# The Effect of Heat Glazing on the Strength and Extensibility Properties of Polyamide Climbing Ropes

**A. J. McCartney, D. Brook, M. Taylor**

## Introduction

Polyamide kernmantle ropes are universally used for mountaineering, climbing and on indoor walls because of their excellent strength and extensibility. Rapid abseiling, hauling or lowering off however can cause glazing damage to the sheath of these ropes. This study has been designed to ascertain the effect of glazing damage on the properties of the load bearing central core strands of two types of climbing rope, one with a thick sheath and one with a normal sheath.

To create glazing some of the sheath yarns must be melted by being subjected to a temperature of 250°C or more. This is achieved in use by heat generation due to friction which cannot be dissipated quickly enough by transfer to the environment or the rope. Until dissipation equals heat generation the temperature of the friction device will continue to rise.

# Experimental Methodology

## *General Procedure*

1. The strength and extensibility of three strands from the core of an unglazed section of the rope were tested. These were used to calculate an average strength for a single strand and were used as a control to compare the strands from the glazed ropes against. The reason that the strands were tested was because this would allow analysis of how different parts of the core are effected by the glazing that generally only occurs on one side of the rope. The load at break had to be determined using the strands because it was not possible to test the whole rope due to the fact that the Instron tensile testing machine was not strong enough to break the whole rope. See Section 3.2 for the whole method.
2. With another piece of unglazed rope the extension for the complete rope at a given load was determined. This was done so that it would be possible to see if any changes in the properties of the core strands appeared in the properties of the whole rope. See Section 3.3 for the whole method.
3. The rope was glazed to the desired degree. See Section 3.4 for the method of glazing.
   i) Select strand closest to the glazed section of the sheath and test its strength and extensibility as stated in Section 3.2, this one will be called the "adjacent strand".
   ii) Repeat with strand on opposite side of the core to the glazing and test its strength and extensibility as stated in Section 3.2, this one will be known as the "opposite strand".
   iii) Take a section of the whole rope and test for the extension at a given load as described in section 3.3.

## *Test for Strength and Extensibility of Core Strands*

1. An Instron tensile testing machine was set with a gauge length of 100 mm and the crossheads were set to move apart at 100 mm/sec.
2. A 30 cm length of core strand was taken from the of rope.
3. An overhand knot was tied in the centre of the strand to ensure that it would not fail due to a jaw break as was happening in the preliminary trials. The overhand knot

weakens the rope by roughly 50% [4]. The exact decrease in the strength does not really matter because the situation is identical in all the trials so the size of the decrease will be the same in each case.

4. An overhand knot was tied in either end of the strand and clamped in the jaws with the knots above and below the jaws. The knots were there to stop the strand from slipping through the jaws as this was found to be a problem in preliminary trials.
5. The load-extension curve and the maximum load (in kN) and extension (expressed as a percentage of the samples gauge length) at break were then recorded.

## *Extension of Whole Rope at Known Load*

A 20 cm section of the rope was taken and put in the Instron tensile testing machine. It was the extended until the load applied was 2 KN. The extension of the rope was then calculated as a percentage of the gauge length of the sample. To ensure that the rope did not slip through the jaws of the machine the ends of the sample was soaked in Araldite and allowed to dry. This caused the end of the rope to become solid so that it could not slip through the jaws.

## *Glazing of the Ropes*

### Initial Methodology

The first method that was used to try and glaze the ropes was to heat a figure of eight descender in an oven until it was at the required temperature. The reason that the oven was used was because this would ensure that the descender's temperature was as even as possible. The descender was then removed and clamped to a stand. The rope was then threaded through the figure of eight in the correct manner and pulled through at a steady rate. A figure of eight descender was used to glaze the rope because this is one of the pieces of equipment that is prone to causing glazing and it is therefore more realistic than using something like a heated metal rod and running it along the surface of the rope.

It was found, however, that heating the descender in the oven was too slow and that it was difficult to get the temperature high enough to glaze the rope. Originally it was thought that heating the descender to 200°C would be sufficient to glaze the rope with the friction, caused when the rope is pulled through the figure of eight, producing the extra heat needed to take the temperature above the melting point of 225°C of the nylon. This did not happen and so it was necessary to increase the temperature of the descender. Instead of using the oven to heat the figure of eight a Bunsen burner was used. This allowed the temperature to be changed and increased much more quickly. This method however does make it much harder to get the whole descender to an even temperature. The temperature of the figure of eight was measured using a Comark thermometer and the temperature was kept the same for the two different ropes. In all, the ropes were glazed at four different temperatures, as shown in Table 1 below, and this produced four different degrees of glazing.

| Temperature of Descender (°C) | Degree of Glazing | Description of Glazing |
|---|---|---|
| 230 | Light | Glazing only just visible |
| 260 | Mild | Pattern of weave still visible but sheath strands starting to stick together |
| 300 | Heavy | Separate sheath strands hard to identify |
| 340 | Severe | Core visible through parts of sheath |

**Table 1: The various degrees of glazing and the temperatures at which they occurred**

### 3.4.2 Final Methodology

This is the final methodology that was used to glaze the ropes.

1. The figure of eight was heated to the required temperature (see Table 1) using a Bunsen burner.
2. A 1m length of rope was then threaded on to the descender in the proper way and then pulled through at a steady rate. This rate was kept the same for all the different temperatures.

### Ropes Tested

Two ropes were tested during this experiment

1. Beal Wall Master II.
   a) Diameter - 10.5 mm

b) Number of strands in core - 7

c) Number of bobbins used for the sheath - 32

d) Made from Nylon 6

e) Designed for use in climbing walls and therefore needs extra protection from extensive use provided by the thicker sheath. The thinner core means that it has less strength and lower energy absorption properties.

2. Beal Apollo

   a) Diameter - 11 mm

   b) Number of strands in core - 13

   c) Number of bobbins used for the sheath - 48

   d) Made from Nylon 6

   e) Designed for normal climbing and therefore needs the thicker core with its higher strength and energy absorption properties.

## Results

Tables 2 and 3 show the results from the three control strands that were taken from both ropes. These results were then averaged and the mean was used to represent the properties of the unglazed strands which were compared with the core strands from the glazed ropes.

Table 2 shows that the variation in the results of the tensile strength of the Wall Master II strands was about 0.05 kN and for the Apollo it was about 0.03 kN. This table also shows that there is very little difference between the strength of the core strands of either of the two different ropes.

| Strand | Wall Master II | Apollo |
|---|---|---|
| 1 | 0.8191 | 0.8158 |
| 2 | 0.8279 | 0.7863 |
| 3 | 0.7764 | 0.8148 |
| **Mean** | **0.8078** | **0.8056** |

**Table 2: Ultimate tensile strength of the core strands from the unglazed ropes**

Table 3 shows that the variation in the results of the percentage extension of the Wall Master II strands was about 8% and for the Apollo it was about 10%. As with the strength

| Strand | Wall Master II | Apollo |
|---|---|---|
| 1 | 97.81 | 97.58 |
| 2 | 105.70 | 105.40 |
| 3 | 100.30 | 94.55 |
| **Mean** | **101.27** | **99.18** |

**Table 3: Percentage extension of the core strands from the unglazed ropes**

of the core strands there appears to be very little difference in the extensibility of the strands of the two ropes. This similarity in the two ropes would indicate that the cores are made up from similar strands, the only difference being in the final construction of the rope where the Apollo has thirteen strands to the Wall Master's seven.

## *Effect of Glazing on the Rope Core*

### Wall Master II - Ultimate tensile strength

Figure 1 shows that there is very little difference in the ultimate tensile strength of the core strands at any of the levels of glazing or whether the strand came from next to the glazed part of the sheath (adjacent) or not. The changes that can be seen in Figure 1 are no greater than the deviation shown in the three strands that were used to calculate the average strength of the unglazed core strands (see Table 2). A paired t-test showed that these differences between the glazed strands and the unglazed strands were not significant (P=0.05).

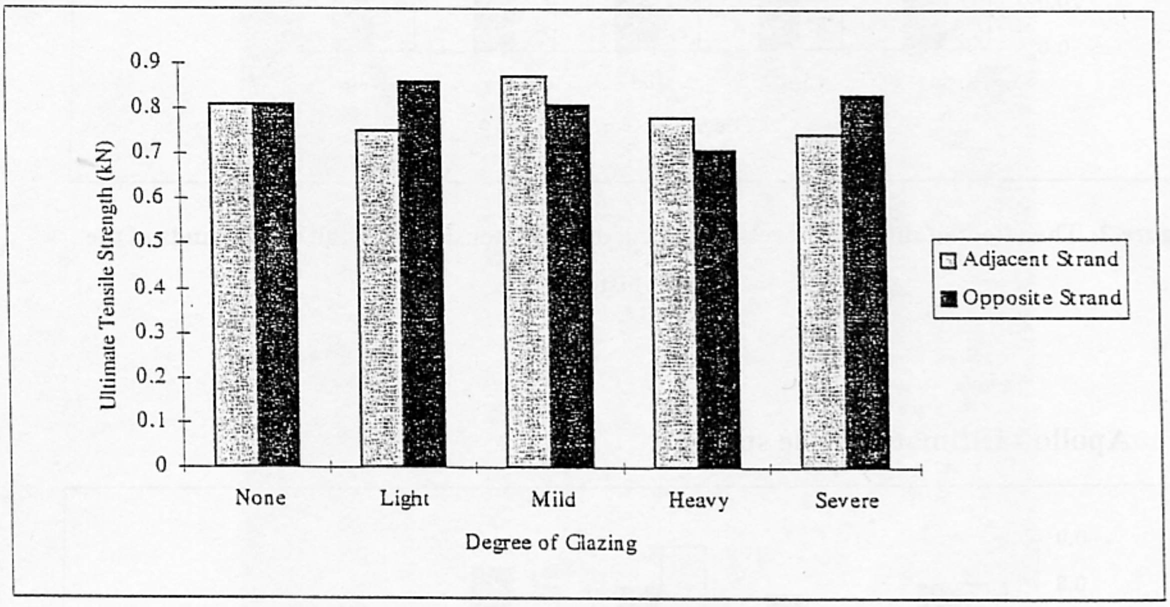


**Figure 1: The effect of different levels of glazing on the strength of the core strands of the Wall Master II**

### Wall Master II -Extensibility

Figure 2 shows that glazing the sheath of the rope increases the extensibility of the adjacent core strands by about 40% except in the extreme glazing case were the extension is increased by 62%. The glazing in the opposite strands of the first three levels of glazing is about 10-20% worse than the control strands. In the severe glazing case the extension in the opposite strand is in fact greater than the adjacent strand with 70% extension. This result should possibly be disregarded due to the fact that it is so different from the apparent pattern that the other strand show. These differences from the control results are all greater than the spread of the results shown in Table 3. A paired t-test showed that these differences between the glazed strands and the unglazed strands were significant (P=0.05). The increase in extensibility of the strands does not change with an increase in the degree of glazing until the severe level is reached.

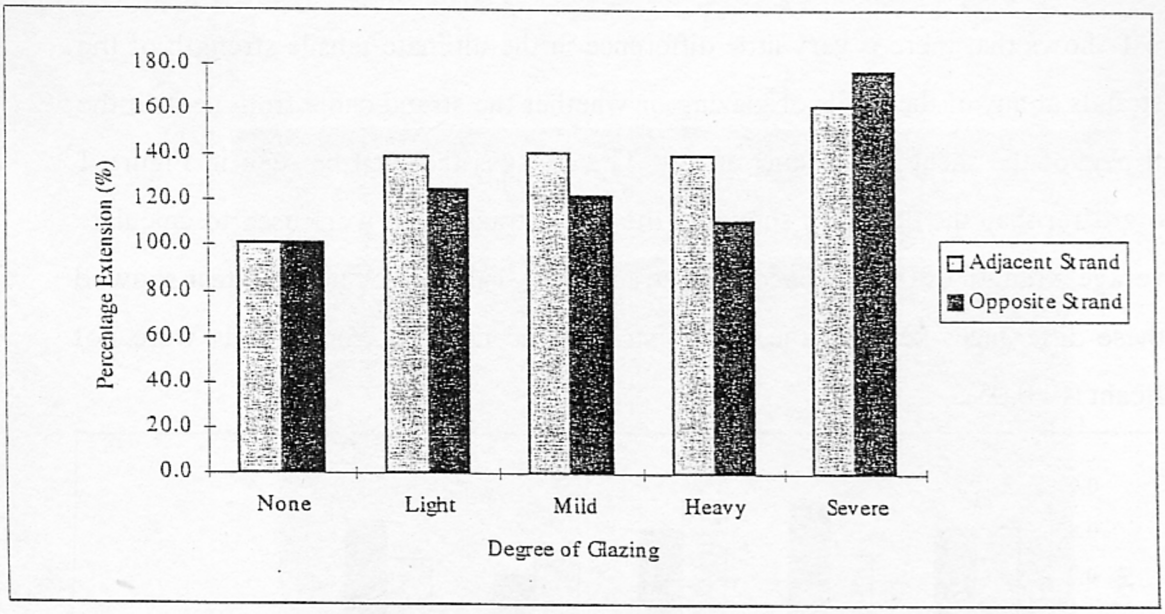


**Figure 2: The effect of different levels of glazing on the extensibility of the core strands of the Wall Master II**

## Apollo - Ultimate tensile strength

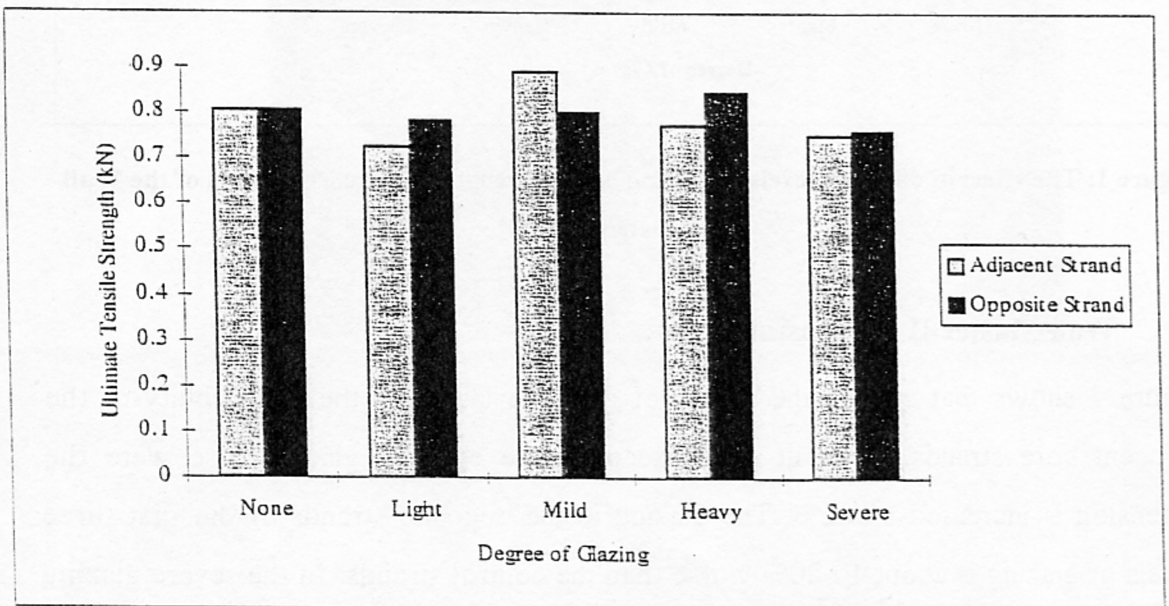


**Figure 3: The effect of different levels of glazing on the strength of the core strands of the Apollo**

As was shown with core strands from the Wall Master II the strength of the core strands of the Apollo are unaffected by glazing of any degree as can be seen in

Figure 3. None of the results for either the adjacent or the opposite strands show any difference from the variation shown in the unglazed strands shown in Table 2. A paired t-test showed that these differences between the glazed strands and the unglazed strands were not significant (P=0.05).

### Apollo - Extensibility

Figure 4 below shows that the glazed ropes of all degrees had an increase in

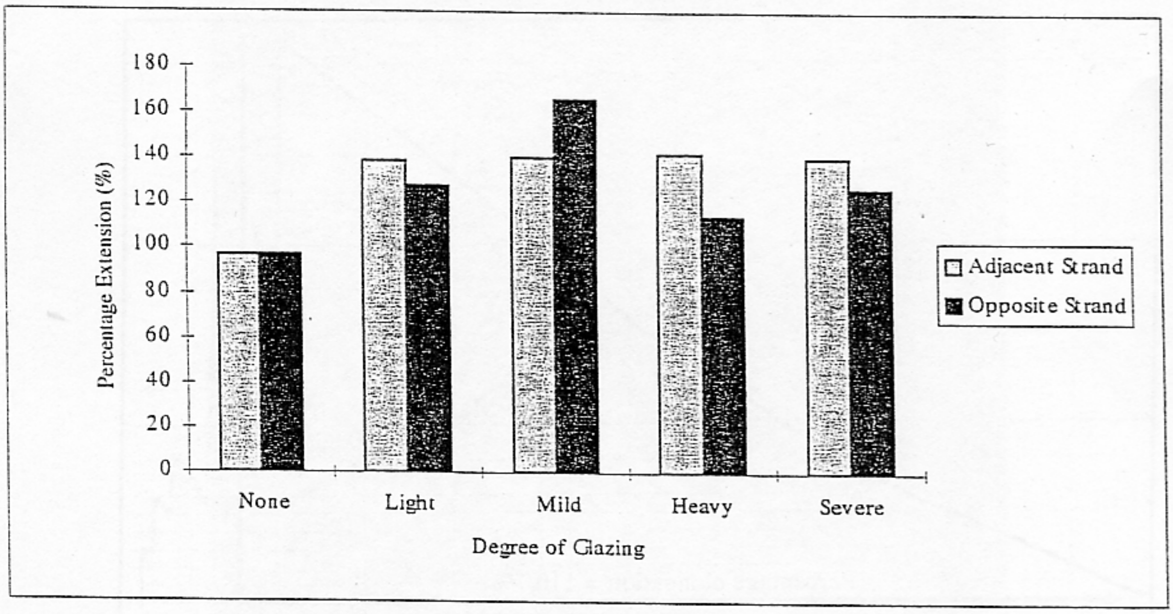


**Figure 4: The effect of different levels of glazing on the extensibility of the core strands of the Apollo**

extensibility of the core strands when compared with the control samples (20-60%). All the glazed strands had a significantly (P=0.05) larger extension than the control whether they were adjacent or opposite to the side of the rope that was glazed. The adjacent strands did show a greater increase in the extensibility than those on the opposite side at all degrees of glazing except for the heavy degree. In this case the opposite strand had the greater extension. This result, however should possibly be rejected due to the fact that it is so far out from the pattern that is shown by the other samples. The increase in extensibility of the strands does not change with an increase in the degree of glazing.

## *Load-extension Curves for the core Strands*

### No Glazing

Figures 5 and 6 below show that the load extension curve for the core strands from the unglazed rope is almost totally linear. The slight glitch half way up the curve is probably due to one of the overhand knots slipping or tightening suddenly. The consistency of the slope shows that the core strand is following a pattern a normal elastic deformation up until the point at which it breaks. The reason that no plastic

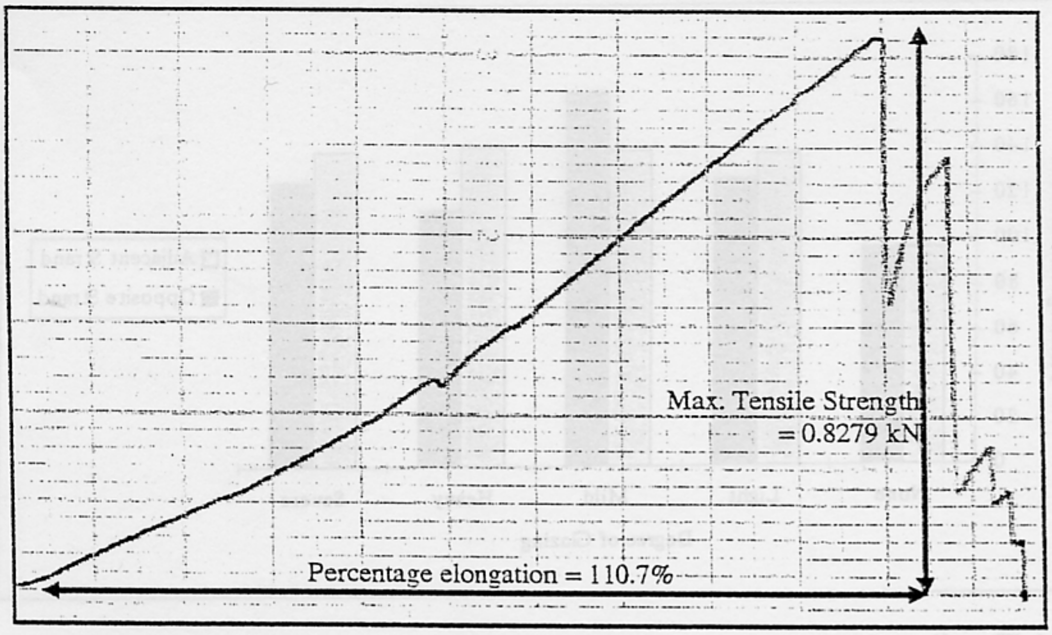


**Figure 5: Example load-extension curve from the unglazed Wall Master II core strands**

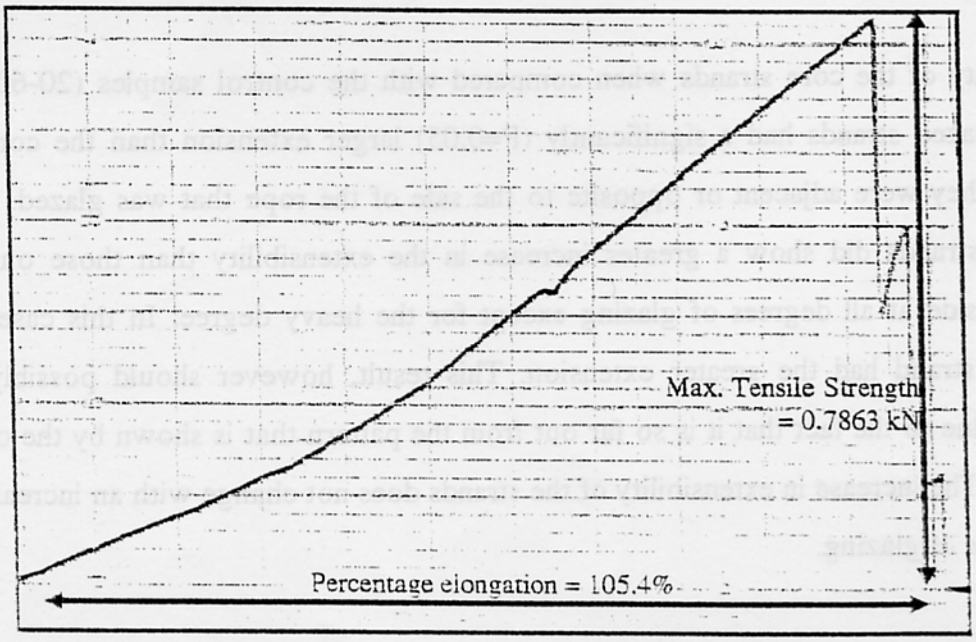


**Figure 6: Example load-extension curve from the unglazed Apollo core strands**

deformation is seen is due to the fact that the overhand knot in the centre of the strand is causing the strand to break before plastic deformation can occur. A comparison of Figures 5 and 6 show that the shape of the curve is almost identical in the strands from the two different ropes.

## Glazing

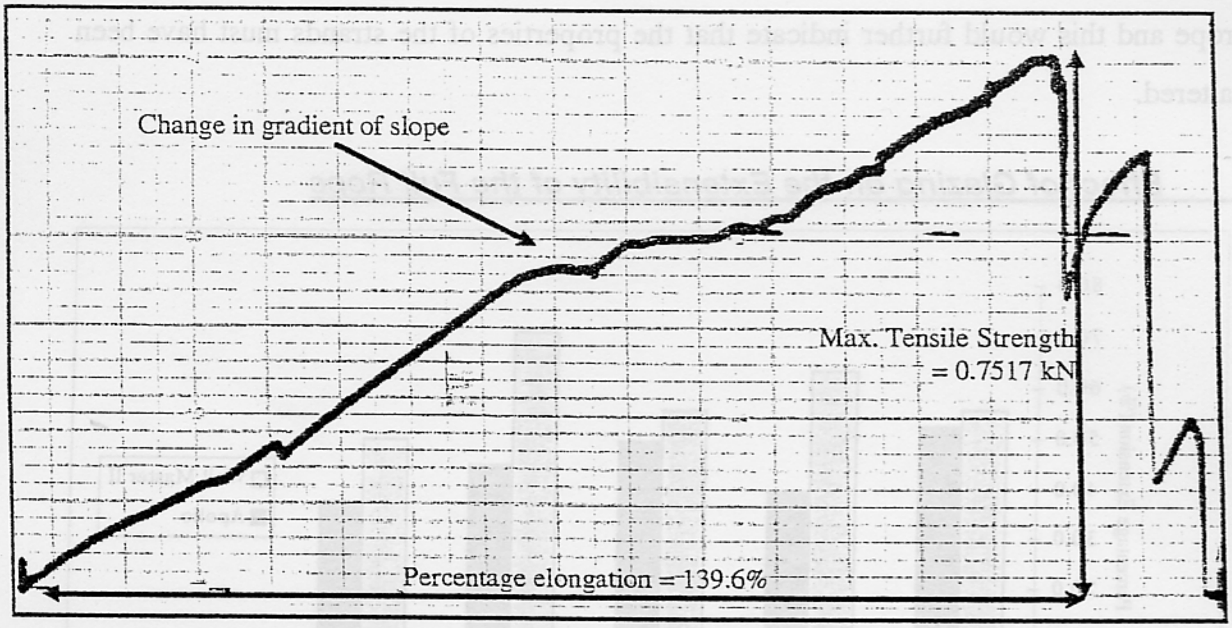


**Figure 7: Load-extension curve of the lightly glazed adjacent core strand from the Wall Master II**

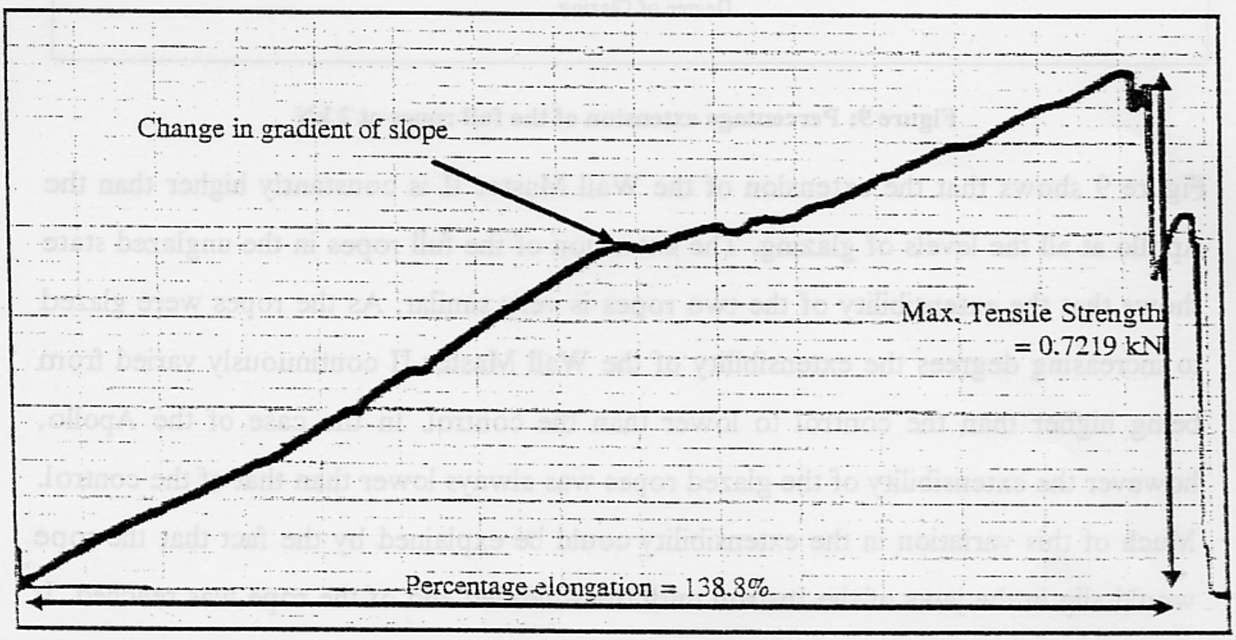


**Figure 8: Load-extension curve of the lightly glazed adjacent core strand from the Apollo**

Figures 7 and 8 show typical examples of the effect that glazing has on the load-extension curve of the core strands. All of the strands from the glazed ropes showed a similar pattern. The important feature to note is the decrease in the gradient of the graph. Up until this point the curve had been following exactly the same pattern of elastic deformation that is seen in the strands from the unglazed rope. After this point the change in gradient would indicate that something different is happening within the rope and this would further indicate that the properties of the strands must have been altered.

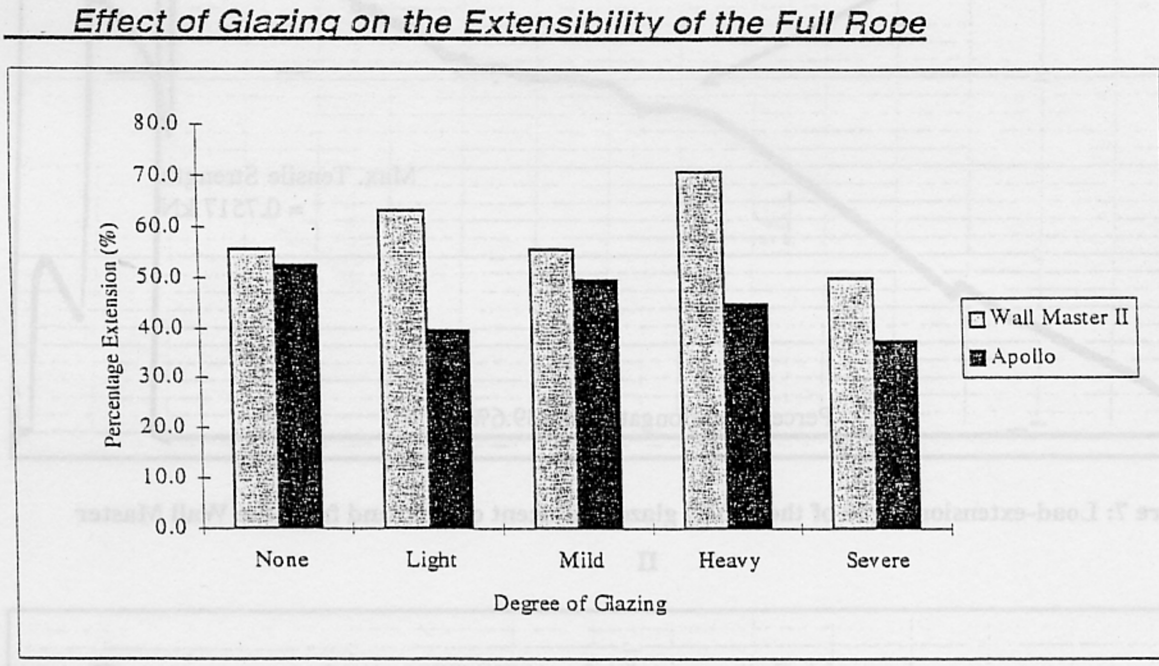


**Figure 9: Percentage extension of the full ropes at 2 kN**

Figure 9 shows that the extension of the Wall Master II is constantly higher than the Apollo at all the levels of glazing. The extension of the full ropes in the unglazed state shows that the extensibility of the two ropes is very similar. As the ropes were glazed to increasing degrees the extensibility of the Wall Master II continuously varied from being higher than the control to lower than the control. In the case of the Apollo, however the extensibility of the glazed ropes was always lower than that of the control. Much of this variation in the extensibility could be explained by the fact that the rope would slip in the jaws of the Instron until the solidified end of the rope was reached. It was extremely hard to place the samples in the jaws exactly at the point where the Araldite ended because this varied from sample to sample.

## *Differences between the Wall Master II and Apollo*

Figure 10 shows that there is no difference in the ultimate tensile strength of the adjacent core strands of the two different ropes at any level of glazing.

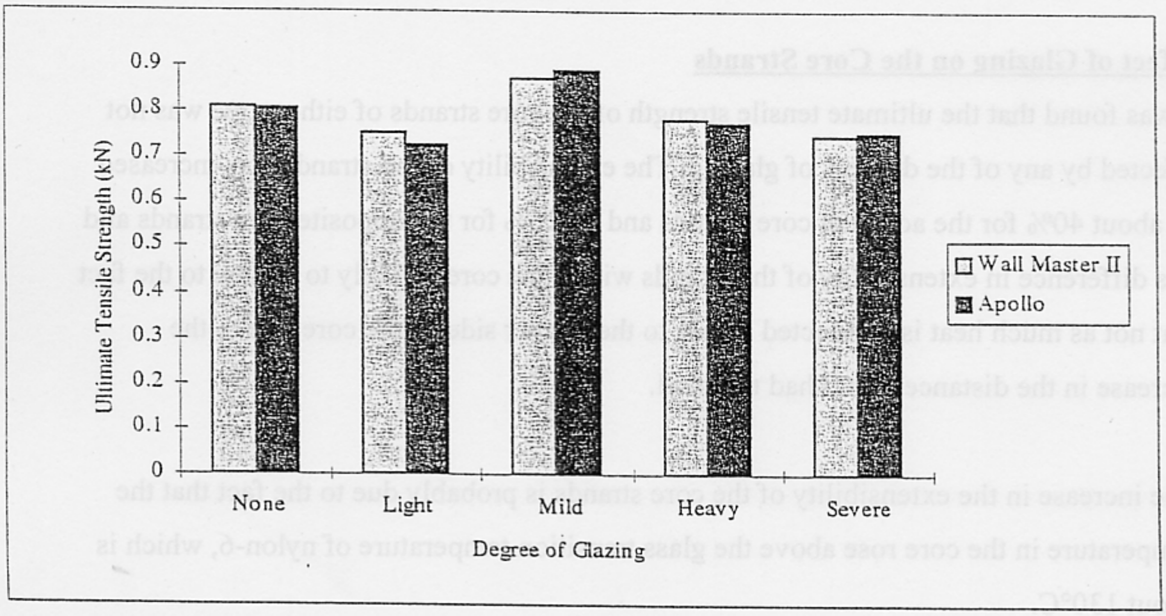


**Figure 10: Comparison of the ultimate tensile strength of the adjacent core strands in each rope**

Figure 11 shows that the percentage elongation was the same for the adjacent core strands in both the ropes at every degree of glazing.

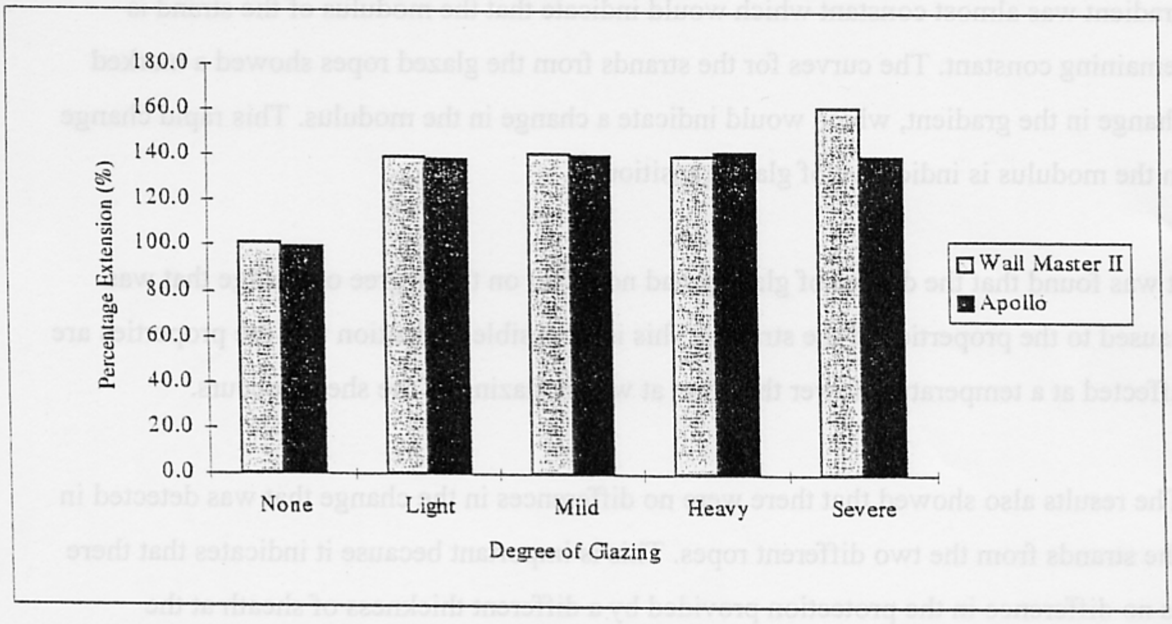


**Figure 11: Comparison of the percentage extension of the adjacent core strands in each rope**

## Discussion

### Effect of Glazing on the Core Strands

It was found that the ultimate tensile strength of the core strands of either rope was not affected by any of the degrees of glazing. The extensibility of the strands was increased by about 40% for the adjacent core strands and by 20% for the opposite core strands and this difference in extensibility of the strands within the core is likely to be due to the fact that not as much heat is conducted across to the further side of the core due to the increase in the distance that it had to travel.

The increase in the extensibility of the core strands is probably due to the fact that the temperature in the core rose above the glass transition temperature of nylon-6, which is about 130°C.

Further evidence that the increase in extensibility is due to the temperature in the core rising above the glass transition temperature comes from the load-extension curves that were recorded when the strands were tested. On the curve for the unglazed strands the gradient was almost constant which would indicate that the modulus of the strand is remaining constant. The curves for the strands from the glazed ropes showed a marked change in the gradient, which would indicate a change in the modulus. This rapid change in the modulus is indicative of glass transition [3].

It was found that the degree of glazing had no effect on the degree of change that was caused to the properties of the strands. This is a possible indication that the properties are affected at a temperature lower than that at which glazing of the sheath occurs.

The results also showed that there were no differences in the change that was detected in the strands from the two different ropes. This is important because it indicates that there is no difference in the protection provided by a different thickness of sheath at the temperatures which can cause glazing.

## Effect of Glazing on the Full Rope

At medium loads (up to 5kN) no great increase in extension in either rope has been detected, but the differential change in extension across the core strands could lead to breakage by tearing at higher loads. The increased overall extension however, may decrease peak loads at high impact forces but this is only speculation. Manufacturers engineer the ropes with closely defined properties to protect climbers and any changes caused by heat damage should obviously be avoided.

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