Assessing the Service Life of Aged Hard Armour Composite Material Products

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Abstract. World-leading companies have been racing in the past few decades to design and develop ultra-light and durable protective hard armour materials and inserts. Storage of UHMWPE personal armour inserts for long times or exposure to UV light tend to cause physical and chemical degradation and hence reduction in the mechanical properties and ballistic protection capabilities. Similarly, extensive use tends to degrade the protection capabilities of these inserts (Wear). NIJ test standards assess the ballistic performance of hard armour inserts at the time of manufacturing and guaranty their performance for a period of time (Warranty period). However, there are only a few studies on the effect wear/ageing has on the ballistic performance of hard armour inserts. Therefore, this study was conducted to generally investigate the effect ageing has on the ballistic resistance capabilities of hard armour (inserts) by investigating the ballistic protection capabilities of five excessively used (worn-out)/aged inserts (older than 5 years; exceeding the warranty period) as well as five Non-Used (Aged)/ Stored Inserts also exceeded their warranty period. The main finding was that excessively used (worn-out)/aged inserts have constituted failure when tested for their perforation resistance according to NIJ standards at fair impact velocities unlike the Non-Used (Aged)/ Stored inserts, indicating that they could retain their ballistic protection capabilities. Furthermore, some of the excessively used (worn-out)/aged inserts from the same batch number were re-built by "re-pressing" using temperatures and pressures similar to the ones used when the inserts were originally made, as a cost-effective solution to utilize the excessively used (worn-out)/aged hard armour inserts. It was found that "re-pressing" excessively used (worn-out)/aged hard armour inserts increased the ballistic protection capabilities and could hence be a potential cost-effective solution.

1. INTRODUCTION

Wear and ageing of composites in personal hard armour inserts are important topics to understand as many technologies in lightweight hard armour inserts are made of UHMWPE. The use of UHMWPE personal armour inserts for long periods of time over many years and their exposure to different environmental conditions during service tend to cause physical and chemical degradation and hence reduction in their mechanical properties and ballistic protection capabilities [1].

Test standards such as NIJ 0101.04 and NIJ 0108.01 assess the protective armour's resistance to penetration and back face signature P-BFS at the time of manufacturing or use [2 and 3]. However, they do not provide any guidance or warranty regarding the validity of test results (protection capabilities) after the test inserts have aged, this results in an increased cost on the customer because of the necessity to replace the personal armour inserts purchased after the warranty period is over. Therefore, studying the effect ageing and wear have on the ballistic resistance of personal armour is important in determining their protection capabilities after the warranty period is over. In the meantime, there is not enough investigation on the effect ageing has on the ballistic resistance capabilities of personal armour. Because of this lack of knowledge, customers world-wide do not know the suitable commercial and technical warranty period that must be agreed upon with the manufacturer before purchasing personal armour inserts.

In 2007, the former Canadian police research center CPRC have carried out a program to develop an aged armour replacement protocol. This protocol is very detailed and technical providing guidance on "investigating the issue of life expectancy of personal hard armour with respect to issues including the manufacturer's warranty period and replacement time" [4]. This study aims to simplify the topic studied previously by the CPRC to demonstrate the effect ageing/wear has on the ballistic protection capabilities of hard armour inserts older than 5 years. The main objectives of this study were to demonstrate the effect ageing/wear has on the ballistic perforation resistance of vests and inserts and to investigate the validity of re-build solutions "re-pressing" using temperatures and pressures similar to the ones used when the inserts were originally made on the excessively used (worn-out)/aged hard armour inserts as a cost-effective solution allowing the extension of the warranty preiod of those inserts.

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2. LITERATURE REVIEW

2.1 Degradation of hard armour inserts due to wear

The main cause of degradation on personal hard armour inserts is abrasive wear due to continuous use resulting in loss of mechanical strength and hence ballistic protection capabilities. There are three main components to abrasive wear: (a) friction, (b) surface cutting and (c) fiber plucking. Abrasive wear is seen on the affected personal hard armour as surface damage to individual fibers; cracks and fiber failure [5].

2.2 Previous work on warranty periods and replacement time [4], [6].

The most suitable ways to assess future aged hard armour performance is perforation testing at a fair range of speeds rather than V50. Assessing the ballistic protection capabilities of excessively used (worn-out)/aged inserts must be conducted by selecting inserts from the same lot at 5 years of age and then repeated annually until the inserts show no resistance to perforation at fair speeds according to the level of protection they provide according to NIJ 0101.04.

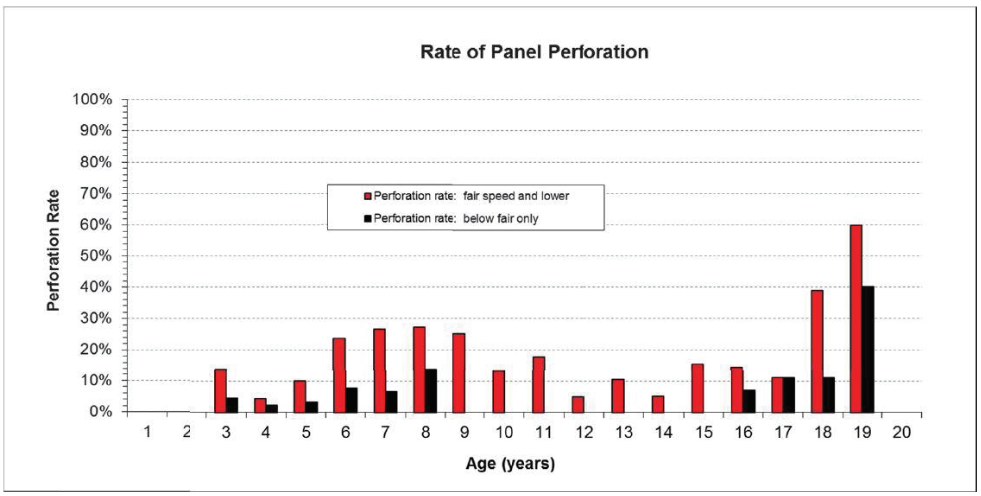

Figure 1. Perforation rate of armour panels as age increases in years [5].

Figure 1 shows that there is no clear correlation between age and perforation rate or (ballistic protection). However, it shows an increase in perforation rate after 5 years until 8 years. This implies that there are other factors affecting the perforation rate other than wear or ageing. Therefore, this study will be conducted on hard armour inserts older than 5 years in age.

This paper was prepared following previous publication by the same authors of this paper. The last publication investigated the ballistic penetration resistance capabilities of worn-out "Used" inserts and the effectivity of "re-pressing" as a potential cost-effective solution. However, this paper aims to further ensure the findings from the previous study by investigating the ballistic penetration resistance of three times the insert size of worn-out "Used" inserts as well as un-used "aged" stored inserts and the effectivity of "re-pressing" worn-out inserts as a potential cost-effective solution.

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3. METHODOLOGY

Step 1: A random selection of fifteen hard armour inserts manufactured in 2011, 2012, 2013, 2014 and 2015 were selected form the same batch. Three inserts from each year of manufacture were selected to bring the total number of inserts in this study to fifteen.

Step 2: Five excessively used (worn-out)/aged inserts manufactured in 2011, 2012, 2013, 2014 and 2015 were tested ICW 3A 9mm Vests (2015 Production) according to NIJ 0108.01 test standard [2] by firing five (7.62x39mm PS) Special Type shots at each impact side placed at 15 m from the muzzle to test ballistic penetration only.

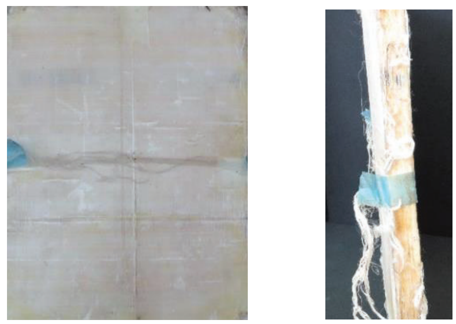

Photo No. 1 Excessively Used (Worn-out)/Aged Hard Armour Insert (2013 Production).

Step 3: Five Non-Used (Aged)/ Stored Inserts manufactured in 2011, 2012, 2013, 2014 and 2015 were tested ICW 3A 9mm Vests (2015 Production) according to NIJ 0108.01 by firing five (7.62x39mm PS) Special Type shots at each impact side placed at 15 m from muzzle to test ballistic penetration only.

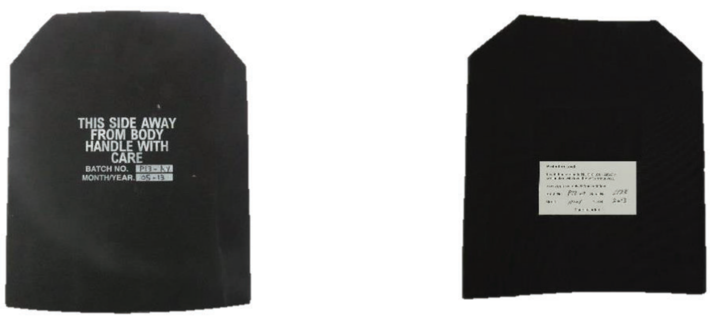

Photo No. 2 Non-Used (Aged)/ Stored Hard Armour Insert (2013 Production).

Step 4: Five Re-built Excessively Used (Worn-out)/Aged hard armour inserts (re-built by re-pressing polyethylene hard layers with the temperature and humidity used when they were first manufactured) were tested ICW 3A 9mm Vests (2015 Production) according to NIJ 0101.04 test standard [3] by firing six (7.62x39mm PS) Special Type shots at each impact side placed at 15 m from the muzzle to test ballistic penetration and back face signature P-BFS.

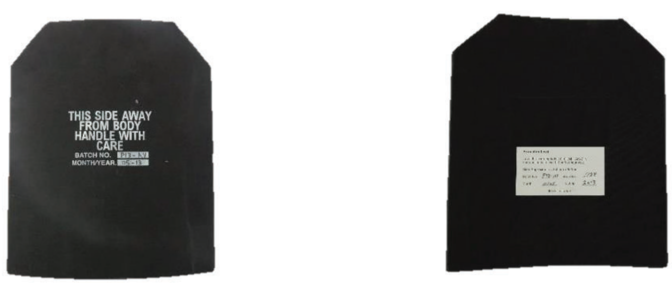

Photo No. 3 Re-built Excessively Used (Worn-out)/Aged Hard Armour Insert (2013 Production).

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Step 1
Random Selection of:

3 Body Armour Insert (2011 Production)
3 Body Armour Insert (2012 Production)
3 Body Armour Insert (2013 Production)
3 Body Armour Insert (2014 Production)
3 Body Armour Insert (2015 Production)

↓

Step 2
Excessively Used (Worn-out)/Aged Inserts - Ballistic Resistance Testing (NIJ 0108.01) Special (7.62x39mm PS)

1 Body Armour Insert (2011 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2012 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2013 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2014 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2015 Production) ICW 3A 9mm Vest (2015 Production)

↓

Step 3
Non-Used (Aged)/ Stored Inserts - Ballistic Resistance Testing (NIJ 0108.01) Special (7.62x39mm PS)

1 Body Armour Insert (2011 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2012 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2013 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2014 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2015 Production) ICW 3A 9mm Vest (2015 Production)

↓

Step 4
Re-built Exsessively Used (Worn-out)/Aged Inserts - Penetration and Backface Signature Testing (NIJ 0101.04) Special (7.62x39mm PS)

1 Body Armour Insert (2011 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2012 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2013 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2014 Production) ICW 3A 9mm Vest (2015 Production)
1 Body Armour Insert (2015 Production) ICW 3A 9mm Vest (2015 Production)

Figure 2. Methodology of work including sample selection criteria, number of samples and testing sequence.

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4. RESULTS

4.1 Excessively Used (Worn-out)/Aged Inserts - Ballistic Resistance Testing (NIJ 0108.01)

Table 1. Ballistic Penetration Test Results - Hard Armour Inserts (2011 and 2012 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2011 Production) ICW 3A 9mm Vest (2015 Production)		Hard Armour Insert (2012 Production) ICW 3A 9mm Vest (2015 Production)	
	Bullet Velocity m/s	Status CP / PP	Bullet Velocity m/s	Status CP / PP
1st	741	PP	736	PP
2nd	747	PP	741	PP
3rd	743	CP	733	PP
4th	-	-	746	CP
5th	-	-	-	-

Table 2. Ballistic Penetration Test Results - Hard Armour Inserts (2013 and 2014 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2013 Production) ICW 3A 9mm Vest (2015 Production)		Hard Armour Insert (2014 Production) ICW 3A 9mm Vest (2015 Production)	
	Bullet Velocity m/s	Status CP / PP	Bullet Velocity m/s	Status CP / PP
1st	728	PP	728	PP
2nd	728	PP	744	PP
3rd	734	PP	731	PP
4th	726	CP	736	PP
5th	-	-	740	CP

Table 3. Ballistic Penetration Test Results - Hard Armour Inserts (2015 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2015 Production) ICW 3A 9mm Vest (2015 Production)	
	Bullet Velocity m/s	Status CP / PP
1st	736	PP
2nd	740	PP
3rd	739	PP
4th	728	PP
5th	741	CP

Photo No. 4 Status of Excessively Used (Worn-out)/Aged Inserts (2013 Production) ICW 3A 9mm Vest, Complete Penetration

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4.2 Non-Used (Aged)/ Stored Inserts - Ballistic Resistance Testing (NIJ 0108.01)

Table 4. Ballistic Penetration Test Results - Hard Armour Inserts (2011 and 2012 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2011 Production) ICW 3A 9mm Vest (2015 Production)		Hard Armour Insert (2012 Production) ICW 3A 9mm Vest (2015 Production)	
	Bullet Velocity m/s	Status CP / PP	Bullet Velocity m/s	Status CP / PP
1st	728	PP	730	PP
2nd	723	PP	734	PP
3rd	727	PP	734	PP
4th	728	PP	727	PP
5th	734	PP	729	PP

Table 5. Ballistic Penetration Test Results - Hard Armour Inserts (2013 and 2014 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2013 Production) ICW 3A 9mm Vest (2015 Production)		Hard Armour Insert (2014 Production) ICW 3A 9mm Vest (2015 Production)	
	Bullet Velocity m/s	Status CP / PP	Bullet Velocity m/s	Status CP / PP
1st	749	PP	738	PP
2nd	746	PP	726	PP
3rd	745	PP	732	PP
4th	753	PP	729	PP
5th	746	PP	740	PP

Table 6. Ballistic Penetration Test Results - Hard Armour Inserts (2015 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2015 Production) ICW 3A 9mm Vest (2015 Production)	
	Bullet Velocity m/s	Status CP / PP
1st	729	PP
2nd	733	PP
3rd	731	PP
4th	740	PP
5th	732	PP

Photo No. 5 Status of Non-Used (Aged)/ Stored Inserts (2013 Production) ICW 3A 9mm Vest No Complete Penetration

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4.3 Re-built Excessively Used (Worn-out)/Aged Inserts - Penetration and Backface Signature Test (P-BFS) (NIJ 0101.04)

Table 7. Ballistic Penetration Test Results - Hard Armour Inserts (2011 and 2012 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2011 Production) ICW 3A 9mm Vest (2015 Production)			Hard Armour Insert (2012 Production) ICW 3A 9mm Vest (2015 Production)		
	Bullet Velocity m/s	BFS Depth (mm)	Status CP / PP	Bullet Velocity m/s	BFS Depth (mm)	Status CP / PP
1st	739	14	PP	735	12	PP
2nd	725	11	PP	738	13	PP
3rd	733	11	PP	744	10	PP
4th	749	6	PP	753	11	PP
5th	738	6	PP	741	6	PP
6th	738	7	PP	746	7	PP

Table 8. Ballistic Penetration Test Results - Hard Armour Inserts (2013 and 2014 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2013 Production) ICW 3A 9mm Vest (2015 Production)			Hard Armour Insert (2014 Production) ICW 3A 9mm Vest (2015 Production)		
	Bullet Velocity m/s	BFS Depth (mm)	Status CP / PP	Bullet Velocity m/s	BFS Depth (mm)	Status CP / PP
1st	755	28	PP	736	10	PP
2nd	743	12	PP	743	17	PP
3rd	738	22	PP	732	17	PP
4th	725	10	PP	740	10	PP
5th	741	9	PP	732	15	PP
6th	736	9	PP	724	23	PP

Table 9. Ballistic Penetration Test Results - Hard Armour Inserts (2015 Production)

Shot No @15m 7.62x39mm PS	Hard Armour Insert (2015 Production) ICW 3A 9mm Vest (2015 Production)		
	Bullet Velocity m/s	BFS Depth (mm)	Status CP / PP
1st	738	20	PP
2nd	730	16	PP
3rd	735	17	PP
4th	743	16	PP
5th	749	13	PP
6th	738	14	PP

Photo No. 6 Status of Re-built Excessively Used (Worn-out)/Aged Inserts (2013 Production) ICW 3A 9mm Vest, No complete Penetration and BFS Depths are less than 44mm

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5. DISCUSSION

Personal hard armour inserts tend to degrade with time due to many factors. The major cause of wear according to literature in personal hard armour including, vests and inserts is abrasive corrosion. This reduction in protection is very common in excessively used (worn-out)/aged hard armour inserts. Therefore, a re-build or replacement protocol must be adopted and followed to ensure the functionality of such inserts after exceeding their warranty period.

Re-building hard armour inserts could be a cost-effective solution instead of total replacement. There are special techniques used in re-building hard armour inserts. Some of those techniques add more protective fabric layers to the impact and rear face of the excessively used (worn-out)/aged inserts to compensate for their reduction in protection. However, in this study, the excessively used (worn-out)/aged inserts were re-pressed using the same temperature and pressure during manufacturing of the hard inserts. The re-building techniques and the finished inserts need to be validated, tested and inspected annually to ensure the delivery of the intended protection level at fair impact velocities.

Table 2 and Photo 4 represent a clear example of an excessively used (worn-out)/aged hard armour insert manufactured in 2013. The 2013 (worn-out hard armour) showed a complete penetration at 726 m/s. Comparing the penetration resistance of the 2013 worn-out insert with the same after rebuild, the rebuilt insert showed partial penetration against the same threat at a slightly higher velocity as could be seen in Table 8 and Photo 6. For further assurance, a number of rebuilt hybrid hard armour inserts which passed the penetration resistance test according to NIJ 0108.01, were further tested according to NIJ 0101.04 to evaluate their back face signature values which they passed resulting in values less than 44mm in P-BFS depth and therefore validating the rebuild process adopted to be an effective solution in contrast to complete replacement.

Tables 4, 5 and 6 clearly show the results of the penetration test using stored inserts manufactured at the same years as the worn-out and re-built inserts for fair comparison and analysis. The tables clearly show no complete penetration in any insert leading to the conclusion that non-used (aged)/ stored inserts stored at ambient temperatures away from direct UV light or excessive humidity and moisture tend to retain their penetration resistance capabilities even after exceeding their designated warranty period (5 years).

Those findings were a living proof that personal hard armour inserts tend to degrade with extensive use and age. Those inserts could be re-built as a cost-effective solution instead of replacements specially if bought in large quantities. Hard armour inserts need to be checked and tested annually after they exceed their warranty period as there is a high probability that they fail at fair velocities.

6. CONCLUSIONS

- The main cause of degradation on personal hard armour is abrasive corrosion due to continuous use and environmental conditions.
- There is no clear correlation between age and perforation rate (ballistic protection capabilities). However, there is a very high probability that a worn-out product fails after exceeding the warranty period at fair impact velocities.
- Inserts stored at ambient temperatures away from direct UV light or excessive humidity and moisture tend to retain their penetration resistance capabilities even after exceeding their designated warranty period (5 years).
- Excessively used (worn-out)/aged personal hard armour inserts could be re-built as a cost-effective solution instead of replacement.
- Re-build or replacement protocols must be adopted and followed to ensure functionality and protection of all excessively used (worn-out)/aged personal hard armour inserts.
- Annual inspection must be carried out on hard armour inserts after exceeding their warranty or service life to ensure their functionality.

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