Make your own flexible ceramic body armour

I cannot afford to work on this any further – so I am publishing to prevent others from claiming it and restricting access to it. If you want to try making the FCC – please do. I made it in my garage – so you could too.

The FCC is patent-free and while I own the Intellectual Property Rights, I permit free and unrestricted use of the IPR.

Introduction

Protecting areas of the body against high velocity threats while allowing the wearer easy movement is difficult. Conventional ballistic panels for use with low-velocity Kevlar vests are rigid and so have to be small to avoid inhibiting free movement of limbs. The groin and the humeroscapular area are left unprotected. Both are vulnerable to arterial bleeding that cannot be stemmed with a tourniquet. The entry of fragments or bullets in other areas not covered by the ballistic panels can also lead to severe internal trauma far from the point of entry.

The Flexible Ceramic Composite (FCC) ballistic material is designed to allow ceramic armour to have greater coverage. FCC can be made as inserts or as a single-piece side-fastening tabard armour with front and rear groin flaps. It is heavy – but for short term wear during periods of predictable high risk, the weight may be considered an acceptable burden. A witnessed test of the latest design iteration was conducted at an appropriately licensed UK range in August this year (2013). The result is given below, proving that it is possible to have fully flexible 5,56 NATO combat rifle protection (and I am assured that the 5,56 is harder to stop than standard AK rounds, although I have not tested with an AK).

The potential for the FCC material to be exploited for other uses is real, as is the potential for designing new armour around the material.

What is the FCC material?

The FCC is remarkably simple. It comprises:

1. multiple layers of Kevlar as a backing (I have used 16 layers of a particular Kevlar to give me a NATO STANAG V50 of 450m/s+), so simulating a simple combat vest;
2. a shear hardening backing material – this stiffens on impact supporting the FCC in front of it (I have used a Bostik product, see below);
3. the FCC itself in a number of layers depending on the threat (I have found that six will stop 5,56 NATO ammunition with minimal blunt trauma).

A standard combat armour with a 450 m/s V50 needs no further explanation.
The shear hardening backing and FCC are explained below.

If you make this, please do test your product to confirm the results before getting anyone to rely on it for protection.
I expressly disclaim any liability for incidental and/or consequential damages.

Shear-hardening backing

I started with some rubber that was made to repair conveyor belts. Sourced from South Africa, it worked quite well but was very expensive and a very dark colour. The colour presented a manufacturing problem because I could not see the ceramic components and confirm that they remained in place. It was a thick goo with a fast RTV (set) time, so a vacuum was needed to pull the air out quickly. A test firing confirmed that it worked, but it was not practical so I looked for alternatives.

All rubbers harden by compressing on impact to some extent. Sometimes called “dilatant”, shear-hardening is more than just compression. I needed a silicone rubber that was flexible but resisted impact as if it were solid. The speed at which it hardens is important, as is the point of catastrophic failure where the material simply tears. I did not know how important it was to have a true dilatant so I tried various readily available rubber materials without success.

Of course, I also tried to source dilatant material from Dow-Corning and from a UK company called D30 both of which advertise dilatant products. Despite their advertising, they did not want to sell me any, and D30 wanted up-front details of the end-product plus some part of the IPR (they cannot have that even now).

As a one-off, I managed to source some DOW CORNING® 3179 DILATANT COMPOUND – which turned out to be what we in the UK know as “Silly Putty”. It does have dilatant properties and weighs little but it “flows” in slow-time so needed to be thickened or otherwise held in place. I worked around the problem – but alas, in tests it really did not work very well (see Annex A below for the test result using it).

While I was doing this, I had one of those “moments” and went down to a local shop to buy a Bostik product – which needed to be encapsulated to prevent it drying out but tended not to flow and really worked rather well. Blu-Tack. Use it in the slabs provided joined together and pressed onto a sheet of Kevlar that is wetted with slow-drying Zhermack ZA-13 translucent silicone, then paint silicone over the top, add another layer of Kevlar and pull a vacuum to remove all air. This has prevented any “slump” or “dry-out” effectively – over several months, at least.

A Blu-Tack back panel is just flexible enough.

I use a cheap vacuum machine bought on-line – and have welded up a few vacuum boxes myself. I use 5mm polycarbonate as the lid for my vacuum boxes. It seals down firmly onto a self made gasket and allows me to see what is going on inside the box.

If you doubt the properties of Bostik’s Blu-Tack (as I did) take a lump half the size of a golf ball and press your thumb nail into the top to leave an indentation, then whack it lightly with a nail hammer. Whack it harder until you can flatten out the thumbnail print….

The successful test described later used the unlikely Blu-Tack as a backing layer.

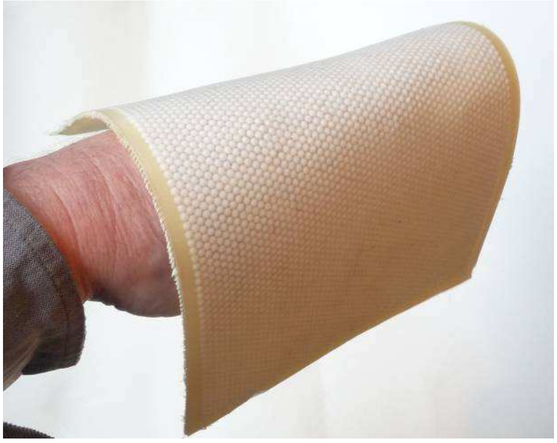
The FCC

The thinking behind the FCC owes something to lots of people but I learnt most from some South Africans who I worked with while they were conducting research on blast resistant boots. They found that layering materials of highly contrasting density had the effect of converting kinetic energy to heat – over remarkably short distances. That research was abandoned and the people moved on or retired, which is a shame. If the research were ongoing, I would have given them this because I believe that the FCC may well make a good flexible sole for blast-resistant boots.

Very simply, the FCC uses materials of contrasting densities with the aim of converting the bullet's kinetic energy into heat. Each FCC panel includes a number of layers of FCC material.

The materials in each FCC layer are:

1. A single sheet of Kevlar backing;
2. A layer of 3mm diameter Ytria stabilised ceramic Zirconia balls (very high density) held to the Kevlar with Zhermack ZA-13 translucent silicone (soft and flexible with a density similar to water);
3. A silicone filler of powdered glass (density in high contrast to the silicone).



This picture shows an FCC layer without any glass filler. After attaching the balls to the Kevlar with as little silicone as possible and drying it in an oven, I apply a layer of glass filled silicone, levelling it off with the top of the balls. This has no obvious effect on the flexibility.

With glass filler

The particular brand of silicone you use is probably not important. It should have a high elastic modulus and be low on the Shore hardness scale. I have tried harder silicone and polyurethane without any success – but not as a single variant in this particular panel design, so it may still be worth experimenting with variants. All materials should be encapsulated into a final product, so avoiding UV or moisture degradation – but temperature stability over a wide range is important.

When dry, use a non-stick spray over the FCC layer to allow each layer to slide over the next, so allowing multiple layers to flex smoothly. A non-stick effect can also be achieved with powders, but avoid anything hydroscopic. A silk layer also works well.

About 10% of the 3mm +/- 0.2mm Ø ceramic Zirconia balls (sourced from the USA, origin China) had to be discarded as mis-shapes or outside the size-range. The sifted balls could then be arranged by hand, but life is too short for that so a friend with a computerised router made me up a "mould" with depressions for each ball cut out of a thick block of perspex. I could then "pour" and level the balls rapidly onto the mould, apply liquid silicone and press on a layer of Kevlar, then vacuum away any excess rubber.

Stack FCC layers according to the threat. As already indicated, I used six FCC layers for the test below.

The FCC test

The FCC panel comprised a dilatant backplate and six layers of FCC all held inside an orange ballistic aramid envelope.

A Kevlar panel (in pale blue) and 3kg of plastecine was placed between the sandbag backing and the FCC. A professional chronograph was set up between the gun and the target to record the velocity of each shot.

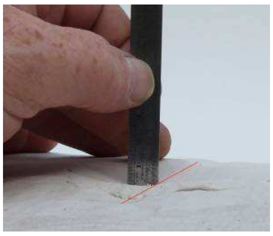
The chronograph setup is shown below.

Two well spaced shots were made from a measured ten metres using 5,56 NATO (US). (Chronograph reading: 863 mps). Impact centres were 120mm apart and 55mm from the nearest side of the panel.

The top image on the right shows the rear of the FCC panel with two burn marks but no material exiting.

The lower image shows the face of the Kevlar panel with a small burn mark but no damage to the Kevlar within.

Both shots were stopped inside the FCC. Tiny burn holes were in evidence in the rear of the Ballistic Aramid envelope containing the FCC panel but, although lightly marked, the Kevlar panel behind was not compromised in any way. The burning was indicative of successful kinetic/heat energy transfer.



Minor blunt trauma was recorded (less than 4mm).

A neodymium magnet was used to help recover what was left of the bullet cores from inside the FCC panel. The lumps top and bottom are the remains of steel cores, both burned and porous.

The material combination in the flexible panel led to the shattering of many ceramic balls and the transfer of the bullet's energy as heat. Soot blackening of the silicone occurred over a several centimetre diameter.

Conclusion

The combination of materials used in the FCC panel stopped the bullets (albeit with minor blunt trauma).

However, the panel was close to being compromised, so improvements are desirable. Also, optimisation to reduce weight is required.

Where next?

The FCC is little more than a proof of concept – but the concept is proven. The potential for improvement is great as long as you have a little investment capital. I have made 26 different panels – most using much bigger balls – and spent a lot of money finding out what would not work reliably. I cannot afford to carry on – but it would be nice if someone did.

If I were carrying on I would:

1. Reproduce the above using cheaper ceramic alumina balls (which may even work better);
2. Reproduce the above using 5mm diameter balls (both ceramic alumina and zirconia);
3. Reproduce the above using fewer layers but one layer made using larger balls;
4. Use a filler power that was a powdered ceramic to match the density of the ball material;
5. Encapsulate each FCC layer in ballistic nylon to guarantee long-term slip between layers (the aramid also "traps" molten metal effectively);
6. Try to find a sheet dilatant material that has a broad temperature stability to guarantee back-plate performance;
7. Try to find a manufacturer willing to sell a setting dilatant to use in place of the silicon…

And so on.

The Appendix below details the test made of a different design of FCC which included the use of Dow Corning dilatant. This panel did stop the bullets – but only inside the Kevlar backing. It performed badly when compared to the above because: the panel had seven layers of ceramic; the bullets were easier to stop than those used above; and because considerable blunt trauma was recorded.

Appendix A

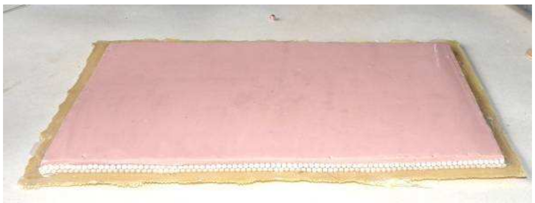
Test of another design of FCC

Content: Dow Corning (DK) DS / Blu-Tack (BT) DS, ZA13 silicon and Ceramic Zirconia (CZ) balls with Kevlar holding sheets.

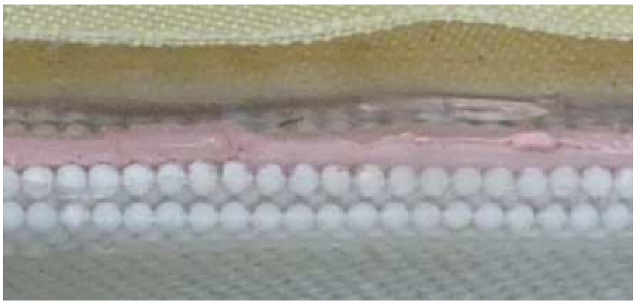
Panel comprised four layers (from back):

1) A 4mm layer of Blu-tak DS encapsulated in Kevlar.

2) a layer comprising a Kevlar back sheet, two layers of nested CZ balls set in silicon, a layer of DC DS, and a layer of balls pressed into it – the whole encapsulated in unfilled silicone ZA13. So 3 x CZ balls, 1 x DC DS and ZA13.



3) A layer comprising a backplate of 4mm BT between two sheets of Kevlar. A layer of balls set in silicon to this. A layer of approx 4mm DC DS rolled over that and two layers of balls encapsulated in silicon ZA13 over that. So 3 x CZ balls, 1 x DC DS, 1 x BT.



4) A layer of 3mm CZ balls backed by Kevlar and held in ZA13 silicone. This layer faced the bullet.

The whole panel was encased in an envelope of orange ballistic aramid.

This panel comprised a total of seven layers of CZ balls nested and stacked with a variety of dilatant sandwiches. By keeping the layers stacked in two 3-deep layers it was hoped that energy transfer between balls might be improved over previous tests. The performance of the two types of dilatant was unknown.

Testing

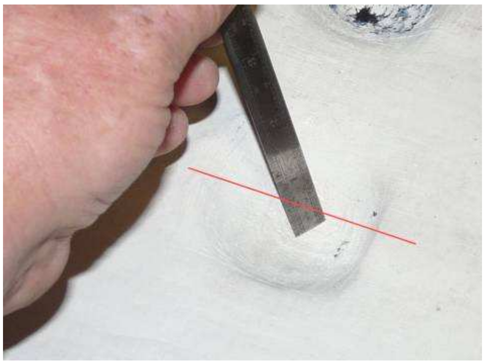
The panel was presented with a Kevlar panel and 3kg of plastecine between the sandbag backing and the panel. A chronograph was set up between the barrel and the target, so allowing the velocity of each shot to be recorded.

It was intended to use two well spaced shots using 762x51 NATO standard ammunition. – (average chronograph reading: 850 mps). The first shot struck the side of the panel so was discounted. Two further shots struck the panel (90mm between centres of impact and both 65mm from closest side of panel)

All three shots were stopped in the Kevlar panel behind the flexible ceramic panel.

The top (orange) image shows the back of the ceramic panel.

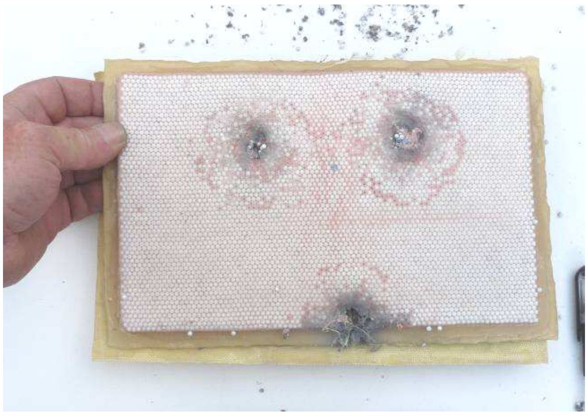
The lower (blue) image shows the front of the Kevlar panel (which was not penetrated)



Significant blunt trauma of 22mm was recorded.

The remains of all three bullets were recovered from the Kevlar panel.

A full examination of the layers in the panel showed that the DC dilatant materials had not apparently hardened on impact.



Ceramic balls were displaced over a wide area without breaking.

Although the combination of the flexible panel and its Kevlar backing did stop the bullets, the result was considered a “failure”. The DC dilatant did not apparently harden on impact in the way that the BT dilatant did and energy transfer by impact between ceramic balls and by heat transfer was less than when the DC dilatant was not used. While the DC dilatant may have been more effective if used solely as a backplate, it is not commercially available and appears to have limited value so should be excluded from further product development.