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DURABILITY OF POLYESTER ROPES – EXTENSION TO STUDY

(MMS PROJECT #344 PROPRIETARY 2008)

FINAL REPORT

EXAMINATION AND TENSILE TESTING OF 10TONNE SCALE ROPES AND FULL SCALE SUBROPE FOR INTERNAL WEAR

Ref: TTI-SJB-2005-321

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CONTENTS

EXECUTIVE SUMMARY

Inter-strand wear (within the sub-rope, not between parallel laid sub-ropes) is confirmed as a mechanism that occurs for the higher load ranges tested herein.

At the lower load ranges, no wear was detected. A cut off point has been established below which wear does not take place.

A bi-variate analysis of the residual strength data has shown there is a consistent trend for all ropes, that tenacity increases with mean load and decreases with load range. This is expected since some locking or reduction of inter-strand slip will occur at the higher mean loads and slip increases with load range.

A comparison of the experimental results with the values predicted by bi-variate approximations is, in general, very encouraging, to the point that it would be possible to use the approximations to predict the performance of similar ropes under different mean loads and load ranges.

There was a significant effect of scale at the 8 and 15% load range, where strength loss was significantly higher in full scale compared to scale. This was expected from the computer modelling of inter-strand slip, which showed up to an order magnitude higher slip scale to full scale.

A new finding has been positively identified, that textile yarn residual tenacity increases with mean load. This was probably due to higher mean load reducing slip.

It has also been established that wear takes place on both sides of the outer yarn in the strand that is exposed to inter-strand slip.

SEM examination showing the depth of inter-strand wear correlates well with the tenacity results and confirms the mechanism.

The findings of this study have generated a sufficient knowledge base and will now enable modelling or calculations of the magnitude of inter-strand wear and its effect on strength loss over lifetime in full scale ropes. It should be noted that effects of creep rupture also need to be taken into account and this is being addressed in separate studies.

It should be noted that even though up to 30% strength loss after 1 million cycles was found in the outer textile yarn at full scale at the highest load range, this reduces to a few percent when compared to the cycles in a mooring line using an example FPSO mooring over 30 year lifetime.

Neither strength loss nor axial compression kinks were found in any of the samples at any of the low minimum load conditions. Thus, axial compression is not an issue for polyester under these tests conditions and rope designs.

This data and findings apply to polyester ropes designed for deepwater mooring and at the lay angles used in these samples.

Reducing lay angle of the full scale sub-rope has been identified to have a significant effect on reducing inter-strand wear. A sufficiently low sub-rope lay angle will reduce inter-strand slip so that there is not any strength loss.

The magnitude of strength increase with bedding-in has been established. This may have important implications for the interpretation of a single full scale insert residual strength test. Such that an increase in strength does not necessarily mean that no internal wear has occurred, if the strength increase due to bedding-in is greater than the strength loss due to internal wear.

NOMENCLATURE AND ABBREVATIONS

ABBREVIATIONS

SEM	Scanning Electron Microscopy
YOY	Yarn-on-yarn
YPS	Yarns per strand
TPM	Turns per metre
WRC	Wire rope construction
PWRC	Parallel strand construction, made from wire rope construction sub-ropes
PSC	Parallel strand construction, made from 3 strand sub-ropes
PBC	Parallel strand construction, made from braided sub-ropes
SR	Sub-rope (could be WRC, 3 strand or braided construction), used in a parallel assembly to make a rope

DEFINITIONS

FILAMENT	Smallest fibre component around 20µm diameter
TEXTILE YARN	Parallel assembly of filaments, typically 100-200µm
ROPE YARN	Twisted assembly of textile yarns
STRAND	Twisted assembly of rope yarns
T-N	Tension-tension fatigue line
TENACITY	Breaking Load of a textile element divided by its Linear Density. Units used in this report are N/Tex or mN/Tex

BREAKING EXTENSION Expressed as a % of the original gauge length of the tensile [Br Ext] test.

1. INTRODUCTION

1.1 Preamble

The overall objective of the study was to evaluate the long term durability of fibre ropes and allow operators to capitalize on the commercial and technical benefits through their utilisation in deep water developments.

This study was an extension to the Durability of Polyester Ropes JIP (ref 1.)

This report consists of a set of sections that summarise and discuss the results and findings of this study, and a set of appendices that are reports of the studies performed on individual 10 tonne and full scale sub–rope strops.

1.2 Objectives

The objectives listed below are from the proposal (ref 2.)

1. Raise API 2SK minimum tension criteria and allowable cycles.

2. Determine scale effect from the previously identified slip induced wear fatigue mechanism at 10 tonne scale and full-scale sub-rope.

3. Provide data to complement the Durability JIP to further understand the relationship between load range and slip induced wear and identify boundary above/below which wear starts/stops. This will enable calculations of both fatigue life and residual strength since the primary fatigue mode that may operate during the mooring lifetime is internal abrasion between strands in sub-ropes.

4. Provide further evidence of the new finding that axial compression is not a fatigue mechanism in low load cycling.

1.3 Sponsorship

This Joint Industry Project Extension into the 'The Durability of Polyester Ropes' was co-promoted by NEL and TTI Ltd and supported, either financially, in kind contribution or both, by the following companies.

Ropemakers

Scanrope (PWRC)
Marlow Ropes (PSC)
Quintas and Quintas (PBC)

Oil Companies

Chevron
BP-Amoco
Statoil
Shell
Texaco
Total Fina Elf

Regulatory/Classification Bodies

US Minerals and Management Service
Bureau Veritas

The technical input and support provided by the company representatives during the quarterly steering committee meetings has proved invaluable and contributed in no small way to the successful outcome of the study. Their input is greatly appreciated by the project promoters. We also acknowledge the considerable effort from the ropemakers in providing well made and designed samples that, has led to an unsurpassed set of data with very low variability.

2. ROPE CONSTRUCTIONS

Figures 2.1, 2.2 and 2.3 show photographs of the rope constructions for the 10tonne ropes, made from a parallel assembly of sub-ropes.

Figure 2.1 PBC rope, made from parallel assembly of braided sub-ropes

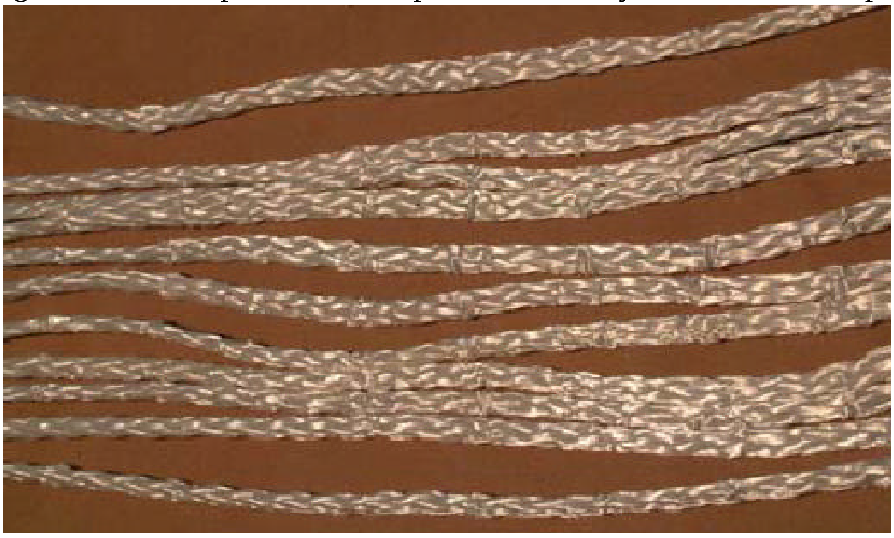


Figure 2.2. PWRC rope, made from parallel assembly of WRC sub-ropes

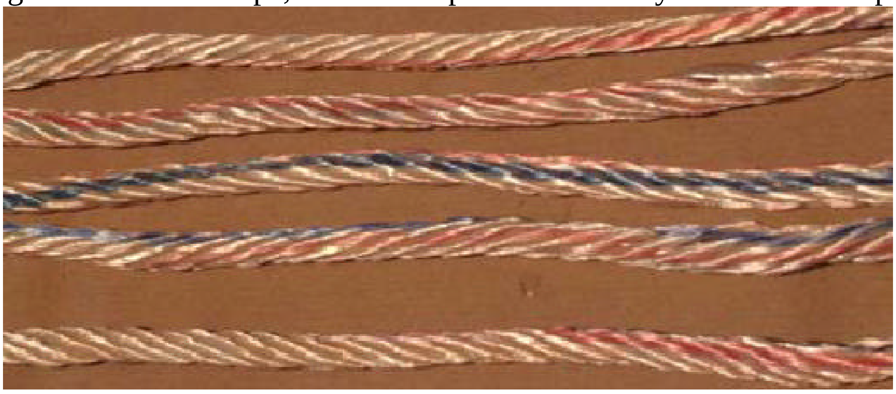
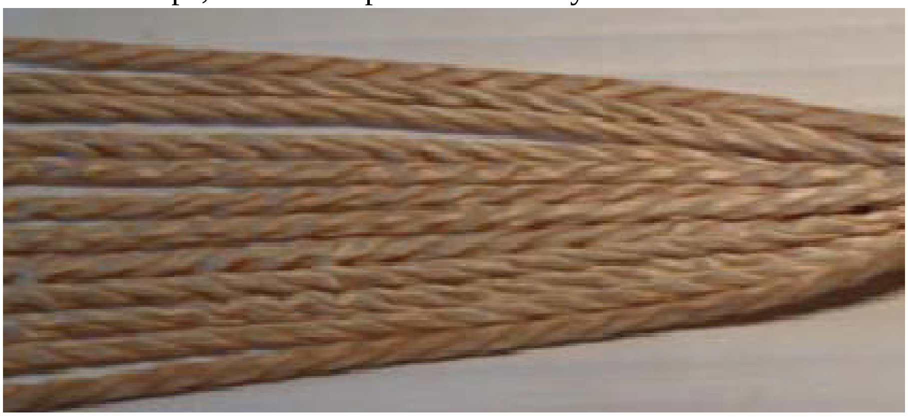


Figure 2.3 PSC rope, made from parallel assembly of braided 3 strand sub-ropes



Figures 2.4, 2.5 and 2.6 show photographs of the rope constructions for the full scale sub-rope

Figure 2.4 Full scale PWRC sub-rope (6 round 1 construction)

Figure 2.5 Full scale PSC sub-rope (3 strand construction)

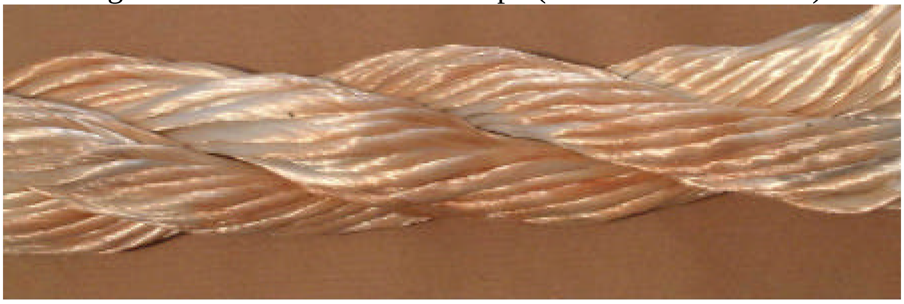


Figure 2.6 Full scale PBC sub-rope (8 strand braided)

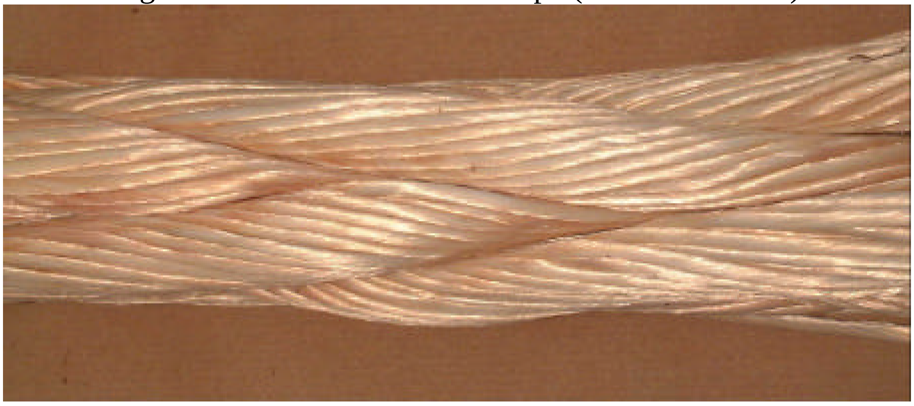
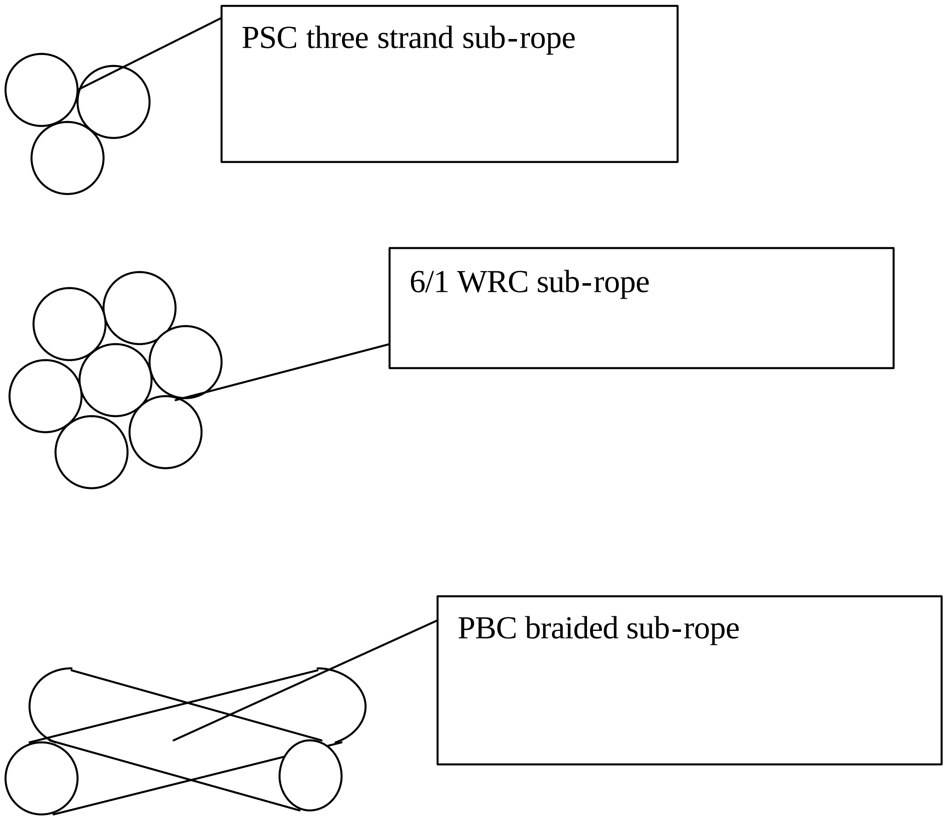


Figure 2.7 shows the main area of interest to study the inter-strand wear at the strand contacts within each sub-rope. When an axial load is applied to the structure, it stretches resulting in a change in helix angle. This change in helix angle creates relative slip between the strands.

Figure 2.7 Diagram of principal area of interest for studying for inter-strand wear at strand contacts in each sub-rope



Note that the 10 tonne PSC and PBC ropes are made from sub-ropes which have only one ropeyarn in the strand ie there are no layers of ropeyarns. Note that the 10 tonne PWRC sub-ropes are 6/1 and have one inner and 6 outer ropeyarns giving two layers of ropeyarns. The strand in the full scale sub-rope has several layers of ropeyarns.

3. OVERVIEW OF TESTING PROGRAMME

Tables 3.1 to 3.3 summarise the investigations performed on the 10 tonne strops received from NEL.

Table 3.1 Investigations performed on 10 Tonne PSC Samples

	Mean load (%ABS)	Load range (%ABS)	Cycles	Tensile testing, textile yarn	Tensile testing, textile filament	SEM
MRXC1	20	20	1,000,000	Yes	-	Yes
MRXC2	5	8	1,000,000	Yes	-	Yes
MRXC3	60	6	1,000,000	Yes	-	Yes
MRXC4	20	10	1,000,000	Yes	-	Yes
MRXC5	3	4	1,000,000	Yes	-	Yes
MRXC6	20	15	1,000,000	Yes	Yes	Yes
MRXC7	60	6	2,000,000	Yes	-	Yes

Table 3.2 Investigations performed on 10 Tonne PBC Samples

	Mean load (%ABS)	Load range (%ABS)	Cycles	Tensile testing	Tensile testing Textile filament	SEM
MRZW1	20	10	1,000,000	Yes	-	Yes
MRZW2	3	4	1,000,000	Yes	-	Yes
MRZW3	4	4	1,000,000	Yes	-	Yes
MRZW4	20	15	1,000,000	Yes	-	Yes
MRZW5	20	20	1,000,000	Yes	-	No
MRZW6	30	10	1,000,000	Yes	-	No
MRZW7	30	15	1,000,000	Yes	-	No
MRZW8	30	20	1,000,000	Yes	Yes	No
MRZW18	5	8	1,000,000	Yes	-	No

Table 3.3 Investigations performed on 10 Tonne PWRC Samples

	Mean load (%ABS)	Load range (%ABS)	Cycles	Tensile testing	Tensile testing Textile filament	SEM
MSAN1	5	8	1,000,000	Yes	-	Yes
MSAN2	30	10	1,000,000	Yes	-	No
MSAN3	10	12	1,000,000	Yes	-	No
MSAN4	30	15	1,000,000	Yes	-	No
MSAN5	30	20	1,000,000	Yes	Yes	No

Tables 3.4 to 3.6 show the investigations performed on the full scale sub-ropes received from NEL

Table 3.4 Investigations performed on full scale PSC subrope

Sample: PSC sub-rope	Mean load (%ABS)	Load range (%ABS)	Cycles	Tensile testing	SEM
MRXC11	60	6	1,000,000	Yes	No
MRXC13	20	15	1,000,000	Yes	Yes
MRXC14	3	4	1,000,000	Yes	Yes
MRXC14 rpt	3	4	1,000,000	Yes	No

Table 3.5 Investigations performed on full scale PBC subrope

Sample: PSC sub-rope	Mean load (%ABS)	Load range (%ABS)	Cycles	Tensile testing	SEM
MRZW14	5	8	1,000,000	Yes	Yes

Table 3.6 Investigations performed on full scale PWRC subrope

Sample: PSC sub-rope	Mean load (%ABS)	Load range (%ABS)	Cycles	Tensile testing	SEM
MASN12	5	8	1,000,000	Yes	Yes

Tensile testing of textile yarns for all strops and sub-ropes, and for all testing conditions, was performed.

Also, tensile testing of single filaments from the 10 tonne strops for PSC 20% mean/15% range, PBC 30% mean/20% range and PWRC 30% mean/20% range were performed.

SEM investigations were conducted on the 10 tonne strops for all the PSC test conditions, for PBC 3% mean/4% range, 4% mean/4% range, 20% mean/10% range and 20% mean/15% range test conditions, and for PWRC 5% mean/8% range condition. Finally, SEM investigations were conducted on all the full scale sub-ropes, apart from the PSC 60% mean/6% range test condition

A minimum of 4 rope yarns were selected from an inner sub-rope from the mid span section of each 10 tonne strop. This was to avoid any affects from jacket damage, which in past studies has been found to generate minor wear. Each rope yarn was divided into inner and outer textile yarns (40-80 for each layer), all yarns being residual strength tested. Since there was only one layer of ropeyarns in the strand, no inner/outer exists. For the full scale sub-ropes, there was more than one layer of ropeyarns in the strand, so inner/outer samples were taken. For the full scale PWRC, there was an inner strand and outer strands, from which inner/outer ropeyarns were taken. These ropeyarns from full scale sub-ropes were split down in the same manner as for the 10tonne ropes. All the individual results are shown in the appendices and the average results are summarised in section 4.

4. SUMMARY OF TENSILE TEST RESULTS AND STATISTICAL ANALYSIS

4.1 10 tonne strops

4.1.1 Textile Yarn tensile test results

Table's 4.1.1 to 4.1.6 summarise the average tensile results from textile yarn tests from the 10 tonne strop samples, for each construction.

Tenacity has been calculated on the basis that textile yarns from the PSC samples are 220 Tex, and textile yarns from the PBC and PWRC samples are 122 Tex

Table 4.1.1 Tensile results of textile yarns from PSC 10 tonne strops

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
Reference	0	0	0	742 sd 30 cv 4.0%	13.7	742 sd 30 cv 4.0%	13.7
MRXC1	20	20	10	688 sd 41 cv 5.9%	10.6	667 sd 31 cv 4.6%	10.2
MRXC2	5	8	1	710 sd 31 cv 4.3%	12.2	678 sd 28 4.0%	11.6
MRXC3	60	6	57	736 sd 25 cv 3.4%	11.6	719 sd 29 cv 4.0%	11.2
MRXC4	20	10	15	711 sd 36 cv 5.0%	11.8	695 sd 38 cv 5.4%	11.6
MRXC5	3	4	1	697 sd 48 cv 6.9%	12.2	674 sd 44 cv 6.6%	11.7
MRXC6	20	15	12.5	686 sd 42 cv 6.1%	11.0	681 sd 35 cv 5.1%	10.9
MRXC7 [$2x10^6$]	60	6	57	731 sd 31 cv 4.2%	11.4	710 sd 30 cv 4.2%	11.0

In table 4.1.1 and 4.1.4, for the duplicate tests MRXC3 and MRXC6 (except cycles), the inner yarn tenacity and break elongation is very repeatable. For MRXC7 which had 2 million cycles, the outer yarn does show a further small reduction of tenacity with increasing cycles, which would be expected due to inter-strand abrasion.

Table 4.1.2. Tensile results of textile yarns from PBC 10 tonne strops

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
Reference	0	0	0	716 sd 43 cv 6.0%	11.1	701 sd 27 cv 3.9%	10.5
MRZW1	20	10	15.0	723 sd 28 cv 3.9	11.1	707 sd 33 cv 4.7%	10.9
MRZW2	3	4	1.0	713 sd 26 cv 3.6%	11.0	692 sd 30 cv 4.4%	10.5
MRZW3	4	4	2.0	723 sd 30 cv4.2%	11.2	709 sd 30 cv 4.2%	10.9
MRZW4	20	15	12.5	674 sd 44 cv 6.6%	10.1	659 sd 25 cv 3.8%	9.8
MRZW5	20	20	10.0	675 sd 46 sd 6.8%	10.3	636 sd 30 cv 4.7%	9.6
MRZW6	30	10	25.0	728 sd 26 cv 3.6%	11.8	705 sd 32 cv 4.6%	11.4
MRZW7	30	15	22.5	710 sd 28 cv 4.0%	11.5	684 sd 38 cv 5.6%	11.1
MRZW8	30	20	20.0	694 sd 41 cv 5.9%	10.9	669 sd 34 cv 5.1%	10.6
MRZW18	5	8	1.0	706 sd 25 cv 3.5%	10.5	689 sd 20 cv 2.9%	10.1

Table 4.1.3. Tensile results of textile yarns from PWRC 10 tonne strops

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
Reference	0	0	0	693 sd 31 cv 4.5%	10.9	685 sd 27 cv 3.9%	10.5
MSAN1	5	8	1	637 sd 31 cv 4.9%	9.2	631 sd 32 cv 5.0%	9.0
MSAN2	30	10	25	702 sd 31 cv 4.5%	11.0	679 sd 41 cv 6.1	10.4
MSAN3	10	12	4	647 sd 40 cv 6.1%	9.6	620 sd 24 cv 3.9%	8.9
MSAN4	30	15	22.5	670 sd 27 cv 4.0%	10.3	660 sd 17 cv 2.6%	10.1
MSAN5	30	20	20	632 sd 37 cv 5.8%	9.7	626 sd 18 cv 2.9%	9.5

In all constructions, the highest tenacity loss was at the highest load range.

In every load condition and construction, it can be seen that yarns taken from the inner layers of a rope yarn have better tensile properties than yarns taken from the outer layer. This is entirely to be expected, and in line with the inter-strand wear mechanism.

Generally, both Tenacity and Breaking Extension are reduced when compared to textile yarn results from reference ropes supplied by the rope manufacturers, particularly for the higher load ranges.

All the 10 tonne results show very low coefficient of variation and was similar to the reference, showing that the nature of damage is consistent and predictable.

Table 4.1.4. PSC 10 tonne strops, textile yarn % strength loss relative to reference

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity	Tenacity mN/Tex	% tenacity change
Reference	0	0	0	742		742	
MRXC1	20	20	10	688	-7.3	667	-10.1
MRXC2	5	8	1	710	-4.3	678	-8.6
MRXC3	60	6	57	736	-0.8	719	-3.1
MRXC4	20	10	15	711	-4.2	695	-6.3
MRXC5	3	4	1	697	-6.1	674	-9.2
MRXC6	20	15	12.5	686	-7.5	681	-8.2
MRXC7 [$2x10^6$]	60	6	57	731	-1.5	710	-4.3

Table 4.1.5. PBC 10 tonne strops, textile yarn % strength loss relative to reference

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
Reference	0	0	0	716		701	
MRZW1	20	10	15	723	1.0	707	0.9
MRZW2	3	4	1	713	-0.4	692	-1.3
MRZW3	4	4	2	723	1.0	709	1.1
MRZW4	20	15	12.5	674	-5.9	659	-6.0
MRZW5	20	20	10	675	-5.7	636	-9.3
MRZW6	30	10	25	728	1.7	705	0.6
MRZW7	30	15	22.5	710	-0.8	684	-2.4
MRZW8	30	20	20	694	-3.1	669	-4.6
MRZW18	5	8	1	706	-1.4	689	-1.7

Table 4.1.6. PWRC 10 tonne strops, textile yarn % strength loss relative to reference

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
Reference	0	0	0	693		685	
MSAN1	5	8	1	637	-8.1	631	-7.9
MSAN2	30	10	25	702	1.3	679	-0.9
MSAN3	10	12	4	647	-6.6	620	-9.5
MSAN4	30	15	22.5	670	-3.3	660	-3.6
MSAN5	30	20	20	632	-8.8	626	-8.6

Table's 4.1.4 to 4.1.6 show the tenacity (or strength loss) loss relative to the reference, new untested textile yarn removed from control samples of rope. Tenacity loss is highest with the highest load range. At the low mean load and low load range, the loss was also high, which was due to high slip induced at low modulus (see section 6 for full explanation).

To confirm that the raw data had integrity, before proceeding with further analysis, tenacity was plotted against break extension from every single test. If there were no problems, it would be expected that tenacity was directly proportional to break extension, and this proved to be the case. Figures 4.1 to 4.3 show Tenacity versus break extension for the outer textile yarns of PSC, PBC and PWRC sets of samples.

Figure 4.1 Relationship between Textile Yarn Tenacity and Breaking Extension for PSC rope yarns

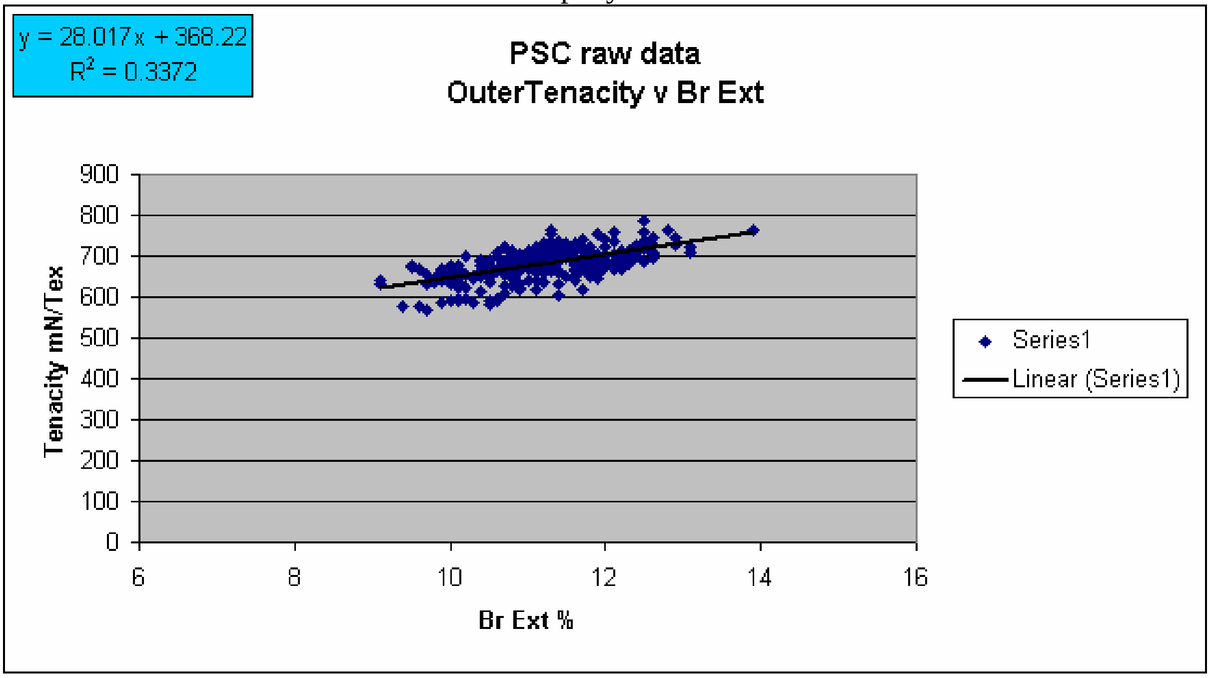


Figure 4.2 Relationship between Textile Yarn Tenacity and Breaking Extension for PBC rope yarns

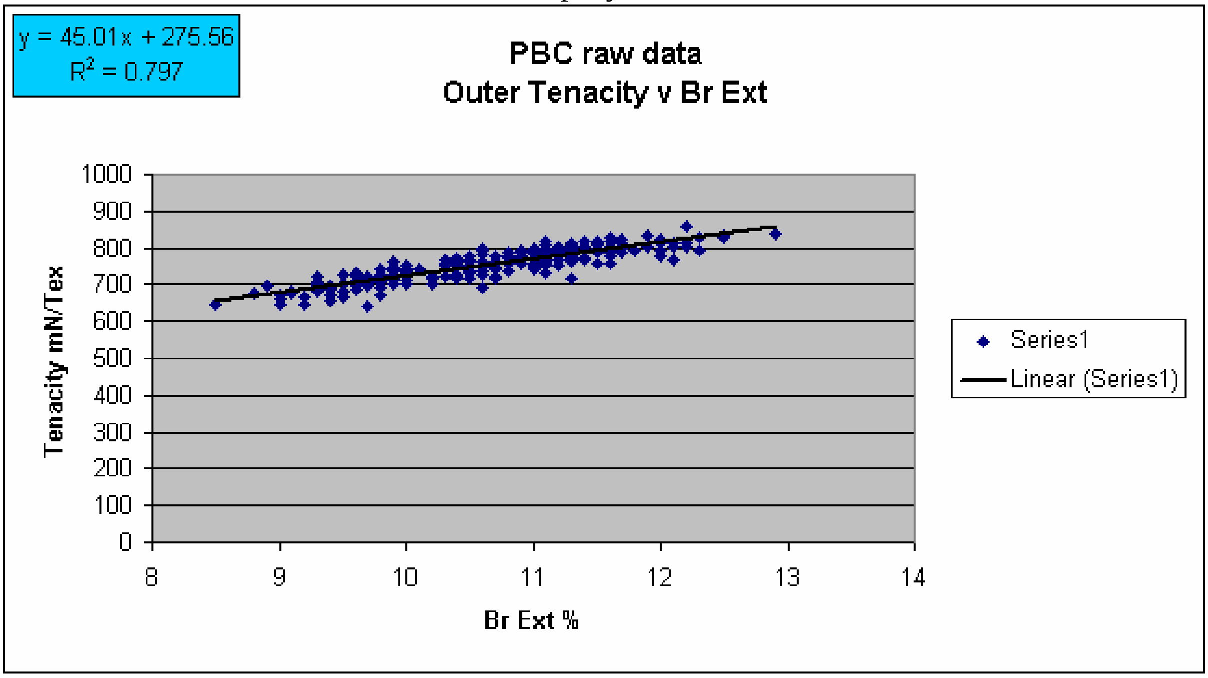
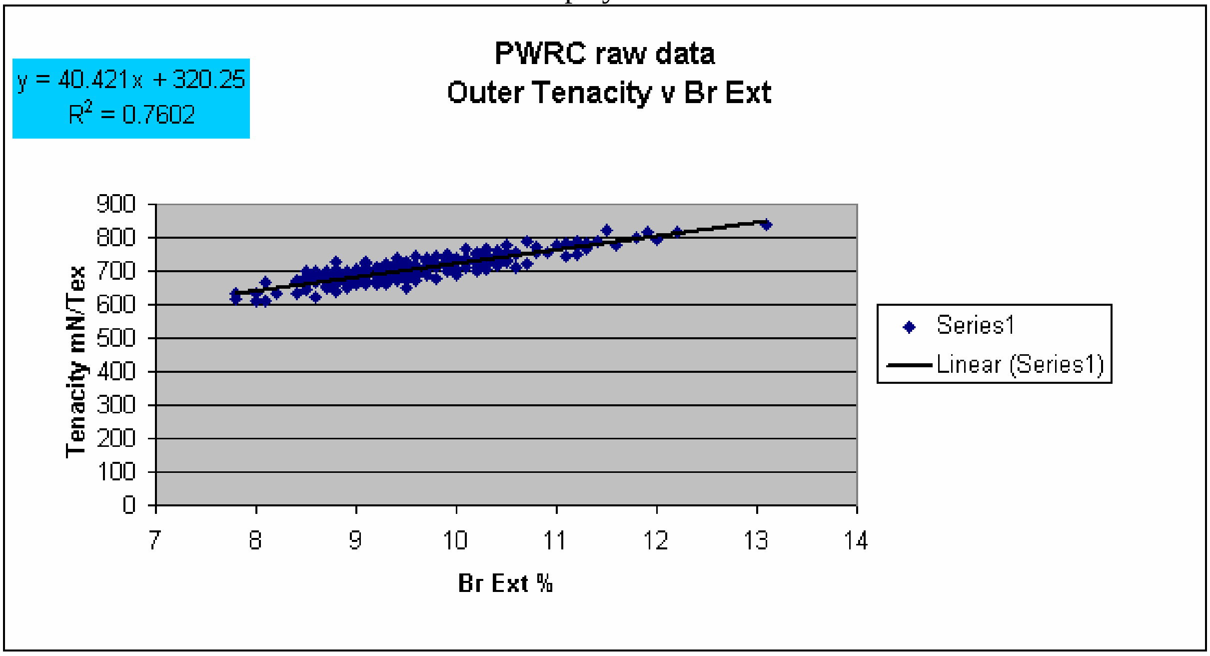


Figure 4.3 Relationship between Textile Yarn Tenacity and Breaking Extension for PWRC rope yarns



The correlation for PSC textile yarn, as represented by R^2 was quite low, but for PBC and PWRC materials the relationship was much better. Similar relationships were found with the raw inner data. As detailed in section 4.4, the higher scatter in the PSC data was due to the fact this was tested to 60% mean whereas the PBC and PWRC was not.

It was concluded that the basic data was sound and could be used for further statistical analysis in section 4.4.

4.1.2 Single Filament tensile test results

This was an exploratory study to see if filament testing provides more information. It was not intended to be part of the original work scope. Furthermore, it is well known that very large numbers of test have to be conducted with single filaments, because of the higher scatter at this size of component, compared to textile yarn.

Tensile strength was measured at the filament level from a selection of the 10 tonne strops, using optical microscopy to classify filaments into groups according to an assessment of the amount of damage found. The specimens selected for dissection down to the filament level were from contact points between strands, though selecting filaments to be from an outer layer of a textile yarn that itself was located in the outer circumference of a rope yarn was very difficult.

It was not possible to mount the filaments in oil, to maximise image quality, as the viewed filaments were then to be tensile tested. Consequently, many features were seen that appeared to be the results of abrasion, but were suspected to be artefacts. Further examination under SEM proved to be just that. However, three categories of filament could be identified, a first category where the filaments appeared in good condition, a second category for filament-filament abrasion and a third category with miscellaneous damage.

Table 4.1.7 is a summary of the results. It can be seen that coefficient of variation was reasonable given the number of tests and was at the lower end expected for fatigue tested material.

Table 4.1.7. Summary of tensile results for textile filaments from 10 tonne strops

Construction and code	Good Condition			Filament-filament abrasion			Miscellaneous damage		
	Ave Br Load mN	SD mN	CoV %	Ave Br Load mN	SD mN	CoV %	Ave Br Load mN	SD mN	CoV %
PSC MRXC6	826	51.4	6.2	810	51.5	6.4	803	59	7.3
PBC MRZW8	515	28.2	5.5	488	N/A	N/A	527	N/A	N/A
PWRC MSAN5	492	37.5	7.6	451	N/A	N/A	477	46.2	9.7

For MRXC6, 51 filaments were inspected and tested:
31% were in good condition
39% showed signs of filament-filament abrasion
30% showed miscellaneous damage

For MRZW8, 50 filaments were inspected and tested:
94% were in good condition
4% showed signs of filament-filament abrasion
2% showed miscellaneous damage

For MSAN5, 48 filaments were inspected and tested:
83% were in good condition
4% showed signs of filament-filament abrasion
13% showed miscellaneous damage

For the investigations performed on the PBC and PWRC samples, the number of filaments assessed to be suffering from either filament-filament abrasion or miscellaneous damage was low, making statistical analysis meaningless.

TTI have been advised that the nominal denier per filament for PSC textile yarns is 9, or 1 Tex, and for PBC and PWRC it is 6, or 0.67 Tex. On this basis, the filament Tenacity is shown in Table 4.1.8.

Table 4.1.8. Summary of Tenacity for textile filaments from 10 tonne strops

Construction and code	Good Condition		Filament-filament abrasion		Miscellaneous damage	
	Ave Br Load mN	Tenacity mN/Tex	Ave Br Load mN	Tenacity mN/Tex	Ave Br Load mN	Tenacity mN/Tex
PSC MRXC6	826	826	810	810	803	803
PBC MRZW8	515	769	488	728	527	787
PWRC MSAN5	492	734	451	673	477	712

Obviously, working on such a small scale means that the chances of establishing a complete view of tensile performance as a function of the degree of abrasion damage at the filament level would require a substantial amount of testing. However, there was some indication that a visual assessment of damage was capable of differentiating filaments into groups of varying levels of damage.

Table 4.1.9 shows a comparison of the single filament tests against the textile yarns tests. For the filaments, we have the good condition, which has not suffered abrasion, giving around 2% to 8% strength loss compared with the abraded filaments. For the textile yarn, clearly the outer filaments only have been subjected to abrasion and the inner filaments protected, giving 0.7 to just under 4% strength loss. The textile yarn strength loss is lower in all cases, which would be expected, since they contain filaments that are not affected by abrasion. These results also show further evidence of the relative magnitude of abrasion damage at the different levels of components.

Table 4.1.9. Comparison of filament and textile yarn tensile tests, % strength loss

Construction and code	Filament tests			Textile yarn tests		
	Good Condition mN/tex	Filament-filament abrasion MN/tex	% strength loss	Inner	Outer	% strength loss
PSC MRXC6	826	810	-1.9	686	681	-0.7
PBC MRZW8	769	728	-5.3	694	669	-3.6
PWRC MSAN5	734	673	-8.3	632	626	-1.0

4.2 Full scale sub rope tensile test results

Table's 4.2.1 to 4.2.14 show the results of tensile testing of textile yarns from the full scale sub-rope testing programme. For PSC and PBC, the results are separated into inner and outer rope yarns sampled from a strand, whilst for PWRC the testing was done from the inner and outer strand of the 6/1 construction. These strands were further separated into inner and outer yarns.

The calculations for Tenacity have been performed on the basis that the linear density for the tensile yarns of the PSC sub-ropes was 222 Tex, for PBC it is 244 tex and for PWRC it was 110 Tex.

Table 4.2.1. Tensile results of textile yarns, full scale PSC sub-rope, inner rope yarns.

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
Reference	0	0	0	718 sd 22 cv 3%	14.1	713 sd 42 cv 5.9%	14.0
MRXC11	60	6	57	736 sd 35 cv 4.8%	11.3	727 sd 42 cv 6.1%	11.4
MRXC13	20	15	12.5	630 sd 97 cv 15.5%	10.5	610 sd 100 cv 16.4%	10.2
MRXC14	3	4	1	691 sd 47 cv 6.9%	13.4	663 sd 53 cv 8.0%	13.0
MRXC14 re-test	3	4	1	698 sd 52 cv 7.4%	13.7	685 sd 62 cv 9.2%	13.4

Table 4.2.2. Tensile results of textile yarns, % tenacity change, full scale PSC sub-rope, inner rope yarns.

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
Reference	0	0	0	718		713	
MRXC11	60	6	57	736	2.5	727	2.0
MRXC13	20	15	12.5	630	-12.3	610	-14.4
MRXC14	3	4	1	691	-3.8	663	-7.0
MRXC14 re-test	3	4	1	698	-2.8	685	-3.9

As shown in tables 4.2.1 and 4.2.2 for the inner ropeyarn, sample MRXC13 20% mean/15% range gave significantly reduced tenacity, but not as large as the outer ropeyarn. There must be sufficient slip to generate wear at full scale between ropeyarns in the 2 outer most layers. For the 60% mean load condition (MRXC 11), the inner and outer textile yarn had marginally higher tenacity.

Table 4.2.3. Tensile results of textile yarns, full scale PSC sub-rope, outer rope yarns

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MRXC11	60	6	57	703 sd 48 cv 6.8%	11.0	679 sd 42 cv 6.1%	10.7
MRXC13	20	15	12.5	589 sd 109 cv 18.5%	10.4	498 sd 98 cv 19.7%	9.3
MRXC14	3	4	1	680 sd 53 cv 7.7%	13.4	664 sd 47 cv 7.1%	13.1
MRXC14 re-test	3	4	1	706 sd 38 cv 5.4%	13.4	693 sd 37 cv 5.3%	13.3

As shown in table's 4.2.3 and 4.2.4 the PSC sample MRXC13, 20% mean/15% range, gave significantly lower tenacity at around 18% lower for inner and 30% lower for outer textile yarn in the outer ropeyarn. Also, breaking extension was significantly reduced and some broken filaments were visible by eye. The effects of slip will of course be much higher in the outer ropeyarns (table 4.2.3) compared to the inner ropeyarn (table 4.2.2), since they sit on a higher helix radius.

Table 4.2.4. Tensile results of textile yarns, % tenacity change, full scale PSC sub-rope, outer rope yarns

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
Reference	0	0	0	718		713	
MRXC11	60	6	57	703	-2.1	679	-4.8
MRXC13	20	15	12.5	589	-18.0	498	-30.2
MRXC14	3	4	1	680	-5.3	664	-6.9
MRXC14 re-test	3	4	1	706	-1.7	693	-2.8

Table 4.2.5. Tensile results of textile yarns, full scale PBC sub-rope, inner rope yarns

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MRZW14	5	8	1	667 sd 46 cv 6.8%	10.3	621 sd 42 cv 6.8%	9.8

Table 4.2.6. Tensile results of textile yarns, % tenacity change, full scale PBC sub-rope, inner rope yarns

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% change	Tenacity mN/Tex	% change
Reference	0	0	0	716		701	
MRZW14	5	8	1	667	-6.8	621	-11.4

Note: Reference tenacity from 10tonne sample

Table 4.2.7. Tensile results of textile yarns, full scale PBC sub-rope, outer rope yarns

	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MRZW14	5	8	1	659 sd 63 cv 9.6%	10.2	599 sd 67 cv 11.1%	9.5

Table 4.2.8. Tensile results of textile yarns, % tenacity change, full scale PBC sub-rope, outer rope yarns

	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% change	Tenacity mN/Tex	% change
Reference	0	0	0	716		701	
MRZW14	5	8	1	659	-8.0	599	-14.6

Table 4.2.9. Tensile results of textile yarns, full scale PWRC sub-rope, inner strand, inner rope yarns

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MASN12	5	8	1	695 sd 46 cv 6.7%	12.4	693 sd 27 cv 3.9%	12.1

Table 4.2.10. Tensile results of textile yarns, % tenacity change, full scale PWRC sub-rope, inner strand, inner rope yarns

	Mean % ABS	Range % ABS	Min % ABS	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% change	Tenacity mN/Tex	% change
Reference	0	0	0	693		685	
MASN12	5	8	1	695	0.3	693	1.2

Table 4.2.11 Tensile results of textile yarns, full scale PWRC sub-rope, inner strand, outer rope yarns

	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MASN12	5	8	1	715 sd 52 cv 7.2%	13.4	655 sd 50 cv 7.6%	11.7

Table 4.2.12. Tensile results of textile yarns, % tenacity change, full scale PWRC sub-rope, inner strand, outer rope yarns

	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% change	Tenacity mN/Tex	% change
Reference	0	0	0	693		685	
MASN12	5	8	1	715	3.2	655	-4.4

Table 4.2.13. Tensile results of textile yarns, full scale PWRC sub-rope, outer strand, outer rope yarns

	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MASN12	5	8	1	672 SD 23 CV 3%	11.8	610 SD 58 CV 9%	10.9

Table 4.2.14. Tensile results of textile yarns, % tenacity change, full scale PWRC sub-rope, outer strand, outer rope yarns

	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% change	Tenacity mN/Tex	% change
Reference	0	0	0	693		685	
MASN12	5	8	1	672	-3.0	610	-10.9

At a comparable level of structure (applies more to the outer layer of textile yarn), the coefficient of variation is higher for full scale sub-rope compared to the scale ropes due to the much higher level of damage.

4.3 Comparison of the tensile results between scale and full scale tests, for the same cyclic test conditions.

Table's 4.3.1 to 4.3.10 compare the tensile test results for the PSC, PBC and PWRC samples. For the % tenacity change data only, the full scale inner ropeyarn data has not been shown as there is no inner ropeyarn in the 10 tonne scale ropes, so it was not possible to make a comparison. Thus, the % tenacity change comparison scale to full scale was made on the basis that the outer layer of textile yarns are both subjected to inter-strand abrasion. It should be noted that the other parameters which affect the magnitude of wear are contact pressure, slip and lay angle, which may vary between scale and full scale.

Table 4.3.1. Comparison of PSC scale and full scale samples, 60% Mean, 6% Range

Linear Density MRXC3 220 Tex MRXC11 222 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MRXC3 Scale	60	6	57	736	11.6	719	11.2
MRXC11 Full scale inner ry	60	6	57	736	11.3	727	11.4
MRXC11 Full scale outer ry	60	6	57	703	11.0	679	10.7

Both inner and outer textile yarns from inner rope yarns appear to be unaffected by scale, but both sets of textile yarns for outer rope yarns have been, showing reduced Tenacity and % Breaking Extension at full scale of around 5% as shown in table 4.3.2.

Table 4.3.2. Comparison of PSC scale and full scale samples, 60% Mean, 6% Range

Linear Density MRXC3 220 Tex MRXC11 222 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
MRXC3 Scale	60	6	57	736		719	
MRXC11 Full scale	60	6	57	703	-4.5	679	-5.6

Table 4.3.3. Comparison of PSC scale and full scale samples, 3% Mean, 4% Range

Linear Density MRXC5 220 Tex MRXC14 222 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MRXC5 Scale	3	4	1	697	12.2	674	11.7
MRXC14 FS inner ry	3	4	1	691	13.4	663	13.0
outer ry	3	4	1	680	13.4	664	13.1
Repeat inner ry	3	4	1	698	13.7	685	13.4
outer ry	3	4	1	706	13.4	693	13.3

As shown in tables 4.3.3 and 4.3.4 tenacity values appear to be unaffected by scale. The repeat data was very consistent.

Table 4.3.4. Comparison of PSC scale and full scale samples, 3% Mean, 4% Range

Linear Density MRXC5 220 Tex MRXC14 222 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
MRXC5	3	4	1	697		674	
MRXC14	3	4	1	680	-2.4	664	-1.5
MRXC14 repeat	3	4	1	706	1.3	693	2.8

Table 4.3.5. Comparison of PSC scale and full scale samples, 20% Mean, 15% Range

Linear Density MRXC6 220 Tex MRXC13 222 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MRXC6 scale	20	15	12.5	686	11.0	681	10.9
MRXC13 Full scale inner ry	20	15	12.5	630	10.5	610	10.2
MRXC13 Full scale outer ry	20	15	12.5	589	10.4	498	9.3

Table 4.3.6. Comparison of PSC scale and full scale samples, 20% Mean, 15% Range

Linear Density MRXC6 220 Tex MRXC13 222 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
MRXC6 scale	20	15	12.5	686		681	
MRXC13 Full scale	20	15	12.5	589	-14.1	498	-26.9

As shown in table’s 4.3.5 and 4.3.6, both Tenacity and % Breaking Extension are reduced with increasing scale, with a significant deterioration seen in Tenacity for both sets of textile yarns from outer rope yarns. In the case of inner textile yarns, the reduction is around 14%, but for the outer textile yarns the reduction is around 27%.

Table 4.3.7 Comparison of PBC scale and full scale samples, 5% Mean, 8% Range

Linear Density MRZW18 122 Tex MRZW14 244 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MRZW18 Scale	5	8	1	706	10.5	669	10.6
MRZW14 Full scale inner ry	5	8	1	667	10.3	621	9.8
MRZW14 Full scale outer ry	5	8	1	659	10.2	599	9.5

As shown in table’s 4.3.7 and 4.3.8 both Tenacity and % Breaking Extension are seen to reduce with scale, with the larger reductions being seen for the outer textile yarns of the outer rope yarns, of about 10%.

Table 4.3.8. Comparison of PBC scale and full scale samples, 5% Mean, 8% Range

Linear Density MRZW18 122 Tex MRZW14 244 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	% tenacity change	Tenacity mN/Tex	% tenacity change
MRZW18 Scale	5	8	1	706		669	
MRZW14 Full scale outer ry	5	8	1	659	-6.7	599	-10.5

Table 4.3.9. Comparison of PWRC scale and full scale samples, 5% Mean, 8% Range

Linear Density MSAN1 122 Tex MSAN12 110 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex	Br Ext %	Tenacity mN/Tex	Br Ext %
MSAN1 SCALE	5	8	1	637	9.2	631	9.0
MSAN12 inner ry	5	8	1	695	12.4	693	12.1
MSAN12 outer ry	5	8	1	715	13.4	655	11.7

The results for the PWRC show a marginal 3% strength loss scale to full scale at. Unlike the PSC and PBC which had similar lay angle, the PWRC had a lower lay angle for full scale compared to scale.

Table 4.3.10. Comparison of PWRC scale and full scale outer strand outer yarn samples, 5% Mean, 8% Range

Linear Density MSAN1 122 Tex MSAN12 110 Tex	Mean % MBL	Range % MBL	Min % MBL	Inner textile Yarn		Outer textile Yarn	
				Tenacity mN/Tex		Tenacity mN/Tex	
MSAN1 SCALE	5	8	1	637		631	
MSAN12 FS outer ry	5	8	1	672	5.5	610	-3.3

4.4 Statistical analysis of the relationship between the tensile properties for Mean and Range, and scale

4.4.1 Analysis of 10 tonne scale ropes

The results in Tables 4.1.1 to 4.1.3 were subjected to statistical analysis. Initially, linear relationships between the textile yarn tensile properties (tenacity, T, and extension at break, e) and mean cyclic load, M, were sought (Eqns (1)), as were independent linear relationships between yarn tensile properties and cyclic load range, L_r, (Eqns (2)).

$$T = a + b\,M$$
$$e = a + b\,M \qquad \ldots(1)$$

$$T = a + b\,L_r$$
$$e = a + b\,L_r \qquad \ldots(2)$$

where a and b are the values of the constants in each particular case.

Table 4.4.1.1 PSC (excluding MRXC7, 2000000 cycles)

		Mean			Range		
Coefficients		a	b	R^2	a	b	R^2
Tenacity mN/Tex	Inner	691.2	0.628	0.467	725.4	-1.978	0.396
	Outer	669.3	0.769	0.725	700.8	-1.441	0.217
Extension %	Inner	11.76	-0.009	0.081	12.60	-0.099	0.826
	Outer	11.345	-0.007	0.060	12.09	-0.085	0.786

Table 4.4.1.2 PBC

		Mean			Range		
Coefficients		a	b	R^2	A	b	R^2
Tenacity mN/Tex	Inner	709.5	-0.245	0.019	732.5	-2.327	0.501
	Outer	693.3	-0.556	0.067	721.0	-3.202	0.638
Extension %	Inner	10.67	0.015	0.090	11.29	-0.031	0.114
	Outer	10.31	0.012	0.051	11.06	-0.044	0.194

Table 4.4.1.3 PWRC

		Mean			Range		
Coefficients		a	b	R^2	a	b	R^2
Tenacity mN/Tex	Inner	632.9	1.175	0.258	683.2	-1.970	0.103
	Outer	614.1	1.346	0.398	657.4	-1.158	0.042
Extension %	Inner	9.07	0.042	0.561	9.97	0.000	0.000
	Outer	8.64	0.044	0.750	9.28	0.022	0.026

These equations (Tables 4.4.1.1 to 4.4.1.3) indicate that increasing the mean load *improves* the residual tensile properties as the 'b' coefficient was positive for the PSC and PWRC constructions. Increasing the load range decreases the residual tensile strength. The simple R^2

correlation test was then applied to these data, with mixed results. Given that $R^2 = 1$ would indicate a perfect correlation between the experimental results and the fitted straight line, while $R^2 = 0$ implies no correlation at all, further investigation was clearly worthwhile.

The experimental data were then reanalysed. It was assumed that the residual tensile properties were linear functions of the two variables of mean load and load range simultaneously (Eqns (3)).

$$T = a + b\,M + c\,L_r$$
$$e = a + b\,M + c\,L_r \qquad \ldots(3)$$

These linear models (Tables 4.4.1.4 -4.4.1.6) have R^2 values much closer to 1, and provide much greater confidence that the changes in the residual tensile properties with mean load and cyclic range can properly be regarded as linear functions. Further, the residual tenacity of all three ropes now increases with mean load, and decreases with increasing range (‘c’ negative).

Table 4.4.1.4. 10tonne PSC (excluding MRXC7, 2000000 cycles)

		Mean and Range			
Coefficients		a	B	c	R^2
Tenacity	Inner	711.5	0.599	-1.871	0.821
	Outer	683.4	0.750	-1.307	0.903
Extn at break	Inner	12.85	-0.011	-0.101	0.936
	Outer	12.29	-0.008	-0.087	0.871

Table 4.4.1.5. 10 tonne PBC

		Mean and Range			
Coefficients		A	b	c	R^2
Tenacity mN/Tex	Inner	729.8	1.494	-4.386	0.826
	Outer	718.2	1.573	-5.374	0.880
Extn at break %	Inner	11.19	0.059	-0.112	0.778
	Outer	10.94	0.066	-0.135	0.860

Table 4.4.1.6. 10 tonne PWRC

		Mean and Range			
Coefficients		a	b	C	R^2
Tenacity mN/Tex	Inner	684.4	2.661	-6.355	0.915
	Outer	658.5	2.631	-5.493	0.977
Extn at break %	Inner	10.00	0.069	-0.115	0.925
	Outer	9.31	0.063	-0.082	0.980

A comparison of the experimental results with the values predicted by these bi-variate approximations is, in general, very encouraging, to the point that it would be possible to use the approximations to predict the performance of similar ropes under different mean loads and load ranges.

For all ropes the ‘b’ coefficient is positive which means that the residual tenacity and break extension increases with increasing mean. Likewise the ‘c’ coefficient is negative, which means that the tenacity and break extension decreases with increasing load range.

Comparing the values of the ‘b’ and ‘c’ coefficients reveals that load range will have a greater effect on tenacity than will mean load. This is most clearly seen if load and range have similar values. A similar trend is seen for % breaking extension, though much less pronounced.

R^2 values for PBC are lower than for PSC and PWRC.

Table’s 4.4.1.7 to 4.4.1.9 [a and b] compare the experimental results and the values predicted by these bi-variate formulae. The agreement is very encouraging, and it would appear to be feasible to use these formulae to predict the performance of other similar ropes under different mean loads and ranges.

Table 4.4.1.7.a. 10 tonne PSC (excluding MRXC7, 2000000 cycles)

TENACITY mN/Tex	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRXC1	687.5	673.2	666.9	672.3
MRXC2	710.2	699.5	678.4	676.7
MRXC3	736.4	736.2	718.6	720.6
MRXC4	710.6	704.8	694.7	685.3
MRXC5	696.8	705.8	674.3	680.4
MRXC6	686.1	695.4	681.3	678.8

Table 4.4.1.7.b 10. tonne PSC (excluding MRXC7, 2000000 cycles)

BREAK EXTENSION %	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRXC1	10.6	10.6	10.2	10.4
MRXC2	12.2	12.0	11.6	11.6
MRXC3	11.6	11.6	11.2	11.3
MRXC4	11.8	11.6	11.6	11.3
MRXC5	12.2	12.4	11.7	11.9
MRXC6	11.0	11.1	10.9	10.8

Table 4.4.1.8.a. 10 tonne PBC

TENACITY mN/Tex	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRZW1	723.0	715.8	706.6	695.9
MRZW2	712.9	716.7	691.8	701.4
MRZW3	722.6	718.2	709.2	703.0
MRZW4	674.2	693.9	659.4	669.1
MRZW5	675.0	672.0	636.3	642.2
MRZW6	728.1	730.8	704.9	711.7
MRZW7	709.8	708.8	683.8	684.8
MRZW8	694.3	686.9	668.6	657.9
MRZW18	705.7	702.2	689.3	683.1

Table 4.4.1.8.b. 10 tonne PBC

BREAK EXTENSION %	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRZW1	11.1	11.3	10.9	10.9
MRZW2	11.0	11.0	10.5	10.6
MRZW3	11.2	11.0	10.9	10.7
MRZW4	10.1	10.7	9.8	10.2
MRZW5	10.3	10.2	9.6	9.6
MRZW6	11.8	11.8	11.4	11.6
MRZW7	11.5	11.3	11.1	10.9
MRZW8	10.9	10.7	10.6	10.2
MRZW18	10.5	10.6	10.1	10.2

Table 4.4.1.9.a. 10 tonne PWRC

TENACITY mN/Tex	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MSAN1	636.9	646.9	630.7	627.7
MSAN2	702.0	700.7	679.2	682.5
MSAN3	647.1	634.8	615.2	618.9
MSAN4	632.0	637.1	626.2	627.6
MSAN5	670.1	668.9	660.5	655.0

Table 4.4.1.9.b. 10 tonne PWRC

BREAK EXTENSION %	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MSAN1	9.2	9.4	9.0	9.0
MSAN2	11.0	10.9	10.3	10.4
MSAN3	9.6	9.3	8.9	9.0
MSAN4	9.7	9.8	9.5	9.6
MSAN5	10.3	10.3	10.1	10.0

4.4.2 Analysis of full scale sub-rope

The analysis could be performed only on the PSC series. Three cyclic conditions were investigated, 60% mean/6% range, 20% mean/15% range and 3% mean/4% range. Test condition 3% mean/4% range was repeated, and the data from this repeat test was added, to make a total of 4 inputs to the analysis.

Table 4.4.2.1. Full scale PSC sub-rope, Inner Rope Yarn

Textile yarn		Mean and Range			
Coefficients		a	b	c	R^2
Tenacity	Inner	721.1	0.987	-7.390	0.995
	Outer	701.1	1.199	-7.671	0.966
Extn at break	Inner	14.6	-0.031	-0.229	0.994
	Outer	14.2	-0.023	-0.237	0.988

Table 4.4.2.2. Full scale PSC sub-rope, Outer Rope Yarn

Textile yarn		Mean and Range			
Coefficients		a	b	c	R^2
Tenacity	Inner	732.5	0.536	-10.283	0.963
	Outer	746.1	0.618	-17.364	0.983
Extn at break	Inner	14.4	-0.029	-0.228	1.000
	Outer	14.5	-0.033	-0.303	0.998

Table 4.4.1.4 is repeated as Table 4.4.2.3 below, to allow easy comparison of scale and full scale statistical data.

Table 4.4.2.3. PSC (excluding MRXC7, 2000000 cycles)

Scale testing		Mean and Range			
Coefficients		a	b	c	R^2
Tenacity	Inner	711.5	0.599	-1.871	0.821
	Outer	683.4	0.750	-1.307	0.903
Extn at break	Inner	12.85	-0.011	-0.101	0.936
	Outer	12.29	-0.008	-0.087	0.871

It may be seen that the residual tenacity coefficient for mean remains positive, confirming that tenacity increases with increasing mean load [at constant range]. Also, the residual tenacity coefficient for load range is negative, confirming that residual tenacity reduces with increasing load range [at constant mean].

There appears to be a significant scale effect for range, with the greatest increase being seen between the scale outer textile yarns and the full scale outer textile yarns, extracted from the outer rope yarns of the strand, from -1.307 to -17.364.

No obvious scale effect is seen for mean.

Apart from the range coefficient for scale outer textile yarn, both the tenacity coefficients are greater for outer textile yarns when compared to their partner inner textile yarns. This is an obvious consequence of the greater fatigue damage that outer textile yarns would suffer.

At full scale, the range coefficients for both inner and outer textile yarns are significantly greater than the coefficients for mean. Thus, the effect of range will dominate the residual tenacity values.

R^2 values for residual tenacity were better at full scale.

For % breaking extension, both coefficients are negative at both scale and full scale, confirming that this parameter will decrease with both increasing mean and increasing range.

Similar to the coefficients for Tenacity, the Range coefficient is greater than the mean coefficient, confirming that range has a greater effect on loss of % breaking extension.

Unlike the results for the residual tenacity coefficients, where a scale effect was clearly seen on Range only, a scale effect was seen for both coefficients of % breaking extension.

R^2 values for % breaking extension were better at full scale.

Table's 4.4.2.4 to 4.4.2.7 compare experimental results with those calculated from the regression analysis. As the R^2 values were so high, agreement is very good.

Table 4.4.2.4. Full scale PSC sub-rope, Inner Rope Yarn

TENACITY mN/Tex	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRXC11	736.0	736.0	726.6	727.0
MRXC13	630.2	630.0	610.4	610.0
MRXC14	691.0	694.5	662.6	674.0
MRXC14 rpt	697.7	694.5	685.1	674.0

Table 4.4.2.5. Full scale PSC sub-rope, Outer Rope Yarn

TENACITY mN/Tex	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRXC11	702.7	703.0	679.3	679.0
MRXC13	588.7	589.0	497.7	498.0
MRXC14	679.7	693.0	663.5	678.5
MRXC14 rpt	705.9	693.0	693.2	678.5

Table 4.4.2.6. Full scale PSC sub-rope, Inner Rope Yarn

BREAK EXTENSION %	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRXC11	11.3	11.4	11.4	11.4
MRXC13	10.5	10.5	10.2	10.2
MRXC14	13.4	13.6	13.0	13.2
MRXC14 rpt	13.7	13.6	13.4	13.2

Table 4.4.2.7. Full scale PSC sub-rope, Outer Rope Yarn

BREAK EXTENSION %	Inner		Outer	
	Experimental	Fitted formula	Experimental	Fitted formula
MRXC11	11.3	11.3	10.7	10.7
MRXC13	10.4	10.4	9.3	9.3
MRXC14	13.4	13.4	13.1	13.2
MRXC14 rpt	13.4	13.4	13.3	13.2

4.5 Comparison of rope strength by realisation with rope break load

This section compares the results of 10 tonne spliced strop (one test) tensile testing at NEL with rope strength calculated by yarn realisation.

The datum strength used to determine the realisation factor was based on the new (average 3) measured rope strength after 10 cycles (since a realisation factor after 1 million cycles was not known). It should be noted that single rope break tests do not always follow the expected trends of mean load and load range on residual strength, due to having only one value and the variance of bedding-in and termination effects. The yarn data provides accurate statistics and removes the termination effect and is the better indicator of mean load and load range effects on residual strength. In the figures below, where some of the rope break tests deviate from the mean load and load range trend against residual strength shown by the yarn tests, it was most likely due to variability in the single rope break test.

The single rope break tests do provide a valuable comparison against the calculated rope strength by yarn realisation and illustrate the magnitude of bedding-in effects.

Table’s 4.5.1 to 4.5.6 show the estimate of % Residual Strength by realisation for the PSC series of 10 tonne PSC strops, 1 x 10^6 cycles, based on the tensile test results from the textile yarns.

The single strop test results from NEL are included, and Figure 4.5.1 gives a comparison of the two sets of data. All the Figures (4.5.1 to 4.5.3) are arranged in order of increasing mean and increasing range.

In the headers for Figures 4.5.1 to 4.5.3, the term ‘actual’ refers to the % Residual Strength calculation based on the single rope break test at NEL, and ‘realised’ refers to the % Residual Strength calculation based on the textile yarn tensile test results. For both realised and measured strength and all ropes, the trends in movement up and down generally follow the statistical trends with mean and range.

Table 4.5.1. 10 tonne PSC rope, calculation of rope strength by realisation and comparison with measured rope strength

PSC MRXC1 20+/-10%	Sub-ropes	Strands [ropeyarns]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
Outer textile yarn	12	3	8	146.7	42.2496	
Inner textile yarn	12	3	12	151.3	65.36	
aggregate yarn break load kN					107.61	NEL MRXC16
realization factor					0.883	
dry rope calculated break load kN					95.02	99.41
minimum new dry break load kN					101.67	101.67
residual strength %					93.5	97.8

Table 4.5.2. 10 tonne PSC rope, calculation of rope strength by realisation and comparison with measured rope strength

PSC MRXC2 5+/-4%	Sub-ropes	Strands [ropeyarns]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
Outer textile yarn	12	3	8	149.3	43.00	
Inner textile yarn	12	3	12	156.3	67.52	
aggregate yarn break load kN					110.52	NEL MRXC8
realization factor					0.883	
dry rope calculated break load kN					97.59	100.99
minimum new dry break load kN					101.67	101.67
residual strength %					96.0	99.3

Table 4.5.3. 10 tonne PSC rope, calculation of rope strength by realisation and comparison with measured rope strength

PSC MRXC3 60+/-3%	Sub-ropes	Strands [ropeyarns]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
Outer textile yarn	12	3	8	158.1	45.53	
Inner textile yarn	12	3	12	162.0	69.98	
aggregate yarn break load kN					115.52	NEL MRXC17
realization factor					0.883	
dry rope calculated break load kN					102.00	98.88
minimum new dry break load kN					101.67	101.67
residual strength %					100.3	97.3

Table 4.5.4. 10 tonne PSC rope, calculation of rope strength by realisation and comparison with measured rope strength

PSC MRXC4 20+/-5%	Sub-ropes	Strands [ropeyarns]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
Outer textile yarn	12	3	8	152.8	44.01	
Inner textile yarn	12	3	12	156.3	67.52	
aggregate yarn break load kN					111.53	NEL MRXC9
realization factor					0.883	
dry rope calculated break load kN					98.48	99.67
minimum new dry break load kN					101.67	101.67
residual strength %					96.9	98.0

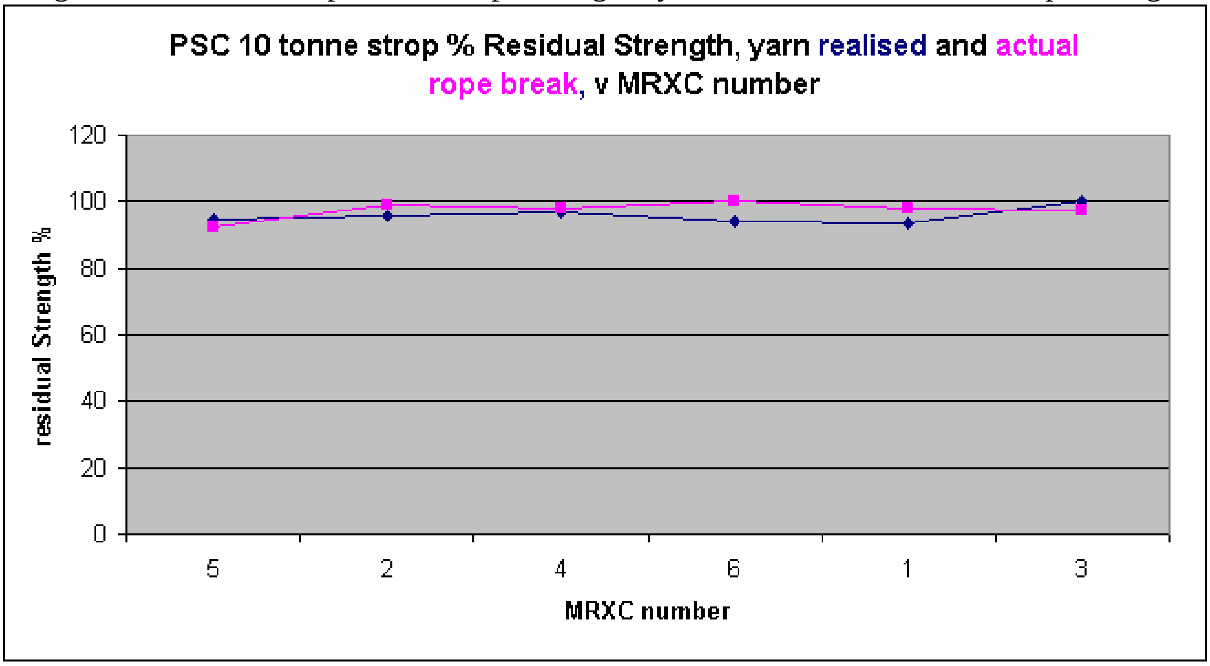
Table 4.5.5. 10 tonne PSC rope, calculation of rope strength by realisation and comparison with measured rope strength

PSC MRXC5 3+/-2%	Sub-ropes	Strands [ropeyarns]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
Outer textile yarn	12	3	8	148.4	42.74	
Inner textile yarn	12	3	12	153.3	66.23	
aggregate yarn break load kN					108.96	NEL MRXC10
realization factor					0.883	
dry rope calculated break load kN					96.22	94.06
minimum new dry break load kN					101.67	101.67
residual strength %					94.6	92.5

Table 4.5.6. 10 tonne PSC rope, calculation of rope strength by realisation and comparison with measured rope strength

PSC MRXC6 20+/-7.5%	Sub-ropes	Strands [ropeyarns]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
Outer textile yarn	12	3	8	149.9	43.17	
Inner textile yarn	12	3	12	151.0	65.23	
aggregate yarn break load kN					108.40	NEL MRXC15
realization factor					0.883	
dry rope calculated break load kN					95.72	101.71
minimum new dry break load kN					101.67	101.67
residual strength %					94.1	100.0

Figure 4.5.1. PSC, comparison of rope strength by realisation with measured rope strength



The trend between the two sets of data is good, given that the NEL data are the results of single rope break tests, whereas there are at least 40 yarn tests for the yarn realised strength. Table 4.5.7 shows the differences between the two sets of data, expressed as a % of the realised values.

Table 4.5.7. 10 tonne PSC rope, comparison single rope break with yarn calculated rope strength

	Yam Realised rope strength % Residual strength	Single rope break strength % Residual strength	% mean load	% load range	Difference (yarn/rope residual strength)
MRXC5	94.6	92.5	3	4	2.3
MRXC2	96.0	99.3	5	8	-3.3
MRXC4	96.9	98.0	20	10	-1.1
MRXC6	94.1	100.0	20	15	-5.9
MRXC1	93.5	97.8	20	20	-4.4
MRXC3	100.3	97.3	60	6	3.1

Table's 4.5.8 to 4.5.16 show the estimate of % Residual Strength by realisation for the PBC series of 10 tonne PBC strops, 1 x 10^6 cycles, based on the tensile test results from the textile yarns. The strop test results from NEL are included, and Figure 4.5.2 gives a comparison of the two sets of data.

Table 4.5.8. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW1 20+/-5%	Sub-ropes	Strands [ropeyarn]	Textile yarns [16]	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	86.2	66.20	
inner yarn	12	8	8	88.2	67.74	
aggregate yarn break load kN					133.94	NEL MRZW20
realization factor					0.857613	
dry rope calculated break load kN					114.87	118.78
minimum new dry break load kN					113.88	113.88
residual strength %					100.9	104.3

Table 4.5.9. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW2 3+/-2%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	84.4	64.82	
inner yarn	12	8	8	87.0	66.82	
aggregate yarn break load kN					131.64	NEL MRZW9
realization factor					0.857613	
dry rope calculated break load kN					112.89	121.96
minimum new dry break load kN					113.88	113.88
residual strength %					99.1	107.1

Table 4.5.10. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW3 4+/-2%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	86.5	66.43	
inner yarn	12	8	8	88.2	67.74	
aggregate yarn break load kN					134.17	NEL MRZW10
realization factor					0.857613	
dry rope calculated break load kN					115.07	120.28
minimum new dry break load kN					113.88	113.88
residual strength %					101.0	105.6

Table 4.5.11. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW4 20+/-7.5%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	80.5	61.82	
inner yarn	12	8	8	82.3	63.21	
aggregate yarn break load kN					125.03	NEL MRZW12
realization factor					0.857613	
dry rope calculated break load kN					107.23	119.91
minimum new dry break load kN					113.88	113.88
residual strength %					94.2	105.3

Table 4.5.12. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW5 20+/-10%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	77.6	59.60	
inner yarn	12	8	8	82.3	63.21	
aggregate yarn break load kN					122.80	NEL MRZW13
realization factor					0.857613	
Dry rope calculated break load kN					105.32	113.43
minimum new dry break load kN					113.88	113.88
residual strength %					92.5	99.6

Table 4.5.13. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW6 30+/-5%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	86.0	66.05	
inner yarn	12	8	8	88.8	68.20	
aggregate yarn break load kN					134.25	NEL MRZW15
realization factor					0.857613	
dry rope calculated break load kN					115.13	108.68
minimum new dry break load kN					113.88	113.88
residual strength %					101.1	95.4

Table 4.5.14. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW7 30+/-7.5%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	83.4	64.05	
inner yarn	12	8	8	86.6	66.51	
aggregate yarn break load kN					130.56	NEL MRZW16
realization factor					0.857613	
dry rope calculated break load kN					111.97	117.30
minimum new dry break load kN					113.88	113.88
residual strength %					98.3	103.0

Table 4.5.15. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW8 30+/-10%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	81.6	62.67	
inner yarn	12	8	8	84.7	65.05	
aggregate yarn break load kN					127.72	NEL MRZW17
realization factor					0.857613	
dry rope calculated break load kN					109.53	115.07
minimum new dry break load kN					113.88	113.88
residual strength %					96.2	101.0

Table 4.5.16. 10 tonne PBC rope, calculation of rope strength by realisation and comparison with measured rope strength

PBC MRZW18 5+/-4%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer yarn	12	8	8	84.1	64.59	
inner yarn	12	8	8	86.1	66.12	
aggregate yarn break load kN					130.71	NEL MRZW19
realization factor					0.857613	
dry rope calculated break load kN					112.10	117.06
minimum new dry break load kN					113.88	113.88
residual strength %					98.4	102.8

Figure 4.5.2. 10 tonne PBC rope, comparison of rope strength by realisation with measured rope strength

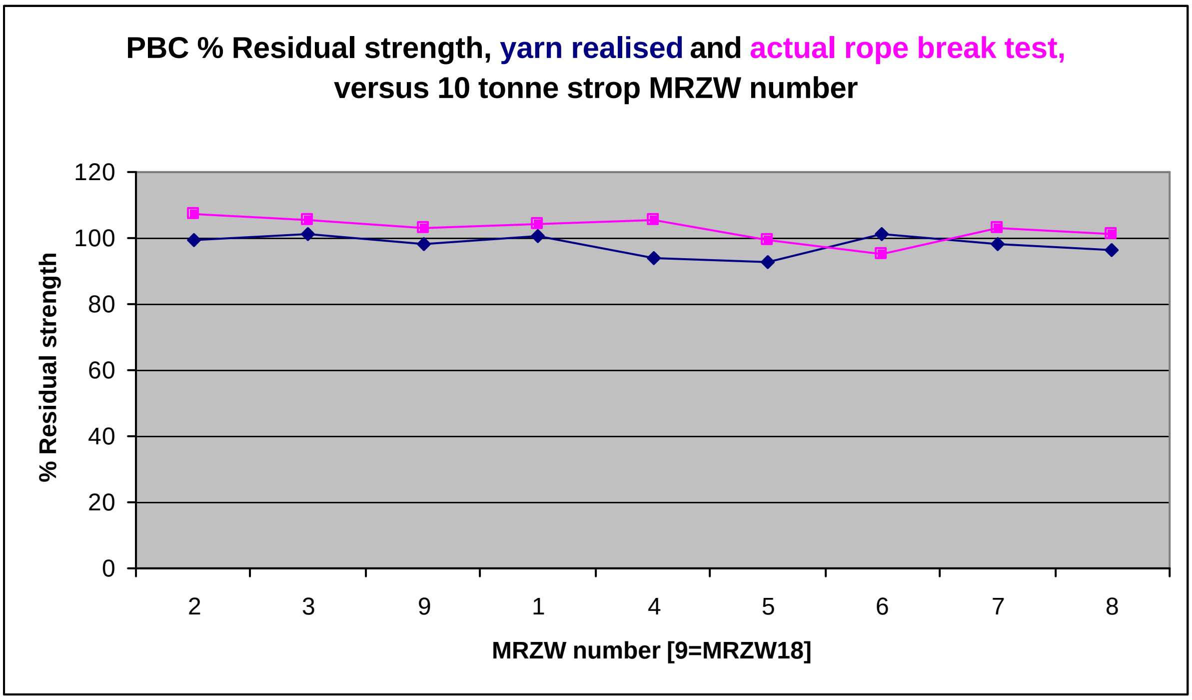


Table 4.5.17 shows the differences between the two sets of data, expressed as a % of the realised values, where all the calculated are lower than measured sub-rope.

Table 4.5.17. 10 tonne PBC rope, comparison single rope break with yarn calculated rope strength

	Yarn Realised rope strength % Residual strength	Single rope break strength % Residual strength	% mean load	% load range	% Difference (yarn/rope residual strength)
MRZW2	99.1	107.1	3	4	-7.4
MRZW3	101.0	105.6	4	4	-4.3
MRZW18 [9]	98.4	102.8	5	4	-4.2
MRZW1	100.9	104.3	20	10	-3.3
MRZW4	94.2	105.3	20	15	-10.6
MRZW5	92.5	99.6	20	20	-7.2
MRZW6	101.1	95.4	30	10	5.9
MRZW7	98.3	103.0	30	15	-4.5
MRZW8	96.2	101.0	30	20	-4.8

The trend between the two sets of data remains good, though the realised value is lower than the actual value for all the tests except one. It appears this is due to bedding-in of the rope and termination, which, was not taken into account in the yarn realisation factor.

Table's 4.5.18 to 4.5.22 show the estimate of % Residual Strength by realisation for the PWRC series of 10 tonne PSC strops, 1 x 10^6 cycles, based on the tensile test results from the textile yarns. The strop test results from NEL are included, and Figure 4.5.3 gives a comparison of the two sets of data.

Table 4.5.18. 10 tonne PWRC rope, calculation of rope strength by realisation and comparison with measured rope strength

PWRC MSAN1 5%+/-4%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	Measured rope break strength
Inner sub-rope	Calculation by realisation					
outer rope yarn, inner textile yarn	7	6	17	77.7	55.48	
outer rope yarn, outer textile yarn	7	6	13	77.0	42.04	
inner rope yarn, inner textile yarn	7	1	20	84.6	11.844	
inner yarn, outer textile yarn	7	1	16	83.6	9.36	
aggregate yarn break load kN					118.7	NEL MSAN6
realization factor					0.85	
dry rope calculated break load kN					100.9	108.2
minimum new dry break load kN					108.2	108.2
residual strength %					**93.3**	**100.0**

Table 4.5.19. 10 tonne PWRC rope, calculation of rope strength by realisation and comparison with measured rope strength

PWRC MSAN2 30%+/-5%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	
Inner sub-rope	Calculation by realisation					Measured rope break strength
outer rope yarn, inner textile yarn	7	6	17	85.9	61.33	
outer rope yarn, outer textile yarn	7	6	13	82.4	44.99	
inner rope yarn, inner textile yarn	7	1	20	88.2	12.35	
inner yarn, outer textile yarn	7	1	16	88.2	9.88	
aggregate yarn break load kN					128.5	NEL MSAN8
realization factor					0.85	
dry rope calculated break load kN					109.3	112.3
minimum new dry break load kN					108.2	108.2
residual strength %					**101.0**	**103.8**

Table 4.5.20. 10 tonne PWRC rope, calculation of rope strength by realisation and comparison with measured rope strength

PWRC MSAN3 10%+/-6%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	
Inner sub-rope	Calculation by realisation					Measured rope break strength
outer rope yarn, inner textile yarn	7	6	17	78.3	55.91	
outer rope yarn, outer textile yarn	7	6	13	75.7	41.33	
inner rope yarn, inner textile yarn	7	1	20	86.1	12.05	
inner yarn, outer textile yarn	7	1	16	85.9	9.62	
aggregate yarn break load kN					118.91	NEL MSAN7
realization factor					0.85	
dry rope calculated break load kN					101.1	97.8
minimum new dry break load kN					108.2	108.2
residual strength %					**93.4**	**90.4**

Table 4.5.21. 10 tonne PWRC rope, calculation of rope strength by realisation and comparison with measured rope strength

PWRC MSAN4 30%+/-7.5%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	
Inner sub-rope	Calculation by realisation					Measured rope break strength
outer rope yarn, inner textile yarn	7	6	17	81.8	58.41	
outer rope yarn, outer textile yarn	7	6	13	79.8	43.57	
inner rope yarn, inner text ile yarn	7	1	20	86.9	12.166	
inner yarn, outer textile yarn	7	1	16	86.1	9.64	
aggregate yarn break load kN					123.8	NEL MSAN9
realization factor					0.85	
dry rope calculated break load kN					105.2	106.2
minimum new dry break load kN					108.2	108.2
residual strength %					**97.2**	**98.2**

Table 4.5.22. 10 tonne PWRC rope, calculation of rope strength by realisation and comparison with measured rope strength

PWRC MSAN5 30%+/-10%	Sub-ropes	Strands [ropeyarn]	Textile yarns	Ave BL N	Sum BL kN	
Inner sub-rope	Calculation by realisation					Measured rope break strength
outer rope yarn, inner textile yarn	7	6	17	77.1	55.05	
outer rope yarn, outer textile yarn	7	6	13	76.4	41.71	
inner rope yarn, inner textile yarn	7	1	20	86.5	12.11	
inner yarn, outer textile yarn	7	1	16	85.4	9.56	
aggregate yarn break load kN					118.4	NEL MSAN10
realization factor					0.85	
dry rope calculated break load kN					100.6	109.9
minimum new dry break load kN					108.2	108.2
residual strength %					**93.0**	**101.6**

Figure 4.5.3 10 tonne PWRC rope, comparison of rope strength by realisation with measured rope strength

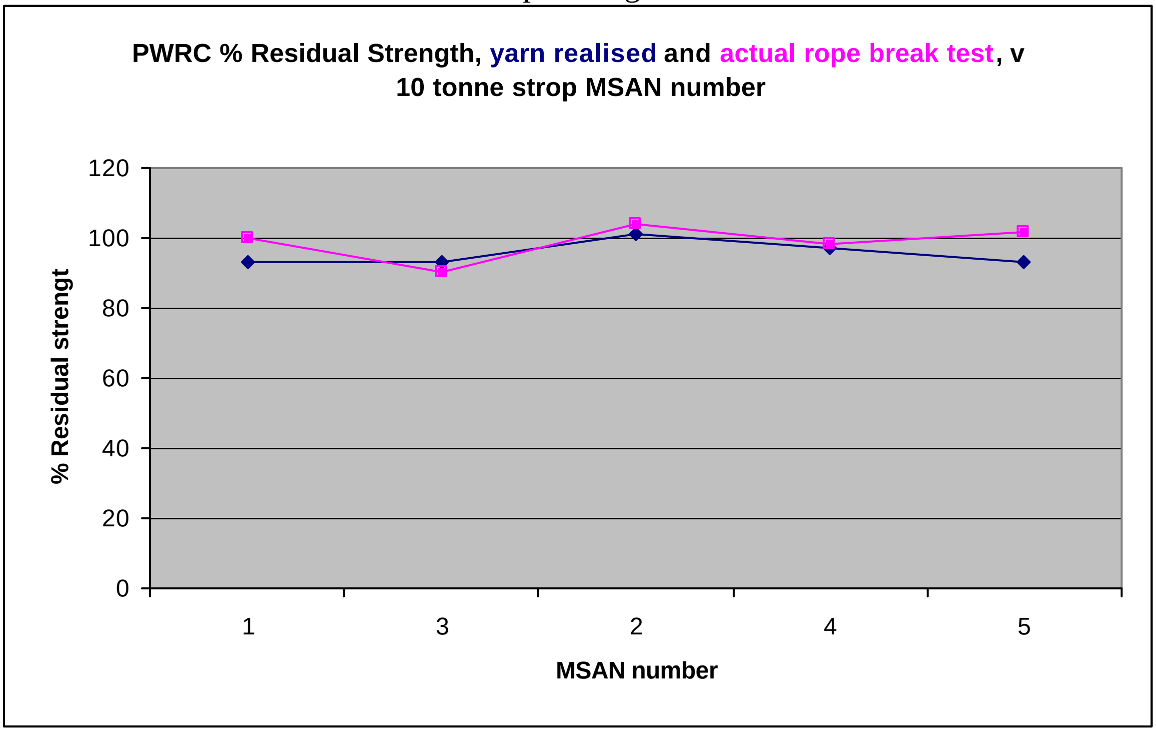


Table 4.5.23 shows the differences between the two sets of data, expressed as a % of the realised values.

Table 4.5.23. PWRC, comparison single rope break with yarn calculated rope strength

	Yarn Realised rope strength % Residual strength	Single rope break strength % Residual strength	% mean load	% load range	% Difference (yarn/rope residual strength)
MSAN1	93.3	112.6	5	8	-6.7
MSAN3	93.4	101.8	10	12	3.4
MSAN2	101.0	116.9	30	10	-2.7
MSAN4	97.2	110.5	30	15	-0.9
MSAN5	93.0	114.4	30	20	-8.4

For the PWRC shown in table 4.5.23, the trend between the two sets of data is reasonable given the single rope breaks where tenacity increases with mean and reduces with load range. However, the realised value was marginally below that of the rope break test. As for the PBC, this was due to bedding-in of the rope and terminations. Based on partial life tests (Ref . 3), the increase with strength up to around 15% of life has been previously shown at around 10% for the PBC. If the realisation factor is increased by 7%, then good agreement was found as shown in table 4.5.24. One value does not give a good comparison, MRZW6 and maybe due to the single rope break test being low (see section 6 for full discussion). Likewise, for the PWRC if the realisation is increased by 5%, then good agreement was found between realised and measured rope as shown in Table 4.5.25.

Table 4.5.24. PBC, comparison single rope break with yarn calculated rope strength, but realised adjusted to compensate for bedding-in

	Yarn Realised rope strength % Residual strength	Single rope break strength % Residual strength	% mean load	% load range	% Difference (yarn/rope residual strength)
MRZW2	106.1	107.1	3	4	-1.0
MRZW3	108.1	105.6	4	4	2.3
MRZW18	105.3	102.8	5	4	2.4
MRZW1	107.9	104.3	20	10	3.4
MRZW4	100.7	105.3	20	15	-4.5
MRZW5	99.0	99.6	20	20	-0.7
MRZW6	108.2	95.4	30	10	11.8
MRZW7	105.2	103.0	30	15	2.1
MRZW8	102.9	101.0	30	20	1.8

Table 4.5.25. PWRC, comparison single rope break with yarn calculated rope strength, but realised adjusted (+5%) to compensate for bedding-in

	Yarn Realised rope strength % Residual strength	Single rope break strength % Residual strength	% mean load	% load range	% Difference (yarn/rope residual strength)
MSAN1	97.9	100.0	5	8	-2.1
MSAN3	98.1	90.4	10	12	7.8
MSAN2	106.0	103.8	30	10	2.1
MSAN4	102.1	98.2	30	15	3.9
MSAN5	97.7	101.6	30	20	-4.0

4.6 Comparison of Load-Extension curves for each of the rope types.

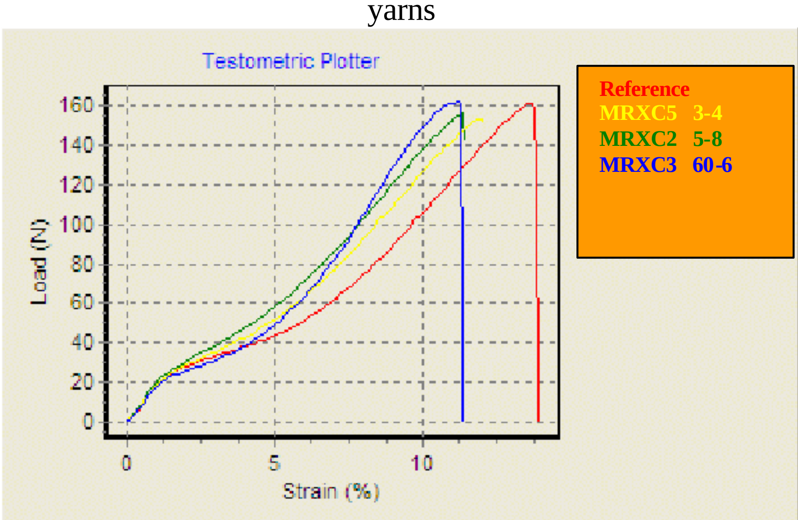
4.6.1 PSC series of scale and full scale ropes

The comparison was made by selecting a single load-extension curve, for each cyclic test procedure, that had a Breaking Load and % Breaking Extension that most closely fitted the average Breaking Load and % Breaking Extension for the particular group of textile yarns tested.

The curves were combined into one chart for each rope type, thus displaying any difference in the shape of the curves as a function of the cyclic load conditions.

Graph 4.6.1.1 is a comparison of the Load-% Extension [L/E] curves of part of the PSC MRXC series. It compares the L/E curves of the reference yarn, with no cyclic loading history, with those of cyclic loading conditions 3% mean/4% range, 5% mean/8% range and 60% mean/6% range, MRXC5, 2 and 3 respectively.

Graph 4.6.1.1 Typical Load-Extension Curves for PSC MRXC 2, 3 and 5, inner textile yarns



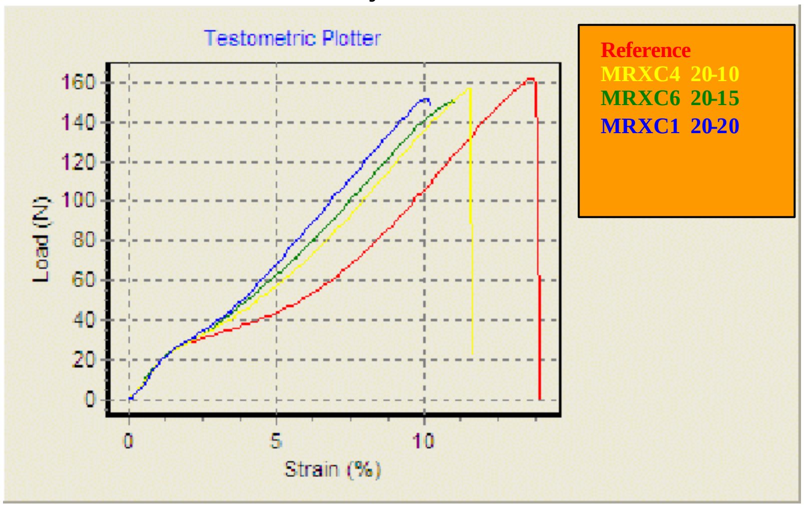
There appears to be a relationship between curve shape and cyclic history. For all the load conditions, a distinct increase in stiffness when compared to the reference is seen beyond the initial yield point that occurs at about 1.25% strain

Comparing conditions 3% mean/4% range and 5% mean/8% range, it may be seen that stiffness at given strain beyond the first knee is higher for the more severe cyclic history, 5% mean/8% range.

A distinct change in shape is seen when comparing condition 60-6 with the others. In this case, up to about 4%, the L/E curve is similar to the reference, but thereafter displays a much higher stiffness than either of the other cyclic loaded samples or the reference sample.

Graph 4.6.1.2 compares the L/E curves of the reference sample and load conditions 20% mean/10% range, 20% mean/15% range and 20% mean/20% range, MRXC4, 6 and 1 respectively.

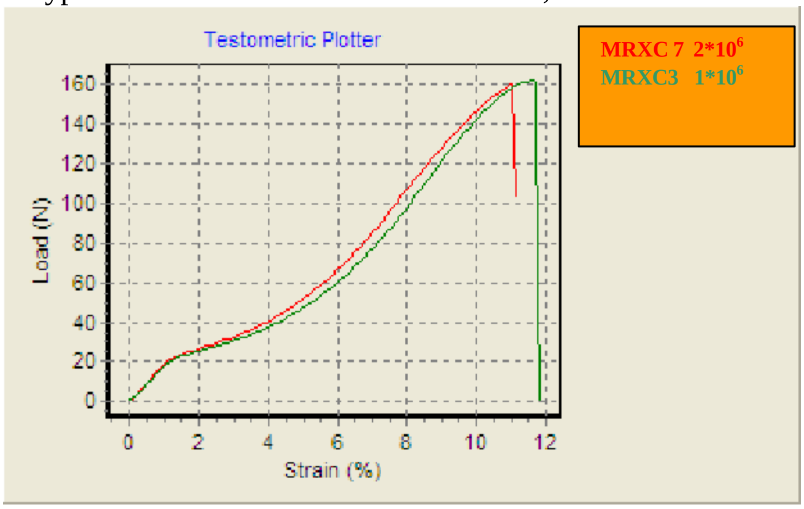
Graph 4.6.1.2. Typical Load-Extension Curves for PSC, MRXC 1,4 and 6, inner textile yarns



Inspection of this set of curves reveals that as the cyclic loading range is increased, the stiffness also is increased.

Graph 4.6.1.3 compares MRXC3 and MRXC7, both tested at load condition 60% mean/6% range, but differing in the number of cycles. It can be seen that there is a small increase in stiffness beyond the first knee with an increase in cycles.

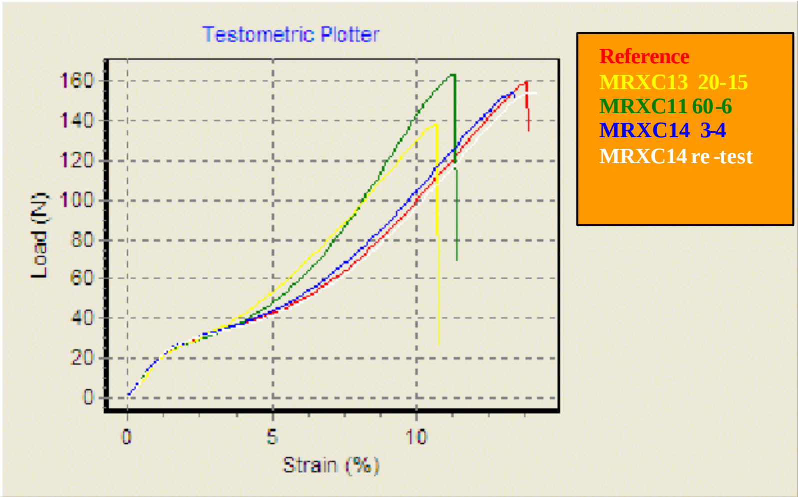
Graph 4.6.1.3. Typical Load-Extension Curves for PSC, MRXC 3 and 7 inner textile yarns



In general, it appears that the polyester material used by PSC for this investigation is sensitive to cyclic loading history. A similar pattern is seen when repeating the analysis for outer textile yarns. It was considered unnecessary to show the curves, as no new or additional features are to be seen.

Graph 4.6.1.4 is a similar comparison of the PSC full scale sub-ropes.

Graph 4.6.1.4 Typical Load-Extension Curves for PSC, MRXC 11 and 13 and 14 inner textile yarns from inner rope yarns

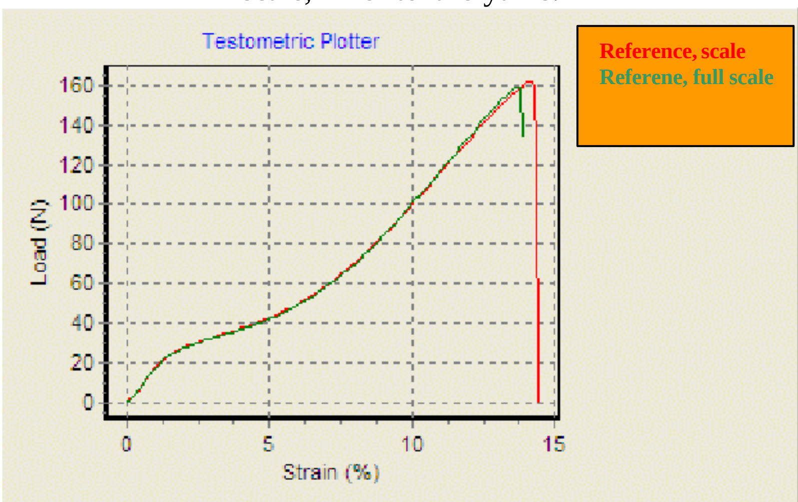


For load condition 60% mean/6% range, a similar L/E curve is seen to the equivalent 10 tonne small scale sample, as seen in Graph 4.6.1.

For the load condition 3% mean/4% range, the two curves MRXC14 and MRXC14 re-test are very similar to the reference, in contrast to the curves of Graph 4.6.1.

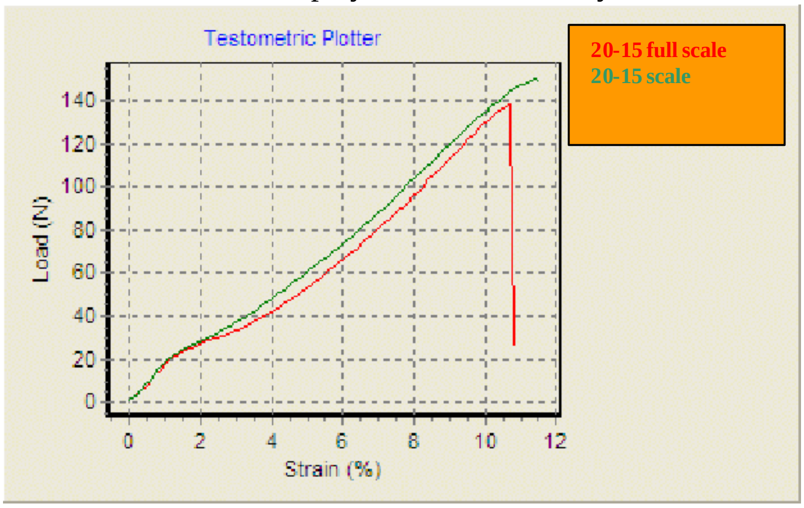
Trends are more easily seen in Graphs 4.6.1.4 to 4.6.1.7, in which individual cyclic conditions for scale and full scale are compared.

Graph 4.6.1.4 Typical Load-Extension Curves for PSC reference samples, scale and full scale, inner textile yarns.



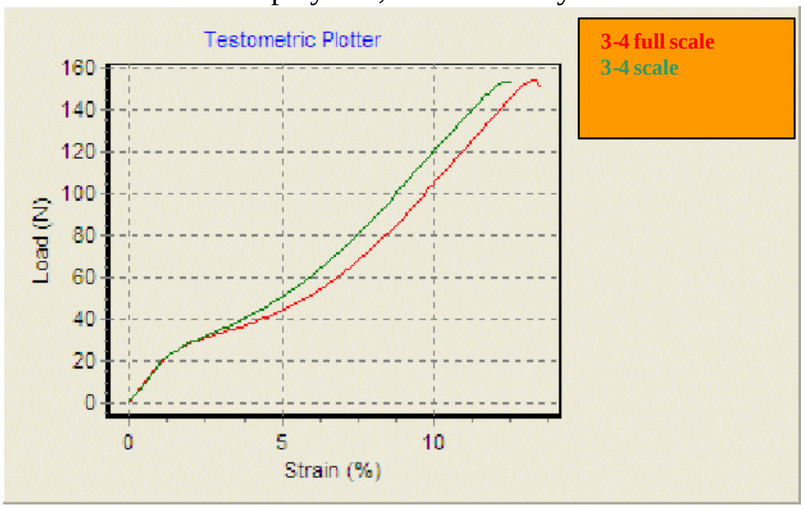
There is little difference in the performance of the reference materials for scale and full scale tests.

Graph 4.6.1.5 Typical Load-Extension Curves for PSC conditions 20-15, scale and full scale, inner rope yarns, inner textile yarns.



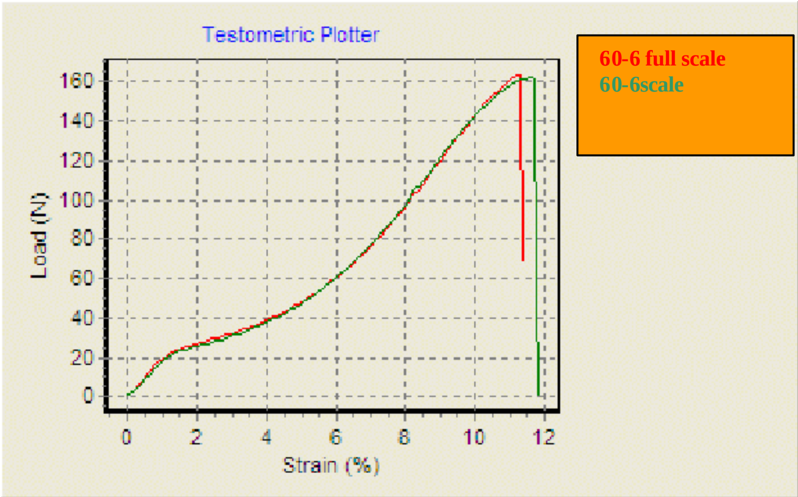
For this cyclic history, it is seen that the scale L/E curve shows a slight stiffening following the first knee.

Graph 4.3.1.6. Typical Load-Extension Curves for PSC conditions 3-4, scale and full scale, inner rope yarns, inner textile yarns.



This cyclic history also shows a slight stiffening of the scale textile yarns.

Graph 4.6.1.7. Typical Load-Extension Curves for PSC conditions 60-6, scale and full scale, inner rope yarns, inner textile yarns.

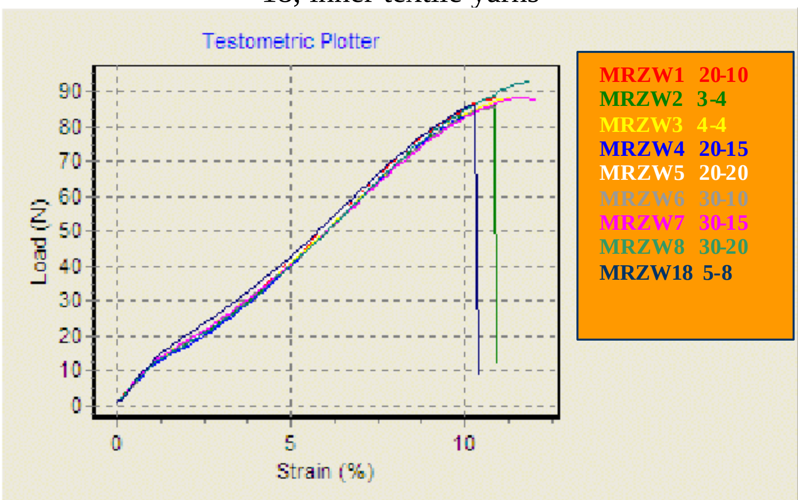


For this load condition, high mean and low range, there is no significant difference in the stiffness between scale and full scale.

4.6.2 PBC series for scale and full scale ropes

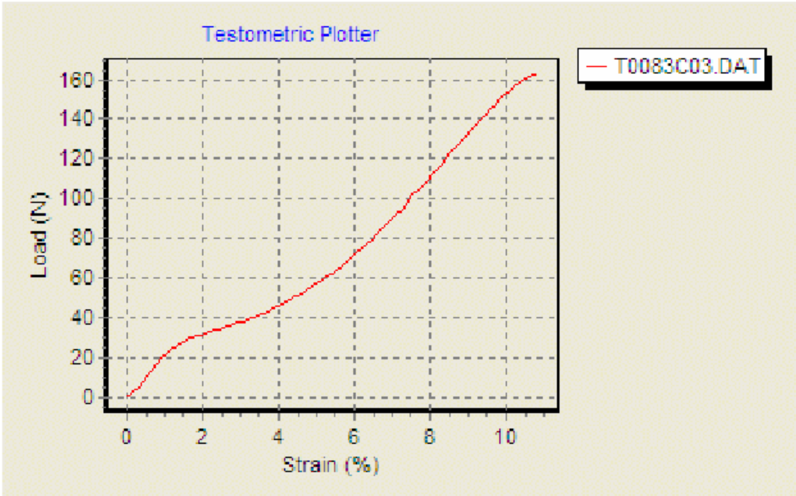
Graph 4.6.2.1 shows the complete set of scale rope L/E curves. There was little obvious difference between the curves for different conditions. This indicates that the yarn type used by PBC for this series of tests was relatively insensitive to cyclic history, when compared to the PSC material.

Graph 4.6.2.1. Typical Load-Extension Curves for PBC series of ropes, MRZW 1 to 8, and 18, inner textile yarns



It was not possible to compare scale and full scale, as yarns of different linear densities were used. However, Graph 4.6.2.2 shows the typical L/E curve for MRZW14, load condition 5% mean/8% range.

Graph 4.6.2.2 Typical Load-Extension Curves for PBC full scale rope, MRZW 14, inner textile yarns

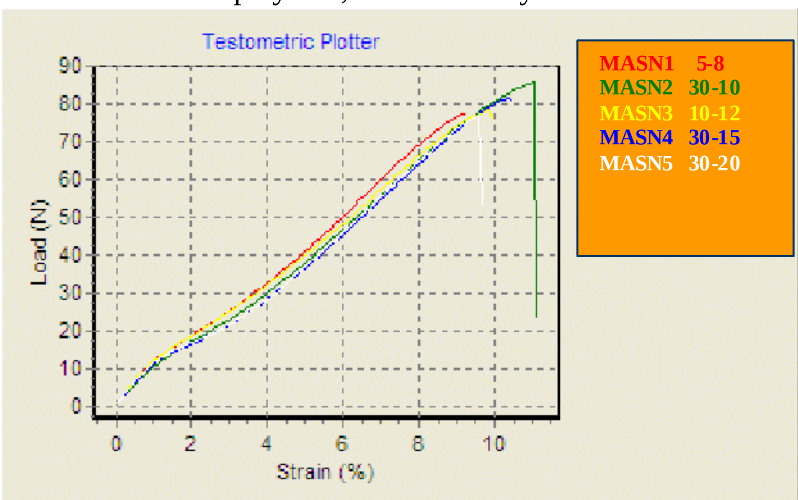


It may be seen that there is a significant difference in the shape of this curve, when compared to those of the scale samples.

4.6.3 PWRC series for scale and full scale ropes

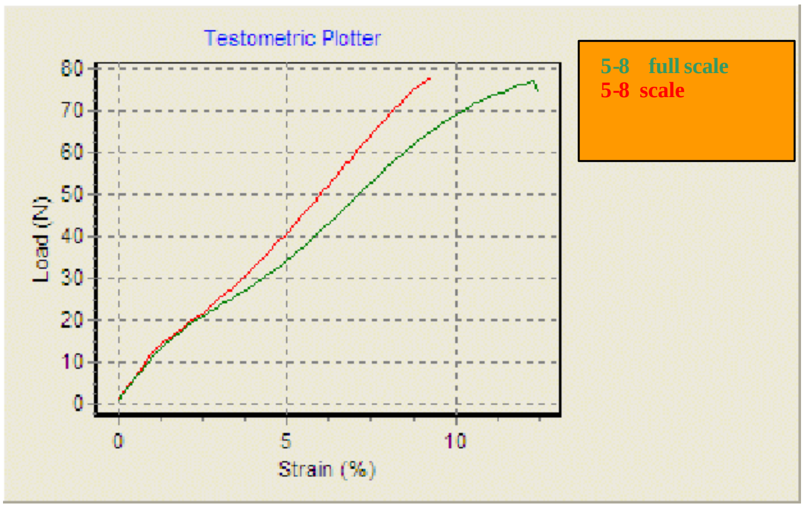
Graph 4.6.3.1 shows the complete set of scale rope L/E curves. As for the PBC results, little sensitivity to cyclic history is seen.

Graph 4.6.3.1. Typical Load-Extension Curves for PWRC series of ropes, MASN 1-5, outer rope yarns, inner textile yarns.



Graph 4.6.3.2 compares the PWRC scale and full scale L/E curves.

Graph 4.6.3.2. Typical Load-Extension Curves for PWRC condition 5-8, scale and full scale, inner rope yarns, inner textile yarns.



Whilst there was a small difference between the linear densities of the textile yarns used in each construction, the shape of the curves are different, with the scale L/E curve being stiffer beyond the first knee and more linear.

5. SEM EXAMINATION

To put the SEM photos in perspective, it should be noted that the majority of filaments are in excellent condition, as shown in the figure below after 40 million cycles 30% mean and 6% range, from the Durability report from the first 2 years study.

Figure 6.6.4. SEM of Mid-span region and end of splice buckled area showing no damage

5.1 SEM examination 10t rope

The following are a selection of photographs taken of the PSC MRXC series. They show features common to the remaining two series of samples.

Photo 5.1.1. 10 tonne PSC, MRXC 1 20% mean/20% range showing diagonal banding at two different angles

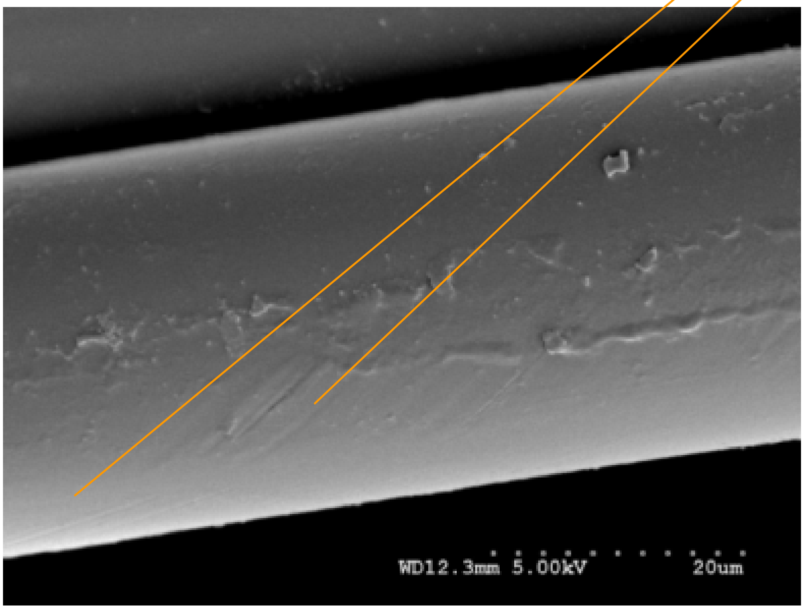
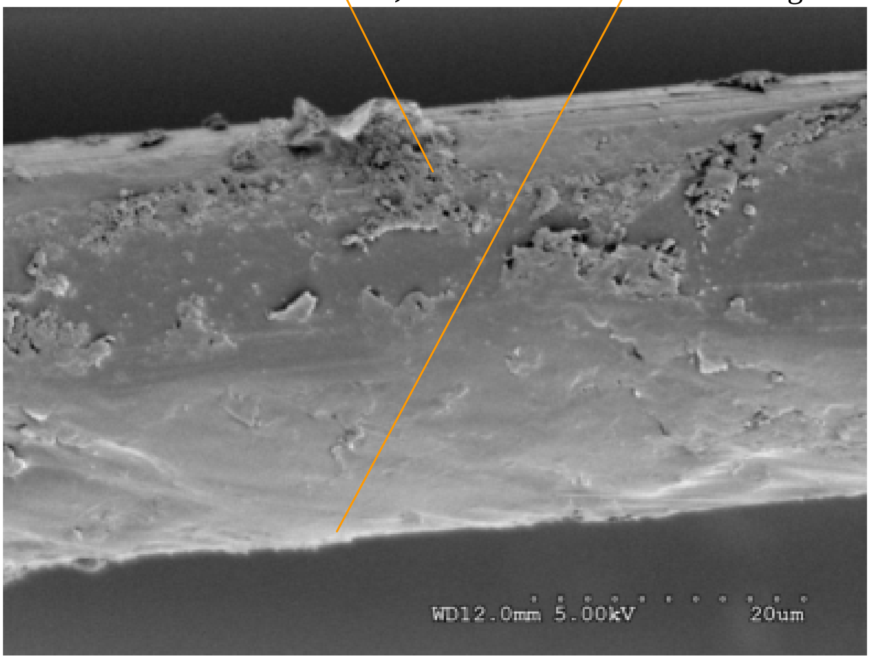


Photo 5.1.2 shows a considerably disrupted surface, with both diagonal features and axial features [at the upper margin of the filament]. The scabrous features may be either material fractured or abraded from the filament and/or could be surface contamination.

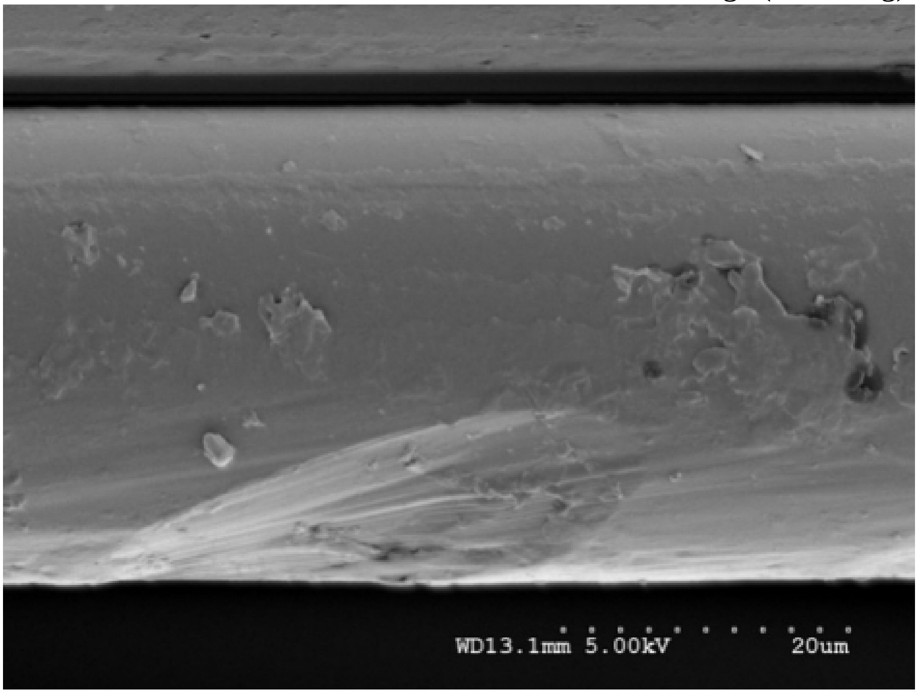
Photo 5.1.2. 10 tonne PSC, MRXC 1 20% mean/20% range



Surface grooves associated with inter-strand contact were more readily found on most of the remaining samples.

Photos 5.1.3, 5.1.4 and 5.1.5 are taken from MRXC 2

Photo 5.1.3. 10 tonne PSC, MRXC 2 5% mean 8% range (x 2K mag)



The feature of note in Photo 5.1.3 is that the abraded depression has been imposed on low-angle diagonal features or banding, this banding being noted on other photographs. This banding can be seen within the depression, but can also be seen to run along the filament surface beyond the depression. The conclusion is that the banding is not just a surface feature, but extends internally to the filament.

From Photos 5.1.4 and 5.1.5 it can be seen that the inter-strand contact has produced only mild abrasion depressions on the filaments. Axially oriented features may also be seen on the filament surface.

Photo 5.1.4. 10 tonne PSC, MXRC 2 5% mean/8% range (x 500 mag)

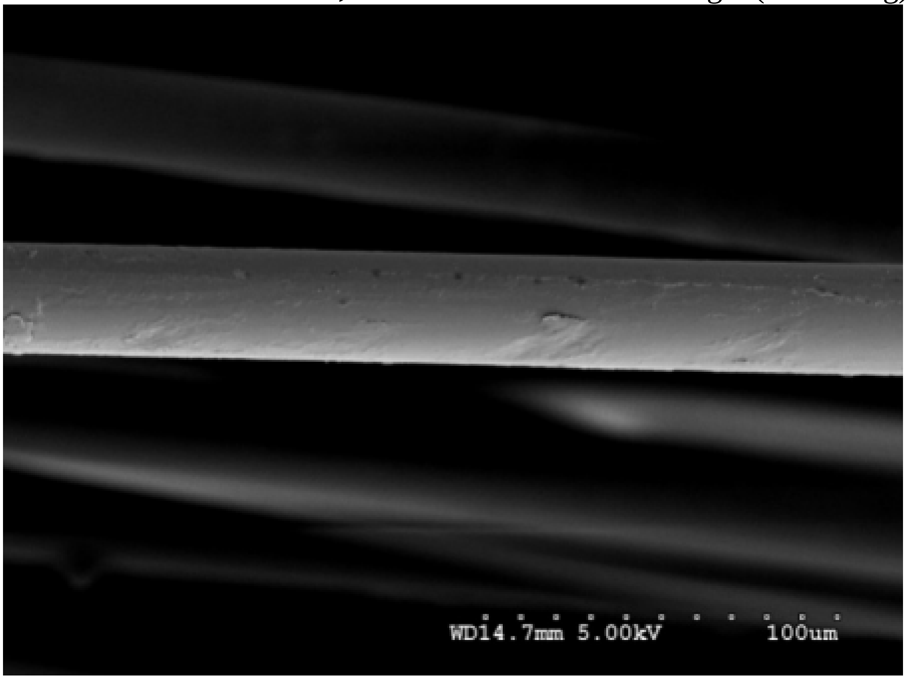
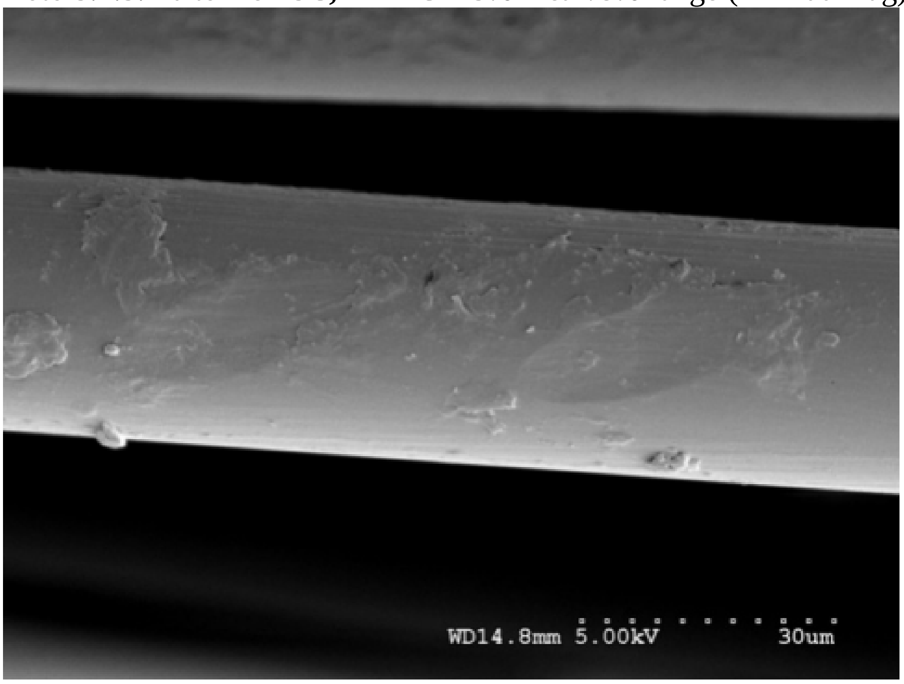


Photo 5.1.5. 10 tonne PSC, MXRC 2 5% mean/8% range (x 1200 mag)



The SEM investigation of MRXC3, 60% mean/6% range, 1 x 10^6 cycles, failed to show any significant filament-filament abrasion. However, surface longitudinal [axial] features were seen.

Photo 5.1.6 shows a typical view. Faint impressions may be seen at an angle expected for filament-filament contact, moving from bottom left to top right

Photo 5.1.6. 10 tonne PSC, MRXC3, 60% mean/6% range, 1 x 10^6 cycles, (x 900 mag typical view)

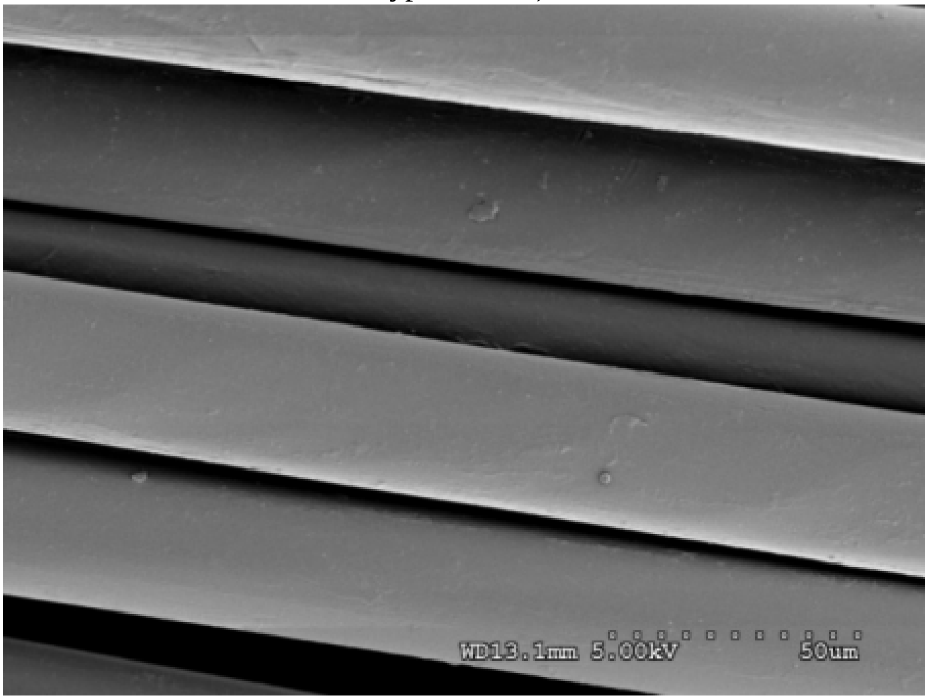
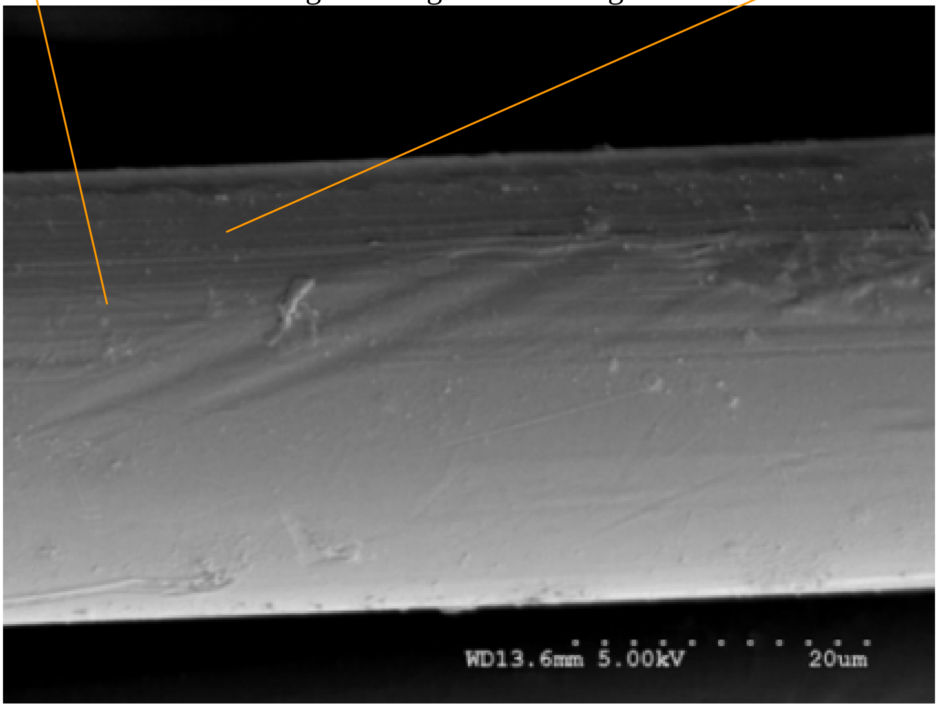


Photo 5.1.7 shows angular surface features that have been imposed on axial features. This may be inferred from inspection of the features, where the more prominent angled ones clearly overlay the axial ones.

The surface of the fibre appears to have longitudinal grooves, as indicated, which maybe due to ropemaking and nothing to do with the tension-tension cycling induced inter-strand movement.

Photo 5.1.7. MRXC3, 60% mean 6% range, 1 x 10^6 cycles, (x 2K mag) showing possible surface longitudinal groove and angled features



Not much was seen from the series of 6 photos taken of MRXC4, 20% mean 10% range, 1 x 10^6 cycles. Photo 5.1.8 shows both longitudinal and angled features as well as some surface disruption

Photo 5.1.8. 10 tonne PSC, MRXC4, 20% mean 10% range, 1 x 10^6 cycles

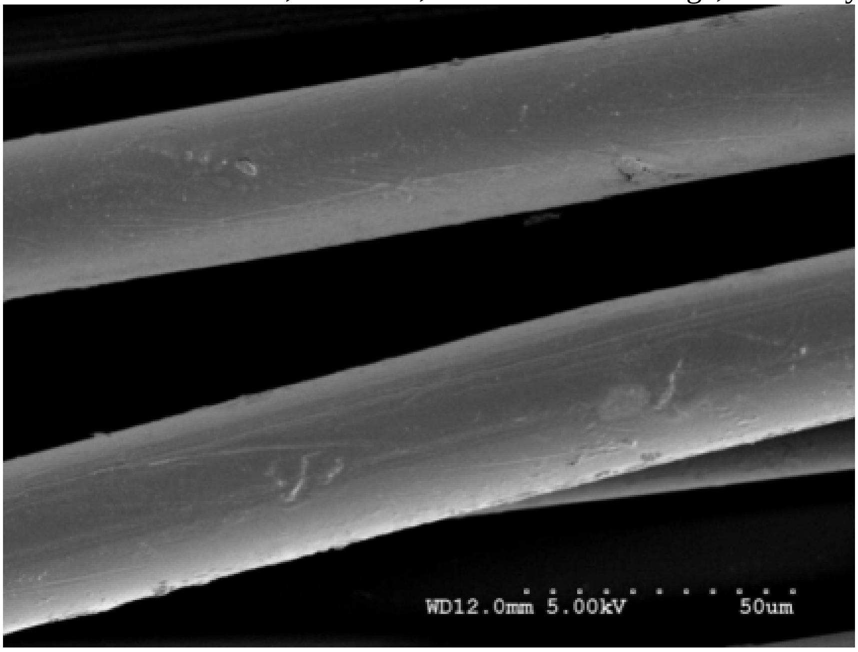


Photo 5.1.9 shows a filament from sample MRXC5, 3% mean 4% range, 1 x 10^6 cycles that appears to have suffered some flattening associated with inter-strand filament-filament contact features. No wear on any filaments**.**

Photo 5.1.9. 10 tonne PSC, MRXC5, 3% mean 4% range, 1 x 10^6 cycles, flattened filament

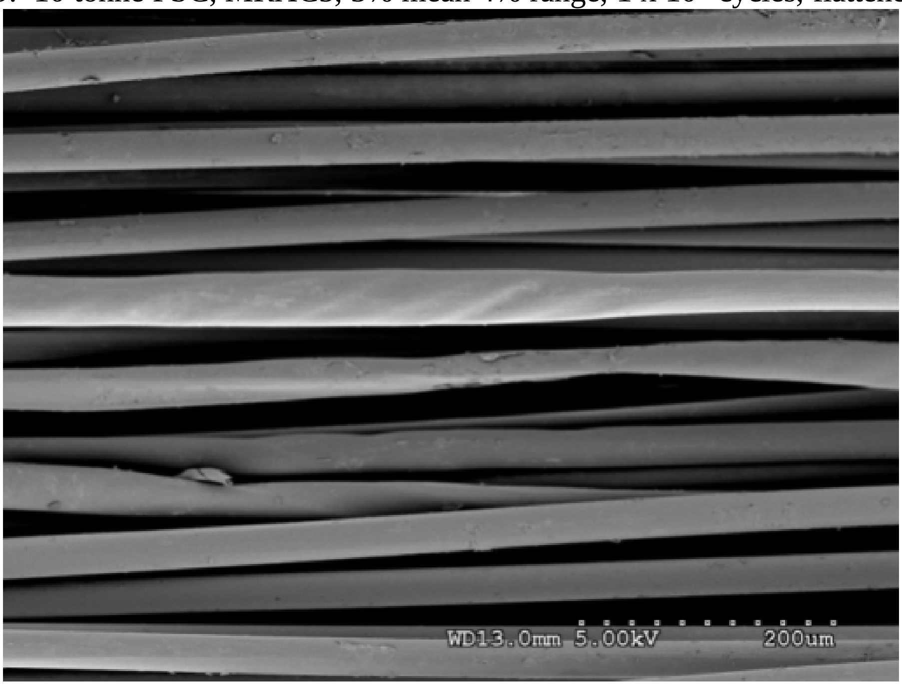


Photo 5.1.10. 10 tonne PSC, MRXC5, 3% mean 4% range, 1 x 10^6 cycles, flattened filament from side, but no evidence of wear. The filament in the background is in perfect condition.

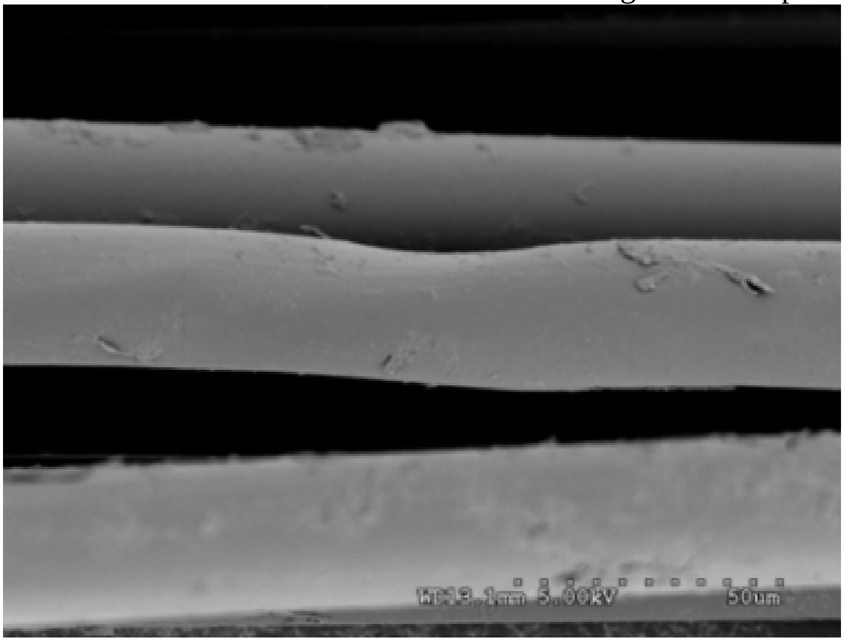
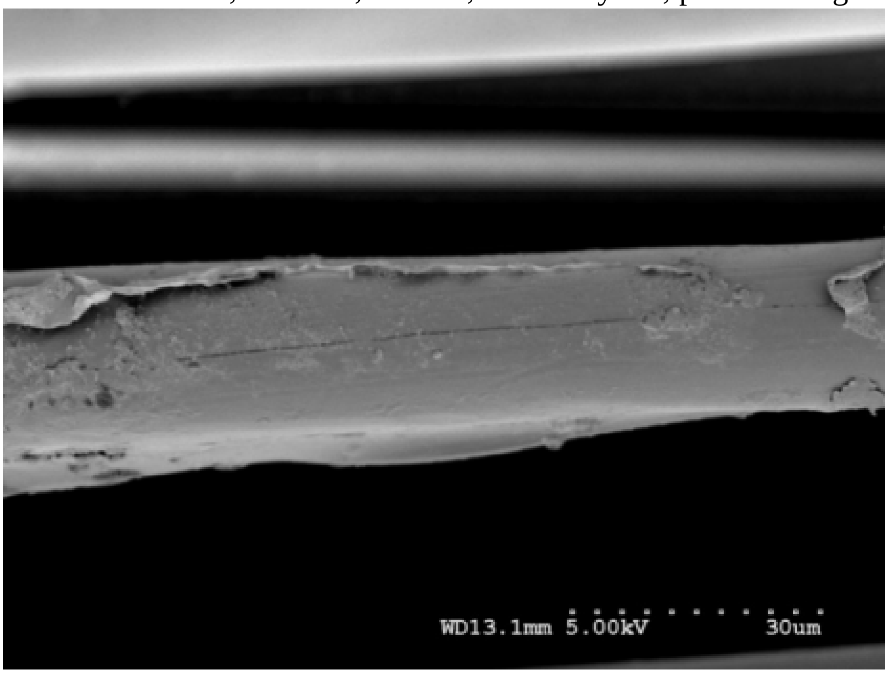


Photo 5.1.11. 10 tonne PSC, MRXC5, 3+/-2%, 1 x 10^6 cycles, possible longitudinal crack



Photos 5.1.12 and 5.1.13 show abrasion fatigue resulting from filament-filament abrasion on sample MRXC6, 20% mean/15% range, 1 x 10^6 cycles.

Photo 5.1.12. 10 tonne PSC, MRXC6, 20+/-7.5%, 1 x 10^6 cycles, inter-strand filament-filament abrasion

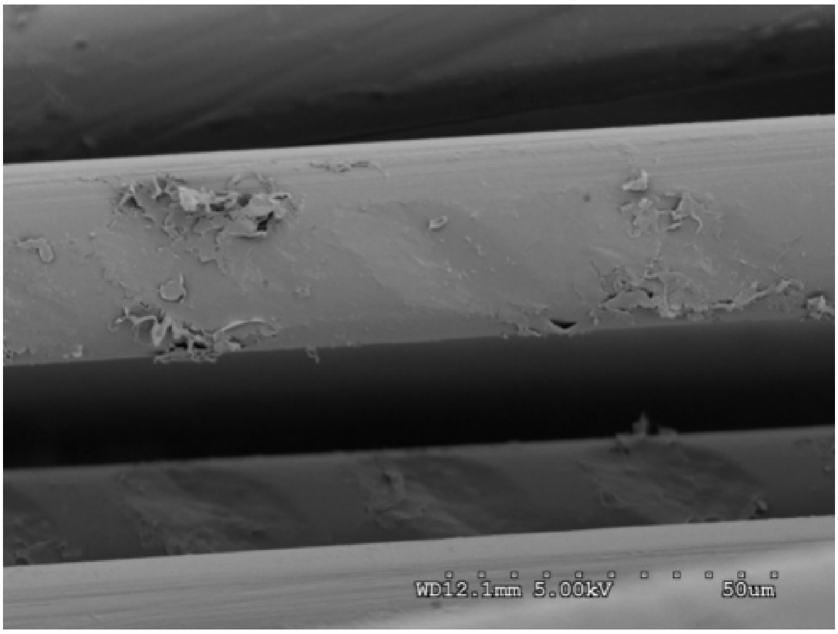


Photo 5.1.13. 10 tonne PSC, MRXC6, 20+/-7.5%, 1 x 10^6 cycles, another example of filament-filament abrasion. Note filament with elongated angled features in the background.

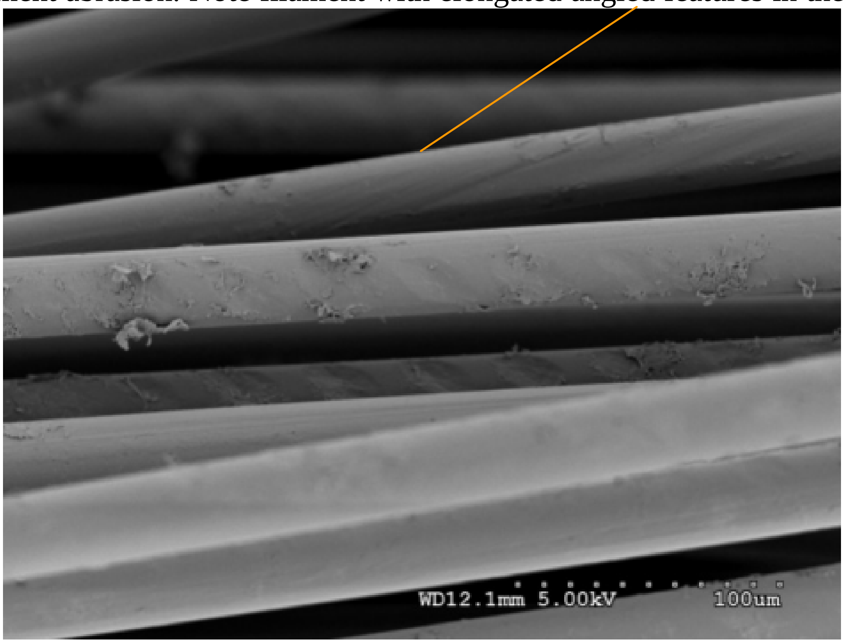


Photo 5.1.14 shows an example of a possible longitudinal crack in the filament.

Photo 5.1.14. 10 tonne PSC, MRXC6, 20% mean/15% range, 1 x 10^6 cycles, longitudinal gauge most likely caused by manufacturing. Also note apparent surface splitting at right angles to axis.

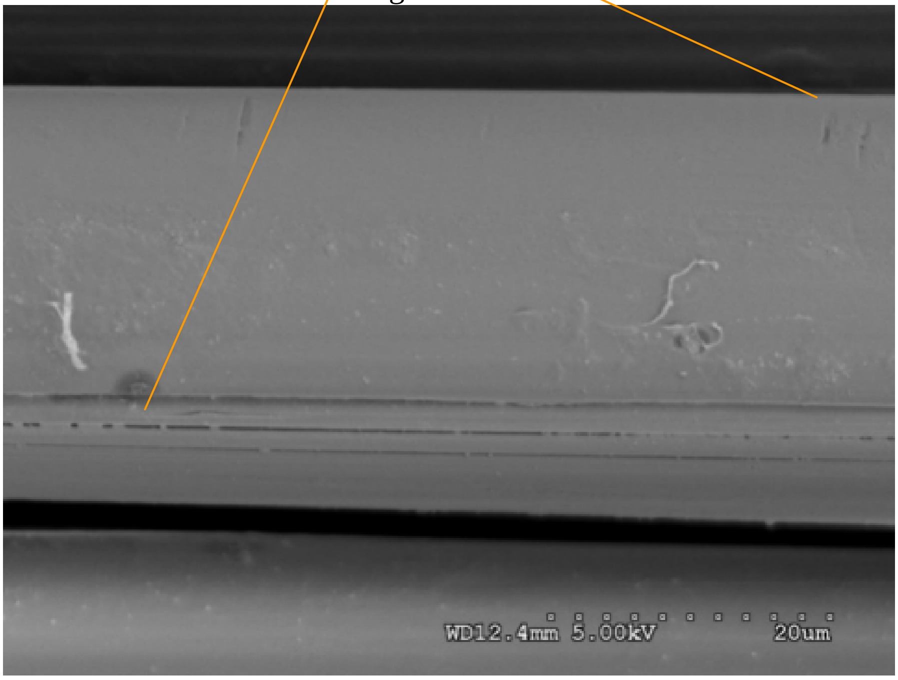


Photo 5.1.15 shows a filament from MRXC7, 60% mean/6% range, 2 x 10^6 cycles, that has been kinked and then trapped under filaments, to create the four 'moulding impressions' seen across the filament. Beneath this filament there are further filaments displaying evidence of filament-filament contact, though it looks more like evidence of localised pressure rather than abrasion. This localised pressure was most likely due to a misplaced filament laying across the filaments rather than nestled alongside.

Photo 5.1.15. 10 tonne PSC, MRXC7, 60% mean/6% range, 2 x 10^6 cycles, no effects of inter-strand wear on filaments. A one off filament that has been out of position has clearly deformed under high pressure.

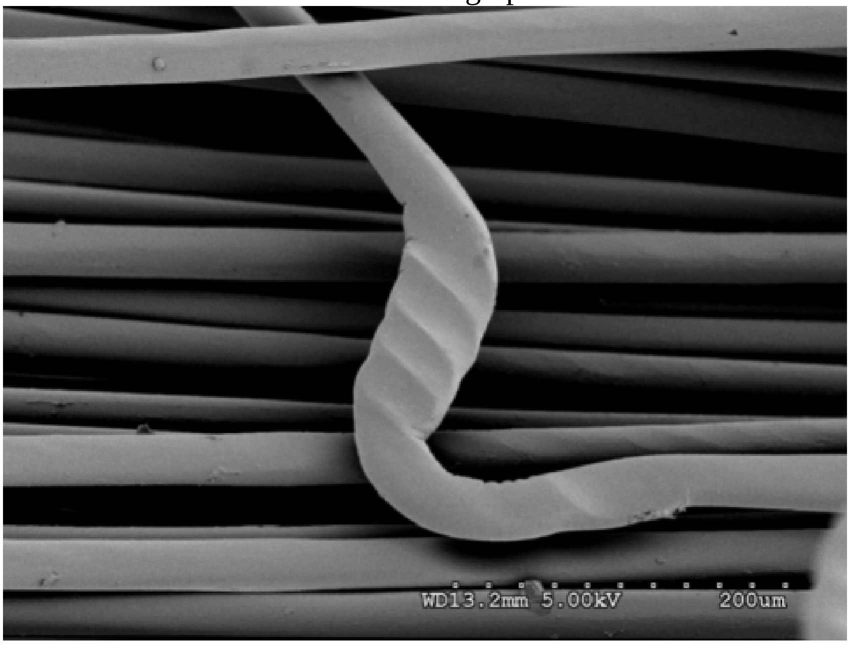
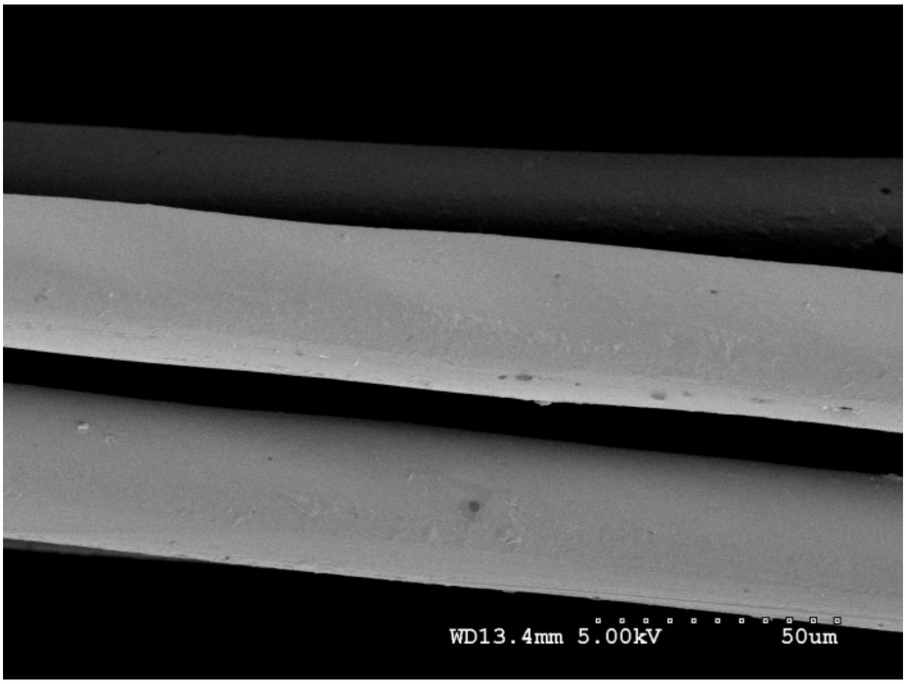


Photo 5.1.16 is another example of sub-sub contact, though it was very mild and, again, has the appearance of being caused by pressure rather than abrasion. There was no evidence of inter-strand wear.

Photo 5.1.16. 10 tonne PSC, MRXC7, 60% mean/6% range, 2 x 10^6 cycles, mild filament-filament interaction



Photographs 5.1.17 to 5.1.22 are a selection from the series taken of PBC rope yarns. Only MRZW 1, 2 and 4 have been investigated since MRZW3 load condition 4% mean/4% range respectively did not show any evidence of inter-strand filament-filament abrasion.

Photo 5.1.17 shows no inter-strand wear, which is in agreement with the tensile results where no strength loss was found.

Photo 5.1.17. 10 tonne PBC, MRZW1, 20% mean/10% range, filaments in perfect condition (marks were due to manufacturing)

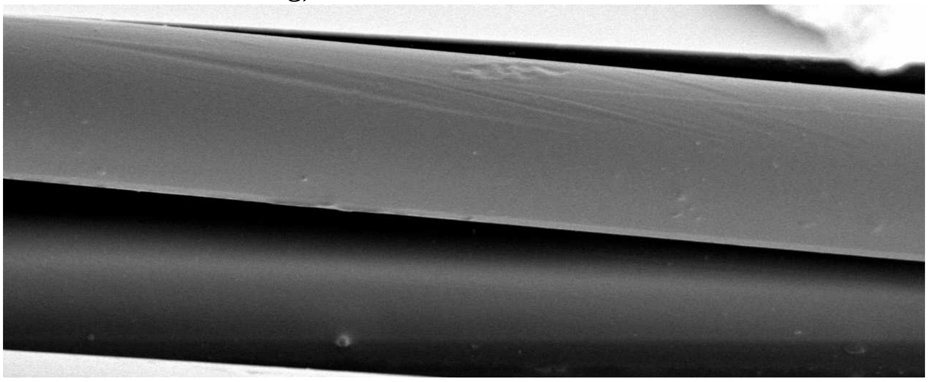


Photo 5.1.18. 10 tonne PBC, MRZW2, 3% mean/4% range, filaments in perfect condition.

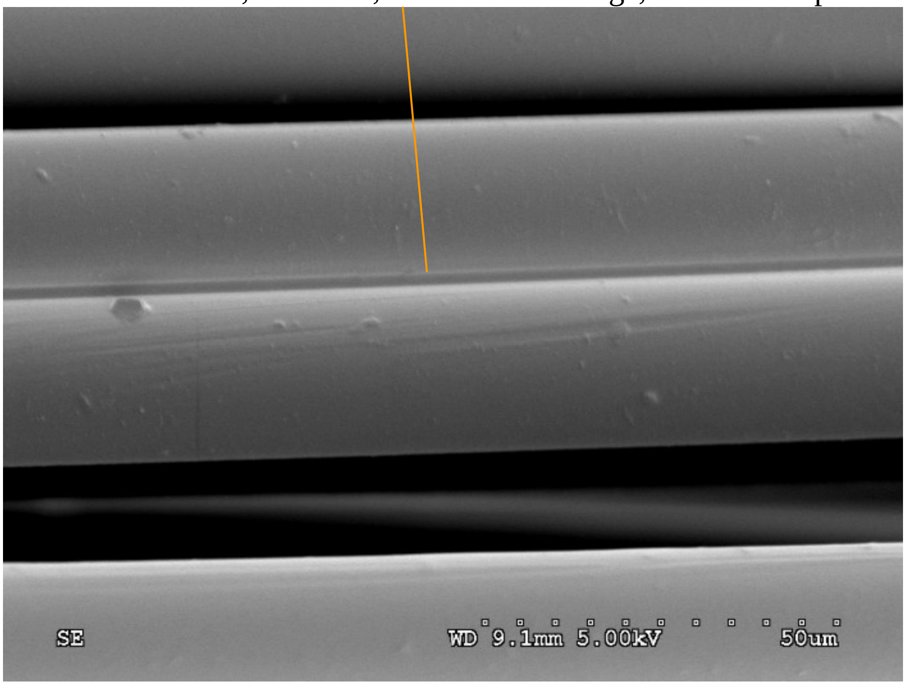
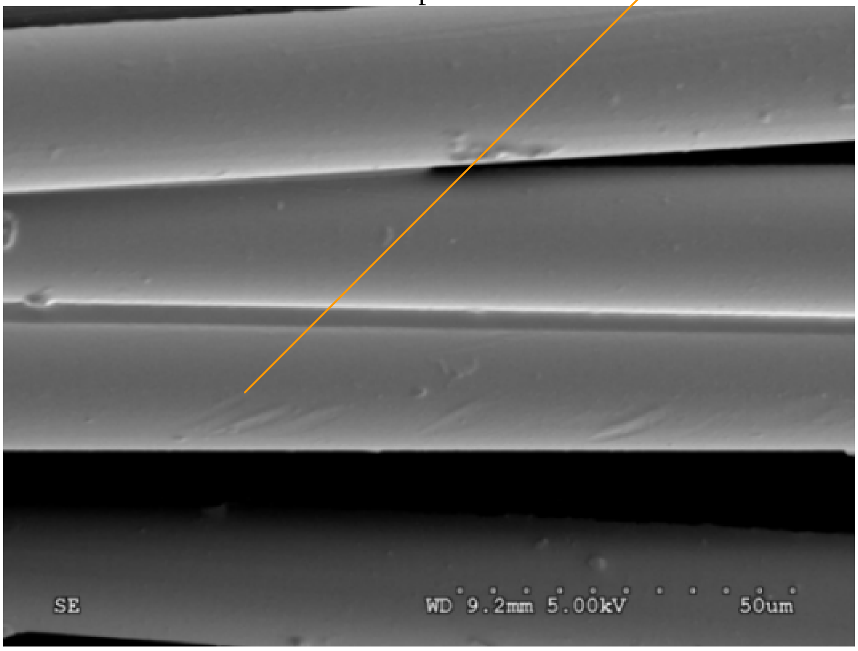


Photo 5.1.19. 10 tonne PBC, MRZW2, 3% mean/4% range, showing grooves in the filament at an angle expected for inter-strand abrasion. However, the separation of these grooves does not match filament diameters, so is not due to the wear mechanism. Note that the surrounding filaments are in perfect condition.



MRZW4 [20% mean/15% range] showed the clearest sign of inter-strand filament-filament abrasion, as shown in Photographs 5.1.20 to 5.1.22.

Photo 5.1.20. 10 tonne PBC, MRZW4, 20% mean/15% range, mild filament-filament abrasion

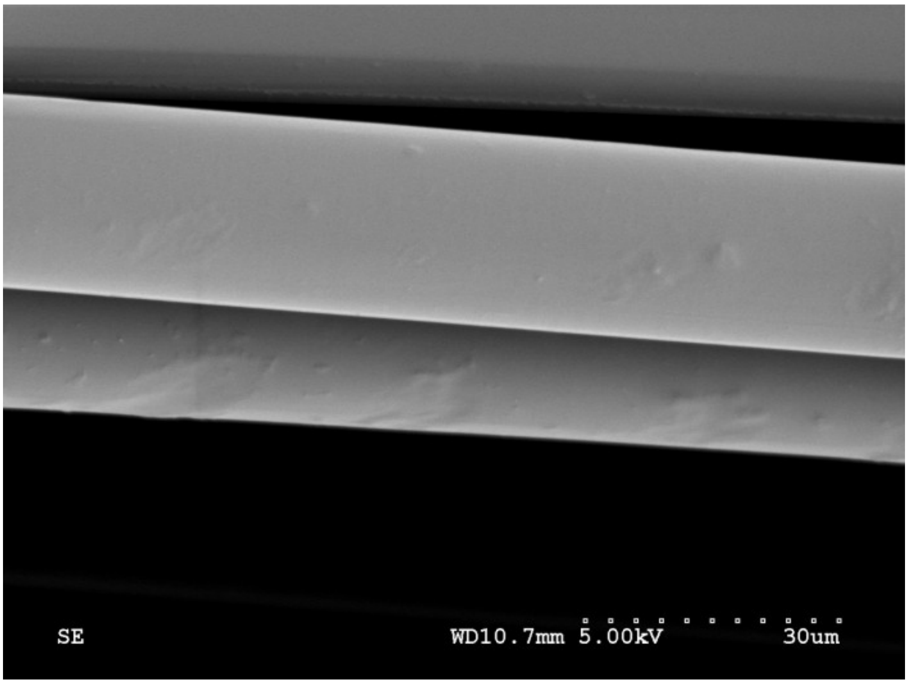


Photo 5.1.21. 10 tonne PBC, MRZW4, further example of mild filament-filament abrasion

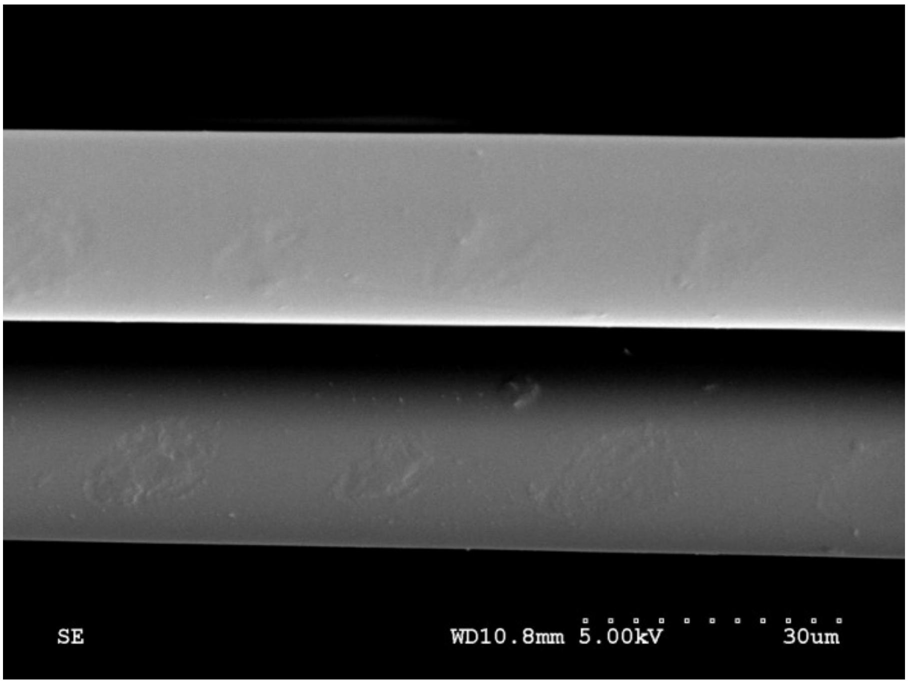


Photo 5.1.22. 10 tonne PBC, MRZW4, filament showing modest depressions, probably caused by inter-strand pressure. Also a suggestion of an upper groove

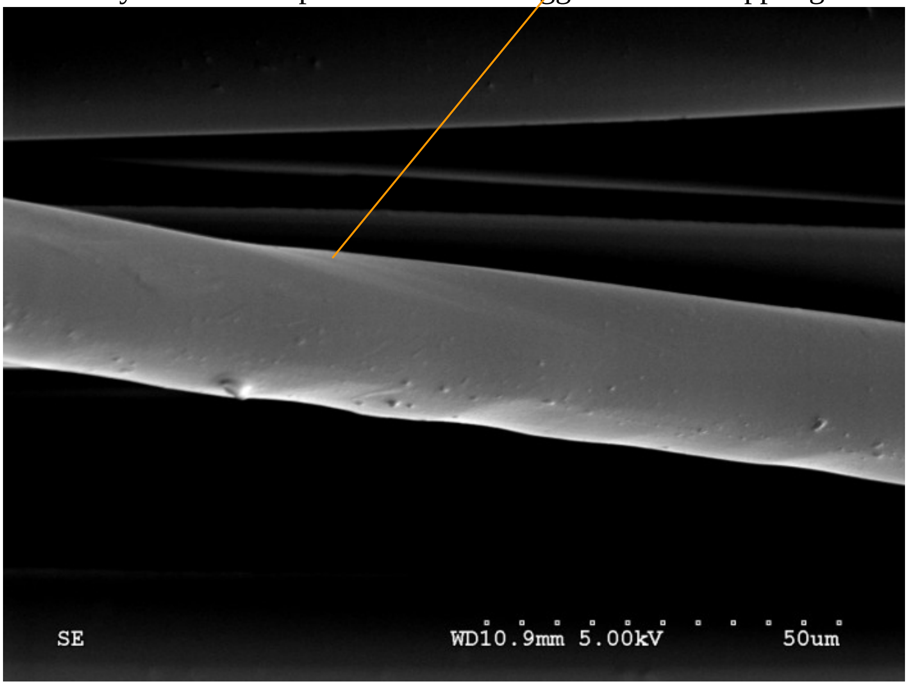
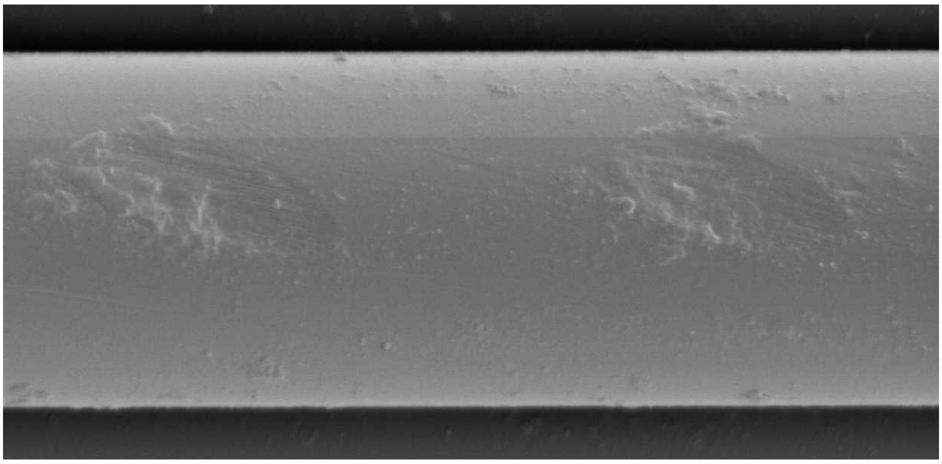


Photo 5.1.23 shows mild inter-strand abrasion for the PWRC at 5% mean/8% range in the outer yarn, outer strand.

Photo 5.1.23. 10 tonne PWRC, MSAN1, 5% mean/8% range, filament showing mild abrasion.



5.2 SEM examination Full Scale Subrope

Below are a selection of SEM images from the PSC subropes 'Reference'[no cyclic loading] MRXC14 [cyclic loading condition 3% mean/4% range] and MRXC13 [cyclic loading condition 20% mean/15% range].

Figures 5.2.1 to 5.2.4 are from the PSC control sample of sub-rope. As expected filaments are in good condition, but some features were present that have been seen on cycled material. This is confirmation that these features are an unavoidable part of filament extrusion/rope making, and have not been caused during cyclic loading.

Figure 5.2.1. Reference, general view, showing absence of damage.

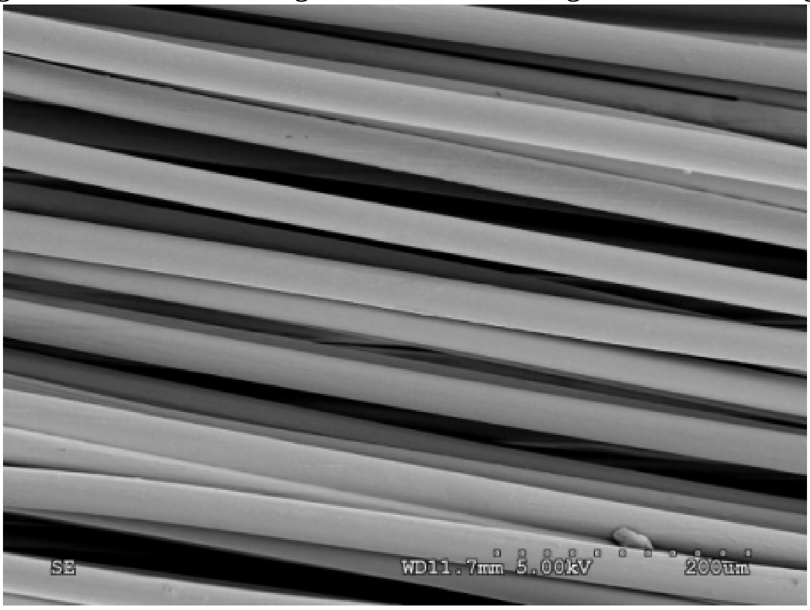


Figure 5.2.2. Reference, surface blemishes [likely origin manufacturing]

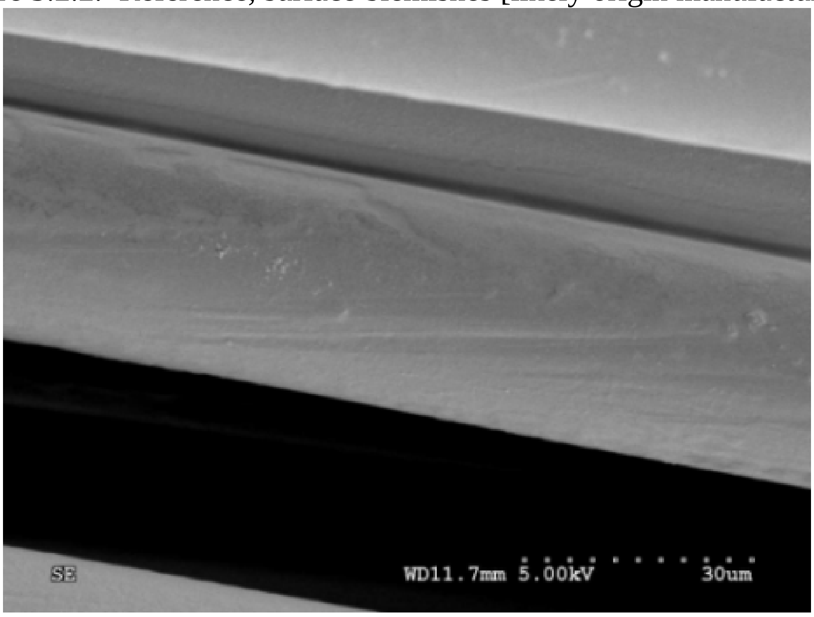


Figure 5.2.3. Reference, axial ‘gouged’ grooves and angled features [likely origin manufacturing]

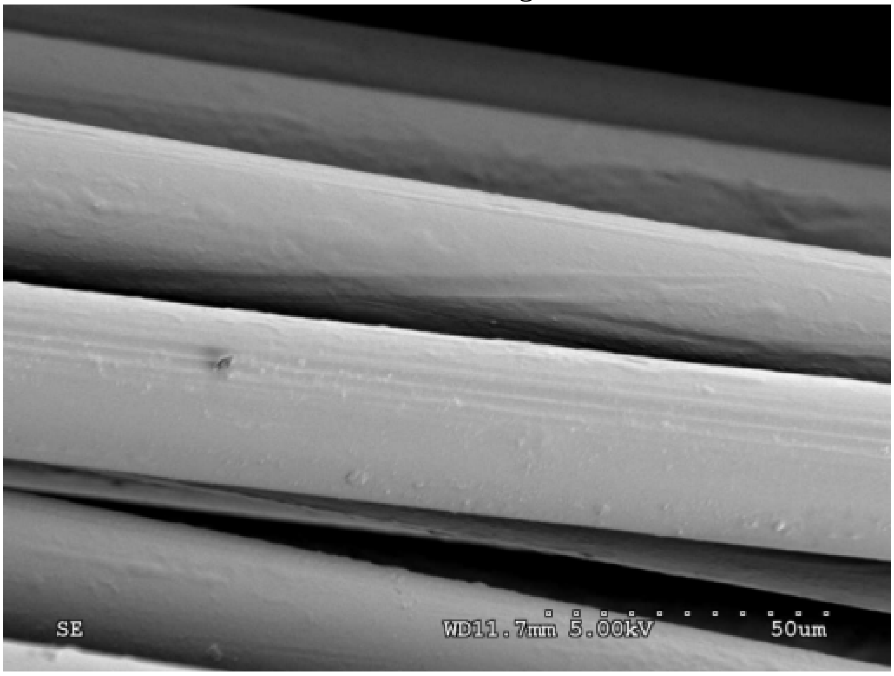
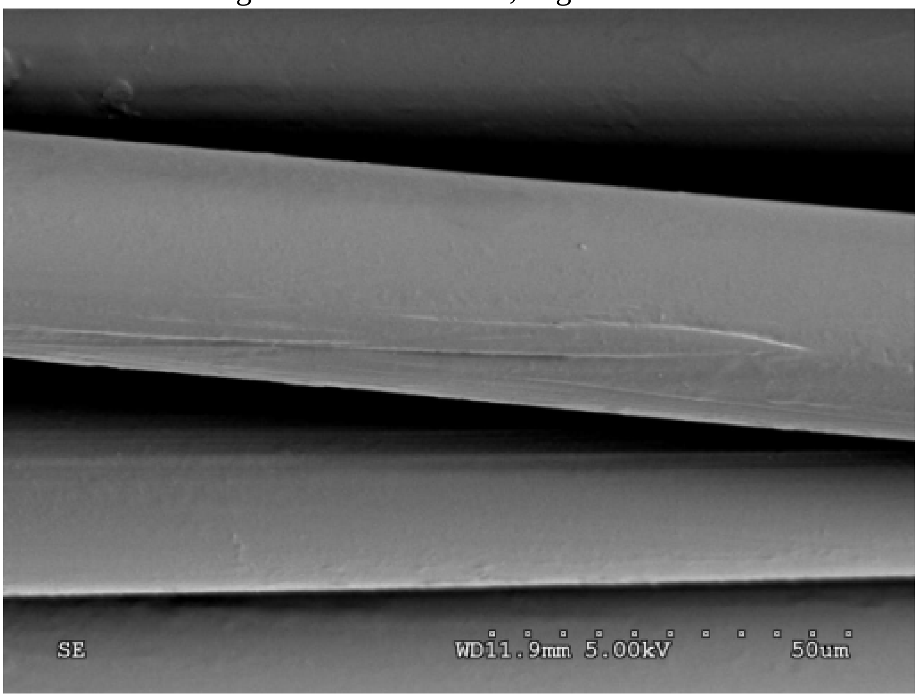


Figure 5.2.4. Reference, angled feature



MRXC14 3%mean 4% range

Very little evidence of abrasion fatigue was found. This is in line with the tensile results for this sub-rope.

Photo 5.2.5. Full scale PSC, MRXC14 3% mean/4% range, general view filaments in good condition

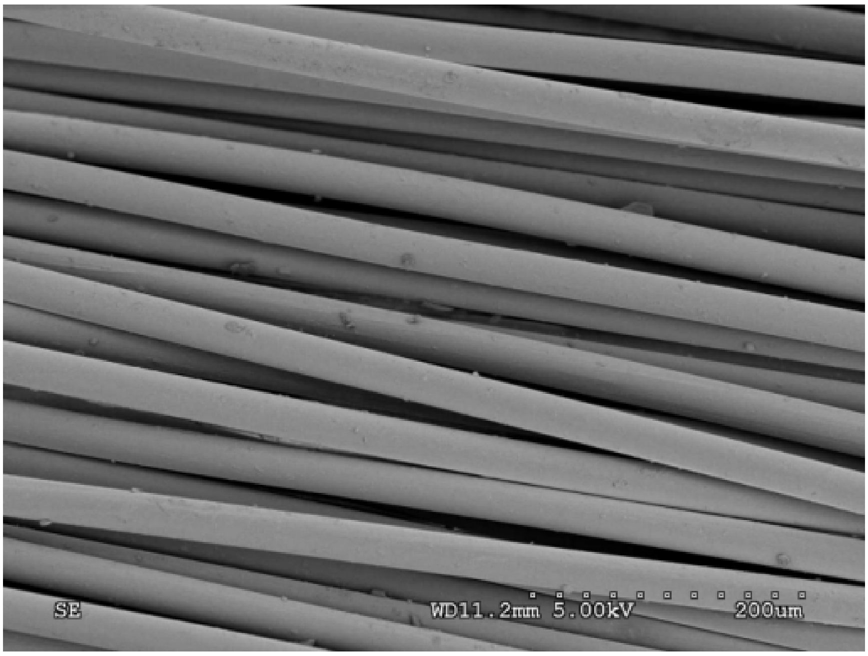
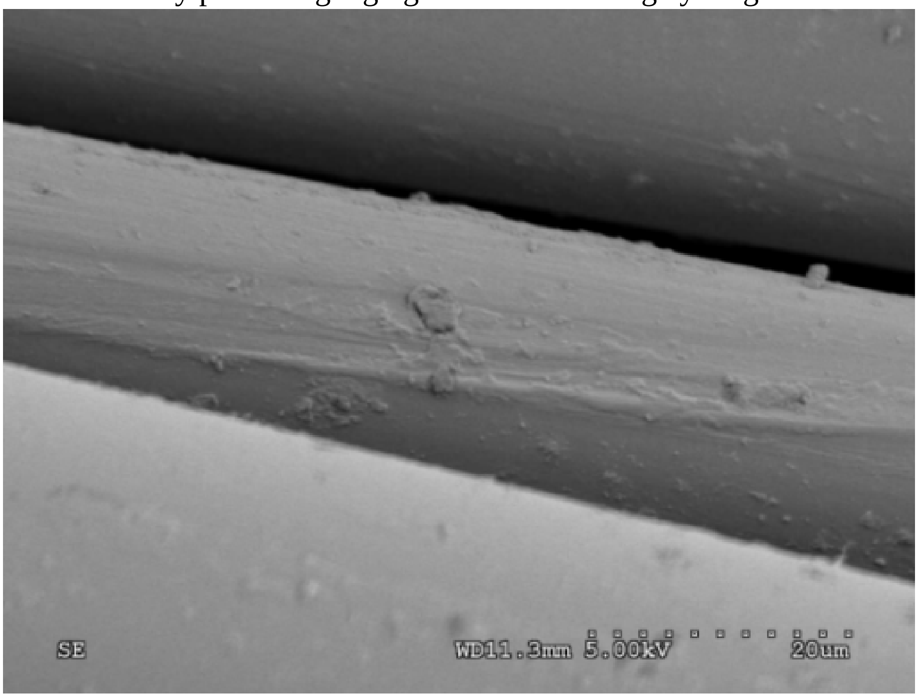


Photo 5.2.6. Full scale PSC, MRXC14 3% mean/4% range, angled features, possibly caused by particles gouging the surface during cycling



MRXC13 20%mean 15% range

The most severe damage was seen on this series of images, as expected from the tensile results.

Photo 5.2.7. Full scale MRXC13, 20% mean/15% range, general view with filament-filament abrasion evident

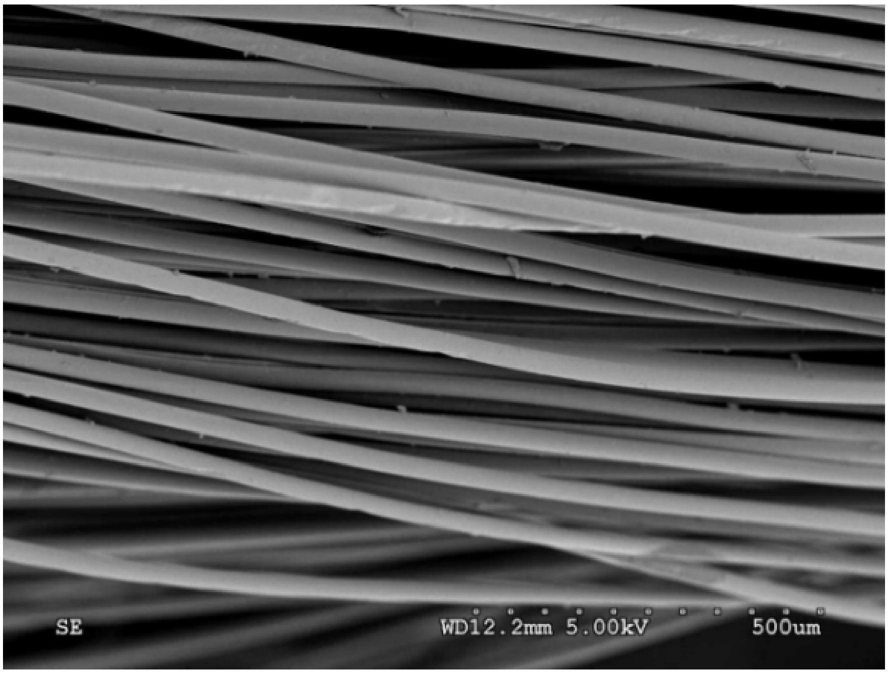


Photo 5.2.8. Full scale MRXC13, 20% mean/15% range, closer view7filament- filament abrasion

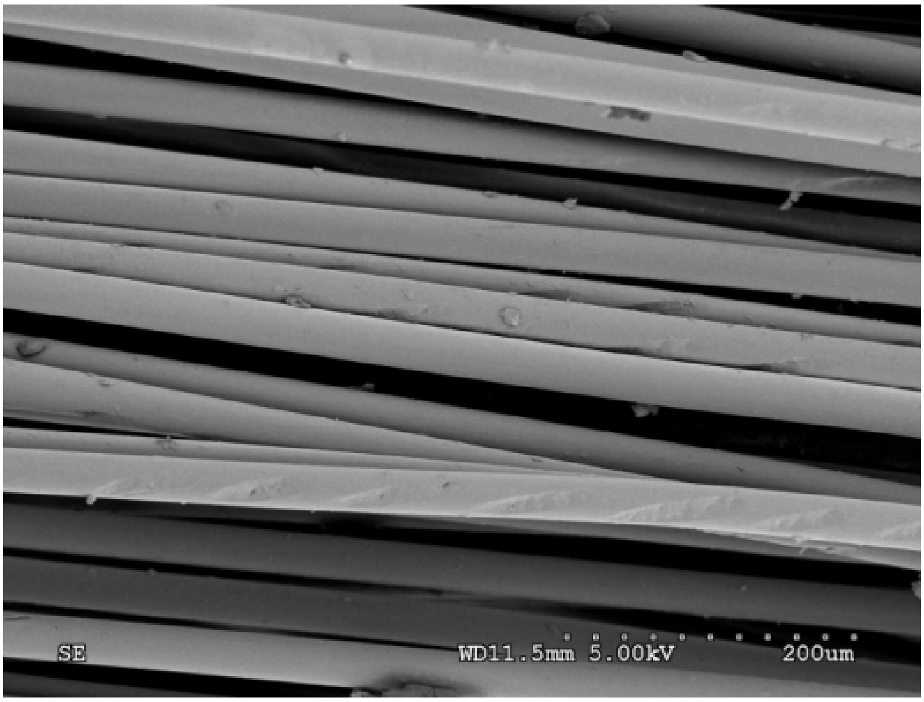


Photo 5.2.9. Full scale MRXC13, 20% mean/15% range, close view filament-filament abrasion

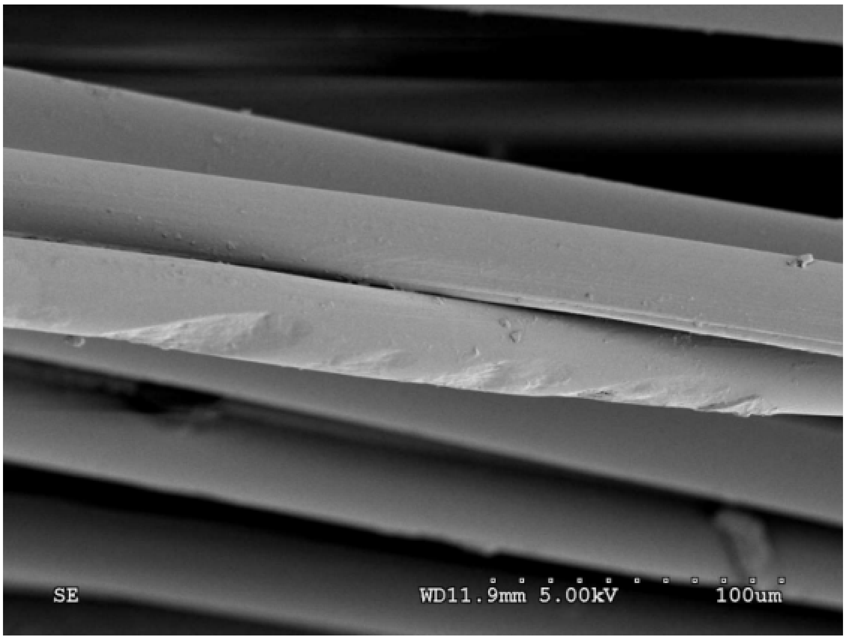
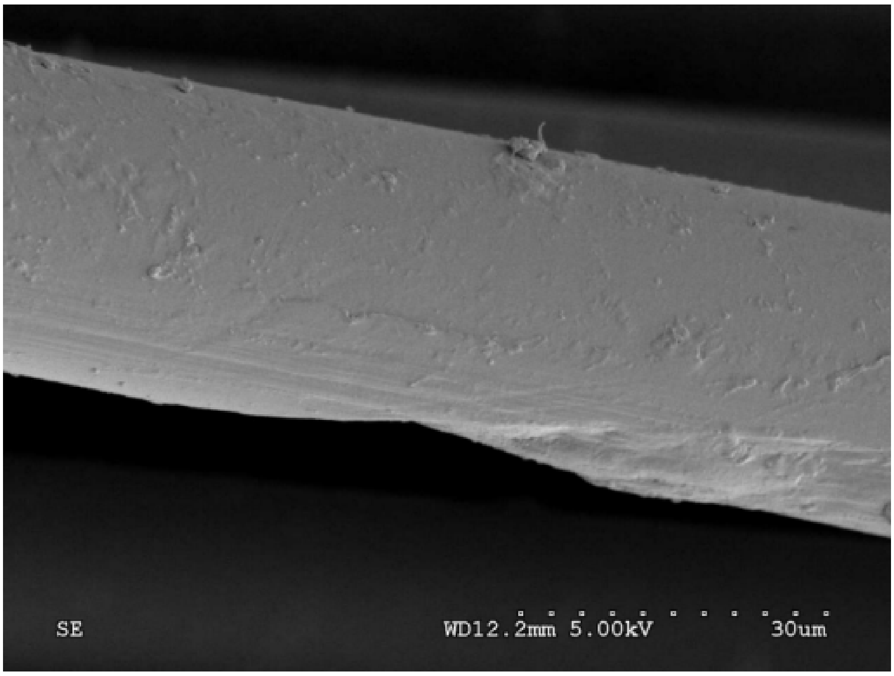


Photo 5.2.10. Full scale MRXC13, 20% mean/15% range, another close view filament-filament abrasion, side on, to reveal groove depth of circa 3 micron, worn into 35 micron diameter filament.



MRZW14 5%mean 8% range

Below are a selection of SEM images from the PBC subrope MRZW14 [cyclic loading condition 5% mean/8% range].

Evidence of filament-filament abrasion was found, but of a reduced severity and frequency when compared to MRXC13, but certainly of increased severity when compared to MRXC14.

Photo 5.2.11. Full scale, MRZW14, 5%mean/8% range general view of non-abraded filaments

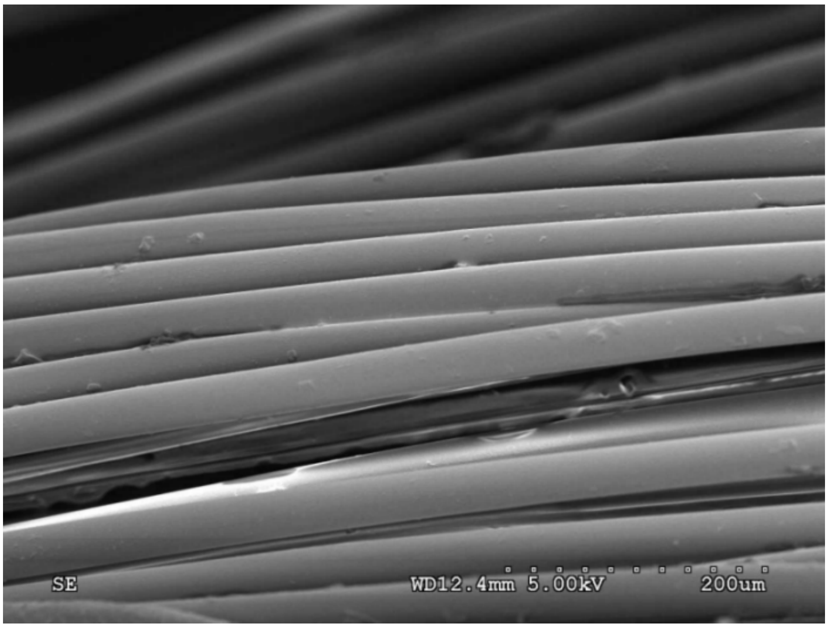


Photo 5.2.12. Full scale, MRZW14, 5%mean/8% range, filament-filament abrasion

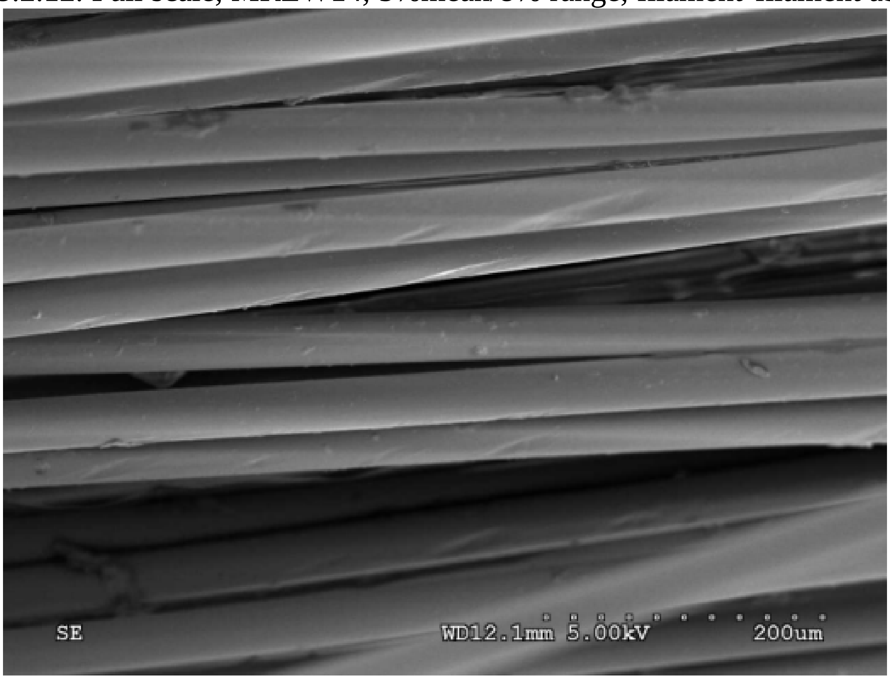


Photo 5.2.13. Full scale, MRZW14, 5%mean/8% range, closer view of filament-filament abrasion.

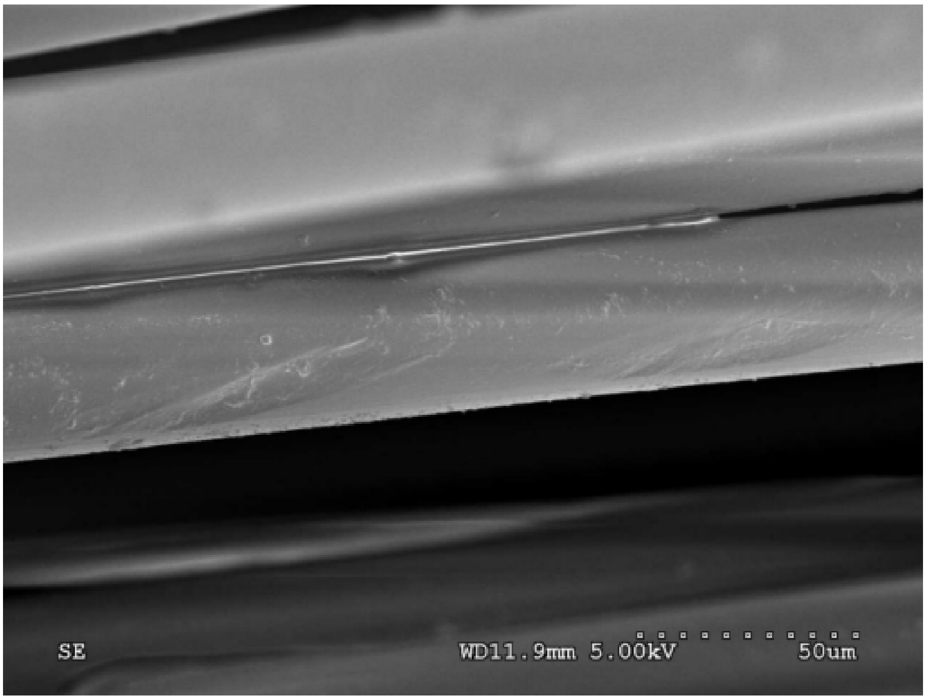
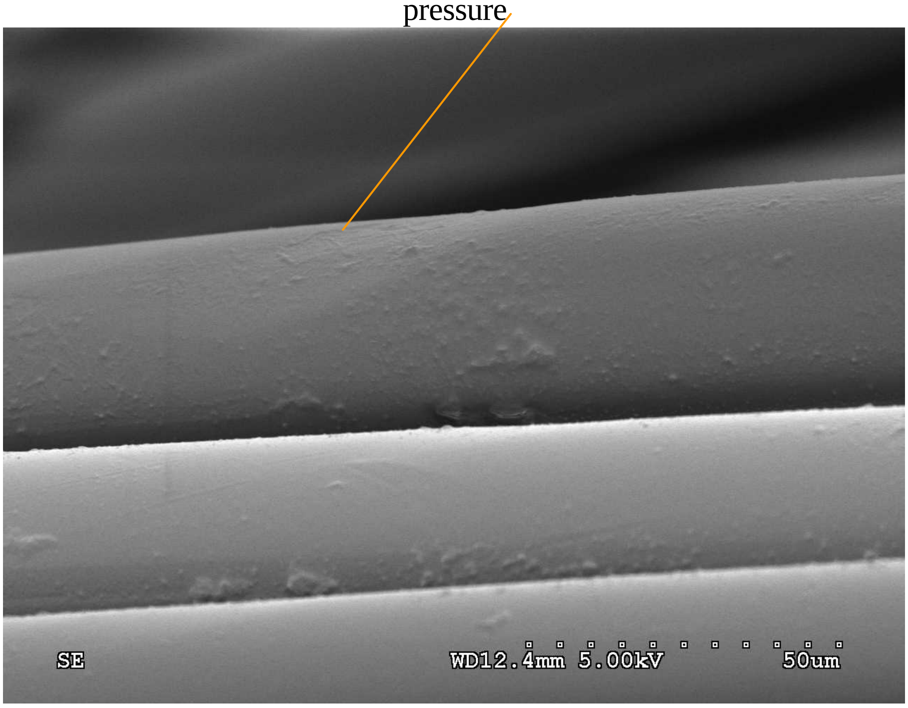


Photo 5.2.14. Full scale, MRZW14, 5%mean/8% range, groove caused by filament-filament pressure



MSAN12 5%mean 8% range

Since inter-strand wear on outer yarns has been conclusively proven, from previous work and above, it was decided to investigate whether wear occurs on the underside of yarns in the outer layer. This is between the outer and next layer down in the strand structure.

Photo 5.2.15. Full scale, MSAN12 5%mean 8% range inner strand, outer ropeyarn, outer face [facing towards the outer strands], general view

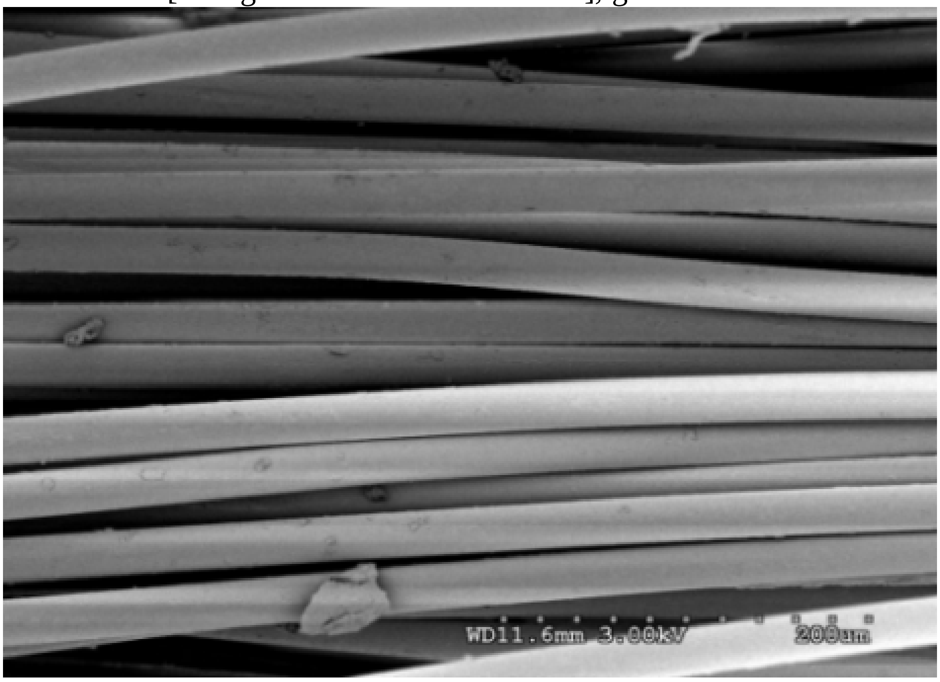


Photo 5.2.16. MSAN12 5%mean 8% range, inner strand, outer ropeyarn, outer face, showing single filament with abrasion grooves

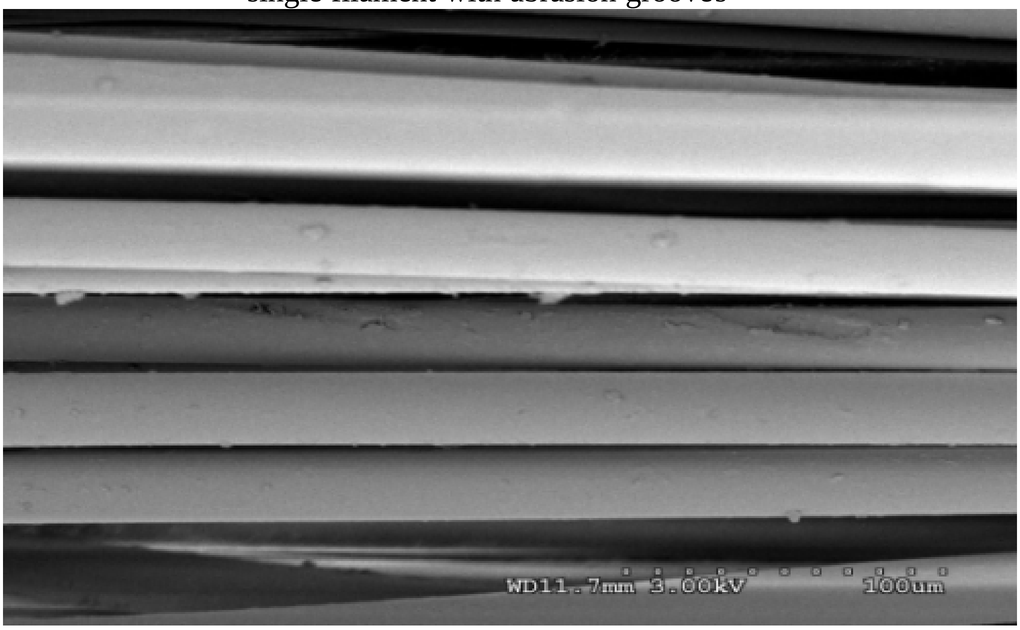
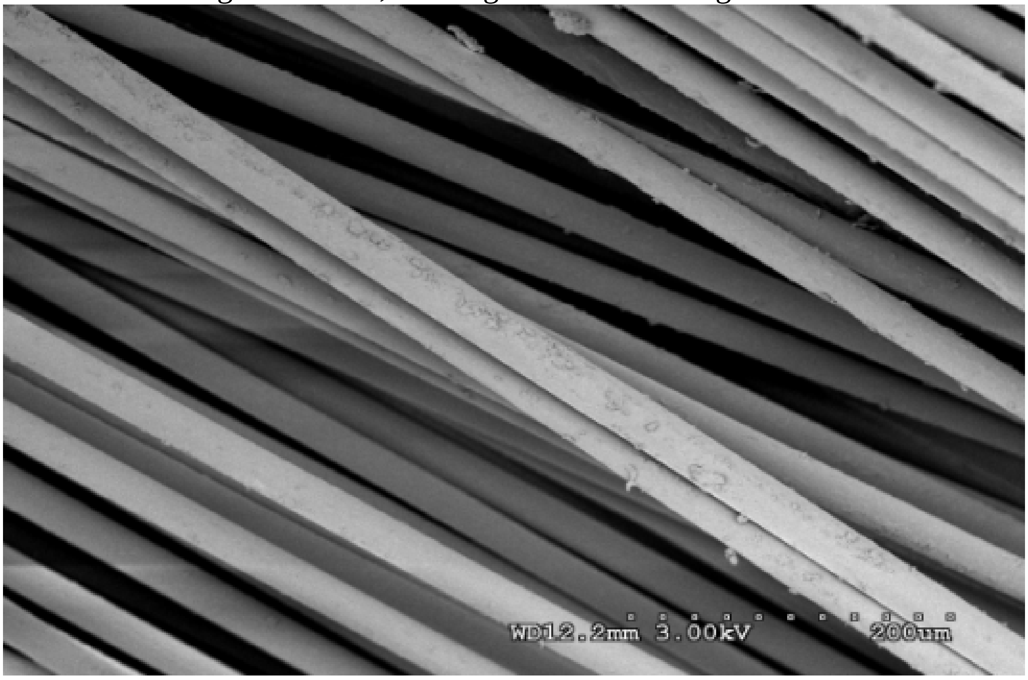


Photo 5.2.17. MSAN12 5%mean 8% range, inner strand, outer ropeyarn, outer face another general view, little sign of abrasion fatigue



horizontal lines are SEM artifact

Photo 5.2.18. MSAN12 5%mean 8% range, inner strand, outer rope yarn, inner face [facing towards inner rope yarn], general view

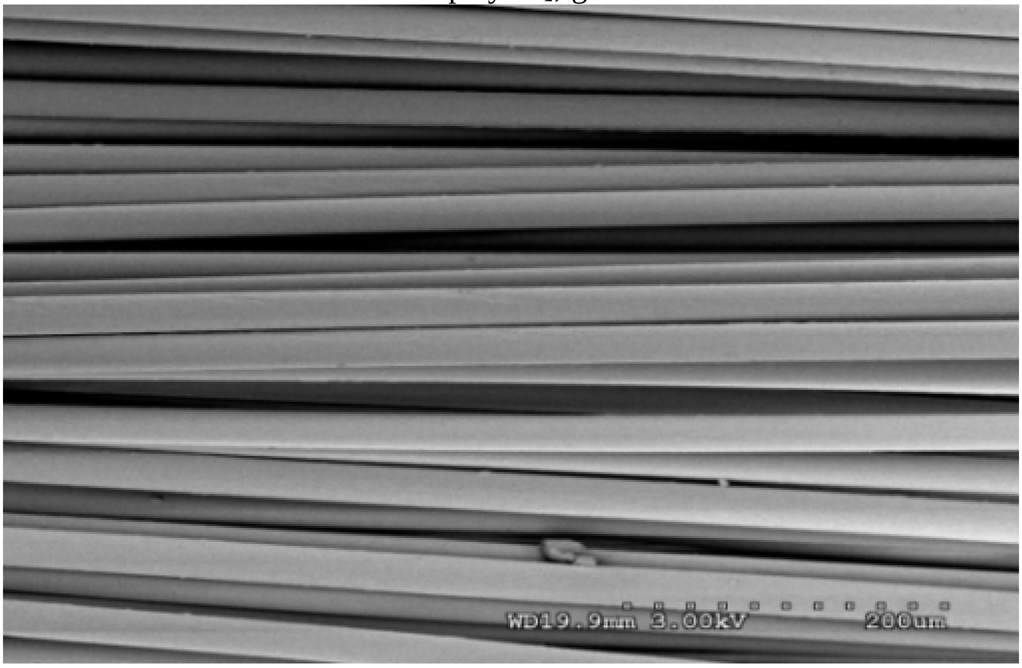


Photo 5.2.19. MSAN12 5%mean 8% range, inner strand, outer rope yarn, inner face, showing abrasion grooves

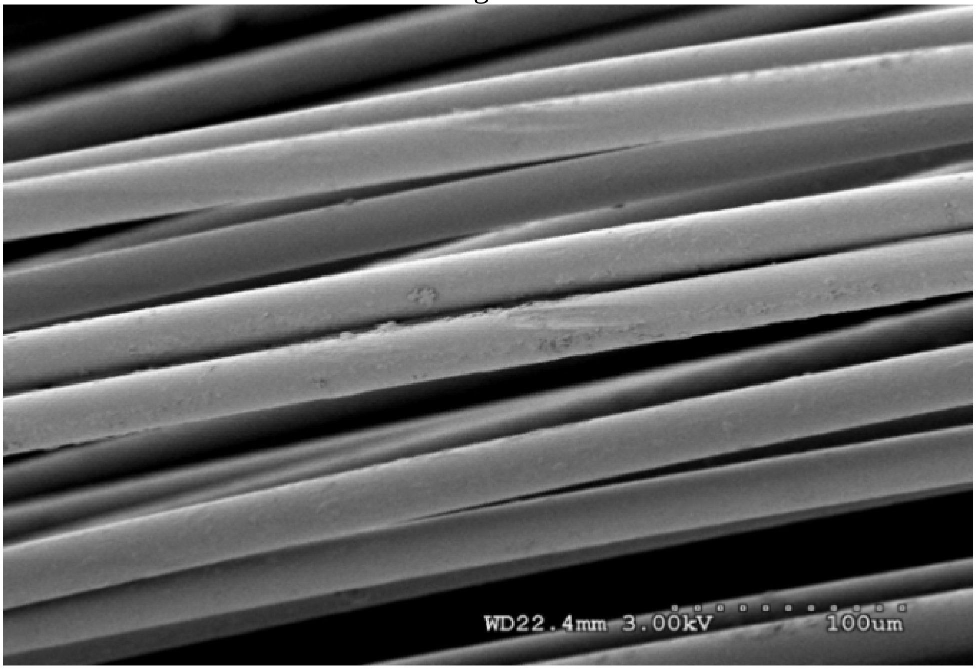


Photo 5.2.20. MSAN12 5%mean 8% range, inner strand, outer rope yarn, inner face, further abrasion grooves

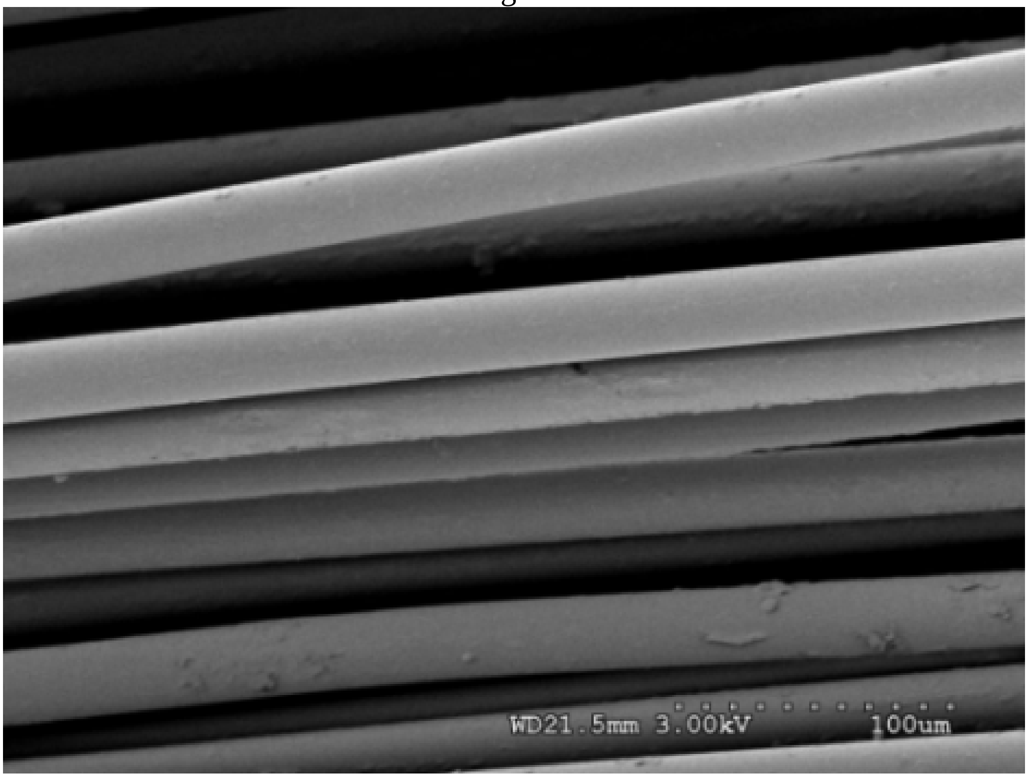


Photo 5.2.21. MSAN12 5%mean 8% range inner strand, core ropeyarn, outer face [facing towards outer rope yarns of strand], general view

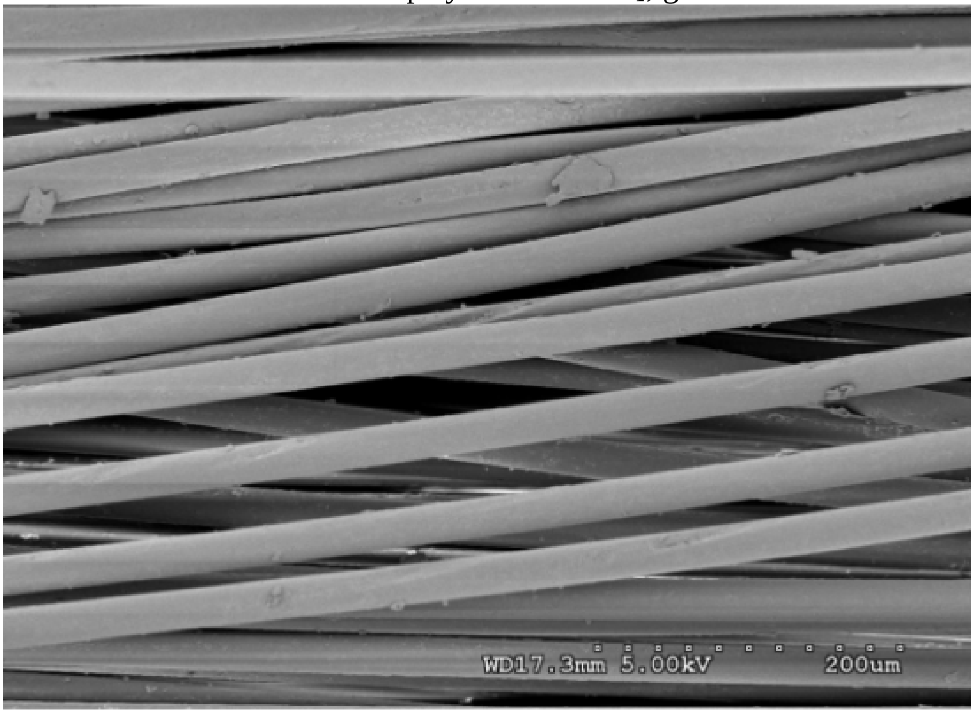


Photo 5.2.22. MSAN12 5%mean 8% range, inner strand, core rope yarn, outer face, close view of central area of Photo 5.2.21

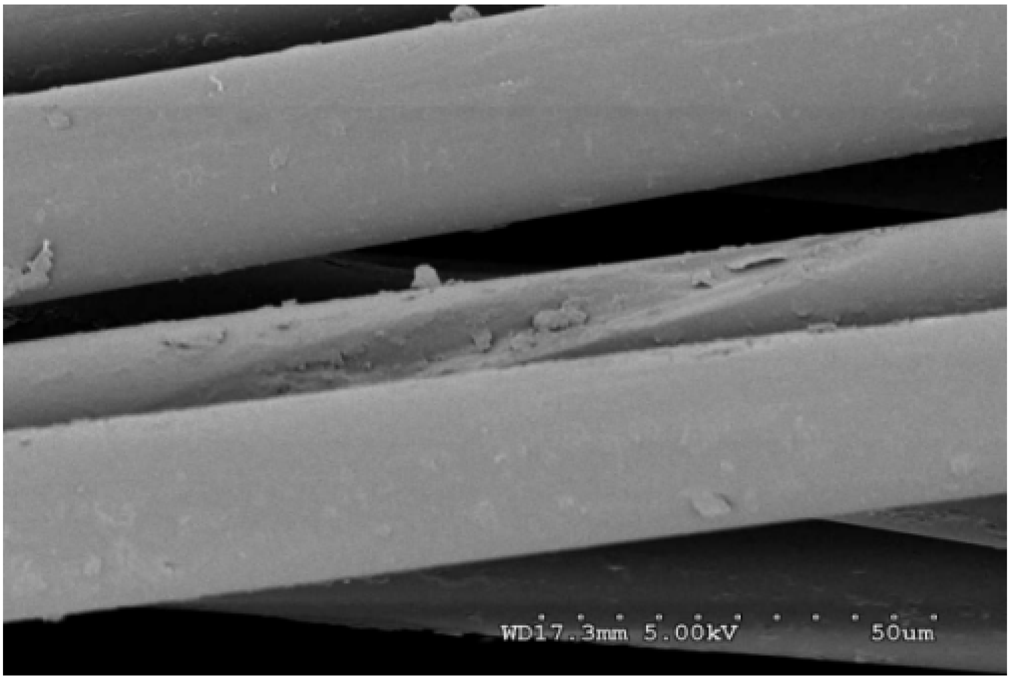
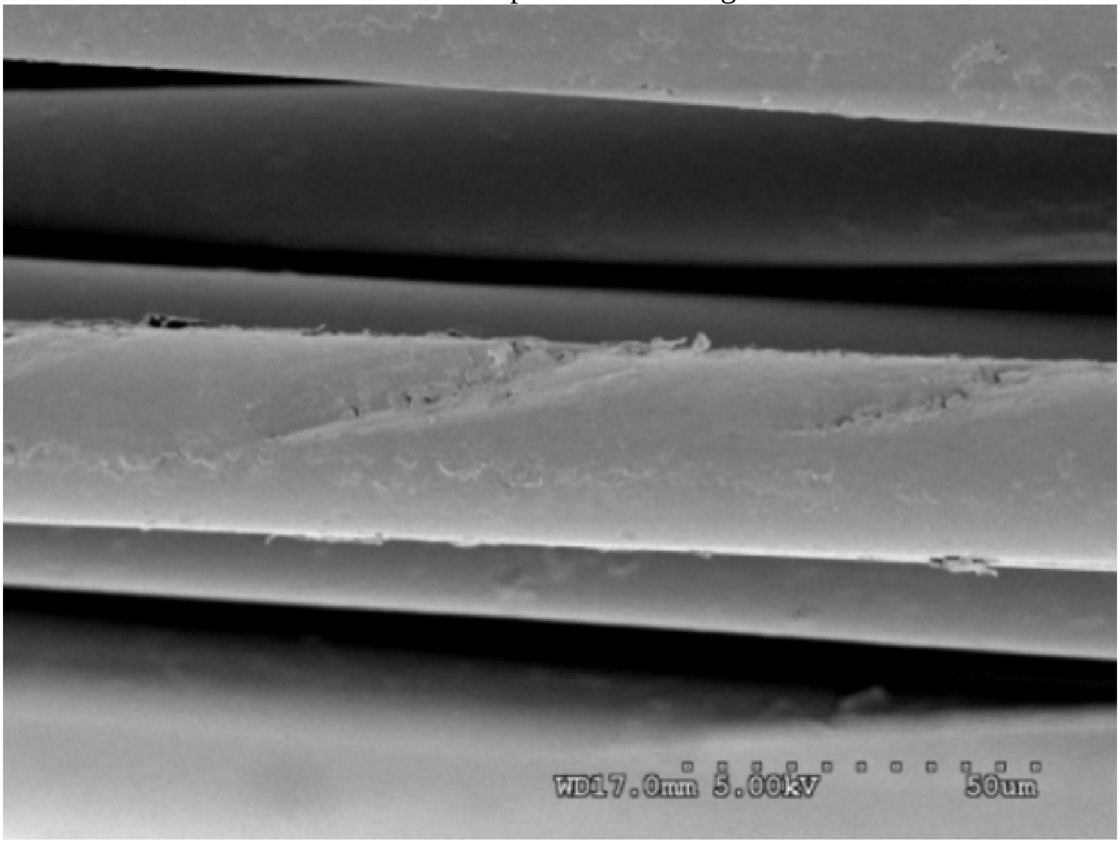


Photo 5.2.23. MSAN12 5%mean 8% range, inner strand, core rope yarn, outer face, further examples of abrasion grooves



These photographs clearly show that abrasion occurs on both sides of the yarns in the outer layer of the strand in the sub-rope.

6. COMPARISON ALL DATA AND DISCUSSION

All the relevant residual strength data over the Main study (ref. 5) and the Extension to the durability of polyester Ropes JIP is summarised in tables 6.1, 6.2 and 6.3 for each construction. This covers the scale samples of parallel strand ropes and the full scale single sub-ropes.

The nominal break load is shown along with the construction type and whether the sample was scale or full scale. The % residual strength data is shown by two methods, firstly from yarn realisation not corrected for bedding-in effects and secondly by the single sample, rope break tests. Not all samples were examined and are listed as NE (not examined) and whether any abrasion was found by SEM. It should be noted that SEM is a microscopic technique and if no inter-strand abrasion is reported, it maybe that it simply had been missed in that sample. Complete review of test conditions, yarn and rope residual strength is required to make a proper assessment of whether abrasion had occurred. Where the SEM appears to contradict the other findings, an ? is shown. Finally the last column shows the outer yarn in the outer strand residual strength, which of course was the most highly abraded component.

The scale effect is very evident at full scale where the residual strength in both rope and outer yarn is much lower than scale samples tested at the same conditions.

Construction	BL tonnes	% residual strength			Mean	Range	Minimum	Cycles millions	Interstrand abrasion	Outer yarn RS %
		Realised	Rope	Difference						
PSC scale	10	95	93	2	3	4	1	1	?	91
PSC FS	35	94			3	4	1	1	?	93
PSC FS	35	98			3	4	1	1	?	97
PSC scale	10	100			30	6	27	40	none	100
PSC scale	250	100			30	6	27	40	none	100
PSC scale	10	100	97	3	60	6	57	1	none	97
PSC scale	10		89		60	6	57	2	?	96
PSC FS	35	99			60	6	57	1	?	95
PSC scale	10	96	99	-3	5	8	1	1	yes	91
PSC scale	10	97	98	-1	20	10	15	1	?	94
PSC scale	10	94			10	18	1	1	yes	93
PSC scale	10	71			10	18	1	5	yes	72
PSC scale	150	82			10	18	1	1	yes	CSR 75 OSR 85
PSC scale	150		85		10	18	1	1	yes	
PSC scale	10	94	100	-6	20	15	13	1	yes	92
PSC scale	10	94	98	-4	20	20	10	1	none	90
PSC FS	35	79			20	15	13	1	yes	70

Table 6.1. Summary of all residual strength data for the PSC construction at scale and full scale

In table 6.1 there was significant strength loss at 10% mean load with 18% load range for the PSC construction. It should also be noted that at low mean load the modulus was very low (ref. 4) by around a factor of 3 compared to high mean load. This lower modulus will generate significant inter-strand slip since there will be significant contributions from both geometry induced slip as well as the induced slip due to material stretch.

In contrast, at higher mean loads the material modulus is much higher, giving lower material stretch induced inter-strand slip. Furthermore, higher contact forces will give much lower (pro rata for same load range) geometric slip. All the evidence shows that at the 60% mean load, contact force is not dominating damage, in terms of additional wear or changing the mode of wear. It may actually have a beneficial effect of reducing slip, since higher contact force may ultimately lead to the whole rope structure locking (this happens in steel wire rope).

At 1 million cycles the 10t PSC at 60% mean load and 6% load range there was no inter-strand wear detectable from either SEM examination or any significant change in tensile test results. However, at 2 million cycles there was significant strength loss on the single rope break test. The yarn residual strength was reduced, but not significantly. The lower rope strength maybe due to some termination effect, which is excluded by the yarn realisation technique in the “Extension Study” where all samples were taken midspan (in the “Main Study” samples were taken in splice and eye where significant differences were found, see ref 5).   Compared to the few cycles experienced in a platform mooring at such high mean, up to 1 million cycles can be regarded as a cut off limit at 60% mean and 6% load range where no significant wear takes place.

At 3% mean and 4% range there was a significant loss in 10tonne and marginal in full scale. The SEM did not identify any wear, but this should be taken as no wear, since a very small area was examined. Thus, for the PSC it is clear that the cut off point was around the 4% range and at some lower range there will be no wear.

Construction	BL tonnes	% residual strength			Mean	Range	Minimum	Cycles millions	Inter-strand abrasion	Outer yarn RS %
		Realised	Rope	Difference						
PBC scale	10	99	107	-7	3	4	1	1	none	99
PBC scale	10	101	106	-4	4	4	2	1	NE	101
PBC scale	10	98	103	-4	5	8	1	1	NE	98
PBC FS	77	89			5	8	1	1	yes	85
PBC scale	10	101	104	-3	20	10	15	1	none	101
PBC scale	10	101	95	6	30	10	25	1	none	101
PBC scale	10	94	105	-11	20	15	13	1	yes	94
PBC scale	10	98	103	-5	30	15	23	1	yes	98
PBC scale	10		95		10	18	1	1	NE	
PBC scale	10		93		10	18	1	5	NE	
PBC scale	150		99		10	18	1	1	NE	
PBC scale	10	92	100	-7	20	20	10	1	yes	91
PBC scale	10	96	101	-5	30	20	20	1	yes	95

Table 6.2. Summary of all residual strength data for the PBC construction at scale and full scale

As shown in table 6.2 for the 10 tonne PBC, there was no wear at 3% mean/4% range and 4% mean /4% range and the 20% mean/10% range from SEM examination. At 5% mean/8% load range and 20%/30% mean/10% range no significant strength loss was measured. At all the higher load ranges strength loss was significant and wear was observed from the SEM examination. For 10tonne PBC the cut off was around 10% load range below which no wear occurs at both 3%, 4% mean and 20% mean.

The effect of scale on inter-strand wear in the outer layer textile yarn and the resultant strength loss was significant for PSC and PBC constructions at the higher load ranges, but marginal at the lowest load range. Also, at 60% mean the PSC showed a marginal effect of reducing strength with scale in the outer layer textile yarn. These are comparable lay angles scale to full scale. Previous computer modelling of contact pressure and slip showed that pressure was near unity and slip increased 10 fold over this scale range. This further confirms the effect of scale is dominated by slip, given equal lay angle between scale and full scale. Hence at 60% mean and 6% range at full scale the cut off must be at some value lower than 6% range.

As shown in table 6.3 the 10 tonne PWRC at 5% mean and 8% range showed mild inter-strand abrasion and significant strength loss. The cut off would be lower than 8% load range at low mean. It should be noted that if the break load (or diameter) is factored, the full scale PWRC shows the lowest effect of scale, due to the fact that it was made at a lower lay angle than the other subropes.

Construction	BL tonnes	% residual strength			Mean	Range	Minimum	Cycles millions	Interstrand abrasion	Outer yarn RS %
		Realised	Rope	Difference						
PWRC scale	10	93	100	-7	5	8	1	1	yes	92
WRC FS	158	90			5	8	1	1	yes	89
PWRC scale	10	93	90	3	10	12	4	1	NE	91
WRC scale	10	91			10	18	1	1	yes	90
WRC scale	10		92		10	18	1	5	yes	
WRC scale	150	67			10	18	1	1	yes	57
WRC scale	150		78		10	18	1	1	yes	
PWRC scale	10	101	104	-3	30	10	25	1	NE	99
PWRC scale	10	97	98	-1	30	15	23	1	NE	96
PWRC scale	10	93	102	-8	30	20	20	1	NE	91

Table 6.3. Summary of all residual strength data for the PWRC construction at scale and full scale

It should be noted that 1 million cycles was conducted for each load condition. Using figure 6.1 as an example, there are around 10,000 cycles in the 30 year lifetime exceeding around 6% range (general area of cut off in full scale sub-rope). If the cut off for wear at full scale is 4% range, this equates to around 350,000 wear cycles. Thus, 1 million cycles is certainly very much worst case using this FPSO mooring and environment as an example. However, it can clearly be seen how sensitive the cut off point is. Of course, different locations around the world and vessels will have different response with lower or higher load range.

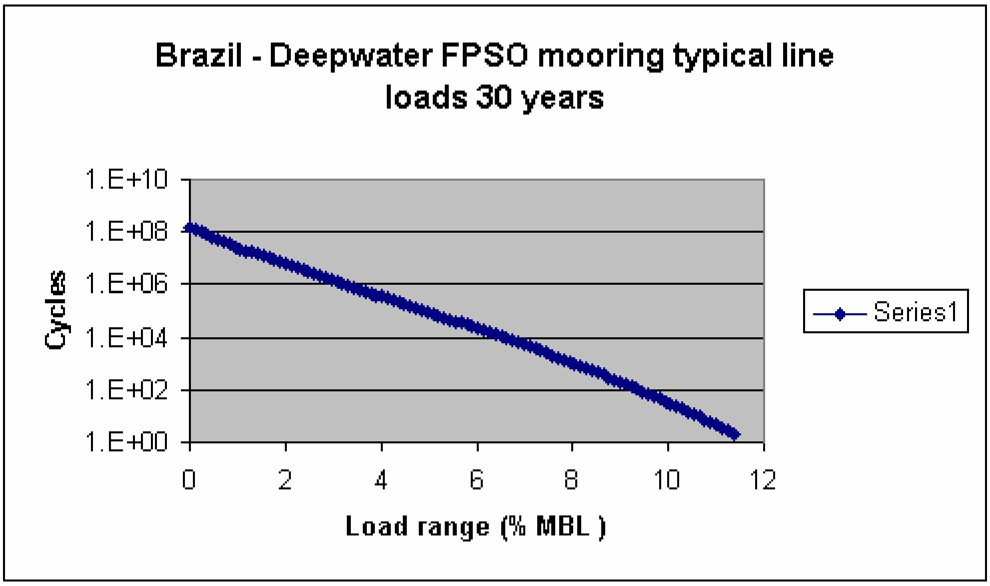


Figure 6.1 Cumulative cycles versus load range for a typical deepwater polyester moored FPSO offshore Brazil

Taking the highest textile yarn strength loss at 30%, table 6.2 shows an example of the strength loss with cycles assuming a linear relationship. For most benign deepwater moorings the numbers of cycles would be expected to be in the lower half of the table. However, it should be noted that the cumulative effect of other load ranges would increase the strength loss.

Table 6.2. Example strength loss with cycles for one load condition, under high load range

Cycles	% strength loss
1000000	30
100000	3
10000	0.3
1000	0.03
100	0.003
10	0.0003

Both single filament tensile tests and SEM examinations confirm strength loss was caused by inter-strand abrasion.

From the single filament tensile tests the abrasion damage was clearly not affecting all the filaments. This is not surprising given that in figure 6.2 there are 9 layers formed with 210 filaments in a typical textile yarn. It was observed in the SEM examination (outer surface of textile yarn) that abrasion could be seen on the outer layers of filaments, certainly no deeper than two filament depths. The filaments actually migrate across layers and in fact it is expected that only the outer layer that was affected, since nowhere was a filament worn through it's entire cross section.

When viewing the underside of the outer yarn, there was also abrasion. This was due to slip between the two outer most layers of yarn in the strand.

The CV for the filament tests in both abraded and good condition (ie no abrasion) was virtually identical. Generally, CV increases with the severity of fatigue damage, especially with severe abrasion. Since the abrasion can be classified as mild (at the filament level), this supports the hypothesis that gradual abrasion which removes cross section of the filament leading to a consistent form of damage.

The CV for the outer textile yarns in the 10 tonne ropes was very low (typically 4-6%) for the all the test conditions. For the full scale sub-ropes, the CV was significantly higher at 11% for the PBC, 9% for the PWRC and 20% for the PSC. This is expected because with increasing abrasion damage, CV increases.

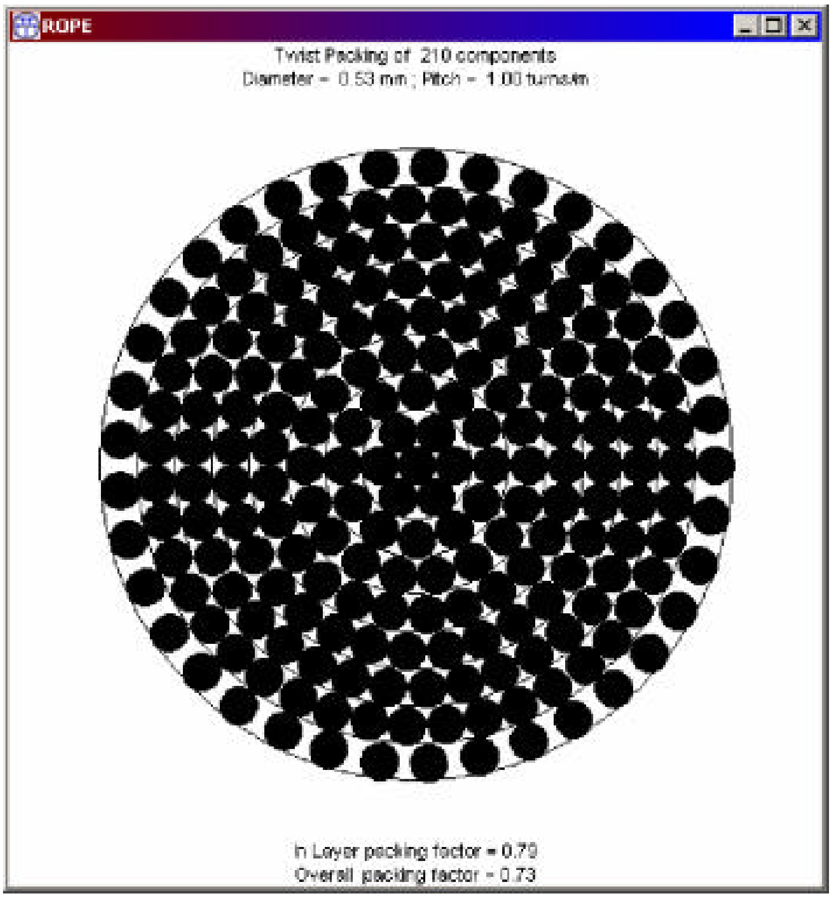


Figure 6.2 FRM output of cross section of typical polyester textile yarn made from 210 filaments

For the 60% mean, the PSC full scale sub-rope inner and outer textile yarn of the protected inner ropeyarn gave a marginal strength increase over the reference. This was probably due to bedding-in at the textile yarn level, which has been found in previous studies.

The 10 tonne PSC rope did not show significant strength increase due to bedding-in effects, whereas the PWRC and PBC did. The exact cause of this strength increase is believed to be primarily due to bedding-in at all levels of the rope structure and terminations.

The PWRC construction showed a weak effect of slip induced inter-strand abrasion at full scale. This maybe due to the slightly lower lay angle compared to the scale sample. It should be noted that lay angle will have a significant effect on slip and contact pressure and any resultant wear. With sufficiently low lay angle (yet retaining ability to splice, since splice needs radial pressure to work), it maybe possible to eliminate the inter-strand abrasion.

Calculation of rope breaking load from textile yarn strength was conducted using the new datum rope strength to calculate the realisation factor. This initial analysis did not allow for any change in strength due to bedding-in. For the 10tonne PSC there was very good correlation with the rope strength by breaking the whole rope. However, with the 10 tonne PBC and PWRC, the realised breaking loads were significantly lower than measured by a rope break test. Using this approach, it clearly highlighted effects of strength with bedding-in. By applying an adjustment to the realisation factor, good correlation was found.

As shown in Table 4.5.24, for MRZW6 there was one rogue data point in the single rope break tests when compared with the realised rope strength. Which one was wrong? This is explained by the trend in rope strength under similar test conditions. We know from the textile yarn results that there is little difference in 20% mean and 30% mean at 10% range. Hence, if we use the value for MRZW1 for the single rope break strength, then the fit is now very good for all points as shown in table 6.3.

This illustrates the inherent variability in spliced terminations, in an isolated test, that could lead to wrong conclusions. One example of the importance of this finding is where an insert is removed from a mooring system and broken and a low value is obtained, this maybe due to the termination variability and not the inherent rope properties. Only textile yarn testing can distinguish between the two.

Table 6.3. PBC, comparison single rope break with yarn calculated rope strength, but realised adjusted to compensate for bedding-in

	Yarn Realised rope strength % Residual strength	Single rope break strength % Residual strength	% mean load	% load range	% Difference (yarn/rope residual strength)
MRZW2	106.1	107.1	3	4	-1.0
MRZW3	108.1	105.6	4	4	2.3
MRZW18	105.3	102.8	5	4	2.4
MRZW1	107.9	104.3	20	10	3.4
MRZW4	100.7	105.3	20	15	-4.5
MRZW5	99.0	99.6	20	20	-0.7
MRZW6	108.2	104.3 Corrected value	30	10	3.7
MRZW7	105.2	103.0	30	15	2.1
MRZW8	102.9	101.0	30	20	1.8

To establish any effects of axial compression on residual strength, we need to first consider the important parameters that influence this fatigue mechanism. Detailed modelling (ref 6, 7) showed that high axial compressive strain, combined with high radial pressure was required to cause polyester to buckle in the damaging plastic mode. These conditions could not be created by modelling the worst case conditions in a polyester mooring system. The highest axial compression combined with highest radial pressure, will be in the inner yarn of the inner strand in a rope structure. Many examinations of fatigue tested ropes have shown the yarns in this position to buckle and even fail (aramid and HMPE, but not polyester). Thus, the worst case construction to generate these conditions would be the inner strand of the PWRC. The inner strand has 6 outer strands providing radial pressure and it runs straight up the centre of the sub-rope, so has less (compared to other constructions) compliance to absorb any compressive strain. Inspite of this, Table 4.2.10 shows that the inner yarns of the inner strand gave no strength loss after 1 million cycles at 1% minimum load. This clearly proves that axial compression in polyester is not a concern.

Furthermore, in all the samples SEM examined, not a single axial kink (kink occurs when compressive strain exceeds the compressive strength limit of the material) was found.

7. CONCLUSIONS

Inter-strand wear (within the sub-rope, not between parallel laid sub-ropes) is confirmed as a mechanism. The effect of the internal wear mechanism and strength loss has been quantified with respect to mean load and load range. Some cut off points in terms of load range have been established below which no wear will take place.

At the lower load ranges, no wear was detected. This would represent the majority of cycles in a fatigue spectrum throughout mooring line lifetime where generally most of the fatigue damage accumulation using Miner's law occurs.

For the higher load ranges wear was detected and strength loss measured. Since 1 million cycles was conducted, this is a severe test relative to the minority of cycles in a fatigue spectrum throughout mooring line lifetime.

Contrary to some thinking, short term loading to 60% mean and with up to several orders higher cycles relative to platform life, does not lead to any short term damage to the polymer on the inner yarns not subjected to abrasion. In fact, there appears to be a marginal strength increase. On the outer yarns, there maybe a marginal strength loss due to abrasion, given sufficiently high load range.

From an initial analysis of the data, on single variables it appears that there is a weak statistical relationship between textile yarn tensile properties and mean cyclic load, or the tensile properties and cyclic load range, when analysed independently.

However, when the data is analysed to determine if Tenacity is a function of both Mean Load and Range, then a much stronger statistical relationship emerges. Thus, by using bivariate analysis of both mean and load range, a very strong correlation was found.

By doing both single and bivariate analysis, this tells us that the effects of mean load and range are linked and cannot be separated.

There was a consistent trend for all ropes, that residual tenacity increases with mean load and decreases with load range.

A comparison of the experimental results with the values predicted by bi-variate approximations is, in general, very encouraging, to the point that it would be possible to use the approximations to predict the performance of similar ropes under different mean loads and load ranges.

There is a significant effect of scale at the 15% load range, where tenacity decreases. This was expected from the computer modelling of inter-strand slip, which increases with load range. From the bi-variate analysis there was a strong effect of range, but not mean load. This infers that contact pressure was not a dominant effect.

A new finding has been positively identified, that textile yarn residual strength increases with mean load.

SEM examination showing the inter-strand wear correlates well with the tenacity results and confirms the mechanism. In the full scale sub-rope, it was also established that wear occurs on both sides of the outer yarn exposed to inter-strand abrasion. Previous modelling of inter-ropeyarn slip has shown that slip can be significant.

After extensive SEM examination of many rope tests down to 1% minimum load in all three constructions, no axial compression was found. Also, no effects on strength at low minimum load were found. Thus, axial compression is not an issue for polyester ropes on these designs and down to 1% minimum load.

Lay angle has been identified to be an important parameter to alter the magnitude of inter-strand wear at full scale. Lower lay angle reduces the wear and strength loss.

The realisation factor method for calculating rope strength has been proven to be accurate, providing bedding-in effects is taken into account.

The results from single rope break tests compared with rope strength calculated by yarn realisation has shown an important finding. The single rope break tests compared with yarn realisation showed a lower than expected breaking load was identified for the single rope break. By use of yarn realisation, it was found that this was due to the variation in measured rope strength, presumably caused by the spliced terminations. There is an implication for single insert samples, whereby a low break load result could be falsely identified as a material or rope durability issue. When in fact, it is just termination variability. Use of textile yarn testing enables sufficient statistics to be gained to identify the real effects of any damage.

References.

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3. The Durability of Polyester Ropes, JIP Final Report, Rope Test Programme and Data Analysis January 2003 report no 068/2002.
4. NEL report 'Extension To The Durability Of Polyester Ropes (Joint Industry Project)', report number 2005/174.
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6. Buckling of fibres and yarns within ropes and other fibre assemblies R.E. Hobbs, M.S. Overington, J.W.S. Hearle and S.J. Banfield, Tension Technology International Ltd, J. Text Inst 2000 91 Part 1 No 3.
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APPENDIX A. ROPE SPECIFICATIONS

FINAL - ROPE SUPPLY SPECIFICATION – 10T POLYESTER ROPE

The supply specification is shown in the table below. This is based on the Main Study and results achieved. The rope construction, termination, material grade must be the same to ensure continuity of results. Previous stock can be used, if a new batch of rope has to be made, please conduct 3 break strength tests to verify strength similar to Main study. The exception is PWRC, who will submit a PSC rather than WRC, but using the same grade fibre.

1. Rope strength, average new spliced wet breaking load, kN	101.7 PSC 113.9 PBC
2. Break strength variability, CV %	Less than 3%
3. Rope construction	Parallel strand, torque balanced
4. Rope diameter mm	Not greater than 20mm
5. Rope jacketing	Standard jacket as supplied for FPS mooring
5. Fibre grade	Marine finish polyester
6. Termination type	Spliced with at least three taper tucks. Eye strands to be tensioned to remove slack on the inner bend of eye. To be effective, the taper zone should be at least 30% of the splice length. Taper to textile yarn thickness.
7. Eye sheathing material	At least two layers HMPE fabric over standard jacket
8. Eye length and included angle	Included angle not greater than 45E
9. Spool root diameter D/d ratio	1.5 to 3
10. Spool outside width (flange to flange)	Between 46 to 47mm (sized to fit clevis width to limit bending of pin)
11. Spool outside diameter (including rope)	Not greater than 126mm
12. Strop length (pin centre lines and at reference tension of 2% minimum break load)	2.0m ∀ 25mm
13. Spool material	Metal or polymer (note for information: stainless steel 431S29, T condition used for clevis and pin) to be supplied by ropemaker
14. Spool hole diameter (for pin)	20.0 to 20.1mm
15. Quantity and Packaging	10 plus 1 spare In boxes, strops held straight on round pegs or on wooden drum (loose hanks etc. not acceptable)
16. Delivery	By January 2004 to NEL
17. Sample for control yarn break load tests	5m cut length

FINAL - ROPE SUPPLY SPECIFICATION – PSC FULL SCALE POLYESTER SUB-ROPE

The supply specification is shown in the table below. This is based on the Main Study and results achieved. The rope construction, termination design and material grade must be the same as in the Main Study to ensure continuity of results.

1. Rope strength, average new spliced wet breaking load, kN	27 tonnes
2. Break strength variability, CV %	Less than 3%
3. Rope construction	3 strand
4. Rope diameter mm	Not greater than 60mm
5. Rope jacketing	No jacket required
5. Fibre grade	Marine finish polyester
6. Termination type	Spliced with at least three taper tucks. Eye strands to be tensioned to remove slack on the inner bend of eye. To be effective, the taper zone should be at least 30% of the splice length. Taper to ropeyarn thickness.
7. Eye sheathing material	At least two layers HMPE fabric
8. Eye length and included angle	Included angle not greater than 45E
9. Spool root diameter D/d ratio	1.5 to 2
10. Spool outside width (flange to flange)	74mm (sized to fit clevis 76mm width to limit bending of pin)
11. Spool outside diameter (including rope)	Not greater than 200mm
12. Strop length (pin centre lines and at reference tension of 2% minimum break load)	4500mm +50 -0mm
13. Spool material	Metal or polymer (note for information: stainless steel 431S29, T condition used for clevis and pin) to be supplied by ropemaker. Size of spool to be made to fit machine as below (note 1).
14. Spool hole diameter (for pin)	51mm (for 50mm pin)
15. Quantity and Packaging	3 plus 1 spare In boxes, strops held straight on round pegs or on wooden drum (loose hanks etc. not acceptable)
16. Delivery	By February 2004 to NEL
17. Sample for control yarn break load tests	Send 5m cut length to Dr. J. Nichols TTI Ltd 3A Charles Avenue Arbroath Angus DD11 2EZ

ROPE SUPPLY SPECIFICATION – PWRC FULL POLYESTER SUB-ROPE

The supply specification is shown in the table below. This is based on the Main Study and results achieved.

1. Rope strength, average new spliced wet breaking load, Kn	150 tonnes
2. Break strength variability, CV %	Less than 3%
3. Rope construction	6/1 WRC
4. Rope diameter mm	Not greater than 60mm
5. Rope jacketing	No jacket required
5. Fibre grade	Marine finish polyester
6. Termination type	Spliced with at least three taper tucks. Eye strands to be tensioned to remove slack on the inner bend of eye. To be effective, the taper zone should be at least 30% of the splice length. Taper to ropeyarn thickness.
7. Eye sheathing material	At least two layers HMPE fabric
8. Eye length and included angle	Included angle not greater than 45E
9. Spool root diameter D/d ratio	1.5 to 2
10. Spool outside width (flange to flange)	74mm (sized to fit clevis 76mm width to limit bending of pin)
11. Spool outside diameter (including rope)	Not greater than 200mm
12. Strop length (pin centre lines and at reference tension of 2% minimum break load)	5000mm +50 -0mm
13. Spool material	Metal or polymer (note for information: stainless steel 431S29, T condition used for clevis and pin) to be supplied by ropemaker. Size of spool to be made to fit machine as below (note 1).
14. Spool hole diameter (for pin)	51mm (for 50mm pin)
15. Quantity and Packaging	3 plus 1 spare In boxes, strops held straight on round pegs or on wooden drum (loose hanks etc. not acceptable)
16. Delivery	By February 2004 to NEL
17. Sample for control yarn break load tests	Send 5m cut length to Dr. J. Nichols TTI Ltd 3A Charles Avenue Arbroath Angus DD11 2EZ

ROPE SUPPLY SPECIFICATION – FULL SCALE POLYESTER PBC SUB-ROPE

The supply specification is shown in the table below. This is based on the Main Study and results achieved. The rope construction, termination design and material grade must be the same as in the Main Study to ensure continuity of results.

1. Rope strength, average new spliced wet breaking load, kN	77 tonnes
2. Break strength variability, CV %	Less than 3%
3. Rope construction	8 strand plaited
4. Rope diameter mm	Not greater than 45mm
5. Rope jacketing	No jacket required
5. Fibre grade	Marine finish polyester
6. Termination type	Spliced with at least three taper tucks. Eye strands to be tensioned to remove slack on the inner bend of eye. To be effective, the taper zone should be at least 30% of the splice length. Taper to ropeyarn thickness.
7. Eye sheathing material	At least two layers HMPE fabric
8. Eye length and included angle	Included angle not greater than 45E
9. Spool root diameter D/d ratio	1.5 to 2
10. Spool outside width (flange to flange)	74mm (sized to fit clevis 76mm width to limit bending of pin)
11. Spool outside diameter (including rope)	Not greater than 200mm
12. Strop length (pin centre lines and at reference tension of 2% minimum break load)	4500mm +50 -0mm
13. Spool material	Metal or polymer (note for information: stainless steel 431S29, T condition used for clevis and pin) to be supplied by ropemaker. Size of spool to be made to fit machine as below (note 1).
14. Spool hole diameter (for pin)	51mm (for 50mm pin)
15. Quantity and Packaging	1plus 1 spare In boxes, strops held straight on round pegs or on wooden drum (loose hanks etc. not acceptable)
16. Delivery	By February 2004 to NEL
17. Sample for control yarn break load tests	Send 5m cut length to Dr. J. Nichols TTI Ltd 3A Charles Avenue Arbroath Angus DD11 2EZ

APPENDIX B. YARN GRADES

The source and grade of the textile yarn or ropeyarn supplied by the fibre supplier to the ropemaker is shown below.

	Grade	Supplier
PSC	855TN	Acordis
PBC	785	Kosa
PWRC	785	Kosa

APPENDIX C. PBC 10 TONNE STROPS - YARN RESULTS
Individual textile Yarn Break Load Test Results

	MRZW1 Mean 20% Range 10%			
	Inner BL	Inner BE	Outer BL	Outer BE
	N	%	N	%
	84.3	10.7	90.2	11.5
	81.1	10.1	86.0	10.8
	84.8	10.9	77.7	9.5
	85.2	10.5	80.7	9.6
	90.7	11.1	90.0	11.3
	79.9	9.6	78.1	9.7
	82.8	10.2	77.2	9.4
	89.5	11.8	86.0	11.0
	88.6	11.1	85.1	10.5
	85.1	10.2	84.5	10.6
	87.8	10.7	87.4	11.5
	86.5	11.0	87.4	11.3
	88.6	10.8	91.4	11.7
	86.1	11.0	90.8	11.1
	92.7	12.1	87.8	11.1
	89.2	11.7	87.4	11.0
	92.5	11.6	95.5	12.2
	91.8	12.1	88.4	11.1
	92.8	12.2	84.9	10.6
	88.5	10.9	84.5	10.4
	85.2	11.2	85.6	10.9
	90.0	11.6	88.2	11.0
	91.3	11.4	84.7	10.5
	88.5	11.0	84.4	10.5
	92.7	11.5	84.0	10.8
	87.5	10.9	86.5	11.3
	91.5	11.9	91.8	11.6
	87.9	11.5	84.0	10.4
	91.3	11.5	89.9	11.1
	88.3	11.0	85.4	10.5
	88.2	10.7	87.4	11.0
	91.5	11.4	86.3	10.9
Mean	**88.2**	**11.1**	**86.2**	**10.8**
SD	**3.4**	**0.6**	**4.0**	**0.6**
CV	**3.9**	**5.6**	**4.7**	**5.9**

Appendix C-2 MRZW2

	MRZW2 Mean 3% Range 4%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	82.4	9.8	83.8	11.1
	83.3	10.0	79.3	10.0
	86.1	10.8	84.5	10.7
	81.3	10.8	84.9	10.6
	82.0	10.0	86.5	10.8
	82.9	10.3	82.4	10.1
	88.6	11.3	79.9	9.7
	83.8	10.4	84.6	9.9
	87.3	10.9	81.3	10.0
	88.1	10.8	79.7	10.5
	81.4	10.0	89.8	11.5
	90.3	11.1	87.8	11.3
	91.0	11.5	86.0	10.8
	87.7	10.9	83.3	10.3
	91.3	12.1	83.5	10.5
	87.7	11.4	88.0	11.0
	84.3	10.6	85.7	10.4
	89.1	11.4	91.2	12.0
	86.1	11.1	86.6	10.5
	88.2	11.3	84.7	10.5
	90.1	11.6	85.1	11.1
	89.7	11.0	88.8	10.6
	84.6	10.6	87.0	11.0
	88.8	10.7	85.0	10.3
	88.0	11.0	78.2	9.5
	87.0	11.4	84.8	10.6
	90.8	11.6	77.4	9.3
	89.4	11.2	75.9	9.5
	92.1	11.3	87.0	10.6
	88.6	11.8	88.6	11.2
	88.3	11.4	83.8	10.4
	83.2	11.1	80.9	10.0
Mean	**87.0**	**11.0**	**84.3**	**10.5**
SD	**3.1**	**0.6**	**3.7**	**0.6**
CV	**3.6**	**5.1**	**4.4**	**5.7**

	MRZW3 Mean 4% Range 4%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	82.8	10.5	86.8	10.6
	86.8	10.7	85.0	10.4
	82.8	10.5	90.0	11.7
	87.8	10.6	90.1	12.0
	91.0	11.8	80.1	9.8
	90.2	11.6	82.1	10.6
	87.2	10.9	88.0	10.9
	90.3	11.1	84.8	10.4
	78.8	9.8	83.2	10.5
	84.7	10.4	75.2	8.8
	91.3	12.0	78.9	9.7
	85.6	10.6	85.7	10.9
	87.5	10.6	83.7	11.2
	90.0	11.8	89.8	11.1
	88.4	11.6	84.7	10.4
	77.4	9.3	87.3	10.8
	90.2	11.2	84.3	10.3
	90.5	11.8	83.1	10.6
	91.6	11.5	87.7	11.1
	90.9	11.8	86.8	11.1
	87.9	11.1	89.7	11.3
	86.5	10.7	88.1	11.2
	88.3	11.3	83.7	10.6
	86.5	11.2	82.5	9.9
	80.8	9.4	88.2	11.3
	90.1	11.7	87.5	10.9
	93.0	11.8	90.7	11.5
	85.8	10.5	89.2	11.2
	84.8	10.1	89.1	11.4
	90.2	11.3	86.6	10.7
	86.5	10.8	87.9	11.8
	88.1	11.3	92.3	11.9
	87.3	11.0	90.6	11.4
	90.8	11.9	88.8	11.3
	91.1	11.6	89.3	11.6
	93.6	11.9	90.7	11.6
	92.9	12.2	84.3	11.1
	91.3	12.3	87.6	10.9
	90.4	11.5	89.0	11.3
	88.6	11.5	87.7	11.2
Mean	**88.0**	**11.1**	**86.5**	**10.9**
SD	**3.7**	**0.7**	**3.6**	**0.6**
CV	**4.2**	**6.5**	**4.1**	**5.9**

	MRZW4 Mean 20% Range15%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	80.5	9.5	79.3	9.6
	91.9	11.7	76.5	9.4
	81.6	10.2	78.7	9.3
	83.9	10.1	77.7	9.3
	89.1	11.3	78.1	9.9
	88.5	11.6	82.2	9.8
	82.3	9.6	84.0	10.4
	82.5	10.0	80.6	9.8
	87.9	11.6	77.4	9.4
	89.3	11.7	83.6	10.3
	92.2	12.0	87.2	10.9
	92.6	11.8	77.4	8.9
	77.9	9.4	77.5	9.3
	80.4	9.8	87.8	10.6
	79.0	9.4	76.3	9.4
	74.6	9.3	77.5	9.3
	76.9	9.3	82.5	10.1
	90.7	11.9	80.5	9.6
	78.9	9.2	80.6	9.9
	87.3	11.2	80.6	9.8
	74.8	9.0	80.1	9.3
	84.3	10.1	79.8	9.7
	78.8	9.2	75.7	9.5
	78.8	9.3	80.2	9.6
	78.9	9.6	81.5	9.6
	76.9	9.6	79.7	9.7
	80.2	9.8	83.8	10.0
	80.3	9.8	85.6	10.9
	79.2	9.4	82.1	9.9
	77.4	9.2	78.9	9.9
	78.4	9.5	82.9	9.9
	76.5	9.2	78.6	9.6
Mean	**82.3**	**10.1**	**80.5**	**9.8**
SD	**5.4**	**1.0**	**3.1**	**0.5**
CV	**6.6**	**10.0**	**3.8**	**4.7**

	MRZW5 Mean 20% Range 20%			
	Inner BL	Inner BE	Outer BL	Outer BE
	N	%	N	%
	92.7	12.5	77.2	9.6
	80.3	10.1	74.1	9.5
	78.6	9.3	77.6	9.3
	76.1	9.3	74.7	9.4
	86.4	11.5	73.9	9.2
	89.6	11.2	89.3	11.2
	75.8	9.4	71.6	8.5
	88.0	12.0	75.6	9.3
	74.8	9.2	80.5	9.9
	85.5	10.7	79.0	9.6
	84.1	10.2	76.6	9.4
	83.0	10.2	77.4	9.4
	87.7	11.2	79.8	9.9
	86.5	10.5	77.1	9.3
	78.9	9.6	76.0	9.3
	77.7	9.7	78.7	9.7
	90.7	11.5	73.1	9.4
	81.2	9.8	73.4	9.0
	89.8	11.7	82.0	10.0
	84.3	10.5	75.1	9.1
	86.6	11.2	79.4	9.8
	90.5	11.8	74.7	9.0
	71.2	9.0	80.2	9.8
	80.9	10.0	75.9	9.1
	82.7	10.2	80.2	9.8
	81.8	10.5	76.8	9.4
	73.2	8.8	79.0	9.8
	76.5	9.1	80.6	9.5
	82.3	10.1	82.4	10.0
	79.6	9.5	71.8	9.0
	81.7	9.7	78.5	9.6
	76.6	9.0	82.5	10.3
Mean	**82.4**	**10.3**	**77.6**	**9.5**
SD	**5.6**	**1.0**	**3.7**	**0.5**
CV	**6.8**	**9.7**	**4.7**	**5.0**

	MRZW6 Mean 30% Range 10%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	90.9	11.5	85.1	11.3
	85.6	11.1	89.4	12.1
	86.0	11.2	89.3	12.1
	84.3	11.0	76.9	10.6
	92.4	12.4	80.3	10.2
	88.4	11.5	81.6	10.6
	93.3	12.6	87.5	11.6
	92.0	12.6	90.1	12.2
	87.1	11.3	88.2	11.6
	88.3	11.5	88.2	11.5
	88.8	12.1	77.9	9.7
	84.3	10.8	86.0	11.3
	84.6	11.0	82.3	10.7
	83.7	10.5	88.8	11.7
	88.3	11.5	85.4	11.2
	92.5	12.7	84.3	11.0
	85.3	11.0	85.9	11.1
	90.8	12.4	84.8	11.3
	88.6	11.9	87.6	11.5
	92.9	12.9	85.4	11.4
	90.8	12.2	88.1	11.5
	90.1	11.9	92.2	12.5
	93.6	12.4	83.9	10.9
	87.6	11.0	83.9	11.6
	88.4	11.3	84.2	10.8
	82.5	10.9	92.4	12.5
	92.9	12.3	85.5	11.4
	86.2	11.7	85.4	12.1
	92.2	12.4	89.2	11.6
	89.2	12.2	80.0	10.7
	91.7	12.9	92.2	12.3
	90.1	11.6	90.3	12.1
Mean	**88.9**	**11.8**	**86.0**	**11.4**
SD	**3.2**	**0.7**	**3.9**	**0.7**
CV	**3.6**	**5.8**	**4.6**	**5.8**

	MRZW7 Mean 30% Range 15%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	75.9	10.0	81.0	10.6
	88.0	11.3	84.1	10.9
	84.8	10.9	85.8	11.4
	85.2	11.7	82.8	11.0
	84.4	10.6	81.7	10.5
	86.8	11.4	86.5	12.0
	86.0	12.0	81.6	10.8
	86.7	11.9	83.0	10.7
	84.0	10.9	83.7	11.2
	85.8	10.9	83.9	11.0
	85.6	11.3	89.0	12.2
	89.3	12.2	71.4	9.7
	87.2	11.3	79.7	10.4
	89.9	11.7	76.7	9.8
	86.1	11.1	71.7	9.2
	88.5	11.8	79.6	11.3
	79.3	10.9	81.3	11.1
	92.3	12.0	81.4	10.5
	88.6	11.8	88.1	12.3
	89.7	11.8	79.1	10.0
	90.5	12.1	82.5	11.0
	84.9	11.2	86.8	11.3
	84.9	11.5	87.6	11.6
	90.2	11.8	90.4	12.1
	87.0	11.6	87.6	11.7
	83.7	10.9	84.2	11.5
	86.5	11.4	89.2	11.9
	88.5	11.9	85.3	11.1
	91.4	12.4	87.7	11.5
	81.7	11.5	87.9	12.0
	87.5	11.8	88.6	11.5
	90.8	12.5	79.7	10.7
Mean	**86.6**	**11.5**	**83.4**	**11.1**
SD	**3.4**	**0.5**	**4.7**	**0.8**
CV	**4.0**	**4.8**	**5.6**	**6.8**

	MRZW8 mean 30% Range 20%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	75.7	9.5	80.1	10.4
	81.0	10.1	76.3	9.6
	84.9	10.8	74.4	9.8
	90.6	11.9	93.0	12.9
	83.7	11.5	87.2	11.1
	89.0	11.9	77.4	9.6
	90.1	11.9	86.2	11.6
	82.4	10.2	84.9	11.1
	78.0	9.8	88.3	11.0
	76.7	9.4	78.2	10.0
	83.9	11.0	83.3	11.0
	78.3	9.9	84.7	10.7
	81.8	10.4	82.0	10.6
	93.1	12.9	78.5	9.7
	93.9	12.1	86.6	11.3
	80.2	9.9	79.4	10.2
	89.5	11.6	82.3	10.1
	81.1	10.0	78.7	9.8
	81.1	9.7	78.0	10.2
	81.8	10.2	77.6	9.7
	89.1	12.0	83.3	10.4
	85.2	10.5	82.0	9.9
	82.5	10.3	78.7	9.7
	88.5	11.6	89.2	11.7
	92.4	12.9	79.9	10.0
	84.7	10.5	79.3	9.7
	83.7	10.6	80.0	10.3
	84.4	10.9	82.2	10.1
	79.2	10.4	81.7	10.0
	86.7	10.8	79.7	10.2
	83.1	10.7	81.0	10.4
	92.6	12.1	76.7	9.4
Mean	**84.7**	**10.9**	**81.6**	**10.4**
SD	**5.0**	**1.0**	**4.2**	**0.8**
CV	**5.9**	**8.9**	**5.2**	**7.3**

MRZW18 Mean 5% Range 8%				
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	86.9	10.5	84.2	10.3
	84.4	9.9	82.3	10.4
	88.3	10.5	83.6	9.9
	91.0	12.1	89.8	10.5
	85.2	10.3	85.3	10.3
	84.7	10.2	84.2	10.0
	85.1	10.7	82.2	9.7
	88.4	11.1	84.7	10.2
	86.3	10.3	87.6	10.4
	87.6	11.2	87.0	10.3
	90.0	10.7	84.9	9.9
	88.3	10.6	79.5	9.7
	86.2	10.1	83.6	10.3
	86.4	10.3	83.9	9.9
	85.5	10.5	80.8	10.0
	92.3	11.2	86.2	10.5
	84.9	9.8	84.1	10.1
	84.8	10.9	84.7	10.1
	83.4	10.1	83.9	10.0
	82.8	10.6	83.4	10.2
	92.8	12.6	80.2	10.2
	83.1	10.2	81.9	10.0
	88.3	10.6	83.4	9.7
	84.4	9.9	82.0	9.9
	82.3	9.8	89.1	10.7
	87.2	10.7	84.1	10.1
	80.6	9.6	83.2	10.0
	84.4	10.2		
	86.8	10.2		
	83.4	9.9		
	85.8	10.2		
	85.0	10.3		
	82.4	9.9		
	84.7	9.9		
	82.8	10.2		
	93.0	12.1		
Mean	**86.1**	**10.5**	**84.1**	**10.1**
SD	**3.0**	**0.7**	**2.4**	**0.3**
CV	**3.5**	**6.4**	**2.9**	**2.5**

APPENDIX D. PSC 10 TONNE STROPS - YARN RESULTS

Individual textile Yarn Break Load Test Results

	MRXC1 Mean 20% Range 20%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	150.3	10.7	140.4	10.0
	136.0	9.8	138.1	10.2
	152.1	10.3	150.3	10.4
	142.5	9.8	143.3	10.1
	145.3	10.5	150.6	10.4
	162.2	11.8	141.0	9.8
	162.5	12.0	147.0	10.0
	143.5	10.2	157.4	11.3
	134.2	10.1	140.5	10.1
	162.2	10.7	146.9	10.4
	145.1	10.3	148.5	10.1
	144.8	10.0	147.4	10.1
	159.2	11.0	152.2	11.0
	144.7	10.2	147.8	10.4
	160.9	11.4	149.9	10.5
	154.1	11.0	132.2	10.1
	152.7	10.6	144.4	10.4
	146.3	10.3	155.0	10.6
	151.3	9.6	152.5	10.7
	158.4	10.7	148.0	10.6
	167.3	11.8	125.7	9.7
	157.5	10.3	159.7	11.6
	133.9	9.3	145.1	10.4
	174.4	12.7	157.8	10.8
	156.0	10.5	141.3	10.1
	158.6	11.0	145.4	10.2
	145.3	10.1	144.2	10.0
	151.8	10.1	148.1	9.9
	158.3	10.7	142.8	9.8
	156.0	11.0	149.1	9.5
	145.8	10.4	140.2	9.1
	154.9	10.6	155.1	10.2
	144.6	10.1	147.8	9.9
	148.6	10.5	150.1	9.5
	139.8	9.6	150.4	10.0
	152.1	10.4	141.8	9.1
	148.1	10.4	148.0	9.6
	148.5	10.3	145.0	9.7
	155.9	10.9	0.0	0.0
Mean	**151.7**	**10.5**	**147.1**	**10.2**
SD	**8.8**	**0.6**	**7.0**	**0.6**
CV	**5.8**	**6.1**	**4.8**	**5.6**

MRXC2 Mean 5% Range 8%				
	Inner BL	Inner BE	Outer BL	Outer BE
	N	%	N	%
	162.0	12.9	145.2	10.7
	149.3	11.5	144.5	11.5
	148.0	11.8	137.3	11.7
	160.7	12.6	147.9	11.6
	145.3	11.9	149.1	11.8
	157.6	13.1	148.6	11.8
	164.4	12.9	139.0	10.8
	170.3	13.5	150.1	12.0
	166.1	13.6	145.9	11.1
	150.1	11.6	146.3	11.8
	152.2	12.0	144.8	11.8
	145.5	11.9	148.8	11.2
	149.5	11.4	154.0	12.2
	157.0	12.2	148.0	11.2
	167.0	12.5	143.4	10.8
	160.9	0.0	153.4	12.0
	151.8	11.9	145.1	11.8
	164.5	12.5	148.0	12.2
	155.9	11.8	146.2	11.4
	152.8	11.6	154.3	11.6
	158.3	12.5	144.7	11.8
	156.3	12.7	156.0	12.6
	150.9	11.5	157.4	12.6
	155.0	11.8	153.8	11.2
	168.3	13.1	157.0	11.2
	149.2	11.6	147.3	11.6
	151.6	11.9	151.3	11.6
	153.5	11.6	145.1	11.6
	158.7	11.6	145.3	11.8
	162.8	12.7	152.6	11.9
	155.6	14.1	151.6	12.3
	157.3	12.4	155.7	12.4
	157.7	11.7	163.5	12.5
	151.9	12.1	156.5	12.0
	144.5	12.0	152.8	12.5
	145.7	12.4	148.1	11.0
	160.6	12.6	148.1	11.2
	162.6	13.4	150.7	11.7
	156.7	12.8	146.4	11.2
	153.0	12.0	154.2	11.7
			147.5	11.3
			151.4	11.2
			144.3	11.6
			132.4	10.6
			147.9	11.9
			152.7	11.6
			169.1	13.9
			151.6	12.3
			151.7	12.1
			150.5	11.6
			158.7	12.2
			150.8	12.0
			149.3	11.1
			141.5	11.2
			155.3	12.4
			143.4	11.9
			146.1	11.9
Mean	**156.0**	**12.0**	**149.5**	**11.7**

SD	**6.7**	**2.1**	**6.0**	**0.6**
CV	**4.3**	**17.1**	**4.0**	**4.9**

	MRXC3 Mean 60% Range 6%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	168.8	12.4	161.7	11.5
	147.3	10.6	159.2	11.1
	164.5	11.6	169.6	12.8
	168.7	12.3	157.7	11.2
	160.2	11.1	149.3	10.8
	162.2	11.6	161.5	11.6
	161.5	11.9	159.1	11.2
	161.5	11.1	160.6	11.7
	158.4	11.0	174.5	12.5
	160.4	11.0	164.5	11.7
	160.9	11.7	162.7	11.4
	166.2	11.7	160.0	11.4
	171.8	12.4	168.6	12.1
	161.3	11.6	167.3	11.3
	164.6	11.9	153.3	10.5
	166.7	11.9	146.3	9.9
	161.3	11.5	160.6	11.3
	158.4	11.5	159.0	11.2
	160.7	11.3	147.3	10.6
	157.2	11.3	154.2	10.8
	167.1	11.8	158.5	11.5
	154.6	11.2	156.2	11.1
	156.5	10.8	162.0	11.2
	152.7	11.0	167.4	11.9
	164.5	11.6	144.1	10.3
	167.7	12.0	158.6	11.3
	154.0	10.6	150.8	10.9
	170.0	11.5	156.9	10.9
	166.8	12.4	154.6	10.8
	162.4	11.8	156.9	11.1
	164.0	11.7	154.2	10.9
	161.0	11.7	163.8	11.4
			155.4	11.3
			145.4	10.4
			157.0	11.1
			152.5	10.8
			162.6	11.5
			158.3	11.3
			153.5	10.9
			157.3	10.6
			155.3	11.1
			156.1	11.5
			154.3	11.3
			162.4	11.5
			161.3	11.6
			160.6	11.1
Mean	**162.0**	**11.5**	**158.1**	**11.2**
SD	**5.4**	**0.5**	**6.3**	**0.5**
CV	**3.3**	**4.2**	**4.0**	**4.7**

	MRXC4 Mean 20% Range 10%			
	Inner BL	Inner BE	Outer BL	Outer BE
	N	%	N	%
	150.8	11.7	147.5	10.9
	145.6	11.0	161.2	11.4
	144.2	10.4	131.5	10.0
	145.8	10.9	155.9	11.5
	134.4	9.8	129.9	9.9
	159.0	11.9	153.9	10.9
	140.9	10.2	138.1	10.1
	158.2	12.0	132.0	10.1
	164.4	12.9	141.6	10.5
	153.5	11.6	135.3	10.7
	148.1	11.2	152.7	12.1
	161.4	12.1	146.3	11.4
	154.3	11.8	152.4	12.0
	163.8	12.4	150.0	11.6
	160.2	12.1	158.3	12.4
	164.3	12.3	160.8	11.8
	148.7	11.3	155.3	11.4
	159.1	11.7	156.3	12.0
	164.4	12.0	152.9	11.6
	157.2	11.5	155.7	12.0
	157.9	12.2	149.5	11.7
	161.6	11.6	156.1	11.9
	164.2	12.9	150.5	11.1
	158.9	11.7	154.9	11.3
	166.5	12.4	153.5	11.8
	165.3	13.3	152.8	11.8
	160.5	12.2	155.7	11.5
	156.5	12.0	154.3	11.4
	154.3	11.6	155.3	11.5
	158.1	11.9	153.5	11.7
	159.9	12.4	160.6	12.4
	159.5	12.7	161.2	12.6
			154.2	11.4
			156.9	12.0
			158.4	11.7
			154.5	11.6
			161.2	12.4
			158.6	12.3
			160.3	12.0
			157.1	11.8
			158.2	11.6
			159.3	12.5
			144.6	11.5
			152.4	11.4
			156.2	12.1
			161.5	12.4
			164.5	11.7
			161.9	12.9
Mean	**156.8**	**11.8**	**153.0**	**11.6**
SD	**7.8**	**0.8**	**8.2**	**0.7**
CV	**4.9**	**6.6**	**5.4**	**5.9**

	MRXC5 Mean 3% Range 4%			
	Inner BL	Inner BE	Outer BL	Outer BE
	N	%	N	%
	154.6	12.1	153.7	12.3
	153.3	12.3	157.9	12.3
	153.3	12.4	151.3	12.3
	150.9	12.1	154.1	12.6
	162.6	13.4	150.9	12.0
	170.3	13.1	153.1	11.9
	154.9	11.9	165.6	12.6
	155.8	12.3	146.6	11.8
	158.0	12.9	157.6	11.8
	152.8	12.2	152.6	12.0
	133.7	10.6	155.6	12.0
	149.5	12.2	145.0	11.9
	160.0	12.4	157.1	13.1
	147.8	11.3	161.0	12.6
	141.6	11.2	131.3	10.1
	149.9	12.5	150.6	12.1
	153.9	11.6	138.4	10.9
	154.6	12.0	142.6	11.0
	144.1	11.6	142.5	11.1
	161.5	12.9	150.8	12.1
	147.8	12.1	148.8	11.7
	163.8	13.3	150.4	11.3
	160.3	13.3	160.9	13.1
	149.1	12.0	149.2	12.0
	149.9	11.3	152.2	11.9
	161.5	12.6	165.0	12.9
	158.2	13.0	161.0	12.4
	143.7	11.5	141.8	11.6
	146.5	11.1	148.1	12.1
	152.7	12.2	163.6	12.1
			144.4	9.9
			148.4	12.2
			161.1	12.6
			150.3	11.6
			129.1	10.5
			131.1	10.5
			140.3	10.9
			137.2	11.1
			148.7	11.1
			131.2	10.6
			137.0	10.9
			134.0	11.4
			140.0	11.4
			147.5	11.4
			149.5	11.3
			129.9	10.3
Mean	**153.2**	**12.2**	**148.2**	**11.7**
SD	**7.5**	**0.7**	**9.8**	**0.8**
CV	**4.9**	**5.8**	**6.6**	**6.7**

	MRXC6 Mean 20% Range 15%			
	Inner BL	Inner BE	Outer BL	Outer BE
	N	%	N	%
	136.8	10.2	147.8	10.6
	141.7	9.9	143.9	10.5
	130.9	9.2	128.3	9.4
	134.8	10.0	158.6	11.6
	145.4	10.6	161.4	11.6
	139.8	9.9	139.7	10.7
	137.3	9.9	132.2	10.2
	140.3	10.0	152.0	11.1
	151.2	10.6	144.9	10.8
	168.8	12.6	146.8	11.1
	150.6	11.4	127.7	9.6
	148.3	11.2	136.0	10.4
	156.7	11.4	160.2	11.5
	157.3	11.7	152.1	11.3
	155.1	11.1	156.2	11.5
	157.1	11.3	153.3	11.4
	146.7	11.2	151.5	11.0
	149.6	11.2	150.3	11.2
	157.0	10.8	154.4	11.0
	146.4	11.0	157.7	11.2
	163.6	11.6	153.6	11.1
	143.3	10.4	163.6	11.4
	161.6	11.2	152.7	10.7
	164.1	12.1	150.2	10.9
	152.1	11.4	157.8	11.4
	154.1	11.2	146.0	10.8
	157.6	11.3	146.5	10.4
	151.8	10.8	155.5	11.1
	165.0	12.1	144.4	10.3
	154.3	11.0	154.8	11.0
	152.7	11.2	143.4	10.3
	157.6	11.4	149.0	10.7
			144.1	10.8
			149.3	11.1
			153.0	11.3
			151.0	11.2
			155.4	11.8
			153.9	11.5
			153.9	10.9
			152.2	10.9
			154.7	11.4
			157.3	11.1
			149.9	10.9
			148.0	11.2
			148.8	10.8
			148.0	10.8
			151.2	10.8
Mean	**150.9**	**11.0**	**149.9**	**10.9**
SD	**9.4**	**0.7**	**7.7**	**0.5**
CV	**6.2**	**6.8**	**5.1**	**4.4**

	MRXC7 Mean 60% Range 6%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	174.2	12.5	164.0	12.0
	165.9	12.1	158.4	11.0
	168.4	12.7	162.0	11.6
	162.1	11.9	163.7	11.4
	164.5	11.9	160.6	11.2
	155.9	11.2	164.8	11.7
	168.6	12.4	157.8	11.4
	164.8	12.4	160.0	11.3
	161.9	11.8	168.3	12.5
	165.2	11.8	161.3	11.4
	158.0	10.9	152.8	10.4
	162.1	10.9	152.9	10.9
	157.4	10.9	158.6	10.8
	158.0	10.9	159.2	11.4
	162.1	10.9	159.6	11.1
	157.4	10.9	155.7	10.8
	161.9	11.5	159.6	11.1
	169.1	12.2	155.7	10.8
	159.4	11.1	158.2	11.2
	162.4	11.2	152.7	11.1
	160.8	11.4	156.6	10.8
	159.1	11.1	169.1	11.3
	163.1	11.8	152.9	10.4
	158.2	11.3	151.5	10.7
	150.4	10.4	153.1	11.3
	155.6	10.8	152.9	11.0
	176.7	12.3	147.9	10.1
	156.4	11.1	149.6	10.5
	157.1	11.1	163.3	11.3
	162.5	11.9	142.2	9.9
	156.0	11.2	158.8	11.0
	160.4	11.0	148.4	10.6
	165.2	12.0	153.1	10.5
	154.6	10.4	144.3	10.1
	151.4	10.0	153.4	10.5
	151.6	10.5	160.3	10.7
	161.6	11.6	150.2	10.1
	162.9	11.7	139.9	9.7
	161.8	11.0	154.8	11.0
	151.7	11.0		
	176.3	11.7		
	151.5	10.6		
	144.1	10.3		
Mean	**160.7**	**11.4**	**156.1**	**10.9**
SD	**6.7**	**0.7**	**6.6**	**0.6**
CV	**4.2**	**5.8**	**4.2**	**5.2**

APPENDIX E. PWRC 10 TONNE STROPS - YARN RESULTS

Individual Textile Yarn Test Results

	MSAN1 Mean 5% Range 8%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	74.0	8.4	75.1	8.5
	76.9	8.7	78.3	9.0
	76.3	9.0	74.0	8.8
	76.8	9.1	76.0	8.5
	77.3	9.0	77.6	8.5
	75.5	8.9	76.6	9.2
	74.2	8.7	73.9	8.7
	77.8	9.2	73.7	9.0
	79.6	9.5	78.3	8.8
	78.5	9.2	83.8	10.8
	77.9	8.7	76.3	8.8
	77.4	9.5	82.2	9.7
	75.7	8.7	80.9	9.1
	82.5	9.6	78.9	9.4
	72.9	8.8	70.5	8.0
	78.2	9.6	74.4	8.8
	76.9	8.9	73.9	8.1
	76.4	8.7	67.8	8.1
	79.9	8.7	77.1	8.7
	79.1	9.6	77.5	8.9
	80.3	10.0	76.3	8.9
	85.1	10.0	74.5	8.9
	80.0	9.7	80.2	9.4
	76.5	8.9	76.2	9.2
	75.5	8.7	77.9	9.1
	80.8	8.9	82.6	9.6
	77.1	9.1	78.6	8.8
	75.1	8.5	77.7	9.1
	76.4	9.1	75.1	8.7
	75.1	8.8	79.9	9.3
	74.0	8.7	77.5	8.7
	91.7	12.2	70.1	8.2
	79.7	9.5	70.0	7.8
	72.4	8.8	80.9	10.0
	78.2	9.3	74.2	8.6
	77.4	8.9	76.2	9.0
	75.2	8.8	78.0	8.6
	77.3	9.2	73.6	8.5
	82.9	9.9	78.0	8.8
	77.0	8.8	77.8	8.8
	77.8	9.1	72.9	8.7
	77.6	8.9	88.8	11.8
	78.0	8.9	73.8	8.4
	77.8	8.9	81.8	9.9
	76.2	9.0	75.3	8.8
	77.3	9.5	83.0	9.9
	77.6	9.0	75.3	8.5
	83.4	10.2	73.5	9.0
	76.2	9.1	77.4	8.5
	70.2	8.4	75.2	8.7
	73.1	8.5	76.8	8.8
	89.9	11.5	76.8	8.7
	72.8	8.5	75.3	8.8
			72.0	8.7
			85.4	10.3
			74.0	8.6
			86.0	11.3
			77.7	8.8
			75.2	8.6
			76.2	8.6
			78.3	9.1
			77.4	8.5
Mean	**77.7**	**9.2**	**76.9**	**9.0**
SD	**3.8**	**0.7**	**3.9**	**0.7**
CV	**4.9**	**7.5**	**5.0**	**7.9**

	MSAN2 Mean 30% Range 10%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	88.2	11.2	78.4	9.7
	87.7	10.7	82.7	11.1
	86.0	11.0	80.7	9.9
	88.4	10.9	80.8	10.5
	93.9	13.5	85.2	11.3
	86.2	10.9	91.3	11.5
	86.4	11.1	87.3	10.7
	86.3	11.4	90.7	12.2
	83.8	10.2	87.1	11.3
	87.5	11.3	93.2	13.1
	84.4	10.5	87.7	11.4
	88.8	10.7	81.6	9.9
	84.6	10.0	86.4	11.0
	83.2	10.3	83.0	10.5
	86.8	11.5	86.5	11.2
	93.4	11.7	79.0	9.6
	89.9	12.2	84.6	10.3
	87.1	12.0	83.6	10.2
	90.6	12.0	83.4	10.6
	84.4	10.8	78.8	9.2
	85.4	10.6	84.6	10.4
	84.6	10.1	81.8	9.4
	84.8	11.1	78.7	9.7
	73.1	9.2	80.3	10.1
	83.4	10.4	78.8	10.2
	76.8	10.0	78.8	9.8
	80.8	10.1	73.6	9.2
	92.5	13.6	75.3	9.4
	83.0	10.4	75.8	9.0
	85.5	10.5	80.4	10.7
	85.0	10.8	84.1	10.9
	82.1	10.2	80.9	9.7
	86.6	11.0	78.5	9.6
	82.2	10.6	83.3	10.3
	90.3	11.9	74.6	9.2
	85.0	10.5	86.5	11.6
	83.8	10.9	90.5	11.9
	83.3	10.3	75.7	9.1
	74.7	9.2	85.9	10.8
	83.6	11.0	83.5	11.2
	89.4	10.8	76.0	9.3
	89.6	11.6	83.7	10.6
	86.1	10.8	86.4	10.5
	85.9	10.5	71.9	8.9
	86.6	10.7	71.0	8.8
	85.1	10.5	86.9	11.1
	83.5	10.6	85.1	10.1
	86.8	11.1	87.4	11.2
	87.0	11.7	81.2	9.7
	87.8	11.2	88.3	12.0
	85.7	11.3	81.2	10.4
	86.3	11.6	81.3	9.9
	93.3	12.4		
	84.6	10.5		
	84.5	10.6		
	88.9	11.3		
	92.4	12.9		
	90.2	11.3		
	90.1	11.2		
	87.9	11.1		
	88.0	10.5		
	80.5	10.2		
	84.5	11.0		
	81.0	9.9		
	87.4	10.5		
	83.3	10.9		
Mean	**85.9**	**11.0**	**82.4**	**10.4**
SD	**3.9**	**0.8**	**5.0**	**0.9**
CV	**4.5**	**7.5**	**6.1**	**9.1**

MSAN3 Mean 10% Range 12%

	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	80.2	9.6	79.8	9.8
	84.1	10.1	76.5	8.6
	88.6	11.3	74.1	8.9
	77.4	9.2	73.4	8.8
	77.6	9.4	79.1	9.4
	79.2	9.7	75.8	9.1
	89.9	12.0	75.6	8.6
	75.4	8.7	74.5	8.4
	82.9	10.5	76.7	9.4
	72.0	8.8	74.9	9.0
	72.6	8.9	68.5	7.8
	78.6	9.3	74.4	8.9
	78.6	9.2	74.1	9.1
	79.4	9.0	71.5	8.5
	78.9	9.2	75.2	8.5
	75.6	6.5	82.2	10.0
	78.5	9.5	74.4	8.7
	72.4	8.5	77.0	8.7
	78.4	9.4	76.0	8.7
	87.9	12.1	76.8	9.3
	77.8	9.5	67.7	8.0
	83.8	10.0	74.1	8.8
	80.1	9.8	76.5	8.8
	81.1	10.0	79.4	9.3
	75.7	8.9	80.1	9.1
	78.4	9.9	74.8	8.9
	82.6	10.3	74.3	9.0
	70.2	8.5	76.9	9.3
	75.6	8.8	74.4	8.6
	78.9	9.3	75.7	9.1
	81.9	9.4	73.9	8.9
	90.5	11.5	76.7	8.9
	76.8	9.3	73.6	8.8
	76.0	9.3	74.7	8.9
	76.5	8.9	74.9	8.7
	76.6	9.4	80.6	8.8
	81.3	9.5	75.2	8.6
	75.2	8.8	75.6	8.8
	69.5	8.7	77.3	8.9
	83.6	12.0	78.4	9.0
	78.2	9.5	76.0	9.0
	88.5	11.6	75.7	9.3
	77.1	9.3	72.5	8.7
	78.8	9.6	69.1	8.6
	75.7	8.8	80.8	9.4
	77.4	8.6	73.7	8.6
	86.3	10.7	76.3	9.1
	73.7	8.5	70.6	8.4
	87.1	10.5	77.4	9.3
	77.9	8.9	75.8	9.3
	76.8	9.4	77.0	8.8
	76.5	9.2		
	87.7	11.8		
	79.6	9.2		
	77.8	9.3		
	76.1	9.2		
	80.1	9.2		
	73.8	8.8		
	69.0	8.2		
	76.6	8.7		
	82.0	9.9		
	77.9	9.8		
	83.6	9.8		
	72.9	8.5		
Mean	**78.9**	**9.5**	**75.5**	**8.9**
SD	**4.9**	**1.0**	**2.9**	**0.4**
CV	**6.2**	**10.6**	**3.9**	**4.4**

	MSAN4 Mean 30% Range 15%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	78.0	9.9	82.0	10.3
	80.7	10.8	83.7	10.5
	80.5	9.8	80.3	9.8
	82.2	10.1	85.6	10.8
	79.5	9.9	79.2	9.9
	82.6	10.7	82.0	9.7
	90.0	12.5	78.6	10.0
	77.0	9.7	79.8	9.7
	84.0	10.8	85.2	10.3
	80.8	10.0	79.5	10.4
	79.0	9.4	82.6	10.4
	82.5	10.5	83.3	10.2
	82.9	10.3	79.4	9.6
	80.7	9.5	77.6	10.2
	81.3	10.0	78.9	9.3
	78.2	9.6	82.1	10.1
	82.0	11.0	80.5	9.7
	90.0	12.3	78.7	10.1
	91.7	11.9	78.8	10.6
	83.5	10.7	79.5	9.7
	80.1	10.1	78.2	10.3
	78.2	10.0	78.2	9.7
	79.4	10.0	81.6	9.9
	82.4	10.1	79.1	9.4
	81.1	10.2	79.2	10.1
	78.1	10.2	80.3	10.4
	80.2	10.0	79.2	10.2
	78.3	9.5	73.9	9.2
	84.1	10.9	83.4	10.5
	83.0	10.3	78.9	10.2
	78.8	9.4	80.3	9.9
	82.3	10.0	81.9	10.3
	79.0	9.6	80.9	10.4
	81.3	10.4	81.3	10.5
	79.9	9.8	81.0	10.0
	84.0	10.3	81.0	10.0
	82.5	10.6	82.4	9.8
	85.2	10.7	78.8	10.1
	81.8	10.4	77.9	9.9
	80.9	10.0	78.9	9.7
	79.8	9.7	81.6	10.1
	79.6	9.5	81.9	10.1
	82.4	10.1	82.7	10.3
	83.5	10.1	82.5	9.6
	88.7	11.9	81.9	10.1
	82.6	10.7	80.0	10.3
	80.9	10.6	80.9	9.5
	77.5	9.1	82.1	10.2
	86.9	10.8	79.8	9.9
	82.9	10.6		
	78.1	9.9		
	81.1	10.7		
	84.2	10.0		
	74.8	9.5		
	80.1	10.3		
	84.9	11.1		
	83.2	10.5		
	80.7	10.3		
	87.9	12.1		
	80.6	10.4		
	81.4	10.2		
	77.1	9.6		
	84.1	10.2		
Mean	**81.8**	**10.3**	**80.6**	**10.0**
SD	**3.3**	**0.7**	**2.1**	**0.3**
CV	**4.0**	**6.8**	**2.6**	**3.5**

MSAN5 Mean 30% Range 20%				
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	77.0	9.4	75.7	9.5
	82.0	10.2	76.8	9.6
	81.7	11.1	75.6	9.4
	74.9	9.3	74.0	9.3
	74.6	9.1	76.5	9.7
	79.8	10.0	78.8	9.6
	73.6	9.4	75.2	9.8
	80.1	10.0	75.9	9.1
	83.2	11.0	73.6	9.3
	88.4	11.8	79.5	9.5
	89.6	12.2	76.1	9.3
	78.7	9.4	74.7	9.1
	74.2	9.1	74.6	9.5
	77.3	9.6	79.7	9.7
	84.8	10.6	74.6	9.1
	75.0	9.0	74.2	9.3
	81.3	10.0	78.3	9.6
	76.6	9.9	78.6	9.3
	79.7	10.0	76.5	10.0
	80.3	10.1	79.9	9.8
	80.5	10.4	74.5	9.6
	78.8	9.8	77.7	9.3
	75.5	9.6	74.6	9.3
	79.2	10.0	78.2	9.6
	73.5	9.2	73.5	9.1
	74.9	9.5	80.8	10.1
	75.7	9.2	76.3	9.3
	78.8	9.8	76.1	9.6
	79.6	9.6	72.4	9.5
	87.2	11.6	78.0	9.5
	75.5	9.7	74.1	9.0
	83.4	10.9	74.5	9.5
	77.9	9.5	76.0	9.1
	76.5	9.6	74.9	9.2
	75.8	9.6	80.2	10.2
	77.0	9.4	78.1	9.5
	70.3	8.6	76.1	8.9
	72.5	9.2	74.8	9.0
	65.7	8.9	74.8	9.1
	77.3	9.6	76.6	9.2
	74.5	9.4	79.1	10.1
	76.7	9.3	76.2	9.3
	75.4	9.4	74.9	9.4
	69.1	8.8	74.5	9.3
	77.8	9.8	81.4	10.3
	72.5	9.3	75.4	9.5
	70.8	8.6	77.6	9.9
	73.6	8.7	75.6	9.3
	79.1	9.7	75.0	9.4
	76.9	9.7	73.9	9.3
	76.3	9.4	82.0	9.7
	76.1	9.4		
	75.0	9.2		
	75.1	9.5		
	79.3	9.7		
	76.8	9.6		
	73.9	9.5		
	77.1	9.9		
	78.3	9.9		
	80.7	10.4		
	80.2	9.8		
	92.5	13.0		
	78.1	9.7		
	77.3	9.5		
	73.7	9.0		
	77.4	9.0		
Mean	**77.6**	**9.8**	**76.4**	**9.5**
SD	**4.5**	**0.8**	**2.2**	**0.3**
CV	**5.9**	**8.3**	**2.9**	**3.4**

APPENDIX E. PSC FULL SCALE SUBROPES - YARN RESULTS

Individual textile Yarn Break Load Test Results

	MRXC11 Inner rope yarn Mean 60% Range 6%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	171.3	11.6	159.6	11.4
	170.5	11.7	158.9	11.0
	166.1	11.7	166.6	11.5
	170.0	11.4	167.1	11.6
	164.7	11.5	155.8	10.7
	171.6	11.7	158.0	11.0
	161.0	11.1	166.3	11.8
	174.3	12.2	167.1	11.5
	168.0	11.7	170.5	12.0
	163.2	11.3	152.8	11.0
	162.3	11.1	157.8	11.3
	154.0	11.0	153.7	10.9
	167.8	11.7	160.1	11.1
	150.7	10.5	169.2	11.4
	172.9	11.7	164.9	11.4
	173.7	11.8	164.9	11.3
	182.7	12.5	157.4	11.2
	167.2	11.6	176.1	11.8
	167.6	11.9	155.0	10.9
	157.1	10.8	163.7	11.4
	161.1	11.0	170.9	12.1
	163.3	11.0	161.6	11.6
	161.4	11.0	170.2	12.0
	159.9	11.6	163.9	11.5
	173.3	12.0	159.9	11.3
	162.0	11.3	164.1	11.8
	151.8	10.8	161.1	11.2
	162.7	11.5	149.9	11.0
	153.2	11.0	155.6	11.1
	161.4	11.0	163.5	11.6
	167.7	11.5	160.5	11.4
	172.4	12.3	158.9	11.2
	168.9	12.0	160.8	11.3
	149.3	10.7	138.7	10.4
	161.0	11.2	165.5	11.7
	147.9	10.6		
	152.1	10.7		
	165.8	11.3		
	156.0	11.0		
	157.6	10.8		
	167.2	11.8		
	164.5	11.4		
	156.8	10.9		
	153.2	10.9		
Mean	**163.3**	**11.4**	**161.4**	**11.4**
SD	**7.8**	**0.5**	**7.0**	**0.4**
CV	**4.8**	**4.2**	**4.3**	**3.3**

	MRXC11 Outer rope yarn Mean 60% Range 6%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	161.0	11.1	162.0	11.2
	156.3	10.9	153.3	10.6
	153.2	11.0	159.1	10.9
	140.2	10.1	145.1	10.1
	162.3	11.0	156.6	11.0
	120.1	9.2	131.0	9.8
	157.7	11.3	151.4	10.6
	157.5	11.4	138.3	10.1
	155.8	10.7	158.0	11.0
	137.2	10.0	156.1	10.9
	152.4	10.9	160.9	11.1
	158.6	11.3	151.9	10.7
	164.2	11.6	144.8	10.3
	171.3	12.1	149.8	10.7
	159.8	11.0	157.2	11.2
	158.8	11.1	145.2	10.4
	162.4	11.8	157.8	11.3
	163.5	11.4	157.0	10.9
	164.4	11.5	156.2	11.3
	167.7	11.6	152.0	10.9
	156.6	11.0	151.4	10.4
	149.9	10.6	161.0	11.7
	155.9	11.1	140.4	10.1
	135.6	9.6	143.5	10.6
	152.7	11.2	153.3	10.8
	161.8	11.3	147.3	10.4
	152.4	10.6	157.6	11.2
	161.2	11.4	158.7	11.0
	155.3	10.9	121.6	9.4
	158.9	11.4	141.1	10.3
	161.8	11.0	145.2	10.4
	164.7	11.4	143.8	10.6
	156.1	10.9	167.9	11.7
	149.8	10.7	144.3	10.6
	149.8	10.5	154.4	10.5
	165.2	11.6	152.1	11.0
	154.0	10.9		
	144.4	10.4		
	163.9	11.4		
	135.4	10.4		
	175.8	11.8		
	174.0	12.0		
	154.7	10.8		
Mean	**156.1**	**11.0**	**150.8**	**10.7**
SD	**10.7**	**0.6**	**9.3**	**0.5**
CV	**6.8**	**5.4**	**6.1**	**4.6**

	MRXC13 Inner rope yarn Mean 20% Range 15%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	153.0	10.3	138.9	10.3
	146.1	10.9	133.7	9.9
	146.7	10.5	149.5	10.7
	154.5	11.4	170.3	12.4
	169.9	12.4	144.2	10.7
	142.5	10.5	141.1	10.4
	145.9	10.5	142.1	10.5
	142.5	10.3	158.1	11.3
	144.0	10.0	135.5	10.4
	142.2	10.4	140.8	10.6
	143.5	10.6	161.1	11.7
	142.7	10.6	149.2	11.0
	164.3	12.2	159.7	11.9
	148.7	11.1	149.7	10.9
	167.7	12.6	143.4	10.5
	148.0	11.2	161.5	11.4
	156.8	11.6	143.2	10.8
	145.7	10.7	138.1	10.4
	161.1	11.9	88.3	7.6
	143.5	10.6	83.9	7.2
	145.0	10.5	107.0	8.5
	173.3	12.7	114.5	9.0
	109.7	8.7	93.2	8.1
	106.9	8.5	105.9	8.8
	96.5	8.2	96.2	8.4
	96.1	8.1	150.6	11.2
	125.7	10.0	100.6	8.8
	115.1	9.0	136.5	10.0
	99.5	8.5	145.6	10.4
	173.2	13.3	135.9	10.3
	120.4	9.6	167.6	11.8
	98.9	8.5	154.9	11.7
	95.4	7.9	132.9	9.8
	163.1	11.5	135.4	10.3
	141.8	10.4	135.5	9.9
	137.4	10.2	134.5	10.0
	165.5	12.1		
	141.5	10.6		
	131.8	9.7		
	142.5	10.8		
	162.4	11.9		
	138.5	10.7		
	135.5	10.2		
	131.0	10.1		
Mean	**139.9**	**10.5**	**135.5**	**10.2**
SD	**21.7**	**1.3**	**22.6**	**1.2**
CV	**15.5**	**12.3**	**16.7**	**12.1**

	MRXC13 Outer rope yarn Mean 20% Range 15%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	122.7	9.8	106.9	9.2
	126.1	10.4	140.7	10.8
	153.0	11.6	136.6	10.3
	102.8	8.8	83.8	7.9
	78.7	8.1	83.5	8.4
	125.6	10.4	118.6	9.5
	106.4	9.5	125.9	9.8
	106.0	9.1	98.5	8.7
	140.1	10.7	127.7	9.7
	128.4	9.7	93.2	8.4
	147.5	10.9	93.7	8.8
	106.9	9.3	141.6	11.3
	163.2	12.7	107.7	9.2
	126.8	10.3	101.6	8.7
	127.3	9.7	113.1	9.3
	96.3	8.9	120.0	9.8
	109.7	8.8	111.6	9.0
	102.9	8.2	114.8	9.5
	94.1	7.8	116.1	9.3
	116.0	9.4	92.6	9.0
	116.8	9.7	130.9	10.2
	161.4	11.7	163.7	12.8
	166.4	12.7	82.8	8.5
	129.1	10.2	108.7	9.0
	157.1	12.4	85.8	8.1
	160.4	12.0	95.2	8.4
	129.1	10.0	77.1	7.5
	157.2	11.4	101.4	8.5
	112.7	9.2	86.9	7.9
	128.8	9.9	130.8	10.6
	164.4	12.7	86.9	7.6
	167.3	12.6	123.1	10.0
	138.1	11.4	91.0	8.3
	144.7	11.3	154.2	11.3
	120.7	9.7	122.4	9.7
	139.0	11.2		
	167.2	12.4		
	118.9	9.5		
	83.8	8.3		
	160.5	12.2		
	125.1	10.3		
	156.9	11.9		
	151.7	11.7		
	112.6	9.4		
Mean	**130.7**	**10.4**	**110.5**	**9.3**
SD	**24.2**	**1.4**	**21.7**	**1.1**
CV	**18.5**	**13.5**	**19.7**	**12.4**

	MRXC14 Inner rope yarn Mean 3% Range 4%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	146.2	13.0	136.3	12.6
	168.1	12.6	133.5	13.0
	143.7	13.1	143.9	10.8
	152.8	13.2	145.7	12.7
	148.7	13.0	156.3	13.7
	148.7	13.6	137.4	12.6
	131.8	12.3	144.5	12.8
	138.5	13.1	136.2	12.9
	151.9	13.1	132.6	10.9
	146.1	12.8	148.6	13.2
	147.2	12.3	153.7	14.0
	138.9	12.8	147.7	13.2
	155.8	14.2	143.8	13.0
	164.3	14.1	145.0	13.5
	160.0	13.8	147.6	13.5
	167.2	14.5	152.9	13.0
	143.0	13.0	161.2	14.0
	166.7	13.7	158.0	14.2
	149.7	12.7	154.6	13.1
	155.0	13.8	156.6	13.7
	155.2	13.7	152.6	13.5
	155.9	13.5	152.7	12.9
	150.3	13.1	104.1	10.7
	142.1	12.5	156.7	13.3
	154.0	13.5	153.6	13.6
	152.9	13.8	155.2	13.8
	165.8	14.1	144.8	11.1
	148.5	13.6	154.1	13.2
	154.8	13.7	123.3	11.7
	162.9	13.9	153.7	13.2
	153.9	13.3	135.3	12.7
	164.1	14.0	158.1	14.0
	160.0	14.0	141.8	12.5
	145.8	13.0	157.2	13.9
	147.9	13.1	159.4	13.8
	135.9	12.0	156.9	13.6
	152.5	13.4		
	173.1	12.0		
	159.7	14.2		
	134.7	12.2		
	168.0	14.0		
	170.6	15.0		
	154.0	13.7		
	163.9	13.9		
Mean	**153.4**	**13.4**	**147.1**	**13.0**
SD	**10.1**	**0.7**	**11.7**	**0.9**
CV	**6.6**	**5.1**	**8.0**	**7.1**

	MRXC14 Outer rope yarn Mean 3% Range 4%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	125.8	12.0	129.7	11.7
	153.9	13.6	151.9	13.5
	146.7	13.2	140.6	12.7
	137.3	12.7	138.3	12.8
	151.4	13.1	152.7	13.2
	166.5	14.6	149.6	13.1
	163.4	14.1	156.9	13.4
	143.8	13.1	132.4	12.2
	151.8	13.3	149.5	13.1
	127.4	11.6	127.6	12.3
	138.8	12.6	137.1	12.4
	153.7	13.8	151.7	13.5
	154.5	13.8	149.5	13.5
	164.8	14.1	141.4	13.3
	135.3	12.7	154.0	13.3
	160.8	13.8	144.9	13.1
	147.4	13.1	152.2	13.3
	160.8	13.7	146.1	13.0
	160.8	12.1	151.3	13.1
	147.0	12.6	161.7	14.0
	122.9	11.7	129.0	12.7
	158.2	14.2	166.2	14.6
	140.5	13.1	156.5	11.8
	160.7	13.7	159.0	13.8
	153.3	13.8	134.4	12.5
	154.5	13.3	146.1	13.4
	159.7	14.4	149.9	13.7
	153.8	13.6	150.5	13.6
	152.5	13.9	125.2	12.0
	146.7	12.8	147.0	13.3
	158.8	13.5	161.7	13.6
	152.9	13.6	147.0	13.3
	152.0	13.6	147.2	13.0
	119.2	12.1	145.7	13.1
	150.2	13.7	155.0	13.8
	151.8	13.3	164.6	13.7
	154.7	13.7		
	157.1	13.7		
	161.6	14.1		
	166.2	14.8		
	165.9	14.3		
	157.4	13.2		
	143.2	12.5		
Mean	**150.8**	**13.4**	**147.3**	**13.1**
SD	**11.7**	**0.8**	**10.4**	**0.6**
CV	**7.7**	**5.7**	**7.1**	**4.8**

	MRXC14 Re-test Inner rope yarn Mean 3% Range 4%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	161.4	14.3	152.5	13.6
	165.1	14.6	155.9	13.6
	164.3	14.5	158.2	14.2
	157.8	14.1	154.6	13.6
	158.4	13.6	143.9	12.8
	156.8	13.7	162.8	14.5
	169.7	14.2	154.8	13.2
	162.6	13.4	164.0	14.0
	166.9	14.2	157.0	14.0
	163.0	14.4	159.7	13.8
	134.9	12.2	157.0	13.8
	131.6	12.4	148.2	12.7
	120.5	11.9	135.7	12.7
	148.8	12.9	124.0	11.7
	141.2	13.3	160.1	13.7
	133.1	12.2	145.2	13.3
	167.3	14.5	149.1	13.5
	150.4	13.8	123.1	11.7
	158.0	14.0	144.7	13.1
	158.4	13.9	131.5	12.3
	158.5	13.5	138.3	12.8
	154.6	14.1	122.7	12.0
	153.6	13.4	125.1	11.3
	157.8	13.7	139.3	12.5
	159.6	13.6	162.6	13.7
	152.9	13.7	163.3	13.8
	158.0	13.9	153.5	13.6
	166.0	14.1	156.6	14.1
	158.6	14.1	151.8	11.4
	146.6	13.5	162.8	14.4
	160.5	13.9	164.0	14.0
	161.3	14.2	164.4	14.6
			175.6	15.3
			163.7	14.3
			139.6	12..6
			150.3	13.5
			155.0	13.3
			156.9	13.2
			165.1	13.9
			153.6	13.6
			172.2	14.9
			144.6	12.9
			160.7	14.1
			148.7	13.4
			154.2	13.5
			154.8	13.6
			160.1	13.9
Mean	**154.9**	**13.7**	**151.9**	**13.4**
SD	**11.5**	**0.7**	**12.6**	**0.9**
CV	**7.4**	**5.1**	**8.3**	**6.5**

	MRXC14 Re-test Outer rope yarn Mean 3% Range 4%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	152.7	12.7	156.5	12.9
	157.6	13.0	166.9	14.1
	152.6	13.4	162.8	13.7
	166.2	13.8	147.0	12.8
	158.1	13.1	151.8	13.2
	163.6	13.8	154.2	13.1
	155.6	13.6	158.3	13.7
	158.3	14.1	139.4	12.4
	151.1	13.0	143.3	12.4
	163.2	13.8	159.3	13.1
	164.2	14.0	149.8	12.5
	141.6	12.4	162.9	14.0
	163.3	14.3	146.5	12.9
	155.3	13.6	153.8	12.6
	150.5	13.5	177.8	15.1
	153.8	13.6	158.3	13.4
	174.4	15.1	146.7	12.4
	176.9	14.4	150.1	13.2
	165.0	14.1	143.5	12.4
	143.2	12.3	150.6	14.4
	154.9	12.8	142.2	12.4
	150.0	13.5	168.1	14.5
	135.0	11.8	144.8	13.0
	151.3	13.2	154.5	13.6
	150.2	13.0	146.1	12.9
	148.0	12.6	163.0	13.6
	166.2	14.4	156.0	13.1
	152.1	12.9	157.7	13.5
	154.0	13.0	145.1	12.5
	167.0	15.2	153.1	13.0
	159.0	13.5	157.5	13.1
	159.4	13.0	150.9	13.1
	163.8	13.0	153.1	13.6
	149.1	14.4	154.9	13.6
	157.9	13.7	154.1	13.2
	156.7	13.4		
	151.0	12.7		
	157.4	11.6		
	161.8	13.9		
Mean	**156.7**	**13.4**	**153.7**	**13.2**
SD	**8.4**	**0.8**	**8.2**	**0.7**
CV	**5.4**	**5.9**	**5.3**	**4.9**

APPENDIX F. PBC FULL SCALE SUBROPES - YARN RESULTS

Individual textile Yarn Break Load Test Results

	MRZW14 Inner rope yarn Mean 5% Range 8%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	162.5	10.8	131.8	9.4
	160.2	10.3	156.6	9.1
	176.1	11.2	166.7	10.9
	144.1	9.5	136.4	9.7
	147.1	9.6	124.6	9.2
	156.1	9.9	149.4	9.9
	164.0	10.4	134.8	9.0
	157.0	10.8	160.3	10.1
	161.8	10.7	140.6	9.9
	149.3	9.8	145.3	9.3
	175.5	11.1	169.8	10.3
	150.8	9.4	157.1	10.5
	157.4	9.6	146.9	9.9
	162.5	10.7	164.5	10.1
	164.9	10.4	155.8	10.5
	158.4	9.5	155.8	9.5
	171.6	9.8	149.5	10.2
	145.5	9.5	151.6	9.5
	156.1	10.5	158.7	9.9
	147.1	9.0	152.8	9.4
	160.1	10.7	167.1	10.7
	124.2	8.7	160.4	9.6
	169.1	10.4	159.7	9.7
	183.7	12.0	163.3	9.8
	168.4	9.9	160.3	9.9
	175.7	10.7	166.4	9.7
	177.4	11.1	152.7	9.7
	163.1	9.7	155.5	10.2
	147.4	8.7	148.8	10.1
	163.5	10.1	146.5	9.1
	172.7	10.6	159.8	9.9
	172.9	10.9	137.1	9.3
	151.4	9.2	169.0	11.3
	147.4	9.6	130.5	9.0
	178.6	12.1	129.4	8.7
	160.3	9.6	142.3	9.4
	164.2	10.7		
	177.3	10.6		
	163.5	10.0		
	172.8	10.7		
	181.0	12.0		
	179.2	11.0		
	161.8	9.6		
	176.2	11.2		
Mean	**162.7**	**10.3**	**151.6**	**9.8**
SD	**12.4**	**0.8**	**12.2**	**0.6**
CV	**7.6**	**8.0**	**8.1**	**5.8**

	MRZW14 Outer rope yarn Mean 5% Range 8%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	177.6	10.8	171.7	10.9
	170.3	10.3	137.2	9.4
	156.0	9.1	154.3	10.0
	181.3	12.0	141.8	8.9
	174.9	10.8	103.5	7.5
	168.4	10.6	147.8	9.3
	125.3	8.7	155.8	10.1
	149.7	9.4	131.5	9.4
	172.3	11.3	149.0	10.0
	169.0	10.8	141.7	9.5
	148.7	8.9	153.1	9.6
	137.8	9.4	154.0	10.3
	152.2	9.3	149.9	9.9
	178.1	11.7	138.9	9.0
	172.2	11.3	131.4	8.8
	168.2	10.7	157.5	9.7
	161.6	9.2	146.6	9.1
	174.3	11.3	166.2	10.6
	148.6	10.0	143.5	9.8
	180.3	11.2	104.6	8.0
	160.3	10.0	173.1	10.9
	151.0	9.9	133.5	9.0
	138.0	9.4	147.5	9.3
	160.7	10.7	175.7	11.1
	153.1	10.0	128.8	8.6
	176.5	10.9	168.8	11.5
	157.3	9.6	116.9	8.1
	160.9	9.9	142.1	9.0
	166.3	10.9	159.0	9.8
	115.3	8.3	131.7	8.5
	178.8	11.3	134.5	8.6
	162.6	9.4	147.6	9.9
	130.1	8.6	154.8	9.8
	156.8	10.0	152.0	9.7
	172.0	10.4	152.4	9.1
	136.0	8.7	160.2	10.0
	172.8	10.3		
	156.1	10.2		
	152.0	9.8		
	171.2	10.8		
	176.4	10.0		
	161.5	10.2		
	166.0	10.4		
	171.8	10.7		
Mean	**160.7**	**10.2**	**146.1**	**9.5**
SD	**15.6**	**0.9**	**16.9**	**0.9**
CV	**9.7**	**8.7**	**11.5**	**9.2**

APPENDIX G. PWRC FULL SCALE SUBROPES - YARN RESULTS

Individual textile Yarn Break Load Test Results, Inner Strand

	MASN12 Inner strand, Inner rope yarn Mean 5% Range 8%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	77.6	11.9	76.6	11.9
	70.6	12.1	76.0	12.2
	78.6	12.5	77.6	12.0
	68.0	10.4	78.3	12.1
	74.0	12.1	73.9	12.7
	78.5	13.1	80.6	13.5
	80.9	12.9	78.8	11.7
	79.4	14.1	75.8	12.5
	69.0	11.3	75.9	11.8
	81.8	12.4	79.6	13.3
	78.6	13.6	72.5	12.1
	75.6	11.4	66.8	9.8
	83.6	13.9	77.1	12.9
	77.6	13.1	77.0	12.5
	82.9	13.7	73.5	12.0
	70.8	10.2	74.8	11.0
	66.8	10.2	79.1	12.2
	81.7	14.8	78.0	12.9
	77.2	12.2	75.6	11.5
	75.4	12.2	76.5	12.3
Mean	**76.4**	**12.4**	**76.2**	**12.1**
SD	**5.1**	**1.3**	**3.0**	**0.8**
CV	**6.6**	**10.4**	**4.0**	**6.7**

	MASN12 Inner Strand, Outer rope yarn Mean 5% Range 8%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	70.6	11.6	69.7	10.9
	80.3	14.3	71.3	11.0
	76.6	12.1	65.6	10.6
	85.7	14.7	69.9	10.2
	70.0	10.3	67.6	11.6
	75.2	14.1	73.2	11.3
	74.3	11.4	70.6	10.8
	82.8	14.7	71.3	11.3
	80.2	14.1	74.6	12.2
	84.0	14.8	67.7	10.6
	76.4	13.1	69.4	11.1
	69.5	10.9	81.6	15.6
	70.7	10.8	63.3	10.4
	75.3	15.5	87.6	15.2
	84.2	15.4	74.8	12.3
	83.4	13.9	70.1	10.8
	85.7	15.3	71.1	11.2
	79.8	12.7	70.2	11.4
	85.6	14.0	72.7	12.6
	84.4	15.1	79.1	13.0
Mean	**78.7**	**13.4**	**72.1**	**11.7**
SD	**5.7**	**1.7**	**5.5**	**1.5**
CV	**7.3**	**12.5**	**7.7**	**12.5**

Individual textile Yarn Test Results, Outer Strand

	MASN12 Outer strand, Inner rope yarn Mean 5% Range 8%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	80.2	12.4	73.9	13.3
	85.9	15.3	83.5	13.3
	85.8	14.6	69.0	13.4
	86.4	16.2	82.5	13.9
	85.4	14.8	69.2	10.4
	78.3	12.0	72.2	11.0
	83.8	14.2	77.2	11.9
	87.1	14.8	74.4	11.0
	81.2	13.6	60.9	9.5
	81.2	13.8	75.1	11.2
	84.6	13.7	71.9	12.5
	81.8	13.6	70.7	10.0
	84.8	13.7	57.1	11.4
	79.5	14.1	77.4	14.2
	85.7	14.9	74.2	11.7
	86.2	15.6	78.5	12.3
	83.3	14.0	77.3	11.8
	83.5	15.3	74.0	13.4
	83.4	13.4	77.6	11.8
	81.9	14.2	68.2	10.8
Mean	**83.5**	**14.2**	**73.2**	**11.9**
SD	**2.5**	**1.0**	**6.4**	**1.3**
CV	**3.0**	**7.2**	**8.7**	**11.1**

	MASN12 Outer Strand, Outer rope yarn Mean 5% Range 8%			
	Inner BL N	Inner BE %	Outer BL N	Outer BE %
	75.1	12.2	70.9	12.7
	75.2	12.0	80.8	13.9
	73.1	11.2	76.8	13.1
	67.6	9.8	60.9	10.3
	86.2	13.6	63.2	10.9
	86.1	14.9	75.6	12.2
	65.5	9.6	61.8	9.3
	62.7	9.3	61.6	11.1
	76.7	11.6	63.2	9.8
	62.9	10.7	66.6	10.2
	63,5	10.0	65.0	11.1
	77.6	12.7	66.0	9.5
	79.4	12.4	72.3	10.0
	72.7	11.2	65.8	11.2
	76.8	12.0	58.2	10.1
	78.7	16.7	70.5	12.2
	66.7	10.4	60.2	10.2
	81.6	12.8	70.9	11.3
	72.4	12.2	69.7	10.8
	78.0	11.5	62.3	9.2
Mean	**74.5**	**11.8**	**67.1**	**11.0**
SD	**6.9**	**1.8**	**6.1**	**1.3**
CV	**9.3**	**15.2**	**9.1**	**11.9**