliquity, the resistance usual to the target surface deviated the projectile, and instead of penetrating into thickness, the projectile began penetrating in the target's plane and ricochet. It's also important to note that projectile ricochet at 59° obliquity.

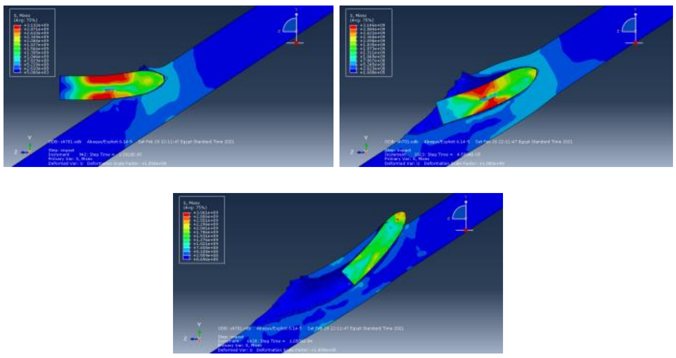


Fig -6: Steps of penetration for angle (59)

Table -2: Resistance of targets against varying obliquity

Oblique angle	Experimental results		Numerical results for Senthil and Gupta	Numerical results
	Impact velocity (m/s)	Residual velocity (m/s)	Residual velocity (m/s)	
00	818.0	661.5	658.42	670
15	842.7	671.6	677.73	672.8
30	801.8	598.0	603.97	587.6
45	808.0	555.3	515.82	554
50	808.0	-	409.59	500
57	809.0	368.9	0.0	305.3
59	815.3	Ricochet	Ricochet	Ricochet

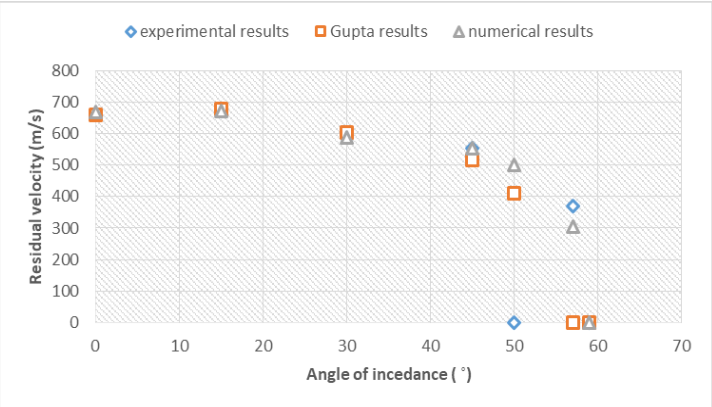


Fig -7: Residual velocity of projectile function of obliquity

The actual and predicted deformation of the target as a result of projectile ricochet has been compared in Fig- 5,6. While sliding over the target surface, the projectile reported an elliptical deformation pattern and material erosion. Numerical models have projected a precise sequence of deformation and material erosion.

2.1 *Effect of varying thicknesses of target on ballistic resistance*

Table-3 shows the experimental and numerical findings versus normal incidence for 4.7, 6, 10, 12, 16, 20, and 25 mm thick targets. The velocity fall was found to be almost linear in relation to the thickness of the target. The target's resistance has been shown to grow approximately linearly with the target's thickness (see Figure 8).

With a margin of error of 2%, the residual projectile velocity for 4.7 and 6 mm thick targets was estimated. For 10- and 12-mm-thick targets, the predicted and observed residual projectile velocity were found to be identical. At 16 mm thick target, a maximum deviation of 8% was found between the actual and predicted residual velocities.

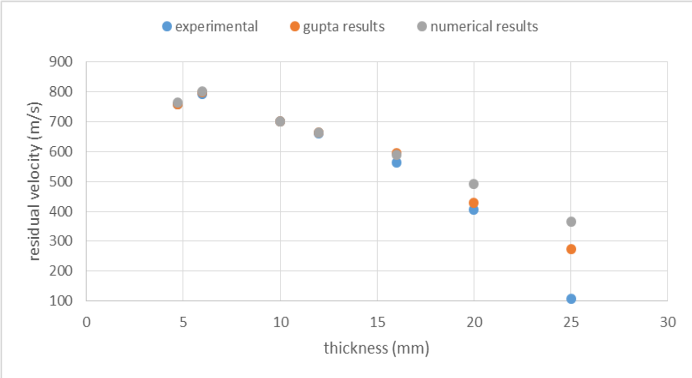


Fig- 8: Residual velocity of projectile function of thickness

Table- 3: Resistance of targets against varying obliquity

Thickness of target (mm)	Experimental results		Numerical results for Senthil and Gupta	Numerical results
	Impact velocity (m/s)	Residual velocity (m/s)	Residual velocity (m/s)	
4.7	821	758.6	757.2	765
6	866.3	792.2	799.79	801
10	827.5	702.2	701.4	700.3
12	818	661.5	662.42	665
16	819.7	562	594.09	590
20	820.6	404.8	429.15	490.75
25	842.3	107.6	272.62	365

At 20 and 25 mm thick targets, a maximum deviation of 50% and140% was found between the actual and predicted residual velocities. It's possible that the experimental residual velocity was not correctly recorded. The 7.62 AP bullet was unable to penetrate the target due to hole expansion. Experiments have also revealed the development of petals on the front surface and a protrusion on the back surface.

The failure mode, including the size of the hole, petalling at the front, and the bulging at the back, was precisely anticipated using numerical simulations. The hole that was created in the target was slightly larger in size in the front than it was at the back.

The target failed due to ductile hole expansion, which resulted in a visible circular hole and a bulge on the front surface. The hole on the front surface of the target was bigger than the hole on the back surface.

3. CONCLUSION

On 12 mm thick mild steel targets, numerical tests were conducted against 7.62 AP projectiles at various angles of incidence. The effect of angle of incidence was investigated, and the findings were compared to existing data to draw the following conclusions. The residual projectile velocities, critical angle of ricochet, and target failure mechanism were correctly predicted by simulations at various angles of incidence and thicknesses. The target's resistance has been shown to increase as the target's obliquity and thickness increases.

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