Analysis of Ice Axes under Loading

Technical Paper

Douglas Harvey 4th year Mechanical Engineering

Advisor: A. McLaren

Tuesday 18th April 2006
Abstract

In this report a DMM Xeno technical ice axe was tested representing loading in a real situation to analyse the strain pattern generated. The shaft was tested according to the relevant British standard. A study into the difference between ratings of picks was undertaken and the failure modes were investigated.

The ice axe was loaded using the Zwick 2061 test machine, strain gauges were used throughout to gather data, both non-destructive and destructive testing was carried out. A replacement shaft and dyneema slings were used when required.

At a load of 0.4kN the maximum strain measured was near the tip of the pick at a value of 990µε tensile. Failure occurred between 2.5kN and 3.8kN. The two ratings of picks supplied gave similar results, on investigation they were found to be of the same dimensions, material and heat treatment, contrary to the manufacturers claims. It was concluded that the British standard was appropriate but will soon require updating as a result of recent progression in ice axe design and use.
Nomenclature

\( \varepsilon \)  Strain
\( \sigma \)  Stress (Pa)
\( a \)  Vertical radius of shaft cross-section ellipse (m)
\( b \)  Horizontal radius of shaft cross-section ellipse (m)
‘B-rated’  Basic Rating
BS  British Standard
\( c \)  Pick thickness (m)
\( d \)  Distance from applied force (m)
E  Young’s Modulus (Pa)
F  Force (N)
\( h \)  Pick cross-section height (m)
I  Second moment of Area (m\(^4\))
M  Bending Moment (Nm)
SG  Strain Gauge
‘T-rated’  Technical rating
\( Y \)  Distance from neutral axis (m)
## Contents

Abstract ............................................................................................................1

Nomenclature ..................................................................................................2

Contents ..........................................................................................................3

Introduction to Ice axes ....................................................................................4

Aims .................................................................................................................6

Further detail on ice axes .................................................................................8

Apparatus ......................................................................................................10

  DMM Xeno .................................................................................................10

  Slings .........................................................................................................10

  Strain Gauge ..............................................................................................11

  Replacement Shaft.....................................................................................12

Testing ...........................................................................................................13

  Strain Assessment .....................................................................................13

  Shaft Strength ............................................................................................16

  ‘B’ and ‘T’ Pick Non-destructive.................................................................21

  ‘B’ and ‘T’ Pick Destructive .......................................................................27

  ‘T’ Pick and shaft........................................................................................30

Discussion .....................................................................................................32

Further Testing ...............................................................................................34

Conclusions ...................................................................................................35

Recommendations ........................................................................................36

Acknowledgements .........................................................................................37

References ....................................................................................................38

Appendix ........................................................................................................39
**Introduction to Ice axes**

Ice axes, also referred to as ‘ice tools’, are very versatile mountaineering tools, primarily for use in winter climbing. The first ice tools consisted of a long wooden shaft with a pick and adze made from steel fixed to the top. Over the years there have been major advances in ice axe design, improving the usability and strength and reducing the weight. Today, the pick is generally made from alloy steel that has been heat treated to achieve the specific properties required in winter mountaineering while the shaft is made from aluminium or titanium tubing. Ice axes have developed into two main categories: mountaineering and technical. Mountaineering axes have a long straight shaft and are held at the head, like a walking stick, so that it is in the correct position for self arrest in the event of a fall. The pick on a mountaineering axe is generally straight and the adze, a triangular shaped plate, is used to cut steps in snow in the absence of crampons. Technical ice axes have been developed to climb vertical ice with the use of crampons. These axes have shorter shafts that are curved to give better clearance while climbing and are held at the opposite end of the shaft to the head. The picks are curved, or reverse curved to make it easier to remove them from the ice and to aid in ‘hooking’ on mixed ground and are often interchangeable with different styles and rating of pick. Two ice axes are used when climbing vertical ice, the second one usually has a hammer replacing the adze; the hammer is more useful for placing and retrieving gear and also for ‘torqueing’ on in small cracks and crevices.
There are two main types of winter climbing: ice and mixed. In ice climbing the pick is used to penetrate solid ice such as frozen waterfalls, usually only a depth of a centimetre or so is required to provide adequate grip. Mixed climbing is a technique where not only ice is used but rock outcrops are hooked with the tip of the pick to aid progress. Scotland is renowned for its good mixed ice climbing. A third type of climbing that uses ice tools has developed from mixed climbing. It is called dry-tooling and is the practise of using ice tools on climbs with no ice. Primarily it was used as a training method for mixed ice climbing as it was far more accessible but it is now being seen as a category in its own right with specific tools having been developed and regular competitions.

Most ice tools are developed for self arrest. Self arrest is the act of stopping an uncontrolled slide down snow or ice without the aid of a rope or other belay system. Ice tools designed for dry-tooling differ from other ice tools as they are not designed to be used for self arrest [1][2].
Aims

1. To analyse the stress/strain pattern in ice axes under loading.

2. To compare an ice axe to the requirements set by the British Standards.

3. To compare the strain pattern in B and T-rated picks under loading and to ascertain the main differences between the two.

4. To establish the maximum loads and therefore failure modes of ice axes under static loading.

5. To discuss if updating the British Standard for ice axes is necessary.

In order to resolve the aims listed above suitable testing methods had to be developed. The British standard EN13089 was referred to, to gain an initial insight into methods of testing that have been used on ice axes [3]. However, the testing methods used in the standard have not been followed rigorously, only used as a guide, in an attempt to gain more knowledge about the performance of the ice axe not specifically tackled in the British standards. Bearing in mind that for an ice axe to be sold to the public it will already have passed stringent tests to assure that it has met the requirements of this standard.

For the majority of the test undertaken it was decided to load the ice axe in a way that best represent the loading it would experience in normal use, i.e. the tip supported with the load pulling downward from the grip position on the shaft. Due to time constraints and the difficulty that obtaining a suitable block of ice that represents real conditions would cause, it was decided to fix the
pick in another manner [4]. The British standard uses two methods of securing the pick: using a circular cross section bar and by clamping the pick between two vice jaws with a Vickers hardness value greater than that of the test sample [3]. A circular cross section bar was chosen to support the pick as this would, in effect act as a point load on the tip of the pick. This method would be unrealistic for ice but as the majority of modern ice tools are designed for use on mixed climbs it was deemed accurate for the purpose of these tests.

The following tests were used to provide results for the aims of the report:

1. To gain general results for the strain pattern in the ice axe under loading a load was applied, as stated above, between the tip of the pick and the spike on the end of the shaft.
2. To compare the ice axe to the EN13089 standard a shaft strength test was carried out according to section 5.3.3 of the British standard [3].
3. To compare B and T-rated picks they will be loaded from the grip position using a replacement shaft that acts as a direct rigid link.
4. To examine the failure modes of the picks destructive testing was undertaken using both the replacement shaft and the original shaft.
Further detail on ice axes

Figure 1 shows three of the different types of ice tool available on the market today. The parts labelled are as follows:

1. Pick
2. Head
3. Adze
4. Leash
5. Leash stop
6. Shaft
7. Spike

In accordance with the conditions set by the British Standards the shaft and pick will each receive a rating of ‘B’ or ‘T’, which stand for basic and
technical respectively \[2][3\]. It is common for the option of B and T-rated picks to be available but it is not likely for shafts to be interchangeable, the majority of technical ice axes would use a T-rated shaft. T-rated picks are required to be stronger than B-rated, this is achieved by increasing the thickness of the pick \[3][5\]. The increased strength makes T-rated picks more suitable for mixed climbing where large torsional and twisting forces can be applied to the pick. However, the increased thickness of the pick is a hindrance when climbing ice as the chances of the ice shattering or ‘dinner plating’ on impact is greater. The thinner, lighter B-rated picks cut into the ice much easier so are well suited to waterfall ice \[5\].

When considering which ice tool to purchase for testing the area of most interest was in technical ice tools, this eliminated mountaineering and dry tooling axes. A technical axe of recent design was required to assess the relevance of the British Standard EN 13089 for present day ice tools.

The DMM Xeno (ice axe B in Figure 1) is a high end technical ice axe with interesting features, within the budget and with readily available replacement picks of ‘B’ and ‘T’ type. Therefore it was acquired for testing purposes and is shown in more detail in the next section.
Apparatus

*DMM Xeno*

The DMM Xeno (Figure 1) is a technical axe designed for use on vertical ice or mixed climbing. It features a shaft that’s is curved in three sections (Tribend) that increases clearance and reduces the likelihood of bashing knuckles, aided by a supportive knuckle rest. The curve is also more ergonomic than straight shafts and coupled with the light weight increases the comfort of using the Xeno for extended periods of time. The pick and spike of the DMM Xeno are hot forged form 4340, 1.5% NiCrMo steel, the shaft is T-rated and is made from extruded 7075-T6 Aluminium (Al – 5.6%Zn – 2.5%Mg) [1][5][6]. There are options of both B and T-rated picks, both of which are ground to sharpen. Adze and hammer version are both available, weighing 675g and 680g respectively. The head and spike are fastened to the shaft with two rivets each and the pick is bolted into the head with two M8 bolts. All parts of the axe have a painted surface finish and there is a rubber grip glued to the lower section of the shaft.

*Slings*

Lyon Equipment Dyneema Slings that are 60cm long and 15mm wide were used to support the axe where necessary. All of the slings were rated up to 22kN strength. Lyon Equipment’s Dyneema slings are covered by the British standard EN566. Dyneema is a synthetic fibre based on ultra high molecular weight polyethylene, 15 times stronger than steel and up to 40% stronger than Kevlar, both on weight to weight basis. Dyneema’s strength is derived from the extreme length of each individual molecule [7][8][9].
Strain Gauge

In order to get more information from testing than permissible with the methods used in the British standard tests strain gauges were fitted at key points on the shaft of the ice axe and the pick. A strain gauge is a device that is used to measure the deformation, therefore strain, of an object. It consists of a metal foil pattern supported within a flexible backing. Once a strain gauge is attached to the ice axe and a load applied, the strain gauge will flex changing the electrical resistance of the foil material. This is due to the piezoresistive effect and can be measured using a Wheatstone bridge allowing the strain to be calculated according to the gauge factor \[10\][11].

Using the strain values retrieved from the gauges it was possible to further verify the results from each test by comparing with calculations from appropriate models and also to determine if there were any lasting effects from the non-destructive testing.

Both the pick and the shaft of the DMM Xeno ice axe have a surface finish to protect the metal underneath. It is very important that for the strain gauge to work properly it is securely attached to the bare metal of the ice axe. Once the surface finish was removed the strain gauges were attached using standard procedures.
The strain gauges were attached in five different places on the axe, two on the shaft and three on each pick, as shown below:

![Diagram of strain gauge placement on the DMM Xeno ice axe used for experimental testing.](image)

### Replacement Shaft

A replacement shaft was constructed to eliminate the effect of the original shaft on the loading of the pick. It provided what could be taken to be a direct rigid link between the point of loading and the pick. The shaft was made from two plate sections of steel that bolted together through the pick. The replacement shaft can be seen in Figure 7.
Testing

**Strain Assessment**

**Aim**
- To analyse the stress/strain pattern in ice axes under loading.

The following test was used to find typical values of load to apply as little was known about acceptable values. The resulting strain was monitored using strain gauges to ensure the ice axe did not yield.

**Procedure**

The Zwick 2061 Tensile Test machine was used to load the ice axe as shown in the diagram below:

![Diagram of loading procedure](image)

*Figure 3 - Loading of original shaft and B-rated Pick. The insert shows how the Lyon Equipment sling was used to grip the shaft for destructive testing of the T-rated pick.*
The strain gauges (SG 1-4) were wired into a data logger that could plot the strain (incorporating the gauge factor) against the load delivered by the test machine. For simplicity the ice axe was loaded through the hole in the spike and under the very tip of the pick using a 15mm diameter steel rod.

The strain values given by the data logger were closely monitored and used to assess the response of the ice axe to the application of load. The test was repeated five times, ramping the load up to 0.4, 0.5, 0.75, 1 and 1.2kN based on the assumption that a typical climber would weigh 75 kg, therefore would apply a load of 750N.

Results

![Strain Gauge results from Zwick 2061 test machine (B-rated pick)](image)

Figure 4 - Graph showing the strain values, SG 1-4 for loading to 1.2kN and SG 1’-4’ for loading to 0.4kN of the B-rated pick and original shaft.
Discussion
The results collated were as expected, SG 1 on the pick and SG 4 on the shaft give a negative strain showing they are in compression while SG 2 and 3 are positive and in tension. The graph above shows the strains during the application and release of load, this is important as by comparing the two paths generated, the amount of residual strain can be calculated for the position of each strain gauge. In each test it was observed that the release line exactly follows the line of application of load returning to the original value of strain, consequently, it can be concluded that there has been no residual strain. The load lines for both pick and shaft were straight, validating the material is linear elastic. The close proximity of the two lines is evidence that there was no mechanical hysteresis [11][12][13].

If the weight of a typical climber was to be assumed to be 75kg then the results retrieved show the ice axe has performed more than adequately, but this was to be expected. The data has confirmed that the DMM Xeno would comfortably hold 1.2kN, the equivalent of a 120kg climber and has shown a range of values to work within where no failure should occur.
Shaft Strength

Aim

- To compare an ice axe to the requirements set by the British Standards.

In order to get an understanding into the methodology of tests required by BS EN13089 the shaft strength test was carried out. SG 4 and 5 were attached to the data logger to collect strain readings from the top and bottom surfaces of the shaft.

Procedure

The shaft was supported horizontally in a stable position so as to eliminate any rotation of the shaft. It loaded as in the diagram below:

Figure 5 - Diagram of testing apparatus for shaft strength experiment.
The force ($F_k$) to be applied was calculated using the following equation

$$F_k = \frac{F \times 250}{I_k}$$

where $F = 3.5\text{kN}$ for T-rated shafts

Therefore $F = \frac{3.5 \times 250}{202.5} = 4.375\text{kN}$

The load of 4.375kN must be held without shock for 60 +/- 5s.

The maximum permissible deformation ($d_k$) at the point of application of the load is:

$$d_k = 3\left(\frac{I_k}{250}\right)^2$$

$$= 1.97\text{mm}$$

Where $I_k$ is the distance in mm from the middle of the shaft to the middle of the outer tapes, positioned at the ends of the shaft.
Results

Upon retrieval from the test machine there was no measured deflection at the point of application of the load.

Figure 6 - Graph of British Standard's 'shaft strength' test, with strain gauges positioned as detailed in Figure 2.
Calculations

Wall thickness: \( t := 0.0025 \)  
Dimensions (m): \( a := 0.01375 \) \( b := 0.00925 \)

Youngs Modulus (Pa): \( E := 73 \cdot 10^9 \)  
Reaction Force (N): \( F := 2000 \)

Distance from support (m): \( d := 0.075 \)

Bending Moment (Nm): \( M := F \cdot d \)  
\[ M = 150 \]

\( K_2 := 0.1349 + 0.1279 \frac{a}{b} - 0.01284 \left( \frac{a}{b} \right)^2 \)

\( K_3 := 0.1349 + 0.1279 \frac{b}{a} - 0.01284 \left( \frac{b}{a} \right)^2 \)

Second Moment of Area (m^4):

\[
I := \frac{\pi}{4} \cdot t \cdot a^2 (a + 3 \cdot b) \left[ 1 + K_2 \left( \frac{a - b}{a + b} \right)^2 \right] + \frac{\pi}{16} \cdot t^3 (3 \cdot a + b) \left[ 1 + K_3 \left( \frac{a - b}{a + b} \right)^2 \right]
\]

\[ I = 1.574 \times 10^{-8} \]

Distance from neutral axis (m): \( y := a + 0.5t \)

Stress (Pa): \( \sigma := \frac{M \cdot y}{I} \)

\[ \sigma = 1.43 \times 10^8 \]

Strain:

\[
\varepsilon := \frac{\sigma}{E}
\]

\[ \varepsilon = 1.959 \times 10^{-3} \]

Strain reading at 4000kN load from test data, \( \varepsilon = 2.046 \times 10^{-3} \)
Discussion

Again the load and release sections of the graph follow the same, straight, line, further confirming that the there is no hysteresis and that the material is linear elastic [11][12]. Close inspection at the point of zero load shows the shaft has no residual strain and upon examination the displacement between the points of application of the load was seen to be zero. This confirms that the shaft meets the EN 13089 standard, but this was to be expected otherwise the shaft would not have been available commercially [3]. However, other findings from the test provided useful information on the strain values. It can be seen that the strain gauge result are equal and opposite for the opposing sides of the shaft, confirming that the neutral axis of the shaft is at its mid point and that the shafts cross section is symmetrical.

Verification

MathCAD was used to calculate the strain at the point of SG 4 on the shaft. The second moment of area for a hollow ellipse with constant wall thickness was used to represent the cross-section of the shaft. The shaft was considered to be a straight beam as its radius of curvature was greater than twelve times its depth, the errors in treating a curved beam as straight are very slight if the radius of curvature is more than eight times the depth of the beam [11]. The difference between the calculated result for the strain and the value taken from the experimental data is only 4.4%, this is a very small percentage so the experimental data was taken to be correct.
‘B’ and ‘T’ Pick Non-destructive

Aim
- To compare the strain pattern in B and T-rated picks under loading and to ascertain the main difference between the two.

Procedure
Using the replacement shaft, supported in the grip position and at the tip of the pick by a 15mm diameter rod, the pick was loaded as shown in Figure 7.

Figure 7 – Photograph of T-rated pick as set up for the non-destructive test.
Prior to testing the picks were conditioned at -65°C +/- 5°C for at least one hour. The picks were tested within 5 minutes from removal from conditioning, at room temperature (20 +/- 5°C). Both B and T-rated picks were tested using the same procedure to values of 0.5kN and 0.8kN respectively.
Results

Strain Gauge results from Zwick 2061 test machine
B-rated Pick

Figure 8 – Graph of load and release paths for the B-rated pick using the replacement shaft.

Strain Gauge results from Zwick 2061 test machine
T-rated Pick

Figure 9 - Graph of load and release paths for the T-rated pick using the replacement shaft.
Calculations

Young's Modulus (Pa):

\[ E := 204.8 \cdot 10^9 \]

Applied Force (N):

\[ F := 400 \]

Thickness (m):

\[ c := 0.004 \]

Cross section

<table>
<thead>
<tr>
<th>SG 1</th>
<th>SG 2</th>
<th>SG 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m):</td>
<td>h1 := 0.031</td>
<td>h2 := 0.026</td>
</tr>
<tr>
<td>Distance from applied force (m):</td>
<td>d1 := 0.135</td>
<td>d2 := 0.096</td>
</tr>
<tr>
<td>Bending Moment</td>
<td>M1 := F \cdot d1</td>
<td>M2 := F \cdot d2</td>
</tr>
<tr>
<td>M1 = 54</td>
<td>M2 = 38.4</td>
<td>M3 = 21.6</td>
</tr>
</tbody>
</table>

Second Moment of Area (m^4):

| l1 := \frac{c \cdot h_1^3}{12} | l2 := \frac{c \cdot h_2^3}{12} | l3 := \frac{c \cdot h_3^3}{12} |
| l1 = 9.93 \times 10^{-9} | l2 = 5.859 \times 10^{-9} | l3 = 1.365 \times 10^{-9} |

Distance from Neutral Axis (m):

| y1 := -0.5 \cdot h_1 | y2 := 0.5 \cdot h_2 | y3 := 0.5 \cdot h_3 |

Stress (Pa):

\[ \sigma_1 := \frac{M_1 \cdot y_1}{l_1} \]
\[ \sigma_2 := \frac{M_2 \cdot y_2}{l_2} \]
\[ \sigma_3 := \frac{M_3 \cdot y_3}{l_3} \]

\[ \sigma_1 = -8.429 \times 10^7 \]
\[ \sigma_2 = 8.521 \times 10^7 \]
\[ \sigma_3 = 1.266 \times 10^8 \]

Strain:

\[ \varepsilon_1 := \frac{\sigma_1}{E} \]
\[ \varepsilon_2 := \frac{\sigma_2}{E} \]
\[ \varepsilon_3 := \frac{\sigma_3}{E} \]

\[ \varepsilon_1 = -4.116 \times 10^{-4} \]
\[ \varepsilon_2 = 4.161 \times 10^{-4} \]
\[ \varepsilon_3 = 6.18 \times 10^{-4} \]

Strain readings at 400N from experimental data:

\[ \varepsilon_1 = -1.235 \times 10^{-4}, \varepsilon_2 = 8.405 \times 10^{-4}, \varepsilon_3 = 9.264 \times 10^{-4} \]
Discussion

From inspecting the graphs for the tests of B and T-rated picks once conditioned it would appear there had been some permanent deformation on account of the residual strain left after releasing the load. While the maximum loads reached are lower than when previously tested, the values of strain are much greater. This can be attributed to the use of the replacement shaft as it was far stiffer than the original shaft of the axe, therefore transmitting more strain into the pick. However, even though the gradient of strain slope is greater than the previous tests the maximum strain is still much less than that reached in earlier tests so the replacement shaft does not explain the residual strain. The only other difference between this test and previous test was that the picks were both conditioned at -65°C immediately before the testing. It is known that the modulus of steel changes in relation to temperature as shown in the graph below:

![Graph of Young's Modulus Against Temperature for Cr-Mo steels Cr 0.5% - 2%](image)

Figure 10 - Variation of Young's Modulus with Temperature for a similar alloy steel. Re-plotted from data in engineeringtoolbox.com [14]
At -65°C young’s modulus (E) can be taken to be 209.2 GPa while at 20°C, 
E = 204.8 GPa. This would result in a decrease in strain of only 2.15% thus 
would not affect the permanent deformation.

It is possible that the apparent residual strain can be attributed to the 
temperature increase in the pick. For the B-rated pick the test took 420 
seconds to complete, during which time it was exposed to convection from the 
air, conduction from the replacement shaft and radiation from the surrounding 
lights. Upon cooling the pick would contract more than the strain gauge and 
as a result the strain gauge will experience a deformation and register a 
change in strain, and as the pick warms back up the pick will expand, 
interfering with the results. To eliminate this error the strain in the pick should 
be monitored during the conditioning process and throughout the test 
procedure but without the application of load. The resulting strain/time curve 
could be subtracted from a subsequent cold-conditioned test to give results 
without the effect of the temperature increase creating a residual stain.

Verification

For the calculations above the pick was assumed to be a cantilever beam of 
variable section [11]. MathCAD was used to calculate the strain at the points 
on the pick that correspond to SG 1-3. The calculated results did not match up 
very accurately, although they are reasonably acceptable. It would be 
recommended that an in-depth FEA study of this problem be considered to 
properly validate the experimental results.
‘B’ and ‘T’ Pick Destructive

Aim
- To establish the maximum loads and therefore failure modes of ice axes under static loading.

Procedure
Again the pick was loaded using the replacement shaft as shown in Figure 7. Prior to testing the picks were conditioned at -65°C +/- 5°C for at least one hour. The picks were tested within 5 minutes from removal from conditioning, at room temperature (20 +/- 5°C). The load was applied increasingly until failure occurred.
Results

**Strain Gauge results from Zwick 2061 test machine**

**B-rated Pick, Destructive**

Figure 11 - Graph of load and release paths for the destructive test of the B-rated pick using the replacement shaft.

**Strain Gauge results from Zwick 2061 test machine**

**T-rated Pick, Destructive**

Figure 12 - Graph of load and release paths for the destructive test of the T-rated pick using the replacement shaft.
Discussions
The purpose of this test was to determine how the picks would fail, to see if they failed in the same way and to determine that if brittle fracture occurred in either pick, if the fracture occurred near the tip of the pick or at the base where it was connected to the shaft. Neither the B nor T-rated pick fractured in the destructive tests, both of the picks failed by twisted and buckled to the side, under the restraining bar. It would be possible to restrict this effect by constraining the shaft so as to not rotate about its vertical axis. The quick release of strain in SG 3, shown in the graph above, on the B-rated pick occurred as the pick bent to the point that it popped free from the restraining bar.

As it was expected the T-rated pick failed at a higher value than that of the B-rated pick, however this data is not beyond question due to the shaft being unconstrained as discussed above. The B-pick failed at a value of 2.5kN, for a climber weighing 75kg this is a safety factor of 3.3, which is more than adequate. Both picks exhibit residual stress upon total release of the load, this was in part due to the conditioning, but a small amount was also due to the failure of the pick.
‘T’ Pick and shaft

Aim
- To establish the maximum loads and therefore failure modes of ice axes under static loading.

Procedure
The original shaft was used with the T-rated pick to perform a destructive test. The purpose of this test was to discover the weakest component of the ice axe. The shaft was loaded at the pick with a 15mm diameter rod and at the handle in the centre of the grip position with an unused Lyon Equipment sling, fastened as shown in Figure 3. Prior to testing the whole ice axe was conditioned at -65°C +/- 5°C for at least one hour. The ice axe was tested within 5 minutes from removal from conditioning, at room temperature (20 +/- 5°C).

Strain Gauge results from Zwick 2061 test machine
T-rated Pick, Destructive

![Graph of load and release paths for the destructive test of the B-rated pick using the original shaft.](image)

Figure 13 - Graph of load and release paths for the destructive test of the B-rated pick using the original shaft.
Discussions

Similarly to the destructive test with the replacement shaft the pick failed by buckling and twisting. It was observed that the rubber on the grip stretched further down the shaft before the pick began to buckle, this would not have affected the results dramatically, only slowing the rate of increase of load. It can be seen that while the strain in the shaft follows the same path for load and release the pick yielded near the tip at 2.4kN. Beyond this point SG 1 and 2 show a large increase while the load decreases, signifying total failure. However, once the load is released the strain reduces with the same gradient as when the load was applied and the residual strain is relatively small.
Discussion

The first table given in the appendix compares the strain at 0.4kN and the maximum strain for SG 1-5 for each test performed. Which type of pick used, whether conditioned and if the replacement shaft was used is noted so the results are easily comparable. The results at 0.4kN do not show any noticeable trends, they are in fact quite wide spread. There would appear to be no noticeable effect of temperature, this is most likely due to ineffective conditioning. As discussed earlier the heat gain and subsequent expansion in the material produced what appears to be residual strain at the end of the test. For more accurate testing this effect would need to be reduced or eliminated and multiple tests performed to reduce the consequence of rouge results.

The failure load for the T-rated pick with the original shaft was considerably less than that of the destructive tests performed using the replacement shaft. It was discussed earlier that the replacement shaft increased the strain in the pick which would result in failure occurring at a lower load. However, the strain values in the picks were the same at 2.5kN for both the original and replacement shaft. Thus, the results are more likely explained by the fact the original shaft distorts more, altering the direction of the load and increasing the chance of the ice axe twisting free from the desired position and loading off axis.

To provide an easy comparison between B and T-rated picks the maximum load and corresponding strain have been plotted on the graph Appendix 2.
Appendix 2 illustrates that B and T rated picks undergo similar strain values at corresponding values of load. If, as the manufacturer claims, the T-rated pick was stronger the strain would be noticeably less than that of the B-rated pick [5]. To obtain a rough guide of how much stronger the T-rated pick should be the British Standard states it should meet the same requirements of permanent deformation for 1.5 times the load of the B-rated pick [3]. The standard way to increase the strength of a pick is to make it thicker, but both picks are 4mm thick. It is possible that the picks are made out of different material or have received different heat treatment. To confirm or deny these theories Vickers hardness tests and metallographic examinations were carried out as described in the next section.
Further Testing

Vickers Hardness Test
The Vickers hardness test was carried out in accordance with the standard procedure. A 5 kg weight was used for both picks. Both picks were 447-460 Hv5kg. This indicates that they have had the same heat treatment.

Metallography
The magnified pictures of the grain structure of the B and T-rated picks were taken using the standard procedures. They indicate that the microstructure of both materials is tempered martensite with insignificant difference between them.

From this information it was safe to assume that both B and T-rated picks were made from the same material and knowing that both picks are of the exactly the same geometry, DMM’s claims that the T-rated pick is stronger than the B-rated pick caused some confusion.
Conclusions

Using the first strain assessment as a benchmark it was confirmed that no component of the ice axe would fail below a loading of 1.2kN, equivalent to a 120kg climber suspended from the ice axe in a condition comparable to real use.

The shaft strength test from the British Standard EN 13089 was investigated with the aid of strain gauges. It was concluded that this test was appropriate for assessing the static strength of the shaft. However, it is the author’s opinion that the ongoing advances in ice axe based sports may render the BS EN 13089 obsolete and require it to be updated.

Due to stipulations in the BS EN 13089 B and T-rated picks were loaded to different values according to their different strengths, but on further investigation there was found to be no difference between the picks contrary to the manufacturers claims. As a result, on comparison of B and T-rated picks they were found to be indifferent. This point was taken up with the manufacturer, but at the time of writing no reply in way of an explanation has been received.

The difficulty in obtaining concordant results has highlighted the scope for inaccuracies and variation in test results for any ice axe scrutinised by British Standard EN 13089. The development of a more rigorous standard, incorporating technical advances, with stricter guidelines would help increase the consistency and accuracy of ice axe testing procedures.
Recommendations

- In-depth research into how relevant BS EN 13089 is for dry-tooling specific ice axes.
- FEA of ice axes under loading.
- Further investigation into cold-conditioning.
- Research into effectiveness of BS EN 13089 for modern techniques, e.g. torqueing.
- Dynamic testing of ice axes.
Acknowledgements

I would like to thank:

- Dr Andrew McLaren – Project Advisor
- Andy Crocket – Manager of Materials Testing Laboratory
- James Kelly – Materials Technician
- Jim Doherty – Stores Manager
- Chris Cameron – Lab Superintendent
References


[3] BS EN 13089, Mountaineering equipment - Ice tools - Safety requirements and test methods, British Standards, 1999


[6] CES


Appendix

<table>
<thead>
<tr>
<th>Pick</th>
<th>Replacement Shaft</th>
<th>Conditioning</th>
<th>Strain at 0.4kN (µε)</th>
<th>Max Load</th>
<th>Max Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SG 1 SG 2 SG 3 SG 4 SG 5</td>
<td>SG 1 SG 2 SG 3 SG 4 SG 5</td>
<td>SG 1 SG 2 SG 3 SG 4 SG 5</td>
<td>SG 1 SG 2 SG 3 SG 4 SG 5</td>
</tr>
<tr>
<td>Strain assessment</td>
<td>B</td>
<td></td>
<td>-196</td>
<td>716</td>
<td>533</td>
</tr>
<tr>
<td>Shaft Strength</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non destructive</td>
<td>B</td>
<td>•</td>
<td>-123</td>
<td>840</td>
<td>926</td>
</tr>
<tr>
<td>Non destructive</td>
<td>T</td>
<td>•</td>
<td>-120</td>
<td>971</td>
<td>990</td>
</tr>
<tr>
<td>Destructive</td>
<td>B</td>
<td>•</td>
<td>-173</td>
<td>918</td>
<td>840</td>
</tr>
<tr>
<td>Destructive</td>
<td>T</td>
<td>•</td>
<td>-208</td>
<td>872</td>
<td>923</td>
</tr>
<tr>
<td>Destructive</td>
<td>T</td>
<td>•</td>
<td>-211</td>
<td>797</td>
<td>865</td>
</tr>
</tbody>
</table>

Appendix 1 - Collation of results from testing performed on the DMM Xeno ice axe.

Graph of Max Strain at Max Load for each test

Appendix 2 - Comparison of strain for B and T-rated picks.