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Designing a Low-Cost, Reusable Bulletproof Vest: Comparative Evaluation of Clay and Ceramic Armor Plates

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Abstract

The study is a conception to prepare an ideal bulletproof vest for the armed forces and police in low cost as well as with multiple usages. In this study a novel bulletproof vest is designed which can be used multiple time by replacing the damaged part of the vest like armour plate or inner part i.e., kevlar in general but in this research, it is fiberglass mat. The armour plate is prepared by red clay and compared with ceramic plate. The results of the testing revealed that the clay plate is better than the ceramic plate as well as the fibreglass mat the damage is not much deeper the penetration in the armour plate has been seen in all the plate of both clay and ceramic but, the impact on the fiberglass mat was found only on the ceramic plate whereas on clay plate the fibreglass mat is not at all damaged and there is no any impact site which indicates that the clay plate as completely neutralised the bullet it has received the full impact leaving the inner armour safe and secure.

Keywords: Bulletproof Vest; Novel Design; Fiberglass; Clay Plate; Ceramic Plate

Introduction

Hostility is an emotion of human which leads a man into war and in war the protective armour is being used since very long back. Body armour is not a newly evolved concept it is well explained about the varma i.e., protecting the body using armour in shruthi, smrithi, ithiasa, puran and veda, especially Agni Purana in Rig Veda speaks about war art and protection wears in war Frawley D, et al. [1], Mishra A, et al. [2]. The great Indian epics like Ramayana & Mahabharat which is 7000- to 8000 year-old provides some of the literatures about the body armour Gangopadhyay BK [3]. Even it is believed that one of the prime character Karna was born with body armour. Hence, the protection wear and body armour are not new to human. The armour has not evolved just like that it has under gone evolution from tree bark, animal hide, metal sheet and metal wire woven shields and fibres as well as ballistic protective materials. The development of science and technology has revived the size, shape, and new polymers or fibres in accordance to the person Marszalek A, et al. [4].

Bulletproof vest is now part of the armed forces including police force as the weapons are is easily available in nuke and corners to people. Hence, the body armour plays a vital role in protecting the personal from the risk. The modern bullet proof vests came into market in late 19th century and the materials used in making bulletproof vest started with kevlar which has drastically changed the phase of armour Stopforth R, et al. [5]. The bulletproof vest is not just a suit it is a sandwich of multilayered protective materials which have hard material like ceramic plate and soft material like Kevlar Sastranegara A, et al. [6].

Designing the vest itself is very important thing which needs special attention while preparing the bulletproof vest Sheshadri VV, et al. [7], Muruganantham S, et al. [8]. While reviewing the articles on the bullet proof vest major articles are concentrating upon replacing the Kevlar with graphene and glass fibre Domun N, et al. [9], natural composite polymers Kumar R, et al. [10], Nurazzi NM, et al. [11], Fiber Carbon Composite and Hollow Glass Microsphere Pulungan MA, et al. [12], cordura and ballistic nylon using polyurethane Fayed AIH, et al. [13] etc, list of material will be very long but, when it is about the armour plate in the bulletproof vest the attention is less or not found. Thus, the research gap led us to take up study to design and develop a cost-effective, reusable bulletproof vest with replaceable components, including armor plates and inner protective layers and to conduct performance tests on clay and ceramic armor plates, evaluating their ability to absorb and neutralize bullet impact in small arms, as well as the level of protection provided by the inner fiberglass mat.

Material & Methods

Vest Design

First stage is designing a novel design for bulletproof vest which can be used multiple time so, the design was created with multiple pockets in frontside of the bulletproof vest which helps easy replacement of armour plates and from inside of the vest a separate pocket to place the fibreglass mat which is also easily replaceable one. A novel design for bulletproof vest has been designed as depicted below (Figure 1).

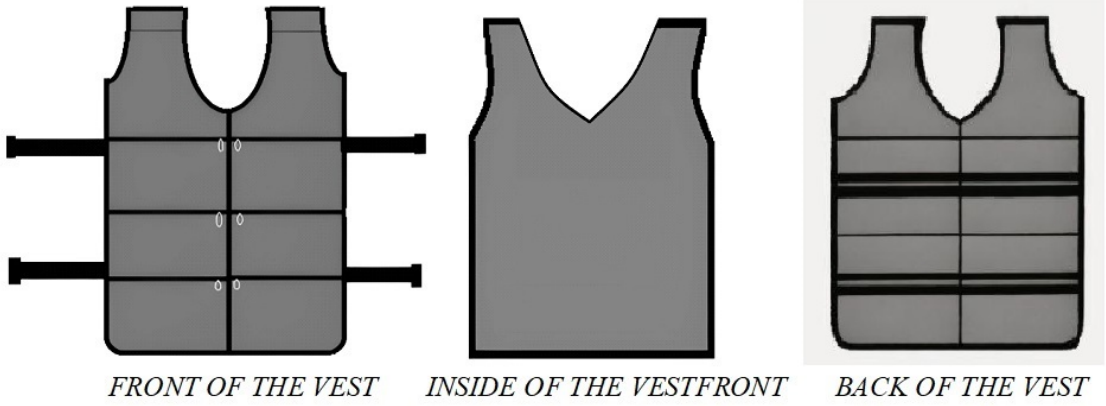


Figure 1: Novel Bulletproof Vest Design.

Ceramic & Clay Plate

Present study is about the integrity of clay and ceramic plates has the armour plates in the bulletproof vest. While choosing the materials ceramic plates is already been used in larger scale in bulletproof vest but moving towards and metallic plates. Such plates are heavy and will be a main hinderance in wearing during operation hence, in the present study at basic level the clay has been chosen after through research about the properties of clay and its usage as armour plates.

In next stage, available ceramic plate is used for the bulletproof vest and compared with clay plate as a novel replacement in the bulletproof vest for small arms. The ceramic plate used is readily available in market made out of calcium silicate, quartz etc., is been used as the ceramic plate and clay plate made out of red clay available in the local pottery market is being used. Clay plates were custom made and baked in kiln in high temperature and used in bullet proof vest has armor plate for testing using small arms or low velocity arms. Each plate weight is uniformly maintained at 400gms. Thickness measures about 1cm, with size in accordance to the pockets designed in vest i.e., height-13cm and breadth-18 cm respectively Gunes R, et al. [14] (Figure 2).

Figure 2: Clay & Ceramic Armour Plates Used for Testing.

Preparation of Fibreglass Protective Gear

In third stage first in accordance to the design the vest was stitched using rexine cloth and from inside to make it comfort used the cotton cloth. Then to reinforce the bulletproof vest from inside different fibreglass materials like, fibre stich mat 450gsm and fibreglass mat 450gsm has been utilised. The fibreglass mat was first layered down and applied the industry grade epoxy resin and then tacked the layer with stich mat and repeated the procedure for four times and then the fibreglass materials was allowed to dry in shade for 3 days and the fibreglass mat shield was ready Fejdys M, et al. [15] (Figure 3).

Figure 3: Inner Armour Prepared using Fiberglass Material.

Limitations of the Study

- Present study is limited to usage of small arms for testing due to lack of accessibility to higher caliber arms.
- Present study is limited to testing of design of bulletproof vest and to check its integrity.
- Present study is limited to comparison of clay and ceramic plates as armors in bulletproof vest.

Testing

Finally, all the parts were brought together and the bulletproof vest is ready for testing. For testing purpose permission is sought from Madurai Rifle club and bulletproof vest is tested using. 22 caliber one of the low velocity arm, Walther KK500 rifle was used for firing from three ranges i.e., 50-meter, 25-meter and 15-meter respectively. Torque of the rifle is between 3 to 4nm and it varies with respect to the different ranges where if the target is near the rifle velocity will be relatively high as the range increases the velocity decreases and damage caused by the bullet also varies. The testing was limited to 22 caliber rifle a low velocity arm and due to the non-availability of any other small arms for testing (Figure 4).

Figure 4: Test Fire on Bulletproof Vest.

Results & Discussion

Bullet proof vest was tested and the results are as follows (Figure 5).

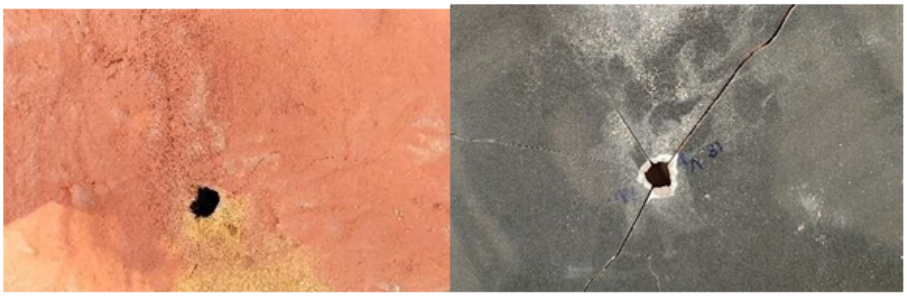
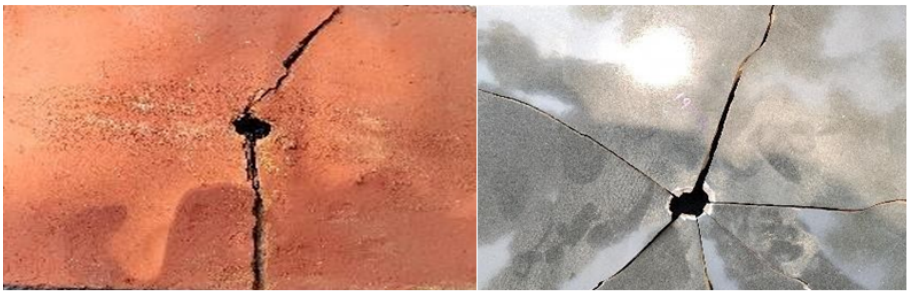


Figure 5: Damage to the armour plates at 50meter distance.

The above figures indicate the damages created by the bullet on the armour plates kept inside the bulletproof vest. Where it is very clear that at 50meter distance the. 22 calibre rifle penetration is found very clearly without breaking the clay plate it has just one single bullet hole but, at the same time the ceramic plate as sustained a full crack and it has broken into 4 pieces (Figure 6).



Clay Plate Ceramic Plate

Figure 6: Damage to the armour plates at 25meter distance.

The above figures represent the damage on plates at the distance of 25meter firing test where the damage to clay plate is less compared to the ceramic plate where the ceramic plate is broken into 6 pieces whereas clay plate into just 2 pieces (Figure 7).

Clay Plate Ceramic Plate

Figure 7: Damage to the armour plates at 15meter distance.

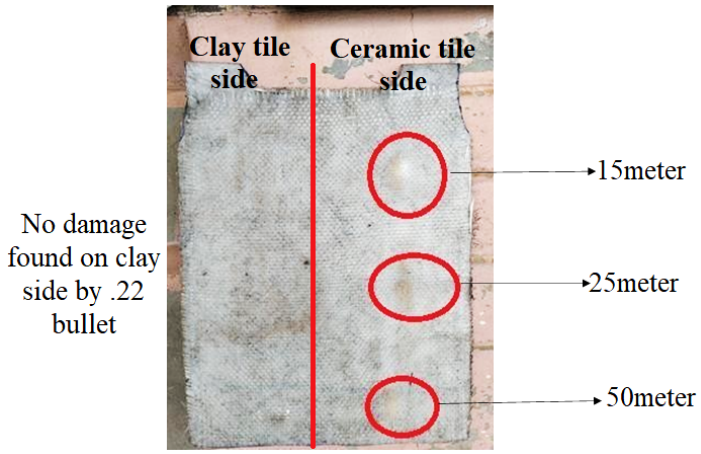


Figure 8: Damage to the fiberglass at different firing distance.

The above figures give an insight that the damage to the armour plate due to the firing test at 15meter where the damage to clay plate is comparatively less with that off ceramic plate. The ceramic plate has been broken in two directions in both radial as well as concentric fracture indicating its weakness compared to clay plate (Figure 8).

The above figure provides the impact mark on the fiber, it seems to be less damage in long distance and more damage in short distance, the impact mark seemed to be deeper compared to long distance on ceramic plate side. As far as the analysis of fibre and vest were completed and overall comparison based on damage on the ceramic plate and clay plate sides it is easy to identify which type of armor plate is more stable and has more resistant against the bullet.

Discussion

Performance of Ceramic Plates

- Significant damage was detected on the ceramic plate side, especially at closer ranges.
- The damage decreased with increased firing distance as the bullet's velocity reduced. At longer ranges, only surface-level contact damage was observed.
- The ceramic plates exhibited cracks and fractures upon impact, which compromised their structural integrity. This is attributed to the material composition and production methods of the ceramic plates. According to Rahbek DB, et al. [16], ceramic plates are prone to cracking due to the restraining effect under high-impact conditions, reducing their resistance to ballistic impacts.

Performance of Clay Plates

- In contrast, the side of the vest protected by clay plates showed no damage to the inner vest or fiberglass mat, even at closer firing distances.
- The clay plates effectively absorbed and dispersed the energy of the projectile, preventing any penetration or damage to the inner layers of the vest. This suggests that clay plates offer better overall protection.
- The study suggests that the superior performance of clay plates may be due to their material properties, including higher elasticity, contraction, and greater energy absorption capacity.

Comparison of Material Properties

Ceramic Plates: Ceramic plates are kiln-fired at high temperatures, but their durability is limited by their material composition and firing process. The study highlights that the ceramic plates used in this test were less dense, softer, and more porous compared to porcelain, which contributed to their fragility.

Clay Plates: The clay plates demonstrated greater resistance and durability. Their effectiveness is largely due to the clay's mineral content, which provides advantageous properties such as higher elasticity, squeezability, and lower shear strength, as noted by Wagner J [17]. These characteristics make clay plates more resistant to ballistic impacts and less prone to cracking. Additionally, clays are characterized by very low hydraulic conductivity and gas penetrability, as highlighted by Yu M, et al. [18].

Influence of Firing Range

As firing distance increased, both plates experienced reduced damage, with clay plates consistently showing superior performance. The outermost layer of the vest sustained only minor contact damage at longer ranges, while the inner fiberglass mat remained intact on the clay-protected side.

Conclusion

The current research explores the potential of ancient armor plating techniques, particularly the use of clay plates, to withstand modern weaponry. The experiment aimed to assess whether these traditional methods could offer viable protection against contemporary arms. The results indicate that clay plates outperformed ceramic plates in the tests, demonstrating better resistance to impact and causing less damage to the fiberglass mat of the vest. While the study did not involve firearms with higher velocities, the findings are promising, suggesting that clay plates could be further refined and tested under more extreme conditions to evaluate their effectiveness against more powerful weapons. This research provides a valuable foundation for improving and adapting age-old techniques for modern applications.

Future Research

The researcher for further higher-level study suggests that the clay's integral structure can be improvised with some supplementary materials and a better and weightless armour plates can be produced for testing. For better understanding of the clay plates significance heavy calibre weapons may be utilized for testing in future research.

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