REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF NANOTECHNOLOGY AND ENGINEERING SCIENCES

# ANALYSIS OF OBLIQUE IMPACT BEHAVIOR FOR AL-LDPE-AL HYBRID MATERIALS

FURKAN NURİ KARAOĞLU
NANOTECHNOLOGY AND ENGINEERING SCIENCES

ADANA 2020

**REPUBLIC OF TURKEY**
**ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY**

**GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**
**DEPARTMENT OF NANOTECHNOLOGY AND ENGINEERING SCIENCES**

# ANALYSIS OF OBLIQUE IMPACT BEHAVIOR FOR AL-LDPE-AL HYBRID MATERIALS

**FURKAN NURİ KARAOĞLU**
**NANOTECHNOLOGY AND ENGINEERING SCIENCES**

**SUPERVISOR**
**Asst. Prof. Dr. AHMET REFAH TORUN**

**ADANA 2020**

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Furkan Nuri KARAOĞLU

# ABSTRACT

**ANALYSIS OF OBLIQUE IMPACT BEHAVIOR FOR AL-LDPE-AL HYBRID MATERIALS**

Furkan Nuri KARAOĞLU
Department of Engineering Science and Nano Technology Engineering
Supervisor: Asst. Prof. Dr. AHMET REFAH TORUN
May 2020, 43 pages

Strength tests have been carried out on the Al-LDPE-Al composite panel used in the architectural field with a different approach to the weight and durability, which is one of the problems of armor technologies from the past to the present. These tests were examined in terms of the oblique impact and tested on layers. Until complete protection is achieved, the accuracy of each layer at different angles and to different regions is performed, its accuracy is compared with simulation.

Rifle bullets were used in real shots. The reason for using the rifle is to increase the hit rate to the desired angle and point. 9 mm bullet, which is commonly used in simulation experiments, was used. Rifle bullets and pistol bullets have similar characteristics, so 9 mm bullets impacted at simulations.

The normal effect and the oblique effect were compared with different layers at 0˚, 30˚, and 60˚ angles. The sloping effect has been observed to provide more resistance than the steep effect. In experiments with Al-LDPE-Al material, it has been observed that 7-layer material provides full protection. When the results that are consistent with the simulation results are examined, it is seen that the oblique effect provides more resistance than the normal effect.

**Keywords:** Oblique impact, Ballistic, Composite Material, Al-LDPE-Al

# ÖZET

## AL-LDPE-AL HİBRİT MALZEMELER İÇİN EĞİK ETKİ DAVRANIŞININ ANALİZİ

Furkan Nuri KARAOĞLU
Mühendislik Bilimleri ve Nano Teknoloji Mühendisliği Anabilim Dalı
Danışman: Asst. Prof. Dr. AHMET REFAH TORUN
Mayıs 2020, 43 sayfa

Geçmişten günümüze kadar gelen zırh teknolojilerinin problemlerinden olan ağırlık ve sağlamlık üzerine, farklı bir yaklaşım ile mimari alanda kullanılan Al-LDPE-Al kompozit paneli üzerine sağlamlık testleri gerçekleştirilmiştir. Bu testleri eğik etki açısından incelenmesi yapılarak, katmanlar üzerinde denenmiştir. Tam koruma sağlanana kadar her katmana farklı açılarda ve farklı bölgelere gerçek atışlar gerçekleştirilerek, simulasyon ile doğruluğu kıyaslanmıştır.

Gerçek atışlarda tüfek mermisi kullanılmıştır. Tüfek kullanılmasının sebebi istenilen açı ve noktaya isabet oranını arttırmaktır. Simulasyon deneylerinde, yaygın olarak kullanılan 9 mm mermi kullanılmıştır. Tüfek mermisi ile 9mm tabanca mermisinin benzer özellikleri olduğu için simulasyonlarda 9 mm tabanca mermisi tercih edilmiştir.

Farklı katmanlara 0˚, 30˚ ve 60˚ açılar kullanılarak, normal etki ile eğimli etki kıyaslanmıştır. Eğimli etkinin dik etkiye göre daha fazla direnç sağladığı gözlemlenmiştir. Al-LDPE-Al malzeme ile yapılan denemelerde 7 katmanlı malzemenin tam koruma sağladığı gözlemlenmiştir. Simulasyon sonuçları ile gerçek deney sonuçlarının tutarlı çıkmasıyla eğik etkinin, normal etkiye göre daha fazla direnç sağladığı doğrulanmıştır.

**Anahtar Kelimeler:** Eğik etki, Balistik, Kompozit materyal, Al-LDPE-Al

*For my mother-in-law Gülşen and father-in-law Hayati and*

*My mother Sultan and my father Abbas*

# ACKNOWLEDGEMENTS

I would like to express my gratitude to my consultant, Asst. Prof. Dr. Ahmet Refah TORUN, for the valuable time and guidance he spent during our work.

I would also like to thanks Şeyma Helin KAYA for fruitful cooperation.

I extend my thanks to my wife Ayşegül KARAOĞLU, who supported my work with all her heart.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# NOMENCLATURE

| | |
|---|---|
| Al | : Aluminum |
| LDPE | : Low Density Polyethylene |
| $E_i$ | : Initial energy |
| $E_f$ | : Final energy |
| $E_{abs}$ | : Absorbed energy |
| $m$ | : Mass of bullet |
| $V$ | : Velocity of bullet |
| Fig | : Figure |
| PVDF | : Polyvinylidene Fluoride |
| Si | : Silisium |
| Fe | : Iron |
| Cu | : Copper |
| Zn | : Zinc |
| HDPE | : High Density Polyethylene |

# 1. INTRODUCTION

The first armors were made of leather. Later, monolithic steel armor was produced for more durability. Although this situation is suitable as robustness, it is a negative situation in terms of weight. Therefore, instead of monolithic steel, the armor material consisting of different layers may be lighter in the same strength. [5,8] It has been determined that composite materials provide better protection than monolithic materials.[10] As a result, multi-layer composite materials were observed to be more effective than the materials in monolithic structure.

In this study, resistance tests of armor material were carried out by using composite material Al-LDPE-Al. This material is generally used architecturally for exterior cladding of buildings. Tests were made with low density polyethylene coated with aluminum from the 3003 Series. After choosing material for armor, projectile selection was made. This selection was made based on the bullet type of the most used pistols. Simulations made according to 9mm bullets have been proven with 36 caliber real condition tests. The reason for using 36 caliber bullets in real condition tests is that the 36 caliber bullet is the closest to 9mm pistol bullets in terms of size and weight. The average hit rate is higher with 36-caliber bullet that can be fired with a rifle. The rifle was used to hit the desired point in 5 m shots. The rifle is more suitable for real experiments, as the barrel length increases, the hit rate increases. The consistency of the results was tested with the results obtained from the rifle and the commercial software program, which was solved by the finite element method. In these results, our expectation was that the oblique effect could resist more than the perpendicular effect. The most important reason for examining the oblique effect is the low probability of projectile perpendicular under real conditions.

When appropriate results are obtained in the tests made with the selected material, the potential of armor material will be tested with recycled Al-LDPE-Al. Thus, a material that is lighter and more cost-effective and has a high resistance can be applied for armor.

# 2. LITERATURE REVIEW

## 2.1. The Armor History

In ancient times, Sumerians produced vests and helmets using leather (2800 B.C.). 1300 years later, Mystics used leather on shields and armor. Although archaeologists could not reach these armor remains because they are made of organic materials, they were determined according to the pictures that can be solved from the Egyptian hieroglyphs. These organic materials were generally used as wood and leather. Akkadians reported to be the first to use metal helmets in wars. It was later determined that it was strengthened with small metal plates on boiled leather armor. The Assyrians were the best armor producers. They reinforced their armor using wool wood iron felt and bronze. According to the findings, the helmet used by the Greeks was made of bronze and it was completely in a head covering, Figure 2.1.

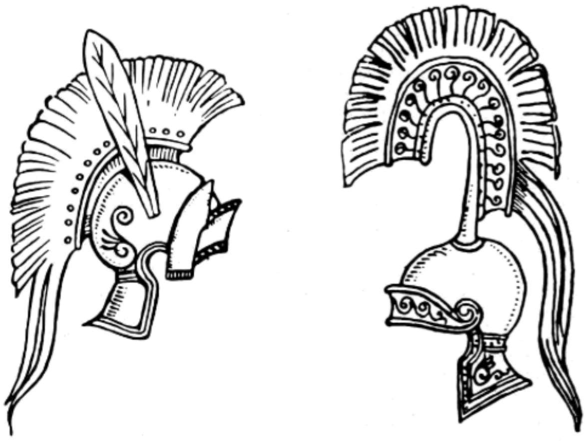

Figure 2.1: Greek helmet made of bronze, without cheek part [34]

The Romans used iron as armor material, but oxidation and weight of iron became a negative problem. After the oxidation of iron, armor consisting of rear and front parts were produced in laminated form of seven layers of steel. Figure 2.2 shows Roman laminated armor.

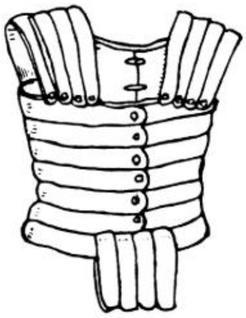

Figure 2.2: Roman laminated steel armor [34]

The armor has a body-hugging structure. This armor has a suitable weight distribution consisting of 40 plates. it provided easier movement with proper jointing. The protection of steel plates and iron armor was appropriate, but its weight and reduced mobility caused a problem. This problem was tried to be solved with chain armor. It was more comfortable than other types of armor. However, chain armor could not provide full protection. Most documents showed the types of armors that primarily leather, leatherwood, leather iron, iron, steel sheet, and chain. [1-7,34].

### 2.2. Modern Armor

It was designed according to the probability of injury zones in a battle when designing modern armors. When World War 2 and the Korean War were analysed. The wound zones are as seen in table 2.1.

Table 2.1: The percentage of the wound areas [34]

| The Part of The Body | Percentage |
|---|---|
| Head and Neck | 12 % |
| Thorax | 16 % |
| Abdomen | 11 % |
| Upper Limbs | 22 % |
| Lower Limbs | 39 % |

The number of injuries could have decreased by 74% if these analyzes were applied prior to the World War 2 and protection was provided. Similarly, it could have decreased by 70% in the Korean War. [34]

Work has been done to provide lightness and flexibility besides reinforcements in protection zones. In order to provide more movement opportunities, tests on running, climbing and aiming were made. As seen in Figure 2.3, modern armor was made based on the changes of the lines determined on the model.[1-7,34]

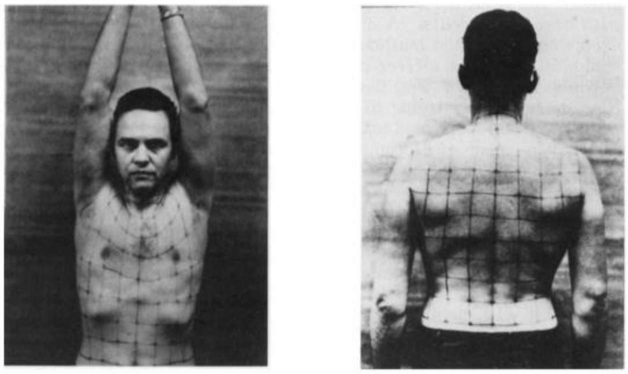

Figure 2.3: The test mannequin front and back view [34]

Using anatomy to reduce pressure on the body. Pressure on bones and muscles is reduced. Thus, the mobility has been increased.

First of all, the steel armor was placed in the jackets and modern armors were created.

Figure 2.4: The Modern vest for more protection and more comfort [34]

Modern vest (Figure 2.4), which are about 3.9 kg, have been studied on comfort, lightness and durability. With the study on comfort, the pressures on the human body were tested (Figure 2.5). Different composite materials were studied for lightness and durability.[34]

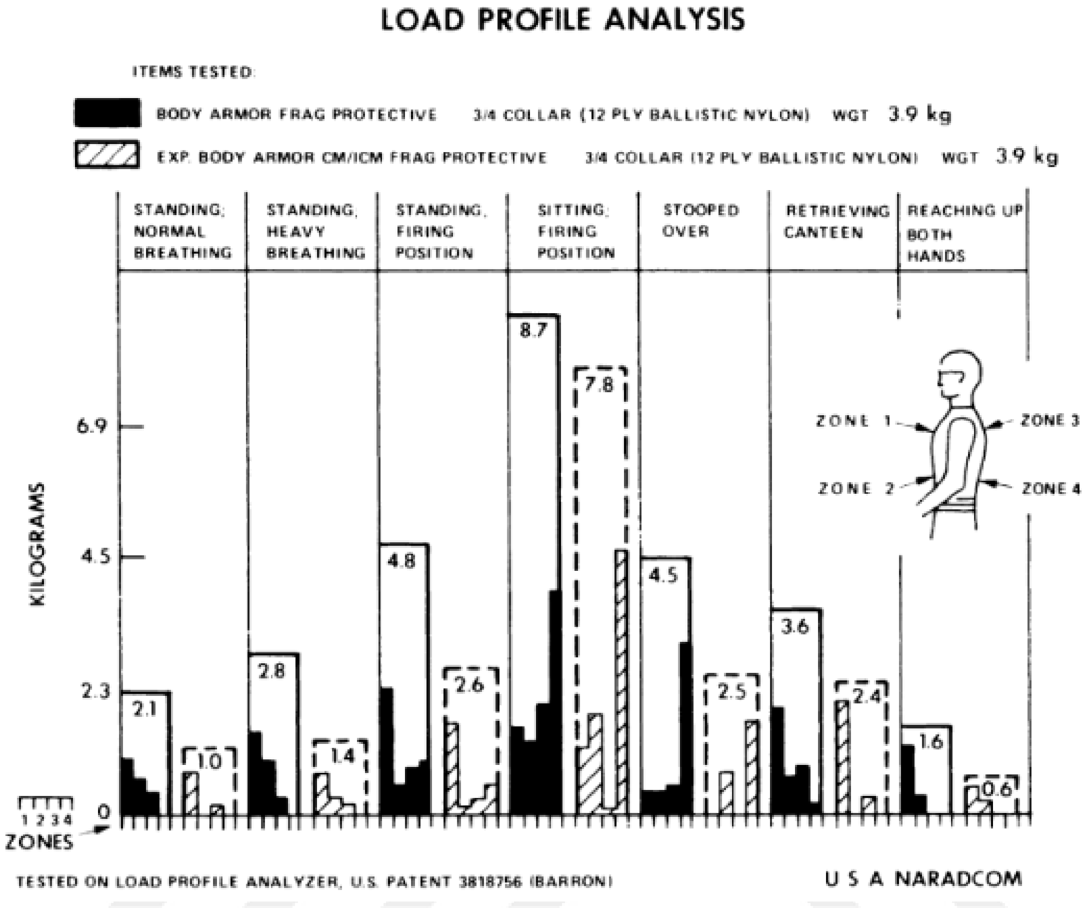


Figure 2.5: The pressure of human body for different situations [34]

### 2.3. The Impact Model on Composite

Impacts can be orthogonal or oblique to the surface. If the angle is 0 then this impact is normal or orthogonal but the angle changes, it is oblique impact. In oblique impact, the distance the projectile takes is longer than the normal impact. It also affects the target's ballistic resistance, target thickness, projectile speed, and shape [7,8,35-44]

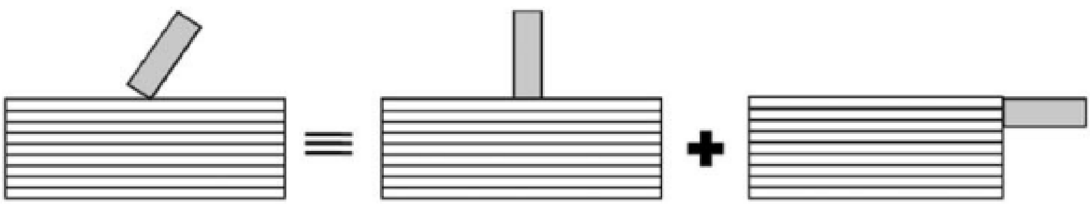

Figure 2.6: Lateral and orthogonal impact to define the oblique impact [35-44]

### 2.3.1. Normal Impact

During the projectile impact, the upper layers of the target try to make compress the lower layers. Stopping the projectile results in compression of the substrate. Energy damping mechanisms are determined in 2 ways. One is stuck in the first layer struck by the bullet and the other in the 2nd layer.[35-44]

Since the projectile surface will affect less area in perpendicular impact, the interception energy must be higher. Lower energy is required for interception as this surface increases in oblique impact.

### 2.3.2. Lateral Impact

Lateral is the impact between layers in the composite target. The target will be compressed from the side to absorb energy. Separation between layers may occur in lateral impact. Prevention of this separation depends on the friction force between the composite layers.[35-44]

### 2.3.3. Oblique Impact

Another important effect in ballistic protection is oblique impact. In the studies performed, no significant observation up to an angle of 30 degrees was provided, but the protection increased more due to increased kinetic energy absorption at higher angles.[19-21]. It was also observed that the oblique effect caused structural distortions as a negative aspect. For this reason, it is very important to investigate the oblique effect for the aviation and automotive industry where composite materials are used. [22-29] when literature review is done, we can see that there are many studies on curvature. One of these studies shows that the bullet changes direction as the slope and thickness increase.[30,31] An armor that can be formed with aluminum and low density polyethylene can prevent oblique impact with lightness and robustness.

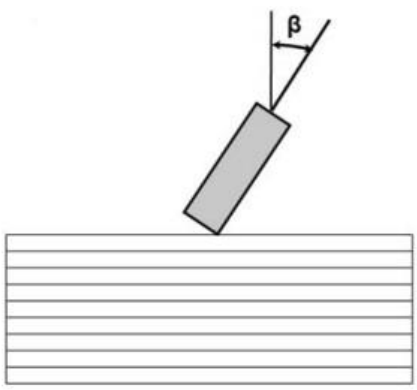


Figure 2.7: Oblique impact on composite [34]

We examine the effect of a projectile β˚ angle on the composite. The results caused by the oblique effect are observed with Figure (2.7-2.12).

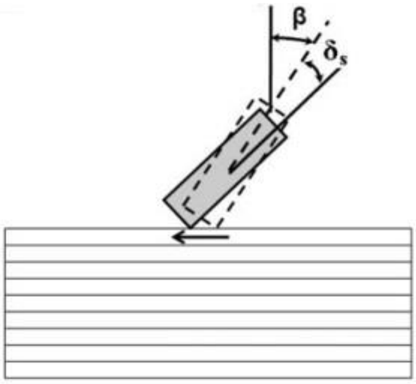


Figure 2.8: Deflection with the first effect [34]

There may be a deflection of X degrees by the effect of the first impact. However, perforation begins to occur after this deviation.

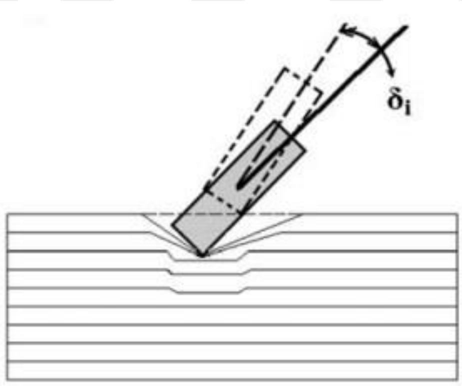


Figure 2.9: The first deflection is completed and the bullet begins to disrupt the layers [34]

The layers begin to deteriorate at this stage and absorb the projectile energy, to continue until the bullet loses its energy and stops at the point where its energy is not enough for the puncture energy.

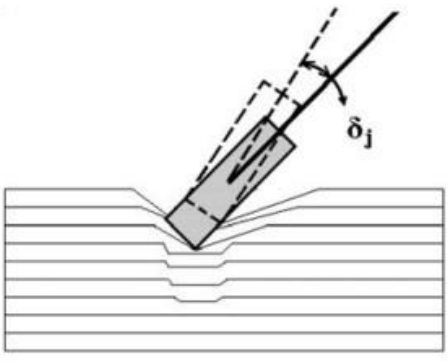


Figure 2.10: Impact proceeds to sub-layers [34]

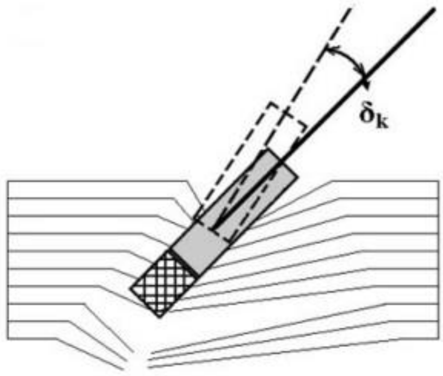


Figure 2.11: Impact proceeds to sub-layers [34]

With the pushing effect of the bullet, breaks in the lower layers occur. For this stage the bullet can stop at this stage. It depends on the energy of the bullet. If the bullet energy is more than the composite after this stage, full puncture occurs as seen in the Figure 2.12.

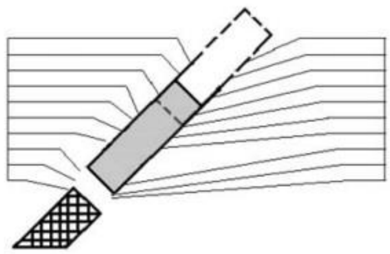

Figure 2.12: Full puncture [34]

In this model, oblique impact stages are shown.[Figure 7-9] The bullet has been accepted as flat tip. It is assumed that the projectile speed and slope are always constant. It progresses by losing some of the energy at each stage with friction between composite and projectile. [35-44]

In this study, we only the target thickness and changed the target angle. Target thickness change was made only on Aluminum for composite, so it was tested on the composite target. A multi-layered composite target may exhibit greater resistance than the monolithic layer for a projectile. J. G. Hetherington and P.F. Lemieux's latest studies have shown that layered composites are more durable than monolithic targets. In layered plates, the pressure affecting the bullet increases and causes the bullet to slow down and flatten.[9-11] The target may be in the spaced or adjacent form. Spaced targets were observed to be weaker than adjacent targets.[12-18,35-44]

# 3. MATERIALS AND METHODS

## 3.1. Test Materials

In this study, Al-LDPE-Al is used as composite material. Aluminium Composite Panel (Al-LDPE-Al) is building material which is formed layer of fill between two aluminum plates and the core .Aluminium composite panels consist of two layer of polyethylene building cladding systems. Nowadays, it has an area of utilization and has continued to spread with an increasing trend as the day goes on in advertising, promotion, and a wide range of decorative applications. As can be seen in Figure 3.1, Aluminum layers are 0.4 mm low density polyethylene layer, 3.2 mm thick.

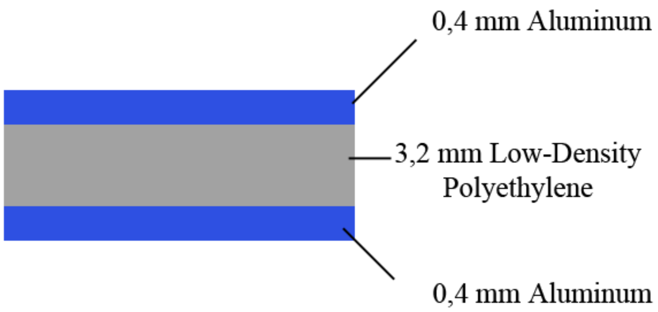


Figure 3.1: The Layer of composite module

Al-LDPE-Al outer coating is often used in architecture as it can be coated with polyvinylidene fluoride (PVDF). This Composite Panel becomes more resistant to external factors with PVDF. As seen in the Figure 3.1, the panel of 4 mm thickness is not enough for ballistic stop. For this, tests were carried out on 1 layer composite and 5 layers composite.

See the chemical properties of the aluminum layer in table 1. The aluminum layer is not pure aluminum and its chemical properties have changed with the other elements in it. This type of aluminum is called 3003 aluminum alloy.

Table 3.1: EN AW 3003 Aluminum Composite outer shells chemical properties

| **Si** | **Fe** | **Cu** | **Mn** | **Zn** | **Al** |
|---|---|---|---|---|---|
| **0.6** | 0.7 | 0.05-0.2 | 1.0-1.5 | 0.1 | Remaining |

Mechanical properties for Al-LDPE-Al are shown in table 3.2. Using these mechanical features, the impact effect is simulated by applying Abaqus Explicit modeling.

Table 3.2: Mechanical properties of the layers of Aluminum composite panel

| ***Materials*** | **3003 aluminum** | **Low density polyethylene** |
|---|---|---|
| Young's modulus | 75 (GPa) | 0.30 (GPa) |
| Poisson's ration | 0.33 | 0.45 |
| Yield stress | 125 (MPa) | 10 (MPa) |
| Tensile strength | 130 (MPa) | 14 (MPa) |

Instead of pressurized ballistic containers, these tests used real bullets. The target was tested with real-life conditions in an open field instead of laboratory conditions with 36-caliber bullets. The target was placed at a distance of 5 m. Open-air conditions had 27 degrees and 64% humidity. The rifle barrel is 68 cm and the bullet dimensions are as shown in the Figure 3.2. Projectile weight is 7,4 g.

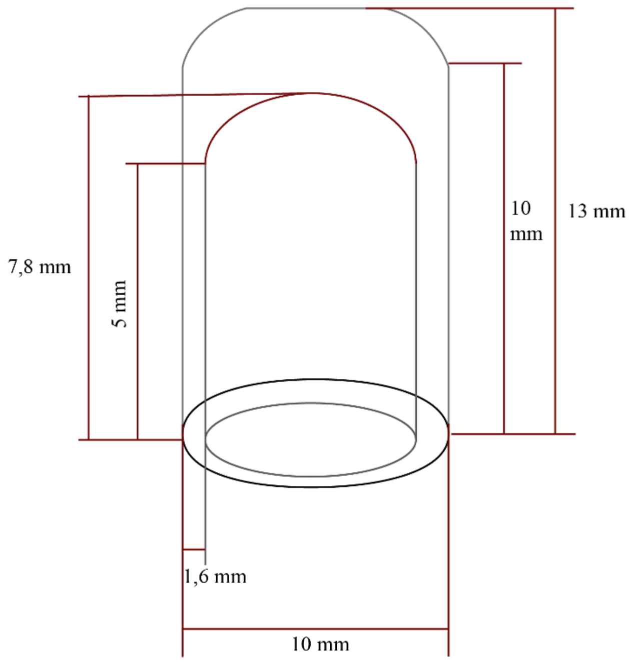


Figure 3.2: The 36 - Caliber projectile of rifle

The composite panel dimensions for the test sample are set as a square with 250 mm side lengths. The open area of the plate, which is fixed with a steel holder, is a circle with a diameter of 200 mm. As shown in Figure 3.3, many test repetitions are possible with this holder. After each test, the sample can be changed easily and has a compressible structure with new sample. The important parameter is the distance of the puncture point to the center.

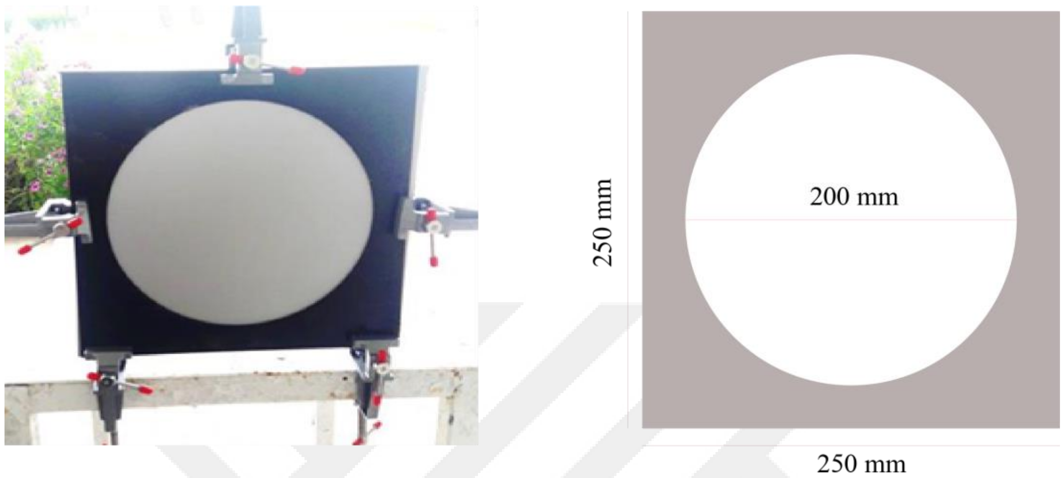


Figure 3.3: The sample holder

Measurements were made with the velocimeter used to measure the inlet and outlet velocities of the bullets.As seen Figure 3.4, the principle of operation of this measuring device is the projectile velocity obtained by multiplying the time between the first probes passing through the last probes and the distance between the probes. It was measured 5 times without target for bullet velocity measurement. Then the target was placed and a velocimeter was placed behind it, so the projectile output speed was measured.

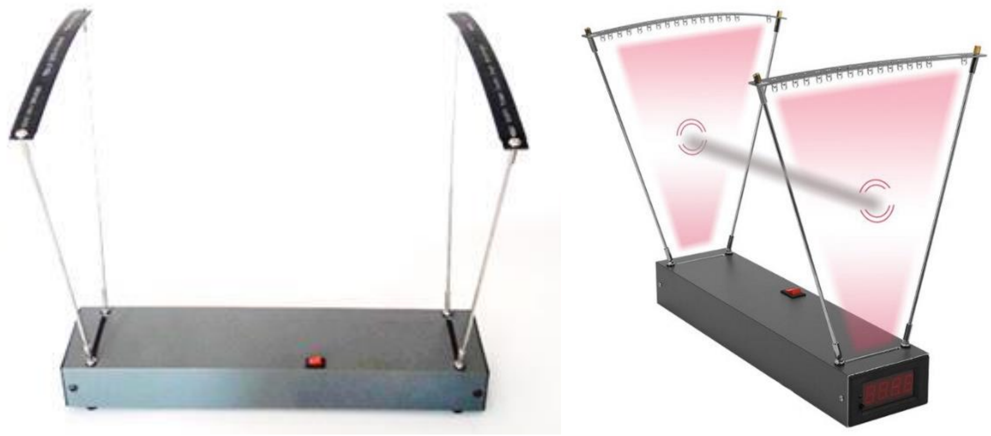

Figure 3.4: The velocimeter device for measuring penetration speed and the exit velocity.

The measured projectile speed was taken as an average of 479 m / s. kinetic energy calculations will be calculated according to this speed. Bullet weight is 7.4 g. Numerical modeling of the bullet was done to see the result of the oblique effect of the 9 mm pistol bullet on Al-LDPE-Al

(Figure: 3.5). 9mm projectile weight is 7,1 g. The speed of 9mm bullet is 335 m/s. Rifle bullet and pistol bullet energies calculated follow.

$$E = \frac{1}{2} m v^2$$

$$\mathrm{E}_{rifle} = 0{,}5 * 7{,}4 * 479^2 = 848{,}9\ J$$

$$\mathrm{E}_{Pistol} = 0{,}5 * 7{,}1 * 335^2 = 398{,}3\ J$$

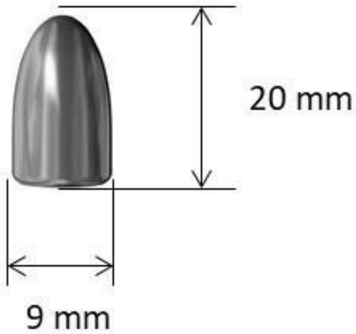


Figure 3.5: 9mm pistol projectile

## 3.2. Testing Method

A total of 33 different impact were tested in this study. Together with these tests, 33 different simulations were performed using finite analysis method. Projectiles were sent at ±30˚, ±60˚ and perpendicular to the centers of 5 different types of targets. In addition, impact effects were performed at distances of center, 40 cm and 80 cm at stucked 5 layers, equivalent 5 and a single layer to study center edge effect.

In real environment tests, a target of 200 mm diameter was used. In the finite analysis method, a target of 100 mm diameter was preferred. All physical properties of materials for analysis are defined on Abaqus Explicit.

Analysis was done with an explicit solution. Tested of 100 mm radius Al-LDPE-Al composites. Tested materials are single layer 0.4-3.2-0.4 mm Al-LDPE-Al, respectively. 3 adjacent Al-LDP-Al, each layer is 4mm and the total layer thickness is 12mm. 5 adjacent Al-LDPE-Al, each layer is 4mm and the total layer thickness is 20mm. 7 adjacent Al-LDPE-Al, each layer is 4mm and the total layer is 28mm. Finally, materials with a thickness of 8.4-3.2-8.4 mm and a total thickness of 20 mm were examined. In the Table 3.3 below, a list of the targets with finite analysis is given.

Table 3.3: The targets thickness

| Layer | Layer Thickness | Total Thickness | |
|---|---|---|---|
| **Single layer** | 0,4 -3,2 -0,4 mm | 4 mm | Figure 3.6 |
| **3 Layer** | 0,4 -3,2 -0,4 mm | 12 mm | Figure 3.7 |
| **Stacked 5 Layer** | 0,4 -3,2 -0,4 mm | 20 mm | Figure 3.8 |
| **Equivalent 5 Layer** | 8,4–3,2 –8,4 mm | 20 mm | Figure 3.9 |
| **7 Layer** | 0,4 -3,2 -0,4 mm | 28 mm | Figure 3.10 |

Impact was applied to the modeled targets at angles of 0˚, 30˚ and 60˚. For single layer, stacked 5 layer, and equivalent 5 layer, collisions were made not only in the center but also in areas 40 and 80 mm from the center.

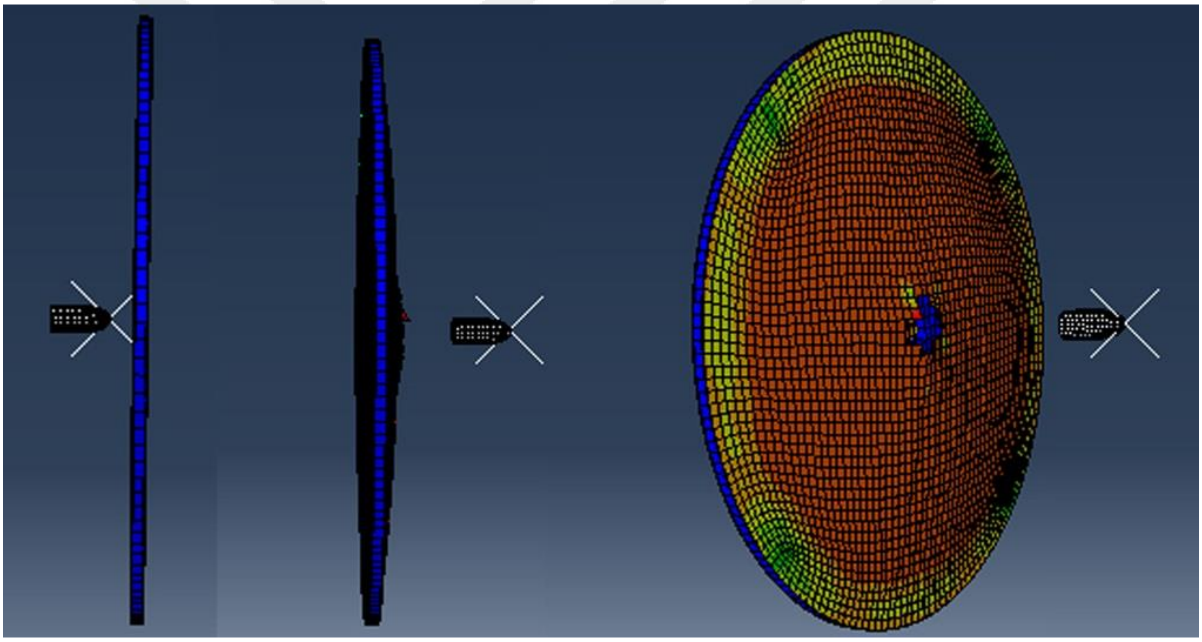

Figure 3.6: Single layer Al-LDPE-Al orthogonal impact.

As a result of the orthogonal impact effect for the single-layer composite panel, the bullet entered at a speed of 335 m / s. The measured ascent speed is 304.9 m / s. Input energy and output energy are calculated below. The absorbed energy is the difference of input energy and output energy.

$$E = 0,5 * m * V^2$$

$$E_i = 0,5 * m * V^2 = 0,5 * 7,1 * 335^2 = 398,39\,J$$

$$E_f = 0,5 * m * V^2 = 0,5 * 7,1 * 304,9^2 = 339,02\,J$$

$$E_{Abs} = E_i - E_f = 398,39 - 339,02 = 59,37\,J$$

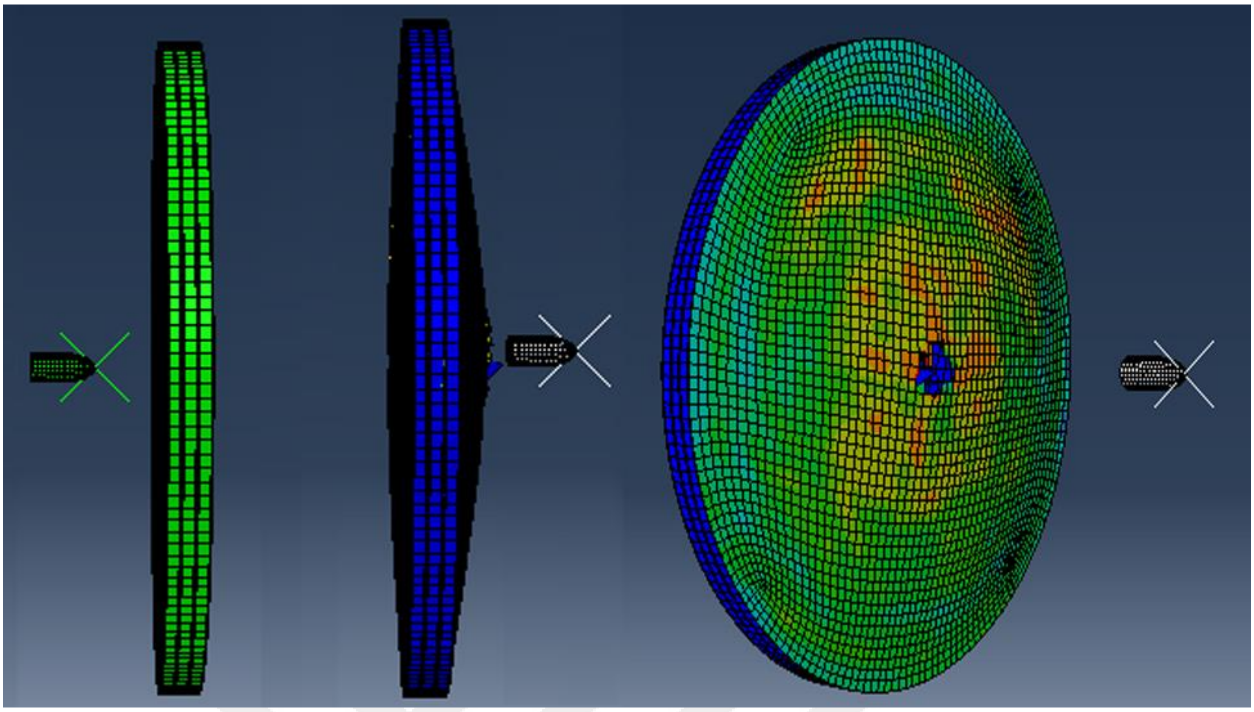

Figure 3.7: Triple layer Al-LDPE-Al orthogonal impact.

The initial velocity of the bullet before impact 335 m/s and the output velocity of the bullet is 233,2 m/s. The absorbed energy is 205,5 J.

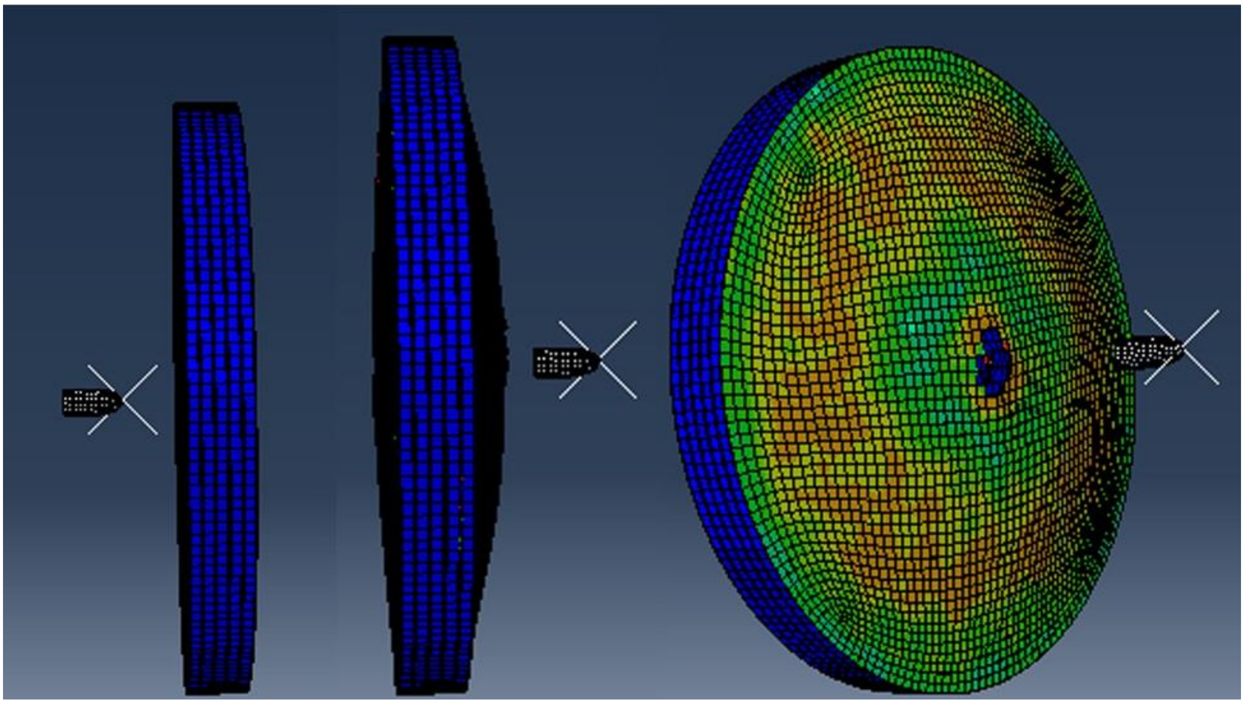

Figure 3.8: The orthogonal impact for stacked 5 layer

The output velocity is 132,3 m/s for stacked 5 layer.The final energy is 62.13 J, so the absorbed energy is 336,26 J.

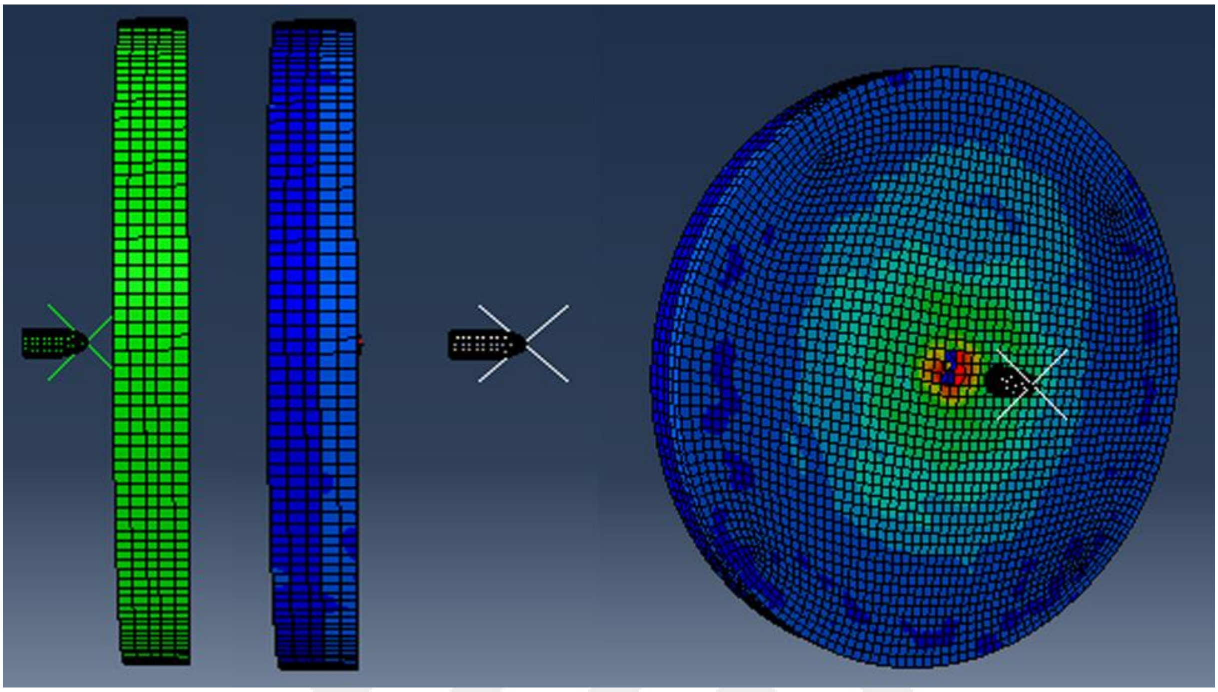

Figure 3.9: The orthogonal impact for equivalent 5 layer. The thickness are 8,4 – 3,2 -8,4 mm

The final velocity of bullet is 184,6 m/s. Absorbed energy is 277,5 J. The absorbation is lower than the stacked 5 layer. These two materials are same thickness but the layers' thickness are different.

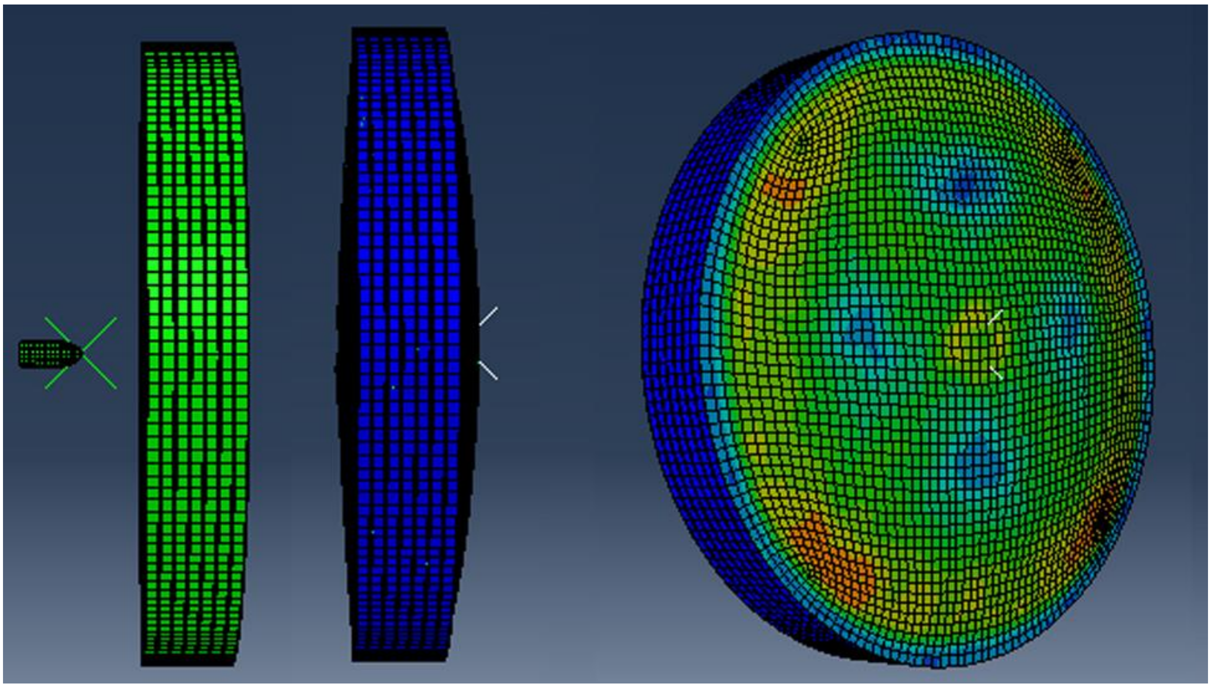

Figure 3.10: The orthogonal impact for 7 layers

The initial velocity of the bullet before impact 335 m/s and the output velocity of the bullet is 0 m/s. The absorbed energy can't calculate. Because the bullet didn't pass the target.
The number of elements and type of elements calculated with Abaqus Explicit. Table 3.4 shows the number of elements and types.

Table 3.4 : The number of elements and type of elements

| Part | Number of elements | Type of elements |
|---|---|---|
| **36 caliber rifle bullet** | 368 | 2 x R3D3 and 366 x R3D4 |
| **9 mm Caliber bullet** | 446 | 2 x R3D3 and 444 x R3D4 |
| **Single layer (0.4 Al-3.2 LDPE-0.4 Al)** | 8466 | C3D8R |
| **3 layer Al-LDPE-Al** | 25398 | C3D8R |
| **5 stacked single layer** | 42330 | C3D8R |
| **Equivalent 5 layer** | 14110 | C3D8R |
| **7 layer Al-LDPE-Al** | 59262 | C3D8R |

As shown in the Figure 3.11, the hit positions and angles of the projectile are indicated. The target hit with 0˚, ±30˚ and ±60˚ to the center was also applied in areas 40 and 80 cm away from the center.

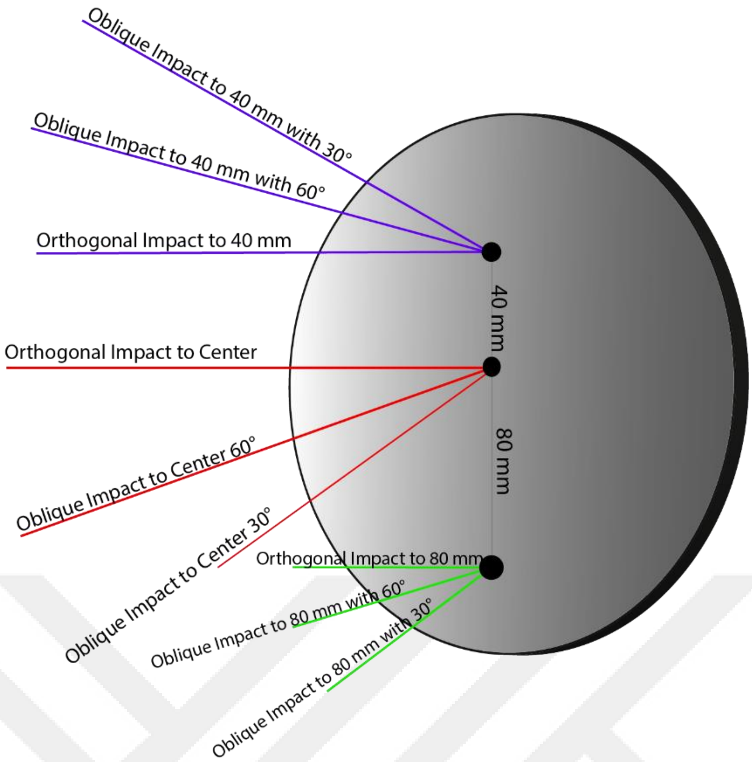


Figure 3.11: The Impact points on targets

The central effect of single layer, stacked 5 layer and equivalent 5 layer were studied. Apart from the Centers of these targets, rounds were sent at different angles at 40 cm and 80 cm distance points, so that the values of the energy absorbed in the center were compared with the energy absorbed as they moved toward the edge.

# 4. RESULTS AND DISCUSSIONS

In this study, real conditions and rifles were used. In modeling, the closest and most widely used pistol type was preferred. As can be seen from previous literature studies, these firing tests take place under laboratory conditions, but real guns do not only have a speed factor, but also bullet spin motion and external ambient conditions. The most important reason we do real experiments with the rifle is to shoot at the angle and point we want from 5 meters distance more easily. Because the longer the barrel tip, the easier it is to hit the desired point. In modeling, the most important reason we use pistols is that gun usage is more. There is a difference of 0.03 g in weight between pistol bullets and rifle bullets. This difference is at a negligible level.

The results of 5 attempts without a target for rifle bullet speed measurement are in Table 4.1. In addition, exit speeds from the target are given in table 4.1.

Table 4.1: The velocity of rifle's bullet

| Entrance velocities (m/s) | Mean value (m/s) | Standard deviation (m/s) |
|---|---|---|
| 476.8 ; 486.8 ; 469.6 ; 476.4 ; 486.9 | 479.3 | 7.5 |
| Exit velocities after penetration (m/s) | Mean value (m/s) | Standard deviation (m/s) |
| 446.4 ; 445.9 ; 436.9 ; 442.3 ; 432.1 | 440.7 | 6.1 |

### 4.1. Modelling Results

In the modeling, the results of all the targets examined at different angles and at different positions were examined. All targets and layer thicknesses are given in Table 3.3. These targets were tested with the 9mm pistol bullet modeled.

#### 4.1.1 Single Layer Al-LDPE-Al

The tests performed on a single layer are listed below. The results are given in Table 4.2. In addition, modeling figures are listed for each angle and each target point.

Table 4.2: Single layer results

| Targetspan Angle | Entrance Velocity m/s | Exit Velocity m/s | Entrance Energy J | Exit Energy J | Absorbed Energy J | Figures |
|---|---|---|---|---|---|---|
| **Rifle 0°** | 479 | 437.9 | 848.9 | 709.8 | 139.2 | Figure 4.1 |
| **Center/0°** | 335 | 304.9 | 398.5 | 330 | 68.6 | Figure 3.6 |
| **Center/±30°** | 335 | 302.2 | 398.5 | 324 | 74.4 | Figure 4.2 |
| **Center/±60°** | 335 | 314.3 | 398.5 | 351 | 47.8 | Figure 4.3 |
| **40 mm/0°** | 335 | 310.3 | 398.5 | 342 | 56.6 | Figure 4.4 |
| **40 mm/+30°** | 335 | 305.7 | 398.5 | 332 | 66.7 | Figure 4.5 |
| **40 mm/-30°** | 335 | 305.9 | 398.5 | 332 | 66.3 | Figure 4.6 |
| **40 mm/+60°** | 335 | 313.4 | 398.5 | 351 | 47.3 | Figure 4.7 |
| **40 mm/-60°** | 335 | 315.4 | 398.5 | 349 | 50 | Figure 4.8 |
| **80 mm/0°** | 335 | 311.4 | 398.5 | 344 | 54.3 | Figure 4.9 |
| **80 mm/+30°** | 335 | 305.2 | 398.5 | 331 | 67.9 | Figure 4.10 |
| **80 mm/-30°** | 335 | 304.8 | 398.5 | 330 | 68.7 | Figure 4.11 |
| **80 mm/+60°** | 335 | 311.3 | 398.5 | 344 | 54.5 | Figure 4.12 |
| **80 mm/-60°** | 335 | 313.4 | 398.5 | 349 | 49.8 | Figure 4.13 |

Figure 4.1: The 36mm rifle projectile orthogonal impact [32]

In real experiments, rifles and 36-caliber bullets were used. Rifle bullet velocity was determined according to the measurement results with velocimeter. Figure 4.2 shows the result of full penetration.

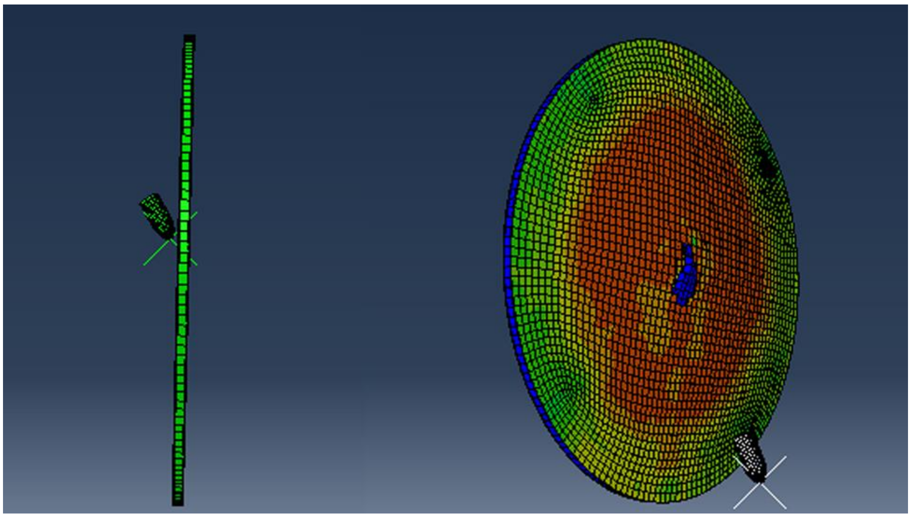

Figure 4.2: Single layer oblique impact to center of target with 30˚

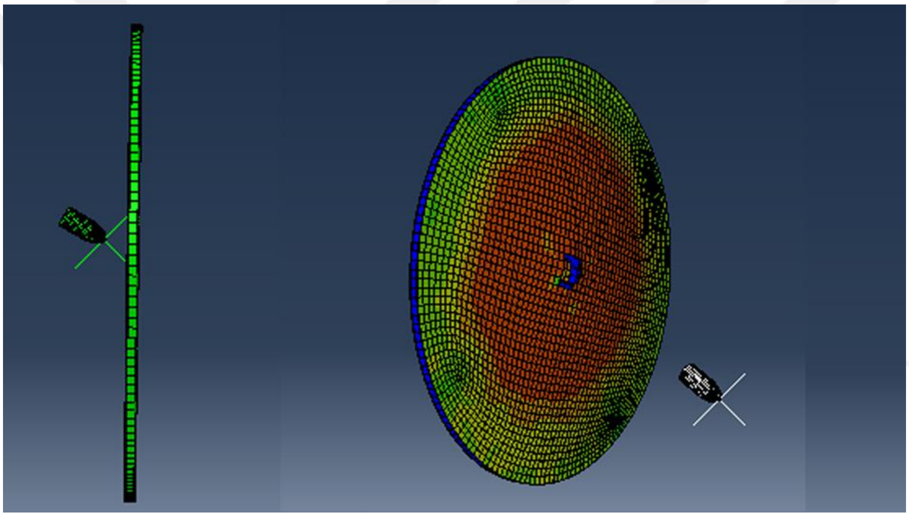

Figure 4.3: Single layer oblique impact to center of target with 60˚

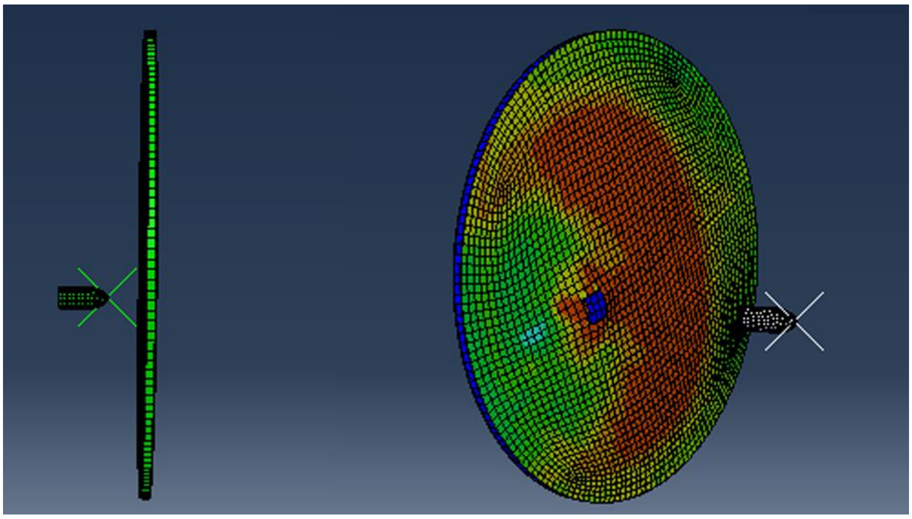

Figure 4.4:Single layer orthogonal impact to 40 mm away from center

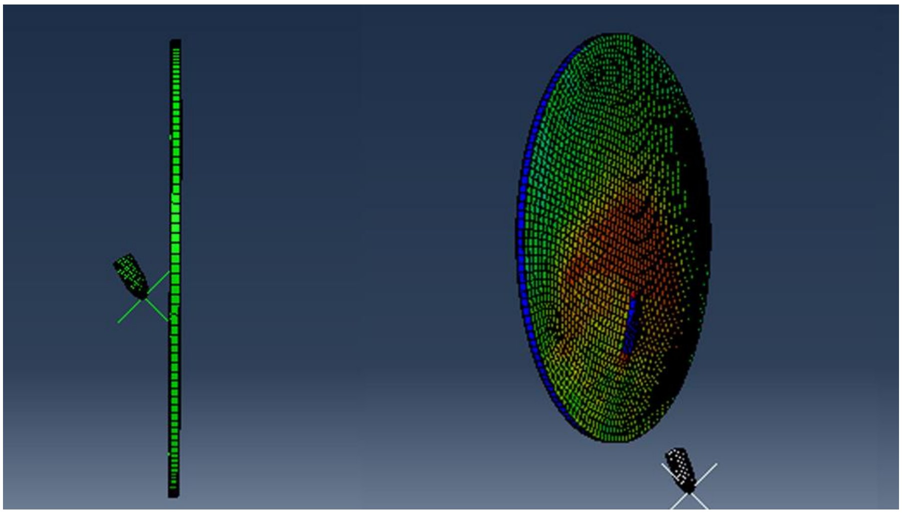

Figure 4.5: Single layer oblique impact to 40 mm away from center with +30˚.

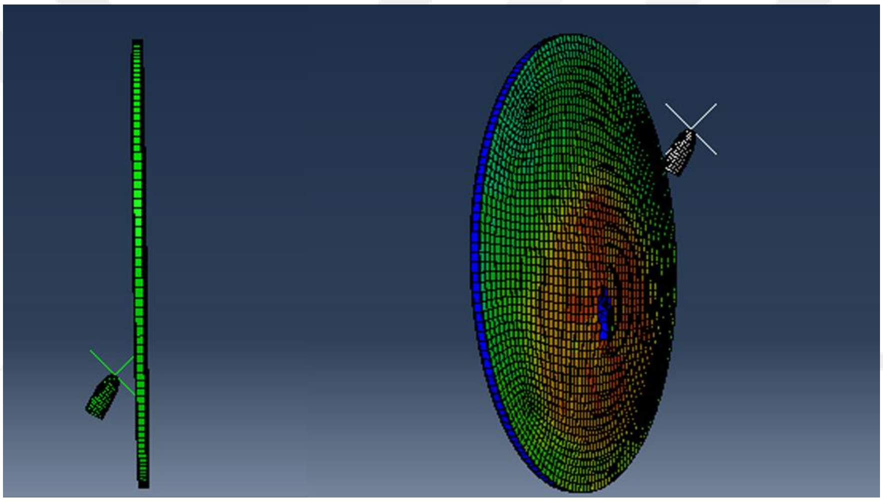

Figure 4.6: Single layer oblique impact to 40 mm away from center with -30˚.

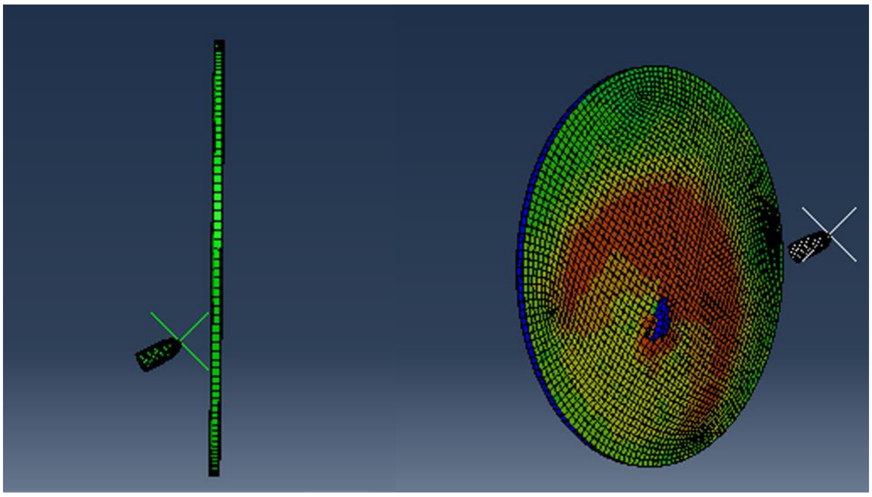

Figure 4.7: Single layer oblique impact to 40 mm away from center with -60˚

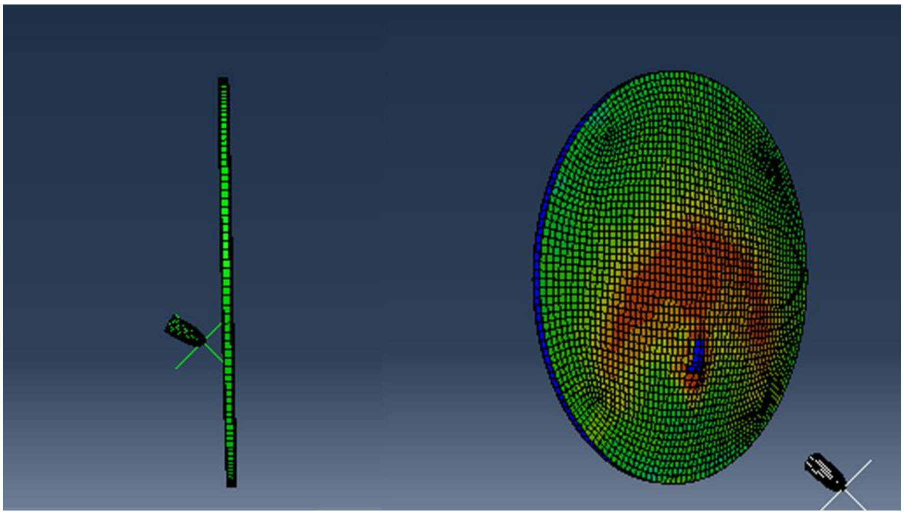

Figure 4.8: Single layer oblique impact to 40 mm away from center with +60˚.

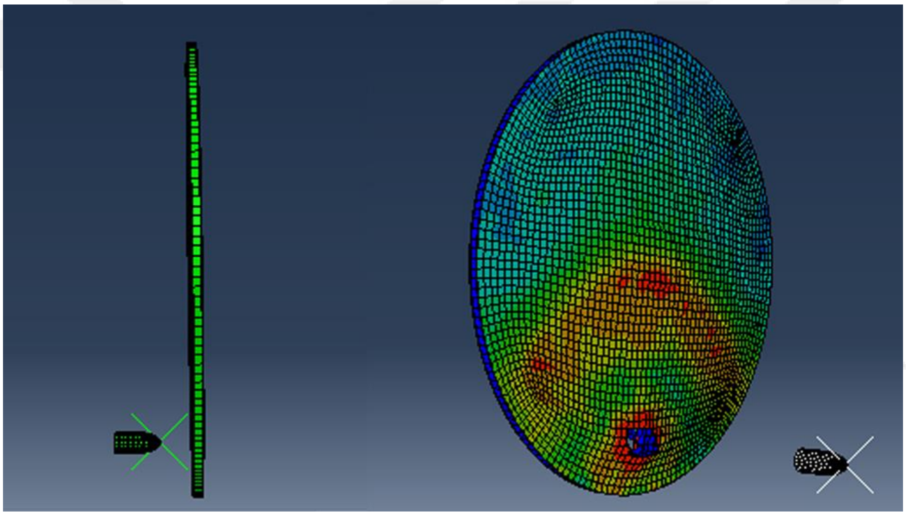

Figure 4.9: Single layer orthogonal impact to 80 mm away from center.

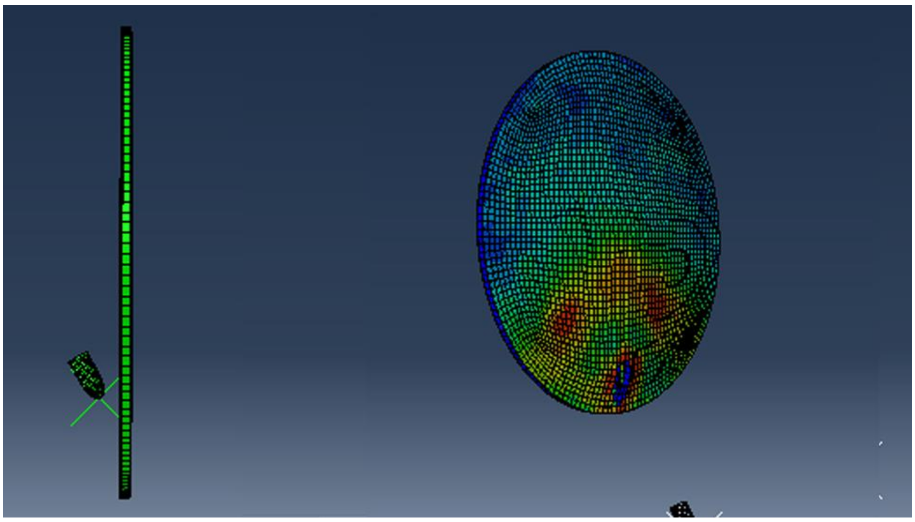

Figure 4.10: Single layer oblique impact to 80 mm away from center with +30˚

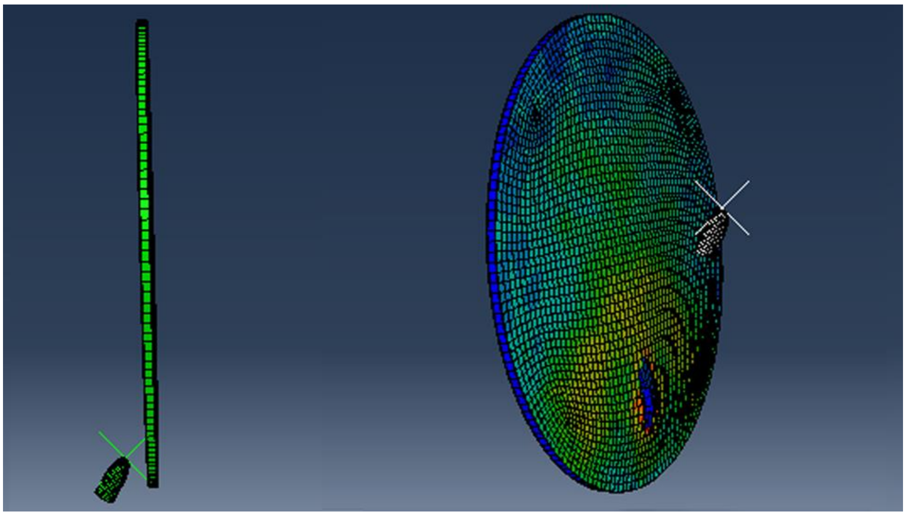

Figure 4.11: Single layer oblique impact to 80 mm away from center with -30˚.

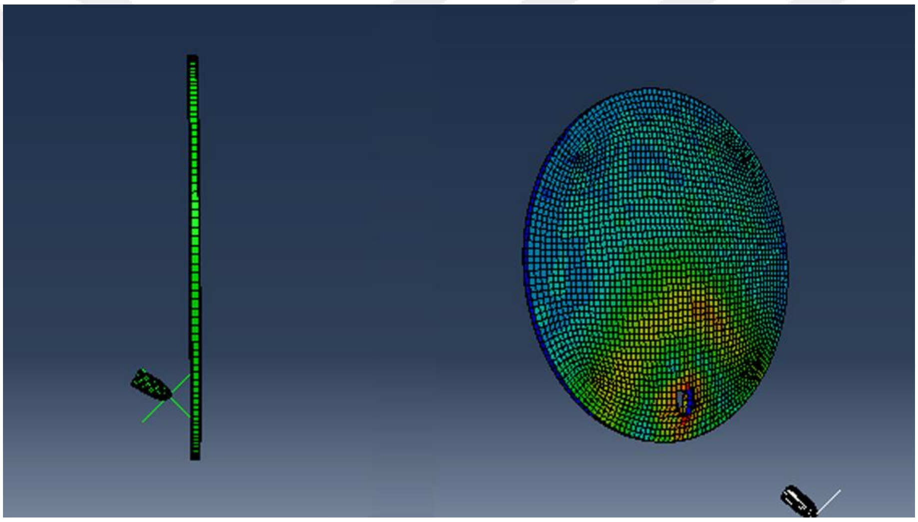

Figure 4.12: Single layer oblique impact to 80 mm away from center with +60˚.

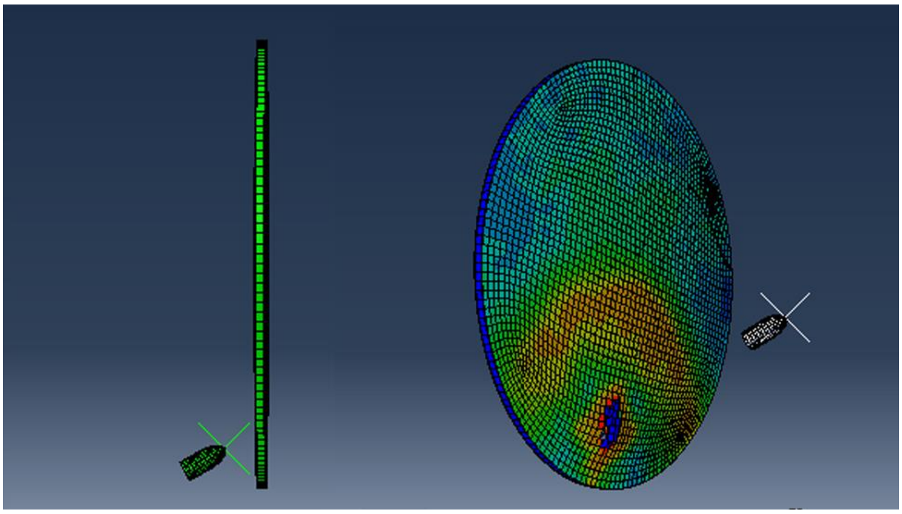

Figure 4.13: Single layer oblique impact to 80 mm away from center with -60˚

### 4.1.2 Triple Layer Al-LDPE-Al

The tests performed triple layer are listed below. The results are given in Table 4.3. In addition, modeling figures are listed for each angle and each target point.

Table 4.3: Triple layer results

| | Entrance Velocity m/s | Exit Velocity m/s | Entrance Energy J | Exit Energy J | Absorbed Energy J | Figures |
|---|---|---|---|---|---|---|
| **3 layer 0˚** | 335 | 233.2 | 398.5 | 193 | 205.5 | Figure 3.7 |
| **3 layer 30˚** | 335 | 210 | 398.5 | 157 | 241.5 | Figure 4.14 |
| **3 layer 60˚** | 335 | 239 | 398.5 | 204 | 194.5 | Figure 4.15 |

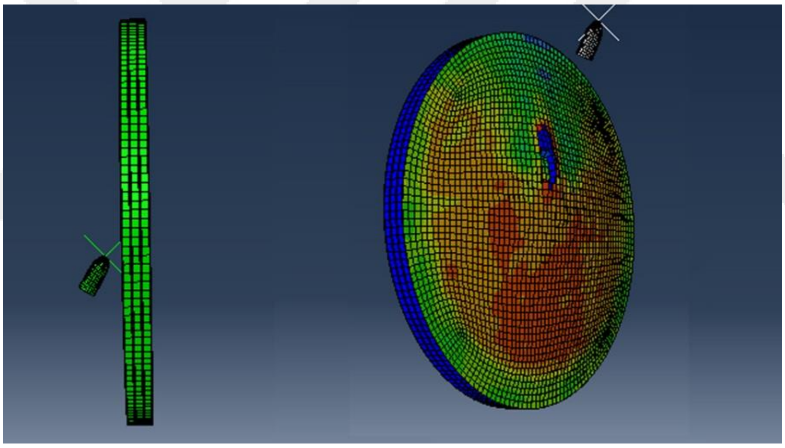

Figure 4.14: Triple layer oblique impact to center of target with 30˚

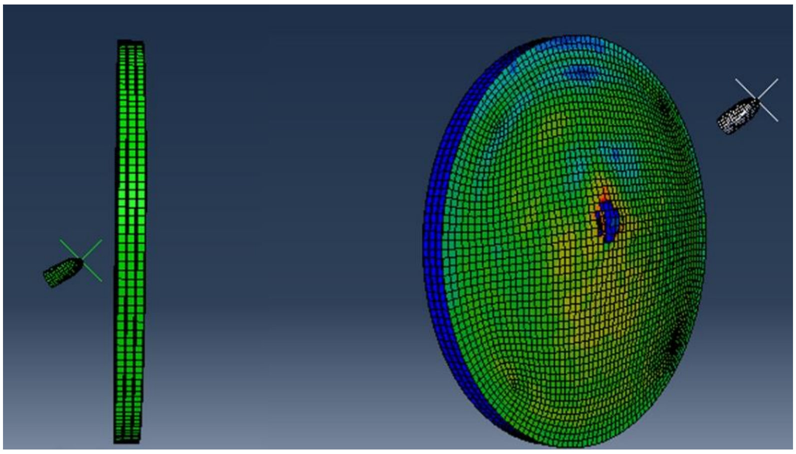

Figure 4.15: Triple layer oblique impact to center of target with 60˚

### 4.1.3 Stacked Five Layer Al-LDPE-Al

5 pcs Al-LDPE-Al were used for this target. The total thickness is 20 mm. The results are given in Table 4.4. In addition, modeling figures are listed for each angle and each target point.

Table 4.4: Stacked five layer results

| Target span/Angle | Entrance Velocity m/s | Exit Velocity m/s | Entrance Energy J | Exit Energy J | Absorbed Energy J | Figures |
|---|---|---|---|---|---|---|
| **Center/0°** | 335 | 132.3 | 398.5 | 62.1 | 336.4 | Figure 3.8 |
| **Center/ 30°** | 335 | - | 398.5 | - | 398.5 | Figure 4.16 |
| **Center/ 60°** | 335 | 126.9 | 398.5 | 57.2 | 341.3 | Figure 4.17 |
| **40 mm/0°** | 335 | 162 | 398.5 | 93.2 | 305.3 | Figure 4.18 |
| **40 mm/+30°** | 335 | - | 398.5 | - | 398.5 | Figure 4.19 |
| **40 mm/-30°** | 335 | 119.9 | 398.5 | 51 | 347.5 | Figure 4.20 |
| **40 mm/+60°** | 335 | 176 | 398.5 | 110 | 288.5 | Figure 4.21 |
| **40 mm/-60°** | 335 | 152.9 | 398.5 | 83 | 315.5 | Figure 4.22 |
| **80 mm/0°** | 335 | 190.6 | 398.5 | 129 | 269.5 | Figure 4.23 |
| **80 mm/+30°** | 335 | - | 398.5 | - | 398.5 | Figure 4.24 |
| **80 mm/-30°** | 335 | Ricochet | 398.5 | Ricochet | - | Figure 4.25 |
| **80 mm/+60°** | 335 | 186.1 | 398.5 | 123 | 275.5 | Figure 4.26 |
| **80 mm/-60°** | 335 | 197.2 | 398.5 | 138 | 260.5 | Figure 4.27 |

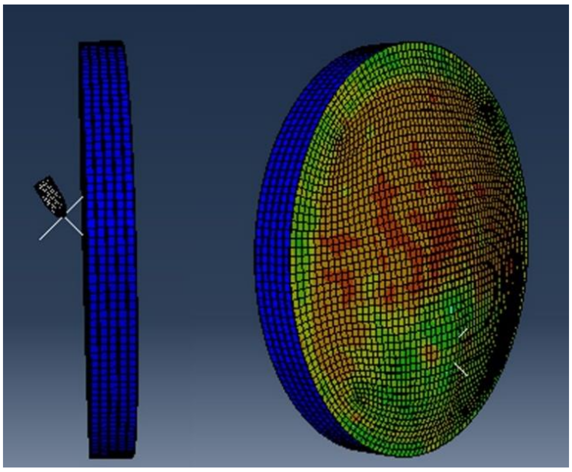

Figure 4.16: Stacked 5 layer oblique impact to center of target with 30°

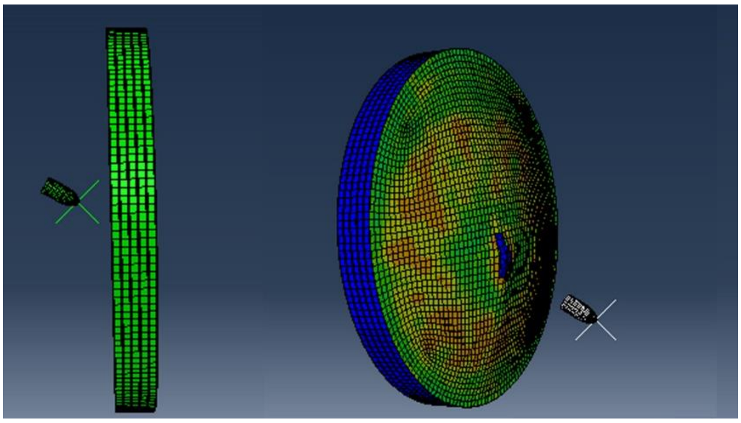

Figure 4.17: Stacked 5 layer oblique impact to center of target with 60˚

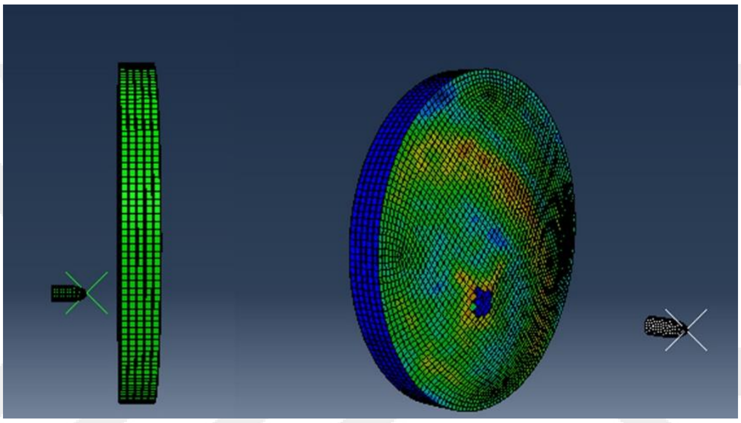

Figure 4.18: Stacked 5 layer orthogonal impact to 40mm away from center

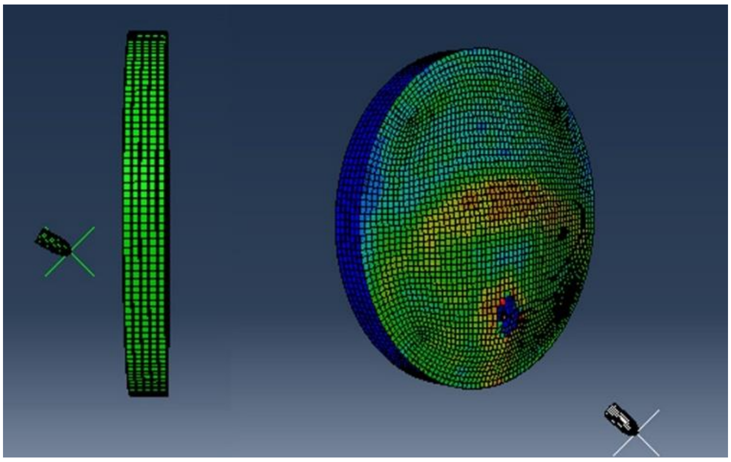

Figure 4.19: Stacked 5 layer oblique impact to 40 mm away from center with +30˚.

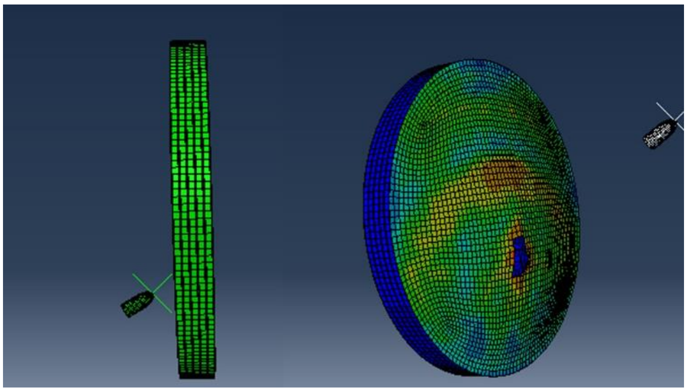

Figure 4.20: Stacked 5 layer oblique impact to 40 mm away from center with -30˚.

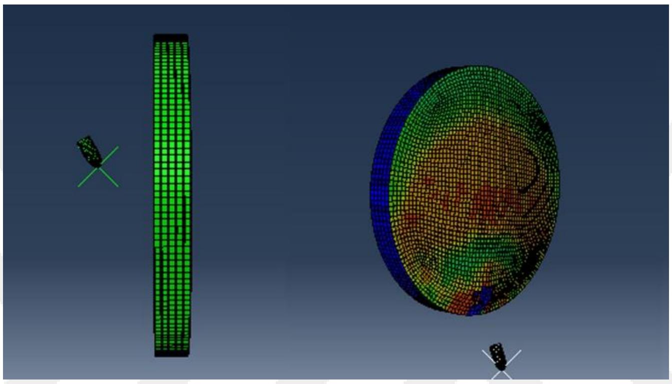

Figure 4.21: Stacked 5 layer oblique impact to 40 mm away from center with +60˚.

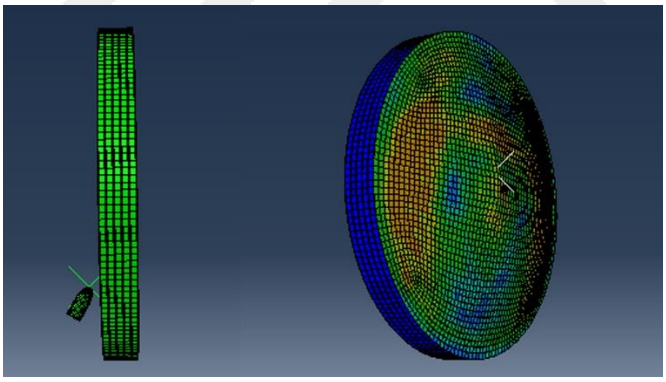

Figure 4.22: Stacked 5 layer oblique impact to 40 mm away from center with -60˚

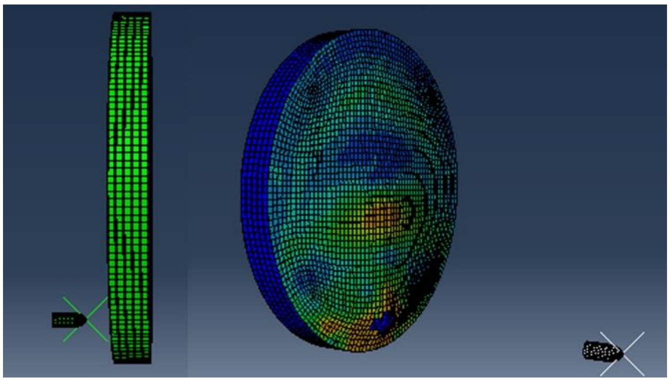

Figure 4.23: Stacked 5 layer orthogonal impact to 80mm away from center

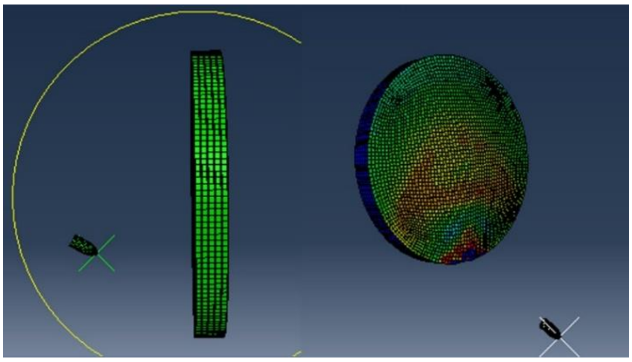

Figure 4.24: Stacked 5 layer oblique impact to 80 mm away from center with +30˚

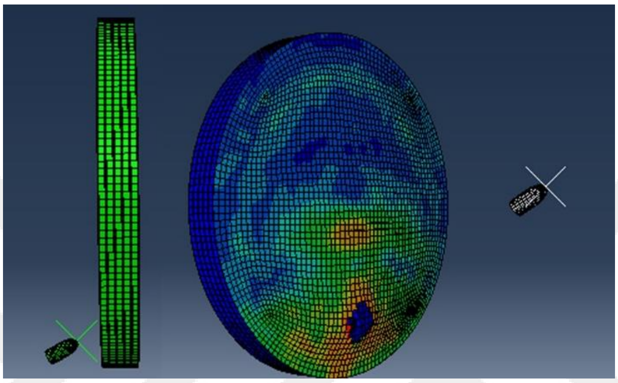

Figure 4.25: Stacked 5 layer oblique impact to 80 mm away from center with -30˚

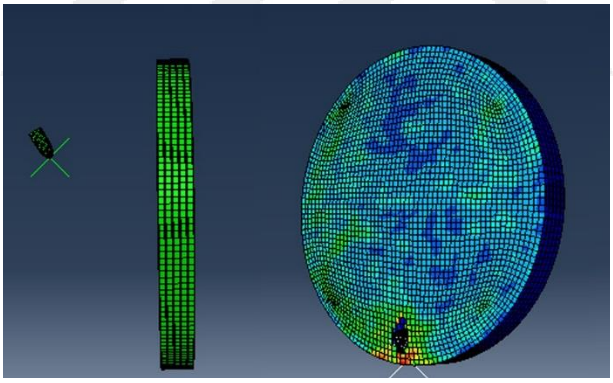

Figure 4.26: Stacked 5 layer oblique impact to 80 mm away from center with +60˚

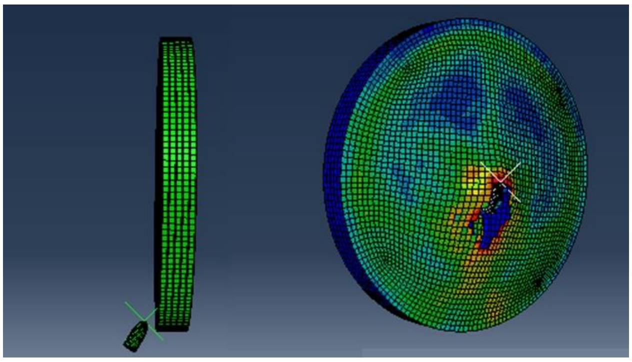

Figure 4.27: Stacked 5 layer oblique impact to 80 mm away from center with -60˚

### 4.1.4 Equivalent Five Layer Al-LDPE-Al

The equivaltent 5-layer target consists of 2 pieces of 8.4 mm thick aluminum layers and a 3.2 mm thick LDPE layer. Our aim in testing this goal is to compare materials of the same thickness and different hardness. Stacked 5 layer thickness is 20 mm. A total of 10 parts of 0.4mm Aluminum sheets and 5 parts of 3.2mm LDPE plates were used for the stacked layer. Stacked 5 layer total thickness is 20 mm. The results are given in Table 4.5. In addition, modeling figures are listed for each angle and each target point.

Table 4.5: Equivalent 5 layer results

| *Target span/Angle* | Entrance Velocity m/s | Exit Velocity m/s | Entrance Energy J | Exit Energy J | Absorbed Energy J | Figures |
|---|---|---|---|---|---|---|
| Center/0˚ | 335 | 184.6 | 398.5 | 121 | 277.5 | Fig 3.9 |
| Center/-30˚ | 335 | - | 398.5 | - | 398.5 | Fig.4.28 |
| Center/-60˚ | 335 | 126.7 | 398.5 | 57 | 341.5 | Fig.4.29 |
| 40 mm/0˚ | 335 | 213 | 398.5 | 161 | 237.5 | Fig.4.30 |
| 40 mm/+30˚ | 335 | - | 398.5 | - | 398.5 | Fig.4.31 |
| 40 mm/-30˚ | 335 | - | 398.5 | - | 398.5 | Fig.4.32 |
| 40 mm/+60˚ | 335 | 183.9 | 398.5 | 120 | 278.5 | Fig.4.33 |
| 40 mm/-60˚ | 335 | 191.4 | 398.5 | 130 | 268.5 | Fig.4.34 |
| 80 mm/0˚ | 335 | 217.5 | 398.5 | 168 | 230.5 | Fig.4.35 |
| 80 mm/+30˚ | 335 | - | 398.5 | - | 398.5 | Fig.4.36 |
| 80 mm/-30˚ | 335 | Ricochet | 398.5 | Ricochet | - | Fig.4.37 |
| 80 mm/+60˚ | 335 | 169.5 | 398.5 | 102 | 296.5 | Fig.4.38 |
| 80 mm/-60˚ | 335 | 173.6 | 398.5 | 107 | 291.5 | Fig.4.39 |

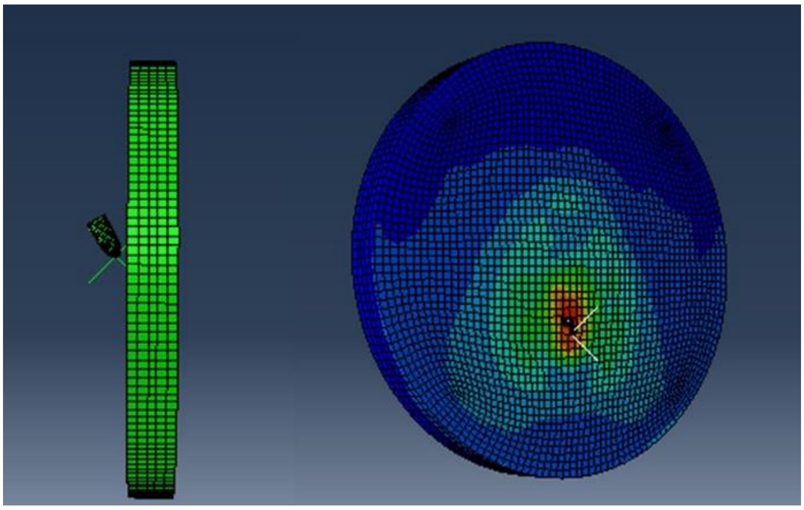

Figure 4.28: Equivalent 5 layer oblique impact to center of target with 30˚

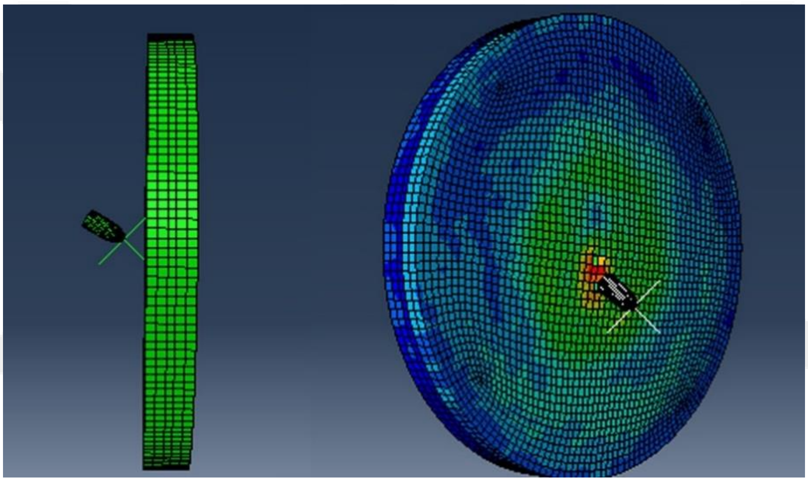

Figure 4.29: Equivalent 5 layer oblique impact to center of target with 60˚

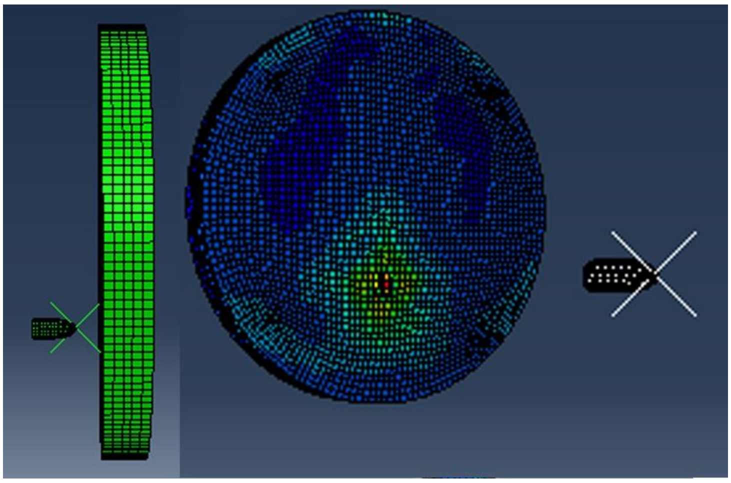

Figure 4.30: Equivalent 5 layer orthogonal impact to 40mm away from center

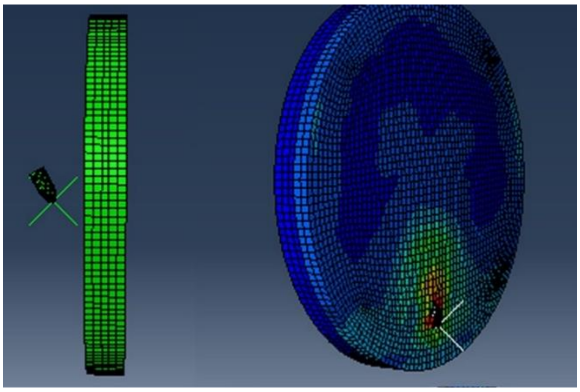

Figure 4.31: Equivalent 5 layer oblique impact to 40 mm away from center with +30˚

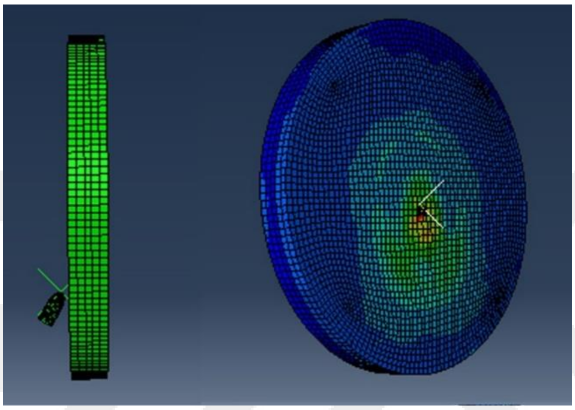

Figure 4.32: Equivalent 5 layer oblique impact to 40 mm away from center with -30˚

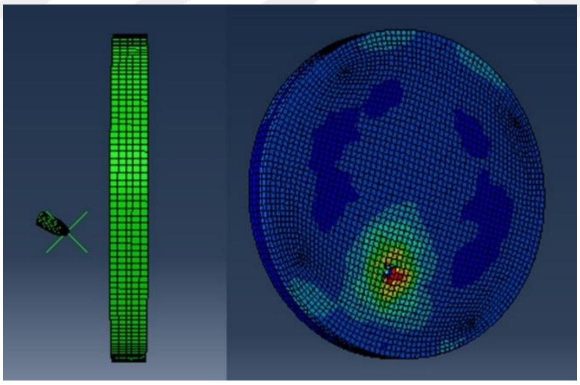

Figure 4.33: Equivalent 5 layer oblique impact to 40 mm away from center with +60˚

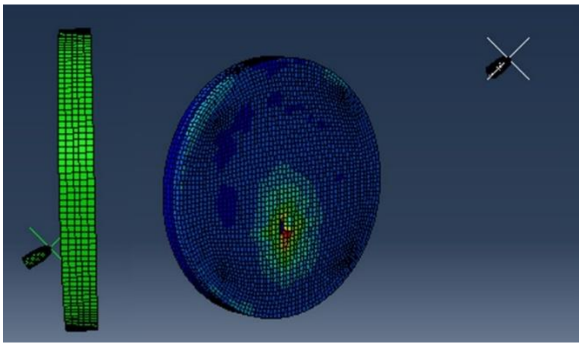

Figure 4.34: Equivalent 5 layer oblique impact to 40 mm away from center with -60˚

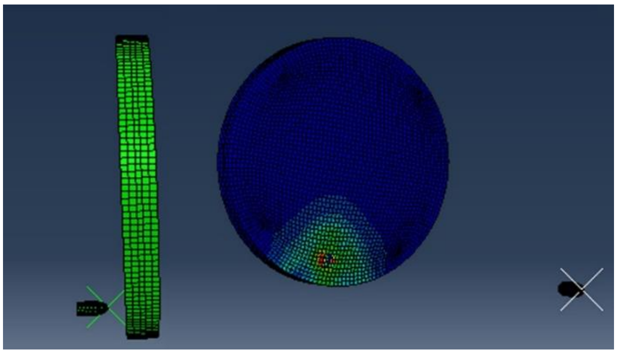

Figure 4.35: Equivalent 5 layer orthogonal impact to 80 mm away from center

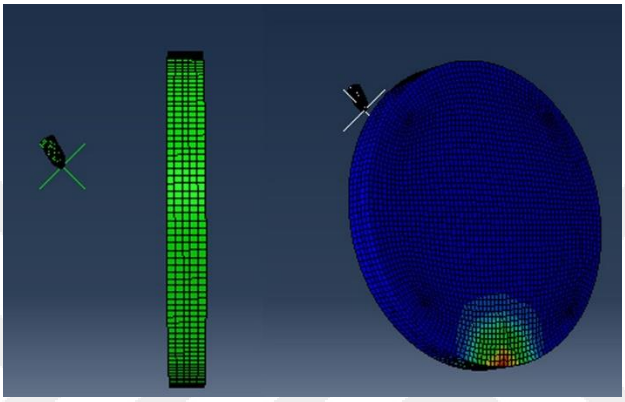

Figure 4.36: Equivalent 5 layer oblique impact to 80 mm away from center with +30˚

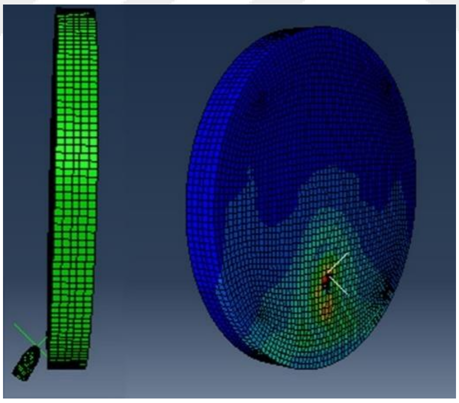

Figure 4.37: Equivalent 5 layer oblique impact to 80 mm away from center with -30˚

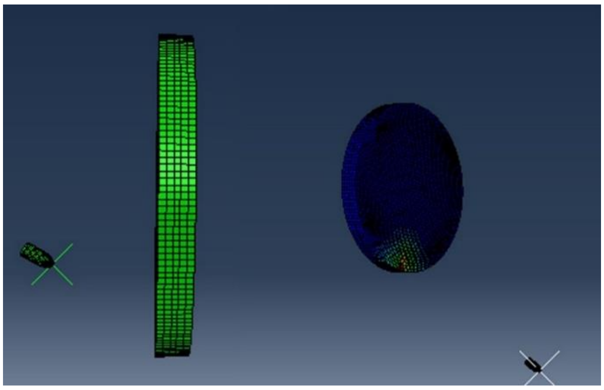

Figure 4.38: Equivalent 5 layer oblique impact to 80 mm away from center with +60˚

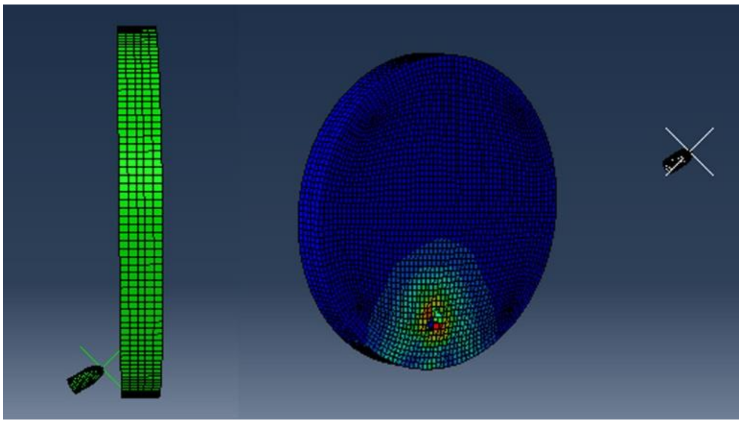

Figure 4.39: Equivalent 5 layer oblique impact to 80 mm away from center with -60°

### 4.1.5 Seven Layer Al-LDPE-Al

No penetration was observed on the seven-layer target. Full protection in orthogonal and oblique impacts. Shooting was done at 0 degrees, 30 degrees and 60 degrees angles only in shooting simulations applied to the center. The results are given in Table 4.6. 7 layers Al-LDPE-Al total thickness is 28mm. It consists of 14 layers of Aluminum and 7 layers of LDPE. 7-layer Al-LDPE-Al composite material can be used on steel vests upon full protection.

Table 4.6: Seven layer results

| | **Entrance Velocity m/s** | **Exit Velocity m/s** | **Entrance Energy J** | **Exit Energy J** | **Absorbed Energy** | **Figures** |
|---|---|---|---|---|---|---|
| 7 layer 0° | 335 | - | 398.5 | - | - | Fig.3.10 |
| 7 layer 30° | 335 | - | 398.5 | - | - | Fig.4.40 |
| 7 layer 60° | 335 | - | 398.5 | - | - | Fig.4.41 |

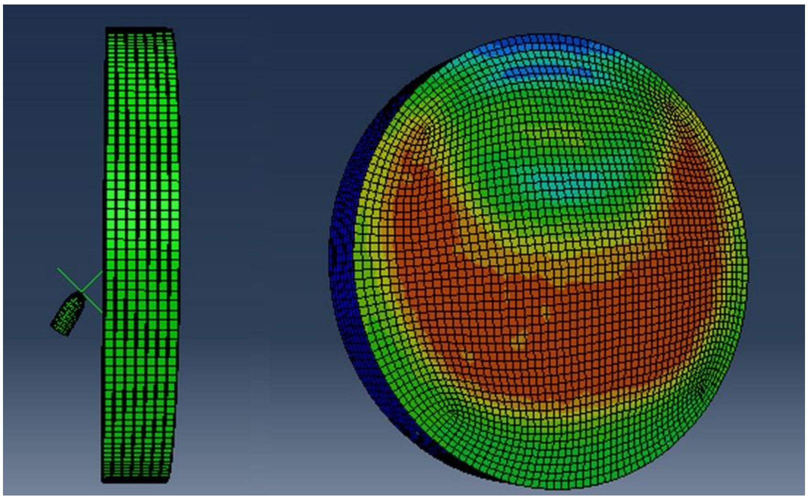

Figure 4.40: 7 layer oblique impact to center of target with 30˚

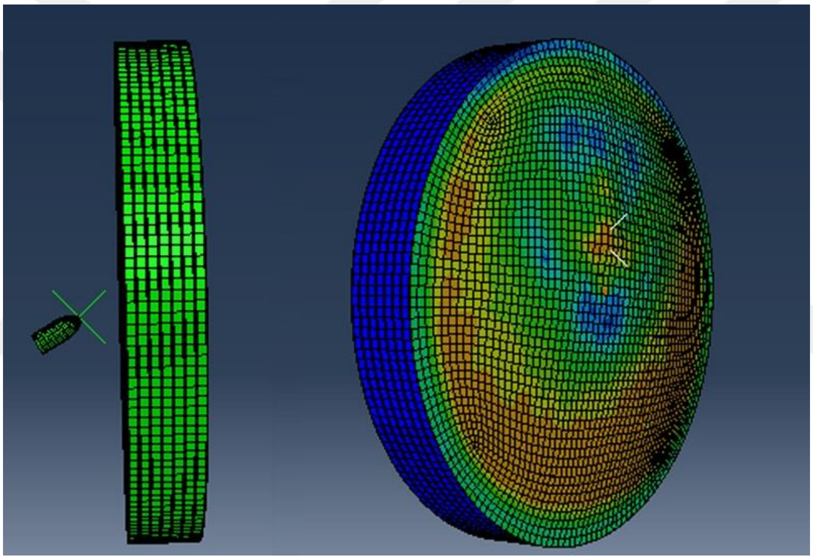

Figure 4.41: 7 layer oblique impact to center of target with 60˚

# 5. CONCLUSIONS

In this study we conducted on ballistic study, the modeling results we made with the experimental and finite element method are consistent with each other. As we expected in oblique impact, energy absorption is higher. Feature the energies absorbed at the 30 degree impacts are highest. Energy absorption of 30 degree bumps is available in Table 5.1.

Table 5.1 : Energy absorbation at 30˚

| Target | Point | Absorbed Energy J |
|---|---|---|
| **Single Layer** | Center | 74.4 |
| **Single Layer** | 40 mm | 66,7 |
| **Single Layer** | 80 mm | 67,9 |
| **Triple Layer** | Center | 241,5 |
| **Stacked 5 Layer** | Center | No penetration |
| **Stacked 5 Layer** | 40 mm | 398,5 |
| **Stacked 5 Layer** | 80 mm | Ricochet |
| **Equivalent 5 Layer** | Center | No penetration |
| **Equivalent 5 Layer** | 40 mm | No penetration |
| **Equivalent 5 Layer** | 80 mm | No penetration |
| **Seven Layer** | Center | No penetration |

The energy absorption of the oblique effect appears clearly as a result of oblique impacts at an angle of 30 degrees by simulation. This effect was not clearly observed in a single layer. Full protection is provided with only 7-layer Al-LDPE-Al at all angles. This armor to be designed with this recycled material (Al-LDPE-Al), we can use it as the lightest among modern armors. 7-layer Al-LDPE-Al composite material is suitable for use for armor.

# 6. RECOMMENDATIONS

Aluminiums of 3000 series were used for the experiments, however, as can be seen in Table 6.1, there is aluminum from different series. In this kind of aluminum, the strength increases more in the higher series. The number of layers can be reduced by using aluminum from 6000 or 7000 series.

Table 6.1: Series of Aluminum Alloys

| Series | Alloying Elements |
|---|---|
| 1000 | Aluminum |
| 2000 | Copper |
| 3000 | Manganese |
| 4000 | Silicone |
| 5000 | Magnesium |
| 6000 | Magnesium and Silicone |
| 7000 | Zinc |

Less layer of armor material can be produced by using reinforced polyethylene or high density polyethylene and aluminum from 6000 - 7000 series. Experiments should be repeated with this armor material that can be produced. Fewer layers are more suitable for armor, and we can also change the lightness by reducing the armor thickness.

# REFERENCES


1. Malhotra, A., F. Guild, and M. Pavier, Edge impact to composite laminates: experiments and simulations. Journal of materials science, 2008. 43(20): p. 6661

2. Malhotra, A. and F. Guild, Impact damage to composite laminates: effect of impact location. Applied Composite Materials, 2014. 21(1): p. 165 177.

3. Xiong, J., et al., Compression and impact testing of two-layer composite pyramidal - core sandwich panels Composite Structures 2012. 94(2): p. 793-801.

4. Rhead, A.T., D. Marchant, and R. Butler, Compressive strength of composite laminates following free edge impact.Composites Part A: Applied Science and Manufacturing, 2010. 41(9): p. 1056-1065.

5. Z. Fawazi, W. Zheng, K. Behdinan, Numerical simulation of normal and oblique ballistic impact on ceramic composite armours, Compos. Struct., 63 (2004), 387-395, doi:10.1016/S0263-8223(03)00187-9

6. Akella, Kiran & Naik, Niranjan. (2015). Composite armour - A review. Journal of the Indian Institute of Science. 95. 297-312.

7. Anurag Rajagopal and Niranjan K Naik, Oblique ballistic impact behavior of composites, 2014, Vol. 23(4) 453–482 doi: 10.1177/1056789513499268

8. M.A. Iqbal, P.K. Gupta, V.S. Deore, S.K. Tak, G. Tiwari, N.K. Gupta, Effect of target span and configuration on the ballistic limit, Int. J. Impact Eng., 42 (2012), 11–24, doi:10.4028/www.scientific.net/KEM.535-536.52

9. N.K. Gupta, M.A. Iqbal, G.S. Sekhon, Effect of projectile nose shape, impact velocity and target thickness on the deformation behavior of layered plates, Int. J. Impact Eng., 35 (2008), 37–60, doi:10.1016/j.ijimpeng.2006.11.004

10. J.G. Hetherington, P.F. Lemieux, The effect of obliquity on the ballistic performance of two component composite armours, Int. J. Impact Eng., 15 (1994), 131–137, doi: 10.1016/S0734-743X(05)80026-0

11. I. Marom, S.R. Bodner, Projectile perforation of multi-layered beams, Int. J. Mech. Sci., 21 (1979), 489–504, doi: 10.1016/0020-7403(79)90011-0

12. J. Radin, W. Goldsmith, Normal projectile penetration and perforation of layered targets, Int. J. Impact Eng., 7 (1988), 229–259, doi: 10.1016/0734-743X(88)90028-0

13. S. Dey, T. Børvik, X. Teng, T. Wierzbicki, O.S. Hopperstad,On the ballistic resistance of double-layered steel plates: An experimental and numerical investigation, International Journal of Solids and Structures, Volume 44, Issue 20, (2007), Pages 6701-6723, ISSN 0020-7683, https://doi.org/10.1016/j.ijsolstr.2007.03.005

14. Almohandes, A.A., Abdel-Kader, M.S., Eleiche, A.M., 1996. Experimental investigation of the ballistic resistance of steel–fiberglass reinforced polyester laminated plates. Composites Part B: Engineering 27 (5), 447–458.

15. Ben-Dor, G., Dubinsky, A., Elperin, T., 1998a. On the ballistic resistance of multi-layered targets with air gaps. International Journal of Solids and Structures 35 (23), 3097–3103.

16. Ben-Dor, G., Dubinsky, A., Elperin, T., 1998b. Effect of air gaps on ballistic resistance of targets for conical impactors. Theoretical and Applied Fracture Mechanics 30, 243 249.

17. Ben-Dor, G., Dubinsky, A., Elperin, T., 2006. Effect of air gaps on the ballistic resistance of ductile shields perforated by non-conical impactors. Journal of Mechanics of Materials and Structures 1 (2), 279–299

18. G.N. Wurick, C.N. Walter, The ballistic penetration of multiple thin plates separated by an air gap, Proceedings of SEM conference on experimental mechanics, Inc. 1990, 631-7

19. J. Awerbuch, S. R. Bodner, An investigation of oblique perforation of metallic plates by projectiles, Exp. Mech., 17 (1977), 147–153, doi:10.1007/BF02324213

20. Werner Goldsmith, Non-ideal projectile impact on targets,International Journal of Impact Engineering,Volume 22, Issues 2–3,1999,Pages 95-395,ISSN 0734-743X, https://doi.org/10.1016/S0734-743X(98)00031-1.

21. R. Zaera, V. Sánchez-Gálvez, Analytical modelling of normal and oblique ballistic impact on ceramic/metal lightweight armours, International Journal of Impact Engineering, Volume 21, Issue 3, 1998, Pages 133-148, ISSN 0734743X https://doi.org/10.1016/S0734-743X(97)00035-3.

22. M.A. Iqbal, K. Senthil, V. Madhu, N.K. Gupta, Oblique impact on single, layered and spaced mild steel targets by 7.62 AP projectiles, Int. J. Impact Eng., 110 (2017), 26–38, doi: 10.1016/j.ijimpeng.2017.04.011

23. D. M. Norris, J. K. Scudier, W. H. McMaster, M. L. Wilkil, Mechanics of long-rod penetration at high angles of obliquity, Conference on high density alloy penetrator materials, Charlottesville USA 1976, 7

24. Awerbuch J and Bodner SR (1977) An investigation of oblique perforation of metallic plates by projectiles. Experimental Mechanics 17: 147–153.

25. Borvik T, Dey S and Clausen AH (2009) Perforation resistance of five different high-strength steel plates subjected to small-arms projectiles. International Journal of Impact Engineering 36: 948–964.

26. Borvik T, Forrestal MJ and Warren TL (2010) Perforation of 5083-H116 aluminum armor plates with ogivenose rods and 7.62 mm APM2 bullets. Experimental Mechanics 50(7): 969–978.

27. Borvik T, Hopperstad OS, Berstad T, et al. (2002) Perforation of 12 mm thick steel plates by 20 mm diameter projectiles with flat, hemispherical and conical noses, part II: numerical simulations. International Journal of Impact Engineering 27: 37–64.

28. Borvik T, Olovsson L, Dey S, et al. (2011) Normal and oblique impact of small arms bullets on AA6082-T4 aluminium protective plates. International Journal of Impact Engineering 38: 577–589.

29. S. Dey, A. Karmakar, Effect of oblique angle on low velocity impact response of delaminated composite conical shells, Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci., 228 (2014), 2663–2677, doi: 10.1177/0954406214521799

30. N.K. Gupta, V. Madhu, Normal and oblique impact of a kinetic energy projectile on mild steel plates, Int. J. Impact Eng., 12 (1992), 333–343, doi:10.1016/0734-743X(92)90101-

31. N.K. Gupta, V. Madhu, An experimental study of normal and oblique impact of hard-core projectile on single and layered plates, Int. J. Impact Eng., 19 (1997), 395–414, doi: 10.1016/S0734-743X(97)00001-8

32. A.R. Torun, Ş.H. Kaya, N. Choupani, Evaluation of recycled Al–LDPE–Al sandwich panels as ballistic protection material, Green Materials, (2020), 1-9, doi: 10.1680/jgrma.19.00062

33. Simulia, Abaqus CAE 6.14 User's Guide. 1–1146 (2014).

34. R.C.Eliable,"Ballistic Materials and Penetration Me chanics," Methods and Phenomena: Their Applications in Sci and Tech., 1980, vol. 5, pp. 9-22.

35. Anderson Jr CE and Bodner SR (1988) Ballistic impact: the status of analytical and numerical modeling. International Journal of Impact Engineering 7: 09–35.

36. Awerbuch J and Bodner SR (1974) Analysis of the mechanics of penetration of projectiles in metallic plates. International Journal of Solids and Structures 10: 671–684.

37. Awerbuch J and Bodner SR (1977) An investigation of oblique perforation of metallic plates. Experimental Mechanics 17: 147–153.

38. Backman ME and Goldsmith W (1978) The mechanics of penetration of projectiles into targets. International Journal of Engineering Science 16: 1–99.

39. Benloulo CIS and Sanchez-Galvez V (1998) A new analytical model to simulate impact onto ceramic/composite armors. International Journal of Impact Engineering 21: 461–471.

40. Billon HH and Robinson DJ (2001) Models for the ballistic impact of fabric armor. International Journal of Impact Engineering 25: 411–422.

41. Chen XW, Fana SC and Lib QM (2004) Oblique and normal perforation of concrete targets by a rigid projectile. International Journal of Impact Engineering 30: 617–637.

42. Chen XW, Li Q and Fan S (2006) Oblique perforation of thick metallic plates by rigid projectiles. Acta Mechanica Sinica 22: 367–376.

43. Chen XW, Li W and Song C (2005) Oblique penetration/perforation of metallic plates by rigid projectiles with slender bodies and sharp noses. Explosion and Shock Waves 25: 393–399.

44. Cunniff PM (1999) Dimensionless parameters for optimization of textile-based body armor systems. In: Proceedings of the 18th International Symposium on Ballistics, San Antonio, TX. Lancaster, PA: Technomic Publishing Co., pp. 1303–1310.

# CURRICULUM VITAE

**Furkan Nuri KARAOĞLU**

Address : Yurt Mh. Mavi Blv. 70/3 No:4
Çukurova / Adana
Phone: +90 553 621 73 28
E-mail: furkannurikaraoglu@gmail.com

**Education**

| | | | |
|---|---|---|---|
| 2009 - 2015 | Bachelor of Science | University of Gaziantep | Physics Engineering |
| 2017 - Still | Master of Science | Adana Alparslan Türkeş Science and Technology University | Nanotechnology and Engineering Sciences |

**Experiences**

| | | |
|---|---|---|
| July 2014 – Feb. 2016 | Zahit Enerji San. Tic. LTD.ŞTİ | Photovoltaic QC Specialist and Production Engineer |
| Feb. 2016 – Feb. 2019 | Upsolar Middle East DIŞ. TİC. LTD. ŞTİ. | Sales and Technical Engineering for Photovoltaic Modules ( Turkey and Middle East) |
| Feb. 2019 – Feb. 2020 | Aldo Enerji | Photovoltaic Module Consultant |
| Feb. 2020 – Still | Çatalbaş Elektrik | Sales Enginner for PV Systems |

**Project**

| | | |
|---|---|---|
| 2014 | Argeti’14 Undergraduate Project | Projects competition winner with Sun, Moon and Mars Tracking system for Newtonian Type Telescope automation. |

**Certificates**

TSE Metrology and Calibration 2014
TSE EN ISO / IEC 17025 General Conditions for the Qualifications of Education Laboratory
Safety, Quality, Safety Discipline and Project University of Gaziantep
IKSAD – 2019 – Scientefic Presentation about Edge effect of impact
Literature Researching Techniques

**Social Educations**

| | | |
|---|---|---|
| 2014 | Mersin University | AB’14 Scientific Computing Course – Phyton Programming |
| 2016 | Uzman Language School | Improvement of speaking English |
| 2019 | Udemy | Ethical Hacking |

**Skills**

| | |
|---|---|
| Computer Software | Microsoft Office, HTML, C++, Visual Basic, Solidworks, Matlab, Arduino, Android Programming, Computer Hardware, Adobe Photoshop, Adobe After Effect, Adobe Premier Pro, Adobe Illustrator. |
| Languagers | Advanced in English |
| Visited Countries | Greece, Thailand, Iran, Jordan, Montenegro, Bosnia & Herzegoniva, Albania |