Behind armour effects for overmatch threats

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Abstract. Body armour systems, such as bullet-resistant vests or fragment-resistant helmets, are tested extensively according to different norms and standards before being introduced into service, in order to ensure the systems can provide the required level of protection. Unfortunately, a number of issues have recently emerged with in-service body armour and personal equipment for which currently no clear answer exists. This includes, among other things, differences in ballistic performance that have been noted due to differences between how in-service body armour behaves in operational circumstances, and how it behaves under controlled laboratory conditions during evaluation testing. This work will more specifically focus on the influence of the torso body armour on the wounding capacity of the projectile in case of overmatching threats. A selection of four different projectiles was made, based on their availability and their overmatching capabilities for different types of ballistic vests. For the soft armour vest the 7.62 x 39 mm M43 and the 5.56 x 45 mm NATO Ball projectiles were used. For the ceramic plate in conjunction with the soft armour vest, the .338 AP Lapua Mag and the 7.62 x 51 mm AP8 projectiles were selected. The residual wounding potential of the overmatching threats is determined using the standard approach of evaluating the energy deposit of the projectile inside gelatine, next to assessing the integrity of the projectile. This work will help better understand the behind armour effects for overmatch threats for several combinations of projectiles and ballistic vests. The effects of high velocity rifle bullets on soft armour vests will be investigated as well as the effects of armour-piercing sniper ammunition on hard armour plates. The results will give an idea about which combination of ammunition and ballistic protection is worth investigating more thoroughly during further research. Combining all the results of the four different combinations, it is possible to conclude that the temporary cavity on the gelatine occurred sooner when ballistic protection is worn. This research confirms that cavitation occurs sooner when the body armour is worn. However, no clear answer can be found to the question whether wearing body armour causes more damage or not to the body in the case of an overmatching threat. Some factors influencing wound severity seem to be worse in case of protected gelatine blocks (45 x 15 x 15 cm), while others do not. The gelatine block is 20 % concentration. Nonetheless, this research came with some new insights into the behind armour effects of overmatch threats for ceramic plates in conjunction with soft ballistic armour vests. The behaviour of the two projectiles impacting the ballistic armour with the ceramic plate is different to the two projectiles impacting the soft vest directly. In summary, regardless of whether the ballistic vest is worn or not in the case of an overmatch threat, all shots can cause a lot of damage on the human body which would most likely result in a neutralized target if they hit a vital organ.

1. INTRODUCTION

Police officers and military personnel wear body armour to prevent injuries from different threats, including firearms. The purpose of armour is hence to protect its wearer from specific threats [1]. In the case of a ballistic protection, a ballistic vest typically absorbs the kinetic energy of a bullet or fragments it in order to stop the fragments. Unfortunately, a ballistic vest does not stop every bullet. When a projectile completely perforates a specific vest, one speaks about an overmatch threat for that type of vest. There has been only limited research caried out on the effect of rifle bullets on tissue after the perforation of ballistic armour. This is the reason why this additional research was deemed necessary. Breteau et al. produced some remarkable hypothesis in 1989. During test firing on animals, they found that entrance wounds were larger for animals protected by soft and hard body armour, than those observed without protection. For the former case, the scientists also remarked that the neck was shorter and the cavity occurred earlier in the body. As a conclusion, Breteau et al. hypothesised that wearing body armour would cause greater damage [2].

These experiments have given rise to many ideas, even some scientists that started to think about the usefulness of not wearing armour. Their reasoning is in line to the hypothesis that Breteau et al. stated. As projectiles seem to have the tendency to tumble earlier inside the body when they have to pierce a ballistic vest, they might cause more damage compared with not wearing a vest. The quicker a projectile is destabilized, the earlier it induces larger cavities. The moment at which the projectile tumbles (prompt or late), determines the size of the entrance wound and the magnitude of the internal cavity. If its longitudinal axis does not deviate from its trajectory, the bullet does not cause as much damage.

To give the wound ballistics world some insight about this rumour, several researchers performed test firings. Their research led to some of the following insights.

https://doi.org/10.52202/080042-0010

As a first deduction, scientists confirmed that the projectile is destabilized much faster after perforating the vest, causing it to tumble sooner. However, Lanthier [3] remarked that this does not necessarily mean that more damage is inflicted to the tissue. During his experiments, he noticed that the total size of the cavity was smaller when a 5.45 x 39 mm bullet first perforated a soft armour vest compared with an unprotected body. Nevertheless, Mabbot et al. discovered that “earlier cavitation in a human target could cause more disruption and damage to a more susceptible area” [4].Yet, the authors also found that the cavity decreases for some projectile-armour combinations when the targets are armoured and conclude that “overmatching cannot be generalised for all overmatching scenarios” [4].

Secondly, one of the experiments conducted by Missliwetz et al. showed that the diameter of the temporary cavity was larger for the shots where body armour was present. The tests were conducted with 5.56 x 45 mm ammunition on light Kevlar® vests. Nonetheless, they did not mention a potential reason for this observation [5].

Thirdly, when ballistic protection surrounds a body, projectiles seem to have the tendency to bounce back in the body when they impact on the back armour after passing through the body. That way, the projectile can damage more vital organs and the risk of infection increases [1].

In conclusion, unambiguous insights have yet to be found regarding behind armour effects for overmatch threats. Yet it is already clear that a lot depends on which type of vest is combined with which projectile.

2. EXPERIMENTAL SETUP

The research described here, considers two different ballistic personal armour systems: a soft armour vest (NIJ-0101.06 level IIIA) and an in-conjunction plate with armour vest (NIJ-0101.06 level IV) (Figure 37). The two projectiles used for the soft vest test were: 7.62 x 39 mm M43 and the 5.56 x 45 mm NATO Ball. Both projectiles are full metal jacket (FMJ) constructions with a steel core or penetrator. For the soft vest in combination with the ceramic plate (Setup 2), two different armour-piercing ammunition types were used: .338 AP Lapua Mag and the 7.62 x 51 mm AP8. Both projectiles consist of a brass jacket and a tungsten carbide core.

Soft armour vest Level IIIA   In-conjunction plate + vest Level IV

Figure 37. Left: soft armour vest; right: in conjunction vest (soft vest with a ceramic insert).

Figure 38 shows the schematic representation of the experimental tests. For these tests, a universal receiver with interchangeable barrel was used and the targets were placed at 15 m from the muzzle. A double velocity base was used to measure the projectile velocity. Two different target configurations were tested: the stand-alone gelatine block called Setup 1 and the two armour systems with the gelatine block on the back called Setup 2. For each type of projectile, three shots were performed.

Table 21 summarises all different experimental tests performed.

Table 21. Experimental tests

Projectile	Average Impact velocity (m/s) Setup 1	Target Setup 1	Impact velocity (m/s) Setup 2	Target Setup 2	Number of tests	Name

https://doi.org/10.52202/080042-0010

7.62 x 39 mm M43	746	gelatine	740	Soft armour vest Level IIIA + gelatine	3	Combination 1
5.56 x 45 mm NATO Ball projectile	979	gelatine	981	Soft armour vest Level IIIA + gelatine	3	Combination 2
.338 AP	858	gelatine	859	In-conjunction plate + vest Level IV + gelatine	3	Combination 3
7.62 x 51 mm AP8	903	gelatine	903	In-conjunction plate + vest Level IV + gelatine	3	Combination 4

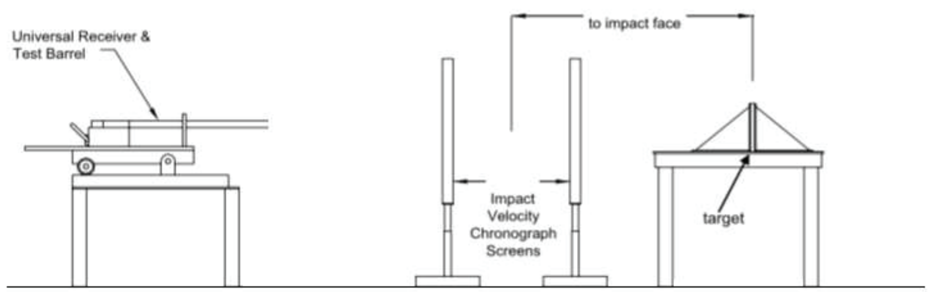

Figure 38. Schematic representation of the experimental tests.

3. RESULTS AND DISCUSSION

3.1 Quantitative analysis

For the quantitative comparison, two methods are used to obtain results related with the temporary cavity and the amount of kinetic energy that is transferred from the projectile to the gelatine block. The first method is a manual and labour-intensive practice, and is known as the Crack Length Method (CLM), whereas the second method is based on analysing the image recordings of the high-speed cameras using the PFV-software of the cameras.

3.1.1 Crack length method

By using the CLM, it is possible to estimate the transferred kinetic energy to the gelatine block. The method is based on measuring the total sum of the lengths of the cracks in different cross-sections of a block of gelatine. This Total Crack Length is proportional to the kinetic energy deposited by the projectile into the gelatine. The higher the Total Crack Length, the higher the transferred kinetic energy, consequently more tissue is damaged.

However, this method does not give a precise result in terms of kinetic energy. For example, poor visibility in the block can cause some cracks not to be taken into account. It is also possible that secondary cracks emerge from handling the block. Furthermore, the crack patterns are difficult to preserve since the gelatine deteriorates over time [6].

3.1.2 PFV-software

Due to the aforementioned issues with the CLM method, the transferred kinetic energy will also be calculated using the PFV-software, in order to confirm the accuracy of the results obtained by measurement of the different cracks.

https://doi.org/10.52202/080042-0010

In the software provided with the high-speed camera (Photron), different calculations can be performed, based on the images recorded from the high-speed cameras. First of all, the velocity of a projectile can be measured using the tracking function. This function enables the user to manually track the course of an object, in this case the bullet and its fragments, frame per frame. Knowing the pixel-to-mm ratio and the moment at which each frame was recorded, one can easily calculate the projectile's velocity. For each shot, the velocity of the respective projectile was calculated just before penetration of the ballistic gelatine and just after exiting the block, using this tracking method. Hence, knowing the entrance and exit velocity of a projectile allows calculation of the transferred kinetic energy. When using the same technique for each shot, it will allow correct comparison of the results between different settings. However, this method is not flawless either. Manually tracking the projectiles, can lead to small mistakes, resulting in diverging velocities. The PFV-software also allows to quantify the dimensions of the temporary cavity at a certain moment in time.

3.1.3 Analysis of the results

Combination 1: 7.62 x 39 mm M43 and soft armour vest

The first combination that is examined is a soft armour vest Level IIIA vest with a 7.62 x 39 mm M43 projectile. Plotting the crack length for each slice of gelatine (3 cm thickness each) on a graph, provides a graphical visualisation of the cavity within the gelatine block, for the 2 different setups (with and without gelatine). By comparing the graphs between the two setups, it is clear that the maximum dimensions of the cavity, represented by the maximum crack length for a slice, occur sooner for the test where the vest is in place.

In Figure 40, the curve without vest (dark grey colour), the maximum cavity takes place at a penetration depth of 21 cm. On the other hand, when the vest is in place (light grey colour) the maximum cavity occurs at 15 cm depth in the gelatine block. This result suggests that the projectile will start tumbling earlier after penetration of a Level IIIA soft armour. In terms of maximum values, the difference is only 17 mm between the 2 graphics. It is thus clear that a Level IIIA vest does not absorb a remarkable amount of the projectile's kinetic energy. In both cases, the projectile completely perforates the 45 cm long gelatine block. The average transferred kinetic energy of the shots fired in setup 2 is 3.5% higher than the average transferred kinetic energy in setup 1. This would mean that more damage is caused to the body when a 7.62 x 39 mm projectile has to perforate a Level IIIA body armour first (see Figure 39), although more data would be required in order to assess the statistical significance of this particular conclusion.

Figure 39. Left: 7.62 x 39 mm M43 on a gelatine block (Setup 1) - Right: 7.62 x 39 mm M43 on a gelatine block after penetration of a Level IIIA vest (Setup 2)

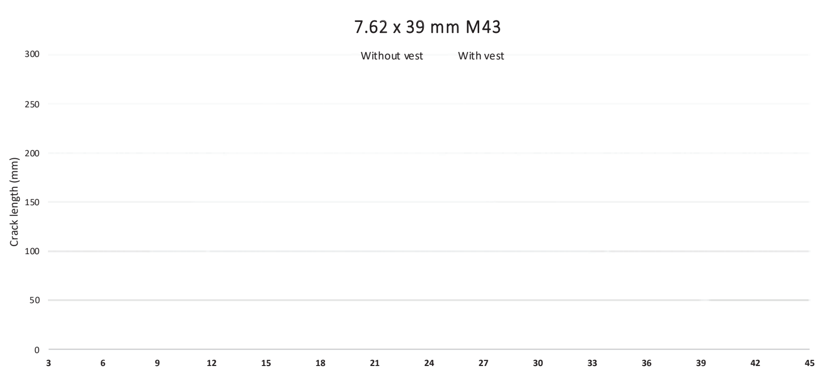

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Figure 40. Crack length as a function of gelatine section (setup 1 – without vest and setup 2 – with vest)

When no body armour is in place, the projectile clearly has a longer stable phase, resulting in a longer neck in the ballistic gelatine. Due to this stable phase, the projectile loses less energy since it experiences less resistance. However, using the Crack Length Method (CLM), the opposite conclusion came out of the results. With a difference of 3% between both setups, according to the CLM, and a difference of 3.5% following the PFV-software calculations, it is not possible to state that one result is more significant than the other. Nonetheless, it is certainly clear that the Level IIIA body armour does not absorb a significant amount of the projectile's kinetic energy for the considered overmatch threat.

Combination 2: 5.56 x 45 mm NATO Ball and soft armour vest

In contradiction to the previous combination, here, the soft armour vest clearly absorbs part of the projectile's kinetic energy. Comparing the average Total Crack Length for the three shots in both setups (with and without vest), the Total Crack Length for the setup without vest is 273 mm higher than the value for the other setup. In this case, the soft armour vest does absorb a significant amount of kinetic energy when a 5.56 x 45 mm projectile penetrates it. This would thus intuitively result in less damage to the gelatine block.

For this projectile, the crack length measured in each slice of gelatine was again plotted on a graph (see Figure 41). Comparing the different curves for the two setups, it is obvious that the maximum dimensions of the cavity, represented by the maximum crack length for a slice, occurs sooner in setup 2 (with vest) than in setup 1 (without vest). As shown on the graphs below, the maximum cavity in setup 2 occurs at 15 cm in the gelatine block. In setup 1, this maximum cavity takes place at 21 cm. This result suggests once again that the projectile will also start tumbling earlier after perforation of the soft armour.

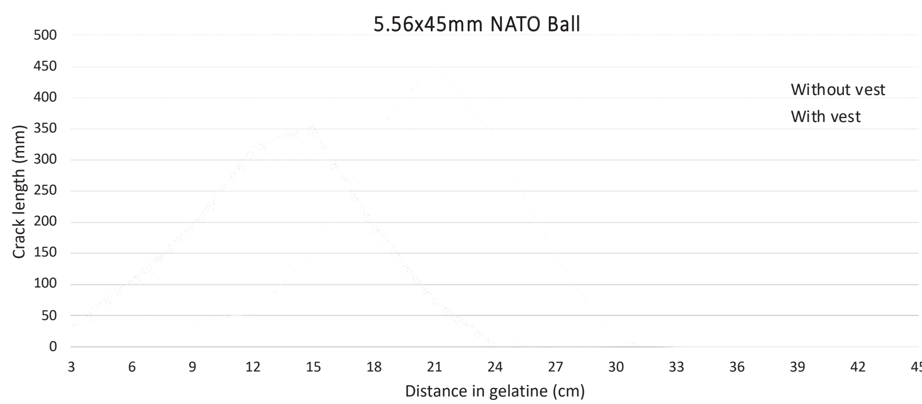
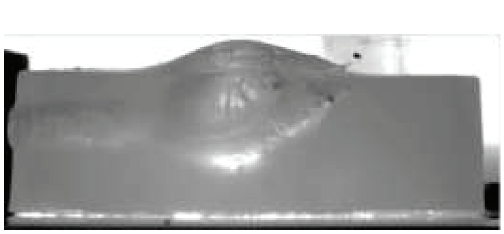


Figure 41. Crack length as a function of gelatine section (setup 1 – without vest and setup 2 – with vest)

Contradictory to the previous combination, the maximum crack length in a slice is significantly greater for setup 1, with a value of 456 mm. The tracking and measurement tools in the PFV-software confirm that wearing a vest will noticeably reduce the projectile velocity. The average entrance velocity of the bullet is 930 m/s for setup 1. For the other setup, the projectile loses on average 85 m/s when penetrating through the soft vest, hence, the projectile loses 17.4 % of its kinetic energy by penetrating the body armour. During its passage through the ballistic gelatine, the 5.56 projectile has the tendency to fragment. In both setups, the projectiles breaks into pieces in the ballistic gelatine.



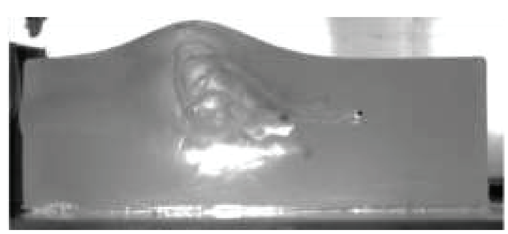


Figure 42. Left: 5.56 x 45 mm NATO Ball affecting a gelatine block - Right: 5.56 x 45 mm NATO Ball affecting a gelatine block after penetration of a Level IIIA vest

Looking at the images of Figure 42, the effect of the projectile's early tumbling is visible. The cavity on the right picture occurs earlier than the one on the left. Additionally, the dimensions of the cavity and neck in the Y and Z directions are similar for both settings. This means that the local damage is approximately the same with or without vest. In conclusion, the transferred kinetic energy is higher for the setup where the gelatine block is unprotected. A ballistic soft vest hence reduces the transferred kinetic energy of a 5.56 x 45 mm NATO Ball projectile.

Combination 3: .338 AP and soft vest with the ceramic insert

The impact on the body armour (now consisting of a ceramic plate combined with a soft vest) of a .338 AP projectile leads to an enormous amount of the projectile's kinetic energy to be absorbed by the body armour. The ceramic insert shatters the tungsten carbide core in such a way that the soft vest can absorb a large part of the remaining kinetic energy of the various fragments. The energy-absorbing capability of this in-conjunction system is nonetheless not high enough. There are still many fragments that pierce the vest and damage the gelatine block (Figure 43).

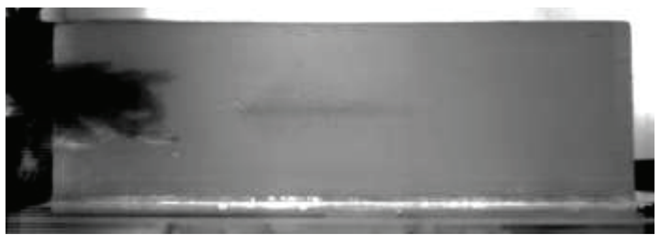


Figure 43. Fragmentation cloud of a .338 AP projectile entering the ballistic gelatine after perforation of an in-conjunction Level IV armour (Setup 2)

The average crack length measured in each slice is plotted in Figure 44 for both setups. Observing the graph, a clear difference is visible compared with the previous combinations. In this case, the maximum cavity in gelatine occurs directly at the entrance of the block for the setup 2 (with the soft vest in combination with the ceramic insert). For previous combinations, there was a more gradual build-up to this maximum value.

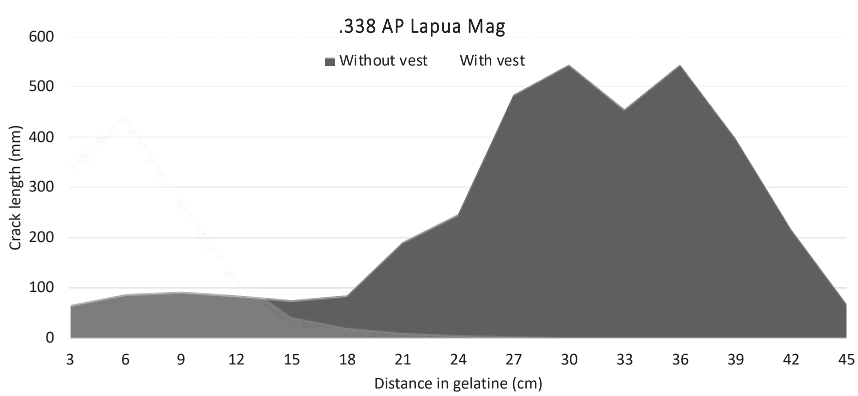


Figure 44. Crack length as a function of gelatine section (setup 1 – without vest and setup 2 – with vest)

Comparing the graph for the two setups, it is obvious that the maximum dimensions of the cavity, represented by the maximum crack length for a slice of gelatine, occurs sooner in setup 2 than in setup 1. Furthermore, it is also clear that the maximum crack length in setup 2 is lower than in setup 1. The difference between the location of the average cavity is however significant. The cavity that occurred for setup 2 is directly formed in the beginning of the block, while the cavity for setup 1 takes place in the second half of the ballistic gelatine. Notice that a difference in the location of the maximum cavity for both setups was also the case for previous combinations. The reason why in those cases the cavity

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occurred sooner, lies in the tumbling of the projectile. However, for this combination, there is not any residual projectile (nor, as a consequence, any tumbling) visible after perforation of the in-conjunction armour. The projectile is completely fragmented and the particles propagating through the gelatine block consist of dust, ceramic fragments, projectile pieces and other materials. Figure 45 shows a snap-shot of the .338 AP penetrating the gelatine block, without and with armour system present respectively.

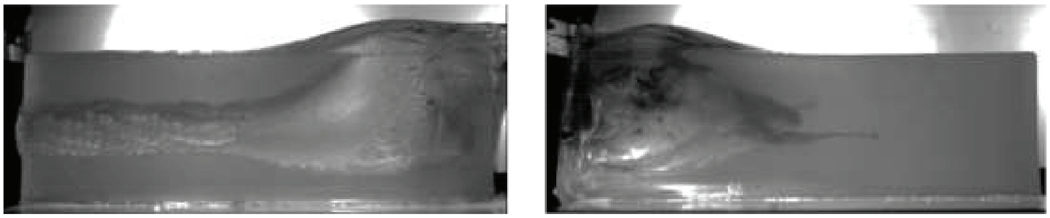

Figure 45. Left: .338 AP impacting a gelatine block (setup 1) - Right: .338 AP impacting a gelatine block after penetration of a Level IV vest (setup 2)

Combination 4: 7.62 x 51 mm AP8 and soft vest with the ceramic insert

Based on the comparison of the average Total Crack Length between both setups, it is possible to conclude that the soft vest in-conjunction with the ceramic insert again absorbs a lot of the projectile's kinetic energy, just as for the .338 AP. The Total Crack Length is 80 % lower in setup 2. As is the case for the previous combination, the ceramic insert shatters the tungsten carbide core in such a way that the soft vest can again absorb a large part of the remaining kinetic energy of the various fragments. The energy-absorbing capability of this in-conjunction system is nonetheless not high enough to protect the wearer. Some fragments are still able to perforate the vest and damage the gelatine block. Due to the fact that they enter the block in a fragmentation cloud, they leave a large entrance wound containing a lot of debris. The average crack length, measured in each slice is plotted in Figure 46.

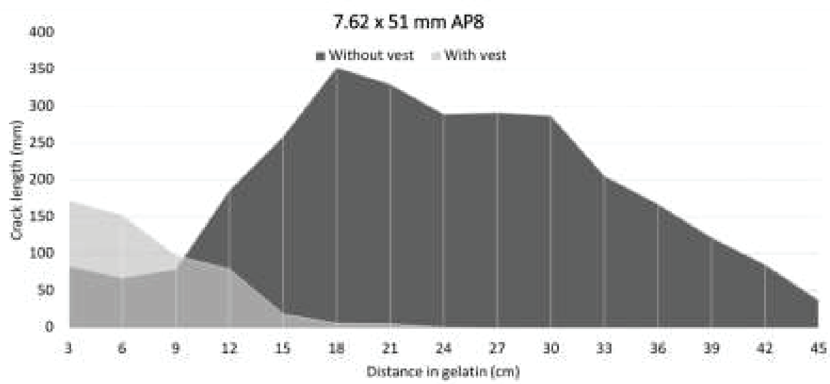

Figure 46. Crack length as a function of gelatine section (setup 1 – without vest and setup 2 – with vest)

Comparing the two setups, similar results as for the previous combination are observed. In this configuration it is clear that the maximum dimension of the cavity occurs sooner in setup 2 (with the vest) than in setup 1 (without the vest). Unlike the previous configuration, the maximum crack length found in setup 1 differs much more from the one in setup 2 (a drop between setups of 51% in terms of maximum crack length occurred). To determine the velocity of the fragmentation cloud, the most visible fragment was tracked in the PFV-software. Assuming that the velocity of the other fragments does not differ significantly, an estimation of the kinetic energy transferred to the block was made. The results are in line as the results obtained by the Crack Length Method. The average transferred kinetic energy in setup 2 is 85% lower than in setup 1, confirming that the Level IV protection vest absorbed a lot of the 7.62 x 51 mm AP8 projectile's kinetic energy.

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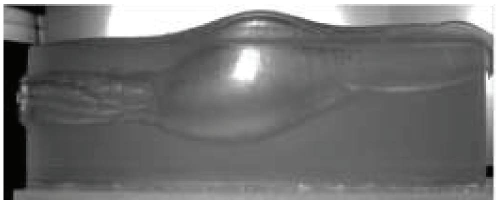 

Figure 47. Left: 7.62x51 mm AP8 on a gelatine block (setup 1) - Right: 7.62x51 mm AP8 on a gelatine block after penetration of a Level IV vest (setup 2)

3.2 Qualitative analysis

3.2.1 Contamination caused by fragmentation

Fragments can occur in a lot of forms, dimensions and materials, diverging in origin. They commonly cause damage to the body just as any other projectile by shredding tissue and transferring their kinetic energy to surrounding materials. When wounds are contaminated, the fragments can complicate the treatment process, which can have severe consequences for the patient. If the person initially survived the primary tissue destruction, contamination is often considered as a major threat to that person's life. Nowadays, doctors are in many cases able to remove all the contaminated tissue while treating the wound [4]. However, this process can better be avoided in order not to waste crucial time treating the patient. Every projectile can cause the created wound to be contaminated. As a bullet propagates through the air, fabric, skin or tissue, it can carry many different bacteria, which can be dispersed through the wound. If fragmentation occurs, there is a higher chance of contamination since the different fragments are from different sources. Some fragments originate from the bullet's core, others from the of the armour vest, or even from the perforated ceramic plate. Clearly, the more sources and different materials entering the body, the higher the chance of contamination. Fragmentation consequently leads to a higher infection risk, which is preferably avoided at all times.

Looking at the test results of the case where the soft vest is worn in combination with the hard plate, it is possible to conclude that fragmentation occurs more frequently after perforation of the body armour compared to when no body armour is worn. For combination 1 and 2 (being the 7.62 x 39 mm – Level IIIA and 5.56 x 45 mm – Level IIIA), no significant difference in fragmentation occurred. The 7.62 mm projectile did not fragment at all in either setup (unprotected gelatine and protected gelatine) and the 5.56 mm projectile has the tendency to fragment equally in both setups. This is shown in Figure 48 and Figure 49.

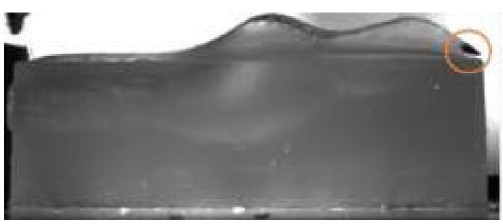 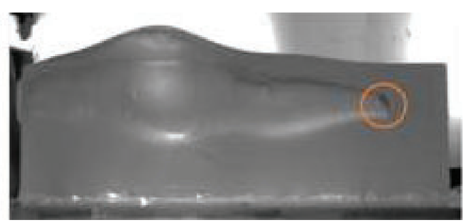

Figure 48. Left: 7.62 x 39 mm M43 projectile propagating through gelatine. No fragmentation occurred. - Right: 7.62 x 39 mm M43 projectile propagating through gelatine after piercing a Level IIIA soft armour. No fragmentation occurred.

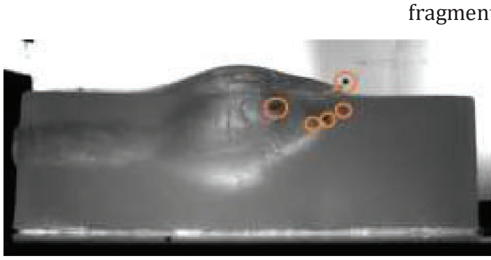 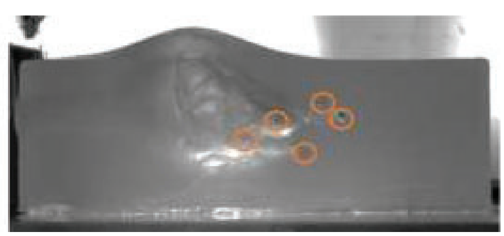

Figure 49. Left: 5.56 x 45 mm NATO Ball projectile propagating through gelatine. 5 fragments can be distinguished. - Right: 5.56 x 45 mm NATO Ball projectile propagating through gelatine after piercing a Level IIIA soft armour. 5 fragments can again be distinguished.

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The .338 AP ammunition fragmented remarkably when impacting the ballistic protection. After perforation, different particles of the projectile's tungsten core, ceramic tile (aluminon oxide) and fabrics of the carrier group together in a fragmentation cloud. Hence, this cloud consists of many different materials, increasing the risk of infection. In the case when no vest is placed in front of the gelatine, only limited fragmentation occurred. The fragments that are still formed obviously only originate from the bullet material. The 7.62 x 51 mm AP8 projectile shows similar behaviour as the .338 AP. In the former case, many fragments consisting of tungsten carbide particles, ceramics and fabrics group together in a fragmentation cloud. However, the dimensions of this cloud are smaller than for the one caused by the .338 AP bullet. Figure 50 and Figure 51 show the penetration of the Combination 3 and 4 for the 2 different setups with the fragmentation in detail.

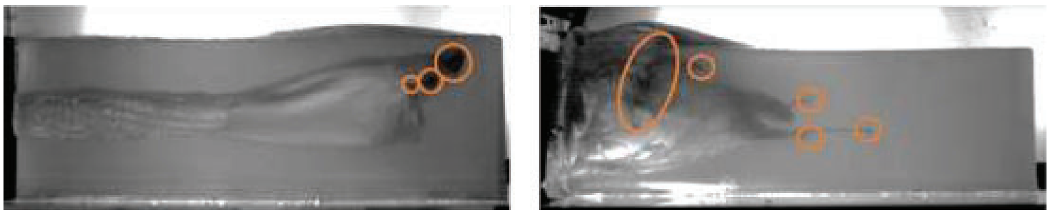

Figure 50. Left: .338 AP projectile propagating through gelatine. Only 3 fragments. - Right: .338 AP projectile propagating through gelatine after piercing a Level IV in-conjunction armour. 4 major fragments and an extensive debris cloud.

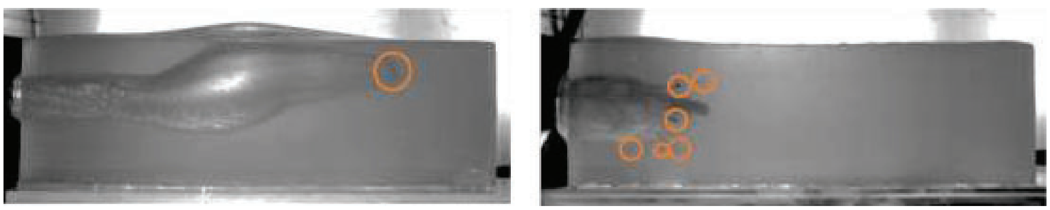

Figure 51. Left: 7.62 x 51 mm AP8 projectile propagating through gelatine. No fragmentation occurred. - Right: 7.62 x 51 mm AP8 projectile propagating through gelatine after piercing a Level IV in-conjunction armour. 6 major fragments and an extensive debris cloud.

4. CONCLUSIONS

The objective of this study was to retrieve data for four different combinations of vest and projectiles, in order to be able to investigate these combinations more thoroughly for overmatch conditions. Therefore, four different projectiles were shot at ballistic gelatine, with and without body armour protection. Two methods were used to retrieve data from the test results: the Crack Length Method and the measurement and tracking tools in the PFV-software. Combining all the results of the four combinations, it is possible to conclude that the maximum dimension of the cavity occurs sooner when a projectile first has to penetrate body armour. For the soft vests, this was because of the earlier tumbling of the projectile. For the tests with the in-conjunction armour, the cavities' dimensions shrunk significantly. However, cavitation occurs sooner.

The Crack Length Method showed that more energy was transferred to a protected body than to a bare block of gelatine. However, this was only the case for two combinations: the 7.62 x 39 mm M43 projectile, shot at a Level IIIA soft armour and the .338 AP ammunition, shot at a Level IV in-conjunction vest. Both the 5.56 x 45 mm NATO Ball and 7.62 x 51 mm AP8 projectiles still inflicted more damage when no body armour was worn compared with shots first perforating the armour systems.

Analysing the test results, not only the transferred energy has to be considered. The degree of fragmentation and the probability that the shot hits vital organs in the chest and abdomen region is also fundamental for this assessment. When projectiles fragment, the risk of infection in the affected tissue is seriously increased. Test firings showed that major fragmentation occurs in the case of a .338 AP projectile and a 7.62 x 51 mm AP8 projectile hitting an in-conjunction armour Level IV. After perforation of both the ceramic insert and the soft armour, all the particles grouped together in a fragmentation cloud of considerable kinetic energy. This fragmentation cloud affected the tissue greatly and thus caused a wide temporary cavity, now filled with debris. This increases the risk of infections, complicating the treatment process.

Because of the earlier cavitation, the greatest dimensions of the wound occur sooner in the body. Nevertheless, overall dimensions of the cavity and exit wounds seem to be smaller if the gelatine is protected.

In conclusion, this research confirms that cavitation occurs sooner if body armour is worn. However, no clear answer can be found to the question whether body armour causes more damage or not. Some factors influencing wound severity seem to be worse for protected gelatine blocks, while others do not. Nonetheless, this research offered some new insights in the behind armour effects of overmatched Level IV in-conjunction vests. The behaviour of the projectiles that hit this level of body armour is very different to projectiles hitting soft armour. Whether body armour protects its wearer or not, overmatching shots still cause a lot of damage, which would possibly result in an incapacitated target.

References

[1] A. Mabbott and D. J. Carr, "Effects of police body armour on overmatching ballistic injury," *Int J Legal Med*, vol. 134, no. 2, pp. 583–590, Mar. 2020, doi: 10.1007/s00414-019-02070-9.

[2] J. Breteau, M. L. Fackler, P. Martin, and I. Sendowski, "The Personal Protective Equipment Provided for Combatants: The Part Played by Wearing a Protection Vest in the Behaviour of Projectiles Wounding Outcomes," in *Proceedings of the 11th International Symposium of Ballistics*, Brussels, Belgium, 1989, vol. 3.

[3] J. M. Lanthier, M. J. Iremonger, E. A. Lewis, I. Horsfall, and P. L. Gotts, "Is the wounding potential of high velocity military bullets increased after perforation of textile body armour," in *Proceedings of the Personal Armour Systems Symposium*, The Hague, Netherlands, 2004, pp. 225–232.

[4] A. Mabbott, "The Overmatching of UK Police Body Armour.," PhD thesis, CRANFIELD UNIVERSITY, CRANFIELD (UK), 2015.

[5] J. Missliwetz, W. Denk, and I. Wieser, "Study on the Wound Ballistics of Fragmentation Protective Vests Following Penetration by Handgun and Assault Rifle Bullets," *Journal of Forensic Sciences*, vol. 40, no. 4, pp. 582–584, Jul. 1995.

[6] S. A. Bolliger, M. J. Thali, M. J. Bolliger, and B. P. Kneubuehl, "Gunshot energy transfer profile in ballistic gelatine, determined with computed tomography using the total crack length method," *Int J Legal Med*, vol. 124, no. 6, pp. 613–616, Nov. 2010, doi: 10.1007/s00414-010-0503-z.

 https://doi.org/10.52202/080042-0010