Arrows against Mail Armour

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Introduction

Historical accounts differ greatly in their description of the effectiveness of arrows against mail armour [1]. This is to be expected, since mail was made in a wide range of ring diameters and wire gauges, from metal of varying quality and with different types of riveted closure. Mail could be worn over or under additional garments of linen, leather, wool or cotton. Such materials may give substantial protection, especially against arrows that do not have sharp-edged heads [2]. Arrowheads varied in type and in the quality of metal. Archers, and their bows, had a very wide range of strengths and might shoot at mailed targets from long to close range. All of these factors might influence the arrow-stopping ability of the composite defensive system. This paper describes tests that were intended to probe some of these factors. However, they were limited in scope by practical considerations. Firstly, they were confined to commercially available components, which limited the study to rings made from 1.22 mm diameter mild steel wire. Secondly, the garment under the mail was represented only by multiple layers of woven linen, of the type that had already been tested for its defensive properties against arrows [2]. Thirdly, my own limitations as an archer confined the tests to close range, so that I could hit the small samples of mail, and to a bow of 74 lb. draw weight.

The Construction of Medieval Mail

Some dated specimens from archaeological excavation show how mail of the 11th and earlier centuries was constructed [3, 4]. Unfortunately, there are very few, perhaps no, surviving specimens of mail that can be securely dated to the 12th and 13th centuries, although historical and sculptural evidence shows that it was very widely used during this period. Examples of mail from the 14th century are known but are scarce [5], and the bulk of surviving European mail is from the 15th and 16th centuries.

Almost all European mail was made in the “four in one” pattern, in which each link passed through four other rings (see Figure 2). Very rarely, the “six in one” pattern was used to make a very densely woven mail for protection of the neck [5]. Mail may be made of alternating rows of solid and riveted rings, or be made of all-riveted construction, with perhaps an edging of solid links. All-riveted construction was traditionally thought to originate around the year 1400, but Richardson dates it to no later than 1340 from documentary evidence in the Tower of London accounts [5]. The great majority of surviving Roman and early medieval mail was of alternating rows of solid and riveted rings [3, 6] but an example of all-riveted construction is known from the Vendel period (ca. 550-793 AD) of Sweden [3].

Metallographic analysis of mail rings shows that they were usually of low-carbon iron,

 Journal of the Society of Archer-Antiquaries vol. 57, pp 62-70, 2014.

rather than hardenable steel [7, 3]. Smith identified steel only in mail of the 16th century or later, and even when rings were of steel, the rivets were of soft iron [7]. Despite the lack of metallographic evidence for steel in medieval mail, the accounts for the Tower of London for 1353-1360 show the purchase of twelve habergeons (*lorice)* of steel *(de acere)* at 73s. 4d. (6s. 1d. each), as compared with ten *lorice* of iron at 40s. (4s. each). The Tower accounts show that later in the fourteenth century the merchant John Salman of London supplied no fewer than 1542 mail shirts, eleven of steel and ranging in price from 66s. 8d. to £4 each and the rest of iron from 16s. 1d. to 46s. 8d each [5]. The wide range of prices presumably reflects an equally wide range of quality in the mail armour. These documents show that mail of steel was available in the fourteenth century, but scarcer and costlier than iron.

The closures of mail rings are of two principal types. Early mail (up to the 11th century) usually had rivets of round section, passing through a hole in the overlapping ends of the links, which had been somewhat flattened. In specimens of mail that have been examined closely, the holes appear to have been formed by punching, rather than drilling [6, 3]. This limits the width of the hole to about one third of the width of the wire, but has the advantage of not removing any metal. Round rivets in medieval mail were therefore of small diameter, often much less than 1 mm. The ends of the rivets were peened over, giving a domed rivet head on both sides of the mail garment. In modern mail-making practice the rivets are closed with pair of pliers having a dimple depression in both jaws that shapes the rivet heads. It is very likely that medieval armourers used a similar tool [6].

By the 14th century, the wedge rivet was usual; this was a small triangle cut from thin sheet iron and pressed through a slit punched through the overlapping ends of the rings (see Figure 1). Although the width of the slit was constrained by the width of the wire, the length was not, so the wedge gave a more secure closure than the round rivet. The rivet was closed with a pair of pliers having a flat face on one jaw, and a dimple depression in the other jaw. This gave a flat finish on the lower side and a raised rivet head on the upper side of the mail garment. Because of the scarcity of securely dated specimens, the date of introduction of the wedge rivet is uncertain. It did not entirely displace the earlier method; Vike [3] describes a 15th century shirt with round section rivets only 0.3 to 0.5 mm in diameter (Item 12 of Table 1).

Some of the range of ring diameters and wire thickness of medieval mail is shown in Table 1, which gives the dimensions of some specimens in museum collections. The closeness of weave is represented by the Aspect Ratio (AR). For mail made of wire of round section, this is the ratio of the internal diameter of the ring to the thickness of the wire. For wire that was not round, a notional equivalent thickness was calculated from $(a \times b)^{1/2}$, where a and b are the maximum and minimum dimensions of the flattened section. The aspect ratio of the medieval mail ranged from approximately 4 (a very close weave) to approximately 8 (very open weave).

Medieval Arrowhead Metallurgy

Four different metallurgical studies of arrowheads show that both steel and low-carbon iron were used for arrowheads throughout the middle ages [8, 9, 10, 11]. The heads could be all-iron, all-steel, or of composite iron and steel construction.8

In an analysis of early medieval artefacts of the Merovingian period (ca. 500-752 AD), three arrowheads (of unspecified type) were included. Two were of iron and one was of steel [8].

Hall [9] analysed six Hiberno-Norse arrowheads of 10th to 12th century date, excavated from Fishamble Street, Dublin. Three were of Halpin's Type 1 (a leaf-shaped blade with tang fitting), two being of iron and one of all-steel construction. One head was of Halpin's Type 4 (a triangular blade with socket fitting) and had strips of medium-carbon steel welded to an iron core. One head with a triangular blade and indeterminate fitting appeared to have an iron core sheathed in steel. One head of Halpin's Type 6 (bodkin blade with tang fitting) was of iron only [9].

Serdon [10] gives the results of the metallographic analyses of 13 arrow and crossbow bolt heads, excavated from Rougemont le Chateau in eastern France. This castle was occupied from 1200 to 1375, when it was destroyed after a battle for its control. Six of the heads were of almost pure iron with non-metallic inclusions. Five of these iron heads were of various bodkin or quarrel types, and one had a wider blade, approximating to the leaf-shaped head of this study but with angular shoulders. Five bodkin heads, of various types, were of medium-carbon steel of hardenable quality. The remaining two heads were of low-carbon steel.

Starley [11] gives the results of the metallographic analyses of 30 arrowheads and possible crossbow quarrel heads, obtained from different sources. Thirteen of the heads were of iron, either ferritic or phosphoric. Five of the heads were of a composite structure, consisting of an iron socket with steel tip and blades. Seven of the heads were described as "other steeled", containing at least some steel in their construction. The remaining five heads were described as "other structure" or "uncertain". Two heads of London Museum (LM) Type 7 (the "needle bodkin") were analysed; one was of iron, the other of unhardened steel. Five heads of LM Type 16 were analysed; three were of composite construction, with iron sockets and hardened and tempered steel blades, one was wholly of iron and one was of uncertain construction.

If the results of these four different studies are pooled, then of 51 arrow and bolt heads 24 were of iron only and 27 contained at least some steel in their construction. Medieval arrowsmiths clearly had a range of techniques and materials to produce heads that were appropriate for their purpose.

Materials and Methods

Mail and Linen

Two different types of mail were included in these tests, both made from commercially-available rings manufactured in India to supply the re-enactors market. Both were of flattened 1.22 mm diameter mild steel wire, but were of different ring diameters and rivet types. Both were of all-riveted construction, rather than alternating rows of solid and riveted rings, to simplify repair after damage by arrows.

One mail square was of rings 6 mm internal diameter closed with round rivets (6 mm RR). The wire had been flattened to 0.84 × 1.4 mm, although individual rings varied slightly. The rings were further flattened at the overlap to 2.5 mm width and total thickness of 0.84 mm of the two overlapping ends. A hole of approximately 1.3 mm diameter was drilled through the overlap, to take a rivet of 1.1 mm diameter. This differs from the medieval method in which the hole was punched, not drilled. Consequently both the hole and rivet in this modern mail were of wider diameter than in medieval mail (e.g. Items 10 and 12 in Table 1). In this modern sample, even when the hole was well centred in the overlap, only ~0.6 mm of metal was left on either side of the rivet hole. About half of the rings were discarded because the rivet hole was not well formed. A square of mail was made up from the selected rings, measuring 0.17 × 0.165 m when stretched out, giving an areal density of 10.3 kg /m^2. This small sample contained 1080 rings and took me more than 30 hours to make. With an aspect ratio was 4.9, it was of closer weave than all except two of the medieval specimens listed in Table 1.

The other mail square was made of rings 8 mm nominal internal diameter, closed with wedge rivets (8 mm WR). It was obtained already made up into a 0.21 × 0.19 m sample, together with a quantity of rings and rivets for repair. The rings had been flattened to approximately 0.7 × 1.9 mm, although individual specimens varied. The internal diameter also varied between individual rings, but was in the range 8.0 to 8.4 mm. A slit was punched through the overlapping ends to take the wedge rivet. Thus, no material was removed and a greater width of metal surrounded the wedge rivet than the round rivet. In terms of wire thickness and diameter, this sample resembled Item 11 of Table 1. The mail was carefully inspected and a few defective rings and rivets were replaced before starting the tests. The 8 mm WR mail had an areal density of 7 kg/ m^2, substantially less than the 6 mm RR mail. The aspect ratio was 6.6, compared with a mean of 5.8 for the medieval specimens listed in Table 1. The two types of rings and rivets are shown in Figure 1, where the greater width of metal around the slit for the wedge rivet can be seen. Figure 2 shows a comparison of the completed mail; the more open weave of the 8 mm mail is clearly seen.

Linen was the same material as had been used in an earlier series of tests [2]. It was of plain weave, with 10 threads per cm in both warp and weft, and weighed 365 grams per square metre (11 oz. per square yard).

Bow and Arrows

One longbow was used for all the shots. It had a bamboo back, core of western red cedar, and belly of ipe (*Tabebuia serratifolia)*. The length was 78 inches between the nocks, and the weight was 74 lb. (330 N) at a 27-inch (0.69 m) draw.

All the arrowheads were hand forged by Hector Cole. Two different shapes were used: the "leaf" and the bodkin (see Figure 3). Leaf-shaped heads were forged from both mild steel and medium carbon (0.6%) steel. They were resharpened frequently during testing.

Three different bodkin heads were tested. One bodkin was of hardened medium carbon steel, one bodkin of similar dimensions was forged from a sample of medieval iron, and one very long head was of mild steel. The very long bodkin (150 mm overall) was a copy of a head excavated at Urquhart Castle, Scotland [12]. It is referred to in this paper as the "Urquhart" head, to distinguish it from the bodkins of more moderate length.

The leaf-shaped heads and the two shorter bodkins were mounted on 28-inch (0.71 m) ash shafts of 3/8 inch (9.5 mm) diameter. The "Urquhart" head was mounted on a 3/8 inch shaft of a lighter wood, American poplar (*Liriodendron tulipifera),* to keep the weight closer to that of the other arrows. The dimensions and weights of the heads and complete arrows are shown in Table 2.

Method

The mail and linen squares were pinned onto a target boss made of layers of polyurethane foam. The boss was new at the start of the tests, and the position of the mail target was changed often so that it was over an undamaged part. All shots were made from a range of 10 yards (9 m). After each shot the depth of penetration into the foam boss was measured from the back of the linen to the tip of the arrowhead. The mail was carefully inspected and a note was made of the number of broken and damaged mail rings and the type of damage. The damage was classified as: (i) breakage of the ring well away from the rivet, (ii) breakage of the ring across the flattened portion at the rivet hole, (iii) tearing open of the rivet hole (iiii) breakage of the rivet and (v) rivet pulling free from the hole. After no more than six hits all damaged rings were cut out and new ones were riveted into place.

Although the effect of different numbers of linen layers was investigated, a standard of eight layers was adopted for comparison between the effectiveness of different types of head, or for comparing the protection given by the two types of mail. In my subjective opinion, about eight layers of this weight of linen is the maximum that could be worn in areas that require good flexibility.

Results

The Bodkin Heads

The result for the hard steel bodkin head are shown in Graphs 1 and 2. As may be seen from Graph 1, linen without mail is moderately effective at reducing penetration of the bodkin, from a mean of 163.8 mm with no linen, to 58.3, 34.8 and 14.83 mm with 8, 16 and 24 layers. Only one "bouncer" was seen, when one of the six shots against 24 layers failed to penetrate. In this series of tests using a polyurethane foam backstop, penetration was always less than had been seen in the previous series when a straw bale was used [2].

Mail alone, without linen backing, gave very little protection against the bodkin (see Figure 4). A mean penetration of 127.3 mm through the 8 mm WR mail was seen; this may be compared with 163.8 mm penetration into the boss with no mail or linen. In shots against 8mm WR mail, there was a steady reduction in the depth of penetration as the number of layers of linen backing was increased. However, it was only with 24 layers of linen backing that there were any instances of the bodkin arrow failing to penetrate, when three out of six shots bounced back. The other three shots penetrated from 10 to 15 mm.

The 6 mm RR mail was no more effective than the 8 mm WR in stopping penetration by the bodkin. With eight layers of linen, mean penetration through the 6 mm RR was 45.9 mm, compared with 42.7 mm for the 8 mm WR. In view of the variance in the individual results, the differences between the two types of mail are not statistically significant. Since the 6 mm RR mail gave no more protection than the 8 mm WR, despite its greater areal density, the 8 mm WR mail was clearly more effective on a weight for weight basis.

The bodkin head forged from a sample of medieval iron had a mean penetration of 47.5 mm through the 8 mm WR mail with 8 layers of linen. That is slightly deeper than for the hard steel bodkin, but the difference is not statistically significant. This is an important result, since it shows that hard steel is not required for effectiveness of the bodkin.

The Urquhart head was tested against both types of mail, with eight layers of linen backing. Against the 6 mm RR mail, it achieved a mean depth of penetration of 71.2 mm (standard deviation 18.7 mm), compared with 45.9 mm (standard deviation 24.8 mm) for the shorter hard steel bodkin head against the same combination. For the Urquhart head, all six shots exceeded 50 mm penetration, compared with four out of ten shots for the bodkin. The difference between the two heads is significant at the 95% confidence level. In five out of six shots with the Urquhart head against the 6 mm RR with eight layers of linen, two rings at each shot were completely broken across the rivet hole. In one shot one ring was broken, and one severely distorted.

Against 8 mm WR mail, the Urquhart head achieved 51.7 mm mean penetration (standard deviation 8.3 mm) compared with 42.7 mm mean penetration (standard deviation 16.3 mm) for the shorter hard steel bodkin. For the Urquhart head, five out of six shots equalled or exceeded 50 mm penetration. In the six shots there were no instances of completely broken rings, and two instances of the rivet failing but without significant opening out of the ring. In four of the shots, the Urquhart head exceeded 50 mm penetration even without any ring breakage or rivet failure. This shows that very long slender heads of this type could reach potentially lethal depths of penetration even without breaking rings. For the 8 mm WR mail, the difference between the Urquhart and shorter bodkin heads is not statistically significant at the 95% confidence level; the Student's T test indicates that the apparent difference could arise with a 16% probability.

The Leaf-shaped Heads

The results for the hard steel leaf-shaped head are shown in Graphs 3 and 4. Linen alone was ineffective at stopping this head; eight layers gave only a very slight reduction in penetration, and even with 24 layers a mean penetration of 96 mm was seen. The leaf heads cut cleanly through the linen threads, unlike the bodkin which pushed them aside and wedged into the weave.

The leaf shaped head was equally effective as the bodkin head at penetrating 8 mm WR mail without linen backing, with a mean penetration of 115.5 mm, compared with 127.3 mm for the bodkin. The difference between the two figures is not statistically significant. However, the results for the leaf-shaped heads against mail and linen combinations were more complex and difficult to interpret than for the bodkin. As may be seen from Graph 4, there was much greater variance in individual results. Even with only eight layers of linen, there were some instances of failure to penetrate. For the hard steel leaf head there were four instances in twelve shots, and for the mild steel leaf there were three instances in twelve shots, when the arrow bounced back from mail with 8 layers of linen. However, when the shots did not bounce back, the penetration was usually much deeper than for the bodkin head. If the "bouncers" are excluded, then the mean penetration of the 8 mm WR/ 8 linen combination by the hard steel leaf was 90.75 mm (standard deviation 18 mm) and the corresponding penetration by the mild steel leaf was 51.2 mm (standard deviation 30 mm). It therefore appears that the hard steel head gives greater penetration than mild steel head. However, twelve shots from each type is not a sufficient number to be certain on this matter: the Student's T-test indicates that the apparent difference between the two heads could arise in 20% of cases even if there had been no real difference between the heads.

At the start of these tests I had expected that they would prove whether the bodkin or leaf-shaped head was the most effective at penetrating mail and linen combinations. However, the results show that "most effective" would depend on the criteria that are applied. The bodkin head is certainly the most reliable, with no failures to penetrate mail with up to 16 layers of linen backing. However, if the criterion for effectiveness had been the number of shots that reached a specific depth of penetration then the leaf-shaped head would be judged the most effective. For example, for the 8 mm WR mail with eight layers of linen, the bodkin head exceeded 50 mm penetration in only one shot out of twelve, compared with three for the mild steel leaf and seven for the hard steel leaf.

In some instances when the leaf-shaped heads bounced back from the mail and linen combination, it was possible to see that that the shot had broken one or two mail rings, which would be sufficient for the arrow to pass through the mail. Thus, the arrow had clearly been stopped by the linen, not the mail. It is known that sharp-edged heads of this type easily pass through multiple layers of linen, but if the edges are blunt then they often bounce back [2]. Therefore, it appears that the effectiveness of the mail and linen combination is due to the mail blunting the edges of the incoming arrowhead, which is then sometimes unable to cut through the linen. This blunting of the head is inconsistent, resulting in a wide variance between individual shots.

Comparison of Round and Wedge Riveted Mail

If the effectiveness of the two types of mail in protecting against the Urquhart head is compared, then the 8 mm WR is distinctly better than the 6 mm RR. The difference in mean penetration between the two types of mail is statistically significant at the 95% confidence level. This is in contrast to the results for the leaf and shorter bodkin heads, when no statistically significant difference in protection between the two types of mail was seen. Since the 8 mm WR weighed only 7 kg/ m^2, compared with 10.3 kg/ m^2 for the 6 mm RR, it clearly superior on a weight for weight basis.

Examination of the broken rings showed that the rivet hole was the major point of weakness of the round-riveted rings. The three commonest modes of failure of the rings were; (i) breakage of the flattened portion across the rivet hole; (ii) tearing open of the rivet hole; (iii) pulling of the rivet head through the hole. Less commonly, the rivet head was sheared off or the ring was broken well away from the rivet. For the round-riveted mail, in 45 instances where the failure mode could be clearly identified, failure occurred at the flattened overlap portion of the ring or the rivet in 40 instances (89%). This is despite the fact that the flattened portion occupied only ~20% of the ring circumference. Breakage of the round-riveted mail well away from the rivet occurred in only five cases (11%). It should be borne in mind that the method of manufacture of this modern mail differed from medieval practice; both the rivet and rivet hole were of wider diameter, so that there was very little metal around the hole in the modern mail. One might expect that medieval mail might have shown fewer breakages across the hole, but perhaps more failures of the rivet itself.

In contrast, for the wedge-riveted mail, the commonest failure mode was breakage of the ring well away from the rivet (42 out of 70 instances, 60%). Breakages associated with the rivet, or the flattened portion of the ring for the overlap, accounted for 40% of the failures. In contrast to the round riveted mail, breakage at the overlap usually occurred at the junction of the flattened and main portions of the ring, rather than across the hole. The failure rate associated with overlap and rivet was still somewhat higher than would be expected from chance alone, since the flattened portion occupies ~20% of the circumference. Thus, although the wedge rivet does not provide a perfect closure, it is definitely superior to the round rivet in terms of strength.

Conclusions

Mail alone gives very little protection against arrows, either with bodkin or leaf-shaped heads. In shots against mail with linen backing, most of the arrow-stopping is performed by the linen, which is inherently effective against arrows of the bodkin type. The value of mail appears to be that it blunts sharp-edged arrowheads, which would otherwise be very effective against multiple layers of linen. The gambeson, aketon or other garment is at least as important as the mail in determining the level of protection against arrows, and it should receive at least as much attention in any trials of weapons against medieval armour.

The bodkin head appears to be equally effective whether made in soft medieval iron or hard steel. This could be an important point in its favour, since iron was much cheaper than steel during the middle ages [11]. The leaf-shaped head appears to be more effective when made in hard steel, although a greater number of tests would be needed to establish this point conclusively.

Identification of the bodkin or the leaf shape as the most effective against mail with linen backing would depend on the criterion adopted. The bodkin head was more reliable in gaining some penetration, but the leaf-shaped head had a higher probability of achieving deep (>50 mm) penetration.

The wedge rivet is superior to the round rivet in terms of strength, with the result that the 8 mm WR mail gave protection that equalled or exceeded the 6 mm RR mail, despite its lesser weight (7 kg/ m^2 vs. 10.3 kg/ m^2).

For the bow and mail used in these tests, approximately 24 layers of medium-weight linen backing are required to reduce the probability of penetration to about 50%. Those 24 layers are 16 mm thick under compression, are stiff, and weigh 8.8 kg/ m^2. In my subjective opinion, such a thickness could perhaps be worn on the torso but not on the arms or legs.

These tests show the importance of having a sufficient number of shots on which to base conclusions during studies of this kind. Even with the same bow, arrow, target and archer there is a wide variance in results, especially for the leaf-shaped heads. One shot might bounce back, and the next shot under apparently identical conditions might reach a lethal depth of penetration. There is thus no contradiction between widely differing medieval accounts of the effectiveness of arrows shot against mail; they could all be true.

Acknowledgements

I thank;

Alison Berry for her advice on the statistical interpretation of the test results;

Hector Cole for his contribution of the medieval iron bodkin for this study;

The Director of the Salisbury and South Wiltshire Museum for permission to measure and photograph mail in the museum’s collection.

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14. Measurements made by the author at Salisbury and South Wiltshire Museum.

Item	Riveted rings			Solid rings			Aspect Ratio (AR) of riveted rings. Comments.	Refer-ence
	Int. Diameter mm	Wire size		Int. Dia. mm	Wire size			
		Width mm	Thick. mm		Width mm	Thick. mm		
1. Mail neck guard attached to helmet, excavated from Coppergate, York, England. 8th C Anglian.	6	1	1	6	1	1	AR 6.0. All measurements approximate because of corrosion. Solid rings may be welded.	[4]
2. Mail coif, European, Royal Armouries III.28, mid 14th C.	7.69	1.41	0.85	7.22	2.1	2.1	AR 7.0	[13]
3. Mail shirt, German, Royal Armouries III. 1279, mid 14th C.	8.66	2.0	1.36	8.31	2.18	1.3	AR 5.25	[13]
4. Mail aventail, prob. German, Royal Armouries III. 1280 Mid 14th C.	8.47	1.8	1.47				AR 5.2	[13]
5. Mail shirt, German, Iserlohn, Royal Armouries III. 1280, Ca. 1430.	9.33	1.82	1.14				AR 5.9	[13]
6. Mail sleeves, European, Royal Armouries III. 3149 A&B, Mid 16th C	4.7	0.9	0.9				AR 5.2. Also with some rings of 1.1 mm thickness	[13]
7. Fragment, Salisbury Museum iiE161. Excavated from Salisbury watercourse, hence deposited after ca. 1230	9	1.4	~1.4				AR 6.4. Round section rings, all riveted (probably wedge rivets) except for some solid rings on the edge.	[14]
8. Fragment, Salisbury Museum iiE163, after ca. 1230.	7.0-7.5	1.4-1.6	~0.85				AR 6.4. All riveted except for some solid brass rings on the edge.	[14]
9. Fragment, Salisbury Museum iiE162, after ca. 1230.	6.0-6.5	1.0-1.3	~0.8	6.0-6.5	1.0-1.3	~0.8	AR 6.5. Alternating rows of solid and riveted rings. Rivets probably round section.	[14]
10. Fragment from grave at Gjermundubu, Norway Oldsaksamlingen Oslo C 273171i 10th C.	5.1	1.25	1.25	4.9	1.6	1.6	AR 3.9. Alternating rows of solid and riveted rings. Round rivets , 0.4 mm dia.	[3]
11. Shirt, uncertain provenance, Verdal Nord Trondelag, Oldsaksamlingen Oslo C 455, 15-16th C.	8.0-9.6	1.5-1.6	0.7-0.8	7.5	1.0-2.1	1.0	AR 7.4-8.5. Wedge rivets. The solid rings are all of same thickness and ID, but vary in width.	[3]
12. Leg protection, Mollardalen, Buskurud, Norway. Oldsaksamlingen Oslo C 2616. Probably 15th C.	3.5	0.8-1.0	0.8-1.0				AR 3.9. Round rivets, 0.3-0.5 mm dia. All rings riveted.	[3]

Table 1. Dimensions of some specimens of medieval mail

Arrowhead	Length mm	Entry * mm	Width of blade mm	Thickness of blade ** mm	Socket external diameter mm	Weight of head grams	Weight of arrow grams
Bodkin, 0.6% C steel	95	62	9.5	7.8	9.9	19.0	55.4
Bodkin, medieval iron	89	56	9.2	6.4	9.4	15.3	53.4
Urquhart bodkin, mild steel	150	110	9	6.3	9.2	26.7	55.3
Leaf, 0.6% C steel	78	36	15	4.2	9.9	16.0	51.2
Leaf, mild steel	95	43	16	3.4	9.4	18.4	50.0
* “Entry” means the distance from the tip to widest part of the blade. ** Thickness measured at the widest part of the blade.							

Table 2. Dimensions and weights of the arrowheads used in this study

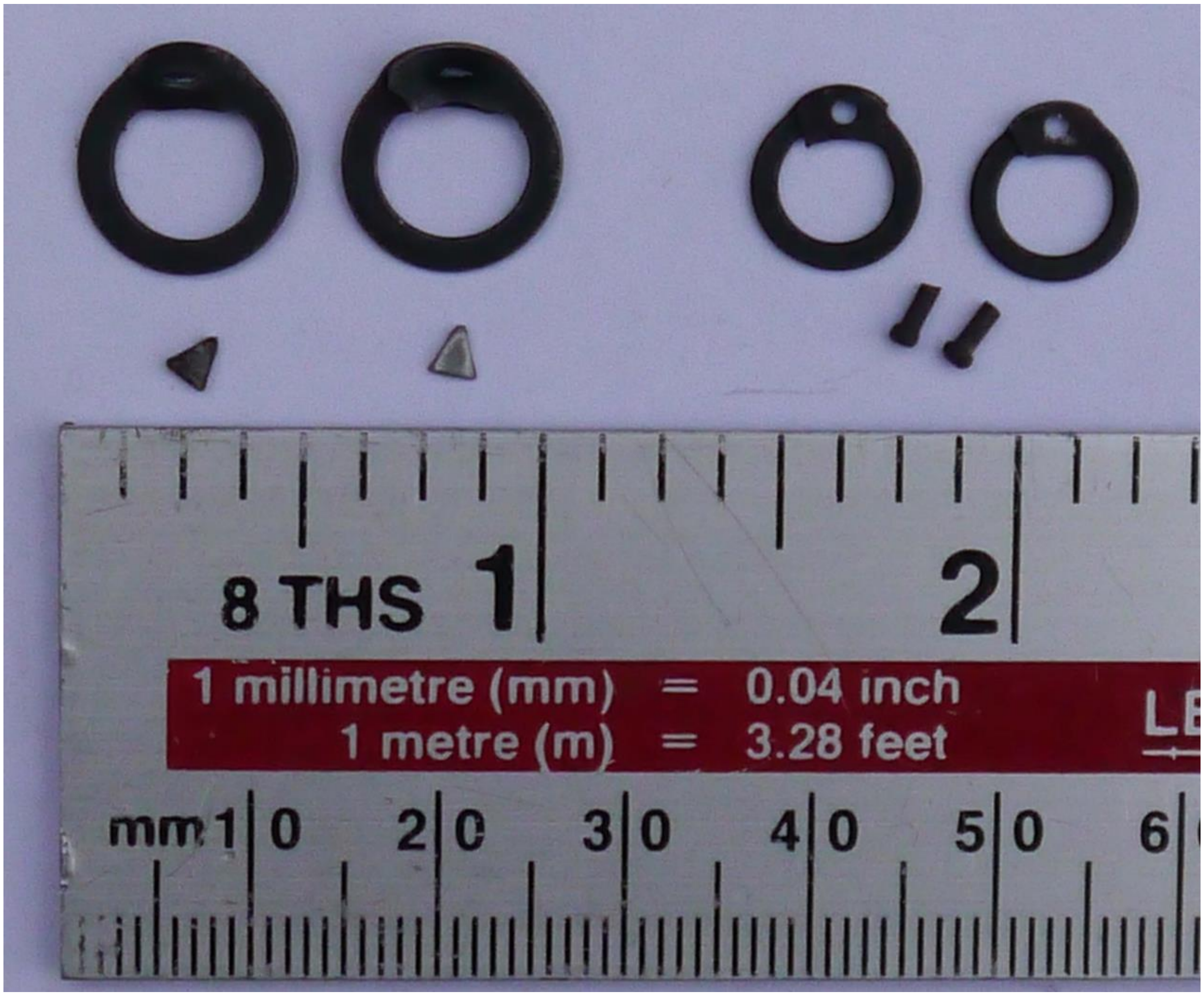


Figure 1. (Left) 8 mm Rings and Wedge Rivets, (Right) 6 mm Rings and Round Rivets

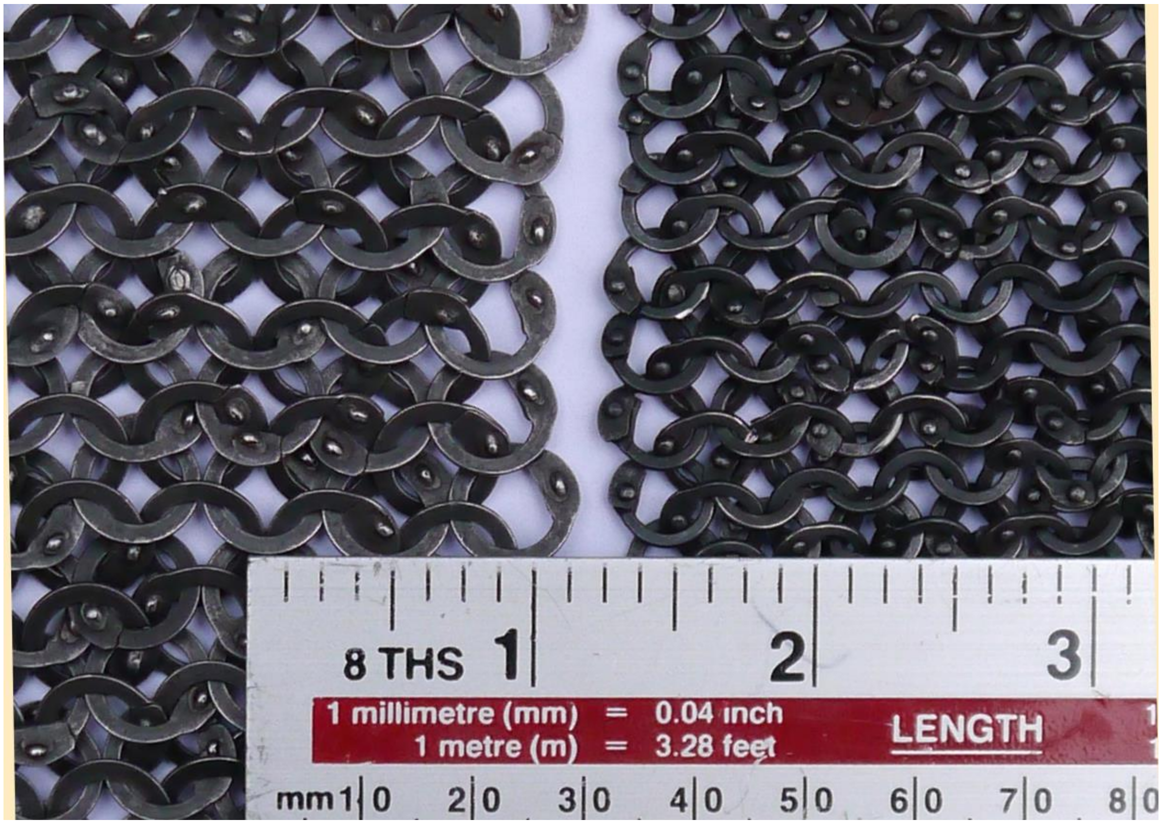


Figure 2. “Four-in-one” Mail

Figure 3. Top, Urquhart Head; Middle, Leaf-shaped Head; Bottom, Bodkin

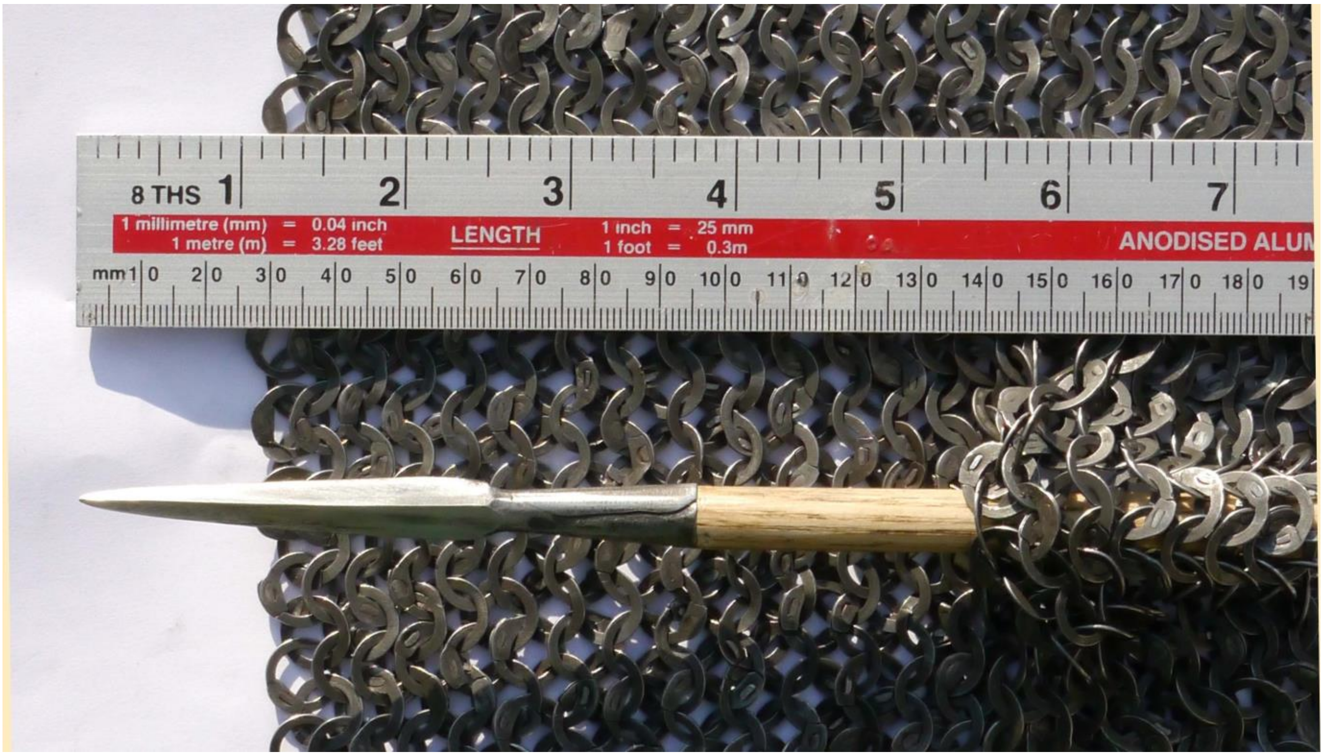
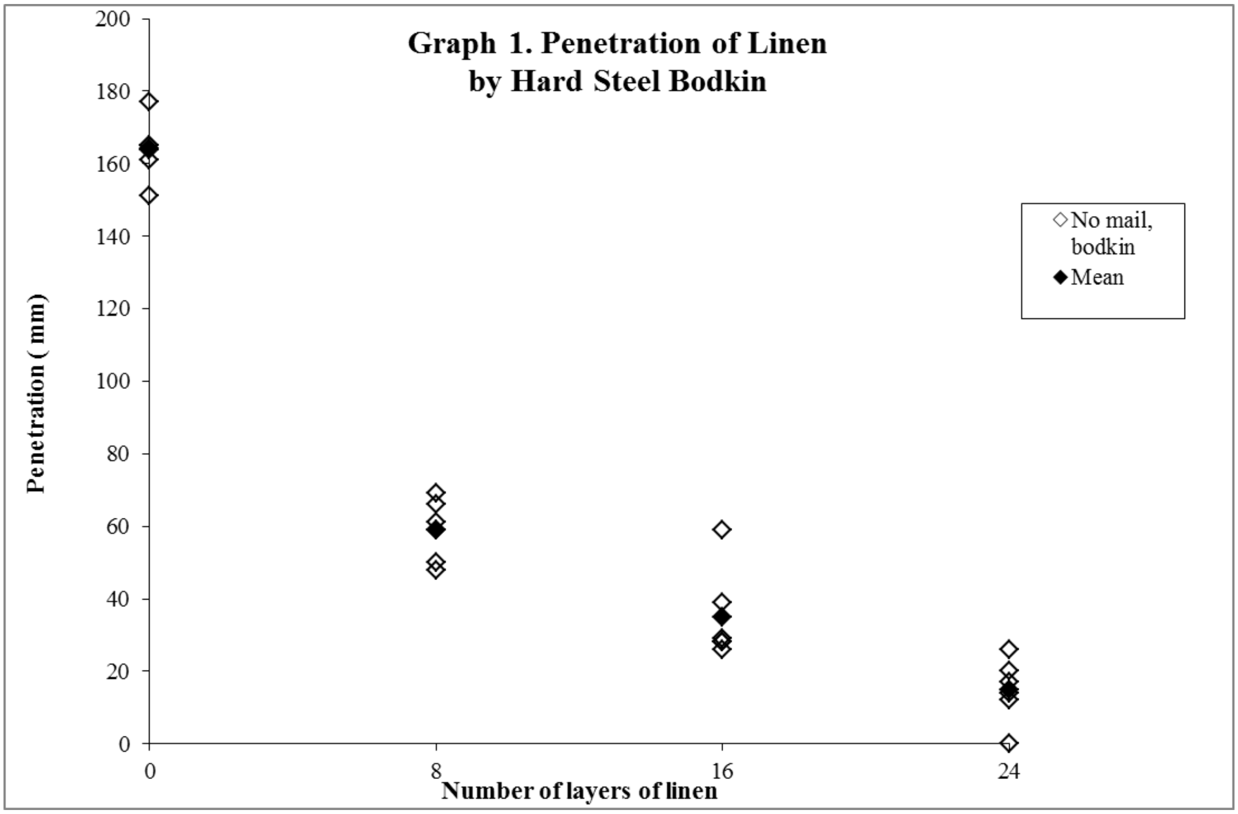
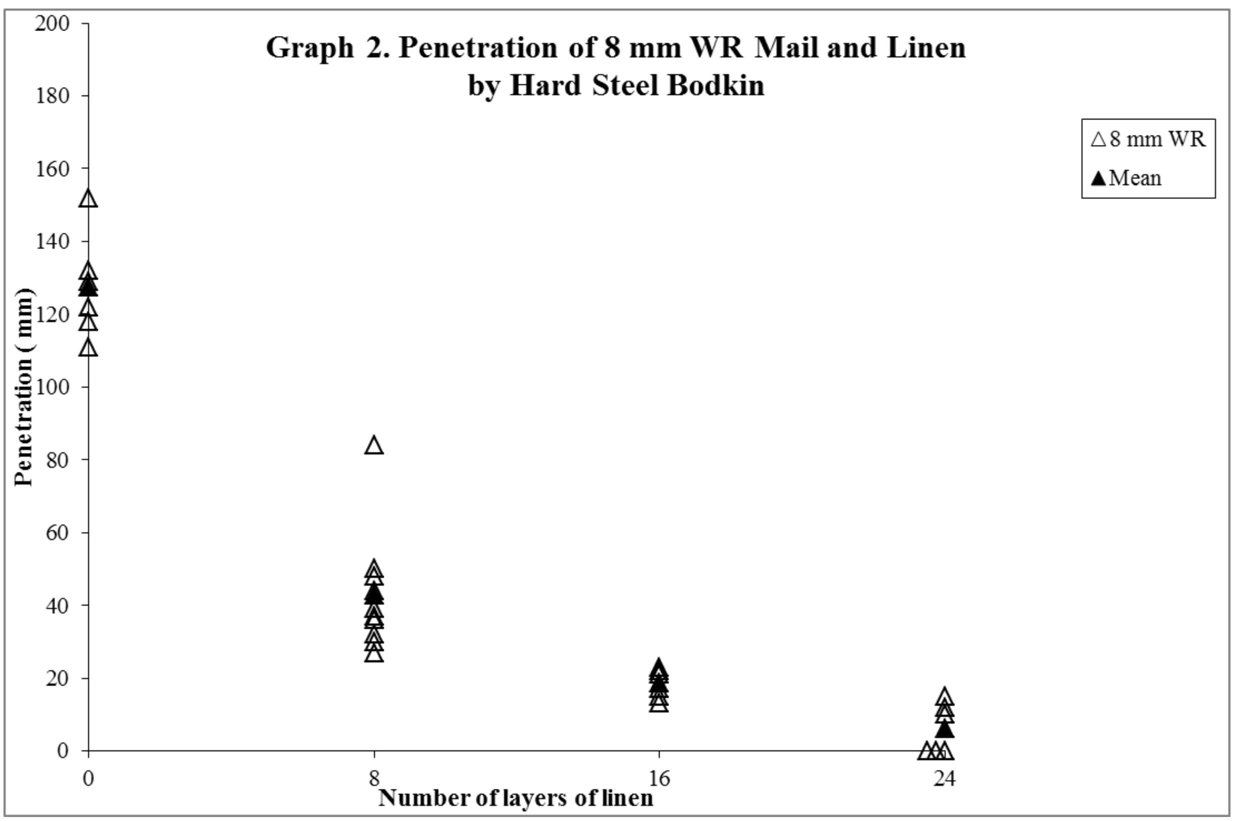
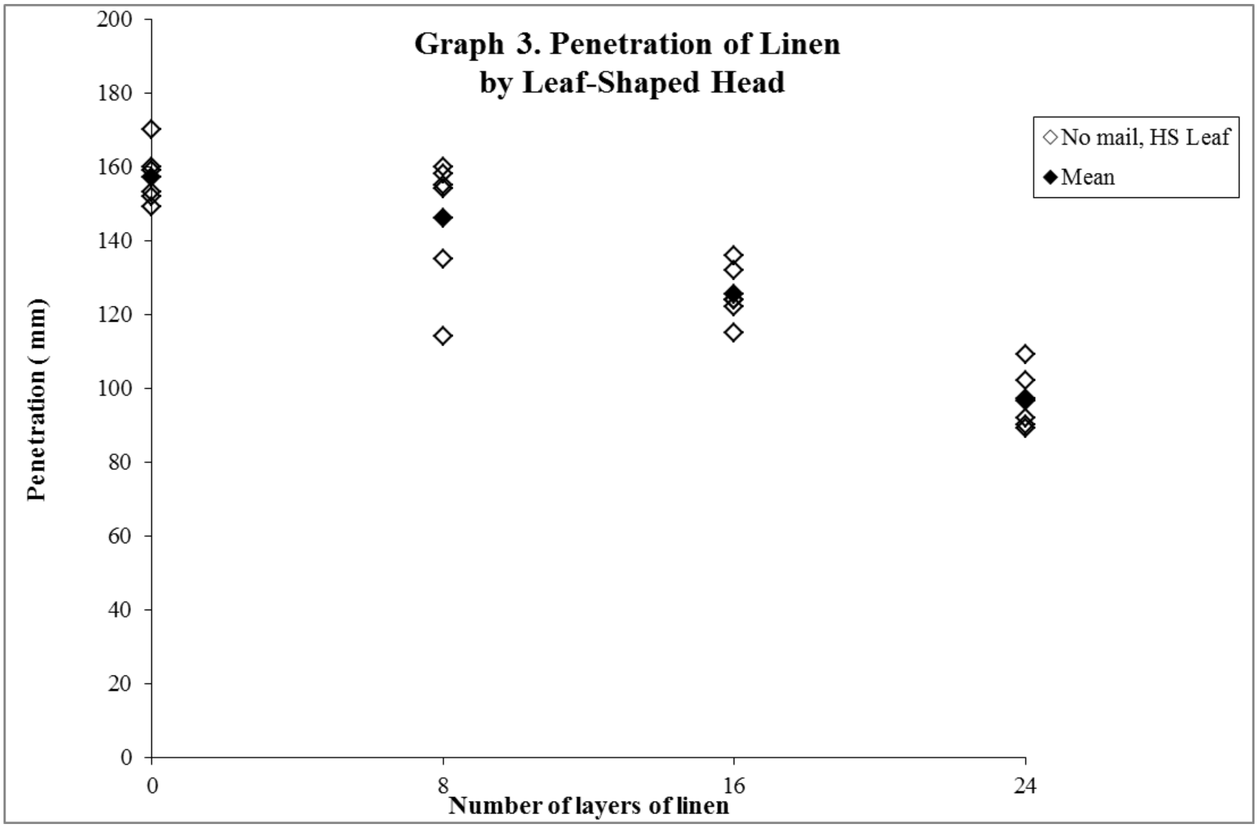
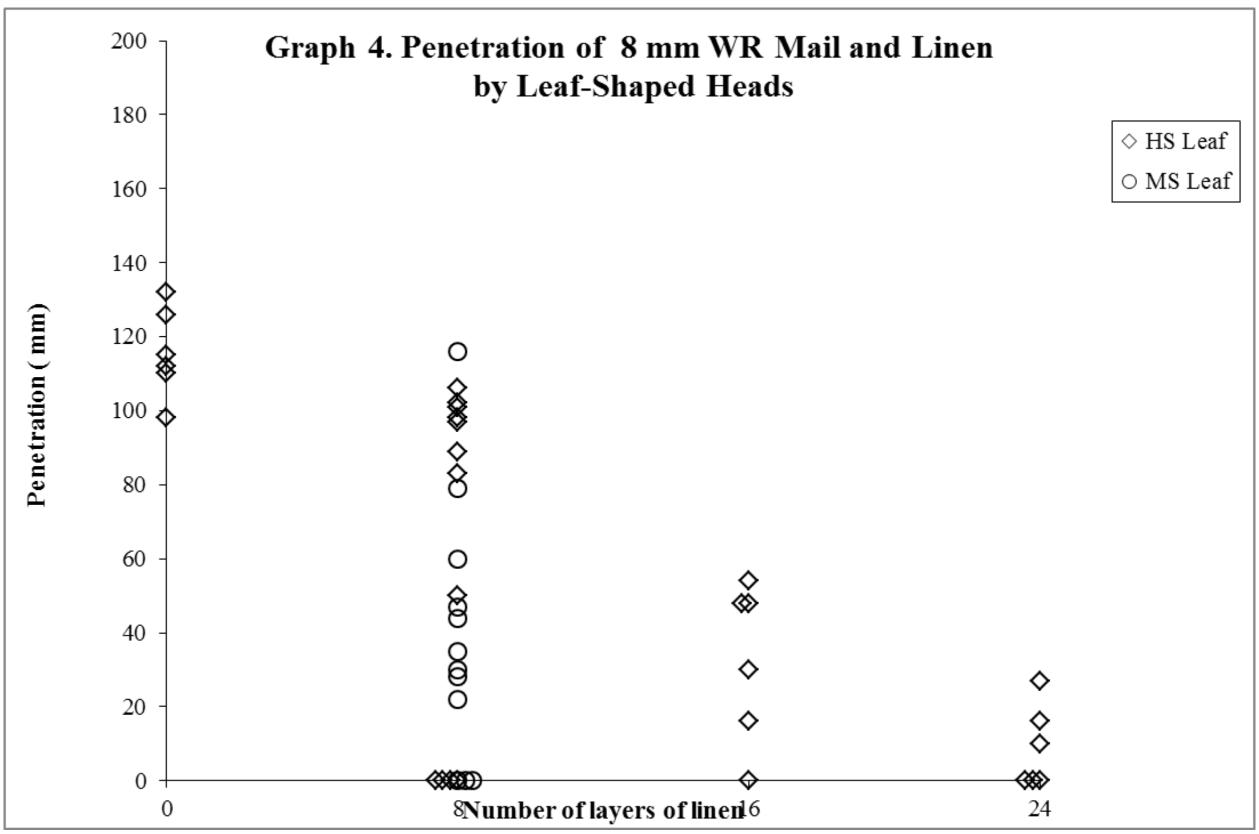


Figure 4. Bodkin Shot through 8 mm Wedge Riveted Mail


Graph 1. Penetration of Linen
by Hard Steel Bodkin
Penetration (mm)
Number of layers of linen
No mail, bodkin
Mean
200
180
160
140
120
100
80
60
40
20
0
0
8
16
24


Graph 2. Penetration of 8 mm WR Mail and Linen
by Hard Steel Bodkin
Penetration (mm)
Number of layers of linen
8 mm WR
Mean
200
180
160
140
120
100
80
60
40
20
0
0
8
16
24


Graph 3. Penetration of Linen
by Leaf-Shaped Head
No mail, HS Leaf
Mean
Penetration (mm)
Number of layers of linen
200
180
160
140
120
100
80
60
40
20
0
0
8
16
24


Graph 4. Penetration of 8 mm WR Mail and Linen
by Leaf-Shaped Heads
HS Leaf
MS Leaf
Penetration (mm)
Number of layers of linen
200
180
160
140
120
100
80
60
40
20
0
0
8
16
24