The Development of the Chisel Nosed Fragment Simulating Projectiles for Personal Armour Testing

PL Gotts[1], M Helliker[2]

[1]Phil Gotts Consulting Ltd, 23 Thorney Rd, Capel St Mary, Ipswich, Suffolk, IP9 2HL, UK
phil@philgotts.com
[2]Policing and Security Group, Defence Science and Technology Laboratory, Porton Down, Salisbury, SP4 0JQ

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Abstract. The testing of personal armour for fragmentation protection typically uses the chisel-nosed fragment simulating projectile (C-N FSP) of different masses. The relevance of these projectiles to modern conventional munition and improvised explosive device (IED) fragmentation has become of interest to the personal armour community in recent years. This is partly because the origin of the design of the C-N FSP has been all but forgotten, to most in the armour community. This paper describes the original development of the FSP at Watertown Arsenal, USA in 1943 and its evolution to its current forms, as specified in MIL-P-46593B and SCRDE A3/6723. From the 1970s onwards studies have been conducted to evaluate the C-N FSP when compared to both conventional munition and IED-formed fragmentation. The paper describes studies conducted within defence research laboratories in both the USA and the UK.

1. INTRODUCTION

In order to test personal armour against the fragmentation threat from exploding munitions, the obvious solution would be to detonate those munitions in an arena surrounded by personal armour worn by mannequins. However, this approach is not simple for a number of reasons:

- Detonating munitions in test arenas will not produce the same result from one detonation to the next, i.e. this test lacks consistency or repeatability.
- The results will only give a pass / fail result without any numerical assessment of the performance of the armour. This means that the test will not discriminate between armours which are borderline performance and those which are over-engineered.
- Of perhaps more relevance in the 21st century, the conduct of arena tests is an expensive process and hence not suited to the development of personal armour.

Therefore an alternative method of testing the performance of personal armour against fragmentation is required. This need for an easy, cheap, objective and repeatable test method led ultimately to the development of the fragment simulating projectile (FSP). There are now few people left in the armour community who are aware of the history of the FSP, and hence this paper aims to describe the history of the FSP as we know it today.

Sullivan [8] in 1945 summarised the limitations which led to the development of the FSP thus, 'Such a test ideally would consist of actual fragmentation of service projectiles, and such tests were promptly suggested by this laboratory, but, because of the inherent variability of fragmentation, the number of rounds, necessary to give results from which any valid conclusions could be drawn, discouraged the application of such methods, and shifted emphasis in the direction of a test that would be simple, reproducible and measurable.' *JF Sullivan, Watertown Arsenal, Oct 1945*

2. TYPES OF FRAGMENTS

The first question to address is what is the fragmentation that needs to be replicated by any FSP. Fragmentation caused during the detonation of a munition may consist of both what is known as primary and secondary fragmentation. There are a number of differences in how primary and secondary fragmentation can be described, tested against and protected against.

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2.1 Primary Fragmentation

Primary fragmentation is that which is produced by the casing or components of the munition itself. Primary fragmentation from munitions, such as artillery shells, mortars and grenades can be considered to be one of two categories:

i) explosively formed 'natural' fragments or
ii) pre-formed fragments [1]

2.1.1 Natural Fragments

Figure 1. Selection of natural fragments from artillery shell (Photo: PGC)

Natural fragments, or explosively formed fragments, are formed when the shell casing of a munition fractures during an explosive detonation. For artillery shells, the overriding consideration in the design of the shells is the need to withstand the forces during launch. Often these requirements detract from the desire for the munition to produce as many fragments as possible (which is desirable to improve the probability of a hit on the target), whilst maintaining sufficient kinetic energy to cause incapacitation[1]. These integrity requirements reduce the efficacy of pre-formed fragments or shell scoring, both of which encourage more regular fragment shapes and distributions, but result in less structural strength during launch. During the detonation of the shell, the pressures within the case increase rapidly forcing the case to expand. Stress fractures in the case will form and the case will ultimately fragment, but in a fairly random pattern. These stress fracture patterns will vary due to the manufacturing of the shell casing. As a result, natural fragments vary in size, shape, mass and velocity. Figure 1 shows a few fragments from a 155 mm high explosive (HE) artillery shell. In Figure 2 the fragment distribution from a typical mortar is presented (by the region of the shell from which they originated). It can be seen that the fragments vary in mass and distribution due to the geometry and material properties of the shell.

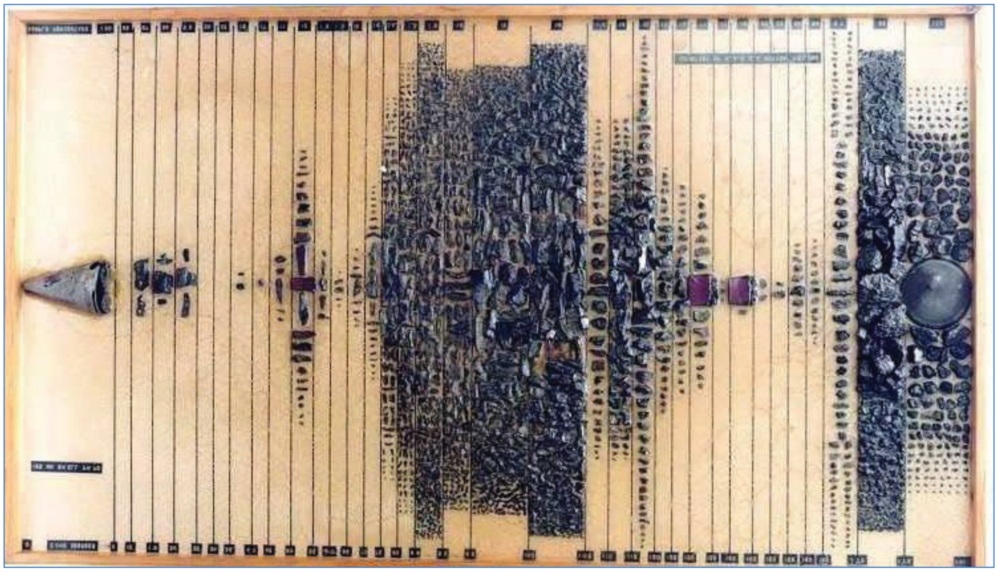

Figure 2. Natural fragment distribution from mortar (Crown Copyright)

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[1] An energy of 80 J is often cited as being required 'to stop a man', but is more closely linked with the time in which incapacitation is required [1]

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2.1.2 Pre-Formed Fragments

Weapons such as grenades, mortars, rockets and mines, do not need to withstand extreme forces during launch, and usually contain scored cases, internal components or pre-formed fragments. The first examples of pre-formed fragments were the development, by Lieutanant Henry Shrapnel, of steel balls within the munition (Figure 3), and these were referred to as 'shrapnel' [2]. Often also referred to as "proof shot", these steel spheres were used in the assessment of fragment protective equipment during World War I (WWI) and through to the end of World War II (WWII) [3].

Pre-formed fragments can take the form of notched wire, cubes, metal spheres or flechettes, although varying shapes and sizes have been used for specialist applications (such as anti-aircraft missiles).

Pre-formed fragments are common in many modern military munitions, but may also be found in many types of improvised explosive devices (IEDs).

Pre-formed fragments are designed to provide an optimum of fragment distribution and kinetic energy, in order to optimise hit probability and terminal effect.

It should be noted that even pre-formed fragments do not always reach the target in the designed geometry. For example, steel balls may fracture under detonation and notched-wire fragments may break into strips of 2, 3 or 4 fragments rather than always as individual fragments.

Figure 3. Sectioned WWI artillery shell showing shrapnel (Photo: PGC)

2.2 Secondary Fragmentation

Secondary fragments are those produced, not by the structure of the munition, but by the environment in which the explosive device detonates. The fragments tend to be part of the environment, which are accelerated to high velocity by the explosion. An example would be the sand and gravel in which an anti-personnel blast mine is buried (figure 4). There are some scenarios for which the definition of whether the fragments produced are primary or secondary fragmentation is not always clear, and may depend upon the focus of the interested party. One example of this is a vehicle-borne improvised explosive device (VBIED). In this case, most of the fragmentation is likely to be metallic components of the vehicle in which the device is contained. This fragmentation can be considered in two possible ways: the vehicle is the environment in which the detonation occurs (i.e. secondary fragmentation), or the vehicle is the casing of the device (i.e. primary fragmentation).

Figure 4. Secondary fragmentation from a buried anti-personnel mine (Courtesy: OTS Ltd)

3. TYPES OF FRAGMENT SIMULATING PROJECTILES (FSP)

When designing FSPs to test fragment protective materials and armours, testing agencies are posed several problems:

i) the need for a representative projectile which provides consistent results and
ii) an understanding of what velocity or energy level to test at.

In theory the first problem can be addressed by the design of a Fragment Simulating Projectile (FSP), which represents the threat to be countered by the armour. The velocity of fragments from any

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given device, at a given range, can be calculated with a reasonable level of confidence from data obtained from arena trials.

For armour testing, a number of FSP types and sizes have been developed and used. These include chisel-nosed fragment simulating projectiles (CN-FSP), right circular cylinders (RCC), parallelepipeds, cubes, spheres and darts [2]. Through extensive analysis it has been shown that no one design or mass of FSP truly reflects the full range of fragments from all explosively formed fragmenting munitions [2, 4, 5, 6] and this is discussed later in this paper.

During WWI the first fragment protective equipment for general service was introduced in the form of the Steel Combat Helmet [3]. The effectiveness of candidate armours was assessed using steel shrapnel balls. As fragmenting artillery shells typically used these steel balls as pre-formed fragments, they were an obvious and simple choice for Fragment Simulating Projectiles (FSP). Other methods to assess the suitability of materials for providing protection from fragmentation included low velocity bullets, typically of .45 cal [7].

Through WWII and the subsequent Korean War, testing of materials and armours to protect both aircrew and later ground troops used a variety of FSPs, including parallelepiped, cubes, ball bearings, right circular cylinders and chisel-nosed FSP [2]. Whilst cubes, ball bearings and parallelepiped FSP were selected due to their similarity to pre-formed fragments, chisel-nosed FSPs, were developed to better represent natural fragments [8].

The original development of the chisel-nosed FSP was conducted at Watertown Arsenal in 1943, in order to aid the development of body armour for US aircrew. The initial requirement for FSPs to replicate natural fragments from German anti-aircraft flak and 20 mm HE shells started in September 1943, and three types of FSP were developed [7]. The chisel-nosed FSP (originally designated the G2 – see Figure 5) was selected for future development work, after initial trials on materials were reported in December of that year [7]. The original G2 FSP of 16 grains (1.04 g) was skirted to engage with a rifled barrel and had a Rockwell Hardness C (RHC) of 20 – 25, with some variation noted in manufacture (see Figure 6). This was later changed to 17 grains (1.10 g) with a RHC of 30 ± 2, to better reflect fragments from US munitions after WWII [4].

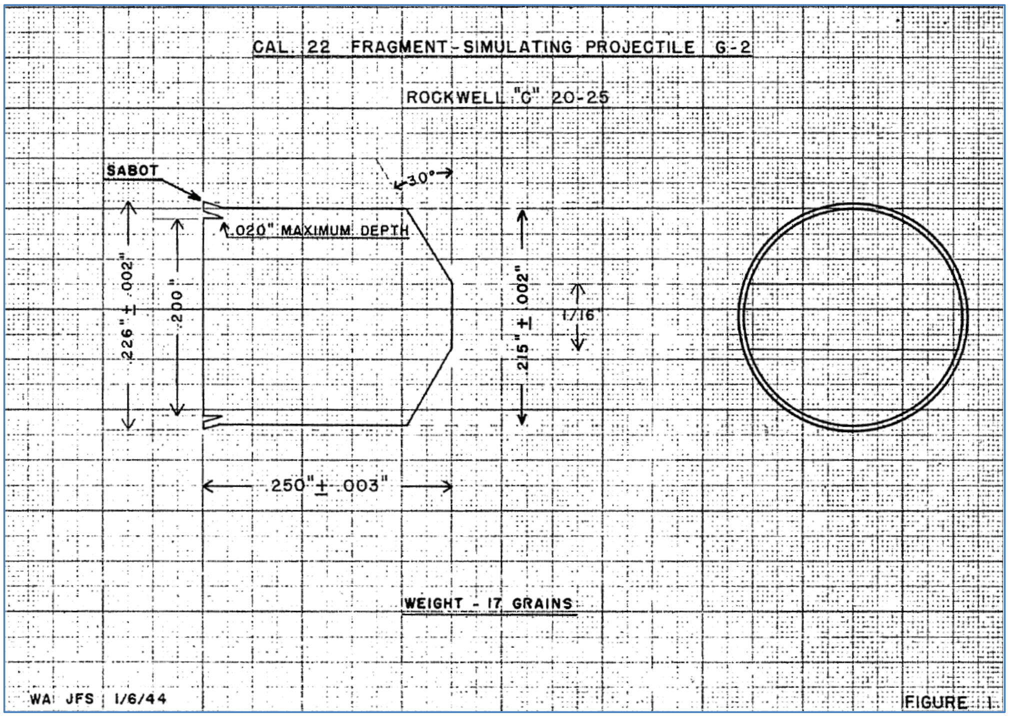

Figure 5. Original drawing of G2 FSP [9]

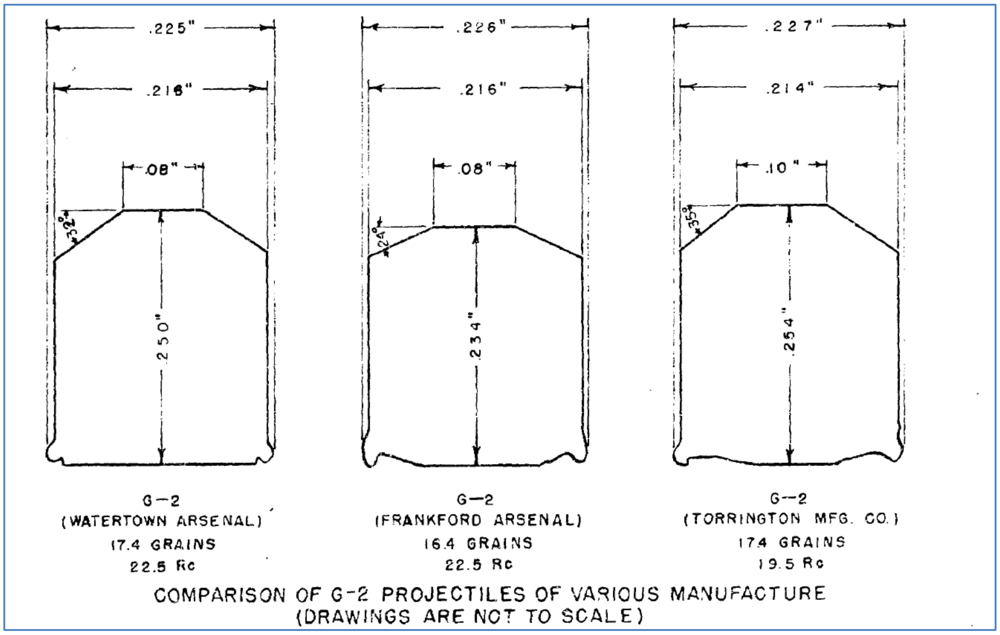

Figure 6. Comparison of G2 FSP of different manufacture [10]

The designation of the FSP changed to the T37, the design of which has not changed since 1948 and this forms the basis of the range of FSPs, which are scaled up versions of the original 17 grain projectile specified in MIL-P-46593B [11] (see Figure 7). The T37 FSPs are fired from an appropriate calibre barrel, which allows the skirt to engage in the rifling of the barrel. The 17 grain (1.10 g) T37, for example would be fired from a 5.56 mm barrel.

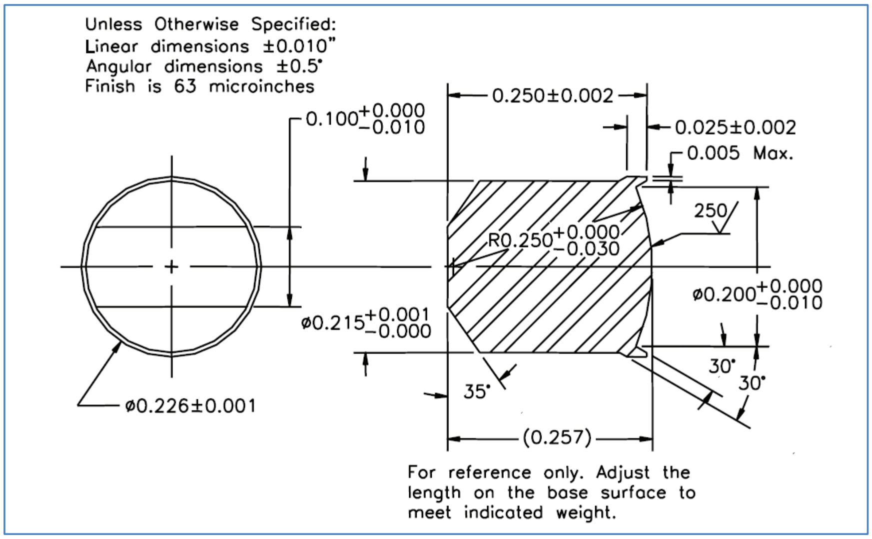

Figure 7. T37 FSP Types 1 and 2 [11]

The UK later adopted the same general projectile, but removed the skirt and scaled the FSP across a mass range from 0.16 g to 2.8 g, as specified in drawing SCRDE/A3/6723 [12] (see Figures 8 and 9). As the UK versions no longer had the skirt, they were fired from a polymer sabot which would engage in the rifling of the barrel. This meant that the FSPs were fired from a larger calibre barrel than the FSP. For

Figure 8. Typical chisel-nosed FSPs (Photo: PGC)

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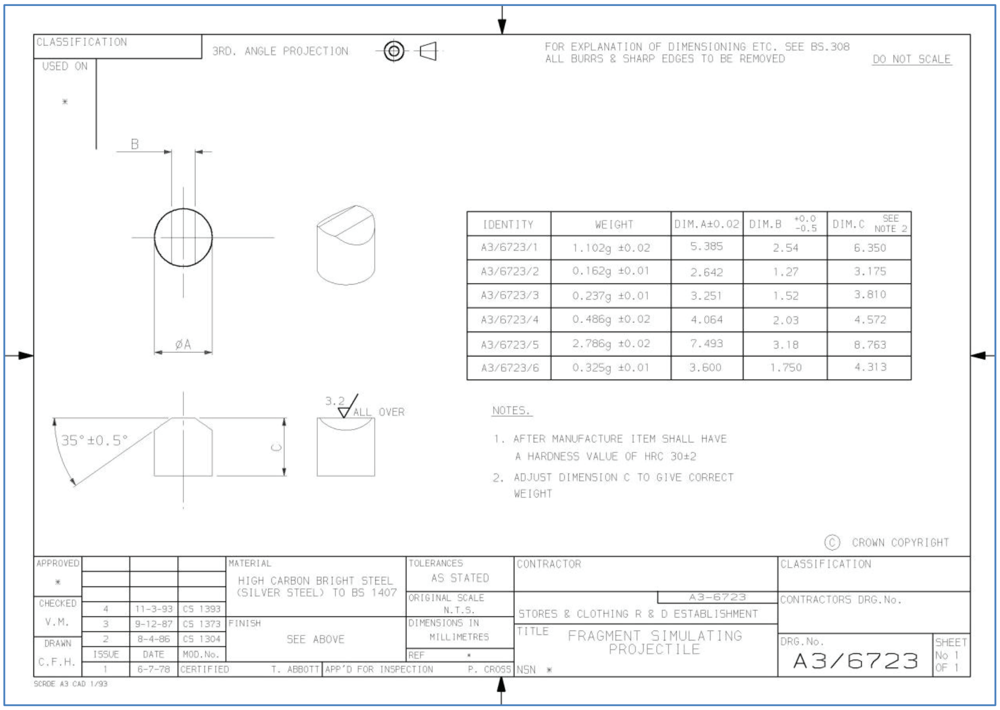
example, the 1.10 g FSP is fired from a sabot in a 7.62 x 51 mm barrel.



IDENTITY	WEIGHT	DIM.A±0.02	DIM.B $^{+0.0}_{-0.5}$	DIM.C SEE NOTE 2
A3/6723/1	1.102g ±0.02	5.385	2.54	6.350
A3/6723/2	0.162g ±0.01	2.642	1.27	3.175
A3/6723/3	0.237g ±0.01	3.251	1.52	3.810
A3/6723/4	0.486g ±0.02	4.064	2.03	4.572
A3/6723/5	2.786g ±0.02	7.493	3.18	8.763
A3/6723/6	0.325g ±0.01	3.600	1.750	4.313

NOTES.

1. AFTER MANUFACTURE ITEM SHALL HAVE A HARDNESS VALUE OF HRC 30±2
2. ADJUST DIMENSION C TO GIVE CORRECT WEIGHT

Figure 9. SCRDE drawing A3/6723 for Fragment Simulating Projectile (Crown Copyright)

The drawing in figure 9 above contains the phrase 'all burrs and sharp edges to be removed'. This phrase has been interpreted differently by different manufacturers of the FSPs. Many manufacturers tumble the finished FSPs together, while others do the same, but with addition of a grinding paste. The two types are easy to distinguish apart as those tumbled without the paste still retain a shiny metallic appearance whereas those tumbled with the paste will have a matt grey appearance. For certain textile materials it is known that the different sources of FSP can affect the test results. In these cases the textile material will exhibit a higher performance when tested with the FSPs tumbled in the grinding paste.

The current NATO test standard AEP-2920 [13] includes the options for a number of different FSPs within Annex C. these include: chisel-nosed FSPs to SCRDE drawing A3/6723, T37 type chisel-nosed FSPs to MIL-P-46593, and RCCs.

4. COMPARISON OF FSPs AND REAL FRAGMENTS

The original comparison of the performance of the G2 FSP against the fragments it was designed to replicate, showed a lack of correlation. Sullivan wrote in his report:

> *"While a disappointing lack of correlation has resulted between the relative resistance of materials to perforation by this projectile and to perforation by actual fragments of statically detonated 20 mm high explosive shells, due to the uniformly efficient manner in which this projectile perforates material and the variable inefficiency with which an actual fragment, because of its random behavior in flight, perforates material, it is believed that the results of firings with this projectile may at least be used to advantage as a basis for evaluation of the control of quality being exercised by the supplier of armor material."* (Sullivan 1945 [8])

What Sullivan means by this very long and complicated sentence, is that although the FSP does not replicate the performance of the real fragments, it can be used to grade or rank materials, particularly for quality assurance purposes. The use of the G2 FSP in Quality Assurance testing ensured its continued use [8].

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Few studies presented in the open literature compare the performance of FSP to natural fragments. Aside from the limited comparison work conducted during the development of the G2 chisel-nosed FSP, which did not present data comparing natural fragments to the FSP under development, most comparison work has remained under limited circulation.

By the early 1970s, a number of research laboratories within the US were involved in ballistic trials with various designs of FSP. In 1974 a number of the establishments conducted a coordinated research programme to compare and quantify the performance of various FSPs with real fragments of the type which posed a threat to dismounted troops [4]. In this study, fragments from a range of fragmenting munitions were analysed. A range of fragments of masses commensurate with a range of FSP masses were collected and fired at five different target types, representative of a range of materials considered suitable at that time for body armour applications. The natural fragments were collected using an arena trial and the fragments recovered from the strawboard witness packs. It should be noted that there is anecdotal evidence to suggest this method of "hard" recovery may result in blunting of the fragments, when compared to "soft capture" methods [14].

In the work by De Luca, the performance of the recovered natural fragments compared with RCC, chisel-nosed, cubes, spheres and parallelepiped FSP designs was conducted. The comparison included V_{50} and residual velocity assessments against titanium, nylon 728 fabric, XP polymer film and glass re-enforced plastic (GRP) targets [4].

The comparison between natural fragments (approximate mass of 1.04 g) and the chisel-nosed FSP (mass of 1.10 g) showed a significant difference in both V_{50} performance and residual velocity measurements. The reduction in V_{50} for the chisel-nosed FSP for the nylon target was approximately 5 – 10 % and for the XP polymer film approximately 15 – 20 %. The 16 grain (1.04 g) RCC with a 5 – 10 % decrease against the nylon and between a 5 - 10% increase against the XP film, proved a closer match. The study concluded that all fragment simulators (chisel-nosed FSP, RCC cubes and spheres) of aspect ratio 1:1 were more penetrative than real fragments of comparable mass. The report goes on to state that the family of RCCs with the same aspect ratio as the natural fragments provided the closest residual velocity data of any of the FSPs [4]. It is not possible to determine from these results whether the natural fragments were blunted in the capture process, or whether the disparity between the masses of the natural fragments and the chisel-nosed FSP would account for the difference in performance.

The results of the work conducted by De Luca were used as the basis for the recommendation that the RCC should be adopted for future testing of fragment protective body armour [15][2].

A later study, conducted at Cranfield University [14], compared the performance of natural fragments recovered from UK mortar shells to the CN FSP, and confirmed some of the findings identified by De Luca [4]. Three masses of CN FSP were compared to equivalent masses of natural fragments (0.24 g, 0.49 g and 1.10 g). This study also showed that the chisel-nosed FSP proved more penetrative than natural fragments of equal mass. This study compared the performance of natural fragments and chisel-nosed FSPs against textile armour typical of modern combat body armours.

Other research in the open literature has compared the performance of FSPs of differing geometries and materials. Work by Prosser compared the performance of chisel-nosed FSPs with RCC FSPs against woven fabric panels [16, 17]. In this study it was determined that the chisel-nosed FSPs were more penetrative than RCC FSPs of the same aspect ratio and mass. The cause of this difference in performance was due to the increased occurrence of fibre slip observed with chisel-nosed FSPs. This was ascribed to the chamfered edges of the chisel-nosed FSP enabling the pushing aside of the primary yarns instead of completely engaging them in tension. This resulted in less energy transfer between primary and secondary yarns and fewer broken yarns encountered with the chisel-nosed FSP. These are mechanisms that have been identified as contributing to the ability of a textile to dissipate energy from a projectile [18, 19]. Other studies have investigated the effect of projectile geometry on their ability to perforate armour systems (for example, Abbott [20], Gibbon [21], Ipson [5], Tan [19], Montgomery [22]).

A study on the effect of FSP material was conducted at Cranfield University, to determine if the material of the projectile played a significant role [23]. In this study, the spherical FSP of differing materials was investigated against textile armour panels of varying layers. It was noted in this study that the softer material (aluminium in this case) deformed upon impact and had a reduced residual velocity as a result. It was also observed that the deformed projectile on average broke more yarns than a spherical FSP of greater hardness. It was also noted that a glass FSP broke upon impact with the textile, although it was not possible to determine whether this affected its ability to perforate the textile target.

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[2] A reference to the letter describing the recommendation has been identified by the author, but not the content. The reference is included as much as is possible for completeness.

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5. DESIGN PARAMETERS RELEVANT TO THE CHOICE OF FSP

The choice of FSP for armour testing should be carefully considered, in order to represent the anticipated threat. The mechanisms by which the projectile interacts with the target should be replicated wherever possible. It can be argued that the choice of a projectile that has a greater ability to slip through a textile rather than fully engage with the fibres may lead to the development of textiles to prevent such slippage. There is then a risk that these textiles will possess other properties that are disadvantageous to the development of a body armour system. For example, to prevent fibre slip, a tighter weave may be employed to reduce the movement of the yarns around a projectile. This textile is likely to be stiffer with less flexibility which may adversely impact the comfort and movement of the wearer.

Of all of the designs of FSP, the RCC, CN FSP and the spherical FSP are the most commonly used in armour testing. The spherical FSP is often chosen due to its inherent stability of flight and low cost. The RCC and CN FSP can present more challenges in launching in a stable flight, particularly low mass variants or at low velocity. The RCC and CN FSP are manufactured specifically for armour testing, whereas spherical FSP are easily available in many materials and with differing properties.

From the summary of the research into the effect of FSP design on performance presented here, different simulators exhibit significantly different properties due to their geometries. The RCC presents a uniform edge in contact with the armour that minimises the amount of fibre slip, in comparison with CN and spherical FSP. There is evidence that this is a better representation of natural fragments of irregular shape where fibre slip would be minimal.

The CN FSP presents two chamfered edges, which allow more yarns to slip past the FSP, reducing the ability of the fabric to transfer energy away from the projectile. With the chamfered edges, the high kinetic energy density of the impact face due to its length to diameter ratio, make the CN FSP more severe than natural fragments of the same mass.

Spherical FSP have a much greater ability to slip through the weave of a fabric, potentially increasing the performance of the FSP against some armour materials. The ability of the spheres to slip through the fibres is affected by its surface finish and hardness. If a spherical FSP is chosen to replicate a preformed fragment (such as a sphere), it is important to consider the hardness and surface finish in the selection of the FSP, as these can have an impact upon the results. In comparison to natural fragments, the reduced kinetic energy density of the spherical FSP can offset the increased fibre slip from its curved surface and reduces the performance of the FSP.

Natural fragments are characterised as being irregular with sharp edges and are less able to push yarns apart than pre-formed fragments which may be rounded or have flat edges. Natural fragments from artillery shells will have a high hardness in comparison with some pre-formed fragments. Secondary fragments (such as stone and sand, or components of IEDs) may present other challenges such as being easily broken up upon impact or be of a low density. As fragments vary greatly in the range of properties discussed in this paper, it would not be possible to develop a single FSP representative of all fragments. Selecting unrepresentative FSPs in these scenarios presents a risk of developing inappropriate protection levels when designing protective systems.

Testing with a wide range of different FSPs can take a significant amount of time and hence be very expensive. With knowledge of the specific armour type to be tested and the realistic threat regimes, and consideration of the information discussed above, it is possible to narrow down the choices of FSPs to conduct the testing with.

6. SUMMARY

There has been little published work in the open literature comparing natural fragments with fragment simulators. Work to date suggests that the RCC FSP may present a better simulator of natural fragments, though there are limitations with this work. Careful consideration should be given to the design and material of any FSP for armour testing to ensure that accurate representation of the threat is made. The inappropriate selection of FSP may result in the introduction of unintended properties, that may have a negative impact upon aspects of an armour's design.

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