Analyses of Joe Byrne's armour

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Abstract

Ned Kelly was a notorious Australian bushranger (outlaw). His gang was active in Victoria (Australia) in the 1880s. Joe Byrne was a member of his gang. The armour worn by Joe Byrne in the gang's final encounter with the police was made available for analysis prior to its display at the National Museum of Australia. Neutron and x-ray diffraction, gamma x-ray fluorescence, and optical metallography were used to determine the method of manufacture of the armour. This paper extends our earlier investigation of the steel in the armour, and reports on the origin of a round mark found on the breastplate.

Keywords: xrd, γ xrf, neutron diffraction, Ned Kelly,armour.

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1. Introduction

Bushrangers were outlaws: initially they were escaped convicts, but, later, they tended to be misfits in the society of the day. The most notorious gang was that led by Ned Kelly (http://www.nedkellysworld.com.au) which was active in northern Victoria (Australia) in the 1880s.

The gang was regarded by the society of the day as horse thieves and police murderers, though many would argue this was a rebellion against the inequities in Victorian society. Because they robbed banks, and distributed some of the proceeds amongst the people they came to be regarded by some to be latter day "Robin Hoods".

In an act of bravado the Kelly gang took over the town of Glenrowan, holding more than forty of the townspeople hostage in a pub (hotel). The four members of the gang (Kelly, Joe Byrne, and two others) were involved in a gun-battle with police. They wore suits of armour which had been fabricated in the months prior to the gun-battle. The battle between the armoured gang and the police at the Glenrowan pub has become a significant event in Australia's history and much folklore has grown up as a result of this. Many stories exist about the fabrication of the armour, and many families now claim that their forebears were involved in the manufacture of the armour.

This work seeks to determine which of the many stories about the manufacture is correct. To be decided were the origin of the steel used, and the method of manufacture. (Were they made by a blacksmith at a smithy? Or were they the work of unskilled workers in a large camp fire?)

The armour (Figure 1) examined belonged to Joe Byrne, Ned Kelly's second-in-command. This was made available for examination by Rupert Hammond, the owner of the armour, prior to display at the special "Outlaws" exhibition at the National Museum of Australia.

This paper extends our earlier investigation of the steel in the armour (Creagh et al, 2004), and reports on the origin of a round mark found on the breastplate.

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Figure 1. Joe Byrne's armour. This comprises: a cylindrical helmet to which the face-guard is attached by bolts; a breastplate made from two pieces of metal crudely riveted together, with holes in the metal filled by metal rod which has subsequently been burred over; a similarly constructed backplate; a lap-plate fashioned from one piece of metal. All the former pieces were fabricated from thick sheets of metal. The two protective side-plates were made from much thinner metal.

2. Experiments

The experiments, undertaken at laboratories of the Australian Nuclear Science and Technology Organization (Ansto), were: neutron diffraction (using its Medium Resolution Powder Diffraction system); x ray diffraction (using a Scintag diffractometer fitted with an energy dispersive detector); a Thermo Measure Tech gamma x-ray fluorescence system (Mercury II); optical metallography of replicas taken from small regions which had been cleaned and electropolished; transmission electron microscopy of the replicas (and EDAX of particles adhering to the replica); Vickers hardness testing.

In this paper we deal, in the main, with neutron, x ray and gamma-xrf measurements.

2.1 Neutron Diffraction

Neutron diffraction reveals the structure of the bulk material. Powder neutron diffraction measurements were made on the Medium Resolution Powder Diffractometer using thermal neutrons (λ = 1.6664 Å) from the HIFAR nuclear reactor at ANSTO.

The diffractometer operates with 32 detector channels and gives medium resolution over an angular range (2θ) from 4° to 138° whilst maintaining a high neutron flux at the sample position. The monochromator consists of eight germanium crystals in a vertically-focussing arrangement, providing a neutron flux of up to 4 x $10^5 ncm^2 s^{-1}$ at the sample position. The range of useable neutron wavelengths is from 1.06.Å to 5.0.Å. Complete diffraction patterns typically take about two hours to collect. Data were collected using a bank of 32 ^3He detectors over the full operation, in 0.1° steps. Structural refinements were carried out by the Rietveld method using the Hunter's RIETICA program (1998), with pseudo-Voigt peak shapes and refined backgrounds. All parts of the armour gave similar neutron diffraction patterns, which subsequent Rietveld analysis showed to have residual preferred orientation and residual strain. Figure 2(a) shows the neutron diffraction pattern taken from the helmet, and Figure 2(b) shows the diffraction pattern from the lap sash. The detailed differences in these patterns indicate the extent to which residual strain exists. The difference between the computed intensities and the observed intensities are shown in Figures 2(a) and 2(b) as the bottom curve on each of the graphs. There is some indication that preferred orientation exists in each component.

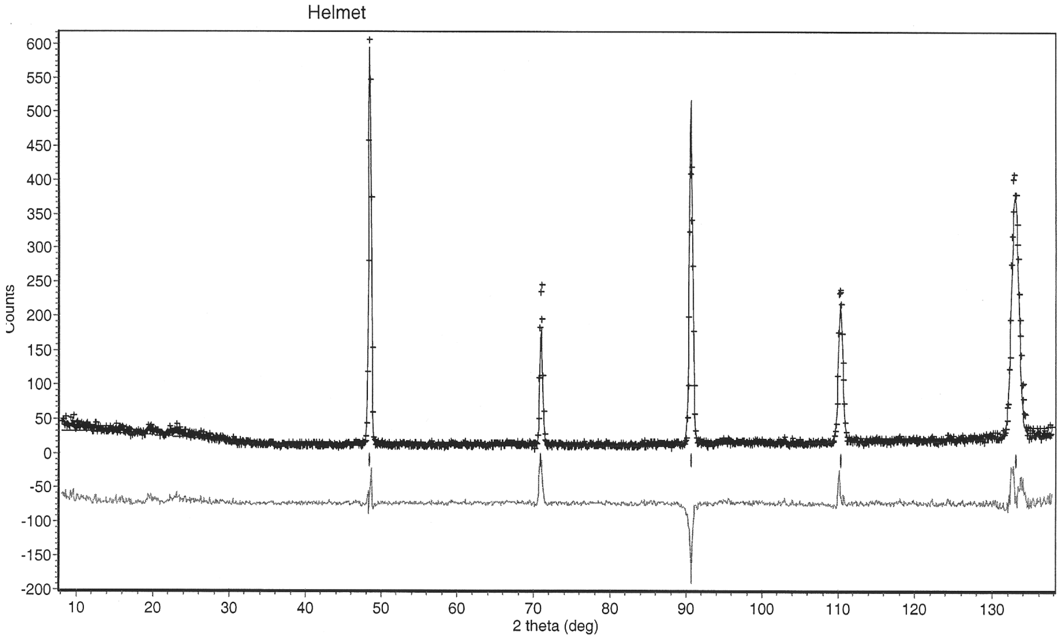

Figure 2(a).
Neutron diffraction pattern of the helmet.

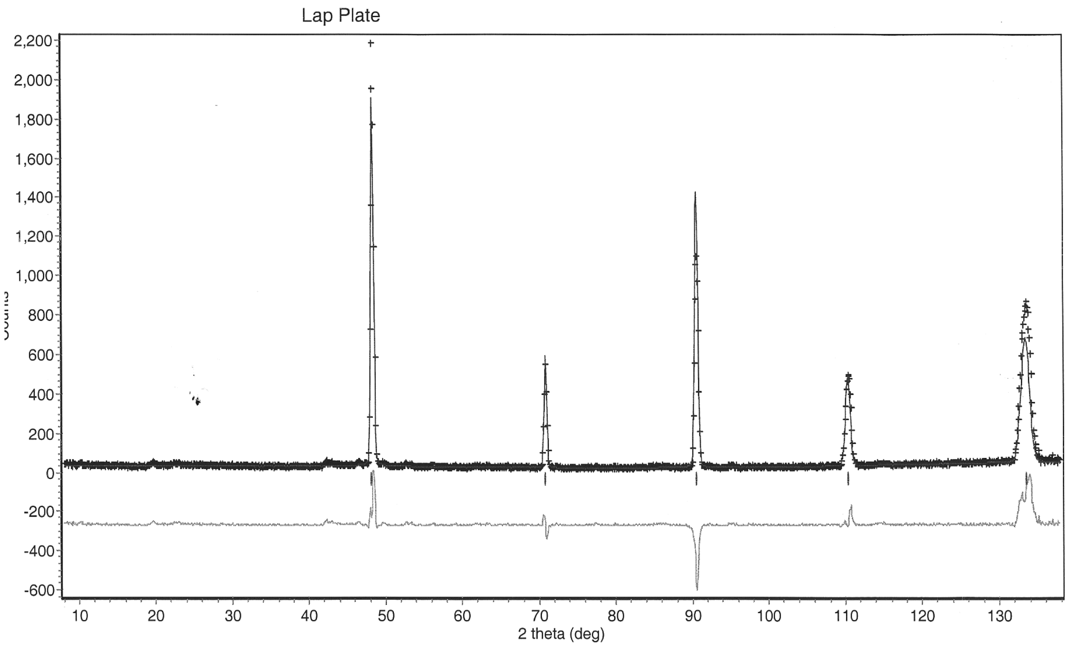

Figure 2(b). Neutron diffraction pattern of the lap-plate.

By comparing the diffraction patterns of all the components of the armour with the JCPDS Data file (JCPDS, 2003) the conclusion was reached that the diffraction patterns from the material are very similar of rolled carbon steel (JCPDS data file number 06-0696).

2.2 X-ray Diffraction

Whilst neutron diffraction yields information related to the physical state of the bulk material, x-ray diffraction reveals the structure of the material close to the surface, since the depth of penetration of the x-rays is only about 10 nm. Most of the components were too large to be examined in the Scintag diffractometer. Only one of the side plates was examined. As well, because of the lack of diffracted beam intensity the data acquisition times were long. The Scintag diffractometer was operated with the specimen horizontal and on the diffractometer axis, using the $\theta-\theta$ mode of operation and $CuK_{\alpha 1}$ radiation. Figure3 shows an xrd pattern from the side plate. The diffraction pattern is typical of steel (bcc structure: a_o=28.672 nm). The poor peak heights relative to background and distorted line shapes which were observed were caused by surface strains. This is evidence that the metal had been cold worked. Peaks other than from iron are seem in Figure3. These are due to the surface coating and surface oxidation. We were not permitted to clean the surface.

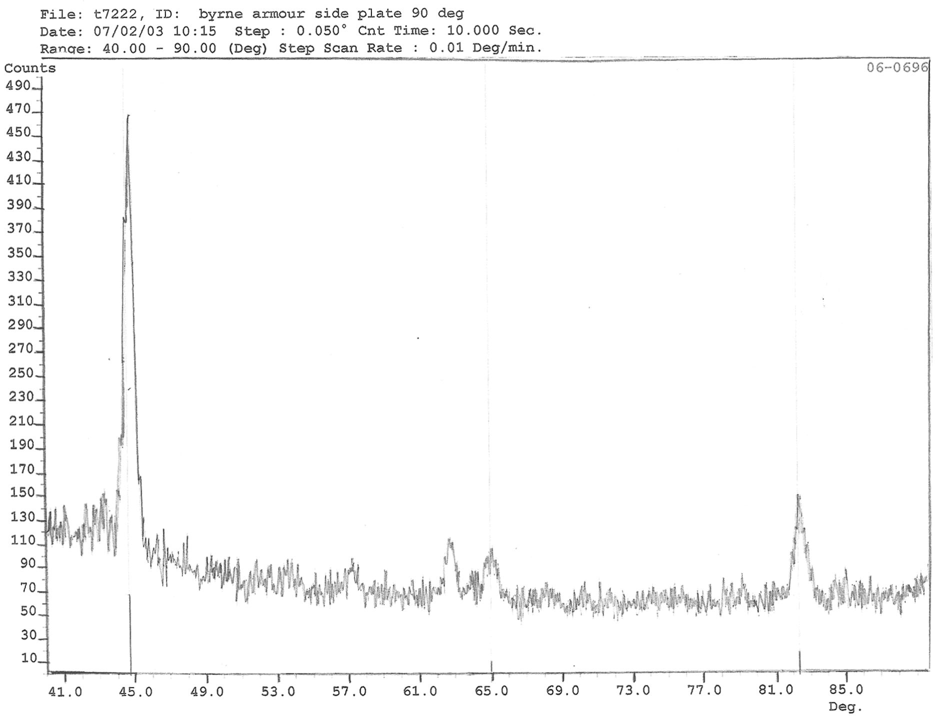

Figure 3. X-ray diffraction pattern from a side-plate. Note the weakness of the diffraction pattern and the width of the diffraction peaks. The solid lines at the bottom of the graph represent the diffraction peaks recorded in the JCPDS datafile for a rolled carbon steel (PDF number 06-0696).

2.3 Gamma x-ray fluorescence spectroscopy

Gammax-ray fluorescence spectroscopy was undertaken on all parts of the armour using a Thermo Measure Tech Metallurgist Pro Mercury II Probe. In this γ-x fluorescence spectrometer two radio-isotope sources (cadmium and iron) are used to excite electronic transitions in the material under examination. The resulting fluorescent radiation from the material is detected by a solid state detector. The charge released by a fluorescent photon in the detector is converted in a preamplifier and passes into a pulse height analyser. The height of the voltage pulse is proportional to the energy of the fluorescent photon. With appropriate calibration it is possible to determine these energies and, by comparison with an internally stored table, to determine the atomic species present in the material. To a good approximation the amplitude of the peak is proportional to the atomic concentration. The use of internal algorithms to compensate for matrix effects enables the display of data which represents the true atomic concentration of a particular species. From this the weight concentration can be deduced.

In Table 1 results for the "helmet" and "breastplate" are shown. As well, measurements are shown for a round mark on the front of the breast-plate ("mark front") for a location at the back of the breastplate, immediately behind the mark ("mark back"). Figure4 shows the mark the origin of which needed to be assessed.

Figure 4. The circular mark on the breastplate at the centre of the picture is what is referred to as "mark" in Table 1. Also to be seen are two rivets holding the two parts of the breastplate together, and two plugs filling what were boltholes in the original material.

In Table 1 the compositions of most materials can be seen to be rather similar. The technique of analysis cannot detect carbon. The major element present in all components is iron. Most of the components contain as minor constituents: manganese, arsenic, tin, and lead.

Several items do not contain manganese, notably the cylindrical helmet, the side panels, and the rivets. It might be therefore be inferred that these were taken from different stock materials from the rest of the steel pieces in the armour. Certainly the side panels were much less thick than the rest of the pieces, and the rivets seemed to come from steel rod.

Table 1. Weight percentage compositions of the major atomic species in materials examined by gamma-xrf spectroscopy. Note that this technique cannot determine carbon content. The comment "general" means that the reading is the average reading taken from various locations on the piece. Minor trace elements have been omitted from the table in the interests of simplicity. Experimental error is typically 0.01%.

LOCATION		Mn	Fe	As	Sn	W	Pb
HELMET	**Faceplate**	0.32	96.56	0.17	1.80		0.18
HELMET	**Cylinder**		94.6	0.1	2.6		0.18
BREASTPLATE	**General**	0.33	96.85	0.07	1.48		0.14
BREASTPLATE	**Mark, front**	**0.27**	**75.35**	**3.15**	**1.14**	**3.17**	**14.4**
BREASTPLATE	**Mark, back**	**0.48**	**97.88**		**0.48**		**0.20**
BACKPLATE	**General**	0.32	96.56	0.17	1.80		0.18
LAP PLATE	**General**	0.31	94.29	0.10	2.6		0.18
SIDE PANEL 1	**General**		95.33	0.11	2.6		0.18
SIDE PANEL 2	**General**		98.14	0.25	0.47		0.09
RIVET	**Typical**		97.65		1.34		
MILD STEEL	**Kiandra**	0.44	98.6				
MILD STEEL	**Modern**	1.07	94.57		2.15		

Note the presence of arsenic, tin, and lead in all the components made from sheet metal. All but the side panels and, remarkably, the helmet, contain significant amounts of manganese. For comparison, the compositions of a modern mild steel and a sample of mild steel typical of artefacts from the Kiandra goldfields are shown (Myles, 2004). The Kiandra goldfield was worked at the time of Ned Kelly and is in a region of Australia not far to the north of Glenrowan.

Questions as to the origin of the steel and the cause of the "mark" need to be answered using different techniques.

2.4 Estimating the thickness of the "mark"

Measurements of composition of the steel in the breastplate were made at the "mark" and on the breastplate directly behind the "mark". The incident γ ray beam is monochromatic (80 keV) and its intensity I_0 remains constant throughout the experiment ($t_{1/2}$ = 330 days). The incident beam is at an angle of 45^o to the surface, and the exit angle from the surface is also 45^o.

Without the surface layer the intensity received at the detector for the iron K-edge radiation is

$$I_2 = I_0 F_s \quad (1)$$

Where F_s is the fluorescent yield for iron with 80 keV radiation into the solid angle defined by the detector slits.

With the surface layer (thickness = t) present the incident radiation I_0 passes through the layer and is attenuated by the lead (linear attenuation coefficient = μ_{L1}) according to the Beer-Lambert Law. The intensity available to excite fluorescence radiation is given by

$$I_1 = I_0 \exp - (\mu_{L1} t/\sin \theta) \quad (2)$$

The fluorescent iron radiation is attenuated by the lead (linear attenuation coefficient = μ_{L2}) as it travels to the detector, and the intensity at the detector, I_3, is given by

$$I_3 = I_0 F_s \exp - ((\mu_{L1} + \mu_{L2})\, t/\sin \theta) \quad (3)$$

The ratio of the intensities with and without the "mark" is given by

$$I_3/I_2 = \exp - ((\mu_{L1} + \mu_{L1})\, t/\sin \theta) \quad (4)$$

Since I_3 and I_2 are known, $\theta = 45^o$, and μ_{L1} and μ_{L2} can be calculated to good accuracy (Creagh and Hubbell, 1998; Chantler, 1995), the layer thickness can be estimated.

The average thickness of the layer was estimated to be 0.4 ± 0.2 μm.

3. Results

The neutron and xrd measurements show that the material from which the armour was fabricated was a typical rolled carbon steel (similar to JCPDS 06-0696). Both showed that significant residual strain and preferred orientation in the components of the armour. This is consistent with the visual appearance of the armour (Figure 1). Individual hammer blows are readily identified: indeed, the armour is so crudely fabricated that it would seem to be unlikely that it could be the work of a professional blacksmith.

The existence of manganese in the gamma-xrf results indicates that, for all of the components the steel was manufactured after the Bessemer process was invented (1856), and, for most of the components, after 1858, because the process of adding manganese to steel to de-oxidize it was invented in 1857 by Mushet. The presence of manganese sulphide globules was confirmed by Thorogood et al. (2003) using an acetate replica technique in conjunction with a JEOL 2000FXII transmission electron microscope. The TEM study sought to investigate the existence of non-carbide phases. The traces of lead, arsenic, and tin found in the γ-xrf examination, were confirmed in the TEM experiment. These impurities were not in separate phases but as a solid solution. Their origin has yet to be explained. One possibility would be the addition of scrap galvanized iron to the melt in the Bessemer process. To date it has not been possible to determine whether the steel was made in Australia, or imported from England. Optical metallography (Thorogood et al., 2003) showed that regions of pearlite structure associated with the original structure still exist, and that these regions were not affected by subsequent heating. In other regions spheroidization consistent with heating to dull red was observed.

Visual inspection of the armour has shown the existence of bolt holes (filled in the armour by steel rod) the spacing between which is consistent with spacings in plough shares. As well some makers' marks were seen. To date these have not been properly identified.

The circular mark (Table 1) is an impregnation of lead in the steel, consistent with the impact of a lead projectile, perhaps a low velocity bullet. This indicates that perhaps at least one bullet hit the armour. Using x ray attenuation arguments based on the decrease of intensity of the lead peak in the xrf spectrum, it is possible to determine that the average thickness of the impregnated lead to be 0.4 ± 0.2 μm. Tungsten is found with the lead. The presence of tungsten is odd if the mark were to have been made at the time of the Glenrowan siege, because tungsten was not introduced into ball ammunition until World War 1. This suggests that the mark was not contemporaneous with the stand at Glenrowan.

4. Conclusions

The armour was made from good quality rolled steel similar to that found in plough-shares. It was fabricated under a low heat (dull red, 600 to 700^{o}C) for several hours, and not to white hot as would have occurred in a blacksmith's forge. This gives support to the belief that the armour was fabricated over a bush fire and formed over fallen trees. The nature of the hammer blows and the degree to which cold-working has occurred supports the notion that the armour was made by amateurs. There is no evidence of bullet impact on this armour, except for the "mark" which might have arisen from the impact of a bullet, but if so, this occurred almost certainly at a later date (after World War 1).

A great deal of effort was expended by the Kelly gang and their assistants in the manufacture of this armour, and three other similar (but not identical)sets of armour. It is reported in some folk-histories that there was some dissent in the gang about the production of the armour. Contemporaneous sketches show men in armour, standing in front of the Glenrowan pub, firing at the police. The armour worn by the gang members must have been hit by bullets, yet, for this armour there is no evidence of bullet impact occurring.

For the record: Joe Byrne died whilst drinking at the bar of the pub whilst wearing the armour. He died of a bullet wound to the groin. A stray bullet had penetrated the walls. His last words were reported to be: "I told Ned that the armour would be the death of us".

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References

Chantler,C.T. (1995). *Theoretical Form Factor, Attenuation and Scattering Tabulation for Z = 1-92 from 1-10 eV to E = 0.4- 1.0 MeV*. J. Phys. Chem. Ref. Data 24, 71-643.

Creagh, D.C., Hubbell, J.H. (1998). *X-ray Absorption (or Attenuation) Coefficients*. In International Tables for Crystallography, Volume C. Edition 2. Section 4.2.4. International Union of Crystallography. Kluwer: Dordrecht. pp 220-236. [International Union of Crystallography: ISBN 0-7923-5268-8]

Creagh, D.C., Thorogood, G.D., James, M., Hallam, D.L. (2004). *Diffraction and Fluorescence studies of bushranger armour*. Radiation Physics and Chemistry. Proofs corrected. In press.

JCPDS (2004). *PDF4 Set of Relational Databases*. International Commission for Diffraction Data. Newton Square, Pennsylvania, USA

Hunter, B.A. (1998). *Rietica – A Visual Rietveld Program*. Commission on Powder Diffraction Newsletter, 20, p. 21.

Myles, V. (2004). *An archaeological survey of the Chinese miners' camp at Kiandra*. MA Thesis. Australian National University. Submitted.

Thorogood, G.J., Creagh, D.C., James, M.,Smith, G., Mitchell, D.R.G. (2003). *The Legend of the Kelly Gang - Distilling fact from fiction*. Science. In preparation.