THE AFFECTS OF USE ON THE STRENGTH OF CLIMBING KARABINERS

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Abstract

This paper investigates the failure modes of karabiners and examines the affects of everyday use on their tensile strength under loading. Experiments were carried out to simulate the wear that might be seen from the use of a karabiner over a long period of time and an investigation was made into the affects of using karabiners in a saline environment. The investigation into the affects of wear on the karabiners found that there was no significant loss in tensile strength in any of the three types of loading completed these being major axis, minor axis and open gate conditions. The biggest difference which was found was when the karabiner was loaded in the open gate conditions where the worn karabiners reached a slightly smaller peak load and only experienced a very small amount of deformation to failure when compared to the newer ones. The sea water investigation found that although there was no loss in mechanical properties of the karabiners there were signs of corrosion about the gate mechanism which might affect the workings of the gate.

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Nomenclature

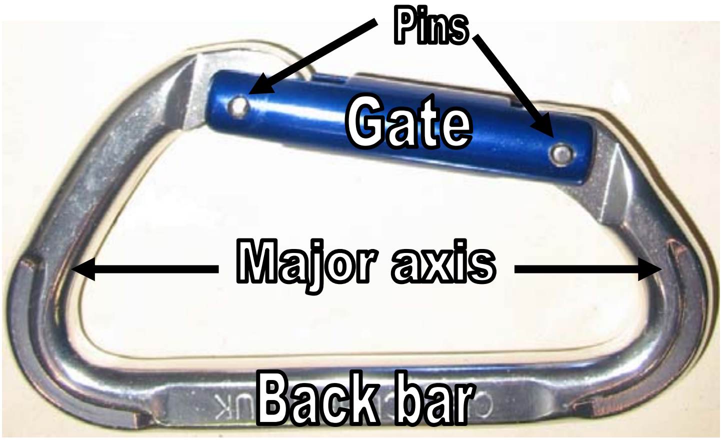

Figure 1: Karabiner main features

A – Indicates the karabiner was loaded in the minor axis (across the gate)

B.B. – Indicates the strain gauge was located on the back bar of the karabiner

C – Indicates the gate was closed

Gate – Indicates the strain gauge was located on the gate of the karabiner

New – Standard Clog 10mm Straight Gate karabiner as new

O – Indicates the gate was open

S.W. – Standard Clog 10mm Straight Gate karabiner which has been exposed to saline environment

Worn – Standard Clog 10mm Straight Gate karabiner worn in upper corner

All units in SI useless otherwise stated.

1.0 Introduction

1.1 What is a Karabiner?

Karabiners are approximately a D-shaped piece of metal that has a spring loaded gate connecting one side. They are used widely in both sport and industrial markets, however, for this project only sport climbing karabiners will be considered. The reason for this is that mountaineering is one of the biggest users of this equipment where they are used to link various components of the climbing system, for example, linking the climber to the rope. As such they play a vital role as a piece of safety equipment and their strength is very important.

1.2 Types of Karabiner

1.3 Body Shape

There are many different shapes and sizes of karabiner available however the most common shape used for general purpose climbing is the asymmetric D-shape. Other types of karabiner shape include ovals, pear shapes and offset D-shapes. Each of these different karabiner shape offer different properties for different climbing situations.

For this project only the standard asymmetric D-shape shall be considered.

1.4 Body Cross Section

The most common types of cross section used for climbing karabiners are the oval and circular cross section. However, as with the body shape there are many different variations available. Oval and circular cross sectional karabiners are simple to manufacture, strong and allow the rope to run freely across and through them.

Other types of cross section which can be found are variations of T sections and I sections. These can have advantages such as being lighter, stronger or having better rope movement. The disadvantages of these types of cross section are that they are harder to manufacture and therefore are more costly than the oval and circular.

The karabiners used throughout this project are of the basic oval cross section with two cuts along their back bar on which their specifications are stamped.

1.5 Gate Shape

There are three types of gate which are used in modern climbing karabiners. The first of these is a straight gate which is a simple cylindrical rod that runs almost the full length of one side of the karabiner. At each end of the rod a vertical rectangle is cut out and a hole is machined horizontally through both sides. The gate is then placed so that the cuts sandwich the ends of the karabiner and a steel pin driven through to connect the gate to the main body of karabiner. The other end of the gate also has a steel pin driven through it but this time it is used to rest on the karabiner’s hook in order to keep it shut.

The second type of gate is the bent gate. This type of gate is the same as the straight gate except that mid way along the gate there is a bend. The reason for this is that it increases the clearance space between the gate and the back bar which allows for quicker and easier rope clipping.

The final type of gate is the wire gate type which is a simple loop of wire that is attached through holes at one end of the karabiner and engages the hook at the other. Although wire gates look weaker than more conventional gates they are equally as strong and much lighter.

This project shall look at straight gate karabiner types.

1.6 Closing Mechanisms

The closing mechanism on a karabiner is primary used to keep the gate shut during normal use but also to allow for easy opening when necessary. There are two main types of closing mechanisms which are used for climbing karabiners.

The most common type of closing mechanism is the snap gate which has a spring assembly at its base which holds the gate shut. In use the karabiner can be opened by applying a small amount of pressure on the gate that once removed allows the gate to snap shut again. This is a very simple and convenient system which is used on almost all karabiners. The only flaw with this type of closing mechanism is that in use the gate can accidentally open creating a far weaker karabiner.

A variation of the snap gate is the locking gate type of closing mechanism. The majority of these types of mechanism utilize the snap gate design but also have a moveable sleeve which can be slid over the hook and gate preventing the gate from opening accidentally. The most common type of locking mechanism is the screw gate which has a threaded sleeve covering the gate. In order to lock the karabiner the sleeve can then be screwed over the free end of the gate/karabiner hook meet preventing it from opening. A disadvantage of this type of locking mechanism is that it takes time to fasten and unfasten the gate and that it can be difficult to unscrew the gate if incorrectly tightened.

There are various other types of locking mechanism which are available however these are usually specific to the company which manufacturers them.

This project shall only use the simple snap gate design of closing mechanism.

2.0 British and European Standards – For Climbing Equipment – Connectors

The most recent British and European Standard which governs all mountaineering connectors, including karabiners, was set in 1998 under “BS/EN 12275 Mountaineering Equipment – Connectors – Safety requirements and test methods”. [**1**]

For karabiners one of the most important areas this specification governs is the minimum tensile strengths for the karabiners under various loading situations.

These are as follows;

Minimum Tensile Breaking Load along Major axis (gate closed)	20kN
Minimum Tensile Breaking Load along Minor axis	7kN
Minimum Tensile Breaking Load (gate open)	7kN

The standard also sets the test standards which are required to be used during testing to the British standard are that the karabiner should be mounted in a standard tensile testing machine and two 12mm diameter steel bars used to apply the loads. This method should be used for both closed and open gate testing.

In order to test the karabiners under minor axis loading steel pins of 10mm diameter shall be used and small test grooves, the size of which are specified by a diagram in the Standard, can be cut into the back bar and gate of the karabiner.

3.0 Project Aims

3.1 Experimental Aims – Comparison of new and worn karabiners

1. To establish the failure load and mode of **new**, unused karabiners under major axis loading.
2. To establish the failure load and mode of **worn** karabiners under major axis loading.
3. To compare how the distribution of the load varies between the **new** and **worn** karabiners as it approaches maximum load.
4. To establish the failure mode and load of **new** karabiners under open gate loading.
5. To establish the failure mode and load of **worn** karabiners under open gate loading.
6. To establish the failure mode and load of **new** karabiners under minor axis (across gate) loading.
7. To establish the failure mode and load of **worn** karabiners under minor axis (across gate) loading.

3.2 Experimental Aims – Testing of karabiners in sea water simulated environment

1. To establish whether the misuse of karabiners whilst in a sea water environment leads to a visual difference in karabiner appearance.
2. To establish whether the misuse of karabiners whilst in a sea water environment leads to a reduction in tensile strength.

4.0 Test Apparatus

4.1 Karabiners

It was decided that during this project the same type of karabiner should be used throughout as to keep consistency of results.

Clog 10mm Straight Gate

Karabiner Ratings –

Minimum Tensile Breaking Load along Major Axis	23kN
Minimum Tensile Breaking Load along Minor Axis	7kN
Minimum Tensile Breaking Load Open Gate	7kN

Cost: £4 each – (Quantity purchased 20)

4.2 Strain Gauges

Vishay Strain Gauge – CEA-06-375UW-120 – General Purpose

Specifications –

Overall Length	0.575 inches
Gauge Length	0.325 inches
Electrical Resistance	120 Ohms
Temperature Range	-75º - 175 º C

Cost: £44.21 (Per pack of 5) – (2 packs of 5 purchased)

4.3 Prodac – Ocean Fish – Salt Solution

It was decided that in order to accurately simulate a sea water environment that a container of sea water should be made up using the salt supplied from a tropical fish shop. The procedure for this follows in section 5.3 - Simulation of karabiners in sea water environment.

Cost: £5 (Quantity 1)

4.4 HB Dyneema Sewn Sling

The slings were used to attach the karabiners to the tensile testing machine.

Maximum Tensile Strength	22kN
Dimensions	12 mm x 150 mm

Cost: £1 each (4 purchased)

4.5 Test Machine – Zwick Tensile Test Machine

This tensile test machine uses a crosshead which is locked into place at the top has a hydraulic piston underneath which can move vertically. In order to apply the load the piston descends downwards pulling the karabiner apart. The crosshead speed of the test machine describes the rate of decent of the piston during testing.

4.6 Safety Equipment

1. Cotton Fabric wrapped a number of times around the karabiners to contain the fragments.
2. Polycarbonate plastic screen to further contain any possible fragments.

5.0 Preparation of Test Specimens

5.1 Simulation of Wear that Might be Seen after Long Term Use

To simulate the wear which might be seen from a karabiner during its lifetime the upper corner of the karabiners were worn away with a circular file. The size of wear was to a depth of 0.5mm with a diameter of 5-6 mm as shown in figure 2, below;

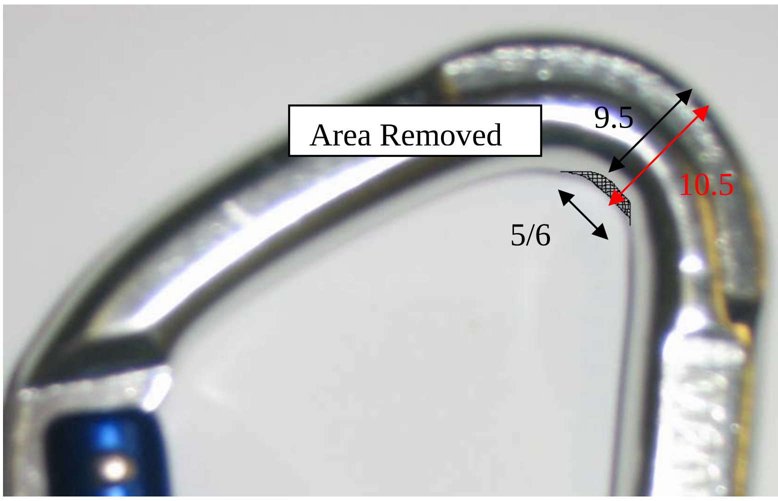

Figure 2: A photograph showing the area removed from the worn karabiners

The reason for size of wear was chosen as this represents the wear that a karabiner would experience if it had been used for all its lifetime alongside the use of nuts. A nut is a piece of climbing equipment that is used to provide support on a rock face by jamming into nocks and crannies. They consist of a wedge shaped block which goes into the rock face and then a loop of coiled wire which goes into the karabiner [**2**]. The diameter of this wire varies from approximately 3-6mm. Over an extended period of time the coil of wire moving on the inside of the karabiner can cause the inside corner to wear during use.

5.2 Attachment of Strain Gauges

In order to gain an understanding of how the load was disturbed throughout the karabiners when worn and unworn whilst loaded in the closed gate condition under major axis loading strain gauges were placed on two of each type of karabiner. The picture below, figure 3, shows the location of the strain gauges on the karabiners.

Figure 3: A diagrams showing the placement of the strain gauges on the karabiners

The location of the strain gauges were chosen because under major axis loading the greatest loads are experience by the gate and back bar and thus by placing the strain gauges here the full extent of the difference between the two types could be seen [**3&4**].

5.3 Simulation of Karabiners used in Sea Water Conditions

To simulate the misuse of the karabiners which had been exposed to a saline environment a solution was made using salt that is used in tropical fish tanks. The reason for this was that by using the instructions on the packet the solution could be made to the correct strength as to represent the sea. The karabiners were then placed within the solution for a period of two weeks before being removed and then left for a week having been dried but not wash properly. This is against the recommendations of the manufacturers who state that any karabiner which has been exposed to a saline environment should be cleaned thoroughly and then dried naturally [**5**].

6.0 Test Procedure – Tensile testing of karabiners

The method of testing the karabiners is listed below. For the open gate, minor axis, and strain gauge tests it was necessary to make some minor differences in the test methods in order that the experiments were valid. These have been stated where applicable.

1. The karabiners were marked using permanent pen on order to establish which part was which once testing was completed.
2. The crosshead was locked at an appropriate height and the tensile test machine and computer were prepared for the test.
3. For the strain gauge tests the wires from the strain gauges were then attached to a separate computer. **For all other tests this step is negligible**.
4. The slings were doubled up and attached to the test machine and karabiner. **For the minor axis (across gate) tests the karabiners were attached to the test machine using two pins of diameter 11mm resting within the grooves cut into the back bar and gate as specified by the British Standard** [**1**]**.**
5. For the open gate tests the gate of the karabiner was taped to the back bar using masking tape to ensure that it stayed open for the duration of the tests. **For all other tests this step is negligible.**
6. Any slack in the slings was then taken up using the tensile test machine. For the minor axis tests a slight load was placed onto the karabiners to ensure that they did not slip.
7. The karabiners were then wrapped in layered cotton cloth and a piece of polycarbonate screen put in front of the machine. This was to catch any flying debris from the karabiner.

8. The tensile test machine was then started using a crosshead speed of 10mm/min and run until the karabiner failed. **For the minor axis trials the crosshead speed was 3mm/min.**
9. The results were recorded to floppy disc.
10. The fragments were the collected together and placed in sample bags for further analysis.
11. Steps 1-10 were then repeated until all of the karabiners had been tested.

7.0 Major Axis Testing

7.1 Results

The following charts plot the failure loads and strain data obtained from testing the new karabiners and the worn karabiners under major axis loading.

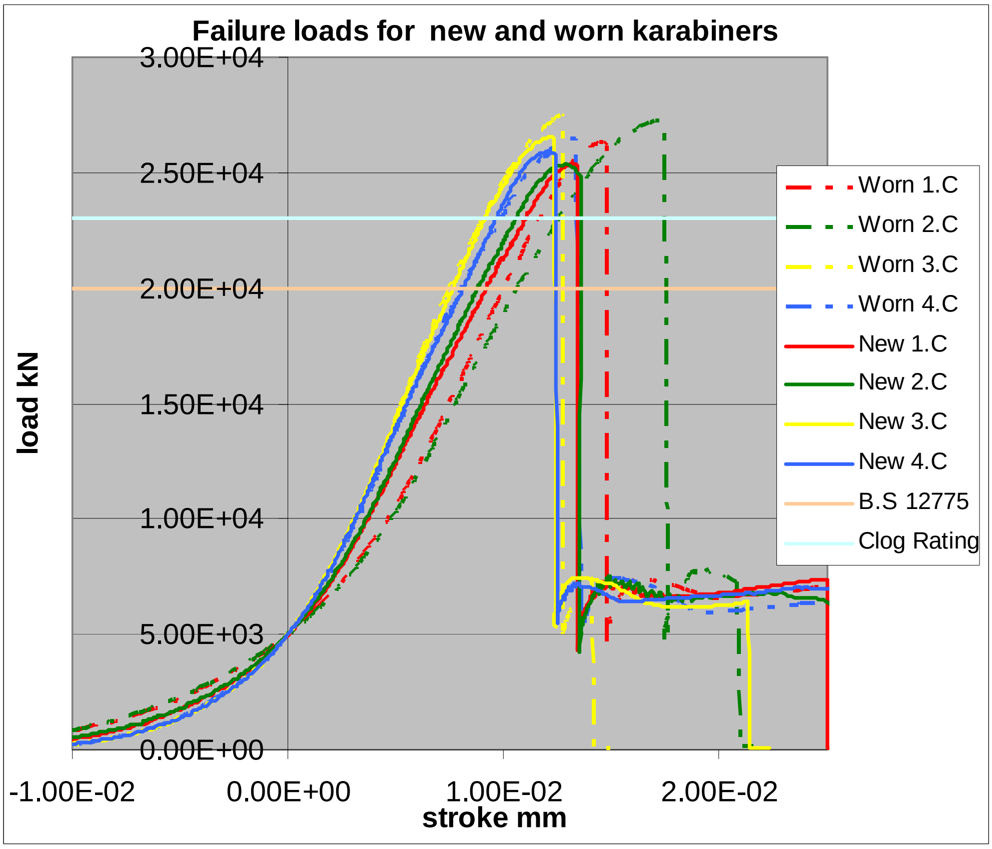

Chart 4: A Graph showing a comparison of the failure loads for the new and worn karabiners under major axis loading

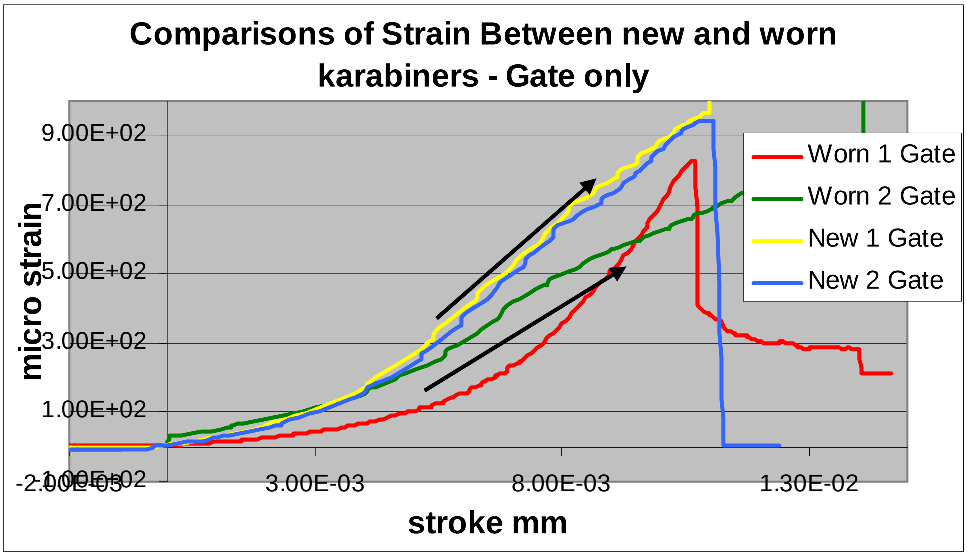

Chart 5: A graph showing comparisons of the strain though the gates of the new and worn karabiners. The two arrows representing the difference in gradient in loading between the new and worn karabiners

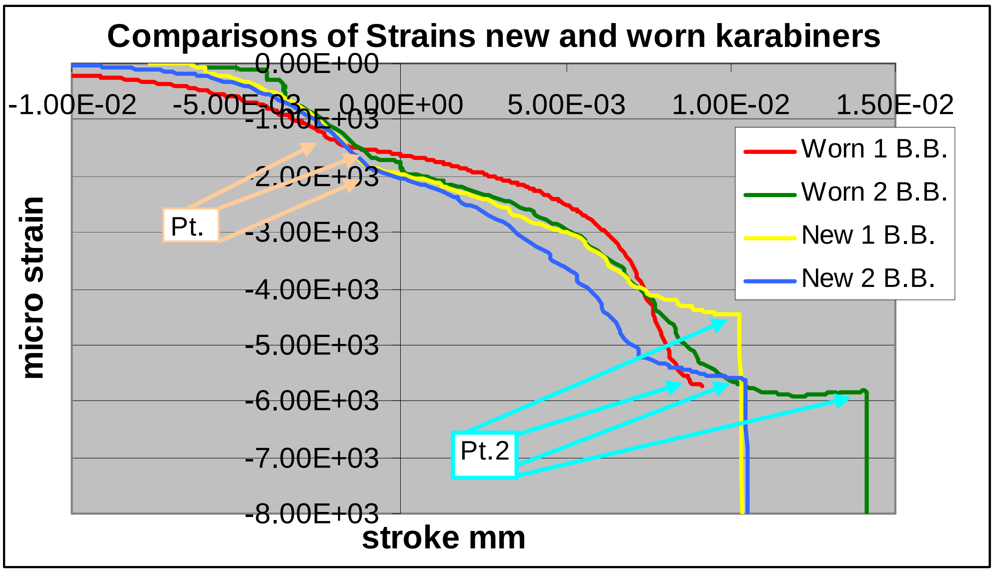

Chart 6: A graph showing the comparisons of the strain through the back bar of the karabiners for new and worn karabiners. Pt.1 shows where the pin first contacts the hinge putting strain onto the gate, Pt.2 shows the karabiner failing and strain being transferred back fully onto the back bar.

7.2 Discussions

The main result that has come from the major axis testing under closed gate conditions is that both sets of karabiners, new and worn, failed having surpassed both the British Standard requirement of 20kN and their manufacturers rating of 23kN. The average failure load for the new karabiners was 25.7kN with a standard deviation of 1.10. The average failure load of the worn karabiners was 26.8kN with a standard deviation of 1.05. These results suggest that the variations between similar types of karabiner are very small with the worn karabiners reaching a slightly high peak load than the new karabiners.

The reasons for these variations in result have most likely been caused by the different modes in which the karabiners have failed. Table 1, below, lists each of the karabiners with their primary and secondary fail positions along with their failure loads.

Karabiner	Primary Fail Position	Secondary Fail Position	Fail load kN
Worn 1	Gate pin tab	Back bar lower corner	26.2
Worn 2	Gate pin tab	Back bar upper corner	27.1
Worn 3	Gate pin tab	Back bar upper corner	27.3
Worn 4	Gate pin tab	Back bar lower corner	26.5
New 1	Hook	Back bar lower corner	25.3
New 2	Hook	Back bar lower corner	25.4
New 3	Gate pin tab	Back bar lower corner	26.5
New 4	Gate pin tab	Back bar lower stretched (no failure)	25.7

Table 1: A table listing the primary and secondary failure modes of each of the major axis karabiners along with their failure loads

By comparing these failure modes to the loads at which the karabiners failed it is possible to postulate how the mode of failure may affect the strength of the karabiner. From table 1 it can be seen that the two karabiners which failed at the lowest loads were New 1 and New 2 and also that these were the only two which primarily failed by the hook. All of the other karabiners went to at least 25.7kN before the primary break occurred along the gate.

A possible reason for the difference in failure mode between the two karabiners which initially failed by their hooks can be seen in chart 5 where a comparison of the strains through the gates has been made using the data from the strain gauges. From chart 5 it can be seen that the rates of loading experienced by the two different karabiner types are different with there being a much sharper increase in strain on the gate of the new karabiners. This faster rate of loading onto the gate causes the pressure on the pins and hooks to increase at a faster rate so that the material around the hook could not adapt and instead fractured and yielded. The other karabiners did not fail in this way because the rate of loading through the gate was slower allowing the hook to adapt better to the loads being applied to it.

It is important to note from charts 5 & 6 is that there is a difference in strains between the two worn karabiners. Unfortunately the test for the worn 1 karabiner was required to be retested using different types of gauges and on a different tensile test machine as the original test did not work correctly. Although the machine was run under the same conditions as the first, with the same stroke speed and method of loading, the fact that a different machine was used meant that not all of the data was available in order to plot the graphs. Compared to the results of the others, worn 1 is a plot of the tensile test machines stroke value versus strain instead of the stroke value recorded by the strain gauges versus strain. This has obviously caused a difference in the graphs appearance however the result was included as there are similarities with the worn 2 data.

8.0 Open Gate Testing

8.1 Results

Below is a chart of the data obtained for the karabiners under open gate loading.

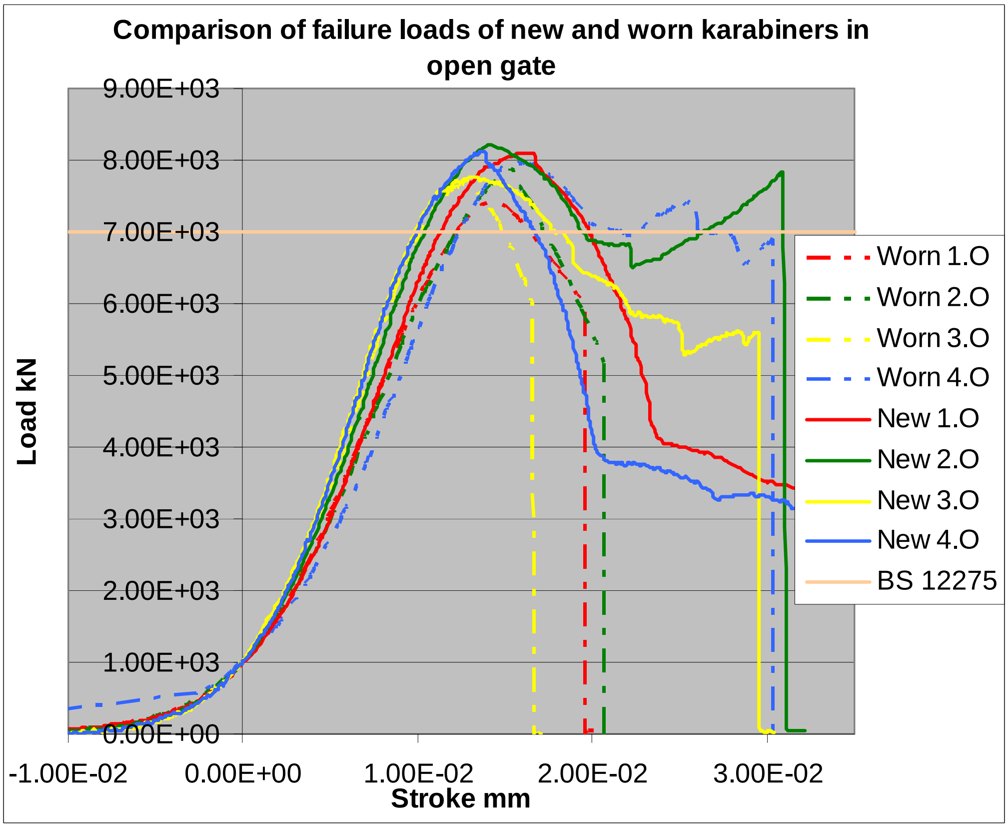

Chart 7: A graph comparing the failure loads of the new and worn karabiners under open gate loading. The horizontal line represents the British Standard requirements. The arrows indicate a difference in stiffing curve between the results.

8.2 Discussions

From the chart 7 it can be seen that both the new and worn karabiners failed having surpassed the open gate specification set by BS 12275. There was however a difference in peak loads between the two variations of karabiner compared with the mean value for the new karabiners being 8.06kN and the mean for the worn karabiners being 7.71kN. From this it can be concluded that there is little difference in peak load between the worn and new karabiners in when loaded under open gate conditions with the difference being only 0.35kN.

The chart, however, indicates a difference in stiffening curves between the two sets of data (indicated by the arrows on chart 7) with three out of the four new karabiners following the steeper gradient and three out of the four worn karabiners following the shallower gradient. The two gradients are approximately 0.59 for the shallower curve and 0.72 for the steeper curve.

This difference in gradient is caused by the reduction in cross sectional area of the filed karabiners and, although not particularly influential in terms of peak load, it does play a significant part in the elastic and plastic behaviour of the karabiners. Under initial loading the displacement-load curves for all of the karabiners are very similar. However at approximately 1250kN the new karabiners begin to stiffen faster than the worn ones. This difference in stiffening causes the new karabiners to reach their elastic limit slightly faster than the worn karabiners however it also occurs at a slightly higher load.

It is once the karabiners have reached their elastic limit where the significant differences between the two types of karabiner can be seen. Whilst the worn karabiners are in their plastic region they deform rapidly and final failure (actual breaking of the karabiner) occurs after only a little deformation. The new karabiners however, act significantly different once they enter their plastic region with a much larger deformation to failure. The mean value of deformation of the worn karabiners during yielding is 0.0094 mm whilst for the new karabiners this grows to 0.0257 mm.

This difference in deformation can also be seen by piecing back together the karabiners which have been failed whilst loaded under open gate conditions. Having pieced the karabiners back together an approximate measurement of the distance between the two ends of the main body which create the gate opening was then taken and compared to the original size. The mean distances for the worn karabiners was 62 mm and for the new karabiners the mean value was 81 mm which when compared to the karabiners when new (30 mm) shows that the worn karabiners extended to twice their original size and the new karabiners to almost a three times their original size.

9.0 Minor Axis Testing

9.1 Results

Below is a chart showing a comparison of the failure loads for new and worn karabiners under minor axis (across gate) loading.

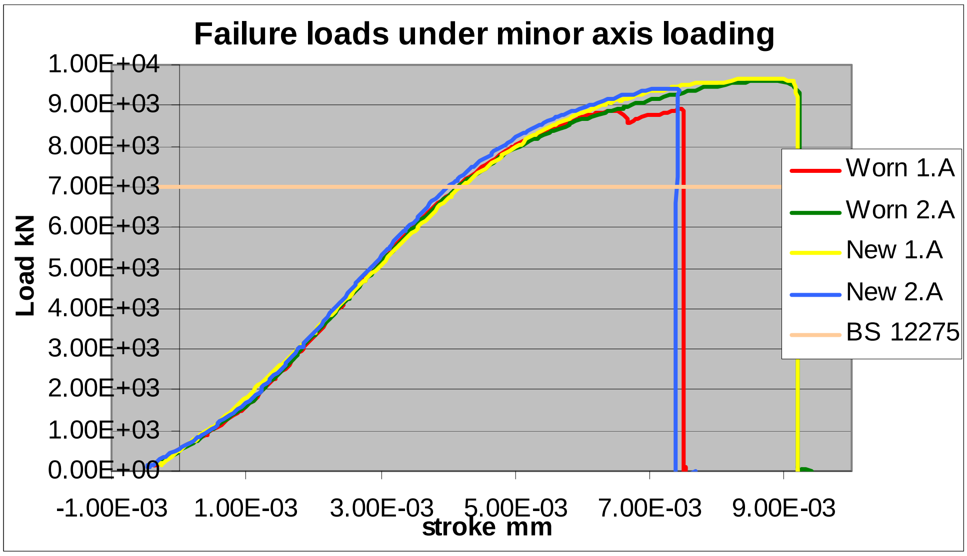

Chart 8: A graph showing a comparison of the failure loads of the new and worn karabiners under minor axis (across gate) loading. The horizontal line represents the British Standard pass requirements.

9.2 Discussions

From the results for the minor axis testing it can be seen that there is very little difference in failure load between the two types of karabiner when loaded under minor axis loading with both surpassing the specification set by the British Standard. On chart 8 a difference in displacement to failure can be seen for both one of worn and new karabiners alike. On comparison of the test specimens after the test the reason for this is quite clear as both Worn 2 and New 1 show signs of bending about the back bar where as Worn 1 and New 2 do not. The most likely cause of this additional bending was slight differences in the depth and placement of the grooves filed onto the back bar to ensure that the karabiner did not slip round during testing.

10.0 Sea Water Karabiners

10.1 Visual Defects having completed Sea Water Simulation

The following table lists the mechanical and visual defects of the karabiners a week after they had been removed from the salt water solution. The photograph below the table shows an example of the corrosion and salt deposits around the base of the gate on S.W.2.

Karabiner	Salt Deposits on Main body?	Salt Deposits around gate pins?	Corrosion to Gate spring mechanism?	Gate Action on Opening
S.W.1	Back bar only	All	Yes	Stiff at first
S.W.2	All of main body	All	Yes	Smooth
S.W.3	All of main body	1 out of 4	Yes	Stiff at first
S.W.4	All of main body	3 out of 4	Yes	Stiff at first

Table 2: A table showing the visual and mechanical defects of the karabiners a week after they had been removed from the saline environment.

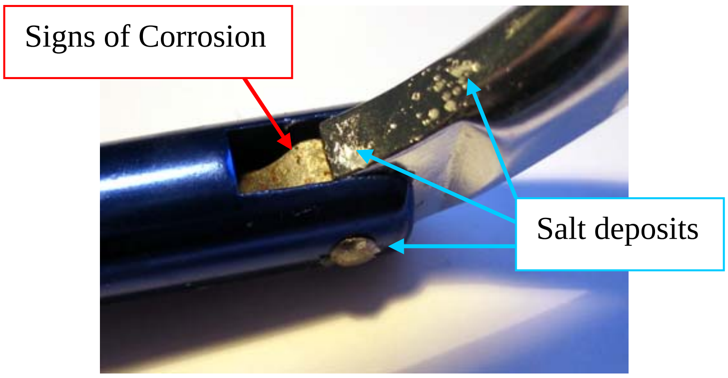

Figure 9: Photograph of S.W.2 showing signs of corrosion and salt deposits 22.02.2007

10.2 Results of break test trials

The graph below shows the results for the tensile break tests for the sea water karabiners compared with the new karabiners.

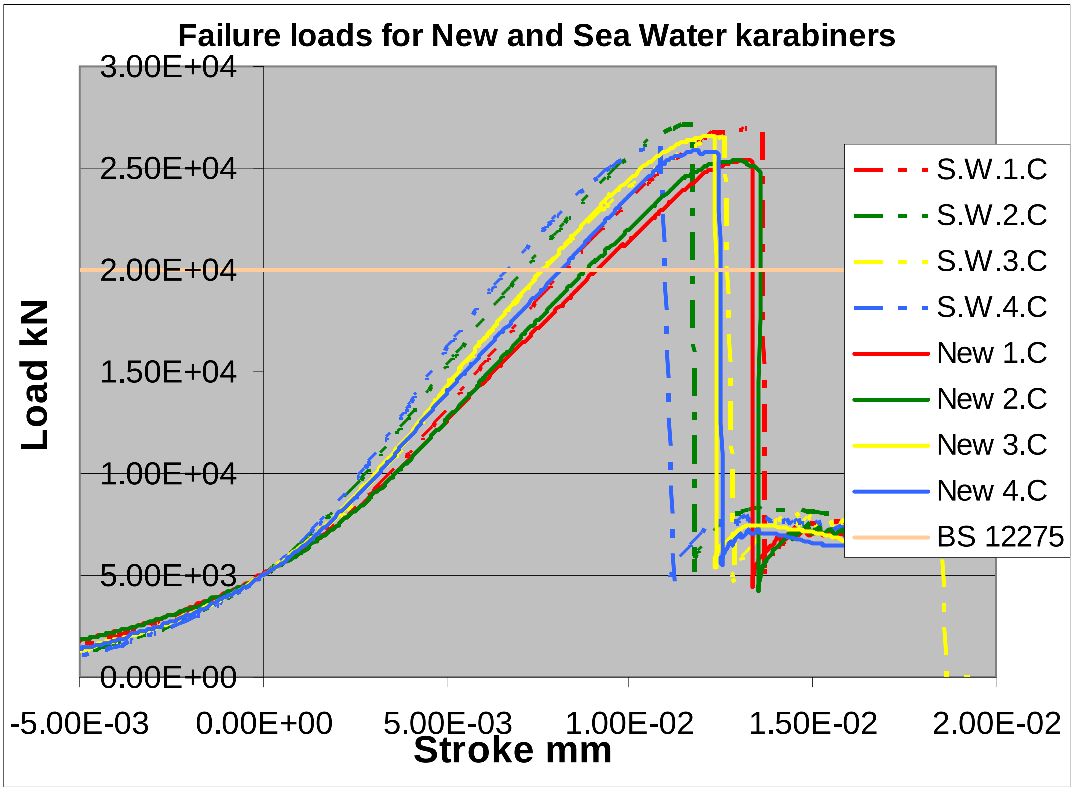

Chart 10: A Comparison of the failure loads of the sea water karabiners to new karabiners

10.3 Discussions

All of the karabiners failed having surpassed the specification set by BS/EN 12275.

After exposure to the saline environment and following a period of non-exposure, as described in section 5.3, simulation of karabiners used in sea water environment, there were recorded a number of visual and mechanic defects. The most common defect was a series of salt deposits along the main body of the karabiners however although visually different the deposits could be removed easily and showed no signs of effecting the mechanical properties of the karabiners.

The second visual fault which was evident was signs of corrosion on the main body at the base of the gate where there is a section of material which is used to ensure that the gates spring remains in place. This corrosion can be seen in figure 9 in section 10.1 and can also be seen below in figure 11 where it has been removed from a broken sea water karabiner and is compared to the same part from a new karabiner.

Figure 11: Comparison of spring retaining clips from sea water karabiner (left) and from new karabiner (right)

The final defect which was noted after the karabiner had been exposed to the salt water solution was the stiffness of some of the gates on initial opening. The reason for this stiffness was most likely caused by rusting both to the clip and to the spring itself.

11.0 Conclusions

From the tests that have been completed there are a number of conclusions which can be made. The most important of these has been that under the tensile test trials along the major axis, minor axis, and in the open gate conditions that all of the karabiners, when new, passed the requirements set by the British Standard 12275. This has shown that even though the karabiners weren't very expensive to purchase, when compared to other types available, they are still made to the standards set.

A further conclusion that can be made about the karabiners is that they can experience a significantly large amount of wear without loss of strength under any of the types of loading that they might experience. The wear used in these tests was a simulation of a very large amount of wear caused by regular use of nuts and various other pieces of climbing equipments in the upper inside corner of the karabiners. This wear was most likely to be rather more significant than what would be seen before a karabiner would be replaced. The test represented an extreme case and found little difference in strength so it can be said that under smaller amounts of wear the karabiners would still be safe to use.

The largest variation that was found was under open gate loading, caused by the fact that the gate cannot contribute to the stress distribution, though even this was relatively small in terms of peak loading. The main variation that could be seen in the open gate testing was when the karabiners began to yield with the worn karabiners totally failing after a much smaller deformation than the newer ones.

The sea water testing was used to simulate the use of karabiners within a saline environment before they were then incorrectly cleaned. The testing has shown that there is a need to properly maintain karabiners after they have been exposed to a saline environment **[6]**. This is because although there were no effects to the material properties of main body, gate or gate pins of the karabiners after exposure there were some effects to the gate closing mechanisms. These karabiners, although having been exposed to the saline environment, have not actually been used for climbing where there would be repetitive use of the gate whilst clipping and unclipping. This repetitive use along with the corrosion might have caused the gate spring mechanism to fail allowing the gate to remain open during use dramatically reducing the karabiners strength or even causing the rope or climbing equipment to fall out.

12.0 Future Research

From the conclusions drawn from the testing completed in this project there are still a number of areas which could be researched further to provide more detailed insight into how karabiners fail and the effects of everyday use on their material properties.

A list of possible future tests is below;

- Further testing of karabiners under minor axis loading to establish to a greater extent the failure modes.
- Further trials comparing the loading of new and worn karabiners under major axis loading in both the closed and open gate conditions with the use of strain gauges in order that the distribution of the loads with the karabiner can be confirmed.
- Further testing of karabiners which have been exposed to a saline environment including simulation of use after exposure in order to see if this affects the working of the gate mechanism.
- Simulation of a karabiner which has experienced a saline environment and then cleaned to the manufacturers recommendations to establish if these are adequate.
- Dynamic testing of a karabiner which has experienced a number of heavy loadings similar to that which might be seen in a fall to establish if this effects the strength of karabiner.

Acknowledgements

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What Determines the Strength of Climbing Karabiners?

Steven McGuinnity, Supervisor: Dr Andrew Mclaren

Final Year BEng Honours Technical Paper 2004

Information on previous studies completed on climbing karabiners.