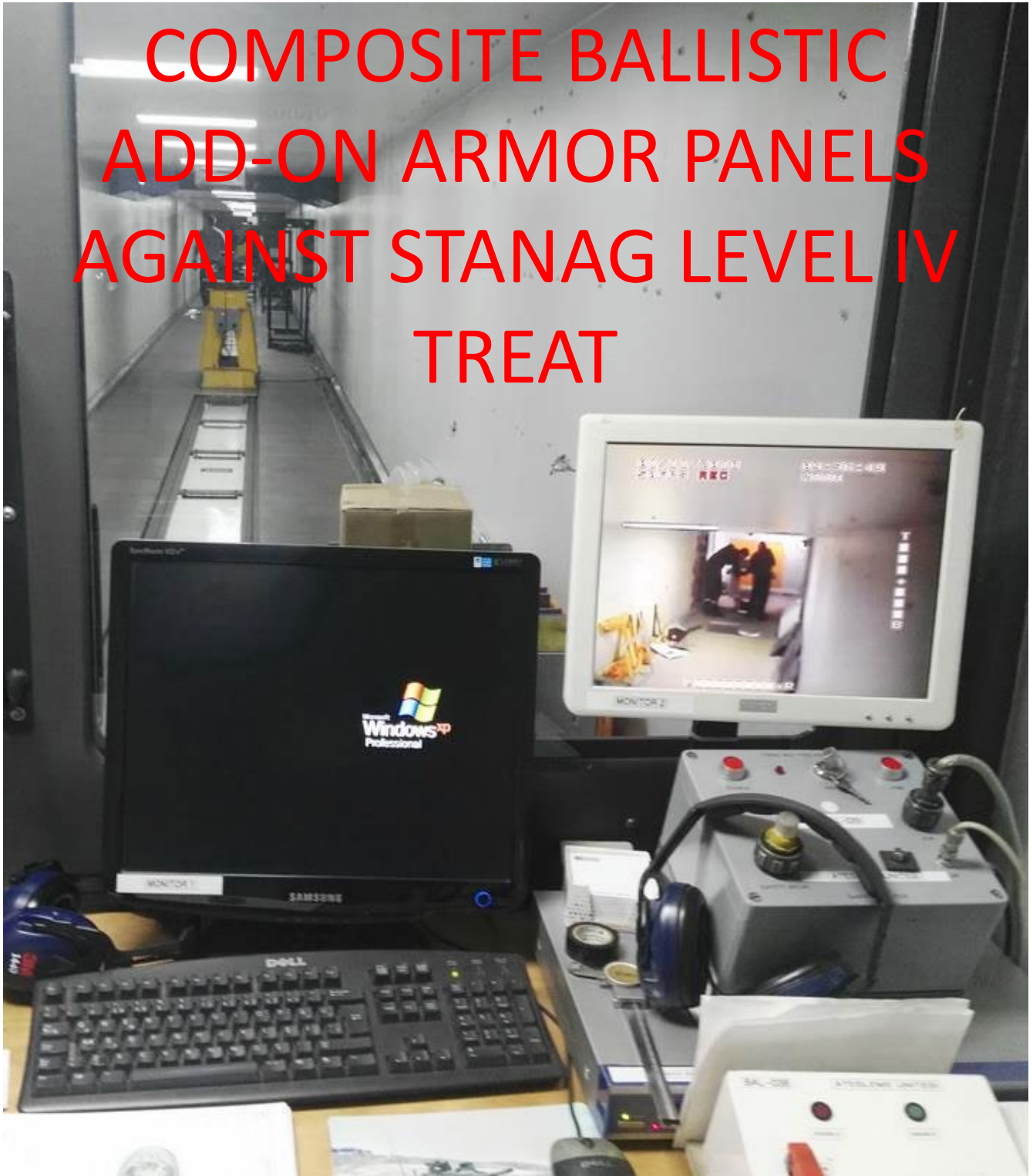


COMPOSITE BALLISTIC ADD-ON ARMOR PANELS AGAINST STANAG LEVEL IV TREAT



Greetings!

We want to introduce to you our project about ceramic faced composite ballistic add-on panels. In this study we concentrate on STANAG Level IV against 14.5 mm x 114 API projectile. This projectile's weight is 59.3–64.2 gram and muzzle velocity is 911 ± 20 m/sec. The energy of the bullet is 30,000 joules. It can penetrate 40 mm of armor steel from 100 meters. It is impossible to use 40 mm steel armor on armor vehicles (APCs) because of the weight. So, the main application for APCs is to use 6 mm armor plate for the body of APC and then add a ceramic faced composite ballistic plate on it, which is called as "Add-On Armor. There is no other practical solution in the world for this level.

The main layer alternatives for designing "Add-On Armor": (Front to back)

1. Spall-Liner

This liner made of UHMWPE (Dyneema) woven cloth.

1. The SiC Ceramics in the Add-On plate:

- a) Breaks the sharp tip of the bullet, causing decrease in the penetration effect of the bullet.
- b) Absorbs big amount of bullet's energy. That's why the "Fracture Toughness" of the ceramic is very important.
- c) It changes the direction of the bullet, so the way of bullet in the plate is increasing and cause to absorb around 30% of the bullet energy.

2. The Elastomer Layers in the Add-On plate:

- a) These elastic layers with different specs, works like a shock absorber in a car. They absorb most of the energy of the bullet and slow-down the speed of the bullet, which is one the most effective factor on the impact force of the bullet.
- b) These layers are made EPDM, EVA, PS or PP foam depending on design of the structure.

3. The 7075-T6 Aluminum Back-Plate and Mesh in the Add-On plate:

- a) Have a big effect on energy absorption (about 30%).
- b) The reason for using the mesh inside of the composite structure is:
 - To make the plate weigh lighter with high resistance to shocks.
 - To have better adhesion of the liners. Using a plate inside the composite backing layer, it will cause the layers delaminate easily under shock.
 - These layers absorb about 20% of the bullets energy.

4. The High-Fracture Toughness Elastic Epoxy Matrix in the Add-On plate:

Just like the other elastomer materials as layers of the plate, the elasticity of the epoxy is very important to absorb the energy and not break apart. If you use standard brittle epoxy, the damage area will be very large and it affects the multi-hit capability of the plate. My below test result pictures are showing the difference very clearly.

5. The Spall-Liner on the Front Surface of Add-On plate:

a) The spall-liner prevents fragmented ceramics to fly around and cause injuries of the soldiers around the armoured vehicle. This case creates serious casualties on the war zone. Spall-liner is one of the most important factors according to standards and regulations.

b) The spall-liner can be made of epoxy + fiberglass woven cloth or epoxy + Kevlar woven cloth or epoxy + UHMWPE woven cloth. In case of using UHMWPE material, it must be a loose woven cloth with enough spacing between the fibers for epoxy getting through from the cloth and adhere to the other layers or ceramics. Otherwise, when the bullet hits, delamination can easily occur and leave a large weak area for the second hit. Another solution for this problem of UHMWPE woven cloth is mixing fiberglass fiber in the woven cloth to have a good adhesion.

The reason to use different layer materials and elastomers is to widen the shock area and decrease the impact force to mm². The principle of this is:

The principle of bullet effect from my books is shown below:

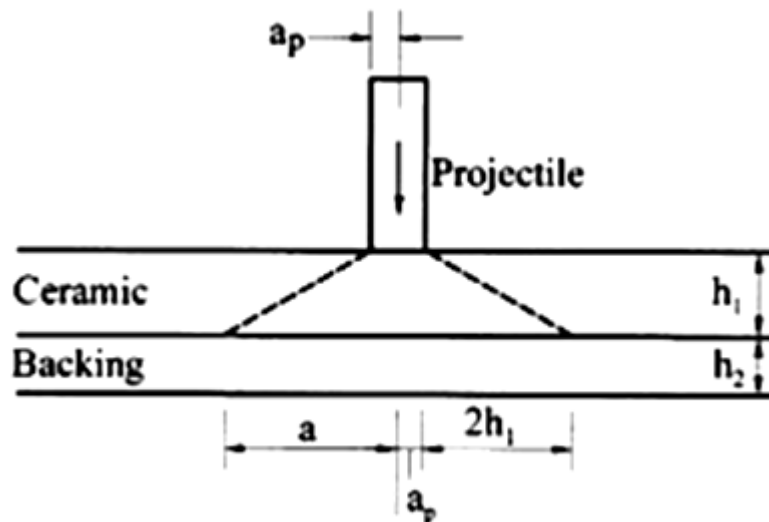


Figure: 1. Cone of Damage Formed in Ceramic Face-Plates in Composite Armor

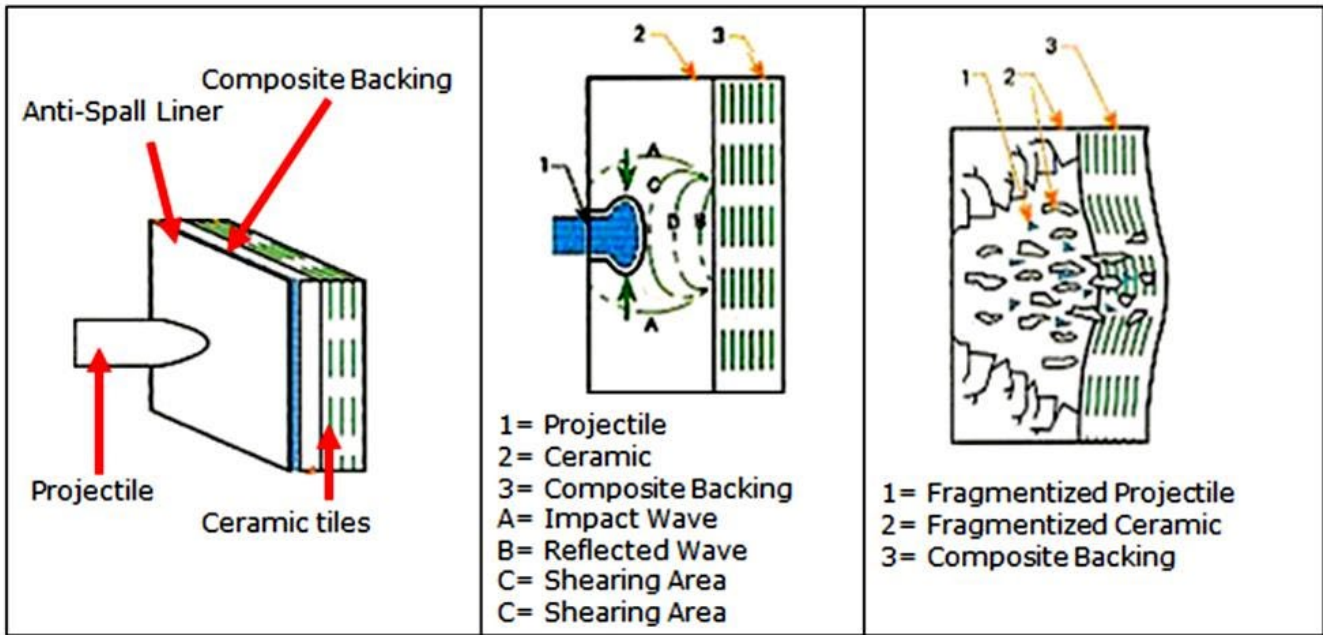


Figure: 2. Main principle of Ceramic-Composite armor

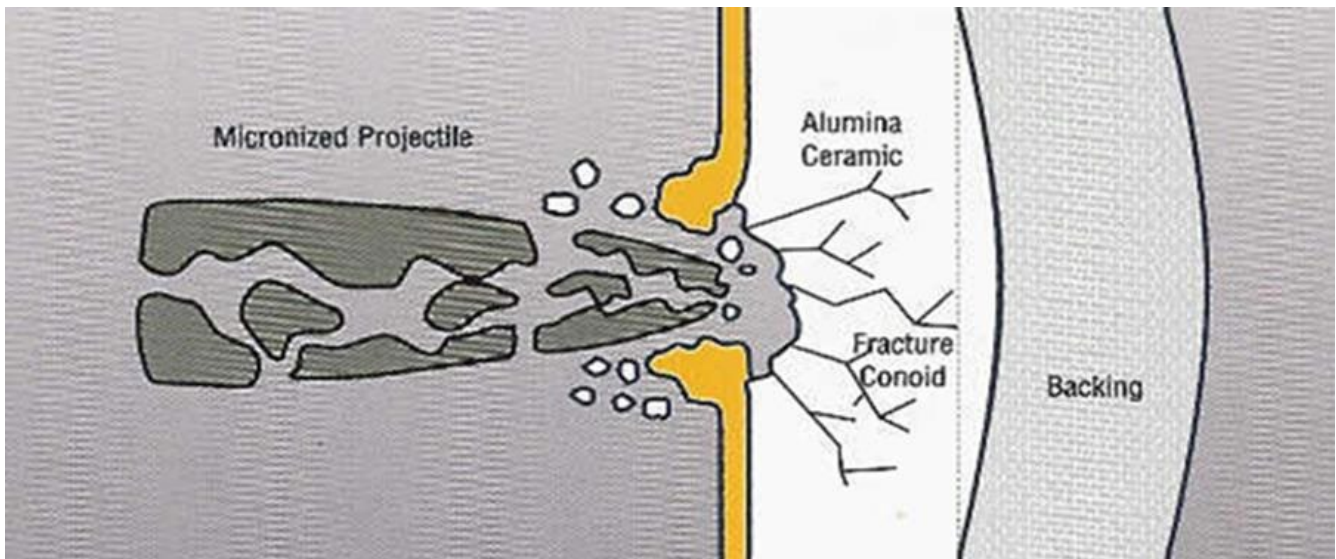


Figure: 3. Penetration and Protection Mechanism

Standard principle of Multi-Hit Type / Level IV Add-On Armor plate design:

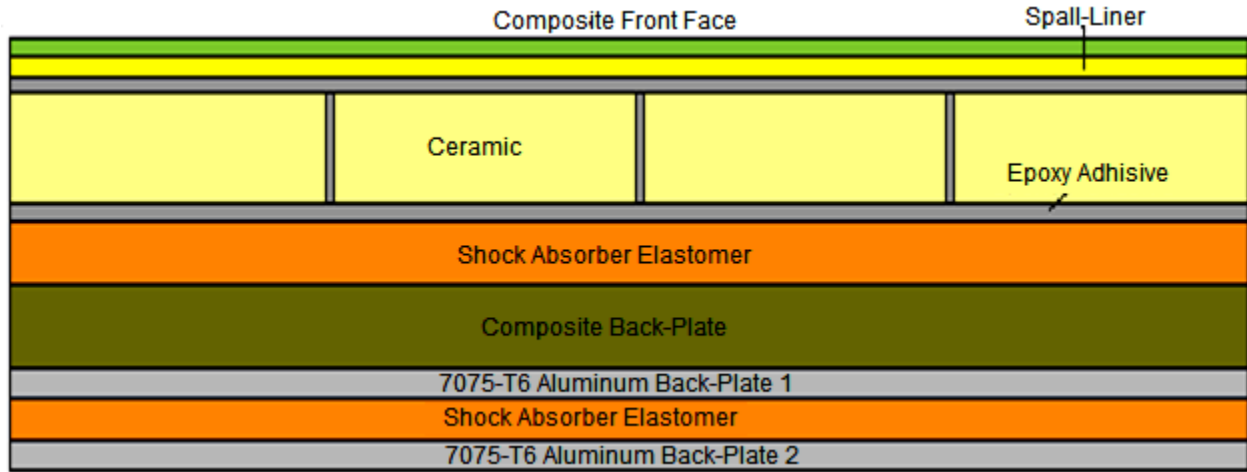


Figure: 4. Multi-Hit Type Panel Side View

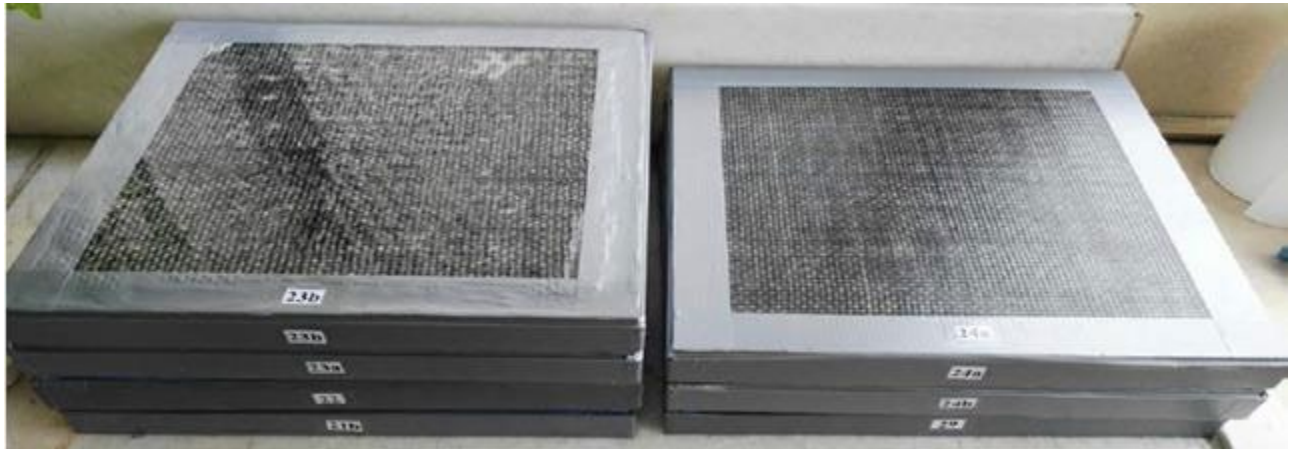


Figure: 5. Our Test Plates with Different Construction Alternatives

As tried to explain above, the main aim for ballistic add-on plate is to absorb the energy of the bullet as much as we can. The effect of energy absorption in different layers is roughly:

- Ceramics: 30%
- Composite backing design: 20%
- Aluminum plates and mesh: 20%
- Process method and application: 15%
- Workmanship quality: 15%

In case that there is something wrong with process method or workmanship, it can change these percentages; even this can destroy the whole result.

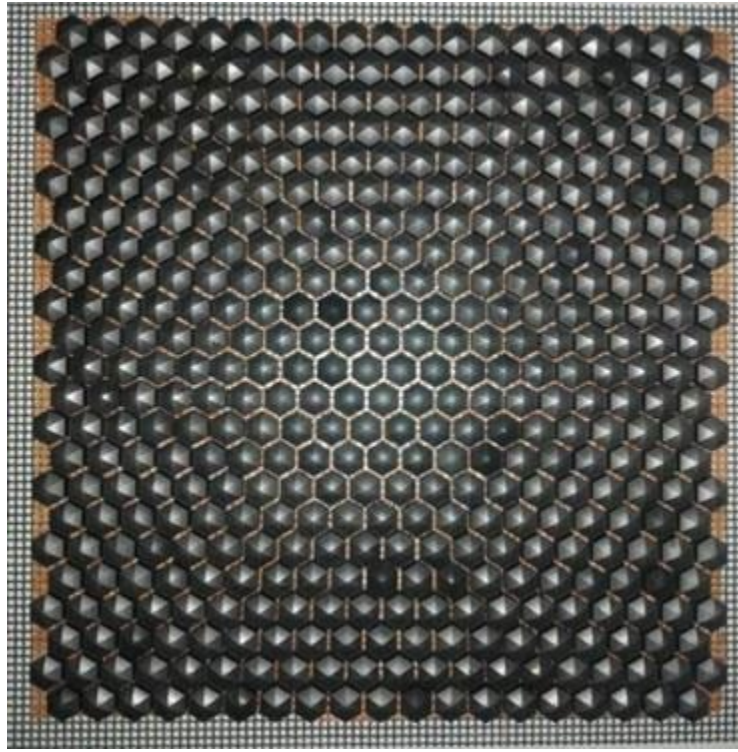
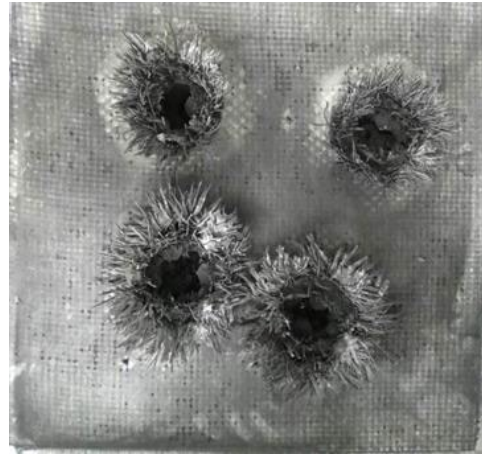


Figure: 6. Application of Ceramic Design and Spacing



Front-Face with 4 shots



Back-Face without Aluminum Back-Plate

Figure: 7. Another Test Panel with 4 Shots for Multi-Hit Application. This panel is has a Teflon Liner and without Aluminum Back-Plate. The result is successful.

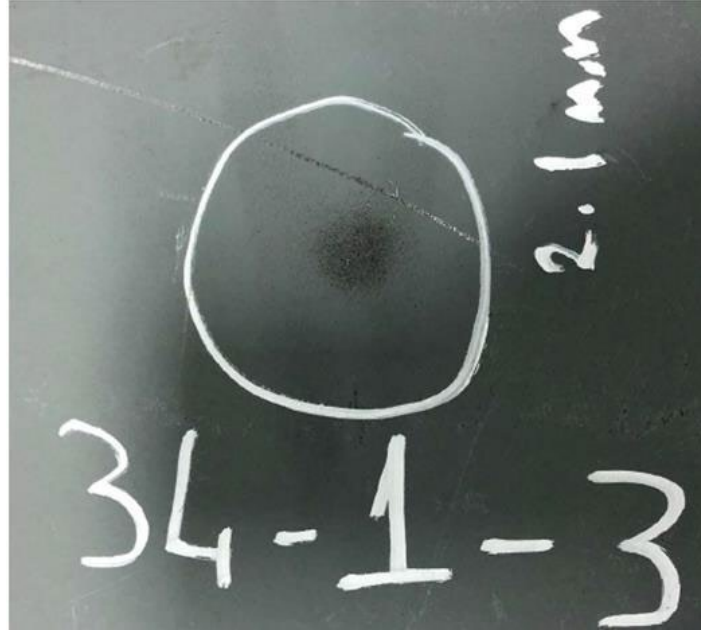


Figure: 8. Back view of the Witness-Plate
Result: Accepted

This application gave one of the best results in the series of tests. But adhesion problem and heavy weight of Teflon layer is creating problem in mass production of big size panel production.

SOME OF THE ACCEPTABLE TEST RESULTS OF THIS RESEARCH

THE TRACES LEFT ON THE 6 mm ARMOX STEEL WHITENESS-PLATE

1. PANEL 21A



Figure: 9. Back view of the Witness-Plate

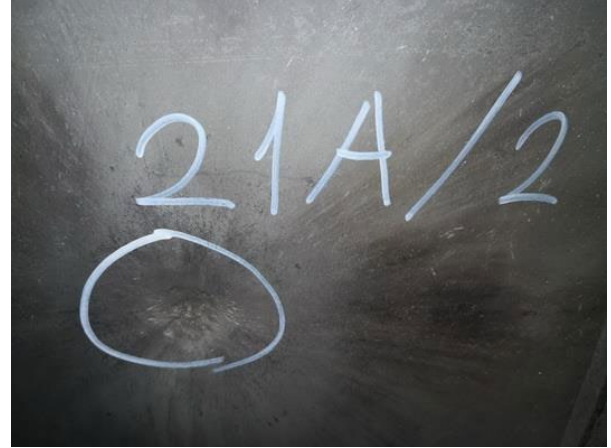


Figure: 10. Front view of the Witness-Plate

Result: Accepted

In Figure 10, traces of fragmentations of bullet core can be seen. This is the proof of effectiveness of ballistic panel construction.

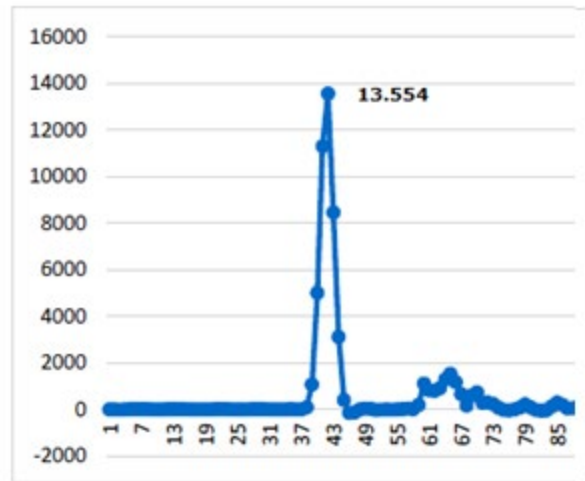
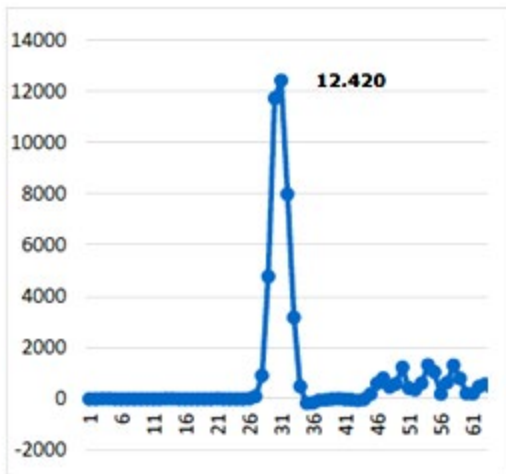


Figure: 11. Test Graphic of Bullet Impact Force (kgf)

2. PANEL 22

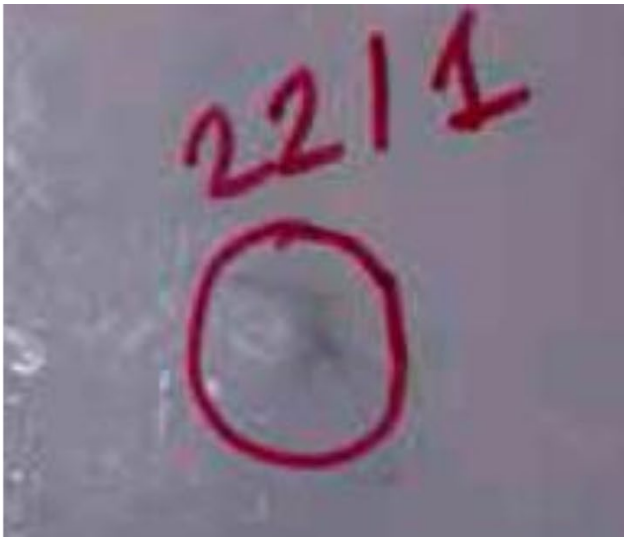


Figure: 12. Back view of the Witness-Plate after 2 shots
Result: Accepted

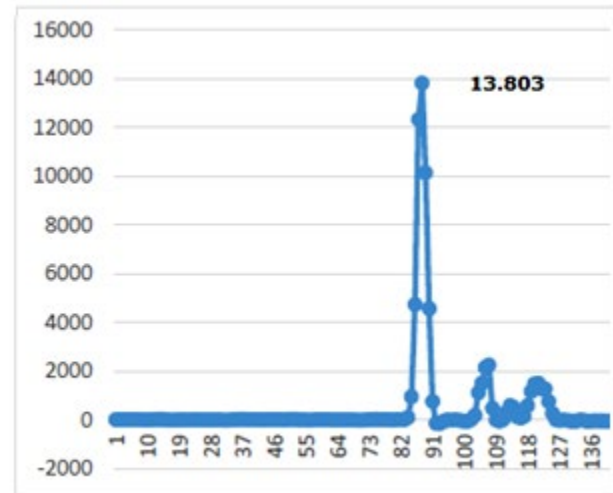
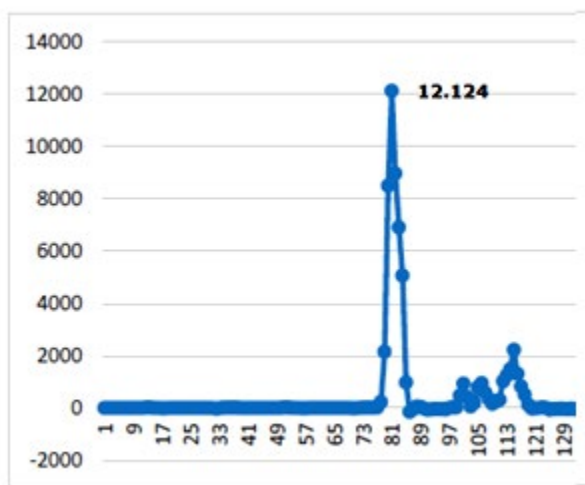
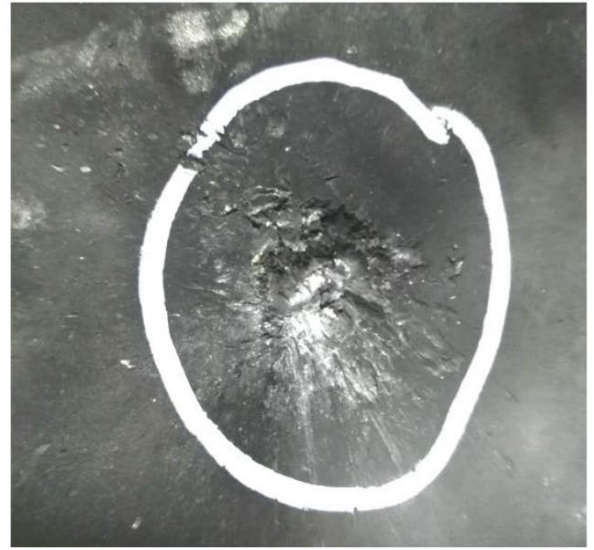
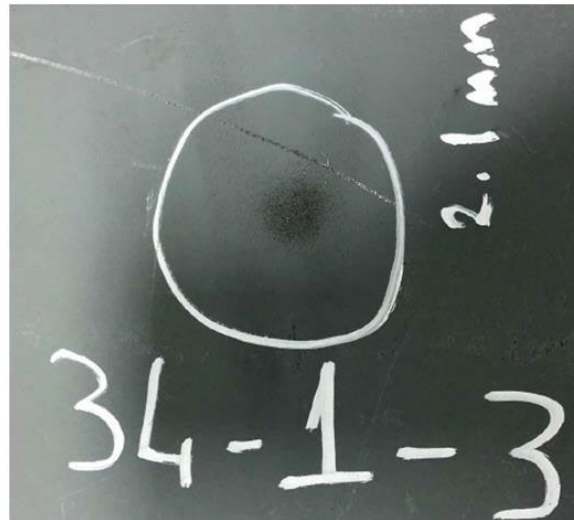


Figure: 13. Test Graphic of Impact Force (kgf)

3. PANEL 31-3**Figure: 14.** Back view of the Witness-Plate**Figure: 15.** Front view of the Witness-Plate**Result:** Accepted

In Figure 15, traces of fragmented bullet core hit point are clearly visible. This is the proof of effectiveness of ballistic panel construction.

4. PANEL 34-1**Figure: 16.** Back view of the Witness-Plate**Result:** Accepted

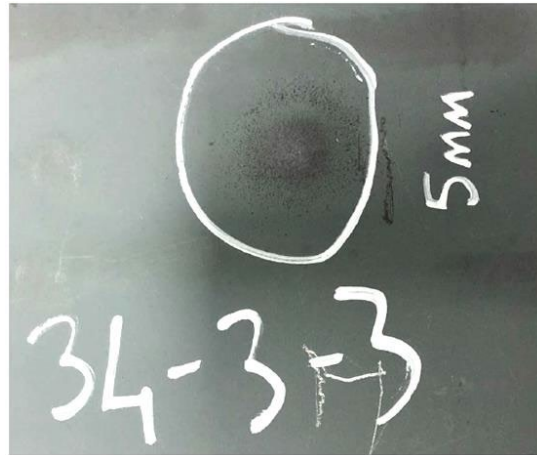
5. PANEL 34-3

Figure: 17. Back view of the Witness-Plate
Result: Accepted

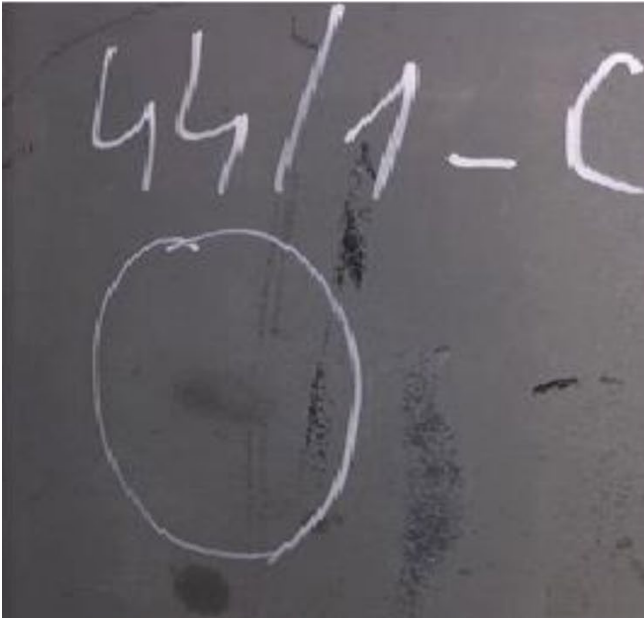
5. PANEL 44-1

Figure: 18. Back view of the Witness-Plate

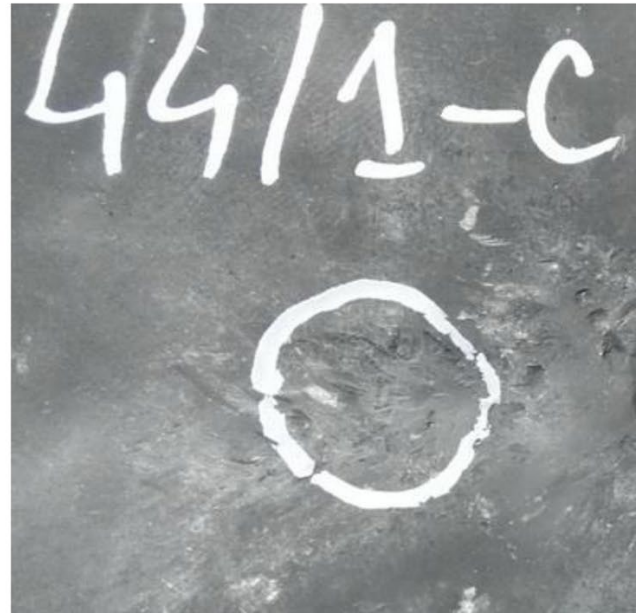


Figure: 19. Front view of the Witness-Plate

Result: Accepted

In Figure 19, traces of scattered small fragmentations of bullet core can be seen. This is the proof of effectiveness of ballistic panel construction.

SOME PICTURES OF 7075-T6 BALLISTIC ALUMINUM BACK-PLATES

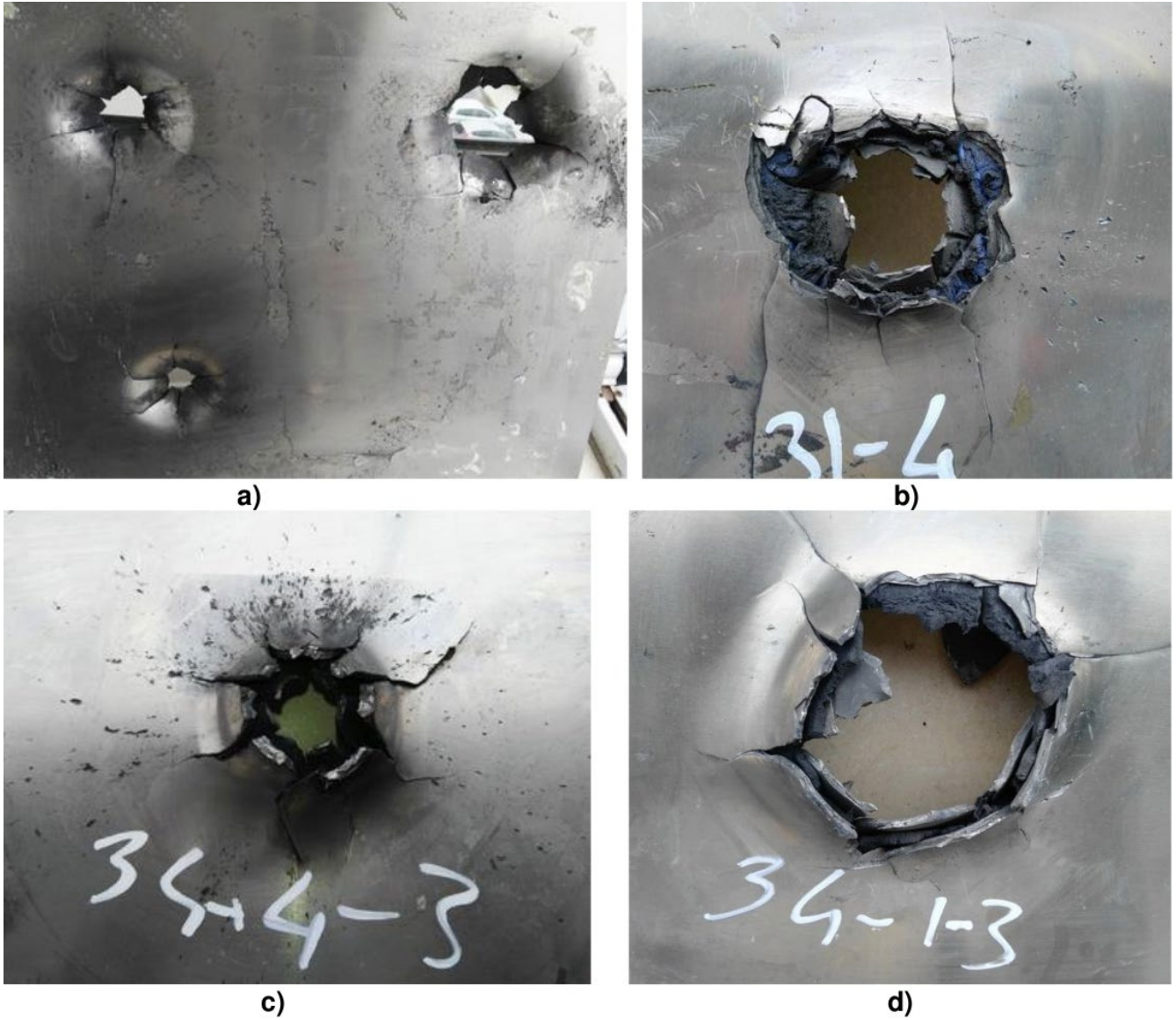


Figure: 20. Back View of Aluminum Back-Plates



Figure: 21. Front View of Aluminum Back-Plates

SOME PICTURES FROM TEST FACILITY



Figure: 22. Test Gun



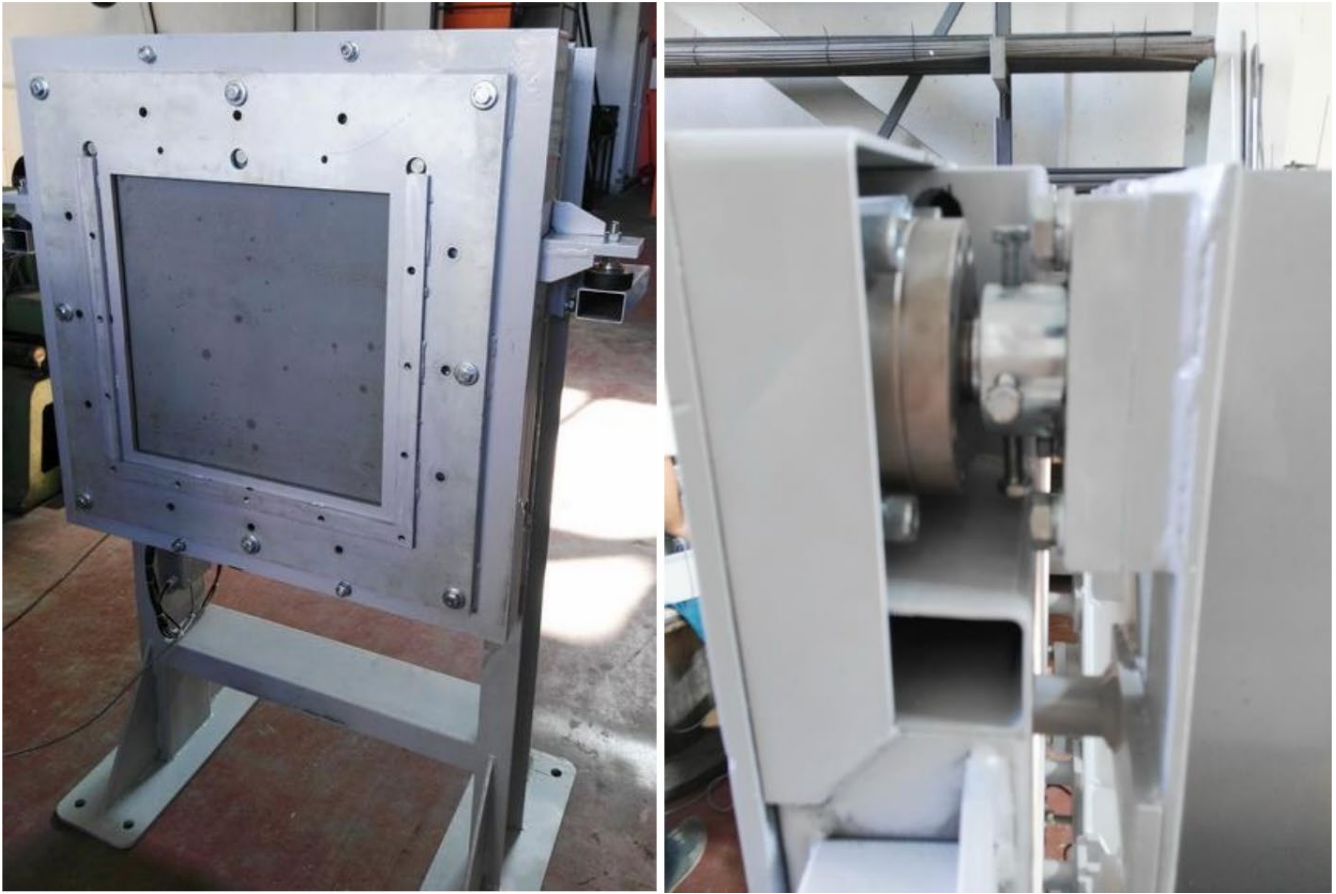
Figure: 23. Fire Control System



Figure: 24. Pictures from test facility in the factory and 14.5 mm bullet



Figure: 25. Target Fixing System of 500 mm x 500 mm Test Panels



a)

a) Test apparatus manufacturing stage in our factory.

b)

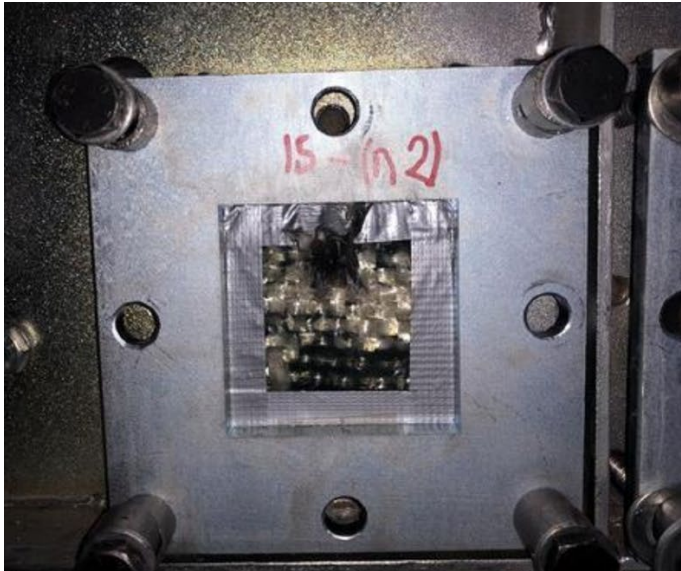
b) Computer controlled load-cell system to measure the hit energy and make energy absorption diagram

Figure: 26. System Details

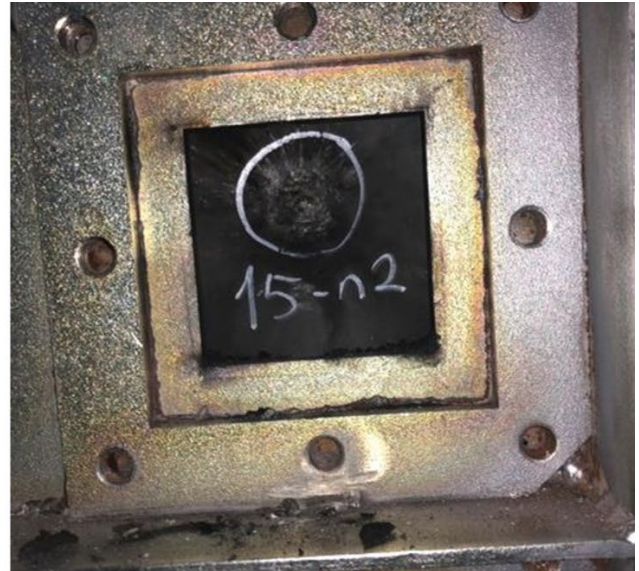
This system has 32 tons measuring capacity



Figure: 27. Target Fixing System of 100 mm x 100 mm Test Panels



a) Front Face



b) Back Face

Figure: 28. Close-Up of View of Target Fixing System of 100 mm x 100 mm Test Panels

CERAMICS USED IN THIS RESEARCH

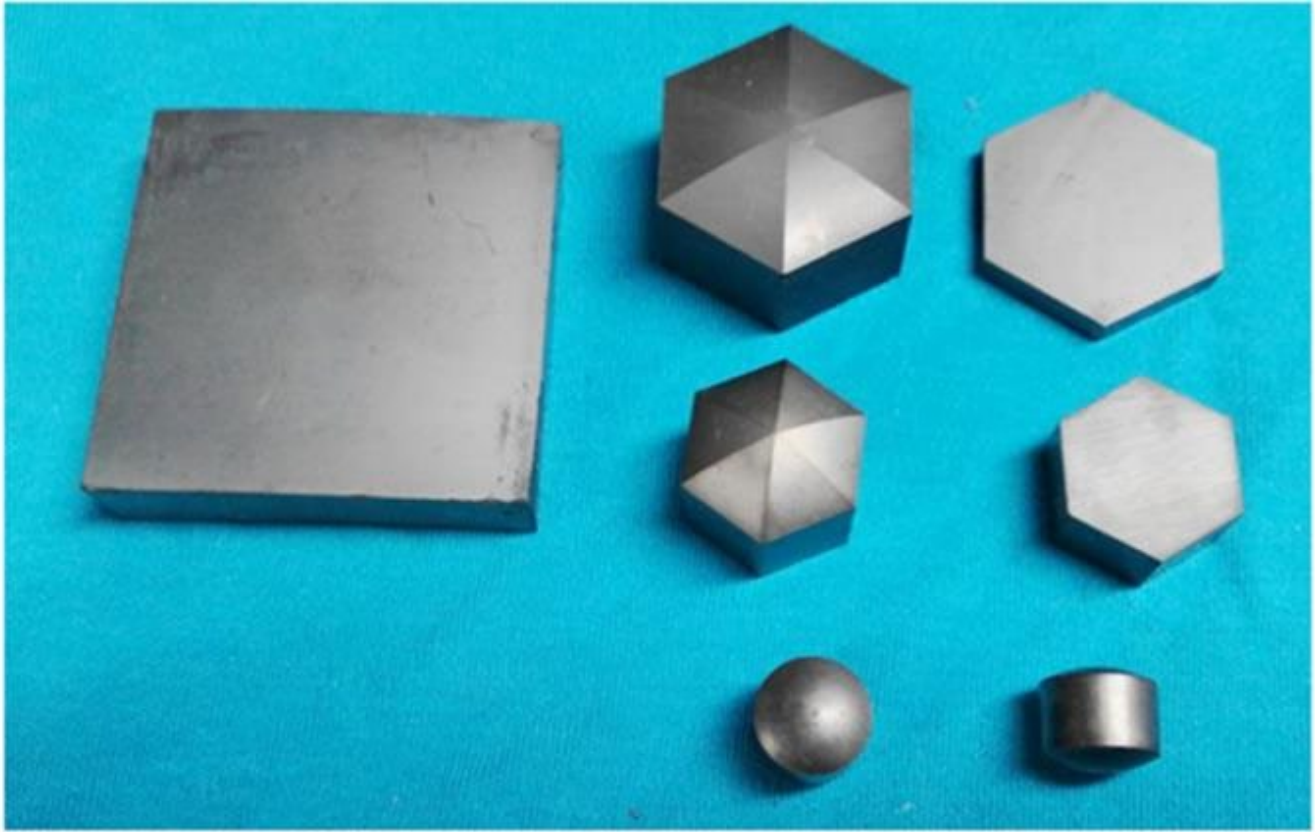


Figure: 29. Some samples of different shapes used in this R&D



Figure: 30. Hexagonal Ball-End Ceramics

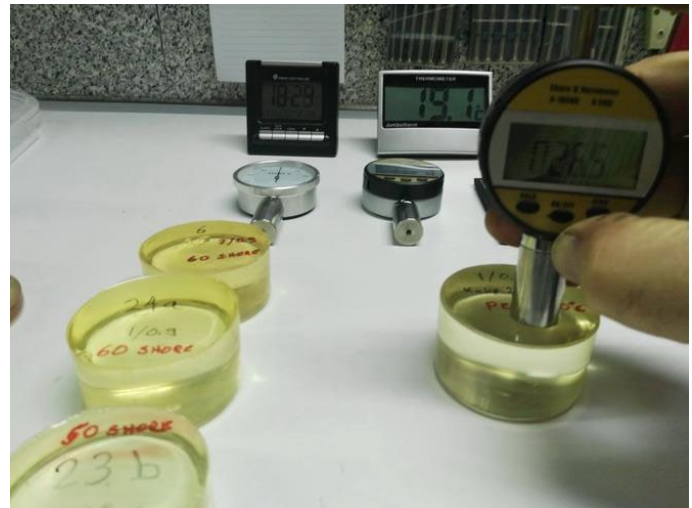


Figure: 31. Hexagonal Flat Ceramics



Figure: 32. Cylindrical Ball-End Ceramics

EPOXY FORMULATION AND APPLICATION RESEARCH







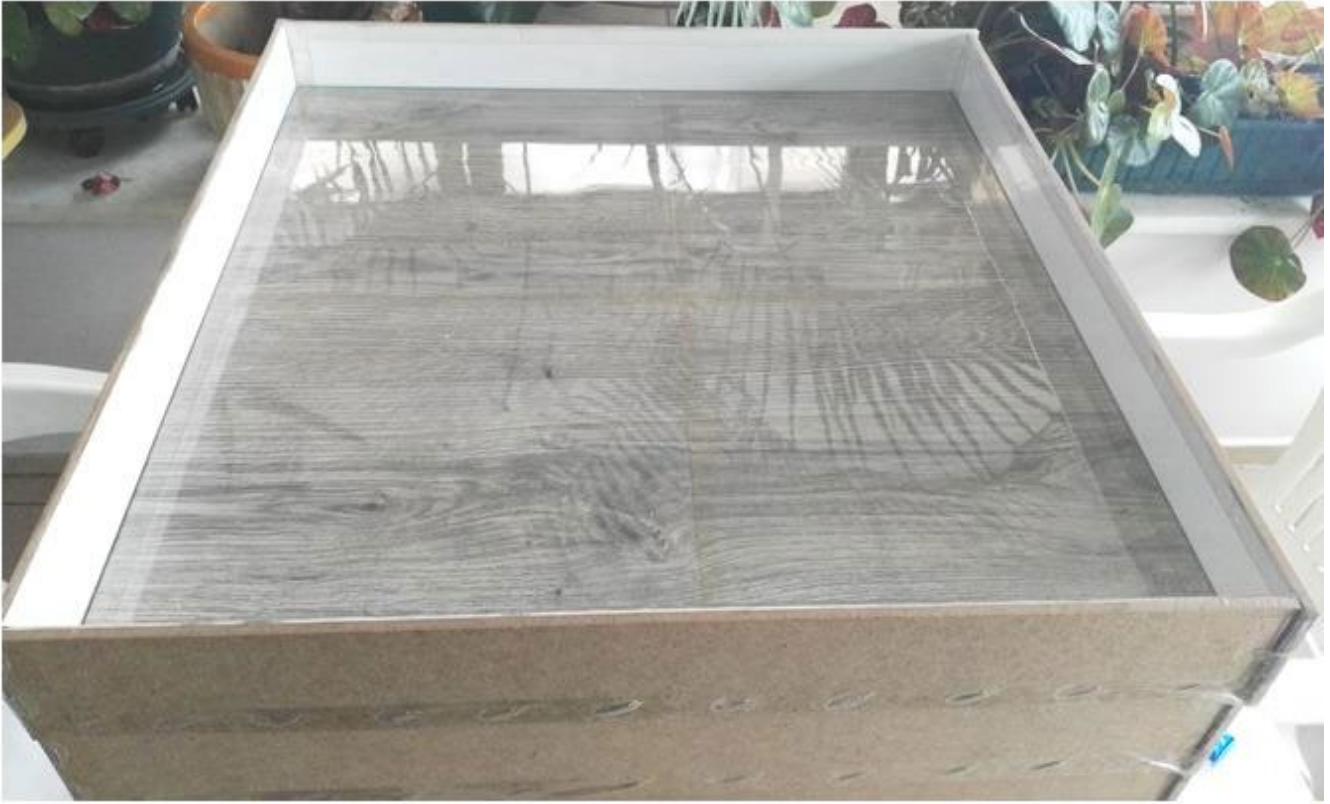




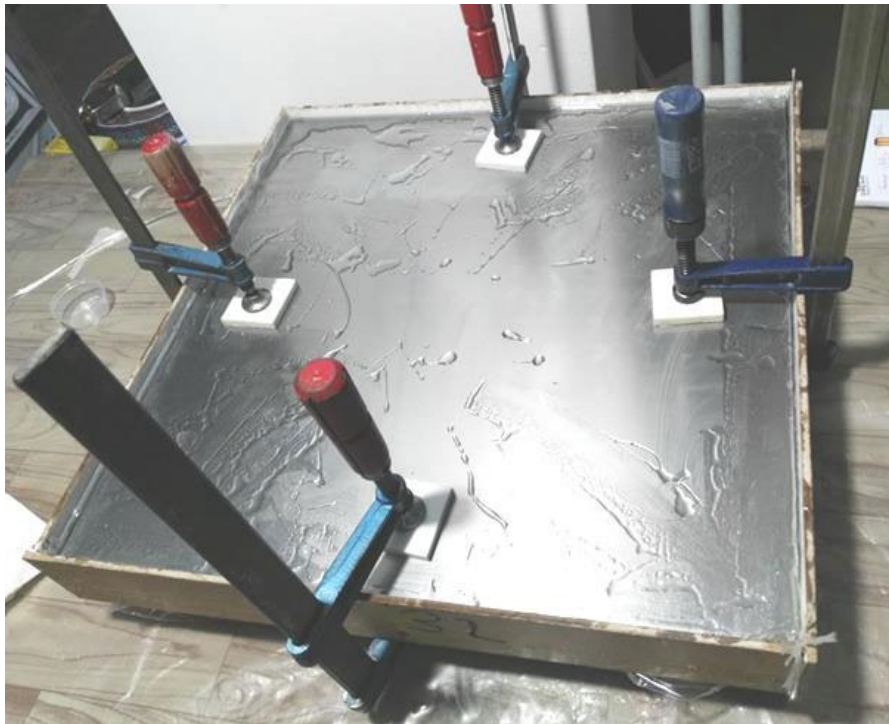
TEST PLATES PREPARING STAGES AND APPLICATIONS







500 x 500 mm test panel mold



Application



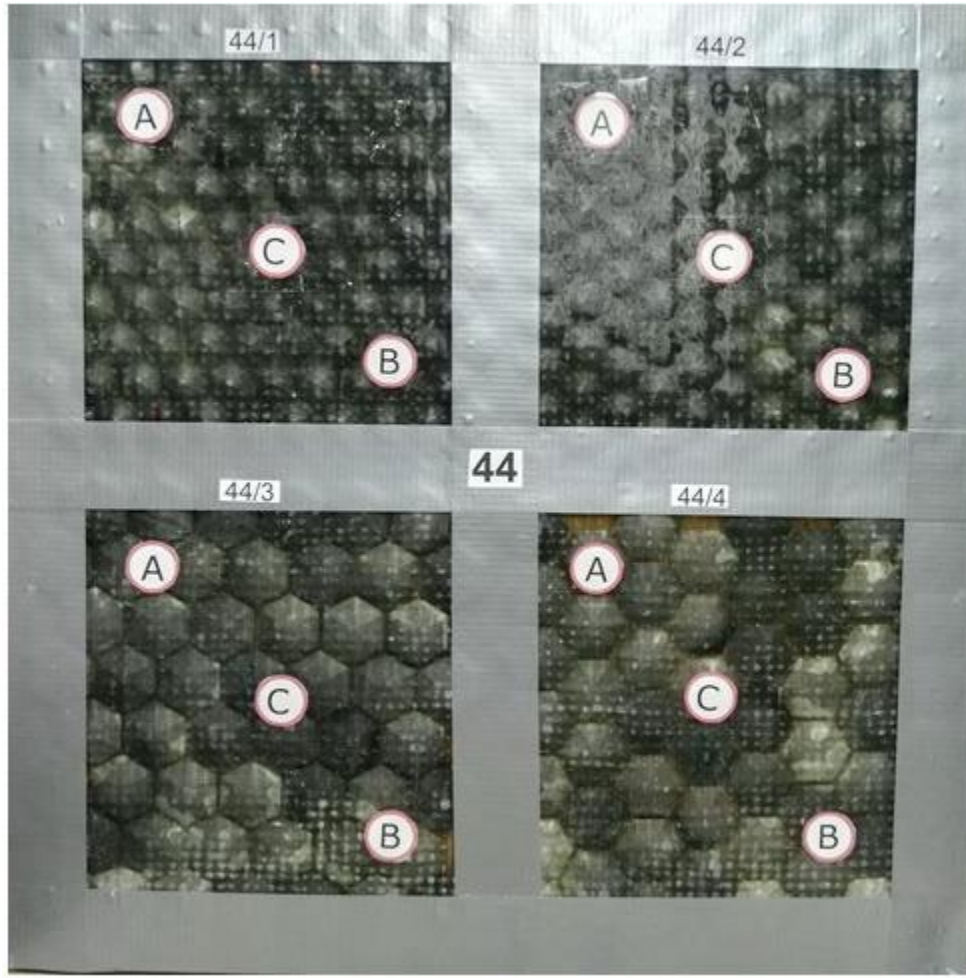
Finished Panel



4 Different ceramic applications in one plate



Epoxy application



Finished Panel ready for firing test