Assessment of aprons for protection against drop forging projectiles

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Assessment of aprons for protection against drop forging projectiles

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European Standards already exist for penetration resistant aprons (EN 412), but the form of the impactor and the energies involved in testing are not appropriate for simulating projectiles which may emanate from drop forging applications. This report describes the development of more appropriate test, impactor, and pass/fail criteria, and the results of applying the emergent test to different types of protective apron.

Samples of available protective equipment (leather, with and without reinforcement; chain mail; plate link) satisfied the requirements of the draft test method, some by a considerable margin. None of the samples was penetrated, but some exhibited potential for substantial ‘blunt trauma’ injury. Other aspects of EN 412 can be used as the basis for a full performance standard for drop forging aprons. Details of the performance requirements for area of coverage, area weight and total mass for example, may need to be adjusted to suit this application. Additional requirements would need to be added to account for drop forging environments.

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SUMMARY

The knife-drop penetration test from EN 412 was modified to provide performance assessment of equipment for drop forging applications. However, the different pass / fail criteria, impact energy and impactor design mean that performance in the existing EN 412 test cannot be used as an indication of likely performance in the modified test.

Available protective equipment samples (aprons made from leather, with and without reinforcement, chain mail and plate link) satisfied the requirements of the draft test method, some by a considerable margin. None of the samples was penetrated, but some exhibited potential for substantial ‘blunt trauma’ injury.

Other aspects of EN 412 can be used as the basis for a full performance standard for drop forging aprons. Details of the performance requirements for area of coverage, area weight and total mass for example, may need to be adjusted to suit this application. Additional requirements would need to be added to account for drop forging environments.

There is existing equipment which is likely to offer adequate body protection against impact from moderately sized projectiles from drop forges, notably aprons made from metal plate-link. A suitable test method has been developed. After the necessary consultations within HSE and with the industry, the method could be forwarded, with any agreed amendments, to the BSI committee responsible for protective clothing against mechanical hazards (PH/3) with the suggestion that it should form the basis for the development of either a new British or European Standard. In the interim, after suitable development, it could be used in the UK as a Product Approval Specification, allowing CE-marking and sale of suitable equipment.
Contents

1. INTRODUCTION 1
2. EXISTING TEST METHODS 1
2.1 EN 412 - SPECIFICATION FOR PROTECTIVE APRONS FOR USE WITH HAND KNIVES 1
2.2 NIJ 0101.03 BODY ARMOUR STANDARD 1
2.3 FLESH SIMULANT 2
3. TEST METHOD DEVELOPMENT 3
3.1 BASIS OF THE TEST 3
3.2 PASS / FAIL CRITERIA 7
3.3 VERIFICATION OF FLESH SIMULANT PROPERTIES 8
4. TEST SPECIMENS 11
4.1 LEATHER APRON WITH REINFORCED AREA 11
4.2 ‘LITE’ CHAIN MAIL 12
4.3 CHAIN MAIL 13
4.4 PLATE LINK 14
4.5 ‘ULTRA’ PLATE LINK 15
4.6 LEATHER SANDWICH 16
4.7 LAB COAT 16
5. TESTING 17
6. RESULTS 17
6.1 UNPROTECTED FLESH SIMULANT 17
6.2 LAB COAT 17
6.3 NON-REINFORCED LEATHER APRON 19
6.4 REINFORCED LEATHER APRON 20
6.5 ‘LITE’ CHAIN MAIL APRON 21
6.6 CHAIN MAIL APRON 22
6.7 PLATE LINK APRON 23
6.8 ‘ULTRA’ PLATE LINK APRON 24
6.9 LEATHER SANDWICH 25
6.10 HIGHER ENERGY IMPACTS 26
7. CONSIDERATION OF OTHER PROPERTIES FOR DROP FORGING APRON 31
7.1 APPLICABILITY OF EN 412 REQUIREMENTS 31
7.2 ADDITIONAL REQUIREMENTS FOR DROP FORGING ENVIRONMENTS 31
7.3 TOWARDS A DRAFT STANDARD 32
8. CONCLUSIONS 33
9. REFERENCES 36
ANNEX 1. SUPPLIERS OF THE MATERIALS TESTED IN THIS REPORT 37
ANNEX 2. PROCEDURE USED FOR IMPACT TESTING OF SAMPLES 38
1. INTRODUCTION

This report describes Phase 2 of work which originated following an injury to a drop forge operator. Phase 1 of the work (Vaughan and Johnson, 1998) estimated the likely impact energy of a projectile which was ejected from a drop forge. Phase 2 describes the testing of aprons which may be considered for protection against this type of impact.

European Standards already exist for penetration resistant aprons, but the form of the impactor and the energies involved are not appropriate for simulating drop forging applications. This report describes the development of more appropriate test, impactor, and pass/fail criteria, and the results of applying the emergent test to different configurations of protective apron.

2. EXISTING TEST METHODS

2.1 EN 412 - SPECIFICATION FOR PROTECTIVE APRONS FOR USE WITH HAND KNIVES

This Standard (CEN, 1993) describes testing and design requirements for aprons resisting penetration by a sharply pointed knife blade. A specified blade is mounted in a defined carrier and dropped vertically onto a test specimen supported on a tray of ‘flesh simulant’. Penetration here is assessed solely as the length of the knife blade which is exposed below the test sample. Tests are carried out both with the test sample and tray surface horizontal, and inclined at 30°. No single penetration must exceed 15 mm, and the mean of all measured penetrations must not exceed 12 mm.

Details of the test procedure (e.g. rotation and tilting of the test sample) are aimed at ensuring the apron does not exhibit significantly different penetration resistance properties if impacted at different knife orientations. Perhaps owing to size and shape of the knife blade and the relatively low impact energies involved in this test (4.9 J), the pass/fail criterion does not address ‘blunt trauma’ hazards associated with the impact.

Other requirements of this Standard (strength, flexibility, area of coverage, means of retention) may be applied to drop forging applications largely unaltered.

2.2 NIJ 0101.03 BODY ARMOUR STANDARD

This American standard (NIJ, 1987) assesses the effectiveness of body armour against bullets. Both penetration and blunt trauma are considered in the pass/fail criteria. Penetration here is differently defined to that in EN 412; penetration is when the bullet passes completely through the armour, and this must not occur. Blunt trauma is assessed by the depth of the ‘back face signature’ (BFS) which results from the impact of the bullet with the armour. The large impact energies involved cause an indentation in the flesh simulant material which is used as the backing to the armour during testing. BFS values up to 44 mm are permitted; it is accepted that this level of indentation may be debilitating to the wearer of the armour, but should be non-fatal.

Suggested alternative methods (Lord, 1998) for assessing blunt trauma also rely on the BFS, but measure the volume, rather than just the depth.
2.3 FLESH SIMULANT

Both the above Standards require a ‘flesh simulant plastic mass’ to support the material under test. The simulant must be incompressible and non-elastic, but deformable with similar inertial properties to flesh. In practice a form of high grade plasticine (Roma Plastilina No 1) is widely used. This is a mixture of clay and non-volatile oils which is commercially available for sculpting purposes. As with other forms of plasticine, its physical properties vary with temperature and time since working - the material becomes harder as temperature falls and as time since last being worked increases.

EN 412 specifies a ‘verification’ procedure to ensure that the flesh simulant has the right properties. This involves conditioning the material at a constant known temperature for more than 48 hours, and then subjecting it to a defined impact and measuring the depth of the resulting indentation. Available information suggests that Roma Plastilina No. 1 should exhibit the correct properties at a temperature between 15 and 30°C, fairly close to normal room temperature.

The behaviour of this material on impact is characterised by deformation and flow, as though it was an extremely viscous liquid. Figure 1 illustrates the typical reaction of the material on being subjected to a fairly blunt impact. The volume of the impactor displaces simulant material outwards. The surrounding simulant obstructs this outward movement, and the surface surrounding the impact is displaced upwards. These effects are more marked for blunt impacts, or where a sharp impact is dissipated by strong or rigid sample.

![Before impact](image1)

![After impact](image2)

Figure 1. Effect of a typical impact on flesh simulant.
3. TEST METHOD DEVELOPMENT

3.1 BASIS OF THE TEST

The principle of the impact test is to support the test specimen on a backing of flesh simulant and repeatedly strike the material at a range of orientations with a defined impactor held in a guided falling block. The impact energy of 12 J selected for these tests was based on the results of Phase 1 of the work. EN 412 is used as the basis for the test developed in this work. The same principles of sample support and orientation, and of test geometry are used. The detailed design of the apparatus, which adapts the test to the types of impact which are to be simulated, is shown in Figures 2 and 3. Full engineering drawings are available from the author. Briefly, the components are as follows:

3.1.1 Flesh Tray

Impact points must be separated by at least 80 mm, be at least 80 mm from any edge, and allow ~35° rotation between impacts. The resulting size and shape of impact tray is 10 cm deep and cylindrical with an internal diameter of 36 cm. The whole tray is able to rotate about a central bolt, and has index holes located at 36° intervals around a circumferencial flange. Three identical trays were manufactured.

3.1.2 Support Plate

This plate adapts the tray to the support pillar in the drop testing machine. The central bolt of the tray is offset to locate the impact point directly above the centre of the drop test rig support pillar. Additional holes are provided for a peg to lock the tray in each of the 10 rotational impact positions, and for securing the wedge adaptor (see 3.1.3. below).

3.1.3 30° Wedge Adaptor

In addition to horizontal impacts, 10 further impacts must be made with the sample and tray inclined at 30°. This adaptor permits these angled impacts. When fitted, the impact point is again located vertically above the central axis of the drop test rig support pillar.

3.1.4 Verification Impactor

EN 412 describes the required form of this impactor, used to ensure that the physical properties of the flesh simulant are correct. The important parameters are the hemispherical shape and diameter of the impactor, and the impact energy with which it strikes the material (19.6 J). Figure 4 shows the steel impactor used in this study. When attached to the carrier which guides the fall of the impactor, the whole assembly has a mass of 1063.1 g. The required impact energy will be generated by free fall from a height of 1.88 m. Impacts of this energy should result in an indentation of 25 mm in horizontally oriented flesh simulant with the correct properties.
Figure 2. Tray assembly for horizontal impacts

Figure 3. Tray assembly for inclined impacts
3.1.5 Test Impactor And Holder

The knife blade of EN 412 is unrealistically sharp and pointed to represent a drop forging projectile. Figure 5 shows the form of the steel impactor tips used in this work. It is based on generalised observations of the projectile which initiated this work. The tips are machined from 5 mm thick by 20 mm wide tool steel to form a 90° point with a 90° bevel. When mounted in a simple slotted cylindrical holder using clamping Allen screws and attached to the carrier which guides the fall, the assembly has a total mass of 698.8 g. An impact energy of 12 J will result from a free fall from a height of 1.77 m.

3.1.6 Sample Retention

EN 412 incorporates an arrangement for tensioning the sample under test by attaching eight 400 g weights which hang over the edges of the impact tray. There was insufficient room in our drop testing rig to use the same approach here. Instead, where possible, a loop of silicone rubber tubing was used around the circumference of the flesh tray to hold the test specimen in place. (Two of the test samples were insufficiently flexible to use this loop. When secured in this way, these materials arched upwards away from the flesh simulant surface, so the loop was not used. Instead, these samples were simply draped over the tray, with an overhang on all sides.)

Specimens were re-tensioned after each impact, without flattening down any deformations in the flesh simulant, or deliberately extracting sample material which had been entrained into the indentations.
3.1.7 Measurements

Because of the different responses of the various materials tested (see the definitions in 3.2 below), a single measurement procedure was not applicable in all cases. Two separate measurement procedures were carried out for all samples tested, and criteria developed for selection of the appropriate data.

Carrier depth - A reference scale was positioned on one of the guide rails of the drop rig, such that the position of the impactor carrier when just in contact with the surface of the flesh simulant was known. Immediately after each impact, the depth of the impactor carrier below this reference position was measured to the nearest 0.5 mm.

Carrier depth was used when:

- penetration occurred without rebound;
- perforation or protrusion occurred without rebound;
• indentation measurements were lower.

**Indentation depth** - After all the impacts on a specimen were complete and the specimen removed from the tray, the depths of the resulting indentations were measured from the level of the initial surface of the flesh simulant, perpendicular to the surface (even for impacts made at 30°). A simple orthogonal gauge was made for this purpose, and measurements recorded to the nearest 0.5 mm.

Indentation depth was used when:

- there was rebound;
- the impactor tip did not protrude
- carrier depth measurements were lower.

Where applicable, carrier depth measurements are likely to be the most accurate measure of impact depth. The lack of recoil in the flesh simulant means that the depth of a scar will not decrease after being inflicted. However, depending on the impact energy involved, and the response of the test sample, subsequent adjacent impacts may cause deformation of a previous scar; the expected form of such a deformation would be to reduce the depth. Indentation depths, which can only practicably be made after all impacts on a specimen are completed, may be subject to this effect, but there is no firm evidence of this happening in practice.

**Inclined tests** - Because the flesh simulant in these tests is inclined at 60° to the vertical, ‘carrier depth’ is not the appropriate measure of penetration. Simple geometry predicts that the perpendicular penetration into the surface of the simulant is given by:

\[
\text{Indentation depth} = \sin 60° \times \text{carrier depth}
\]

\[
\text{Indentation depth} = 0.866 \times \text{carrier depth}
\]

This relationship was applied when comparing the relative size of the carrier and indentation depths for inclined impacts.

### 3.2 PASS/FAIL CRITERIA

#### 3.2.1 Definitions

At this point, definitions are required of precisely what is meant by various terms which will be used subsequently in this report. This terminology does not necessarily agree with that used in the existing Standards quoted above, but is needed to describe the observed effects of these impacts on the materials tested.

**Damage** - A physical change on impact of the test material, which does not spontaneously reverse afterwards, e.g. inelastic stretching, cutting, tearing or breakage.

**Impact depth** - The selected measure of the scar on the flesh simulant (carrier depth or indentation depth) after an impact.

**Indentation** - Deformation of the flesh simulant as a result of the test impact.
Penetration - Where the material under test is damaged on impact so as to allow the full width of the impactor to protrude through the back face of the material.

Perforation - Where material is damaged on impact so as to allow any part of the impactor tip to be exposed on the back face of the material, but not to penetrate.

Protrusion - Where the tip of the impactor is tangible with a finger through the back face of the test sample. (For some of the materials tested, protrusion is possible even before impact. The absence of ‘damage’ makes this distinct from perforation.)

Rebound - Where the impactor carrier comes to rest at a point above the maximum impact depth, as a result of recoil in the specimen. Rebound is observable on impact as a ‘bounce’ of the impactor carriage.

3.2.2 Criteria

Preliminary tests revealed that the simple EN 412 ‘penetrating length’ approach was inappropriate for these tests. Substantial indentations were possible without any penetration or perforation. Similarly, the ‘44 mm BFS’ limit in the body armour standards seem excessive for an industrial occupational situation - the level of injury which may result would be unacceptably high. The following two-part compromise approach was adopted for the pass / fail criteria used in this report, and uses the terminology outlined in 3.2.1.

Penetration - Penetration shall not occur.

Impact depth - No single impact depth shall exceed 30 mm, and the mean of all impacts (horizontal and 30°) on a specimen shall not exceed 25 mm.

Consideration was given to measuring the volume of the BFS, but this would be impractical for some of the materials tested. For these samples, flesh simulant was extruded through the interstices of the test sample on impact, and came away with the sample on removal. Spuriously large BFS volumes would have resulted.

3.3 VERIFICATION OF FLESH SIMULANT PROPERTIES

When impacted in the specified manner, the resulting mean impact depth for flesh simulant with the correct physical properties should be 25 ± 2 mm. If the impact depth falls outside this range, the temperature of the flesh simulant must be adjusted and conditioned for more than 48 hours to give the required properties.

Starting at the ambient room temperature (~19°C), a series of verification impacts was conducted on each of three flesh simulant trays. Impact depths were initially far too small, so the trays were conditioned at successively higher temperatures to soften the flesh simulant. Results are summarised in Table 1 and Figure 6. The correct physical properties were eventually obtained by conditioning the trays at an indicated temperature of 46°C in our environmental cabinet, with testing taking place as soon as possible after removal from conditioning.
Table 1
Verification impacts to establish the conditioning temperature for the flesh simulant

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Mean impact depth (mm) [standard deviation (mm)]</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tray 1</td>
<td>Tray 2</td>
<td>Tray 3</td>
<td>Overall</td>
</tr>
<tr>
<td>~19 (room temperature)</td>
<td>11.9 [0.4]</td>
<td>11.4 [0.6]</td>
<td>9.3 [0.7]</td>
<td>10.9 [1.3]</td>
</tr>
<tr>
<td>~19 (room temperature)</td>
<td>11.3 [0.4]</td>
<td>10.6 [0.6]</td>
<td>11.9 [0.7]</td>
<td>11.2 [0.8]</td>
</tr>
<tr>
<td>25.3</td>
<td>13.8 [0.4]</td>
<td>12.6 [0.8]</td>
<td>14.4 [0.5]</td>
<td>13.6 [0.9]</td>
</tr>
<tr>
<td>35.3</td>
<td>19.1 [1.1]</td>
<td>18.0 [1.0]</td>
<td>19.9 [1.5]</td>
<td>19.0 [1.4]</td>
</tr>
</tbody>
</table>

On the basis of these tests, with a slight extrapolation, a temperature of 46°C was established as the condition which would produce the desired physical properties for the flesh simulant. All test impacts of materials and protective aprons were conducted after conditioning the flesh simulant trays at this temperature for more than 48 hours (typically 72 hours).

The reason why the temperature arrived at here differs so significantly from the temperature range given in other sources of information (15 to 30°C) is unknown. It could reflect variability between batches of nominally identical flesh simulant, or possibly incorrect labelling of the material supplied (Roma Plastilina is available in three grades, No 1 being the softest). This supports the need to verify the properties of each batch of material, rather than simply relying on published information.

Also evident from these tests is the similarity between impacts at a given temperature measured on the three different trays. Differences between trays are neither systematic nor significant, eliminating the need to condition each tray to a different temperature.

After each set of impacts, the flesh simulant surface was restored to a level condition by filling the indentations proud of the surface, and then drawing a straight edge across the simulant, level with the edges of the tray. Trays were then re-conditioned at the selected temperature before re-use.
Figure 6. Effect of flesh simulant temperature on impact depth
4. TEST SPECIMENS

A variety of impact / cut resistant aprons and material samples were obtained for testing. These are described below in more detail. No special pre-conditioning was applied to the test specimens; they were tested as received. Annex 1 lists the sources of the materials tested.

4.1 LEATHER APRON WITH REINFORCED AREA

(Figure 7) This apron was manufactured and supplied by a Sheffield-based company specialising in leather gloves and safety wear. It consists of a single continuous sheet (~1.8 mm thick) of leather, with an additional rectangular sheet of leather (~2 mm thick) to which over a thousand 2.5 mm by 14 mm steel staples have been added as reinforcement. The reinforced area is positioned so as to provide frontal protection to the lower abdomen and groin. Both the single layer of leather and the reinforced area were separately subjected to impacts.

Figure 7. Leather apron with reinforced area, and detail of staple reinforced area.
4.2 ‘LITE’ CHAIN MAIL

(Figure 8) This consists of individual circular 7 mm diameter welded links of 0.7 mm thick steel, interlocked together (4 into 1) to form a continuous sheet. The result is an extremely flexible and cut-resistant protective material. Even before impact, the extreme tip of the impactor can just protrude through the centre of a link.

Figure 8. ‘Lite’ chain mail apron, and close-up of links (0.7 mm thick wire).
4.3 CHAIN MAIL

(Figure 9) Of similar construction to 4.2, but made from steel links with a thickness of 0.8 mm. This apron also has high levels of flexibility and cut resistance, but is ~25% heavier than 4.2. Even before impact, the extreme tip of the impactor can just protrude through the centre of a link.

Figure 9. Chain mail apron and close-up of links (0.8 mm thick wire).
4.4 PLATE LINK

(Figure 10) Overlapping embossed aluminium plates, each ~20 mm square, are held together by welded steel rings. Each plate is attached by four steel rings to eight others. Each ring passes through four plates. The impactor tip cannot protrude through the undamaged material. This material is less flexible than chain mail, and could not be secured to the tray using the loop system (see 3.1.6).

Figure 10. Plate link apron, and close-up of plate / ring construction.
4.5 ‘ULTRA’ PLATE LINK

(Figure 11) Again, overlapping embossed aluminium plates are fastened together by welded steel rings, but this time the plates are ~35 mm by 20 mm. In any horizontal row, alternate links pass through two or four plates. Each plate is fastened to eight others by six rings. This configuration results in less flexibility than 4.4, and the sample could not be secured to the tray using the loop system (see 3.1.6). The impactor tip cannot protrude through the undamaged material.

Figure 11. ‘Ultra’ plate link apron, and close-up of plate / ring construction.
4.6 LEATHER SANDWICH

(Figure 12) This material sample was received through HSE Polymers and Fibres Sector, as an example of a cut resistant material for use in waist aprons. It consists of two ~1 mm thick sheets of leather, between which is a layer of PBO fibre felt (poly(p-phenylene-2,6- benzisoxazole), sold under the trade name of Zylon - a fairly new man-made fibre with exceptionally high tensile strength). The sample measures 12 by 14 cm, and was subjected to five horizontal impacts only, without ensuring a spacing of 80 mm between impacts, or using any form of retention mechanism.

![Side view of leather sandwich material sample](image)

Figure 12. Side view of leather sandwich material sample

4.7 LAB COAT

For comparison purposes, an ordinary laboratory coat (65% polyester, 35% cotton, with an area weight of ~255 g m-2) was subjected to horizontal impacts at a range of energies. This material is similar to typical industrial overalls, and is expected to be indicative of their performance in relation to test impacts.
5. TESTING

All impacts were conducted according to the procedure described in Annex 2. After an initial period of familiarisation with the system, test impacts were conducted on all samples in a horizontal orientation. The wedge adaptor was then installed, and all samples were re-tested at 30°. Testing took place over a 3 month period with three sets of impacts (one per tray) on any one day. The requirement for >48 hours temperature conditioning of the flesh simulant between impacts accounts for much of the duration of the testing period.

Where a single sample was subjected to the impact testing procedure more than once (as was most often the case), care was taken to ensure that no point on the specimen was impacted more than once.

Measurements described in 3.1.7 were recorded, along with observations of the impact, and the effects on the test sample and impactor. In no case did the impactor tip sustain significant damage, but the tip was replaced with a new one after approximately every five sets of impacts.

On completion of the ‘standard’ tests, the test arrangement was re-set to the horizontal position, and further impacts made on selected materials over a range of impact energies. Impact energy was varied by altering the mass and / or drop height of the impactor carrier. The purpose of these additional tests was to establish an upper level for the impact energy at which the different types of equipment would fail to meet the pass criteria.

6. RESULTS

6.1 UNPROTECTED FLESH SIMULANT

A set of impacts were made on unprotected horizontal flesh simulant, to establish a baseline performance for the 12 J impact. In all cases, the full exposed length of the impact tip plus part of the tip holder embedded into the flesh simulant. The mean impact depth was 53.6 mm, (standard deviation 2.9 mm). There was no rebound.

6.2 LAB COAT

These impacts were intended to be representative of the performance of ordinary industrial overalls. They were conducted at a range of impact energies below the 12 J standard impact, to try to determine what level of impact this clothing could be expected to protect against. Results are shown in Table 2 and Figure 13. The test system was not able to produce impact energies sufficiently low to determine this value. All the impacts penetrated the test sample without rebound, and impact energies greater than 2.7 J gave rise to impact depths in excess of 30 mm.
Table 2  
Impacts on lab coat material

<table>
<thead>
<tr>
<th>Impact energy (J)</th>
<th>Impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.9</td>
<td>49</td>
<td>Yes</td>
</tr>
<tr>
<td>5.1</td>
<td>44</td>
<td>Yes</td>
</tr>
<tr>
<td>4.1</td>
<td>41.5</td>
<td>Yes</td>
</tr>
<tr>
<td>3.1</td>
<td>34</td>
<td>Yes</td>
</tr>
<tr>
<td>2.7</td>
<td>30</td>
<td>Yes</td>
</tr>
<tr>
<td>2.1</td>
<td>22.5</td>
<td>Yes</td>
</tr>
<tr>
<td>1.7</td>
<td>23.5</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Figure 13. Impacts on lab coat material

The non-linearity visible in Figure 13 results from the additional resistance to penetration provided by the impactor tip holder. For impact depths greater than ~40 mm, the holder comes into contact with the test material / flesh simulant. This is relatively unimportant, as it can only happen for samples which have already failed the pass criteria.
6.3 NON-REINFORCED LEATHER APRON

Standard 12 J test results are shown in Figure 14 and summarised in Table 3.

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mean impact depth (mm)</th>
<th>Standard deviation (mm)</th>
<th>Maximum impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>21.2</td>
<td>1</td>
<td>23</td>
<td>No</td>
</tr>
<tr>
<td>30°</td>
<td>17.5</td>
<td>1.2</td>
<td>19.5</td>
<td>No</td>
</tr>
<tr>
<td>Overall</td>
<td>19.3</td>
<td>2.2</td>
<td>23</td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 14. Impacts on non-reinforced leather

Impacts typically inflicted some damage on the leather, giving rise to cuts and slight perforation. Penetration did not occur, and there was some rebound. This material passes the requirements of this test.
6.4 REINFORCED LEATHER APRON

Standard 12 J test results are shown in Figure 15 and summarised in Table 4. Impacts again caused damage to the apron; where the tip struck leather the outer layer was typically perforated; where the tip struck staples, they were bent but not cut; the underlying layer of leather was not perforated. There was no penetration, and large rebound was evident.

Table 4

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mean impact depth (mm)</th>
<th>Standard deviation (mm)</th>
<th>Maximum impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>11.7</td>
<td>1.6</td>
<td>13</td>
<td>No</td>
</tr>
<tr>
<td>30°</td>
<td>11.3</td>
<td>0.7</td>
<td>12.5</td>
<td>No</td>
</tr>
<tr>
<td>Overall</td>
<td>11.5</td>
<td>1.2</td>
<td>13</td>
<td>No</td>
</tr>
</tbody>
</table>

The thickness of the sample tended to ‘blunt’ the impact, leading to relatively wide and shallow indentations in the flesh simulant. This material passes the requirements of the test.

Figure 15. Impacts on reinforced leather
6.5 ‘LITE’ CHAIN MAIL APRON

Standard 12 J test results are shown in Figure 16 and summarised in Table 5. Protrusion of the impactor tip (already possible before testing) may have been marginally increased by deformation of the link directly under the impact point. Such links typically became slightly oval, but were not cut or broken. There was no penetration, and no rebound.

The relatively high flexibility of this material tended to allow it to cling closely to the tip of the impactor on impact. Indentations in the flesh simulant were relatively deep and narrow. Indentation was probably assisted by the ability of the flesh simulant to extrude through the interstices of the mail on impact.

![Figure 16. Impacts on ‘Lite’ chain mail](image)

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mean impact depth (mm)</th>
<th>Standard deviation (mm)</th>
<th>Maximum impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>26.7</td>
<td>1.8</td>
<td>30</td>
<td>No</td>
</tr>
<tr>
<td>30°</td>
<td>21.3</td>
<td>3.4</td>
<td>24.4</td>
<td>No</td>
</tr>
<tr>
<td>Overall</td>
<td>24</td>
<td>3.8</td>
<td>30</td>
<td>No</td>
</tr>
</tbody>
</table>

This material is a borderline pass for the requirements of the test. If horizontal impacts were considered alone, it would be classed as a fail. However, the test regime is perhaps slightly unrealistic for this material; the mail would be unlikely to be worn over bare skin, and the presence of a layer of clothing underneath it would almost certainly reduce the tendency for the flesh simulant to extrude through the mail, and would assist in spreading the impact energy over a wider area.
6.6 CHAIN MAIL APRON

Standard 12 J test results are shown in Figure 17 and summarised in Table 6. Protrusion of the impactor tip (already possible before testing) may have been marginally increased by deformation of the link directly under the impact point. Such links typically became slightly oval, but were not cut or broken. There was no penetration, and no rebound.

As with ‘lite’ chain mail, the relatively high flexibility of this material tended to allow it to cling closely to the tip of the impactor on impact. Indentations in the flesh simulant were relatively deep and narrow, and the flesh simulant tended to extrude through the interstices of the mail on impact.

![Figure 17. Impacts on chain mail apron](image)

**Table 6**

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mean impact depth (mm)</th>
<th>Standard deviation (mm)</th>
<th>Maximum impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>21.2</td>
<td>1.7</td>
<td>23.5</td>
<td>No</td>
</tr>
<tr>
<td>30°</td>
<td>20.5</td>
<td>2.4</td>
<td>23.5</td>
<td>No</td>
</tr>
<tr>
<td>Overall</td>
<td>20.8</td>
<td>2</td>
<td>23.5</td>
<td>No</td>
</tr>
</tbody>
</table>

This material passes the test requirements, and would also benefit from the effects of an underlying layer of clothing, as described in 6.5.
6.7 PLATE LINK APRON

Standard 12 J test results are shown in Figure 18 and summarised in Table 7. There was no penetration, but rebound was sometimes evident. Impacted areas of the apron showed localised damage (bending of plates and steel rings) at the impact point, but links remained intact. There was some extrusion / entrainment of flesh simulant within the interstices of the apron material.

Table 7

12 J impacts on plate link apron

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mean impact depth (mm)</th>
<th>Standard deviation (mm)</th>
<th>Maximum impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>12.9</td>
<td>0.7</td>
<td>14.5</td>
<td>No</td>
</tr>
<tr>
<td>30°</td>
<td>13.7</td>
<td>1.1</td>
<td>15.1</td>
<td>No</td>
</tr>
<tr>
<td>Overall</td>
<td>13.3</td>
<td>1</td>
<td>15.1</td>
<td>No</td>
</tr>
</tbody>
</table>

This material passes the requirements of the test in isolation, but would probably benefit from an underlying layer of cloth, to prevent the simulant extrusion effects as noted for the chain mails.
6.8 ‘ULTRA’ PLATE LINK APRON

Standard 12 J test results are shown in Figure 19 and summarised in Table 8. There was no penetration, but rebound was sometimes evident. Impacted areas of the apron showed localised damage (cutting, perforation and bending of plates and bending of steel rings) at the impact point, but links remained intact. There was some extrusion / entrainment of flesh simulant within the interstices of the apron material.

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mean impact depth (mm)</th>
<th>Standard deviation (mm)</th>
<th>Maximum impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>11.6</td>
<td>0.9</td>
<td>13</td>
<td>No</td>
</tr>
<tr>
<td>30°</td>
<td>9.8</td>
<td>0.9</td>
<td>12</td>
<td>No</td>
</tr>
<tr>
<td>Overall</td>
<td>10.7</td>
<td>1.3</td>
<td>13</td>
<td>No</td>
</tr>
</tbody>
</table>

This material also passes the requirements of the test in isolation, but would probably benefit from an underlying layer of cloth, to prevent the simulant extrusion effects as noted for the other forms of mail.
6.9 LEATHER SANDWICH

Only five horizontal impacts at 12 J were carried out on this small sample of material. The results are given in Table 9. The sample was not penetrated, and there was considerable rebound. The outer layer of leather was slightly cut and perforated, but the inner layer remained undamaged.

<table>
<thead>
<tr>
<th>Impact</th>
<th>Impact depth</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19.5</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>21.5</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>16.5</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>No</td>
</tr>
<tr>
<td>Mean</td>
<td>19.1</td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.9</td>
<td></td>
</tr>
</tbody>
</table>

The inability to use any form of retaining system for this small sample may have led to higher values of impact depth (and possible lower levels of damage) being recorded here. Indications are that this material would pass the requirements of the test, and perform similarly to non-reinforced leather.
6.10 HIGHER ENERGY IMPACTS

Three of the test specimens were subjected to a reduced number of progressively higher impact energies (two impacts at each energy level for horizontally oriented specimens only), produced by varying the mass and drop height of the impactor carrier. Results and observations of individual tests are given below, and are summarised in Figure 20.

This approach provides a direct indication of whether mean impact depth and penetration requirements are likely to be met in a full test at these energies. The requirement for maximum impact depth is less easily predictable, and is dealt with separately in 6.10.4.

![Figure 20. Performance of samples at higher impact energies](image)

6.10.1 Reinforced Leather

Table 10 gives the results of these higher energy impacts. Damage to the apron increased slightly with the impact energy - cutting and perforation of the outer layer of leather and bending of staples. However, even at the highest impact energies, the inner layer of leather remained undamaged, and staples were not cut or broken. There was considerable rebound, but no penetration. The mean impact depth limit of 25 mm was not reached for impacts up to 26.9 J.

<table>
<thead>
<tr>
<th>Energy (J)</th>
<th>Mean impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.5</td>
<td>17.3</td>
<td>No</td>
</tr>
<tr>
<td>19.2</td>
<td>19.8</td>
<td>No</td>
</tr>
<tr>
<td>22</td>
<td>22.5</td>
<td>No</td>
</tr>
<tr>
<td>24.7</td>
<td>24</td>
<td>No</td>
</tr>
<tr>
<td>26.9</td>
<td>24.5</td>
<td>No</td>
</tr>
</tbody>
</table>
6.10.2 Chain Mail

Results of these impacts are shown in Table 11. Again damage to the apron material increased slightly with the impact energy, with individual links becoming bent and twisted. However, no links were cut or broken, and there was no penetration or rebound. Extrusion of the flesh simulant continued to be evident. The 25 mm mean impact depth limit was exceeded for all but the 16.5 J impacts.

<table>
<thead>
<tr>
<th>Energy (J)</th>
<th>Mean impact depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.5</td>
<td>33.3</td>
<td>No</td>
</tr>
<tr>
<td>19.2</td>
<td>36.5</td>
<td>No</td>
</tr>
<tr>
<td>22</td>
<td>34.5</td>
<td>No</td>
</tr>
<tr>
<td>24.7</td>
<td>37.3</td>
<td>No</td>
</tr>
<tr>
<td>26.9</td>
<td>38</td>
<td>No</td>
</tr>
</tbody>
</table>

6.10.3 ‘Ultra’ Plate Link

Results of these impacts are shown in Table 12. The severity of damage to the plates increased with impact energy. The highest energy impacts resulted in severe bending, cutting and perforation of the plates, but penetration did not occur. Rebound continued to be observed, and extrusion / entrainment of flesh simulant was evident. The 25 mm limit for mean impact depth was not exceeded for impacts up to 26.9 J.

<table>
<thead>
<tr>
<th>Energy (J)</th>
<th>Mean Impact Depth (mm)</th>
<th>Penetration?</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.5</td>
<td>18</td>
<td>No</td>
</tr>
<tr>
<td>19.2</td>
<td>19.2</td>
<td>No</td>
</tr>
<tr>
<td>22</td>
<td>19.2</td>
<td>No</td>
</tr>
<tr>
<td>24.7</td>
<td>21.8</td>
<td>No</td>
</tr>
<tr>
<td>26.9</td>
<td>23.8</td>
<td>No</td>
</tr>
</tbody>
</table>

6.10.4 Maximum Impact Depth Predictions

The measurements of impact depth at these elevated energies are each based on a mean of two values. The precision of these measurements is likely to be lower than for the usual impact depth means (10 values), and they are unlikely to contain the extremes of measurement needed to assess the ‘maximum impact depth’ requirement in the pass / fail criteria.

By examination of the full set of data for both horizontal and inclined impacts, an estimate of the typical reproducibility of measurements can be made. When the observed standard
deviation of individual sets of 10 measurements is expressed as a percentage, the data from the
different tests can be compared, and an overall reproducibility (mean % standard deviation) for
the test calculated. A value of 8.55% emerges.

If data are distributed normally, the maximum observed value in 10 samples is likely to fall
somewhere in the region of the 95th percentile, which is located at a factor of 1.645 times the
standard deviation above the mean value (in this case $1.645 \times 0.0855 = 1.1406$ times the mean
value). Figure 21 compares the predicted 95th percentile (for impact depth data with the
observed means and a standard deviation of 8.55%), with the observed ‘maximum impact
depth’ values. The level of agreement is extremely good ($r^2 = 0.996$).

Assuming the mean impact depths measured at elevated impact energies to be reasonable
estimates, the predicted maximum likely values (rounded to the nearest 0.5 mm) are shown in
Table 13. (Predicted values which approach 40 mm may be overestimated, owing to the effect
described at 6.2 above. Again, the significance of this is small.)

### Table 13

<table>
<thead>
<tr>
<th>Impact energy (J)</th>
<th>Predicted maximum impact depths for: (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reinforced leather</td>
</tr>
<tr>
<td>12 (observed)</td>
<td>13</td>
</tr>
<tr>
<td>12 (predicted)</td>
<td>13.5</td>
</tr>
<tr>
<td>16.5</td>
<td>19.5</td>
</tr>
<tr>
<td>19.2</td>
<td>22.5</td>
</tr>
<tr>
<td>22</td>
<td>25.5</td>
</tr>
<tr>
<td>24.7</td>
<td>27.5</td>
</tr>
<tr>
<td>26.9</td>
<td>28</td>
</tr>
</tbody>
</table>

![Figure 21. Observer and predicted maximum impact depths](image)

**6.10.5 Implications For Other Test Samples**
The ‘standard test’ performance of the three samples which were tested at higher energies can be compared with the other samples in terms of impact depths. Reinforced leather yields smaller values than non-reinforced leather or leather sandwich materials. Chain mail yields smaller values than ‘lite’ chain mail. ‘Ultra’ plate link yields smaller values than plate link. The samples which were not tested at the higher energies would therefore be expected to give larger impact depths than their tested counterparts at the same impact energies, but there is insufficient information to predict values.

It is less easy to predict with any certainty whether failure by penetration would occur before impact depth-related failures. However, based on experience gained during these tests, I would expect this only to be a possibility for non-reinforced leather.

6.10.6 Comparison With EN 412 Performance

All the equipment tested passes the knife-drop test in EN 412. (This may only apply to the reinforced area of the leather apron; this equipment is self-certified by the manufacturer, and information on claimed performance is somewhat sketchy.) The pass criterion is based simply on the length of the back of the defined knife blade which is exposed below the material after a relatively low energy impact (4.9 J). There is no consideration of ‘indentation’ of the flesh simulant as an indication of blunt trauma.

Because of these differences in the pass / fail criteria, performance in the EN 412 test cannot be extrapolated to drop forging applications with any degree of reliability. The different shape of the impactor, the higher impact energy, and the requirement to consider both penetration and indentation, make the proposed test more exacting.

6.10.7 Overview Of Impact Test Results

None of the protective equipment samples tested in this work exhibited complete penetration. They all successfully stopped the impactor tip, but performed differently in terms of how they absorbed the impact energy. However, users should bear in mind that penetration performance will be highly dependent on the shape and sharpness of the impacting object.

‘Impact depth’ is the criterion which would cause most of the tested materials to fail, if the impact energy was increased. The relatively high flexibility of the non-reinforced leather and the two chain mail samples meant that they allowed much of the impact energy to be transmitted to the flesh simulant directly underlying the impact point, giving large indentations. Stiffer materials (reinforced leather and the two plate links) spread out the impact energy over a wider area, absorbed some of the energy by deformation, and tended to give lower indentation depths.

Test results for the more ‘open’ structures (chain mail and to a lesser extent plate link) may err on the side of caution owing to the tendency for the flesh simulant to extrude through the holes in the material. The test could be modified to include a layer of material (e.g. typical overall material) beneath the mail. This would prevent the extrusion and provide a more ‘realistic’ assessment, but this would need to be done for testing of all materials, and would require either a source of ‘standard’ material, or a procedure to verify the backing material properties. Alternatively, the manufacturer could include such a backing material on their product with the same effect, without having to introduce modifications to the test.

Some of the materials tested were able to meet the proposed performance requirements at impact energies more than double those of the proposed standard test. In view of this, there is
an argument for making the standard impact energy somewhat higher than the current 12 J, even though this is based on estimated energies from a real injury event. An impact energy of 20 J would be equivalent to the projectile which was involved in the initiating incident (54.72 g) travelling at a velocity of 27 m s⁻¹. This is somewhat above the maximum likely estimated velocity for the incident in question, but similar to the observed velocity of small scale particles ejected from the drop forge during the Phase 1 (Vaughan and Johnson, 1998) high speed video measurements (26 m s⁻¹).

None of the materials tested here exhibited any tendency to directionality in performance. This was to be expected for isotropic materials (e.g. leather or chain mail), but could have been a problem for non-isotropic materials (reinforced leather and plate links). It would be a sensible precaution to retain the rotation of samples and tests on inclined samples included in the test procedure, to guard against possible performance directionality in any future materials tested.
7. CONSIDERATION OF OTHER PROPERTIES FOR DROP FORGING APRONS

7.1 APPLICABILITY OF EN 412 REQUIREMENTS

EN 412 contains requirements for the following aspects, which are equally applicable to drop forging applications:

- Dimensions - Minimum dimensions are specified for the protective area of two sizes of apron (both 550 mm wide; either 600 or 750 mm long). Consideration should be given to whether these dimensions are adequate for the area of the body to be protected from drop forging projectiles. (The partly reinforced leather apron tested in this work would not meet this requirement, as the reinforced area did not meet these minimum dimensions.)

- General construction - Basic strength requirements are specified.

- Penetration resistance - The proposed test and pass / fail criteria would be substituted here.

- Tensile strength - No breakages shall occur when tested at 200 N.

- Flexibility - A maximum bending force (6 N) is specified for ease of wearing and movement.

- Dimensions of interstices - A defined gauge shall not pass through any holes in the material, setting a minimum size against which protection is provided.

- Apron support - Straps shall be adjustable and shall not slip in use. Strap dimensions and fastening mechanisms are described.

- Mass - Both area weight limits (4500 g m⁻²) and total weight limits (1350 g or 1700 g, depending on size) are specified. Given the proposed heavy industrial use of the equipment, and the possible need for larger areas of the body to be protected, these limits may be able to be relaxed a little.

- Marking and instructions for use - would need to be developed once the final form of the Standard was established. At least the types of information required in EN 412 should be provided.

Annex A (informative) of EN 412 gives guidance on selection of the correct size of apron. This too would be applicable.

7.2 ADDITIONAL REQUIREMENTS FOR DROP FORGING ENVIRONMENTS

EN 412 essentially considers equipment for use in a butchery environment. Drop forging environments contain additional hazards which will require to be addressed in any Standard for this type of equipment.

- Flammability - No part of the equipment (including straps) should be of a flammable nature when exposed to a flame. EN 531, Protective clothing against heat and flame (CEN,
Clause 6.2 could be used as the basis for this requirement, although preconditioning and the stipulation for the absence of hole formation may be unnecessary in this case.

- Resistance to ignition by contact with hot solids - The temperature of the forging billets being handled is such that they may cause ignition of some materials. Eye protection Standards contain a test which could be applied in this case (EN 168, Clause 7 (CEN, 1995b)).

- Ergonomic aspects - In addition to the flexibility test already contained in EN 412, the thermal environment in drop forging situations requires special consideration. How this should be addressed in any standard is less clear; perhaps an informative annex giving guidance on this aspect of the selection process. In general, open structures such as chain mail and plate link will impose less thermal load on the wearer as a result of retained body heat. Plate link in particular may also be quite effective at reflecting external radiant heat from the workpiece or pre-heating furnace. More impervious materials such as leather will restrict heat and water vapour loss from the wearer, and may be uncomfortable in long-term use. In general, heavier equipment will increase workload, leading to earlier fatigue. Working practices may have to be adjusted accordingly (work / rest schedules adjusted or introduced). There is a balance to be struck between the level of protection offered, and the restriction which this will impose on the wearer.

- Compatibility with other equipment - The apron is intended to be worn with other clothing and equipment. It should not unduly interfere with the performance of the other equipment, or affect the wearer’s ability to use the other equipment correctly and safely. For example, if donning and adjustment of the apron is required to be carried out using gloved hands, this could be assessed as part of the standard test procedure. (The type of glove would need to be defined, and subjective pass / fail criteria included); if adjustment of footwear is required, wearing the apron should not prevent the user from doing so. Any similar aspects could be built into a work simulation or practical performance test.

- Special cleaning and maintenance requirements. If there are particular considerations for equipment used in these environments, then these should be incorporated. I suspect the norm in industry would be for this equipment not to be regularly cleaned. There should, however, be guidance on the regular inspection for the equipment to ensure that it continues to be likely that it will protect in the event of an impact. Repair / replacement criteria could be specified, or alternatively the requirement could be placed on the manufacturer to declare suitable procedures.

7.3 TOWARDS A DRAFT STANDARD

The various performance and design requirements described in 7.1 and 7.2 would form the basis of a draft standard, which would initially at least be submitted to BSI for consideration. The appropriate committee for this is PH/3. They may then decide that the draft should be submitted to CEN (TC/162) for consideration as a new European Standard. If CEN are not interested, BSI could either adopt the draft as a new British Standard following their normal consultation procedures, or (probably on a shorter timescale) use it as a Product Approval Specification (PAS).

Even without a harmonised European Standard, manufacturers of protective equipment could base their CE-marking of aprons for drop forging use on the test method developed here if their Notified Body agreed. Such equipment would be marked through the ‘technical file’ route. Once CE-marked, equipment could be marketed specifically for this application.
8. CONCLUSIONS

Based on available information about the size, shape and velocity of projectiles from drop-forges, a test method and pass / fail criteria have been developed. Using the prototype method, existing forms of protective apron have been tested, and found to meet these tentative pass / fail criteria. These criteria are adapted from those used in the industrial stab-resistance standard and that for body armour for use against bullets, taking into account the acceptable level of likely injury.

The test is based on the established procedure from EN 412, and similarly relies on a flesh simulant. The mechanical properties of the simulant used are fundamental to the outcome of the test, and must be verified. It is not adequate to simply rely on materials and test conditions reported by others.

Some forms of the tested equipment are capable of meeting the required levels of performance at much higher impact energies than have currently been used in the impact test. On this basis, for an improved margin of safety, it may be worth increasing the test impact energy from 12 J to 20 J. This would be likely to exclude non-reinforced leathers and unsupported chain mail on the basis of excessive impact depth; penetration may also occur for the non-reinforced leather.

With some modifications and additions, the other requirements of EN 412 are largely applicable to aprons for use in drop forging situations. Notable additional requirements would be to ensure that materials from which the aprons were made were not likely to catch fire, and to consider the thermal consequences of using this type of equipment in drop forging environments. A draft of the possible standard could be developed along these lines in BSI / CEN, if thought to be worthwhile.

The properties of the tested apron materials, and their relative performance in the prototype impact test, are summarised in Table 14. Assuming aprons made from these materials also satisfy the identified aspects of EN 412 and the above additional requirements specific to drop forging applications, the relative suitability of different apron designs can be tentatively predicted.

Plain leather - Cheap, light and flexible, but likely to provide the lowest level of protection against penetration of all the materials tested here. Durability will also be relatively low.

Reinforced leather - If the double layer / staples extend over the whole of the area, this apron will be heavy, inflexible and uncomfortably hot to wear. It would however provide good levels of protection against both penetration and indentation.

Chain mails - Both forms tested performed similarly, with good penetration resistance but poor indentation resistance. The extreme flexibility and open structure of the mail make this material cool and comfortable, but on its own it is probably insufficiently protective. Backing the mail (e.g. with a leather apron) would probably result in good levels of protective performance for the combination, but at the cost of increased weight, discomfort and expense. Durability of the combination would only be as good as for the backing material, but it may be possible for the combination to be designed so that the backing and mail components could be replaced separately as required; this would moderate maintenance costs.
**Plate link** - The most expensive of the options to buy, but providing high levels of protection. These materials are significantly lighter, more flexible and more durable than a fully reinforced leather apron, and have the added advantages of being both breathable and heat reflective. The high protection, relative comfort in use and durability, outweigh the relatively high initial outlay cost for this type of equipment, and it is likely to be the optimum choice for drop forging applications.

As a final note of caution, these summaries are based on experience gained with the specific materials examined and tested. Extrapolation of performance to apparently similar materials may not be appropriate or justified. There is no substitute for thorough evaluation of individual products against an appropriate performance specification, such as outlined in section 7 above.
Table 14
Summary of properties of apron materials, and their relative suitability for drop forging protection applications

<table>
<thead>
<tr>
<th>Apron material</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Likely suitability for drop forging applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leather (Single layer over whole area)</td>
<td>Light (~500g)</td>
<td>Lowest penetration resistance</td>
<td>Low protection and durability; light but hot to wear</td>
</tr>
<tr>
<td></td>
<td>Flexible</td>
<td>Low indentation resistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barrier to radiant heat</td>
<td>Not breathable, so hot to wear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inexpensive to buy (~£10)</td>
<td>Likely to deteriorate with use</td>
<td></td>
</tr>
<tr>
<td>Reinforced leather (Double layer with staples over whole area)</td>
<td>Good penetration resistance</td>
<td>Heavy (~3500g)</td>
<td>Good protection but poor comfort</td>
</tr>
<tr>
<td></td>
<td>Good indentation resistance</td>
<td>Inflexible</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barrier to radiant heat</td>
<td>Not breathable, so hot to wear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fairly inexpensive (~£40)</td>
<td>Likely to deteriorate with use</td>
<td></td>
</tr>
<tr>
<td>‘Lite’ chain mail (Unsupported by any backing)</td>
<td>Good penetration resistance</td>
<td>Low indentation resistance on its own</td>
<td>Moderate protection and comfort, but durable</td>
</tr>
<tr>
<td></td>
<td>Highly flexible</td>
<td>Little barrier to radiant heat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light (~1100g)</td>
<td>Fairly expensive (~£60)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Highly breathable, so cool to wear</td>
<td>Durable</td>
<td></td>
</tr>
<tr>
<td>Chain mail (Unsupported by any backing)</td>
<td>Good penetration resistance</td>
<td>Low indentation resistance on its own</td>
<td>Moderate protection and comfort, but durable</td>
</tr>
<tr>
<td></td>
<td>Highly flexible</td>
<td>Little barrier to radiant heat</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fairly light (~1500g)</td>
<td>Fairly expensive (~£60)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Highly breathable, so cool to wear</td>
<td>Durable</td>
<td></td>
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<tr>
<td>Plate link</td>
<td>Good penetration / indentation resistance</td>
<td>Relatively expensive to buy (~£80)</td>
<td>High protection, comfort and durability balances initial cost</td>
</tr>
<tr>
<td></td>
<td>Fairly flexible and light (~1500g)</td>
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<tr>
<td></td>
<td>Breathable, so cool to wear</td>
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<td></td>
<td>Reflects and blocks radiant heat</td>
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<td></td>
<td>Durable</td>
<td></td>
<td></td>
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<tr>
<td>‘Ultra’ plate link</td>
<td>Highest penetration/indentation resistance</td>
<td>Relatively expensive to buy (~£80)</td>
<td>High protection, comfort and durability balances initial cost</td>
</tr>
<tr>
<td></td>
<td>Fairly light (~1550g)</td>
<td>Limited flexibility</td>
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<td></td>
<td>Breathable, so cool to wear</td>
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<tr>
<td></td>
<td>Reflects and blocks radiant heat</td>
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<td></td>
<td>Durable</td>
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9. REFERENCES


Annex 1  Suppliers of the materials tested in this report

The following suppliers provided the materials tested in this report. Mention here does not constitute any endorsement of these products by HSL. Other suppliers of this type of equipment exist, and are also listed where known.

Reinforced leather apron:  Hypasafe Ltd, 100 John Street, Sheffield S2 4QU
Tel.0114 273 0740

Leather Sandwich material:  Bennett Safetywear, Mersey Road, Liverpool L23 3AF
Tel. 0151 924 3996

Chain mails:  BRB Industrial Services Ltd, Douro Place, Liverpool L13 1AG
Tel. 0151 259 6161

also:  Manabo UK Ltd, Thirsk Industrial Park, Thirsk, N Yorks,
Y07 3TA  Tel. 01845 525008

Plate link:  BRB Industrial Services Ltd, Douro Place, Liverpool L13 1AG
Tel. 0151 259 6161
Annex 2 Procedure used for impact testing of samples

1. Prepare and condition the flesh simulant trays by storing them in the environmental cabinet at an indicated 46°C for >48 hours.

2. Immediately prior to a series of tests, check the condition of the impactor tip, and if damaged replace it. Ensure the carrier can move freely down the guide rails of the drop rig (lightly grease the rails if necessary). Raise and securely chock the impactor.

3. Remove one tray from the conditioning chamber and mount it on the support pillar of the drop rig, using one of the peripheral holes in the tray to lock it in the first rotational position. Testing should commence within 5 minutes of removal from the conditioning chamber.

4. Check that the scale which indicates ‘carrier depth’ reads zero when the impactor tip is just in contact with the surface of the flesh simulant, then raise and re-chock the impactor carrier.

5. Mount and secure the test specimen on the surface of the tray. Where possible, secure the sample using the rubber band. Alternatively, self-adhesive parcel tape may be used.

6. Close the doors to the impact chamber of the drop rig.

7. Remove the carrier chock and raise the carrier to the required drop height, and release it.

8. Observe the impact for rebound and penetration, then read off the carrier depth (to the nearest 0.5 mm) from the scale provided.

9. Raise and chock the carrier, examining the condition of the tip; if damaged, replace it. Open the impact chamber doors, then index the tray to the next rotational position.

10. Repeat steps 6 to 9 until 10 impacts have been made on the sample.

11. Remove the test sample from the tray, and then remove the tray from the support pillar and place it on a horizontal surface for examination.

12. Examine the specimen for penetration and damage, and record observations.

13. Using the orthogonal gauge, measure the maximum vertical depth of each of the ten indentations in the flesh simulant, and record them to the nearest 0.5 mm.

14. Restore the flesh simulant to a continuous flat surface without enclosed voids, and at the same level as the rim of the tray, then return it to the conditioning chamber.