



**AN INVESTIGATION
INTO
PHYSICAL AND MICROSTRUCTURAL PROPERTIES
OF
ORTHODONTIC WIRES
AND
CHANGES INCIDENT TO BENDING.**

A research report submitted in partial fulfilment
of the requirements for the degree of
Master of Dental Surgery

by

**S.L. WHITTLE
B.D.S. (Adel)**

Department of Dentistry,
Faculty of Dentistry,
The University of Adelaide,
South Australia.

December, 1995

TABLE OF CONTENTS

| | Page No. |
|--|----------|
| LIST OF FIGURES | iv |
| LIST OF TABLES | ix |
| LIST OF ABBREVIATIONS | xii |
| SUMMARY | xiii |
| SIGNED STATEMENT | xvi |
| ACKNOWLEDGEMENTS | xvii |
| | |
| CHAPTER 1 INTRODUCTION AND AIMS | 1 |
| | |
| CHAPTER 2 LITERATURE REVIEW | |
| HISTORICAL ASPECTS OF ORTHODONTIC WIRES | 4 |
| PHYSICAL PROPERTIES OF WIRES | 5 |
| Stiffness | 7 |
| Strength | 10 |
| Springback | 11 |
| Formability | 12 |
| Joinability | 13 |
| Biocompatibility and Stability | 13 |
| Friction | 14 |
| STAINLESS STEEL WIRES | 15 |
| STANDARDS FOR ORTHODONTIC WIRES | 26 |
| BENDS IN ORTHODONTIC WIRES | 32 |
| | |
| CHAPTER 3 MATERIALS AND METHODS | |
| PREPARATION OF WIRES FOR SEM | |
| Materials | 47 |
| Methods | 52 |
| TENSILE TESTING OF WILCOCK™ WIRES | |
| Materials | 67 |
| Methods | 69 |

| | | |
|--|------------------------|-----|
| ARCH-FORM ANCHORAGE BEND ANALYSIS | | |
| Materials | | 72 |
| Methods | | 82 |
| CHAPTER 4 | RESULTS AND DISCUSSION | |
| THE SEM EXAMINATION OF WIRES | | |
| Wire microstructure | | 85 |
| Bending effects from different types of pliers | | 94 |
| Defects and Inclusions | | 109 |
| Fractures | | 118 |
| TENSILE TESTING OF WILCOCK™ WIRES | | 131 |
| ARCH-FORM ANCHORAGE BEND ANALYSIS | | 142 |
| CHAPTER 5 | CONCLUSIONS | |
| THE MICROSTRUCTURE OF WIRES | | 161 |
| TENSILE TESTING OF WILCOCK™ WIRES | | 163 |
| ARCH-FORM ANCHORAGE BEND ANALYSIS | | 165 |
| CHAPTER 6 | FUTURE RESEARCH | |
| THE MICROSTRUCTURE OF WIRES | | 167 |
| TENSILE TESTING OF WILCOCK™ WIRES | | 168 |
| ARCH-FORM ANCHORAGE BEND ANALYSIS | | 169 |
| CHAPTER 7 | BIBLIOGRAPHY | 170 |
| APPENDIX 1 | PHOTOELASTIC MODELING | 185 |

LIST OF FIGURES

| FIGURE | SUBJECT | Page No |
|--------|---|---------|
| 2 - 1 | 'Face centred cubic' (fcc) lattice. | 16 |
| 2 - 2 | 'Body centred cubic' (bcc) lattice. | 16 |
| 2 - 3 | Typical wire drawing die, (Dieter, 1961). | 20 |
| 2 - 4 | Illustration of terms used in the theory of plastic bending. | 35 |
| 2 - 5 | Graphical representation of variation in intrusive force as a function of degree of anchorage bend as measured by several authors. | 42 |
| 2 - 6 | Graphical representation of variation in intrusive force as a function of distance of a 45 degree anchorage bend from the buccal molar tube as measured by several authors. | 44 |
| 3 - 1 | Wire drawing by A.J. Wilcock Scientific and Engineering Equipment, (with kind permission from Mr. A.J. Wilcock). | 48 |
| 3 - 2 | Anchorage bend forming guide. | 53 |
| 3 - 3 | Detail of beaks of stainless steel tipped light wire pliers. | 54 |
| 3 - 4 | Detail of beaks of stainless steel tipped Tweed torquing pliers. | 55 |
| 3 - 5 | Detail of beaks of tungsten carbide tipped light wire pliers. | 56 |

| FIGURE | SUBJECT | Page No |
|--------|--|---------|
| 3 - 6 | Detail of beaks of tungsten carbide tipped high tensile wire pliers. | 57 |
| 3 - 7 | Abramin (Struers) grinding and polishing machine. | 59 |
| 3 - 8 | Surface of 0.016 inch, (0.4064 mm) 'premium plus' Wilcock wire, batch 'TT-TAT', following grinding, polishing, and etching. | 64 |
| 3 - 9 | Philips XL20 Scanning Electron Microscope. | 65 |
| 3 - 10 | Specimen stage of Philips XL20 Scanning Electron Microscope. | 66 |
| 3 - 11 | Hounsfield Vee Wire Grips. | 70 |
| 3 - 12 | Instron Universal Testing Machine. | 71 |
| 3 - 13 | The representative arch form. | 75 |
| 3 - 14 | Arch-wire designs. | 77 |
| 3 - 15 | CAD drawing of the arch-wire testing apparatus. | 78 |
| 3 - 16 | View of apparatus with an activated arch-wire. | 79 |
| 3 - 17 | Arch-wire anchorage analysis apparatus. | 81 |
| 4 - 1 | X-ray micro-analysis of the main bulk of wire in batch 'TT-TAT'. | 88 |
| 4 - 2 | Schaeffler diagram showing effect of alloying elements on the basic structure of chromium - nickel steels, (from Honeycombe, 1981) | 90 |

| FIGURE | SUBJECT | Page No |
|--------|---|---------|
| 4 - 3 | Surface irregularities in the vicinity of a 40 degree bend in 'as-received' TT-TAT, 0.016 inch, (0.4064 mm) 'premium plus'. | 95 |
| 4 - 4 | Specimen showing increased pitting along a longitudinal 'core'. | 97 |
| 4 - 5 | Specimen displaying reduced etching effect. | 98 |
| 4 - 6 | Specimen displaying increased etching effect. | 99 |
| 4 - 7 | Stainless steel light wire plier effect on concave surface of a 50 degree bend. | 101 |
| 4 - 8 | Example of plier edge defect in 30 degree specimen bent with Tweed torquing pliers. | 103 |
| 4 - 9 | Example of plier edge defect in 40 degree specimen bent with tungsten carbide tipped, light wire pliers. | 105 |
| 4 - 10 | Plier edge defect as viewed from the side of an incompletely polished specimen prepared with tungsten carbide tipped light wire pliers. | 106 |
| 4 - 11 | Typical example of specimen prepared with 'dolphin' tungsten carbide tipped pliers. | 108 |
| 4 - 12 | Longitudinal surface markings from the wire drawing process of 0.016 inch (0.4064 mm) Wilcock 'premium plus', batch TT-TAT | 110 |
| 4 - 13 | Photomicrograph of Al - Ti - O inclusion identified in batch 'TT-TAT'. | 112 |

| FIGURE | SUBJECT | Page No |
|--------|--|---------|
| 4 - 14 | X-ray micro-analysis of an inclusion found in batch 'TT-TAT'. | 114 |
| 4 - 15 | Example of polishing particles. | 115 |
| 4 - 16 | Deliberate fracture of 0.016 inch (0.4064 mm) Wilcock 'premium plus', batch 'TT-TAT'. | 121 |
| 4 - 17 | Detail of deliberate fracture of 0.016 inch (0.4064 mm) Wilcock 'premium plus', batch 'TT-TAT'. | 122 |
| 4 - 18 | Further detail of deliberate fracture of 0.016 inch (0.4064 mm) Wilcock 'premium plus', batch 'TT-TAT'. | 123 |
| 4 - 19 | Longitudinal failure ('F') seen in specimen bent at 50 degrees with 'Dentronix 105' pliers. | 125 |
| 4 - 20 | Detail of longitudinal failure seen in specimen bent at 50 degrees with 'Dentronix 105' pliers. | 126 |
| 4 - 21 | Radiating lines ('R') of deformation that may represent a pre-failure condition. | 128 |
| 4 - 22 | Further detail of a radiating line of deformation that may represent a pre-failure condition. | 129 |
| 4 - 23 | Example of a transverse failure of high tensile wire possibly resulting from transverse strain inherent in the wire, (Lee, 1992), (with kind permission from the Australian Orthodontic Journal) | 130 |
| 4 - 24 | Analysis of test arch-wires with 15 degree anchorage bends. | 145 |

| FIGURE | SUBJECT | Page No |
|--------|--|---------|
| 4 - 25 | Analysis of test arch-wires with 30 degree anchorage bends. | 146 |
| 4 - 26 | Analysis of test arch-wires with 45 degree anchorage bends. | 147 |
| 4 - 27 | Analysis of test arch-wires with 60 degree anchorage bends. | 148 |
| 4 - 28 | Analysis of 'plain' arch-wires with varying degree anchorage bends. | 153 |
| 4 - 29 | Analysis of 'inter-maxillary circle' arch-wires with varying degree anchorage bends. | 154 |
| 4 - 30 | Analysis of 'boot hook' arch-wires with varying degree anchorage bends. | 155 |
| 4 - 31 | Analysis of 'loop hook' arch-wires with varying degree anchorage bends. | 156 |
| 4 - 32 | Analysis of 'molar stopped' arch-wires with varying degree anchorage bends. | 157 |

LIST OF TABLES

| TABLE | SUBJECT | Page No |
|-------|--|---------|
| 2 - 1 | Classification of wires (by strength) as required by the Standards Association of Australia, AS 1964 - 1977 for orthodontic wires, (resilient),(excluding precious metal wires). | 27 |
| 2 - 2 | Yield strength requirements as required by the American Dental Association Specification Number 32 for orthodontic wires not containing precious alloys. | 27 |
| 2 - 3 | Anterior intrusive force from 45 degree anchorage bends placed in 0.016 inch (0.4064 mm) Wilcock wires as measured by four separate authors. | 40 |
| 2 - 4 | Anterior intrusive force from anchorage bends of varying degree placed in 0.016 inch (0.4064 mm) 'special plus' Wilcock wire as measured by several authors. | 41 |
| 2 - 5 | Anterior intrusive force generated by 0.016 inch (0.4064 mm) Wilcock 'special plus' arch-wires with 45 degree anchorage bends as a function of distance of anchorage bend from the buccal tube as measured by several authors. | 43 |
| 3 - 1 | Diameter and tensile properties of batch 'TT-TAT' of Wilcock 0.016 inch, (0.4064 mm) 'premium plus'. | 49 |
| 3 - 2 | Normal elemental composition for AISI Type 302 stainless steel, (ASTM ,1990), compared to 'Australian' wire as determined by Newman, (1963). | 51 |

| TABLE | SUBJECT | Page No |
|-------|--|---------|
| 3 - 3 | Details of specimens prepared with various plier types and magnitude of bend placed. | 52 |
| 3 - 4 | Grinding and polishing protocol for preparation of wire specimens. | 58 |
| 3 - 5 | Comparison of orthodontic wire types, as classified by the Australian Standard, AS 1964 - 1977, and A.J. Wilcock Scientific and Engineering Equipment (AJW). | 67 |
| 3 - 6 | Tensile strength of Wilcock wires as measured by A.J. Wilcock Scientific and Engineering Equipment (AJW) and the Australian Dental Standards Laboratory (ADSL). | 68 |
| 3 - 7 | Maxillary cast measurements to determine arch-form dimensions, in millimetres, compared with the results of Borghesi, (1973) and Rohan, (1982) . | 73 |
| 3 - 8 | Degrees of anchorage bend investigated by previous authors. | 83 |
| 4 - 1 | X-ray micro-analysis of electron 'K' shell energy to determine relative concentration of elements in A.J. Wilcock batch TT-TAT 0.016 inch (0.4064 mm) 'premium plus' | 87 |
| 4 - 2 | Compositional analysis of 'Australian' wire by Newman, (1963) . | 92 |
| 4 - 3 | Results of each valid tensile test, (T1 to T6), and the resultant mean tensile load for failure for each batch of specimens. | 132 |

| TABLE | SUBJECT | Page No |
|-------|--|---------|
| 4 - 4 | Tensile strength of Wilcock wires as measured by A.J. Wilcock Scientific and Engineering Equipment, (AJW), the Australian Dental Standards Laboratory, (ADSL), and by experimentation, (SLW). | 132 |
| 4 - 5 | Comparison of orthodontic wire classifications, as classified by A.J. Wilcock Scientific and Engineering Equipment, (AJW), Australian Dental Standards Laboratory, (ADSL), and during experimentation, (SLW). | 133 |
| 4 - 6 | Comparison of wire tensile classification as calculated with actual versus nominal diameters. | 134 |
| 4 - 7 | Percentage differences in tensile strength as tested by the Australian Dental Standards Laboratory, (ADSL), and experimentation, (SLW) when compared to results of A.J. Wilcock Scientific and Engineering Equipment, (AJW). | 138 |
| A - 1 | Elastic (Young's) modulus for components of the stomatognathic system. | 186 |

LIST OF ABBREVIATIONS

| ABBREVIATION | DEFINITION |
|--------------|--|
| ADSL | Australian Dental Standards Laboratory |
| AISI | American Iron and Steel Institute |
| AJW | A.J. Wilcock Scientific and Engineering Equipment |
| ASTM | American Society for Testing Materials |
| bcc | Body centred cubic |
| CAD | Computer Aided Design |
| CEMMSA | Centre for Electron Microscopy and Microstructural Analysis, The University of Adelaide. |
| E | Young's modulus of elasticity |
| fcc | Face centred cubic |
| kg | Kilograms |
| kV | Kilovolts |
| μ A | Microamperes |
| μ m | Micrometres |
| mm | Millimetres |
| MPa | Megapascals |
| N | Newtons |
| nA | Nanoamperes |
| Pa | Pascals |
| PDL | Periodontal ligament |
| SEM | Scanning Electron Microscope |

SUMMARY

Anecdotal accounts of an unacceptable breakage rate of high tensile stainless steel orthodontic wires have been received by their manufacturer, A.J. Wilcock of Whittlesea, Victoria. It would seem that these allegations are directly related to problems in the successful clinical manipulation of the wire with orthodontic pliers. It was decided to investigate some of the bending characteristics of the high tensile 0.016 inch (0.4064 millimetre) 'premium plus' grade Wilcock¹ wire to identify any cause for a higher than expected breakage rate.

Those physical properties considered important in the behaviour of orthodontic wires are: stiffness, strength, springback, formability, joinability, biocompatibility and stability, and friction. These physical properties have been thoroughly investigated, and form the basis for Industrial Standards in a number of countries. However, an examination of the literature concerning stainless steel orthodontic wire reveals disagreement as to which tests best describe the requirements of such fine wires for clinical orthodontic purposes.

Tensile testing of aged wire specimens has indicated that strength may change over time. Results from this investigation found that ultimate tensile strength for aged specimens was up to ten per cent greater than the ultimate tensile strength determined from the same batches of wire by the Australian Dental Standards Laboratory in 1985. Thus the ageing of wire may increase

¹ A.J. Wilcock Scientific and Engineering Equipment, Whittlesea, Victoria, Australia.

its strength, although, differences in the subtleties of testing technique cannot be eliminated as a cause of these differences.

The structure of fine, high tensile orthodontic wires is considered to contribute significantly to their behaviour but has received very little attention in the available literature. This is particularly evident in the inability to calculate Young's modulus accurately (ie: a numerical expression of a materials' relative rigidity). 'As-received' wire was used to produce specimens that simulated clinical manipulation by bending. These were then prepared by longitudinal grinding and polishing and subsequent etching. The internal diameter of these specimens was viewed by Scanning Electron Microscopy to investigate the microstructure in and around the bent region.

Different pliers were used to place bends of varying degrees in a series of wire specimens, and the microstructural features were compared across the diameter of straight and bent portions of the wire. When compared with stainless steel tipped pliers, unmodified tungsten carbide tipped pliers showed a more severe deformation on the concave, internal region of the bend. Modified tungsten carbide tipped pliers however, showed little if any damage to this same region of the wire

No breakages were found during specimen preparation when using a standard clinical bending technique. Therefore, in order to study fracture behaviour, forces inconsistent with those used during normal clinical manipulation were deliberately used to fracture some wire specimens. This was best achieved by bending the wire very quickly with a snapping motion. Scanning Electron Microscopy suggests the wire has a lamellar structure, and that specimen failure is consistent with the 'peeling' seen clinically when faulty manipulation causes unwanted fractures. 'Fast' fractures of this type seem to

originate on the convex, external surface of the bend. A comparison was made between this type of fracture pattern and those seen in some specimens collected in the clinical situation, where the initial failure point was also found on the external, convex surface of the bend.

It is suggested that to avoid fractures in high tensile stainless steel wires, two factors in manipulation are critical. Firstly, bends should be made slowly with the fingers. Secondly, unmodified tungsten carbide tipped pliers should be used with caution, or, the edges of the square beaks modified by smoothing with a cratex type wheel.

Force levels at different points along an arch-wire were measured as a function of the various types of 'canine hooks' employed in the Begg technique, and, according to the amount of anchorage bend placed in the wire. Results suggest that different types of 'canine hooks' have negligible effect on anterior force values, but, consistent with beam theory, forces exhibited in the premolar region are about ten times greater than in the incisal region. These results suggest that caution should be exercised when attaching premolars to an arch-wire designed for anterior intrusion as a part of the Begg technique. This same caution should be exercised if molar tipping is undesirable.

SIGNED STATEMENT

This report contains no material that has been accepted for the award of any other degree or diploma in any other university or tertiary institution. To the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text.

The views and opinions expressed herein do not necessarily state or reflect those of the Government of the Commonwealth of Australia, The Department of Defence, or, the Royal Australian Navy.

I give consent to this copy of my report, when deposited in the University of Adelaide Library, being available for loan and photocopying in accordance with existent copyright conditions.

Samuel L. Whittle.

Fifteenth day of *December* 1995.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to the following:

Dr John V. Bee, Senior Lecturer, Department of Mechanical Engineering, The University of Adelaide, who as a supervisor, readily gave of his expertise, practical advice, and good humour.

Dr Wayne J. Sampson, Senior Lecturer in Orthodontics, Department of Dentistry, The University of Adelaide, who, as a supervisor, inspired in me, a fascination for investigation and research.

Mr Ian Brown, Department of Mechanical Engineering, The University of Adelaide, for valuable information and his assistance in testing techniques.

Mr John Terlett, Centre for Electron Microscopy and Microstructural Analysis, The University of Adelaide, for his technical assistance in using the Scanning Electron Microscope.

Vikki Hargreaves, Margaret Leppard, Peter Dent, and Raoul Petrobon, Department of Dentistry, The University of Adelaide, for their assistance in experimental and photographic techniques.

Arthur Wilcock and Ella White of A.J. Wilcock Scientific and Engineering Equipment, Whittlesea, Victoria, for their ready provision of test material, valuable advice and hospitality.

Garth L. Brice, Orthodontist, of Chapman, Australian Capital Territory, for his role as mentor and true friend during my career in the Royal Australian Navy.

My son Hamish, whose love and ready smile made it all worthwhile.

To my dear wife Heather, without whose unending patience, support and devotion, nothing of this venture would have been possible.