Some notes on bssa advice and HSE document “Chloride stress corrosion cracking in austenitic stainless steel”

**1 INTRODUCTION**

1.1 BCA has had a program of installing anchors running for many years based on work done by CNCC in the early 1990s. These anchors have always been made from stainless steel. Many of the existing anchors were made from a grade 316 (also designated A4 or 1.4401) but recently anchors made from grade 304 (also designated A2 or 1.4301) have been put into use.

**2 British Stainless Steel ASSOCIATION ADVICE**

2.1 The BSSA advice, see Appendix 1, is very positive being: “*In the water treatment industry, taking account of all relevant factors grade 304 is regarded as being suitable for up to 200 ppm chloride. 316 is OK for 100 to 1000 ppm. The levels you are talking about for caving systems are massively below this limit. In addition, the low temperatures found in caves are another positive factor. Overall, the risk of corrosion failure of 316 anchors in these conditions is practically nil.*” It is emphasised that BSSA supply such “*Advice and assistance provided without charge are given in good faith but without responsibility*”. It is emphasised that the above concentrations are for chloride ion. There is a lower threshold for chlorine of 20ppm.

**3 Chloride levels**

3.1 There is a potential for confusion between the chloride ion species and chlorine, often known as “free” and “combined” chlorine in water. Chlorine is added to drinking water for disinfectant purposes. In the past this used to be chlorine gas but is now usually added as a chlorine nitrogen compound. In addition, chlorine can combine with some organic nitrogen species already present in water. The combined chlorine value reflects the level of chlorine present in these compounds, whilst the free chlorine reflects the amount of chlorine dissolved in water having been released by the decomposition of these compounds. Typical free and combined chlorine in drinking water[[1]](#footnote-1) values are around 0.5ppm. However the taste and odour thresholds for chlorine in distilled water[[2]](#footnote-2) are 5ppm and 2ppm, respectively. Given these values, it seems unlikely that free chlorine in cave water exists at a level of 20ppm the threshold for concern for the chlorine species.

3.2 The limits[[3]](#footnote-3) for chloride and sodium in drinking water are 250 and 200ppm whist sodium levels around 200ppm will cause a salty taste. The mean chloride ion concentration in drinking water for the Skipton and Craven area is 8ppm[[4]](#footnote-4) with a maximum value of 10ppm.

3.3 DEFRA[[5]](#footnote-5) provide chloride ion concentrations in rain water for the location at Wardlow in Derbyshire amongst a range of places in the UK. The 10 year mean rain water chloride ion concentration is 2.9ppm with max value 24ppm. Some work[[6]](#footnote-6) indicates a typical value of chloride ion in rain water of 6ppm by the coast and slowly reducing as one goes inland to circa 4ppm. Work[[7]](#footnote-7) at Malham Tarn indicates surface water in moss has a mean chloride ion concentration of 8ppm with a maximum value of 54ppm which is claimed to reflect a concentration effect via evaporation. Chloride ion concentrations in soil[[8]](#footnote-8) are typically 50ppm. Inputs to soil derive from rainfall, fertilisers (mainly muriate of potash - potassium chloride), manures, irrigation water and with seawater flooding. Road run off will contain chloride ion from salt used for de-icing and possibly from weed killers. No estimates for chloride ion concentration in such run offs has been found. Sea water contains around 20,000ppm of the chloride ion.

3.4 DEFRA undertakes an English wide program of water sampling. A request to DEFRA for summary details of chloride ion results covering Yorkshire caves has resulted in a body of data being supplied[[9]](#footnote-9). This data is acknowledged as “Contains Environment Agency information © Environment Agency and database right”. The data has been analysed in two ways, see Appendix 2. A general review indicates that locations whose mean value are above 200ppm are all associated with significant human activity such as engineering works, mining or sea / estuary locations which can easily be identified. A more detailed geographical review of those locations within some tens of kilometres of caves did not reveal any evidence of high levels of chloride ion in comparison to the 200ppm threshold value for 304 stainless steel.

3.5 It has noted that Cheddar Spring bottled mineral water reports having a value of 50ppm[[10]](#footnote-10). John Gunn[[11]](#footnote-11) believes chloride ion levels are mainly due to surface sources, though there could be some chloride ion release from weathering of clay wayboards and volcanic interbeds.

3.6 Communications with R Stenner has identified several papers on the water chemistry of caves located on Mendip, see Appendix 3 which include the measurement of chloride ion concentrations. These indicate levels for three caves (GB, Swildons and Wookey Hole) are generally below 20ppm. But the Swildon’s paper did comment that several single results in Swildons from high level inlets were found to range between 40 and 43ppm. The paper indicates that these high values from high level inlets may well be related to contamination from septic tanks. In addition, the paper reports that one sample at the bottom of Cowsh Inlet in Swildons, known to be connected to Priddy Green Sink was 26ppm. The significance of this result is that Priddy Green Sink lies by a road side and also takes the runoff from a nearby dairy farm yard. Stenner’s work indicates that there can be concentrating effects due to periods of drought and that the sodium / chloride balance is not near unity as may be expected if the source of the chloride ion was solely from sodium chloride / salt. Stenner[[12]](#footnote-12) also reports that the pH in cave water is below 8.5.

3.7 From the above it would seem that one could divide caves into three groups:

1. Those on unimproved moorland or near to human habitation, farms etc,
2. Those near significant potential sources such as engineering works, mining or estuary locations,
3. Those next to the sea.

**4 temperature**

4.1 The HSE document[[13]](#footnote-13) suggests a threshold for chloride stress corrosion cracking above 40C but also notes that it has been seen in laboratory experiments between 25C and 40C[[14]](#footnote-14). In cave[[15]](#footnote-15), one expects all anchors to be around 11C, see Appendix ## where as on the surface, an anchor might see higher temperatures. The average mean UK surface temperature is around 16C[[16]](#footnote-16). The temperature of cave water appears to usually follow that of the cave air temperature, see Appendix 4.

4.2 It therefore seems that the temperature of anchors are at a sufficiently low temperature such that chloride stress corrosion cracking would not occur.

**5 stress**

5.1 Chloride stress corrosion cracking can only arise if the anchor sees some level of a tensile stress. For most of the time an anchor will see no stress in use as a typical fractional usage time is around ¼% based on 30 minute of loading during one trip per weekend. In such use the anchor might see loads of up to 2kN based on an HSE report[[17]](#footnote-17). In an extreme case, one might see loads of up to 20kN in arresting a fall[[18]](#footnote-18).

5.2 Bolt Products state[[19]](#footnote-19) that they do not stress relive the anchors post bending. An attempt to estimate the residual stress left in the manufactured anchors failed, see Appendix 5. It is therefore sensible to assume that there is some residual stress in the manufactured anchors. It is also prudent to assume that the previous source of anchors from DMM also have a residual stress.

5.3 Another HSE document[[20]](#footnote-20) cites two thresholds for chloride stress corrosion cracking of 80MPa and 10% of the 0.2% proof stress (offset yield point). A very crude approach based on assuming the rod is in tension rather than bending, is to take the diameter of an anchor as 8mm, then 80MPa = 80 \* 106 N/m2 which over a cross sectional area of pi \* 0.0042 m2 gives a load of 4kN. The 0.2% proof stress is reported[[21]](#footnote-21) as 290MPa, so 10% of the 0.2% proof stress is equivalent to 29MPa which in an 8mm diameter rod is equivalent to 1.5kN. Thus the 10% of the 0.2% proof stress threshold is around the normal use load, though for only perhaps ¼% of the fractional usage time.

5.4 There is a test for evaluating the stress corrosion cracking resistance of a metal based on boiling a sample in magnesium chloride solution[[22]](#footnote-22). However, the effort required to do this is beyond our capacity and is thought to offer little benefit.

5.5 Should chloride stress corrosion cracking start, then it will cause a reduction in the residual stress so the process is self limiting. Given the likely area of highest residual stress is on the outside of the heads of the anchors, it is feasible to check for the presence of cracks, assuming they are visible. (The recommended process is dye penetrant test which will not work in a damp cave environment.)

**6 precursor corrosion**

6.1 The Health and Safety Executive (HSE) document[[23]](#footnote-23) states that “It is commonly accepted that chloride stress corrosion cracking initiates from sites of active pitting or crevice corrosion …”. It is accepted that crevices may be present between the anchor and the resin at the surface. The Council of Northern Caving Clubs[[24]](#footnote-24) have found that on extraction, some test anchors located on the surface and subject to periodic wetting showed corrosion along their shafts. However it is noted that the test anchors were placed with a resin which is no longer used. But the experience does provide an indication of the potential for crevices being present. However it is expected that the head will be the critical area of the anchor rather than the shaft, see Appendix 5.

**7 Literature reports on chloride stress corrosion cracking**

7.1 The HSE document[[25]](#footnote-25) reports several papers assessing the susceptibility of both 304 and 316. All relate to swimming pool environments which are not relevant to the caving environment.

**8 Assessment of risk**

8.1 The HSE document[[26]](#footnote-26) provides a risk assessment chart. Given that chloride ion concentrations will be above 1ppm and the pH less than 10, then Figure 2 recommends an assessment. Values for chloride ion concentration are expected to be less than 100ppm, temperatures less than 38C and the potential for drying out in cave is negligible, so Table 2 in the document assesses the risk as low. This leads to a predicted crack growth rate of circa 0.6mm / year, see Table 4 in the document. That implies a need for checking the anchor.

8.2 Given the expected location of such cracks is on the head, it seems prudent to amend the advice on checking anchors to include checking the head for any cracks and also have a formal installation check for cracks by both the issuer and the installer. There are some test beds of anchors but it is likely that these are located where chloride ion concentrations are low. It would however seem prudent to keep a set of say 5 anchors from each purchased batch which could be tested if any reports of cracking were made from placed anchors.

**9 BMC**

9.1 A BMC report[[27]](#footnote-27) of 2007 states that no anchor on a UK sea cliff has failed due to chloride stress corrosion cracking. (Anecdotal reports are clearly wrong.) There have been reports of such failures in Thailand and Cayman Brac. The BMC web site has no update so it seems reasonable to consider that this zero reported failure rate remains correct.

9.2 The BMC have investigated the potential problem, see Appendix 6 and have come to the conclusion to advise using “A2 for general purpose, A4 for anywhere near the coast and the expensive HCR for on sea cliffs themselves”.

**10 ADOPTION OF OTHER ANCHORS FOR USE**

10.1 304 anchors are slightly cheaper than 316 (Euro 3.65 v 3.83) so there is a slight advantage for using 304. In addition BCA has a large holding of 304 anchors.

10.2 Although Bolt Products state that their anchors are tested to EN 959[[28]](#footnote-28), the resin they supply is different from that preferred for use by BCA, being KMR. (KMR resin has better curing properties in the presence of water.) Confirmatory tests have been carried out on a set of Bolt Product anchors[[29]](#footnote-29) with KMR resin for axial pull out. Subsequent checking has not been able to confirm which type of stainless steel the tested anchors were made from. Although the strength of 304 stainless steel is somewhat better than 316[[30]](#footnote-30) (621 verses 579MPa for ultimate tensile strength), it is considered that further axial pull out testing of five clearly identified 304 anchors and five clearly identified 316 anchors is required to confirm an expectation that both types of anchors will meet the axial strength requirement of EN 959.

10.3 Whilst there is no immediate demand for placing anchors in sea cliffs, it would seem prudent to also confirm HCR anchors with KMR resin will meet axial strength requirement before a demand arises.

**11 CONCLUSIONS**

11.1 Guidance from BSSA indicates that 304 stainless steel anchors can be used in chloride ion concentrations of up to 200ppm and 316 anchors at concentrations of up to 1000ppm.

11.2 Chloride ion concentrations in cave water are likely to be low but the data is focused on Mendip caves. Surface water data for Yorkshire supports low chloride ion concentrations. However, there is some potential for elevated chloride ion concentrations which indicates it is appropriate to differentiate caves for use with 304, 316 or HCR anchors.

11.3 A suggested approach is:

1. Those on unimproved moorland or near to human habitation, farms etc for use with 304,
2. Those near significant potential sources such as engineering works, mining or estuary locations for use with 316,
3. Those next to the sea for use with HCR.

11.4 Cave temperatures are not well characterised across the UK but are most likely to be below the 25C threshold of 25C.

11.4 The levels of stress in usage is thought to be in excess of some theoretical predictions of a threshold, though only for a very small period of time. Whilst it clear there is some residual stress in the anchors, it is not possible to make an estimate of the likely value.

11.5 The HSE document provides supportive information though there is a possible question over HSE’s risk assessment outcome. It is therefore considered appropriate to:

1. Update the advice on checking anchors prior to use to include checking the head of all anchors for any cracks,
2. Have a formal pre installation check for cracks in anchors by both the issuer and the installer, and
3. Keep a set of say 5 anchors from each purchased batch which could be tested if any reports of cracking were made from placed anchors.

11.6 There is a need to confirm that KMR resin will provide a satisfactory strength when used with both Bolt Product 304 and 316 anchors.

**12 RECOMMENDATIONS**

12.1 E&T consider at its next meeting:

1. Differentiating caves for use with 304, 316 or HCR anchors,
2. A need to better characterise temperature and chloride ion concentrations across the UK,
3. Updating the advice on checking anchors prior to use to include checking the head of all anchors for any cracks,
4. Include requirements for checking for cracks in anchors pre installation by both issuer and installer,
5. Keep a set of say 5 anchors from each purchased batch which could be tested if any reports of cracking were made from placed anchors,
6. Results from testing five 304, five 316 and five HCR anchors to confirm they meet BS EN 959:2007 axial strength requirements, and
7. Designating 304 stainless steel anchors (Bolt Product ref GP6-100-12A2) with KMR resin subject to satisfactory axial testing results.

Bob Mehew

Appendix 1

**From:** Alan Harrison [<mailto:alan.harrison@bssa.org.uk>]   
**Sent:** 05 June 2013 09:14  
**To:** [faye.litherland@blueskyeng.co.uk](mailto:faye.litherland@blueskyeng.co.uk)  
**Subject:** Stainless Steel for Caving ENQ 37421

Faye,

Summarising our discussion:

1. The distinction needs to be made between free chlorine and the chloride ion. Free chlorine is what is found in disinfectants like hypochlorite. Chloride ions are quite different. They are found in some concentration in all natural waters. For example, drinking water is typically 100 ppm.
2. In the water treatment industry, taking account of all relevant factors grade 304 is regarded as being suitable for up to 200 ppm chloride. 316 is OK for 100 to 1000 ppm. The levels you are talking about for caving systems are massively below this limit. In addition, the low temperatures found in caves are another positive factor. Overall, the risk of corrosion failure of 316 anchors in these conditions is practically nil.
3. I can understand the caution from the rock climbing fraternity due to failures in their sphere. However, the conditions in rock climbing and caving are quite different.
4. My understanding of 316 failures in rock climbing is that they are due to stress corrosion cracking. This is caused by the influence of coastal sea spray which on evaporation can produce very high chloride levels. Temperatures are also much higher above ground. A surface temperature of at least 25 deg C is needed for stress corrosion cracking. Caves can reproduce these conditions in only very exceptional cases. You have already recognised this by adopting a safety first policy for coastal caves by using C 22. This is an extremely safe option.
5. Between 316 stainless and C 22, there is a range of options which you might want to explore. These are the duplex stainless steels and the high alloy austenitic grades.
6. I had a discussion with Alan Jarvis of the UIAA in  September 2012 about Stress Corrosion Cracking of rock climbing anchors. I recommended using duplex steels as a cost effective answer to the SCC issue. He told me he was on the safety committee for the UIAA so he may be well known in climbing circles.

I hope you find this information useful.

Regards

Alan Harrison - Stainless Steel Advisory Service (SSAS),   
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GRADESPOTTING - The BSSA has launched an initiative to find out where the less familiar grades of stainless steel are used. See <http://www.bssa.org.uk/latestnews.php?id=648> for more details

For technical and source of supply information on stainless steels visit the British Stainless Steel Association (BSSA) web site <[www.bssa.org.uk](http://www.bssa.org.uk/)>

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Appendix 2 Chloride levels in Yorkshire Streams and Rivers

A request for data from DEFRA’s water sampling program for chloride ion concentrations in an area mostly covering Yorkshire resulted in the supply of data covering 1683 locations citing minimum, mean and maximum values. This data has been sorted and can be summarised as:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ppm Cl | | | |
| data set | mean | max | reaches 90% cumulative | % below 1000 |
| of data set | of data set |
| Mean value | 281 | 24921 | 200 | 97 |
| Max value | 652 | 116000 | 600 | 94 |

So clearly there are locations where a chloride ion source elevates the level of chloride ion way above rain water levels; indeed some exceeding sea water levels. Some care therefore needs to be taken over caves which are near to human activity. But the 163 locations whose mean value are above 200ppm are all associated with significant human activity such as engineering works, mining or sea / estuary locations. (The 116000ppm maximum value is associated with a mine shaft.)

A list of Yorkshire caves was obtained from the web site[[31]](#footnote-31) which covers an area of a rectangle located at NY6608330748, NZ1058530748, SE1058563191 and SD6608363191. This area of cave locations was found to contain 133 of the DEFRA data sampling locations. Of these 133 locations only thirty had maximum chloride ion concentrations above 10ppm. (A 10ppm threshold was chosen on two grounds; that 10ppm was only just above the maximum rain water value and that it was one twentieth of the limit for 304 stainless steel of 200ppm.) The table beneath shows these locations and values sorted by maximum chloride ion concentration.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Chloride Level ppm | | |  |
| Location | min | max | mean | Grid Ref |
| ANGRAM RESERVOIR, PATELY BRIDGE | 4.03 | 168 | 11.63064 | SE0680076800 |
| BROUGH HILL FARM,BAINBRIDGE | 19 | 71.4 | 31.13333 | SD9430090100 |
| WHARFEDALE CARAVAN CLUB LONG ASHES THRES | 5.14 | 71 | 10.11571 | SD9782464768 |
| LONG ASHES CARAVAN PK, THRESHFIELD | 63 | 63 | 63 | SD9804764602 |
| RIVER AIRE AT MALHAM TARN | 4.24 | 44.8 | 7.92937 | SD8942366183 |
| EAST BIRK RIGG FARM APERSETT 3076(2) | 2.92 | 27.9 | 5.86512 | SD8420091600 |
| SCAR HOUSE RESERVOIR, PATELY BRIDGE | 4 | 25 | 6.3986 | SE0680076800 |
| EAST SCAR TOP FARM AYSGARTH 3733 | 5.8 | 23.8 | 8.02365 | SD9600089000 |
| RIVER SWALE AT GRINTON BRIDGE | 7 | 20.6 | 12.7 | SE0470098500 |
| LINTON BECK-LINTON MILL | 20.2 | 20.2 | 20.2 | SD9995463268 |
| TARN BECK AT ENTRANCE TO MALHAM TARN | 4.5 | 20 | 9.2282 | SD8880667045 |
| ARKLE BECK AT REETH | 6.8 | 18.3 | 11.45 | SE0412899178 |
| SPRING AT RAYGILL | 7.82 | 18.2 | 13.15333 | SD9020089700 |
| YW FOSSDALE MOSS WTW INLT YW URN 2613650 | 6.2 | 16.6 | 8.3923 | SD8640094900 |
| GHYLL END FARM SPRING 5777 | 3.89 | 15.8 | 6.62461 | SD8730080800 |
| INGS BECK-THRESHFIELD | 15.3 | 15.3 | 15.3 | SD9945663290 |
| RIVER URE AT WORTON | 14.8 | 14.8 | 14.8 | SD9553990259 |
| RIVER URE AT WENSLEY BRIDGE. | 14.3 | 14.3 | 14.3 | SE0912789443 |
| SWINITHWAITE HALL 4461 LEYBURN | 4.9 | 13.7 | 7.60373 | SE0370087700 |
| SEMERWATER OUTFLOW @ RD BRIDGE | 4.08 | 12.5 | 7.7606 | SD9220087700 |
| RAYGILL SITE BORWINS | 7.68 | 12.2 | 10.26166 | SD9150090300 |
| YW CRUMMA (YW URN 2612180) | 7.6 | 12 | 10.16923 | NZ0897106803 |
| MALHAM BECK AT MALHAM COVE | 3.33 | 11.8 | 7.6976 | SD8986563364 |
| WEST SHAW FARM HAWES 3876 | 3.5 | 11.5 | 5.87825 | SD8650087800 |
| BAIN AT BAINBRIDGE | 11.5 | 11.5 | 11.5 | SD9347490134 |
| RIVER WHARFE AT KETTLEWELL | 11.2 | 11.2 | 11.2 | SD9676072221 |
| THE HAGG, FREMINGTON, RICHMOND | 8.7 | 10.9 | 10.03629 | SE0559098900 |
| BLACKBURN SYKE U/S BLACKBURN F/F (PONDS) | 3.63 | 10.7 | 5.7463 | SD8761889328 |
| RIVER WHARFE AT CONISTONE BRIDGE | 10.3 | 10.3 | 10.3 | SD9791067505 |
| SORREL SYKES FARM FREMINGTON 4465 | 5 | 10.1 | 6.86768 | SE0486098980 |

Given the 167ppm maximum value result for the Angram Reservoir sample set and its upstream location with respect to Manchester Hole and Goyden Pot, a follow up request was made to DEFRA for the individual results for this location. The response indicated that whilst the 167ppm value was as reported but no laboratory note books were available to check for comments on the sample. However the conductivity result of 42uS/cm for the sample is not consistent with such a high chloride ion concentration. A statistical analysis of the data set indicates the 167ppm value is some 5 standard deviations away from the mean value of the data set. It is therefore considered reasonable to discount the value. (It is also worth noting that Scar House Reservoirs is located between Angram Reservoir and the caves. The Angram Reservoir data has two high values, the 167ppm result already discussed and another reported as >50ppm. If these values are stripped out, then the mean concentration drops to a value similar to that for Scar House Reservoir.)

Of these thirty sample locations only ten had a maximum value above 20ppm. In addition to these top ten, the next two locations have mean values above 10ppm. All the rest of the samples have mean chloride ion concentrations at or below 10ppm. Only one of these locations is with 1km of a cave (Fossdale Moss WTW INLT at SD8640094900 is around 0.6km from Fossdale Beck Cave at SD8635095550). Thus locations within the “caving” area do not reveal any evidence of high levels of chloride ion in comparison to the 200ppm threshold value for 304 stainless steel.

It is therefore suggested that there is no evidence from the DEFRA sampling program for Yorkshire that chloride levels exist at levels which might cause concern when compared to the 200ppm threshold value for using 304 stainless steel if no significant human activity is near bye.

Appendix 3 Chloride levels in Cave Water

Stenner et al measured chloride levels as part of their water chemistry work in GB[[32]](#footnote-32), St Cuthberts[[33]](#footnote-33), Swildons[[34]](#footnote-34) and Wookey[[35]](#footnote-35). The papers used a convention of citing results in molarity. A 1 molar solution of the chloride ion contains 1 gram mole of chloride ion per litre of water. Given chlorine’s atomic weight of 35.45, that means a 1 molar solution contains 35.45g per litre of water. Using the approximation that 1 litre of water weight 1kg, then a 1 molar solution contains 35.45 g of chloride ion per 1000 g of water or 35450 parts per million of chloride ion. The convention is to cite molarity of trace constituents of water as 105 \* Molar since typical values are circa 10 \* 10 -5 molar. Thus a value of 10 (105 \* Molar) is equivalent to 3.5ppm. Stenner’s data has been converted to provide the following data set:



Appendix 4 Cave Temperatures

A study[[36]](#footnote-36) in Poole’s cavern indicated that the cave has an almost uniform temperature with a slight increase with height above the cave floor. Its value of 7°C is close to the mean annual temperature recorded at a standard climatological station nearby. A search of ukCaving forum found two threads[[37]](#footnote-37). Neither indicates any quotable source but the comments indicate a typical air temperature of around 10 to 12C.

Stenner et al measured water temperatures as part of their water chemistry work in GB, St Cuthberts and Swildons (see Appendix 3). Values observed were around 10C though several locations in Swildons indicated some maximum temperatures went as high as 17C.

Appendix 5 Residual Stress

A residual stress is placed in a metal when the crystalline and molecular structure is left distorted after some action. In permanently bending a rod, the inside of the bend acquires a compressive residual stress since the volume has been compressed by the bending action. The outside of the bend acquires a tensile residual stress as the volume has been stretched apart. Bolt Products state that the bending is limited to bends of greater than a radius specified by the steel supplier so as to ensure no cracks are initiated. If the rod was bent to an excessive amount, that is to a very small radius of bend, the cracks would appear in the outside of the bend. In the Bolt Products anchor, there are two types of bending, that which shapes the head and that which shapes the shaft. The radius of the bending in the head is smaller than the shaft so the outside of the head is the area where highest tensile residual stresses are expected to be located by the manufacturing process. (Although DMM anchors have a much smaller bend in the shaft which creates the tangs, the presence of two spot welds could well leave behind small areas of residual stress around these weld sites. But the size of the welds are very small in comparison to the diameter of the rod and thus thought to be less significant.) Thus the most likely location for chloride stress corrosion cracking is on the outside of the bottom bend in the head.

At a very simplistic level, if a rod is bent and then straightens back out again on being release, then no residual stress will have been left in the rod. On cutting the head of a Bolt Product anchor, the head only slightly springs apart, see below. So the fact that the metal did not “straighten out” indicates there is some residual stress.



Seven Bolt Product anchors were held in a vice and cut across their head. The results for the displacement in mm of the cut ends from their formed state were:

|  |  |  |  |
| --- | --- | --- | --- |
| Anchor No. | Displacement mm | | Method of holding |
| Apart | Sideways |
| 1225 | 0.3 | 3.2 | None |
| 441 | 1.5 | 2.1 | None |
| 875 | 0.3 | 3.3 | None |
| 171 | 1.8 | 2.6 | Held in vice |
| 1167 | 0.1 | 0.4 | Two weld |
| 301 | 0.7 | 1 | Two weld |
| 739 | 0.5 | 4.4 | Single weld |

It was observed that the two parts of the first three tested anchors subsequently became detached, so the measurements were suspect. Anchor 171 was measured in the vice to avoid possible movement. But concerns were such that two subsequent anchors were spot welded at the top and bottom of the shaft to secure the shaft. Following debate a further anchor was spot weld at the bottom of the shaft. It became clear that the displacement relates to a movement starting from a position way down the shaft within the twisted part of the shaft. At least one anchor suggested a rotational movement of one side of the head.

Discussion on how to estimate the size of the residual stress[[38]](#footnote-38) indicated that the simple data cited above would not provide a route to make credible estimate. It was concluded that there is almost certainly some residual stress but no estimate could be made of the size.

Appendix 6

**From:** Dan Middleton <[dan@thebmc.co.uk](mailto:dan@thebmc.co.uk)>

**Subject: RE: Metallurgical advice required**

**Date:** 27 February 2013 10:43:56 GMT

**To:** Nick Williams <[nick.williams@hucklow.net](mailto:nick.williams@hucklow.net)>

Hi Nick,  
  
What kind of anchors are they? We've ordered both A2 and A4 from Bolt Products, as well as the ones made from special HCR alloy. I spoke to JT about them, and he says that there is more to corrosion resistance than just metal grade, the finish and surface treatment is important too. Passivated or highly polished and smooth A2 performs pretty much identically to A4 according to him, and this appears to be correct based on a little research I did on it. We've therefore suggested A2 for general purpose, A4 for anywhere near the coast and the expensive HCR for on sea cliffs themselves. This is based on the prevalence of chloride ions in the environment, whether there are other types to be concerned about which may leach into cave water, I don't know I'm afraid.  
  
Not getting exactly what you ordered is a different matter altogether!  
  
Best regards  
  
Dan  
  
Dan Middleton  
Technical Officer  
  
Tel:    0161 445 6111  
Direct: 0161 438 3326  
Fax:    0161 445 4500  
Web:    <http://www.thebmc.co.uk>  
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-----Original Message-----  
From: Nick Williams [mailto:nick.williams@[hucklow.net](http://hucklow.net)]  
Sent: 26 February 2013 22:03  
To: Dan Middleton  
Subject: Metallurgical advice required  
  
Hi Dan,  
  
Does the BMC Technical Committee have any views about the choice between A2 and A4 stainless steels for resin bonded anchors?  
  
The British Caving Association have purchased as quantity of anchors from a vendor which were ordered as 316/A4 material, but it appears we have been delivered 304/A2 material. We are wondering what the considered view is as to whether or not the added corrosion resistance of 316/A4 is really necessary in our application (i.e. primarily installation in limestone exposed to rainwater).  
  
Any help and advice BMC Technical Committee members can offer would be gratefully received.  
  
Regards  
  
Nick.  
  
BCA Equipment and Techniques Commitee Convenor

1. See Table 8 in <http://dwi.defra.gov.uk/about/annual-report/2011/northern.pdf> as on 4/9/13 [↑](#footnote-ref-1)
2. See <http://www.who.int/water_sanitation_health/dwq/chlorine.pdf> as on 4/9/13 [↑](#footnote-ref-2)
3. See <http://www.southernwater.co.uk/at-home/your-water/about-your-water/drinking-water-quality/drinking-water-quality-standards.asp> as on 4/9/13 [↑](#footnote-ref-3)
4. Data acquired from <http://www.yorkshirewater.com/extra-services/in-your-area.aspx> as on 4/9/13 [↑](#footnote-ref-4)
5. See <http://uk-air.defra.gov.uk/> as on 4/9/13 [↑](#footnote-ref-5)
6. E Erikson: Tellus, Volume 4 (3) pp215–232, August 1952; “Composition of Atmospheric Precipitation” [↑](#footnote-ref-6)
7. M C F Proctor: , Field Studies, 10, pp 553 – 578, 2003; “Malham Tarn Moss The Surface Water Chemistry ...” [↑](#footnote-ref-7)
8. See <http://www.pda.org.uk/notes/tn13.php> as on 4/9/13 [↑](#footnote-ref-8)
9. DEFRA communication to R Mehew, 2013 [↑](#footnote-ref-9)
10. See item 9 of Minutes of Equipment and Techniques Committee minutes for 14 April 2013 at <http://british-caving.org.uk/equipment/130414%20E&T%20minutes%20unadopted.pdf> as on 4/9/13 [↑](#footnote-ref-10)
11. J Gunn, personal communication, 2013 [↑](#footnote-ref-11)
12. R Stenner, personal communication, 2013 [↑](#footnote-ref-12)
13. See page 4 in <http://www.hse.gov.uk/research/rrpdf/rr902.pdf> as on 4/9/13 [↑](#footnote-ref-13)
14. See page vii in <http://www.hse.gov.uk/research/rrpdf/rr902.pdf> as on 4/9/13 [↑](#footnote-ref-14)
15. The only information comes from two threads on ukCaving forum at <http://ukcaving.com/board/index.php?topic=4646.0> and <http://ukcaving.com/board/index.php?topic=13024.0> as on 4/9/13 [↑](#footnote-ref-15)
16. See <http://www.metoffice.gov.uk/climate/uk/summaries/actualmonthly> as on 4/9/13 [↑](#footnote-ref-16)
17. See page 23 – 28 in <http://www.hse.gov.uk/research/crr_pdf/2001/crr01364.pdf> as on 4/9/13 [↑](#footnote-ref-17)
18. R Mehew, personal work in rope testing, 2013 [↑](#footnote-ref-18)
19. Email J Titt to N Williams 14 June 2013 [↑](#footnote-ref-19)
20. See page 34in <http://www.hse.gov.uk/research/rrpdf/rr902.pdf> as on 4/9/13 [↑](#footnote-ref-20)
21. See data bulletins at <http://www.aksteel.com/markets_products/stainless_austenitic.aspx> as on 4/9/13 [↑](#footnote-ref-21)
22. Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution, G36 − 94 (Reapproved 2006). [↑](#footnote-ref-22)
23. See page 3 in <http://www.hse.gov.uk/research/rrpdf/rr902.pdf> as on 4/9/13 [↑](#footnote-ref-23)
24. See <http://www.cncc.org.uk/documents/Yordas-Eco-Anchor-Test-Report-13-10-2012.pdf> as on 4/9/13 [↑](#footnote-ref-24)
25. See pages 27 & 8 in <http://www.hse.gov.uk/research/rrpdf/rr902.pdf> as on 4/9/13 [↑](#footnote-ref-25)
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27. BMC “Bolt Guidance Document” p21, 2007; see <https://www.thebmc.co.uk/bolts-guidance-documents> as on 4/9/13 [↑](#footnote-ref-27)
28. See <http://www.bolt-products.com/ProtectionBolts.htm> as on 4/9/13 [↑](#footnote-ref-28)
29. See <http://www.cncc.org.uk/documents/Anchorreport15.11.11.-1.pdf> as on 4/9/13 [↑](#footnote-ref-29)
30. Data from AK steel web site <http://www.aksteel.com/markets_products/stainless_austenitic.aspx> as on 4/9/13 [↑](#footnote-ref-30)
31. Obtained from <http://cavemaps.org/data.htm> as at 4/9/13 [↑](#footnote-ref-31)
32. R D Stenner: Proc Univ Britsol Spelaeol Soc 1973, 13(2) pp171-226; “A study of the hydrology of GB Cave...” [↑](#footnote-ref-32)
33. R D Stenner: Proc Univ Britsol Spelaeol Soc 1997, 21(1) pp9-24; “Changes in the distribution of water between surface sinks and stream inlets in St Cuthbert’s Swallet...” and Stenner et al: Proc Univ Britsol Spelaeol Soc 2001, 22(2) pp183-202; “Changes in streams between swalltes and inlets in the cave at St Cuthbert’s Swallet...” [↑](#footnote-ref-33)
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36. P. A. Smithson: Theoretical and Applied Climatology, 1991, Volume 44, Issue 1, pp 65-73; "Inter-relationships between cave and outside air temperatures" [↑](#footnote-ref-36)
37. <http://ukcaving.com/board/index.php?topic=4646.0> and <http://ukcaving.com/board/index.php?topic=13024.0> as on 4/9/13 [↑](#footnote-ref-37)
38. C Bolton CEng FIStructE MICE, personal communication, 2013 [↑](#footnote-ref-38)