SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

Final Report

An investigation into the effects of steel wire rope specimen length on breaking force

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Executive summary.

South Africa has a well-entrenched statutory method of evaluation steel wire hoist ropes used for the conveyance of men, material and rock within mines. The system used is characterized by six-monthly destructive tensile testing of samples cut from the conveyance end of the rope and by complimentary in-situ non-destructive testing. This system is internationally recognized and has been adopted by other nations as their preferred method.

However, in defining the discard criteria for the ropes (the no-go condition), work was traditionally focussed on examining and testing specimens of a gauge length that was predetermined by the diameter of the rope under consideration. This led other researchers to postulate that if different lengths of specimen were evaluated, different discard criteria would have been formulated (van Zyl, 2000).

This report covers work conducted to evaluate the effects of specimen length on the breaking force, in an attempt to validate or refine the discard criteria of SABS 0293: 1996. Inter alia, this included an examination of the postulation of van Zyl (2000). The methodology employed was to test different length of triangular strand and non-spin rope to destruction, and to evaluate these results against SABS 0293:1996. For each rope construction, specimens were prepared both with and without cut wires, giving a total of some 26 triangular strand and five non-spin samples. Unfortunately, anomalous behaviour of the non-spin rope led to the discontinuation of these tests in favour of a greater number of triangular strand rope specimens.

In summary of the conclusions reached in this report, it was found that:

- The gauge length of test specimens has a definite influence on the strength of 50 mm nominal diameter triangular strand steel wire rope. This influence:
  - Affects both uncut (intact) rope samples and cut wire samples; and
  - Acts in the favour of the user who adheres to the discard criteria of SABS 0293: 1996, indicating a greater margin of safety; and
  - Validates the findings of van Zyl (2000), i.e. if different lengths of sample had been studied during the formulation of SABS 0293:1996, different discard criteria would have been arrived at;
- Test specimens that fail at the end cap (rope termination), display behaviour similar to those of a rope with five cut outer wires. Samples failing in this manner should be retested in the case of statutory rope tests.

From these findings, the principal recommendations are that firstly, a test protocol be drawn up by Standards South Africa to standardize test methods and laboratories with respect to quality assurance. Secondly, since the work covered by this report examines only one diameter of rope, that the test regime be extended to cover other diameters and constructions of steel wire rope.

Finally, whilst no price can be levied on the value of human life, the apparently greater-than-anticipated safety margin with the increase in specimen length may be used as a motivation by South African mines to alter the discard criteria to allow for a longer installed time. A study on the cost implications of such a change is recommended to evaluate any financial benefits and increased safety risk.

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Glossary of abbreviations, symbols and terms

Abbreviations and Symbols

Breaking force	BF
Department of Minerals and Energy:	DME
Length:	L
Metre:	m
Millimetre:	mm
Newton:	N
Pascal:	Pa
Safety in Mines Research Advisory Committee:	SIMRAC

Terms

Gauge length:	The length of a rope specimen measured between the inner faces of the end caps.
Nominal diameter:	The diameter of the rope as specified by the manufacturer, for catalogue purposes. This value may differ from the actual or measured diameter.
Non-spin rope:	A steel wire rope that has inner and outer strands twisted (lay) in opposing directions, so as to minimize torque differentials when under load.
Rope:	Stranded steel wire rope.
Rope diameter:	The same as nominal diameter.
Specimen length:	The same as gauge length.
Triangular strand:	An individual strand of a steel wire rope that has been specially formed to take on a triangular cross sectional shape.

1. Introduction

The failure of a hoist rope at Robinson Deep gold mine in 1904 resulted in the deaths of 44 miners (Transvaal Chamber of Mines, 1905), and prompted the then regulatory authorities to introduce statutory testing of such mine hoist ropes. This testing has continued ever since, with the current mining regulations indicating that every mine in South Africa operating a winding plant, shall submit samples of the winding rope to a recognized testing institution every six months. These samples, normally cut from the conveyance, or front end of the rope, are subjected to a destructive test, and the results of this test are then used to determine if the rope is fit to continue in service, or if it must be discarded.

This statutory testing began in a simplistic manner, and in the 99-year history of mine hoist rope testing, the tests have changed very little, mainly migrating from the testing of the individual wires to the tensile destruction of complete rope sections. The length of the specimen used in the current test is a function of the nominal diameter of the rope. Similarly, the level of sophistication of interpretation of the results has altered little, being based on sound engineering practice and evaluation of, amongst other parameters, the specimen breaking force and attendant plastic strain. The current legislation and regulations state that a winder rope shall be discarded if the breaking force drops to below ninety per cent of it's original ultimate load (prior to installation on the winder), and / or the plastic strain of the tested sample reaches a value equal to or below 0,5 per cent (SABS 0293: 1996).

However, it is in the determination of these discard parameters where the majority of recent research has been conducted. The aforementioned parameters have been derived from extensive evaluation of ropes that have actually been discarded by mines, and by testing samples with artificially induced defects. The definitive study that lead to the formulation of the code of practice for the condition assessment of steel wire ropes, SABS 0293: 1996, was conducted principally under the auspices of previous SIMRAC work, most notably in the execution of project GAP 054 (Hecker, 1996). During this study, Hecker (1996) conducted numerous tests, and whilst little mention was made of the specimen gauge lengths, it is apparent from supporting documentation, that these were maintained constant relative to the diameter of specimen. In other words, the samples tested were prepared in accordance with the norms for their respective diameters. More recently, this constant length of specimen is alluded to in the report covering SIMRAC project GAP 502 (van Zyl, 2000), which led van Zyl (2000) to conclude that if different sample lengths had been used in the determination of SABS 0293: 1996, then different discard criteria would have been in place in that document.

It is this premise of predefined test specimen length that has motivated the experimental work underpinning this report. In essence, the scope of this work was to conduct tests on samples of both triangular strand and non-spin rope, at lengths from the standard length to those in excess of eight times this, and to trend the results of such tests. The samples were prepared at each length to include both undamaged rope specimens, and specimens with cut wires such that the discard criteria of SABS 0293: 1996 of 40 per cent of the number of outer wires was not exceeded. All samples were prepared from unused rope.

Destructive tensile testing of these specimens would then allow trending and conclusions to be drawn regarding any changes in steel wire rope properties with variation in specimen length, as the primary output.

2. Literature survey

A literature survey was not part of the original scope of GAP 836, and hence it is explicitly stated that the work presented in this section is by no means exhaustive. Nonetheless, it is felt relevant to include a brief treatise on what has been reported in selected literature, as this does have some bearing on the analysis of the results and the conclusions drawn. Selected literature in this context specifically indicates work previously done for SIMRAC, by various authors and used to develop the code of practice SABS 0293: 1996.

An examination of the CSIR's research reports and literature database indicated little work specifically related to the effect of sample length on it's breaking strength, other than the work paraphrased in section 1 of this report. Examining this, and expanding on the work done by Hecker (1996) for GAP 054, that report comprised seven volumes of written research findings, and it is in volume four where the work on cut wire and discarded rope is reported. As such, Borello and Kuun (1994) conducted tests on 46 specimens of 48 mm nominal diameter triangular strand steel wire rope, with varying numbers and locations of cut wires in each strand. The primary objective of this work was to determine the effect of symmetry of broken wires and the allowable number thereof so as to not exceed a drop in strength of ten per cent from new rope conditions. Whilst each specimen was cut to a length of 3,25 m, the nominal gauge length was 2,75 m between end caps. The authors' principle findings indicated that for all samples tested, the per cent loss in strength never exceeded the per cent loss in metallic area due to the cut wires.

Borello and Kuun (1994) state that this was contrary to results previously available (Harvey and Kruger, 1959, quoted in Borello and Kuun, 1994), indicating that the earlier work returned losses in strength exceeding the loss in metallic area.

As the work of Borello and Kuun (1994) included a minimal amount of tests conducted on ropes of different diameter and tensile grade (but with the same gauge length), they further concluded that there may be effects present that were influenced by these parameters, and that further testing should be conducted.

Hecker and Kuun (1996) repeated the tests of Borello and Kuun (1994), using some 70 specimens of 32 mm, 41 mm, 48 mm and 62 mm nominal diameter ropes. Owing to the non-availability of intact rope strength data for the 32 mm and 48 mm specimens, these results were essentially discarded and it was concluded that the effects of diameter were sufficiently negligible to not warrant alteration of the discard criteria.

Re-examination of the discard criteria of SABS 0293: 1996 by van Zyl (2000), involved an extensive test regime, using some 69 specimens, with an emphasis on examining the behaviour of non-spin rope. The work undertaken included tests on:

- Triangular strand ropes with broken wires;
- Non-spin rope with broken wires;
- Corroded ropes;
- Damaged ropes;
- Very old ropes;
- Triangular strand ropes with diameter reductions; and
- Cut-wire tests on non-spin ropes.

Further to this experimental work, van Zyl (2000) stated that the test results presented in the reports covering SIMRAC projects GAP 324 and GAP 439 were re-examined, in order to draw meaningful conclusions.

van Zyl (2000) indicates that the principal findings were that the behaviour of non-spin rope with broken wires was poorer than expected, with a quoted example of a fishback stranded rope with a 1,5 per cent loss in metallic area recording a 16 per cent drop in breaking force. This rope, whilst still acceptable according to the criteria given in SABS 0293: 1996 in terms of broken wires, was unacceptable in terms of the breaking force being below 90 per cent of new rope strength. However, adjacent specimens taken from the same rope with no broken wires indicated a five per cent loss of strength, which was acceptable. In attempting to explain this anomaly, van Zyl (2000) conducted a failure analysis and concluded that the length of the test specimen was a critical factor affecting the breaking force. The principal motivator for this was stated as being that the inter-wire friction and bedding of adjacent strands in the outer strands of a non-spin rope were lower than that for an equivalent triangular strand or the inner strands of a non-spin rope, and that this dramatically lowered the breaking force of the strand. As indicated in section 1 of this report, van Zyl (2000) concluded that had different lengths of specimen been used in the work leading to the development of SABS 0293: 1996, different discard criteria would have been stipulated.

Extending the literature search to international works, once again it was indicated that little or no specific work had been done on the variation of specimen tensile strength with length, with the exception of the fatigue testing thereof. In a report on a workshop of the International Association for Bridge and Structural Engineering (IABSE) held in September, 1992 (in OIPEEC Bulletin 64, 1992) the editor concluded that statistical evaluations of short sample fatigue tests could not easily and reliably be extrapolated to predict the performance of service lengths of rope. A further note is included that with short samples, manufacturing imperfections and termination (end cap) affects are likely to have a greater influence on endurance performance than with longer samples.

In conclusion to this section, it is reiterated that this literature survey is not totally exhaustive, but has been included to motivate the work conducted to investigate the relationship between breaking strength of steel wire ropes and their respective specimen lengths.

3. Research methodology

The project proposal, as accepted by SIMRAC, stated that the objective was to evaluate the breaking strength of different lengths of both triangular and non-spin rope. The primary purpose of this was to verify or refine the discard criteria of SABS 0293: 1996, whilst a secondary objective was to examine the validity of the specimen lengths used for statutory rope testing.

As such, it was proposed to conduct tests at lengths of 2,75 m, 10 m and 20 m with each type of rope construction, taking new (unused) rope with no cut or broken wires as the reference sample for each rope type at each length. The remaining samples, also taken from new and unused rope, would then have outer wires cut, such that the number of cut outer wires was just less than or equal to the discard criteria of SABS 0293: 1996. The results of these tests would then allow a comparison between the performance of both intact rope and damaged specimens, with respect to the standard length of 2,75 m for normal statutory purposes. It was proposed that these tests would be conducted on both triangular strand and non-spin rope. The latter tests were aimed at providing greater insight into the behaviour of non-spin ropes, as this construction had not received as much attention as the triangular strand ropes in the compilation of SABS 0293: 1996.

CSIR Miningtek has at its disposal two tensile machines capable of testing mine hoist rope, namely a 15 MN capacity machine used on a daily basis for the statutory tests, and a 500 short ton capacity machine with a 27 m bed length used for diverse mechanical testing. As the length of the specimens would exceed the bed length of the 15 MN machine, it was decided to conduct the research work in the 500 short ton machine, but considering cross-calibrating by conducting standard length (2,75 m) tests in both.

Messrs Haggie Steel Wire Rope donated approximately 300 m of 50 mm nominal diameter triangular strand rope as well as approximately the same length of non-spin. The designations of the two ropes were:

? Triangular: 50 mm Nominal diameter - 6x32(14/12/6 ?)/F; Tensile grade 1900 MPa (test certificates in Appendix A of this report);

? Non-Spin: 38 mm Nominal diameter 9x6/6x10(7/3 ?)WMC (test certificates in Appendix B of this report).

3.1 General procedure

The general procedure adopted was as follows:

? All ropes were prepared in the conventional manner for the CSIR Miningtek Rope Test Laboratory, i.e. by cutting to the desired length and casting white metal end caps over the brushed and cleaned ends;

? Ropes selected for wire cutting were marked off at the centre point, and the wires of one strand were carefully cut using an angle grinder, and lifted clear of the remaining wires. From the rope constructions given previously, a total of five wires were cut for the triangular strand (33,3 per cent of the total number of outer wires) and two for the non-spin rope (33,3 per cent);

- The samples were then tested in turn in the 500 short ton machine, completing all tests of one length before resetting the machine to the next length (with the exception of the 2,75 m samples – see the note below);

    - Note: For the 2,75 m specimens, four samples were initially prepared, two with five cut wires and two without cut wires. The two cut wire and one of the intact specimens were initially tested in the 15 MN machine. As alluded to previously, this machine is the standard equipment used for statutory tests, and these results were therefore the benchmark for the remainder of the experimental work. The second intact specimen was tested in the 500 short ton machine, to act as a calibration reference;

- Tests were repeated for rope specimens failing at the termination (end cap), by cutting and preparing new specimens, or where recorded breaking forces were low due to anomalous behaviour, such as strands failing at a brazed core.

3.2 Exceptions and deviations

Given the above general process, during the cross correlation of the 2,75 m and 10 m specimens it became apparent that the standard size cones used to cap the samples was inadequate (standard size refers to the rope diameter based selected cones). For the 50 mm nominal diameter rope, these cones measure 55 mm diameter at the throat (rope end) and 150 mm at the free end, with a length of 250 mm.

Testing the aforementioned ropes in the 500 short ton machine, the specimens consistently broke at the end cap (Figure 3.1). Good laboratory practice dictates that these tests be discarded, as it was apparent that the rope termination had influenced the strength of the rope. Examination of the failures did not indicate any obvious construction anomalies (i.e. brazed wires), and the consistency of the breakage over some 5 tests (three at 2,75 m and two at ten metres) indicated that the preparation and / or procedure was inadequate. Subsequent to this, it was decided to cast the next size up end caps (105 mm x 200 mm x 250 mm long) onto ropes, and these tests then consistently recorded breakage away from the end caps, indicating that the rope was unaffected by the capping process.

Figure 3.1: End cap break, 2,75 mm triangular strand.

The decision was therefore taken to cast all specimens with this size end cap, and discard test results prior to this decision.

A second point of concern was with the non-spin rope. It is usual for non-spin rope to fail at the outer strands, and this is observed and commented on by van Zyl (2000). However, after preparation of the samples for this study (using the larger diameter end cap cones), the ropes consistently failed at the inner rope (Figure 3.2 and Figure 3.3).

Figure 3.2: Failure of 2,75 m non-spin rope.

Figure 3.3: Close up of non-spin rope inner strand failure.

This mode of failure reoccurred despite taking special precautions in replacement sample preparation, such as cutting new specimens from the centre of the coil and ensuring that the rope was tightly and correctly served, before cutting the samples out of the coil. One possible cause of this failure mode was that the outer strands were free to move relative to the inner strands, and therefore the end caps were smelted of the samples and the wires inspected for relative movement. Figure 3.4 shows the brushed out end of the rope.

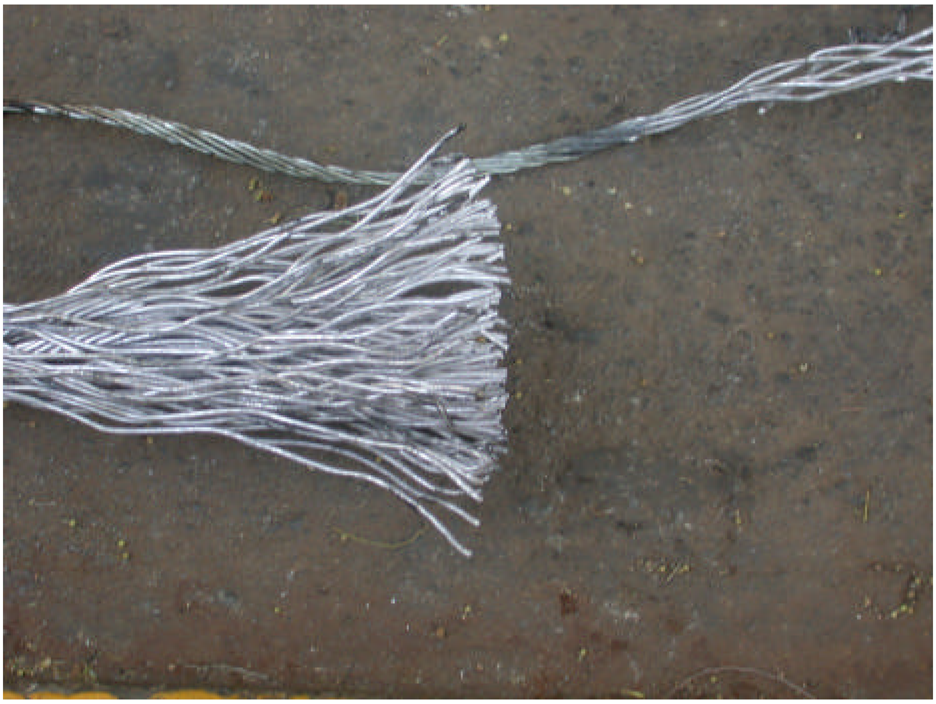

Figure 3.4: Non-spin rope brush.

Inspection of the brushed end of the rope did not indicate any obvious signs of slippage, and this theory was then discarded as a possible cause of the problem.

Messrs Haggie Steel Wire Rope kindly donated this non-spin rope, and unfortunately the new rope test certificates could not be found on the CSIR Rope Test Database. Discussion with Mr M. Borello of Haggie Steel Wire Rope indicated that this rope may have aged, or was an experimental rope, and that this may account for the anomalous behaviour. Attempts to locate an alternative sample of non-spin rope proved difficult, and after discussion with Mr F. Hecker it was decided to abandon the non-spin tests and conduct more experimental work with the triangular strand. This was in line with the discussion surrounding the progress presentation given by the author at SIMPROSS on 2003-07-17. The results of the non-spin tests are included in Appendix B to this report.

As such, additional tests were conducted using same coil of rope as for the previous tests, at lengths of 2,75 m, 4,5 m, 7 m, 10 m, 15,5 m and 23,5 m in both the uncut (intact rope) and cut wire state (five cut wires). Further, considering the controversial statements in the literature (Harvey and Kruger, 1959, versus Borello and Kuun, 1994, see section 2), tests at these lengths were repeated with four cut wires, to provide a cursory examination of the reduction in strength with reduction in metallic area.

Finally, attempts were made to test samples of triangular strand at lengths of 20 m, but this distance fell awkwardly between the reactive head pin holes on the bed of the 500 short ton machine, thus leaving insufficient ram stroke to completely break the specimen. These specimens were then re-prepared at 18 m length, which proved adequate.

3.3 General comment

The range of lengths examined and the number of tests conducted in the execution of this study are summarized in Table 1.

Table 1: Matrix of rope lengths tested.

Nominal length (m)	Number tested	Condition / comments
2,75	7	Uncut and cut (4 wire, 5 wire)
4,5	3	Uncut and cut (4 wire, 5 wire)
7,0	5	Uncut and cut (4 wire, 5 wire)
10,0	4	Uncut and cut (5 wire)
15,5	4	Cut (4 wire, 5 wire)
18,0	3	Uncut and cut (5 wire)
23,5	3	Uncut and cut (4 wire, 5 wire)
Total	**29**	**Excluding non-spin rope**

The test machine used for the vast bulk of this study is not equipped with the software to automatically and on-line analyse the generated data for traditional rope test engineering measures, as generated by the 15 MN capacity machine, which is dedicated for rope testing. In order to generate the slope of the linear-elastic portion, the strain energy to failure, the plastic fraction of the strain energy and the plastic strain, stand-alone software is used. For the purpose of completeness and uniformity, this same software was used to analyse all tests conducted during the execution of this project. The results of these analyses are included in Appendix A (triangular strand) and Appendix B (non-spin) of this report.

4. Discussion of results

The following analysis describes the results achieved during the destructive tensile testing of the specimens prepared as described in the preceding section. As two machines and two differing sizes of end cap were used, it is felt prudent to not mix results, i.e. like end cap to like end cap, machine to machine. The discussions surrounding the cut wire tests will be on a comparative basis, firstly comparing the change in breaking force relative to the uncut 2,75 m sample, since this is the traditional method in which statutory testing of this diameter rope would be performed, and secondly comparing changes at the same length of specimen.

4.1 Uncut rope

Table 2 summarizes the results of the tests conducted on ropes with no cut wires. Note that of the ten specimens tested, three results were discarded due to end cap failures. Similarly, certificate number 225888 was conducted in the 15 MN machine, fitted with the smaller end caps.

Table 2: Test results: Uncut rope.

Certificate number	**Gauge length (m)**	**Breaking force (kN)**	**Comments**
225888	2,75	1941,2	Small end cap (15 MN machine)
T06229	2,75	1860,7	End cap failure
T06245	2,75	1946,4	
T06892	6,92	1930,0	
T06902	9,47	1921,9	
T06499	10,0	1942,7	
T06228	10,0	1840,3	End cap failure
T06897	15,45	1834,3	End cap failure
T06331	18,0	1918,6	
T06903	23,44	1896,1	

Unless otherwise stated, all tests were conducted in the 500 short ton machine.

As indicated in section 3.1, the two tensile machines available for this work were cross calibrated using similar specimens of uncut rope. These are represented by certificate numbers 225888 and T06245 (Table 2). Of note is the relatively small difference in breaking force of the two specimens, differing by some 0,27 per cent with T06245 having a larger end cap than 225888.

Figure 4.1 graphically depicts the results of Table 2. The trend lines are included simply to show the general trend in the data. It is interesting to note that the line through the specimens that failed at the end cap suggest a similar decrease in strength of the specimen with length to the acceptable tests.

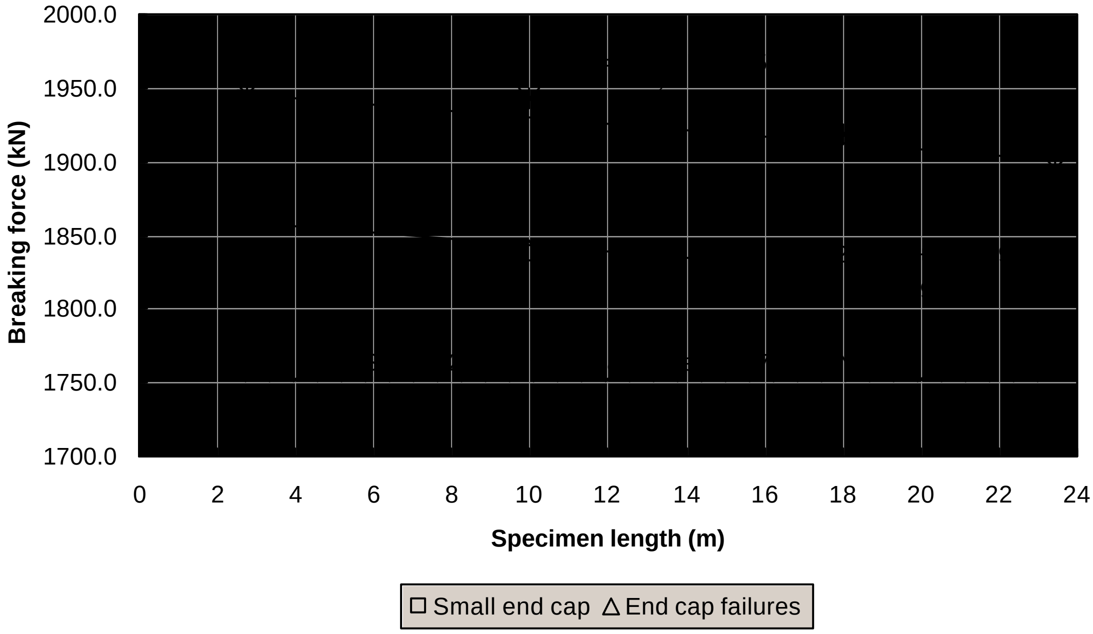

Figure 4.1: Breaking force: Uncut rope results

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Figure 4.2 depicts the general decrease in strength with length of rope specimen, taking the 2,75 m sample of certificate T06245 as the basis, or reference value. The regression equations presented use BF to denote breaking force and L to represent specimen length. Note that the discard criteria (SABS 0293: 1996) lies at a ten per cent drop in strength (Figure 4.2), or 1751,7 kN in the case of Figure 4.1.

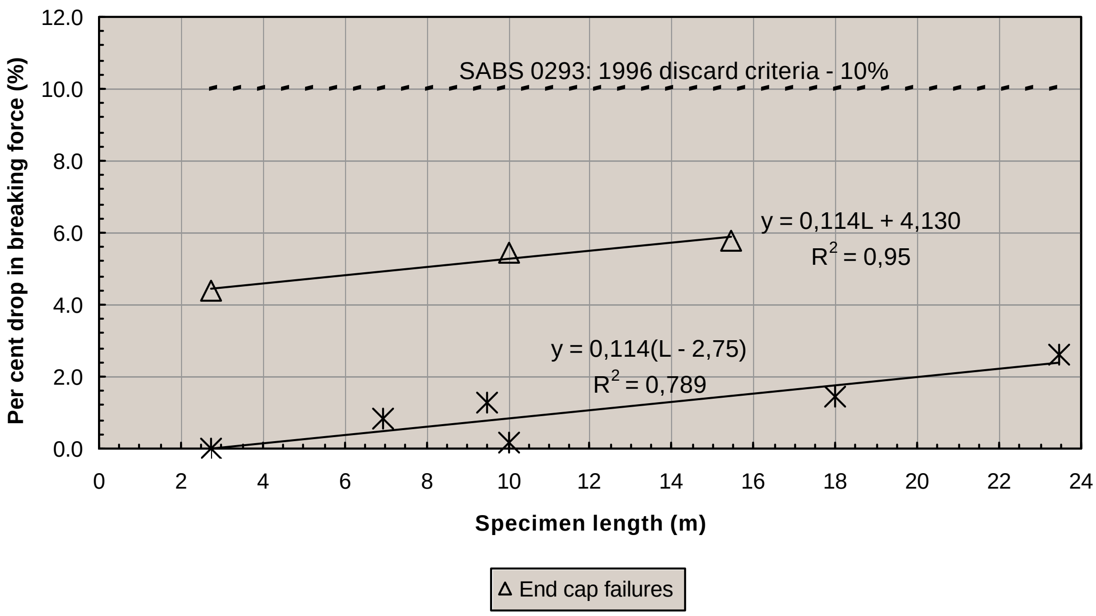

Figure 4.2: Loss of strength: Uncut rope.

Here, y denotes the per cent drop in breaking force, and L the specimen length, for the regression equations. Again, the mirroring of the end cap failure results above the acceptable results is notable. In terms of the data available, this ranged from 4,4 per cent at 2,75 m to some 5,8 per cent at 15,45 m. If, however, it is taken that the gradient of this upper trend line is the same as that for the acceptable tests, then by linear regression, the average drop in strength due to the end cap failure is some 4,1 per cent, over and above the drop associated with the increase in length, with a correlation coefficient, or R^2, of 0,95. This is an unusually high "goodness of fit", and can be attributed to the low sample population. Nonetheless, this result is felt to be significant and will be expanded upon later in this report.

4.2 Five cut wires

Five outer wires were cut in the strands of the prepared specimens. Each wire has a nominal diameter of 3,20 mm, which gives a reduction in metallic cross sectional area of some 3,58 per cent. Table 3 records the results of these tensile tests, and these are graphically depicted in Figure 4.3, along with the results of Table 2 (uncut rope) for reference, with the attendant trend line. Again, unless otherwise stated, all tests were conducted in the 500 short ton tensile machine.

Table 3: Test results: Five cut wires.

Certificate number	Gauge length (m)	Breaking force (kN)	Comments
225890	2,75	1768,8	Small end cap (15 MN machine)
225889	2,75	1796,0	Small end cap (15 MN machine)
T07270	2,67	1764,5	
T07271	4,42	1830,4	
T07272	6,98	1768,6	Discarded
T06234	10,0	1842,5	
T06230	10,0	1755,7	Failed at brazed joint
T06776	18,0	1844,1	
T06771	18,0	1824,2	

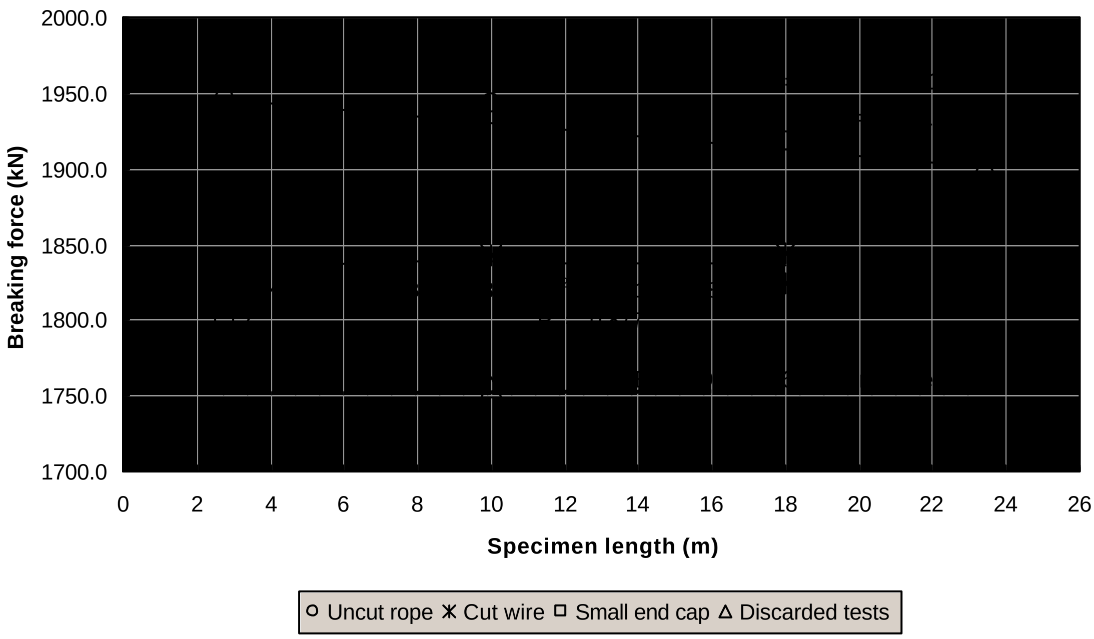

Figure 4.3: Breaking force: Five cut wires.

Note the low result recorded against certificates T06230 and T07272 (Table 3), which in Figure 4.3 lie extremely close to the discard criteria of SABS 0293: 1996. Examination of specimen T06230 revealed that the strand had failed at a brazed core, which is a plausible explanation for this low breaking force. Test T07272 revealed neither obvious preparation nor manufacturing defect, and this low strength behaviour is unexplained.

Above approximately four metres, Figure 4.3 shows an approximately linear trend in the relationship between the length of the specimen and the breaking force. Below this, however, anomalous behaviour appears to manifest, with the recorded forces being consistently and markedly lower than the longer specimen tests. Included in Figure 4.3 are the results at 2,75 m gauge length from the 15 MN machine, with the specimens having been cast with "standard" end caps (i.e. small), as well as the larger end caps in the 500 short ton machine. Initially, and as mentioned in section 3.2, it was thought that this drop in breaking force was attributed to the difference in size of the end caps, and differences between the 15 MN and 500 short ton machines. Subsequent repetition of the test work (certificate T07270), using a large end cap, provided results that were similar in force magnitude to these small end cap results, and it is now felt that this anomalous low force is more a manifestation of the interrelation between short specimen length and significant damage (3,58 per cent loss of metallic area). As such, the trend line of Figure 4.3 has incorporated all 2,75 m tests (other than end cap failures), and this returns a correlation coefficient of 0,88, which is felt to be acceptable, albeit that the relative sample population is low.

Similar to the uncut specimens, the cut wire results trend towards a lower breaking strength with length, albeit at a lower rate. Figure 4.4 shows the loss of strength of the samples, relative to the strength of an intact 2,75 m reference sample.

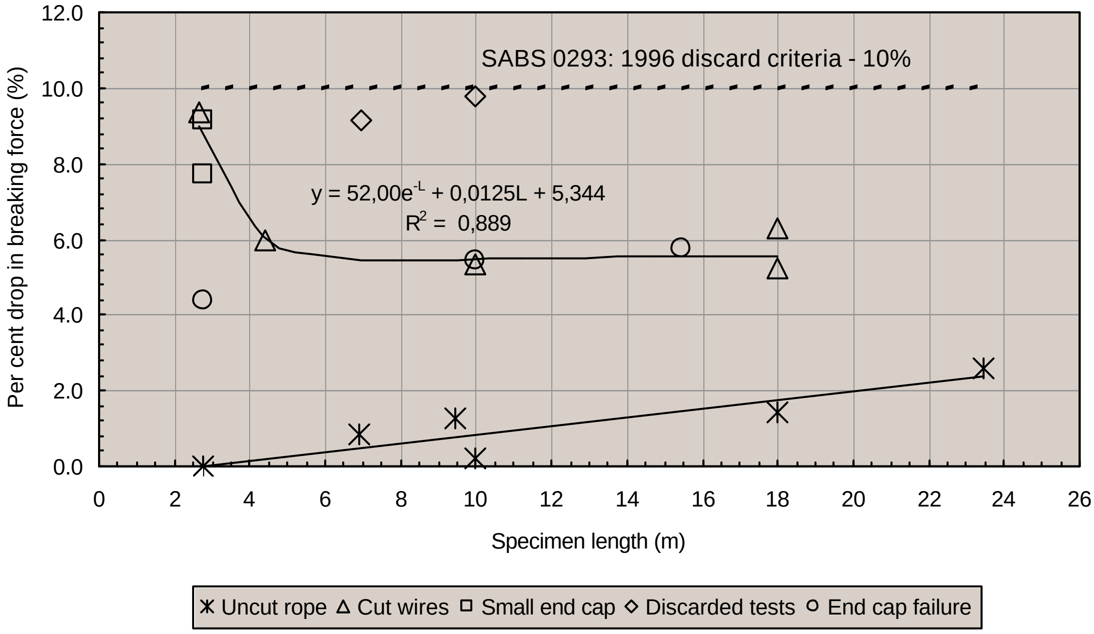

Figure 4.4: Loss of strength: Five cut wires (relative to 2,75 m)

Included in Figure 4.4 are the data points for the samples tested with small end caps in the 15 MN machine as well as the repeated 2,75 m test and the discarded test result. The regression line for the cut wire results bears the same assumptions as those surrounding the data presented in Figure 4.2, with the line through the uncut rope data being reproduced from that figure.

As with the previous discussion, the 15 MN (small end cap) machine results and the repeated 2,75 m test result fall close to the ten per cent discard line, but the longer specimen results move rapidly away from this and appear to settle into a linearly decreasing pattern some four per cent below the discard line. Nonetheless, this closeness to discard at 2,75 m sample length is to be expected, as the forty per cent reduction in the number of outer wires was the basis for the discard criteria of SABS 0293: 1996, and all tests conducted to define this limit were done at this length of specimen.

Of interest in Figure 4.4 is the behaviour of the rope when failing at the end cap, as it appears to act as though five outer wires have been cut. Regression analysis of this data using the same gradient as for Figure 4.2 indicates a correlation coefficient of some 0,64, which is reasonable, considering the number of data points available.

Examining the per cent drop in breaking force relative to the 2,75 m intact specimen and the results from the same length of uncut specimen, allows the development of Figure 4.5.

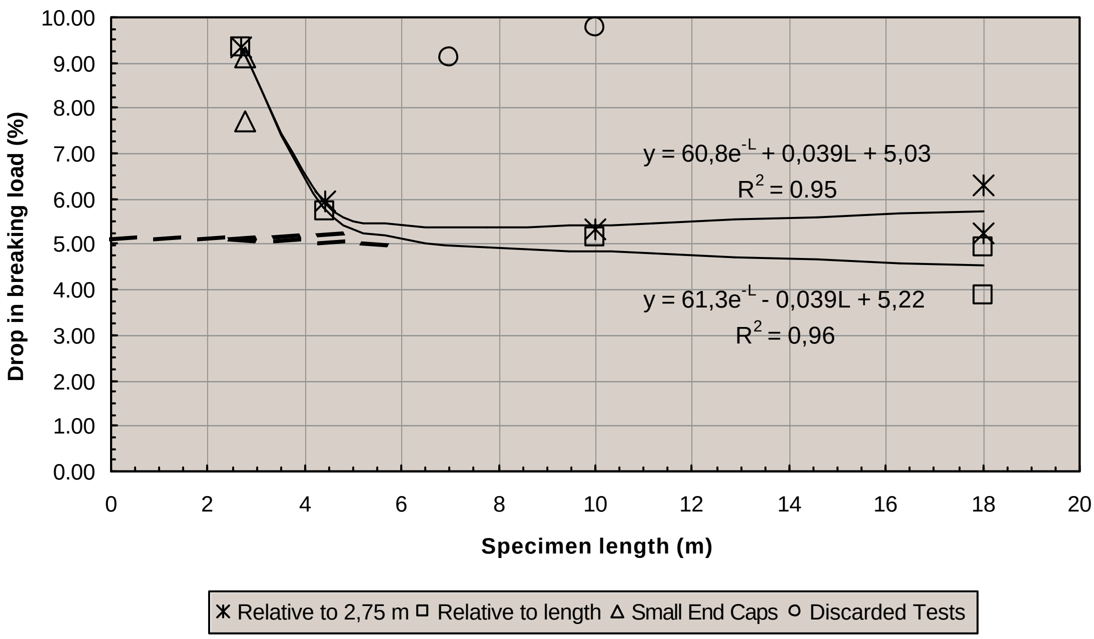

Figure 4.5: Loss of strength: Five cut wires (relative to length).

In the regression equations of Figure 4.5, y represents the drop in breaking force, and L represents the specimen length. Once again, the more severe loss of strength is observed at 2,75 m length, with a general recovery as the sample length increases, towards a linear type relationship above some six metres. For interest in Figure 4.5, this linear relationship is extrapolated back to zero length and returns a value of 5,12 per cent loss at zero length. Similarly, it can be noted that both curves appear to diverge about this value.

4.3 Four cut wires

Similar to the presentation of results in section 4.2, this section will detail the tests conducted with specimens having four cut outer wires, representing a 2,86 per cent loss of metallic area (Table 4).

Table 4: Test results: Four cut wires.

Certificate number	Gauge length (m)	Breaking force (kN)	Comments
T06907	2,67	1865,9	
T06906	4,47	1859,5	
T06891	6,93	1849,8	
T06893	6,94	1859,1	
T06894	15,50	1855,0	
T06898	15,47	1865,3	
T06904	23,49	1853,6	

These results are graphically depicted in Figure 4.6, with BF denoting the breaking force (kN) and L the specimen length in the attendant regression equations.

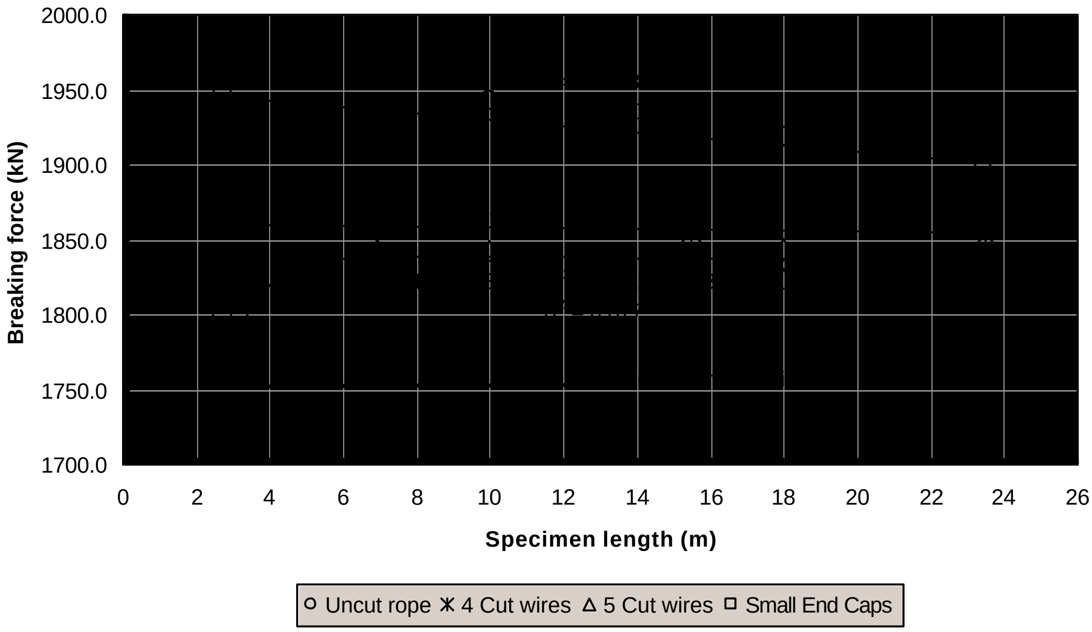

Figure 4.6: Breaking force: Four cut wires.

For reference, the results of the five cut wire tests are included in Figure 4.6, and consistent with engineering theory, these lie below the four cut wire results. The general trend for both of these cut wire test results is towards an increasing decay of rope strength with increasing specimen length, and this is common with the uncut rope results, albeit that it would appear that the curves will intersect at a longer length, with the cut wire trend of Figure 4.6 tending towards horizontal.

Regarding the linear regression equation posed on Figure 4.6 for the four cut wire tests returned an exceptionally low correlation coefficient of 0,094. This is attributed to the excessive variation of the sum of the squares of the fitted curve points about the mean data value of the lengths where more than one point exists at a given length (seven metres and 15,5 m). Averaging these two data sets drives the gradient of the line towards zero, and returns a correlation coefficient of some 0,77. Similarly, utilizing a third order polynomial regression curve derives a correlation coefficient of 0,55. However, owing to the sparse data set, the linear regression lines of Figure 4.6 are retained for indicative purposes.

Figure 4.7 shows the drop in breaking strength relative to the 2,75 m reference sample, and as can be seen, the trend lines for the four cut wire results appears to be similar in slope to the five cut wire tests above approximately six metres specimen length, and both tend towards an intersection with the uncut rope results. Commentary similar to the discussion surrounding the analysis of the coefficient of correlation for the breaking force results of Figure 4.6 applies. Once again it is noted that the end cap failure results show similarity to the results obtained from cut wire tests.

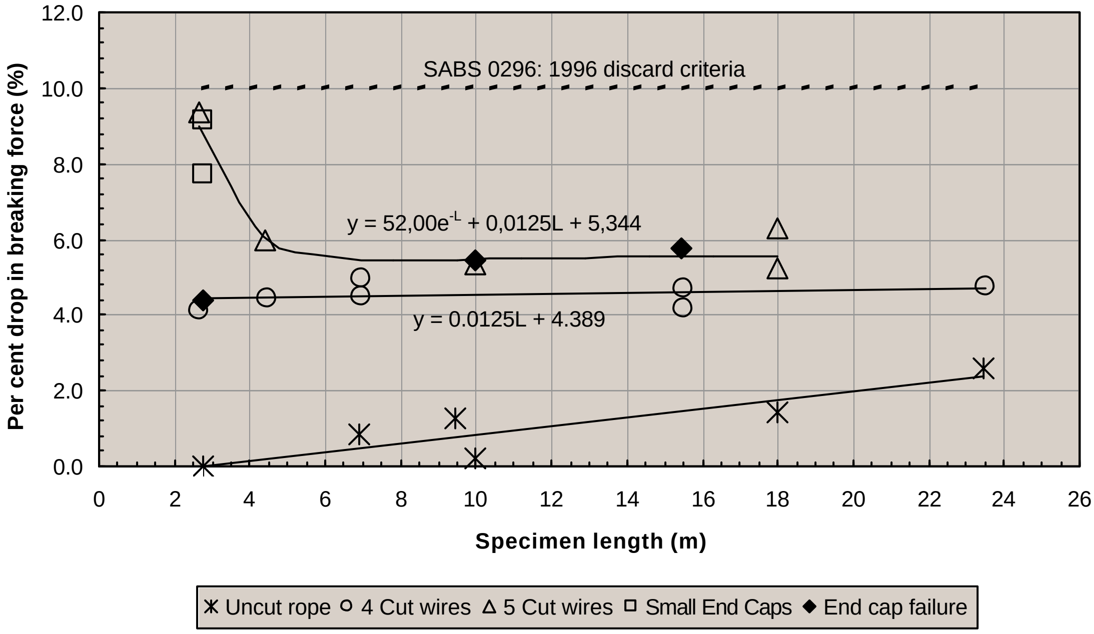

Figure 4.7: Loss of strength: Four cut wires (relative to 2,75 m).

Figure 4.8 depicts the loss in strength of the specimen, relative to the uncut rope at the same gauge length. Plotted on the same axes are the values relative to the 2,75 m specimen of Figure 4.7.

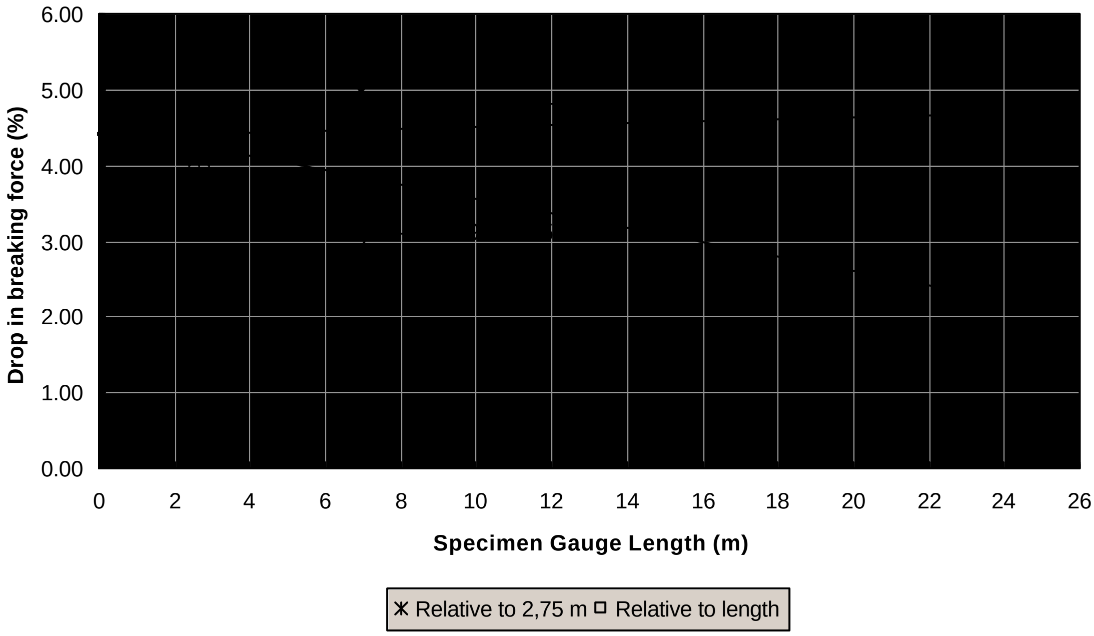

Figure 4.8: Loss in strength: Four cut wires (relative to length).

Once again and similar to Figure 4.5, these linear lines have been extrapolated to zero length, and indicate a value of some 4,40 per cent drop in breaking force.

Again, the diverging trend is evident, with the longest specimen (23,49 m) approaching a loss of breaking strength of some two per cent of the uncut specimen.

4.4 Metallic area loss

As was demonstrated in the literature review of section 2, some controversy was reported by researchers on this matter, with Harvey and Kruger (1959, in Borello and Kuun, 1994) and Borello and Kuun (1994) reporting different results for tests on cut wire specimens. Borello and Kuun (1994) reported that the per cent loss in strength never exceeded the per cent loss in metallic area, which they stated was in contrast to Harvey and Kruger (1959, in Borello and Kuun, 1994). Reiterating here the sentiments of section 2, little is available in these works that definitively states the sample lengths used to allow development of these arguments.

Examining the results obtained in the preceding sections of this report, the plotting of per cent loss in strength versus per cent loss in metallic area yield the simple scatter plot of Figure 4.9. This figure does little to display any definitive trend, although it is apparent that there is a large amount of scatter. Of interest, however, is the fact that the data ranges from 1,44 per cent loss in strength to 0,78 per cent.

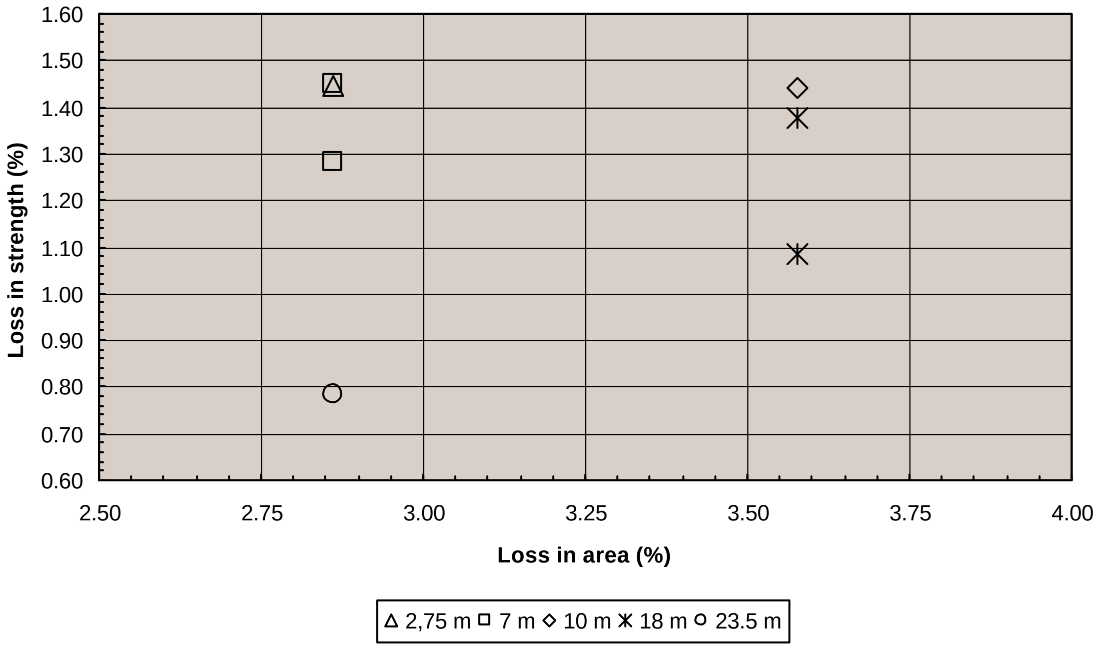

Figure 4.9: Loss in strength vs loss in metallic area.

Considering that there results in Figure 4.9 are for more than one gauge length, it was felt expedient to evaluate the strength and metallic cross sectional area losses in the form of a ratio, so as to be able to present all data on one graph. As such Figure 4.10 shows the ratio of strength loss : area loss of the specimens versus their respective lengths, the loss in strength being taken relative to equivalent uncut lengths.

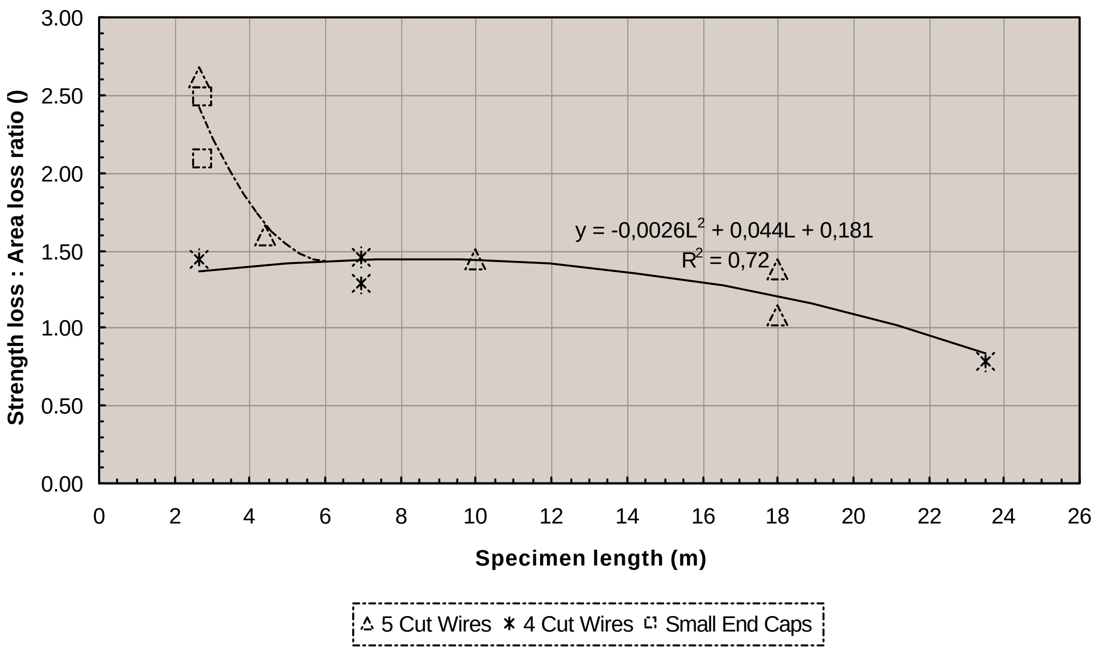

Figure 4.10: Strength loss: Area loss ratio.

A definite trend can be seen (Figure 4.10), with a decrease in strength loss to area loss ratio with increasing length. As with previous observations, the 2,75 m samples (both small and larger end caps) show drastically, but consistently higher values than the longer specimens. The trend line shown, whilst derived using least squares regression techniques and utilizing a second order polynomial, is shown to highlight the apparent "lead in" or recovery effect as the samples increase in length, which runs through the 4,5 m specimen results and intersect, tangentially, at some six metres length. Both four and five cut wire results are shown on Figure 4.10, and the general observation is the ameliorating of the scatter of Figure 4.9 and the co dependence on the specimen length.

Considering the findings of Borello and Kuun (1994), it is apparent that for specimen gauge lengths less than approximately 21 m in length, the loss in strength exceeds the loss in metallic area (ratio > 1,0), whilst for greater lengths, this reverses. Depending on the lengths of sample tested by Harvey and Kruger (1959, in Borello and Kuun, 1994), this may explain the variance in reported results.

Recasting Figure 4.10 in terms of the strength loss relative to the baseline 2,75 m, specimen allows the derivation of

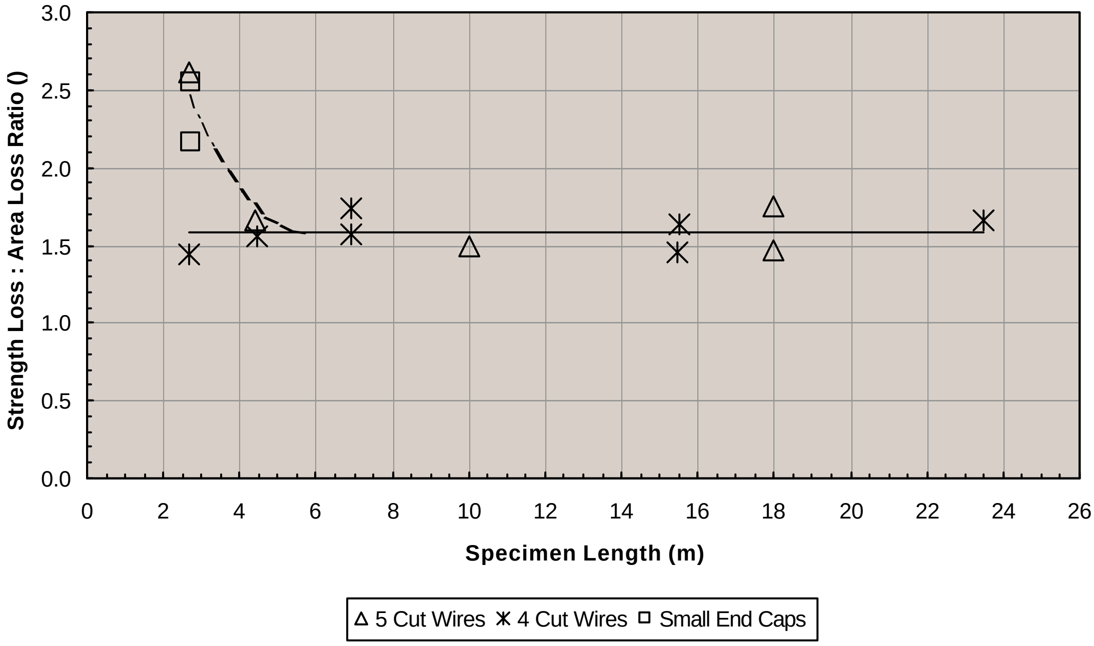

Figure 4.11: Strength : Area Loss Relative to 2,75 m

Immediately apparent in Figure 4.11 is the constant relationship with length, returning a ratio of some 1,59 irrespective of specimen length over approximately six metres. Once again, the recovery length is evident, and the trend is shown on Figure 4.11 for reference.

5. Conclusions and recommendations

Considering the data presented in Figure 4.1, it is apparent that a general decrease in breaking strength exists with a corresponding increase in length. No definitive reason is offered for this, suffice to state that the construction of steel wire rope is complex and these structures are tedious to model mathematically. Nonetheless, it is obvious that factors are present which influence the strength of the wires.

Similarly, the tests conducted with cut wire specimens show likewise trends (Figure 4.3 and Figure 4.6). Whilst linear regression trends have been fitted to the data in the three preceding figures, it is prudent to note that this is unlikely to be the true model of the behaviour at lengths greater than those tested. This linear relationship suggests that there is a constant diminishing of strength with length until appoint is reached where no useful load can be carried. In the case of the uncut specimens of Figure 4.1, this calculates to some 93 m whereupon the ten per cent discard criterion would be reached and some 910 m before the rope has zero strength. Considering the current depths from which men and material are hoisted in South Africa, this is known to be not the case. In reality, there is most likely to be a changing decay in strength with length that either asymptotes to a constant value after a certain length, or reaches zero at an infinite length. Unfortunately, the equipment available to the researcher dictates that the lengths tested in the execution of this project are almost at the practical limits: perhaps a two or so metre longer specimen could be tested, but it is felt that this is unlikely to shed more light on the matter.

Taking the uncut 2,75 m specimen as a reference, since this is the condition in which the statutory tests are conducted, the trends shown in Figure 4.4and Figure 4.7 for five and four cut wire specimens, indicate that as the length of specimen increases, so does the loss in strength. Similar commentary regarding the use of linear regression applies here, albeit that the slope of the linear portions is close to zero, and again it is anticipated that the strength will asymptote to a constant value, or reach 100 per cent at an infinite length. Nonetheless, it is important to note that the losses displayed in these figures are well below the ten per cent discard level of SABS 0293: 1996, and below the defining values realized by the reference tests using standard end caps in the 15 MN tensile test machine. This, by implication, indicates that there exists a reasonable margin of safety with the selection criterion of ten per cent strength loss as the discard level and / or forty per cent broken outer wires.

However, when the loss in strength of cut wire samples is examined relative to an uncut rope sample at the same length, the trend in strength loss appears to decrease with specimen gauge length (Figure 4.5 and Figure 4.8). As with the discussion above, it is anticipated that this will again reach a constant value at some greater length. Considering with the influence of loss of metallic area, Figure 4.10 indicates that it is reasonable to conclude that the disparities reported in the surveyed literature, may well be as a result of differences in specimen length.

Lastly, considering the length of the standard test specimen, as used in execution of the statutory rope tests for South African mine winders (2,75 m in this instance), Figure 4.3 through Figure 4.5, Figure 4.10 and Figure 4.11 indicate that the five cut wire specimens exhibit uncharacteristic strength losses, compared with longer samples. No explanation of this phenomenon can be postulated within the current regime of test work, suffice that these cut specimens returned losses in strength of some ten per cent of their intact counterparts. As the discard criteria contained within SABS 0293: 1996 were based on test work that was largely conducted on specimens with this gauge length, it is thus apparent as to why the “ten per cent” rule was adopted. However, as has been noted by van Zyl (2000), had longer lengths been used whilst researching these discard criteria, a value lower than ten per cent may have been adopted.

In conclusion therefore, it has been demonstrated that:

? The gauge length of test specimens has a definite influence on the strength of 50 mm nominal diameter triangular strand steel wire rope. This influence:

  o Affects both uncut (intact) rope samples and cut wire samples; and

  o Acts in the favour of the user who adheres to the discard criteria of SABS 0293: 1996, indicating a greater margin of safety; and

  o Validates the findings of van Zyl (2000), in that had different lengths of sample been studied during the formulation of SABS 0293:1996, different discard criteria may have been arrived at;

? Test specimens that fail at the end cap (rope termination), display behaviour similar to those of a rope with five cut outer wires (Figure 4.7). Samples failing in this manner should be retested in the case of statutory rope tests.

5.1 Recommendations

It is recommended that:

? From the foregoing, in particular the last bullet of the preceding section, it is imperative that a formal test specification be drawn up to assist the DME appointed test stations to test consistently and provide equivalent results to the mining industry. No such document currently exists in South Africa. Standards South Africa must be approached to formulate and publish such a document, and this document must be referred to by the DME in all relevant acts and regulations, along with appropriate quality assurance surveillance and accreditation.

? The above test work was conducted with a single diameter and construction of rope. Difficulties were experienced with the testing of non-spin rope, and it is recommended that this work be extended to include different diameters of triangular strand rope as well as various common constructions used for the hoisting of men, materials and rock in South African mines.

? Whilst no price can be levied on the value of human life, the apparently greater-than-anticipated safety margin with the increase in specimen length may be used as a motivation by South African mines to alter the discard criteria to allow for a longer installed time. A study on the cost implications of such a change is recommended to evaluate any financial benefits and increase in safety risk.

6. References

Borello, M. and Kuun, T.C., 1994. The effect of cut wires on the strength of winding ropes. *In SIMRAC Final Project Report GAP 054, Volume 4. CSIR contract report number MST(94)MC2333 No. 940286*.

Harvey, T. and Kruger, H.W., 1959. The theory and practice of electronic testing of winding ropes. *Trans. Elect. Eng., June 1959*.

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OIPEEC, 1992. Report of IABSE meeting on length effects of on fatigue of wires and strands, *OIPEEC Bulletin No. 64, November 1992, p. 9, Chaplin, C.R. (Ed.), Reading Rope Research, 70 Northcourt Avenue, Reading, RG2 7HQ, U.K., (Publ).*

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Transvaal Chamber of Mines, 1905. Fifteenth annual report for the year 1904.

van Zyl, M., 2000. Discard criteria for mine winder ropes. *SIMRAC Final Project Report GAP 502. Pretoria: Department of Minerals and Energy.*

6.1 Personal communications

Borello, M., 2003. Telephonic communication regarding the anomalous failure of non-spin rope., October 2003.

Hecker, G.F.K., 2003. Telephonic communication regarding the anomalous failure of non-spin rope and experimental protocol, October 2003.

van Zyl, M., 2003. Telephonic discussions regarding the experimental method and protocol.

7. Appendix A: Test certificates: Triangular strand rope

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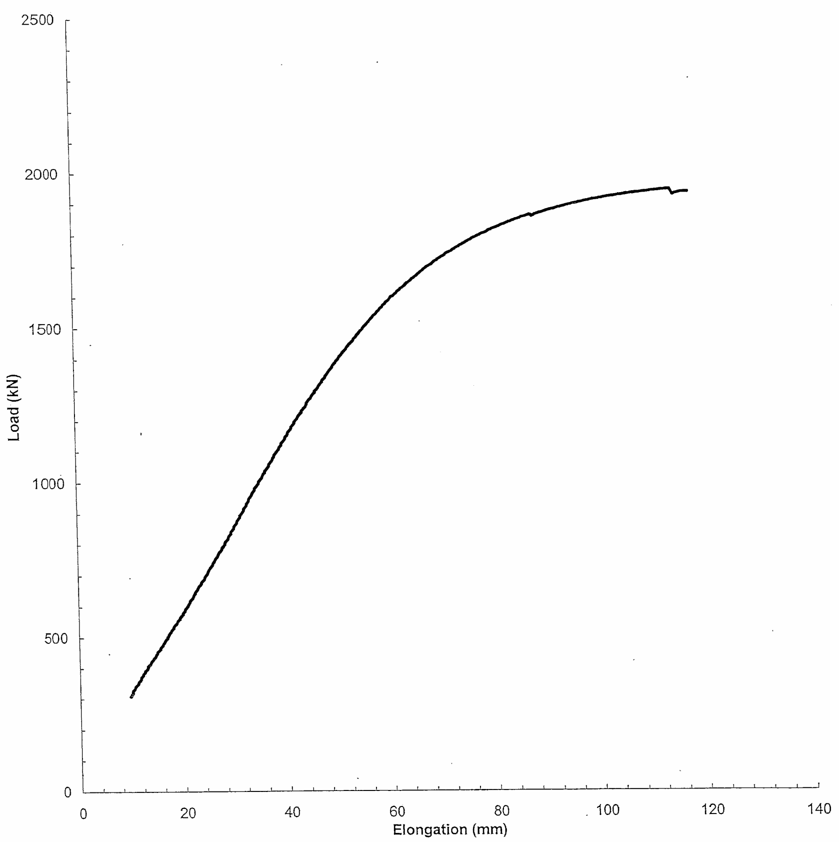
CERTIFICATE No. 225888 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	156.2	Date of test:	16/04/2003
Plastic fraction of energy (kN.m)	90.9	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	50.2 (1.8%)	Gauge length (m):	2.8
Slope (kN/mm)	28.6	Breaking force (kN):	1941.2



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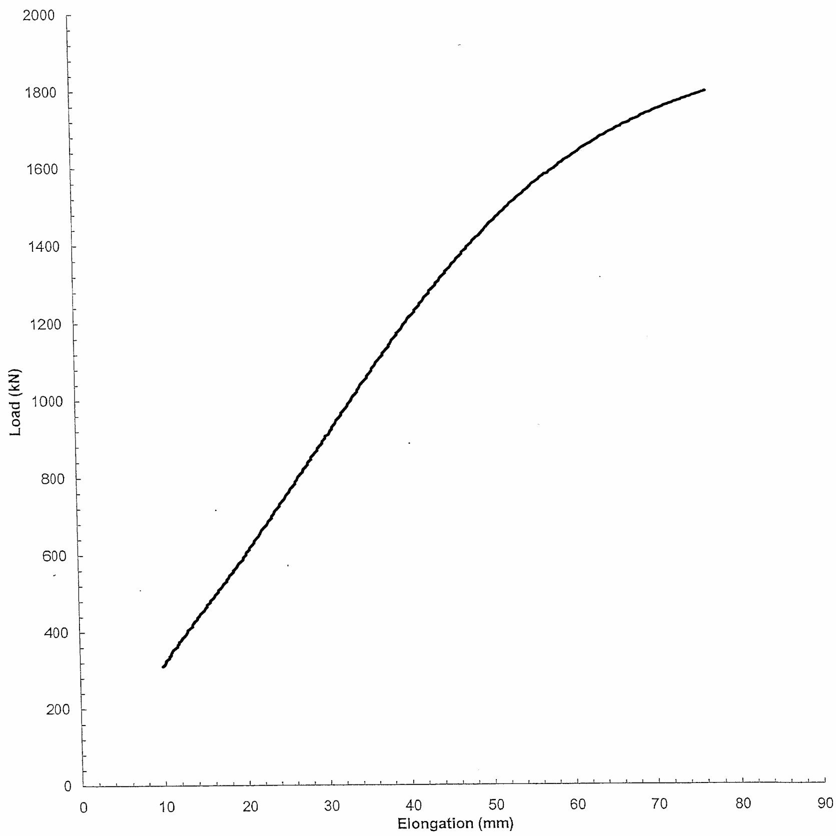
Strain energy to failure (kN.m)	82.3	Date of test:	16/04/2003
Plastic fraction of energy (kN.m)	28.5	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	17.4 (0.6%)	Gauge length (m):	2.8
Slope (kN/mm)	30.0	Breaking force (kN):	1796



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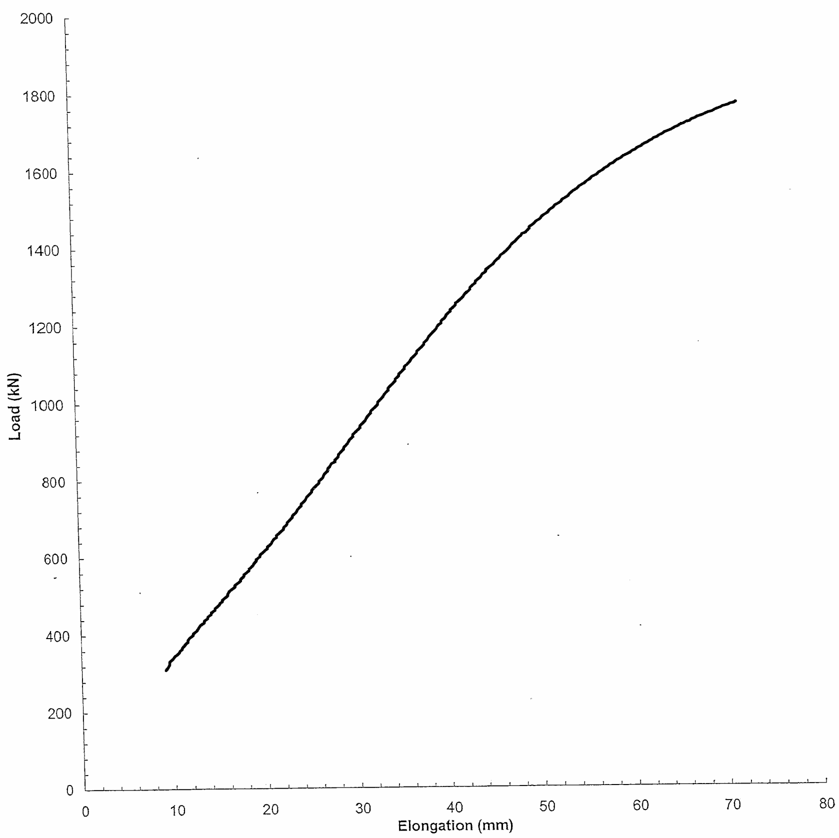
Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	74.2	Date of test:	16/04/2003
Plastic fraction of energy (kN.m)	22.7	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	14.2 (0.5%)	Gauge length (m):	2.8
Slope (kN/mm)	30.4	Breaking force (kN):	1769



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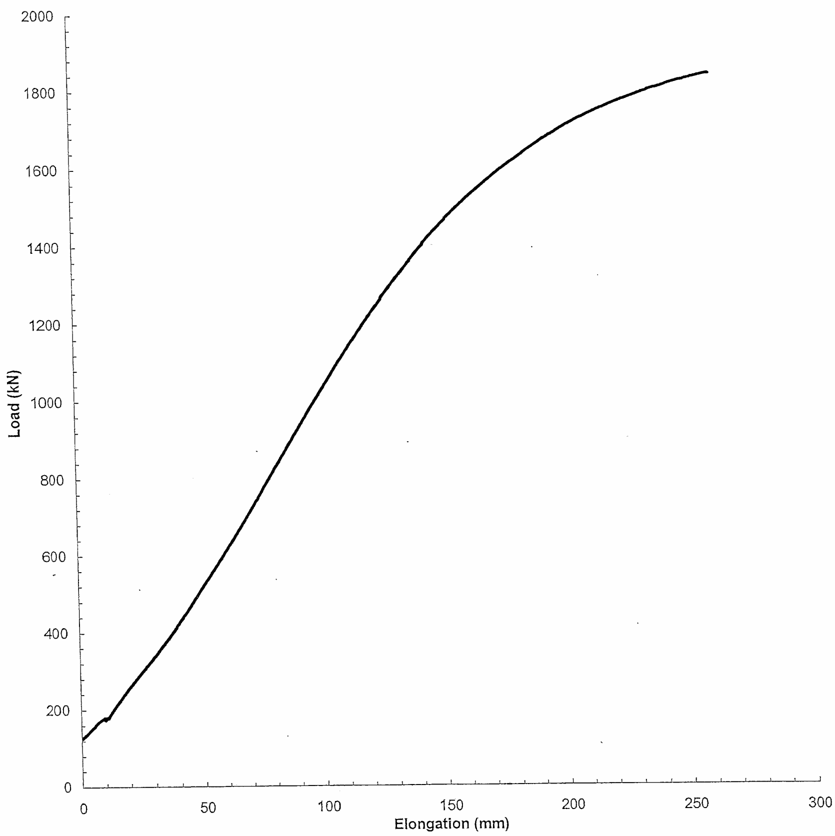
Strain energy to failure (kN.m)	302.0	Date of test:	15/04/2003
Plastic fraction of energy (kN.m)	136.1	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	81.1 (0.8%)	Gauge length (m):	10.0
Slope (kN/mm)	10.2	Breaking force (kN):	1840.286011



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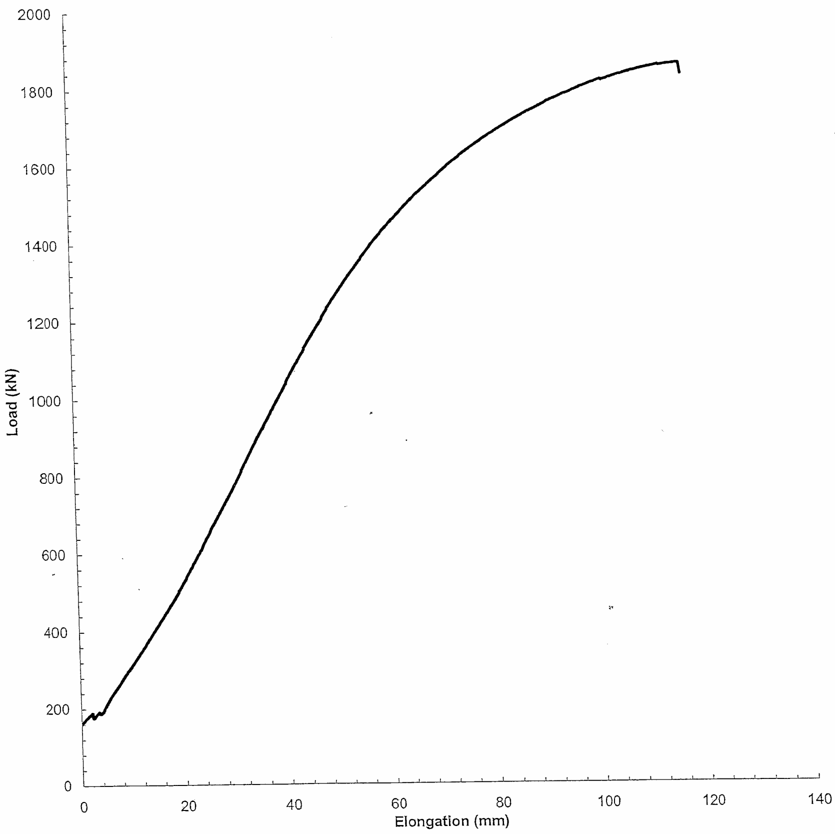
Strain energy to failure (kN.m)	143.5	Date of test:	16/04/2003
Plastic fraction of energy (kN.m)	78.2	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	46.0 (1.7%)	Gauge length (m):	2.8
Slope (kN/mm)	25.7	Breaking force (kN):	1860.680054



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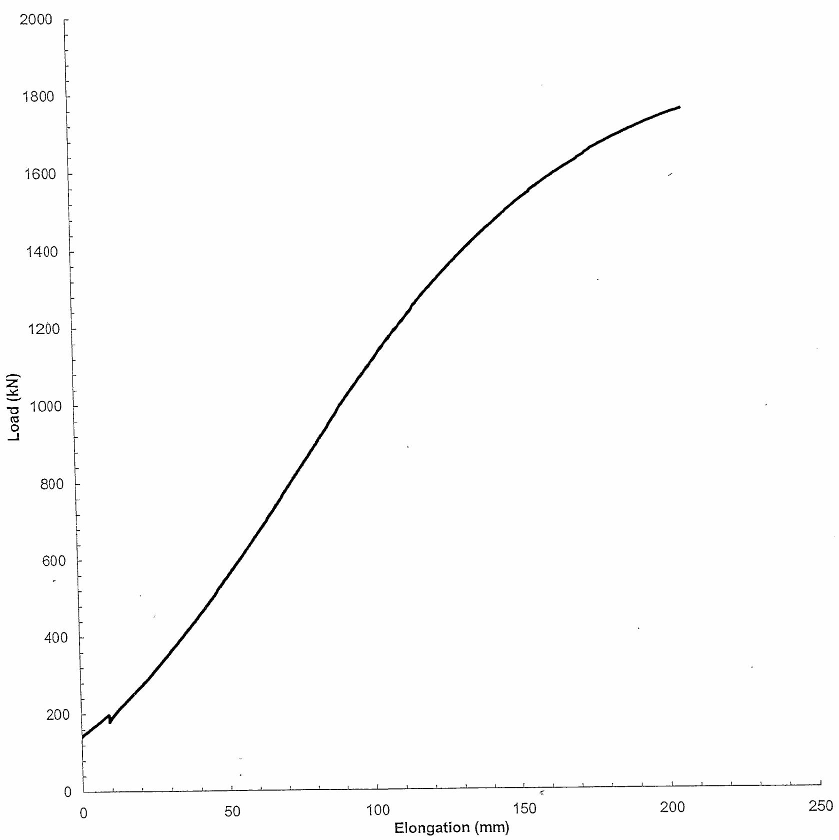
Strain energy to failure (kN.m)	216.9	Date of test:	17/04/2003
Plastic fraction of energy (kN.m)	76.4	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	48.2 (0.5%)	Gauge length (m):	10.0
Slope (kN/mm)	11.0	Breaking force (kN):	1755.665039



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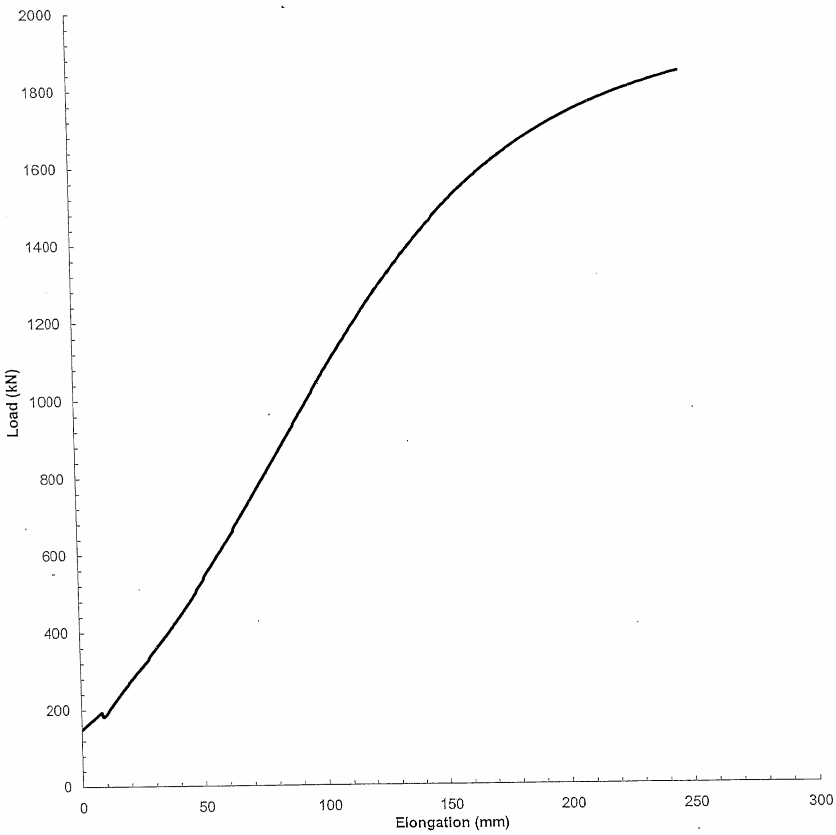
Strain energy to failure (kN.m)	287.4	Date of test:	17/04/2003
Plastic fraction of energy (kN.m)	126.7	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	75.5 (754.7%)	Gauge length (m):	0.0
Slope (kN/mm)	10.6	Breaking force (kN):	1842.546021



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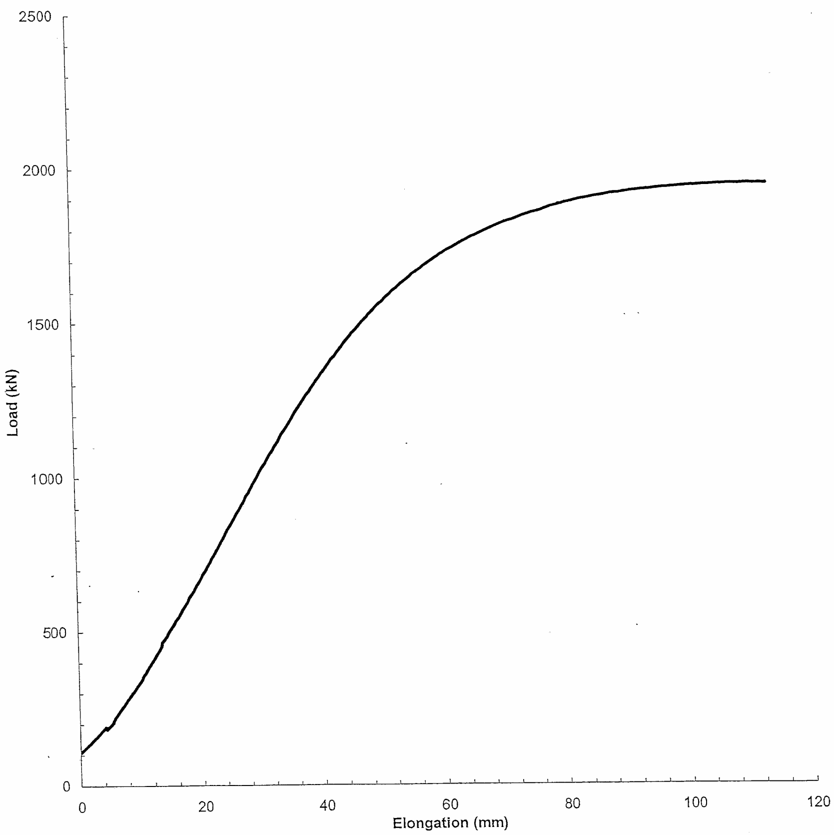
Strain energy to failure (kN.m)	159.0	Date of test:	24/04/2003
Plastic fraction of energy (kN.m)	103.0	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	56.2 (2.0%)	Gauge length (m):	2.8
Slope (kN/mm)	33.7	Breaking force (kN):	1946.378052



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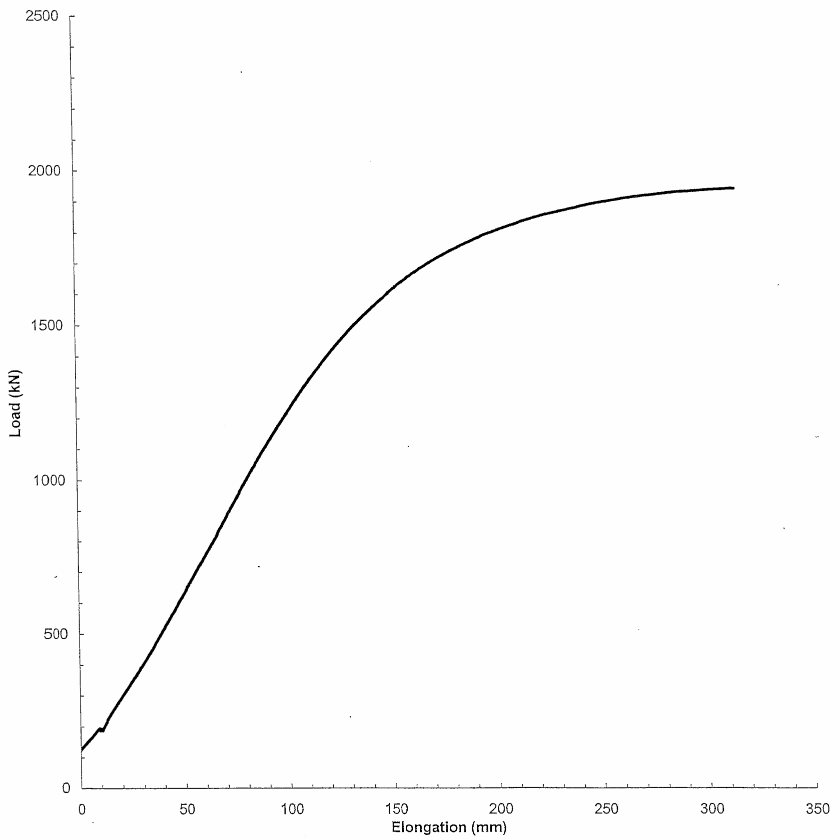
Strain energy to failure (kN.m)	436.7	Date of test:	09/07/2003
Plastic fraction of energy (kN.m)	285.7	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	159.1 (1.6%)	Gauge length (m):	10.0
Slope (kN/mm)	12.5	Breaking force (kN):	1942.661987



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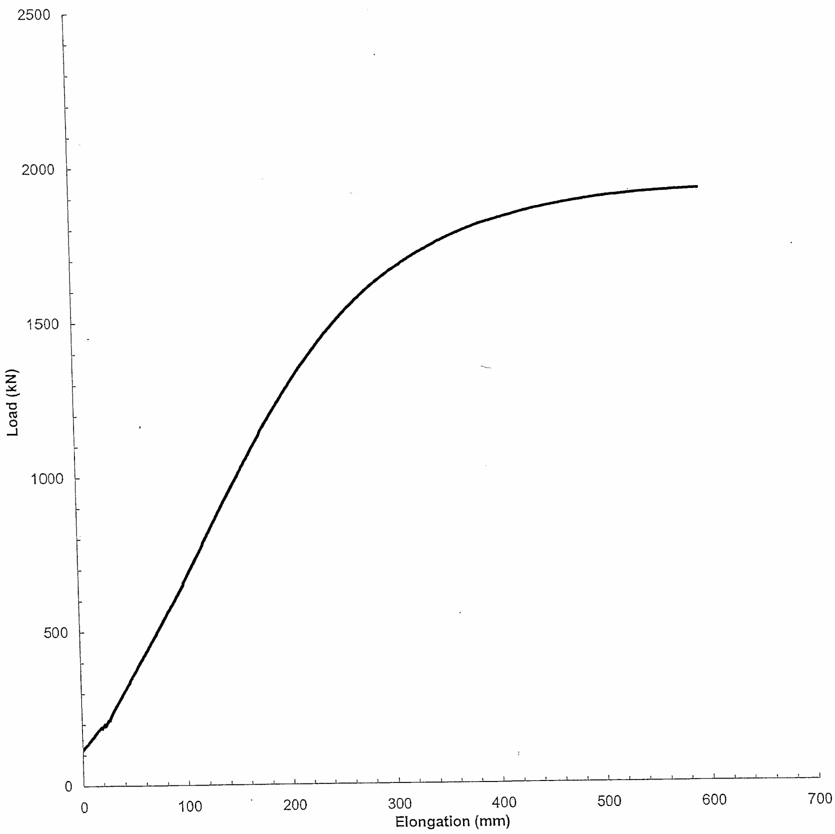
Strain energy to failure (kN.m)	831.3	Date of test:	31/07/2003
Plastic fraction of energy (kN.m)	552.3	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	309.3 (1.7%)	Gauge length (m):	18.0
Slope (kN/mm)	6.6	Breaking force (kN):	1918.642944



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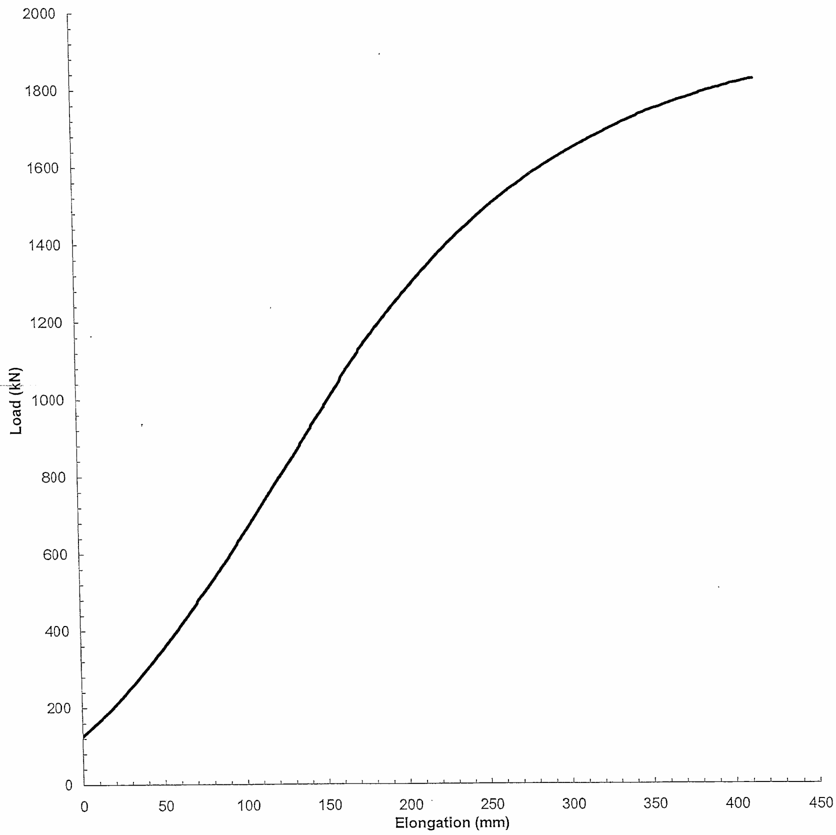
CERTIFICATE No. T06771 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	482.6	Date of test:	19/09/2003
Plastic fraction of energy (kN.m)	226.6	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	137.5 (0.8%)	Gauge length (m):	18.0
Slope (kN/mm)	6.5	Breaking force (kN):	1824.166992



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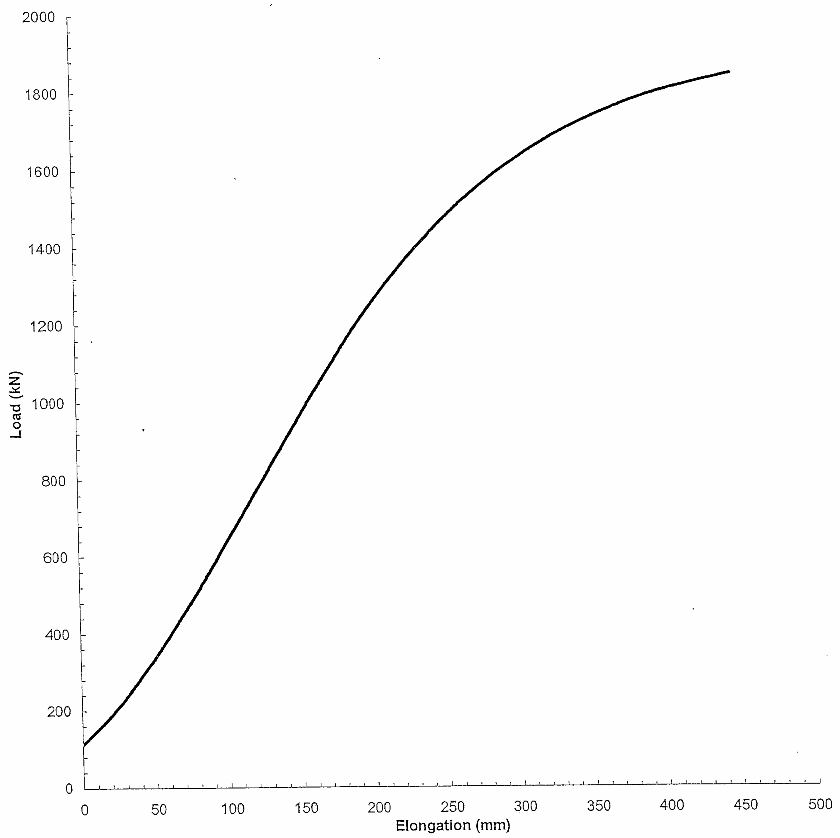
CERTIFICATE No. T06776 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	536.4	Date of test:	22/09/2003
Plastic fraction of energy (kN.m)	269.8	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	161.2 (0.9%)	Gauge length (m):	18.0
Slope (kN/mm)	6.4	Breaking force (kN):	1844.116943



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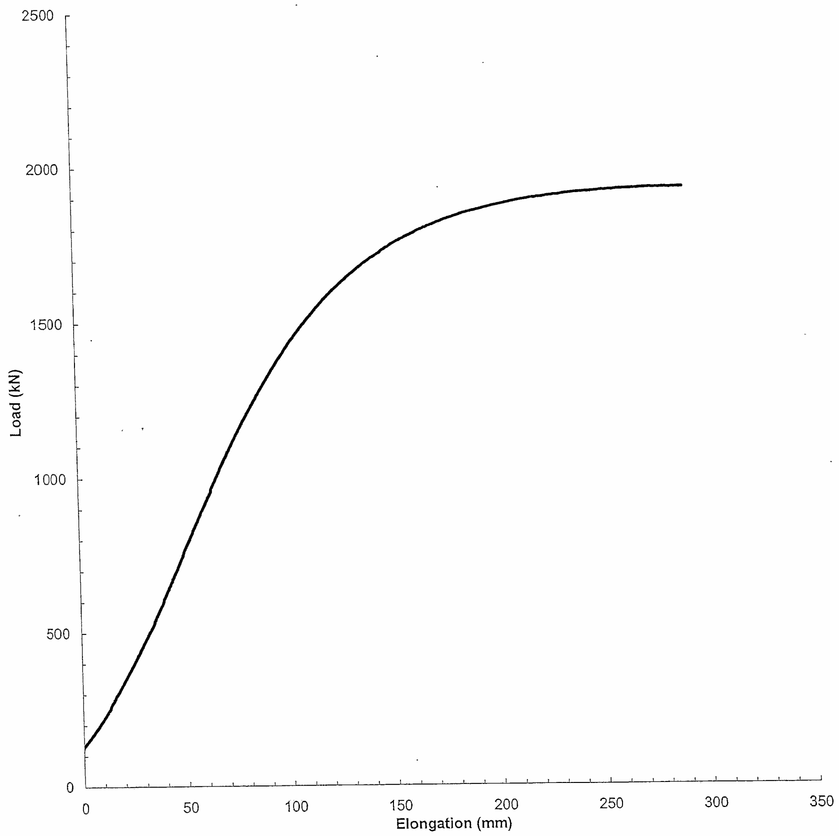
CERTIFICATE No. T06892

COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	419.5	Date of test:	30/10/2003
Plastic fraction of energy (kN.m)	297.5	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	164.4 (2.4%)	Gauge length (m):	6.9
Slope (kN/mm)	15.3	Breaking force (kN):	1929.958984



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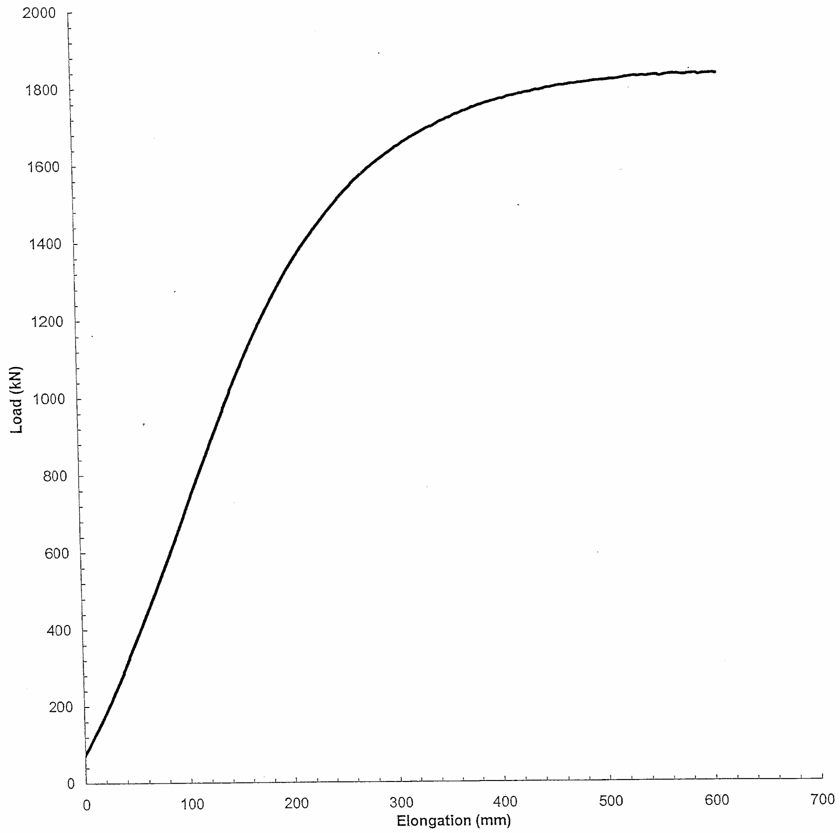
CERTIFICATE No. T06897 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	849.7	Date of test:	31/10/2003
Plastic fraction of energy (kN.m)	612.7	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	357.0 (2.3%)	Gauge length (m):	15.5
Slope (kN/mm)	7.1	Breaking force (kN):	1834.329956



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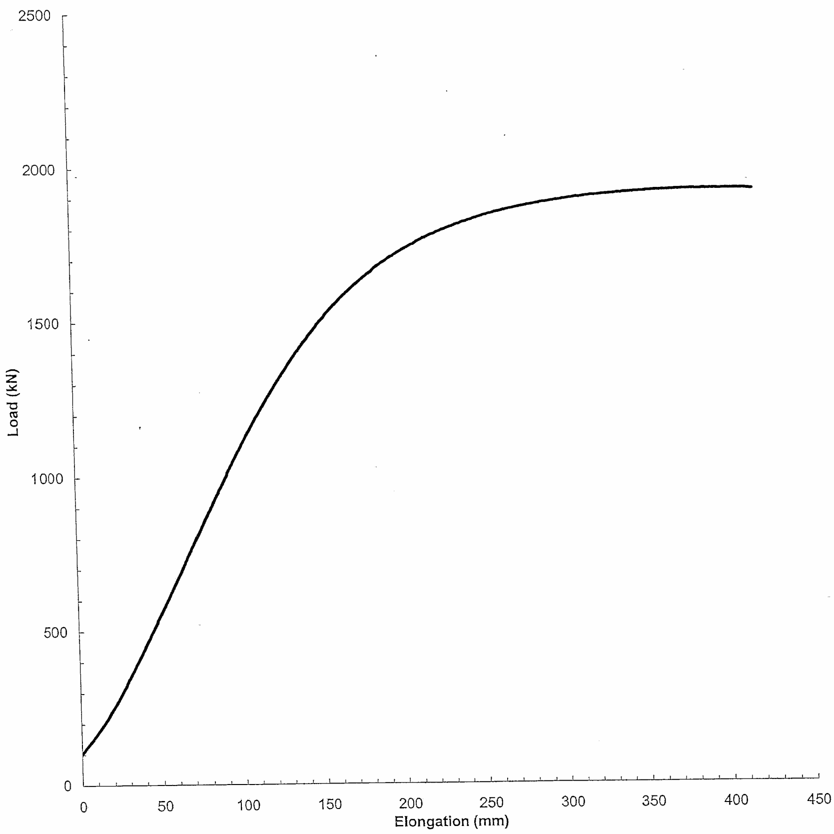
CERTIFICATE No. T06902 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	611.2	Date of test:	04/11/2004
Plastic fraction of energy (kN.m)	443.3	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	244.1 (2.6%)	Gauge length (m):	9.5
Slope (kN/mm)	11.0	Breaking force (kN):	1921.880981



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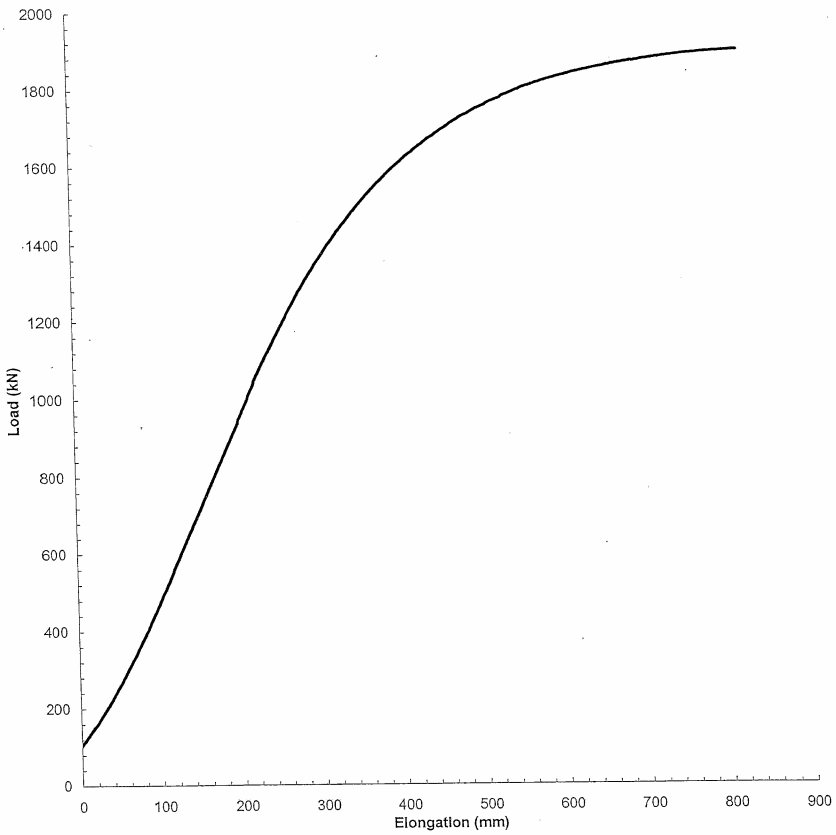
CERTIFICATE No. T06903

COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	1121.3	Date of test:	04/11/2003
Plastic fraction of energy (kN.m)	742.5	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	421.6 (1.8%)	Gauge length (m):	23.4
Slope (kN/mm)	4.7	Breaking force (kN):	1896.08606



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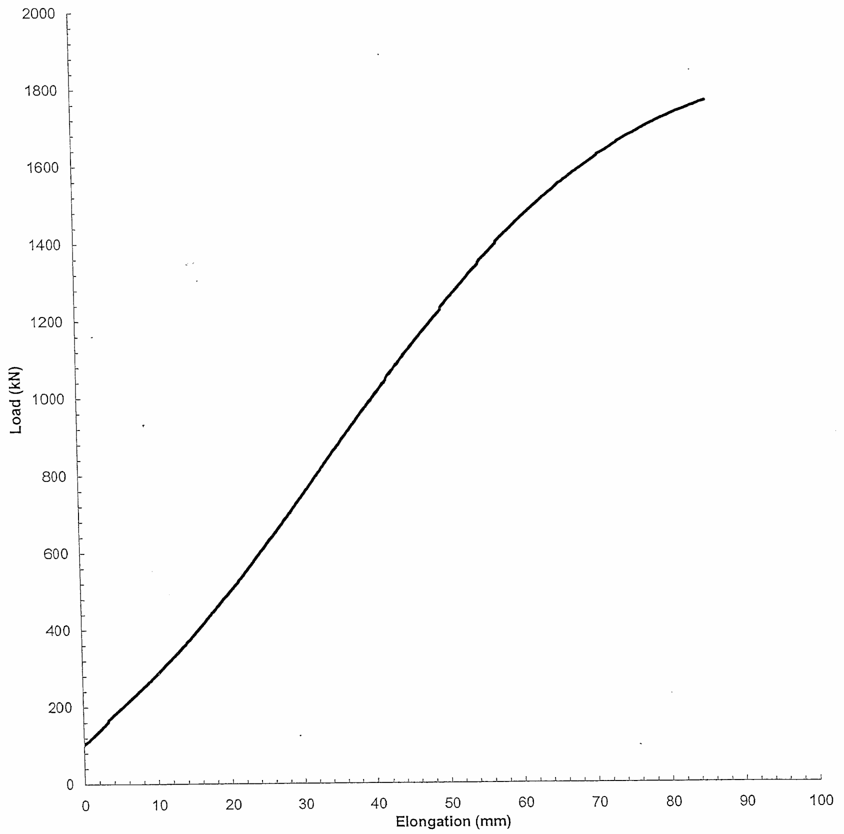
CERTIFICATE No. T07270

COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	87.3	Date of test:	27/02/2004
Plastic fraction of energy (kN.m)	24.3	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	15.0 (0.6%)	Gauge length (m):	2.7
Slope (kN/mm)	24.7	Breaking force (kN):	1764.51001



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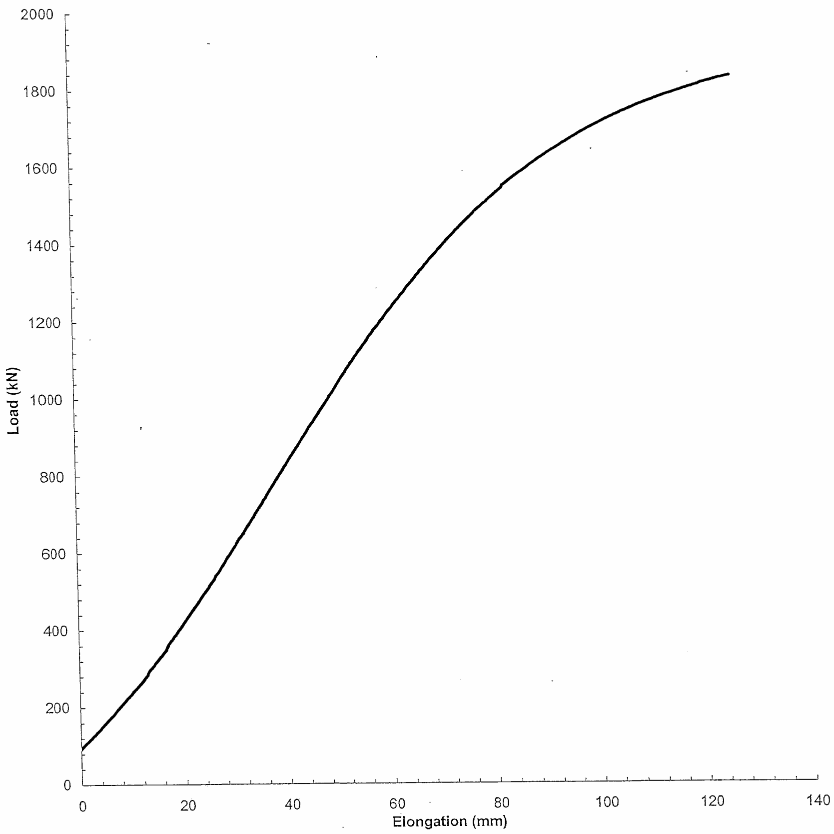
CERTIFICATE No. T07271 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	143.6	Date of test:	27/02/2004
Plastic fraction of energy (kN.m)	62.4	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	37.6 (0.9%)	Gauge length (m):	4.4
Slope (kN/mm)	20.6	Breaking force (kN):	1830.442993



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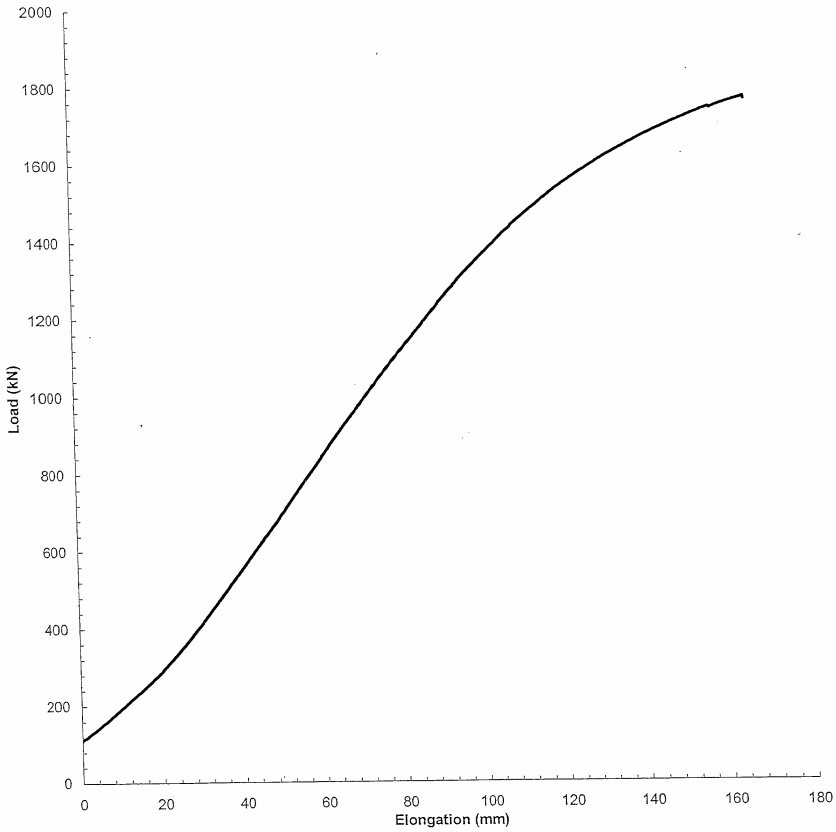
CERTIFICATE No. T07272 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	175.2	Date of test:	27/02/2003
Plastic fraction of energy (kN.m)	64.0	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	39.7 (0.6%)	Gauge length (m):	7.0
Slope (kN/mm)	14.0	Breaking force (kN):	1768.610962



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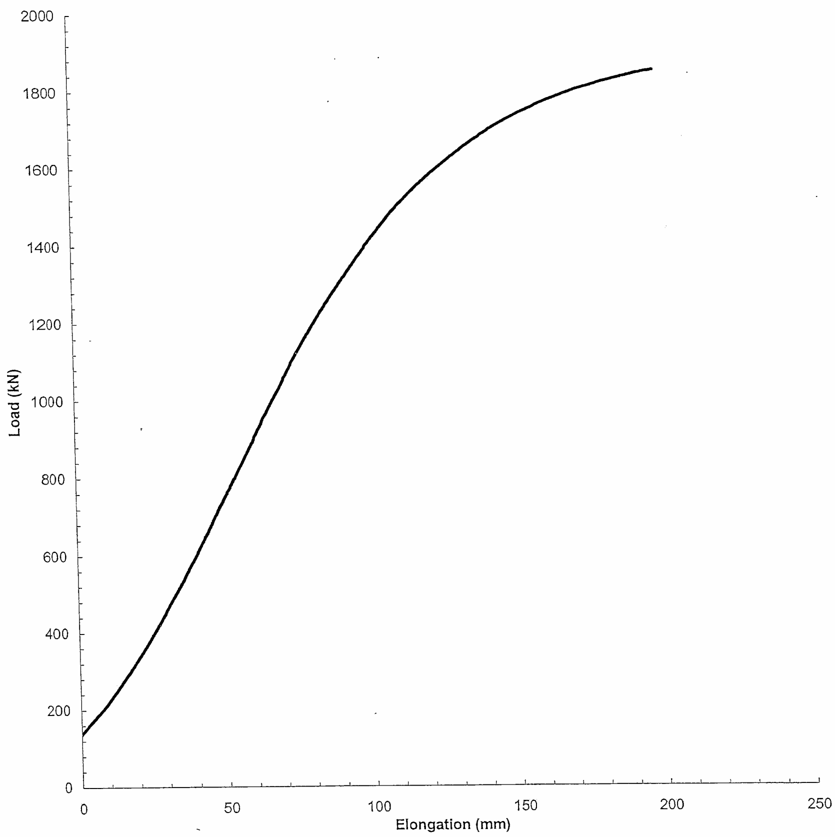
CERTIFICATE No. T06891 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	241.7	Date of test:	30/10/2003
Plastic fraction of energy (kN.m)	127.3	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	75.5 (1.1%)	Gauge length (m):	6.9
Slope (kN/mm)	15.0	Breaking force (kN):	1849.8



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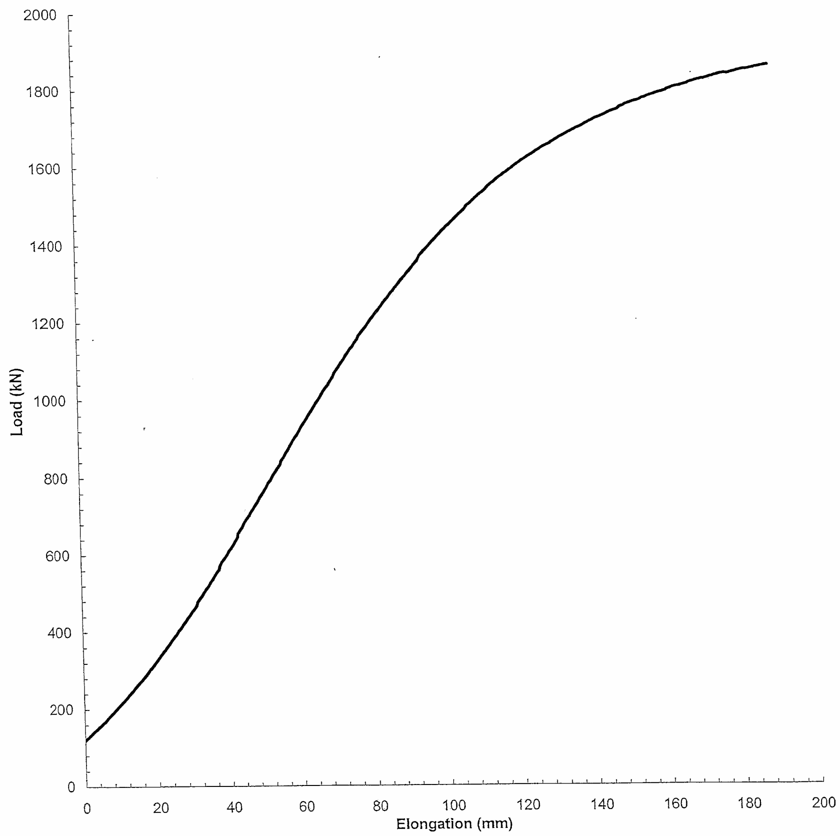
CERTIFICATE No. T06893

COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	227.8	Date of test:	30/10/2003
Plastic fraction of energy (kN.m)	114.5	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	67.8 (1.0%)	Gauge length (m):	6.9
Slope (kN/mm)	15.3	Breaking force (kN):	1859.1



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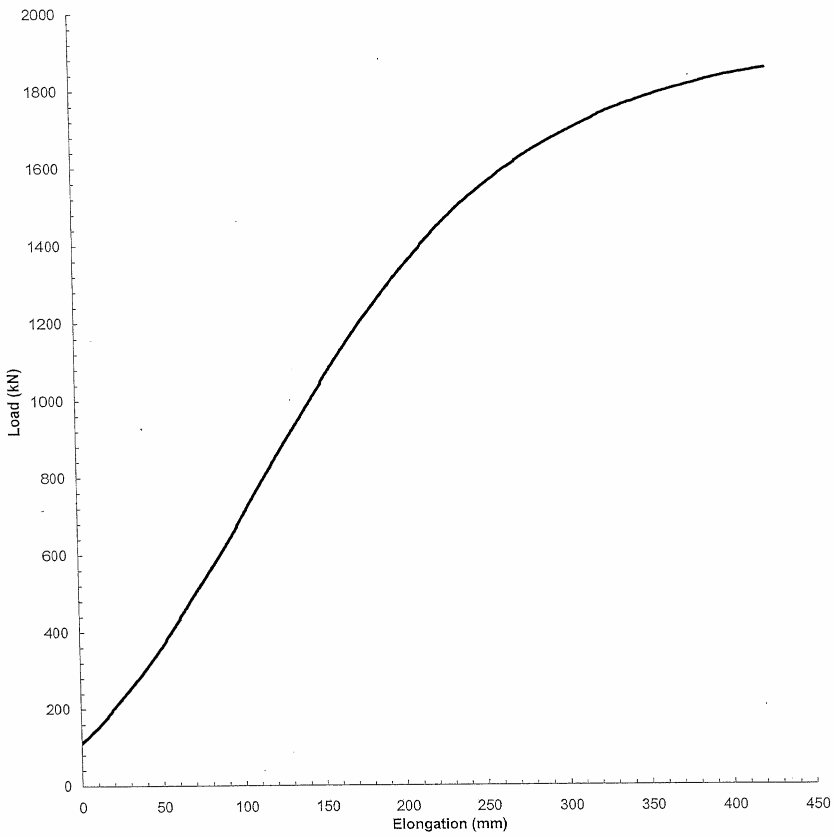
CERTIFICATE No. T06894 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	518.1	Date of test:	30/10/2003
Plastic fraction of energy (kN.m)	271.4	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	161.1 (1.0%)	Gauge length (m):	15.5
Slope (kN/mm)	7.0	Breaking force (kN):	1855.0



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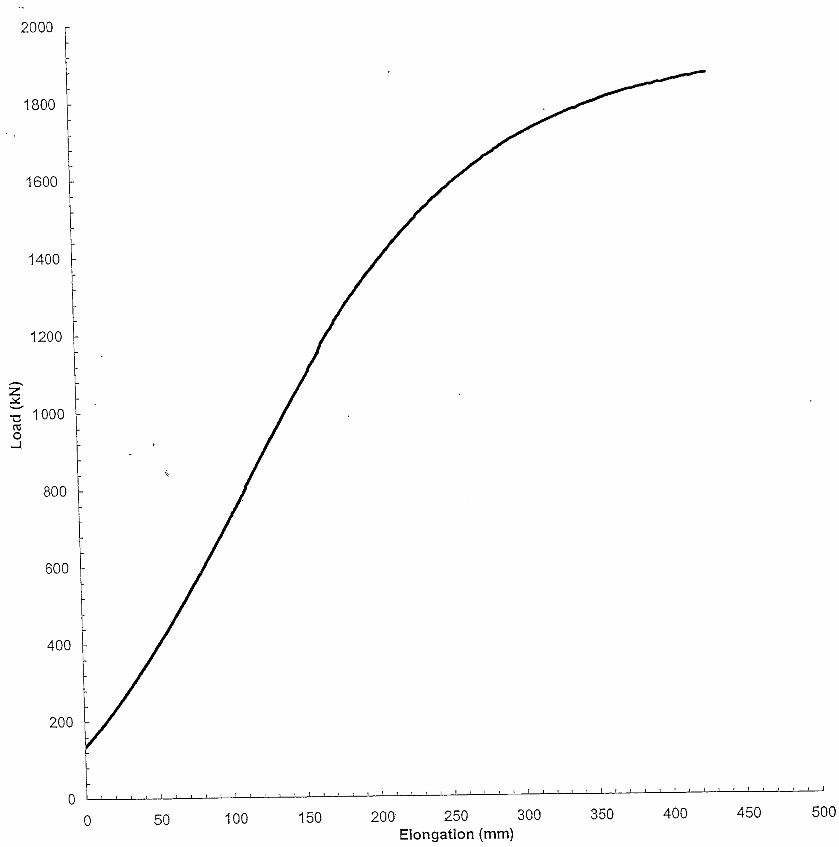
CERTIFICATE No. T06898 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	537.4	Date of test:	31/10/2003
Plastic fraction of energy (kN.m)	294.0	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	173.1 (1.1%)	Gauge length (m):	15.5
Slope (kN/mm)	7.1	Breaking force (kN):	1865.3



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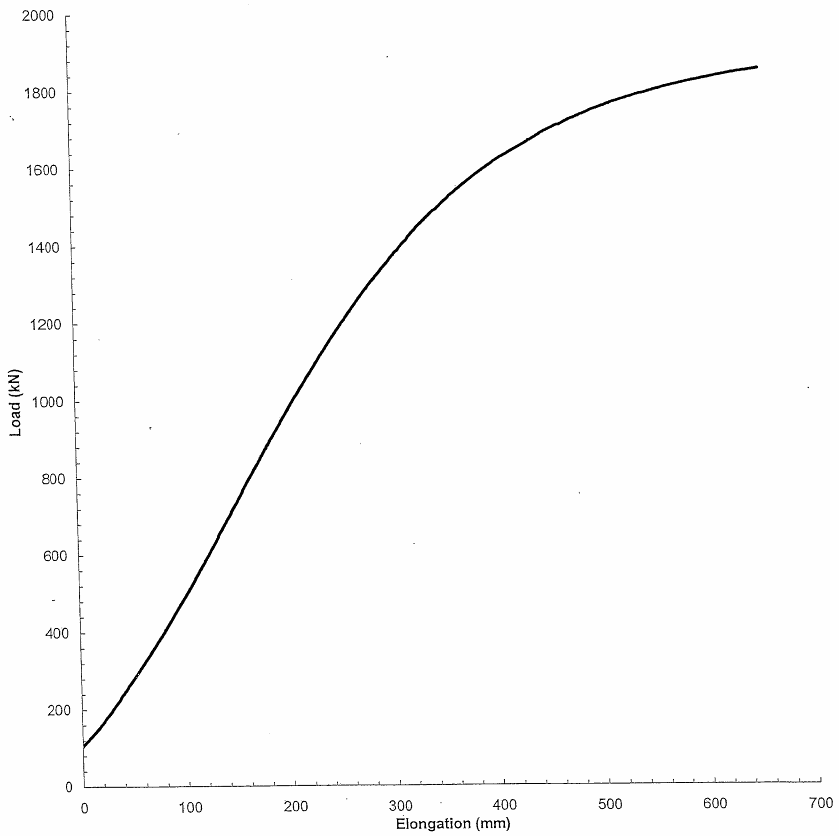
CERTIFICATE No. T06904 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	817.6	Date of test:	04/11/2003
Plastic fraction of energy (kN.m)	465.3	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	276.9 (1.2%)	Gauge length (m):	23.5
Slope (kN/mm)	4.9	Breaking force (kN):	1853.6



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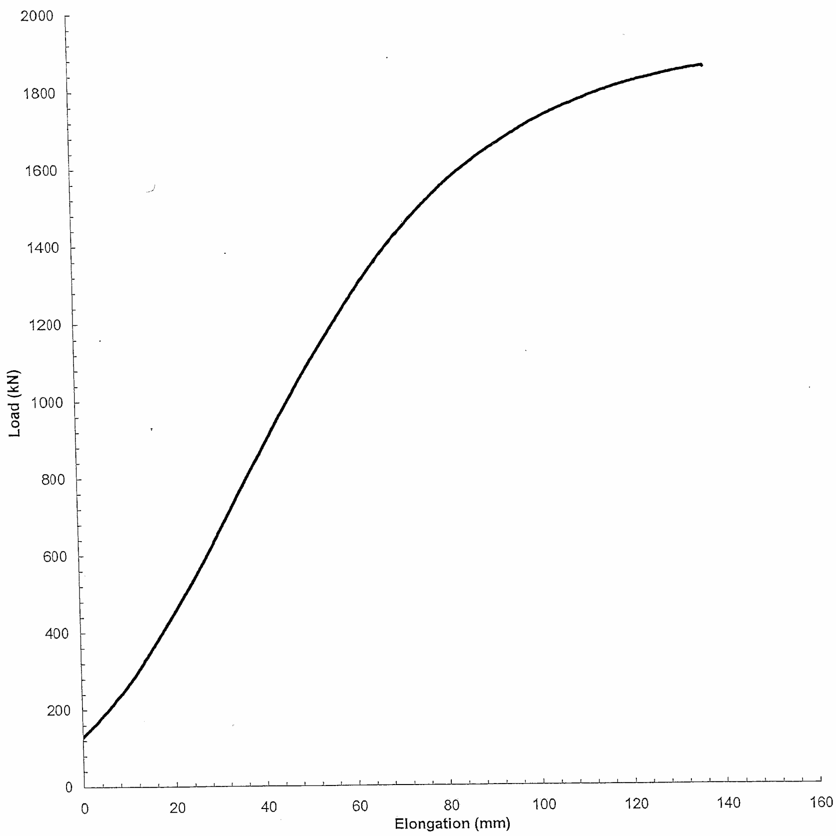
CERTIFICATE No. T06906 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	168.8	Date of test:	04/11/2003
Plastic fraction of energy (kN.m)	89.5	Diameter (mm):	53.0
Plastic fraction of elongation (mm)	52.8 (1.2%)	Gauge length (m):	4.5
Slope (kN/mm)	21.7	Breaking force (kN):	1859.5



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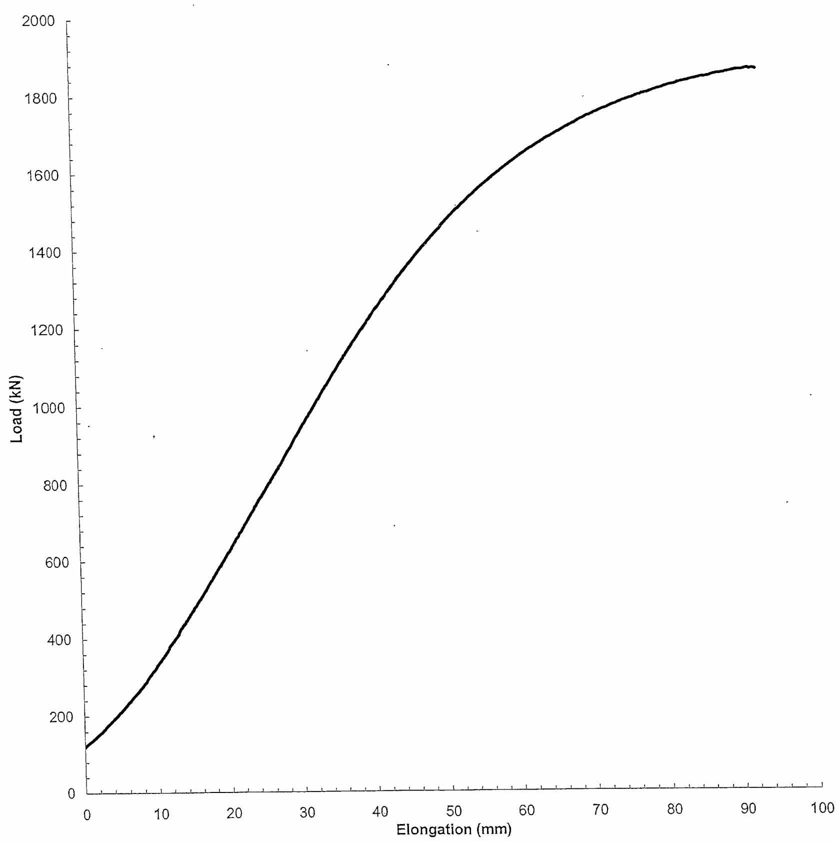
CERTIFICATE No. T06907 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	113.2	Date of test:	05/11/2003
Plastic fraction of energy (kN.m)	57.1	Diameter (mm):	50.0
Plastic fraction of elongation (mm)	33.3 (1.2%)	Gauge length (m):	2.7
Slope (kN/mm)	31.0	Breaking force (kN):	1865.9



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8. Appendix B: Test certificates: Non-spin rope

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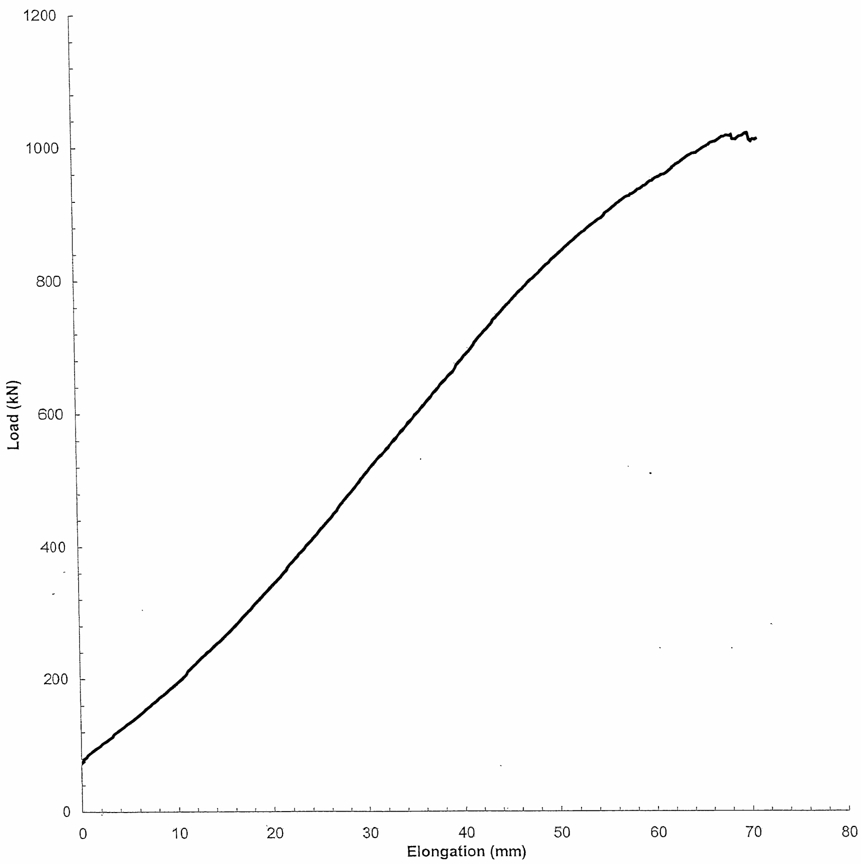
CERTIFICATE No. T06748   COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	41.5	Date of test:	12/09/2003
Plastic fraction of energy (kN.m)	11.1	Diameter (mm):	40.0
Plastic fraction of elongation (mm)	11.6 (0.4%)	Gauge length (m):	2.8
Slope (kN/mm)	16.9	Breaking force (kN):	1021.73999



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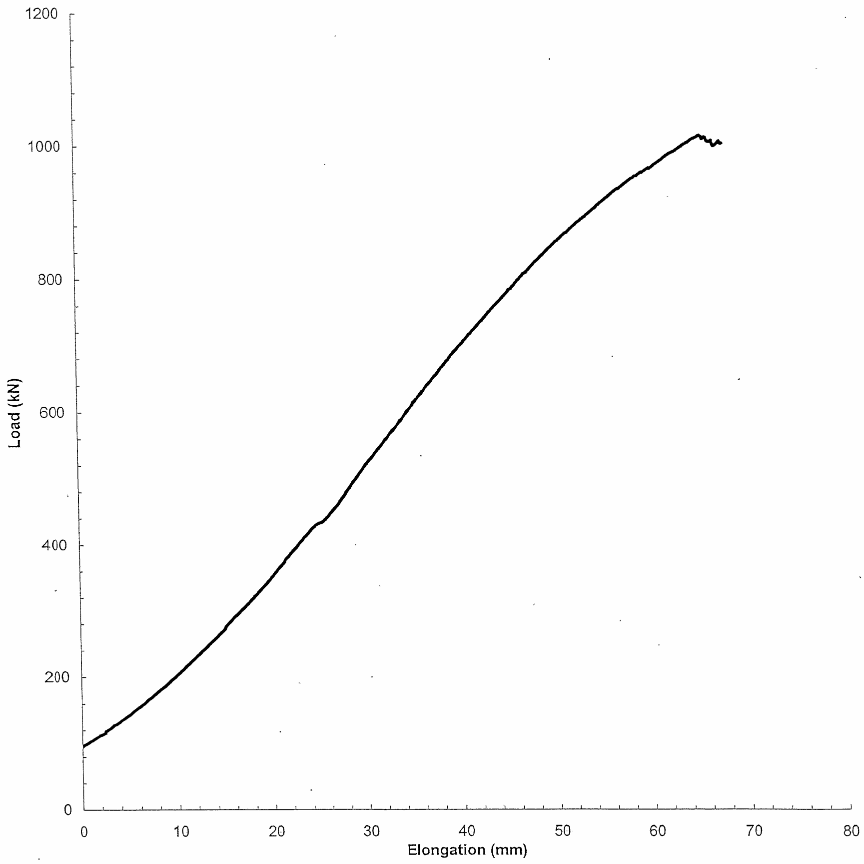
CERTIFICATE No. T06749 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	38.7	Date of test:	12/09/2003
Plastic fraction of energy (kN.m)	9.7	Diameter (mm):	40.0
Plastic fraction of elongation (mm)	10.0 (0.4%)	Gauge length (m):	2.8
Slope (kN/mm)	17.4	Breaking force (kN):	1015.463013



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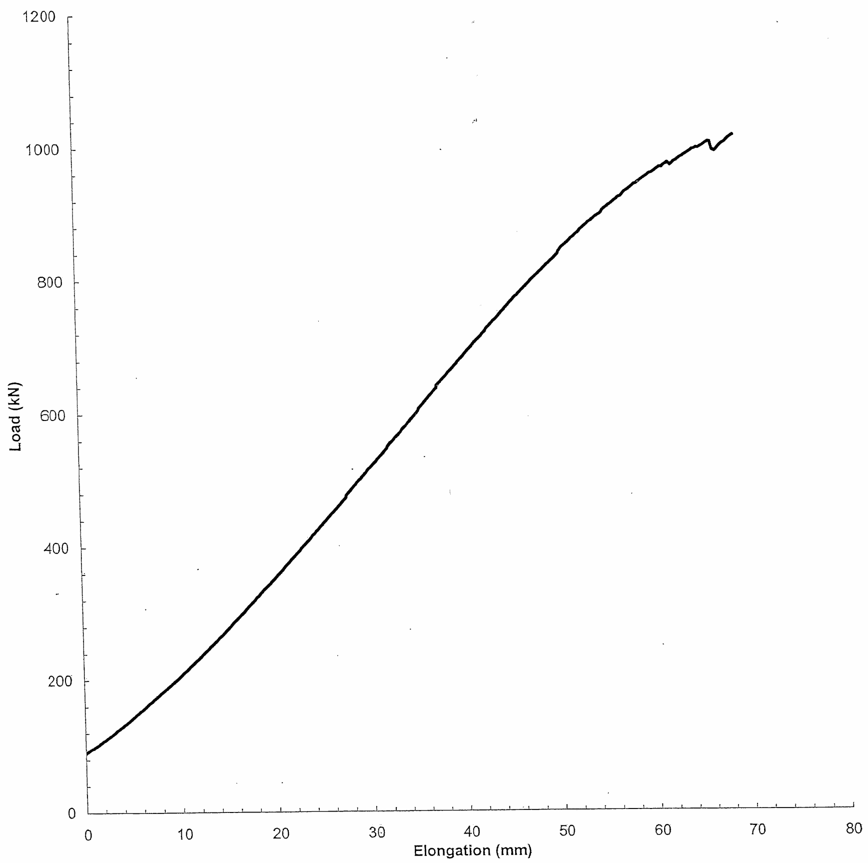
CERTIFICATE No. T06750 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	39.2	Date of test:	12/09/2003
Plastic fraction of energy (kN.m)	9.2	Diameter (mm):	40.0
Plastic fraction of elongation (mm)	9.9 (0.4%)	Gauge length (m):	2.8
Slope (kN/mm)	17.2	Breaking force (kN):	1015.705994



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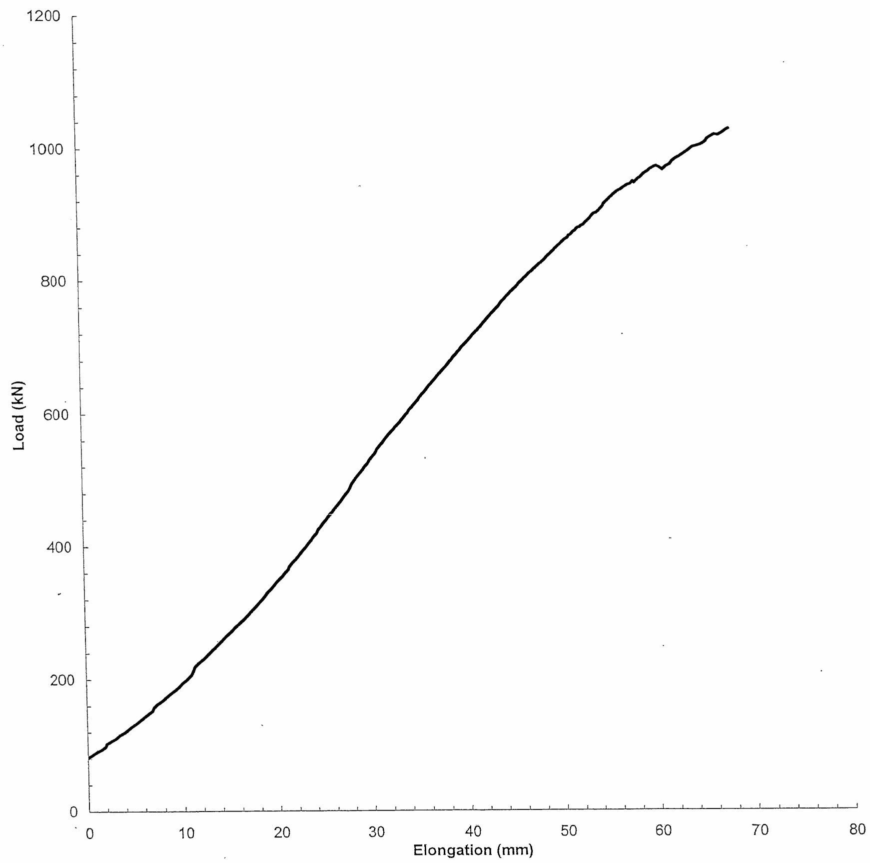
2006 South Africa

Delivery Address:
Cnr. Menton Road and Frost Avenue
Cottesloe 2092 Johannesburg

CERTIFICATE No. T06751 COIL No. No Coil Number

Applicant: SIMRAC GAP 836

Strain energy to failure (kN.m)	39.0	Date of test:	12/09/2003
Plastic fraction of energy (kN.m)	8.9	Diameter (mm):	40.0
Plastic fraction of elongation (mm)	9.7 (0.4%)	Gauge length (m):	2.8
Slope (kN/mm)	17.5	Breaking force (kN):	1026.254028



Private Bax X28, Auckland Park, 2006 Tel: +27 11 482-1300	Engineer:

This Certificate of Test relates only to the samples or components tested and is issued subject to the conditions of the CSIR. Please see overleaf for Conditions of Issue of Test Certificates

Your Technology Partner