ENZYMATIC MODIFICATION OF WOODY CELL WALLS FOR IMPROVED STABILITY OF PULP FIBRES

BY

ELSIE GRETHER STREY

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR DOCTOR OF PHILOSOPHY

IN THE DEPARTMENT OF MICROBIOBIOLOGY AND PLANT PATHOLOGY

FACULTY OF NATURAL AND AGRICULTURAL SCIENCE

AT THE UNIVERSITY OF PRETORIA

PRETORIA

SUPERVISOR: DR J.F. WOLFAARDT
CO-SUPERVISOR: DR J. WESLEY-SMITH

September, 2009
I, the undersigned, declare that the thesis, which I hereby submit for the degree of Doctor of Philosophy at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

..................
Grethe Strey
Signed in Pretoria on September 2009
Al wat staan tussen ‘n mens en wat hy uit die lewe wil hê, is dikwils die **WIL** om te probeer en die **GELOOF** om te glo dit is moontlik.

**Richard M DeVos**
TO MY SAVIOUR
WHO GAVE ME THE ABILITY,
FAMILY AND FRIENDS
TO HELP ME REACH A DREAM
# TABLE OF CONTENTS

**LIST OF FIGURES** ................................................................................................................................. I

**LIST OF TABLES** ........................................................................................................................................ IV

**ACKNOWLEDGEMENTS** ............................................................................................................................. VI

**SUMMARY** ................................................................................................................................................... VII

## CHAPTER 1: LITERATURE REVIEW: FIBRE MOVEMENT IN MECHANICAL PULP AND PROCESSES FOR IMPROVEMENT OF STABILITY ................................................................. 1-1

*Abstract* .......................................................................................................................................................... 1-1

1.1. **INTRODUCTION** ..................................................................................................................................... 1-2

1.2. **MECHANICAL PULP** ................................................................................................................................. 1-3

1.3. **FIBRE BEHAVIOUR** ...................................................................................................................................... 1-6

1.3.1. Fibre collapse ........................................................................................................................................ 1-6

1.3.2. Fibre conformation ................................................................................................................................. 1-10

1.4. **FIBRE STABILITY** ....................................................................................................................................... 1-11

1.4.1. Fibre rising ........................................................................................................................................... 1-11

1.4.2. Cell-wall swelling ................................................................................................................................. 1-12

1.4.3. Puffing ..................................................................................................................................................... 1-13

1.5. **IMPROVEMENT OF FIBRE STABILITY** ................................................................................................. 1-13

1.5.1. Refining .................................................................................................................................................. 1-14

1.5.2. Fractionation .......................................................................................................................................... 1-15

1.5.3. Chemical treatment ............................................................................................................................... 1-16

1.5.4. Enzymatic treatment ............................................................................................................................. 1-17

1.6. **CONCLUSIONS** ....................................................................................................................................... 1-21

1.7. **PROBLEM STATEMENT AND OBJECTIVES** ......................................................................................... 1-22

1.8. **REFERENCES** ........................................................................................................................................... 1-23

## CHAPTER 2: SAMPLE PREPARATION AND QUANTIFYING OF FIBRE MOVEMENT ......................................................... 2-1

*Abstract* .......................................................................................................................................................... 2-1

2.1. **INTRODUCTION** ....................................................................................................................................... 2-2

2.2. **MATERIALS AND METHODS** ................................................................................................................ 2-4

2.2.1. Pulp .......................................................................................................................................................... 2-4

2.2.2. Sample preparation and examination ..................................................................................................... 2-4

2.2.3. Quantifying fibre dimensions .................................................................................................................. 2-6

2.2.4. Modelling of fibre morphology and orientation ....................................................................................... 2-7
CHAPTER 3: THE INFLUENCE OF ENZYMATIC TREATMENT ON THE FIBRE STABILITY OF SPRUCE CTMP

ABSTRACT ...........................................................................................................3-1

3.1. INTRODUCTION .................................................................................................3-2

3.2. MATERIALS AND METHODS ...........................................................................3-3

3.2.1. Pulp preparation ............................................................................................3-3
3.2.2. Enzyme treatment ..........................................................................................3-4
3.2.3. Fibre characterisation and pulp properties ....................................................3-4
3.2.4. SEM examination ...........................................................................................3-5
3.2.5. Experimental design and statistical analysis ...............................................3-5

3.3. RESULTS AND DISCUSSION .......................................................................3-6

3.3.1. Pulp characteristics ......................................................................................3-6
3.3.2. Influence of enzymes on handsheet properties before rewetting ..........3-6
3.3.3. Response of handsheet properties to rewetting .....................................3-7
3.3.4. SEM examination .........................................................................................3-10
3.3.5. Proposed mechanisms .................................................................................3-12

3.4. CONCLUSIONS .................................................................................................3-15

3.5. REFERENCES ....................................................................................................3-16

CHAPTER 4: CHARACTERISATION OF EARLYWOOD AND LATEWOOD CTMP FIBRES AND THE EFFECT OF ENZYMATIC TREATMENT ON THEIR STABILITY

ABSTRACT ...........................................................................................................4-1

4.1. INTRODUCTION ..................................................................................................4-2

4.2. MATERIALS AND METHODS ...........................................................................4-3

4.2.1. Wood sampling and pulping ......................................................................4-3
4.2.2. Enzyme treatment .......................................................................................4-4
4.2.3. Fibre characterisation and handsheet properties ...................................4-4
4.2.4. SEM examination .......................................................................................4-4
4.2.5. Experimental design and statistical analysis ...........................................4-5
4.3. RESULTS AND DISCUSSION ..................................................................................4-5
   4.3.1. Pulp characteristics .....................................................................................4-5
   4.3.2. Influence of earlywood and latewood fractions on handsheet properties ....4-7
   4.3.3. Influence of mannanase on fibre characteristics........................................4-7
   4.3.4. Influence of mannanase on handsheet properties .......................................4-8
   4.3.5. Stability of earlywood fibres .......................................................................4-9
   4.3.6. Stability of latewood fibres ........................................................................4-10
   4.3.7. SEM examination ......................................................................................4-10
4.4. CONCLUSIONS ............................................................................................4-11
4.5. REFERENCES ..............................................................................................4-13

CHAPTER 5: THE IMPACT OF ENZYME TREATMENT ON THE FIBRE STABILITY OF
POPLAR CTMP ........................................................................................................5-1

ABSTRACT ...........................................................................................................5-1
5.1. INTRODUCTION ...............................................................................................5-2
5.2. MATERIALS AND METHODS .........................................................................5-3
   5.2.1. Pulp preparation .......................................................................................5-3
   5.2.2. Enzyme treatment ....................................................................................5-3
   5.2.3. Freeness and fibre characterisation ..........................................................5-4
   5.2.4. Handsheet properties ..............................................................................5-4
   5.2.5. SEM examination ....................................................................................5-4
   5.2.6. Experimental design and statistical analysis ............................................5-5
5.3. RESULTS AND DISCUSSION ........................................................................5-5
   5.3.1. Freeness and fibre characterisation ..........................................................5-5
   5.3.2. Influence of enzymes on handsheet properties before rewetting .............5-6
   5.3.3. Response of handsheet properties to rewetting .......................................5-6
   5.3.4. SEM examination ....................................................................................5-8
5.4. CONCLUSIONS .............................................................................................5-10
5.5. REFERENCES ..............................................................................................5-11

CHAPTER 6: FIBRE STABILITY IN COMMERCIAL PRODUCED PAPER SAMPLES
FROM DIFFERENT PRODUCTION PROCESSES ......................................................6-1

ABSTRACT ...........................................................................................................6-1
6.1. INTRODUCTION ...............................................................................................6-2
6.2. MATERIALS AND METHODS .........................................................................6-3
   6.2.1. Sampling ..................................................................................................6-3
   6.2.2. Properties of commercial paper samples ...............................................6-3
   6.2.3. Experimental design and statistical analysis ............................................6-4
6.3. RESULTS AND DISCUSSION ........................................................................6-4
   6.3.1. Properties of commercial paper samples ...............................................6-4
   6.3.2. Stability of fibres in commercial paper ....................................................6-7
6.4. CONCLUSIONS .............................................................................................6-8
6.5. REFERENCES ..............................................................................................6-10
CHAPTER 7: THE POTENTIAL OF CELL WALL-MODIFYING ENZYMES ON THE DEVELOPMENT OF BCTMP FIBRES

ABSTRACT..............................................................................................................................7-1

7.1. INTRODUCTION..............................................................................................................7-2

7.2. MATERIALS AND METHODS..........................................................................................7-3

7.2.1. Impact of refining on pulp..........................................................................................7-3
7.2.2. Impact of PFI beating on pulp....................................................................................7-3
7.2.3. Influence of enzymatic pre-treatments......................................................................7-4
7.2.4. Experimental design and statistical analysis...............................................................7-4

7.3. RESULTS AND DISCUSSION.........................................................................................7-5

7.3.1. Impact of refining.......................................................................................................7-5
7.3.2. Beating response........................................................................................................7-6
7.3.3. Influence of enzymatic pre-treatment.......................................................................7-7
7.3.4. Stability of BCTMP fibres.........................................................................................7-9

7.4. CONCLUSIONS ..............................................................................................................7-11

7.5. REFERENCES ...............................................................................................................7-12

CHAPTER 8: IMPROVEMENT OF FIBRE STABILITY OF CTMP REJECT FIBRES WITH ENZYMES, OXALATE AND HYDROGEN PEROXIDE

ABSTRACT ...............................................................................................................................8-1

8.1. INTRODUCTION ...............................................................................................................8-2

8.2. MATERIALS AND METHODS ........................................................................................8-3

8.2.1. Fibre audit of screens and cleaners............................................................................8-3
8.2.2. Reject treatments .......................................................................................................8-4
8.2.3. Experimental design and statistical analysis..............................................................8-6

8.3. RESULT AND DISCUSSION ............................................................................................8-6

8.3.1. Fibre audit of screens and cleaners............................................................................8-6
8.3.2. Influence of mannanase on freeness and fibre characteristics.................................8-8
8.3.3. Influence of mannanase on the stability of reject fibres.............................................8-9
8.3.4. Influence of biomimetic treatment on the stability of reject fibres..........................8-9
8.3.5. Influence of chemical pre-treatment.........................................................................8-10

8.4. CONCLUSIONS ..............................................................................................................8-12

8.5. REFERENCES ...............................................................................................................8-14

CHAPTER 9: GENERAL DISCUSSION AND CONCLUSIONS

9.1. REFERENCES .................................................................................................................9-6
LIST OF FIGURES

Figure 1-1: Location of ruptures in fibres as a result of mechanical pulping. (P: primary wall, S1, S2 and S3: layers of the secondary wall, ML: middle lamella, RMP: refined mechanical pulp, SGW: stone groundwood, PGW: pressure groundwood, TMP: thermo-mechanical pulp and CTMP: chemi-thermo-mechanical pulp) (adapted from Franzén, 1986) .................................................................1-5

Figure 1-2: Illustration of a fibre in cross-section showing changes in the lumen area for an A: uncollapsed fibre; B: a partially collapsed fibre and C: a totally collapsed fibre (adapted from Jang and Seth, 1998). .................................................................1-7

Figure 1-3: Schematic representation of a fibre in cross-section to illustrate various cross-sectional parameters (adapted from Jang et al., 1995). .................................................................1-9

Figure 1-4: Proposed model showing a successive decrease in bonding between fibrils in a sheet as result of water absorption (Stone and Scallan, 1968). .................................................................1-13

Figure 2-1: Schematic representation of an uncollapsed and collapsed fibre in cross-section to illustrate parameters defined for modelling. .................................................................2-7

Figure 2-2: Micrographs obtained with ESEM showed, A: a collapsed fibre in a dry handsheet and B: twisting behaviour of the same fibre in a rewetted handsheet… .................................................................................................................................2-8

Figure 2-3: Micrographs obtained with ESEM showed, A: a collapsed fibre in a dry handsheet and B: moving behaviour of the same fibre in a rewetted handsheet… .................................................................................................................................2-8

Figure 2-4: Scanning electron micrographs of different sample preparation techniques including, A: blade hand-cutting, B: frozen and hand-cut, C: laser cut, and D: resin embedding and etch method. (working distance = 12 and 5 KV) .................................................................................................................................2-9

Figure 2-5: Scanning electron micrograph of a paper cross-section that was not rinsed properly before drying. (working distance = 11 and 5 KV). .................................................................................................2-10

Figure 2-6: Composite cSEM micrographs of cross-sections of handsheets embedded in resin after cutting with a microtome. A: backscatter-image of a sample before etching and the same sample B: after etching viewed in SEI mode. (working distance = 11 and 5 KV) .................................................................................................................................2-11

Figure 2-7: ESEM micrographs of fibres, A: under dry conditions and B: during the rewetting stage. The fibre shapes that were observed can be described as, a: partially collapsed fibre, b: totally collapsed fibre, c: uncollapsed fibre, d: fibre puffing observed after rewetting and e: fibre swelling after rewetting. .................................................................................................................................2-12
Figure 3-1: The influence of rewetting on the roughness of untreated pulp and pulp treated with mannanase (MAN), endoglucanase (EG) or a combination of these enzymes (MAN+EG). Bars with the same letter (a, b) indicate that treatments did not differ significantly (p ≤ 0.05, Tukey’s multiple-range test). ........................................3-8

Figure 3-2: The influence of rewetting on the tensile index of untreated pulp and pulp treated with mannanase (MAN), endoglucanase (EG) or a combination of these enzymes (MAN+EG). Bars with the same letter (a, b, c, d) indicate that treatments did not differ significantly (p ≤ 0.05, Tukey’s multiple-range test). ........................................3-9

Figure 3-3: The influence of rewetting on the burst index of untreated pulp and pulp treated with mannanase (MAN), endoglucanase (EG) or a combination of these enzymes (MAN+EG). Bars with the same letter (a, b, c, d, e) indicate that treatments did not differ significantly (p ≤ 0.05, Tukey’s multiple-range test). ........................................3-9

Figure 3-4: The ratio of lumen area (LA) to fibre area (FA) reflects the degree of puffing for thin-walled and thick-walled fibres. Bars with the same letter (a, b) indicate that treatments of thin-walled fibres did not differ significantly. No significant differences were found between treatments of thick-walled fibres (p ≤ 0.05, Tukey’s multiple-range test)............................................................................3-10

Figure 3-5: Cross-sections of spruce CTMP handsheets. (A: Dry control, B: Rewetted control, C: Mannanase treated and rewetted). ................................................3-11

Figure 3-6: The thickness of control and enzyme-treated handsheets before and after rewetting. Bars with the same letter (a, b, c) indicate that handsheets did not differ significantly in thickness (Student’s t-test at 95% confidence level).................................................................3-12

Figure 3-7: Schematic representation of the proposed mechanism for enzymatic modification of thin-walled fibres when combined with beating and rewetting. (A to D: pulp subjected to enzyme treatments, E to H: pulp after beating, I to L: pulp formed into handsheets and, M to P: pulp after handsheets were rewetted).................3-14

Figure 4-1: Distribution of cell-wall thickness in earlywood and latewood fibres in laboratory CTMP. ........................................................................................................4-6

Figure 5-1: The influence of rewetting on the roughness of handsheets from untreated and enzyme treated pulp (p ≤ 0.05, Tukey’s multiple-range test)..................................5-7

Figure 5-2: The influence of rewetting on the tensile index of handsheets from untreated and enzyme treated pulp (p ≤ 0.05, Tukey’s multiple-range test)..................................5-7

Figure 5-3: The influence of rewetting on the burst index of handsheets from untreated and enzyme treated pulp (p ≤ 0.05, Tukey’s multiple-range test)..................................5-8

Figure 5-4: The influence of rewetting, mannanase (MAN) and endoglucanase (EG) on puffing of thin-walled fibres (p ≤ 0.05, Tukey’s multiple-range test)..................................5-9

Figure 5-5: The influence of rewetting, mannanase (MAN) and endoglucanase (EG) on puffing of thick-walled fibres (p ≤ 0.05, Tukey’s multiple-range test)..................................5-9
Figure 6-1: Representative scanning electron micrographs showing the surface structure of the A: base-sheet, B: coated-paper and C: the supercalendered-paper. 

Figure 6-2: The influence of rewetting on roughness of commercial paper from a commercial paper mill. (Columns for each type of paper with the same letter do not differ significantly).

Figure 6-3: The influence of rewetting on the corrected tensile index of production paper from a commercial paper mill. Columns with the same letter do not differ significantly, p ≤ 0.05 (pairs of treatment means were compared using a Student’s t-test).

Figure 6-4: The influence of rewetting on the corrected burst index of production paper from a commercial paper mill. Columns with the same letter do not differ significantly, p ≤ 0.05 (pairs of treatment means were compared using a Student’s t-test).

Figure 6-5: Transverse sections of dry and rewetted samples from different treatments (A: dry base-sheet, B: rewetted base-sheet, C: dry coated-paper, D: rewetted coated-paper, E: dry supercalendered-paper, F: rewetted supercalendered-paper and G: printed-paper).

Figure 7-1: Beating curves for untreated (control) BCTMP and pulp treated with mannanase (MAN) and endoglucanase (EG).

Figure 7-2: Roughness of dry and rewetted handsheets from untreated and enzyme-treated pulps (p ≤ 0.05, Tukey’s multiple-range test).

Figure 7-3: Tensile indices of dry and rewetted handsheets from untreated and enzyme-treated pulps (p ≤ 0.05, Tukey’s multiple-range test).

Figure 7-4: Burst indices of dry and rewetted handsheets from untreated and enzyme-treated pulps (p ≤ 0.05, Tukey’s multiple-range test).

Figure 8-1: Diagrammatic presentation on the impact of screening and cleaning on pulp fibres after refining (adapted from Theunissen, 1998). The screening system separates fibres on the basis of length and the cleaning process on the basis of fibrillation.

Figure 8-2: Diagrammatic representation of the fibre fractionation process at the CTMP mill (1 to 6 indicate sampling points).

Figure 8-3: Ratio of lumen area (LA) to fibre area (FA) as a reflection of the degree of collapsibility of fibres from different screening stages (bars with the same letters do not differ significantly, Student’s t-test, p ≤ 0.05).

Figure 8-4: Ratio of lumen area (LA) to fibre area (FA) as a reflection of the degree of collapsibility of different samples collected at different cleaning stages (bars with the same letters do not differ significantly, Student’s t-test, p ≤ 0.05).
LIST OF TABLES

Table 2-1: Mean fibre dimensions before and after etching. A Student t-test showed no significant differences at 95% confidence interval. ...........................................2-10

Table 2-2: Relative dimensions using arbitrary units of computer-generated model fibres for collapsed and uncollapsed thin-walled and thick-walled fibres cut at a 90º or a 45º. ...........................................................................................................2-13

Table 3-1: Fibre characteristics after beating of untreated (control) pulp and pulp treated with mannanase (MAN) and endoglucanase (EG) or a combination of these enzymes (MAN+EG). ...........................................................................................................3-6

Table 3-2: The influence of different enzyme treatments on properties of dry handsheets. .............................................................................................................................................................................3-6

Table 4-1: Fibre characteristics of pine earlywood and latewood after beating with a PFI mill as determined with the MorFi fibre analyser. ..........................................................................................................................4-6

Table 4-2: Properties of handsheets from pine earlywood and latewood pulps after beating with a PFI mill. ..................................................................................................................................................................................4-7

Table 4-3: Fibre characteristics of earlywood fibres before and after mannanase (MAN) treatment and was beaten with a PFI mill. ........................................................................................................................................................................4-7

Table 4-4: Fibre characteristics of latewood fibres before and after mannanase (MAN) treatment and beaten with a PFI mill. .........................................................................................................................................................................4-7

Table 4-5: The influence of mannanase (MAN) treatment on dry handsheet properties from earlywood and latewood. ........................................................................................................................................................................4-8

Table 4-6: The influence of treatment with mannanase (MAN) and rewetting on pulp properties of handsheets from earlywood pulp. .........................................................................................................................................................................4-9

Table 4-7: The influence of mannanase (MAN) treatment rewetting on pulp properties of handsheets, from latewood pulp. ........................................................................................................................................................................4-10

Table 4-8: Ratio of lumen area (LA) to fibre area (FA) as a reflection of the degree of puffing before and after rewetting for untreated and treated earlywood and latewood fibres. ........................................................................................................................................................................4-11

Table 5-1: Fibre characteristics of untreated (control) poplar fibres and fibres treated with mannanase (MAN) and endoglucanase (EG). .................................................................................................................................................................................5-5

Table 5-2: The influence of different enzyme treatments on dry handsheet properties. ........................................................................................................................................................................................................................5-6
Table 6-1: Mean LA:FA ratio of dry and rewetted samples from different production stages and printed-paper.

Table 7-1: Fibre characteristics of pulp collected before and after commercially refining (Each value represents the mean observation of three measurements for the two surveys).

Table 7-2: Handsheet properties of BCTMP commercial pulp before and after commercial refining.

Table 7-3: Handsheet properties of BCTMP commercial pulp before and after commercial refining or after beating at 500 revolutions with a PFI mill.

Table 7-4: Fibre characteristics of untreated (control) BCTMP and pulp treated with mannanase (MAN) and endoglucanase (EG) after beating at 500 revolutions.

Table 7-5: The influence of different enzyme treatments on dry handsheet properties. All pulps were beaten at 500 revolutions.

Table 8-1: The fibre characteristics of samples collected before and after screening. The change relative to the inlet sample is indicated in brackets.

Table 8-2: The fibre characteristics of samples collected before and after cleaning. The change relative to the inlet sample is indicated in brackets.

Table 8-3: The impact of mannanase (MAN) on the freeness and fibre characteristics of reject fibres.

Table 8-4: The influence of MAN treatment and rewetting on the properties of handsheets from reject pulp.

Table 8-5: The impact of oxalate treatment on the freeness and fibre characteristics of reject fibres.

Table 8-6: The influence of oxalate treatment and rewetting on the properties of handsheets from reject pulp.

Table 8-7: The impact of peroxide ($H_2O_2$) pre-treatment followed by enzyme and oxalate treatment on the freeness and fibre characteristics of pulps.

Table 8-8: The influence of peroxide pre-treatment on the properties of handsheets from reject pulp, followed by MAN and oxalate treatment.
ACKNOWLEDGEMENTS

I would like to express my gratitude and appreciation to the following persons and institutions for their contributions to this project:

FRANÇOIS WOLFAARDT (my supervisor) for giving me vision throughout this roller coaster ride. Thank you for your patience and hours you took to help me through.

JAMES WESLEY-SMITH (my co-supervisor) to whom I cannot express enough appreciation for his encouragement, knowledge and commitment.

THE ELECTRON MICROSCOPY UNIT PERSONNEL at the University of Pretoria (UP) and the University of Kwa-Zulu Natal (UKZN) at Durban and Pietermaritzburg, for their interest in my project and for sharing their expertise in microscopy.

EMPLOYEES FROM SAPPI TECHNOLOGY CENTRE SOUTH AFRICA AND EUROPE who assisted me with pulp samples, pulping methods, refining processes and provided me with information to make this study successful.

JÓHANN STREY (my remarkable husband), for standing by me during this time, even if it was not easy, thank you for always believing in my abilities.

WILLY, HENDA, JANI AND MARI HALLATT (my family), for their comforting and supporting love and concern.

THE STREY FAMILY, whose humour kept my sanity intact.

MARILET, MAGRIET, CORLIA, RENÉ AND HELENE (my friends) that supported me throughout this journey.

CHRIS VAN DER MERWE for his support and encouragement during this project.

TRIPP AND SAPPI MANUFACTURING for financial support
The bonding of fibres in paper is influenced by environmental changes (e.g. moisture) that may cause unstable fibres to move. These movements include cell-wall swelling, fibre lifting and/or puffing that break inter-fibre bonds and lead to reduced strength and surface roughness. Fibre puffing is defined as the expansion of the lumen area as result of changes in the environment.

Puffing was investigated through image analysis of scanning electron micrographs. Detailed images were obtained with samples that were embedded in resin and then etched. Puffing of fibres was then quantified by calculating the ratio of lumen area to fibre area. Stability of softwood and hardwood fibres was studied in this way, and to simulate printing, handsheets were calendered and rewetted. This method was later validated against commercial sheets. Compared to softwood, hardwood fibres were more stable and most of the handsheet properties were retained after rewetting. Mannanase and/or endoglucanase treatments resulted in improved fibre stability by increasing fibre bonding, fibrillation or fibre collapse.
Mannanase improved handsheet smoothness and strength as well as fibre stability, but endoglucanase was less effective. The effect of the enzymes was more difficult to observe on hardwood fibres, because even untreated fibres were more stable under moist conditions. Thin-walled fibres such as earlywood were less stable than latewood fibres, but it responded better to mannanase treatment. Thick-walled fibres (latewood), on the other hand, were more difficult to improve with enzymes.

The potential of enzymes to improve fibre stability of commercial pulp was tested on chemi-thermo-mechanical pulp (CTMP) and bleached CTMP. Enzyme treatment improved fibrillation and reduced beating energy of bleached CTMP. Mannanase again resulted in the most improved fibre stability. On rejects, a lack of response to enzymes was overcome by pre-treating the pulp with alkaline peroxide.

This study provided new insights into the stability of fibres with different morphology. It was also demonstrated that fibre stability can be improved with enzyme treatment and it is expected that this knowledge could have significant commercial value.