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PHYSICAL PROPERTIES OF ORTHODONTIC WIRES

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The Australian Society of Orthodontists asked manufacturers to provide samples of resilient orthodontic wires so that they could be submitted to the Australian Dental Standards Laboratory for test. On completion of the tests, Masson[1] and Ware[2] were asked to report on their relative properties.

Subsequently, samples were received from four manufacturers, namely Dentaurum,[3] Rocky Mountain[4], Unitek[5] and Wilcock[6], and tested to Australian Standard T32 for Resilient Orthodontic Wires (excluding precious metal wires). In addition, the elastic limit, 0.1% proof stress and elongation were taken from the graphs and modulus of elasticity and modulus of resilience calculated.

Test Procedure

The wires were tested with a Shimadzu load-cell testing machine (Fig. 1) with automatic graphing. For measurement of the elastic properties and elongation, a Shimadzu extensometer of special design and with a gauge length adjusted to 100 mm was used. The grips were initially of the wrap-around Hounsfield type to prevent breakage in the grips, but in these tests, in order to accommodate all wires including the 28 cm straight wires in the extensometer, grips of a similar pattern, seen in Fig. 1,

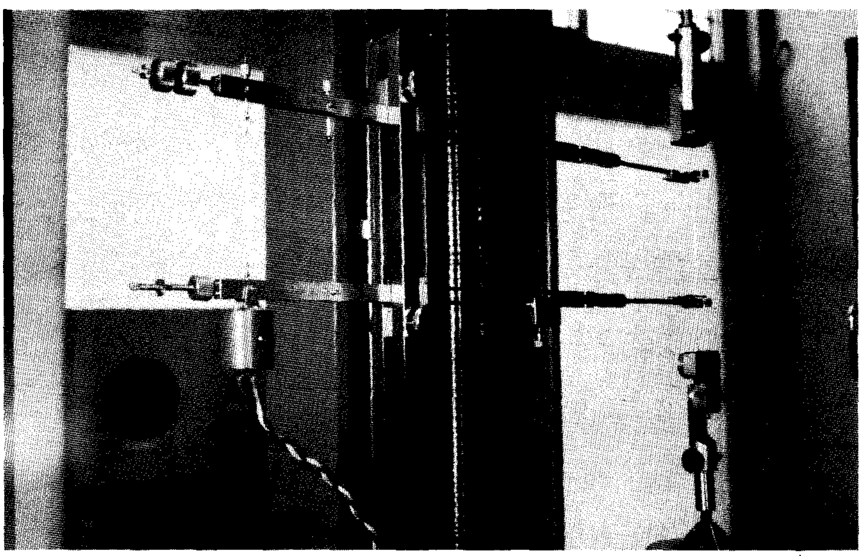

Fig. 1: Adjustable extensometer set at 10 cm gauge length for determining elastic properties of wires.

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were designed with a smaller diameter. Stress-strain graphs were produced for the range of wires to the breaking point. The elastic properties were calculated and the elastic elongation at break measured from the graphs.

Terminology

In order to make the terms of the test results clear to the orthodontist, they will be defined with reference to Fig. 2.

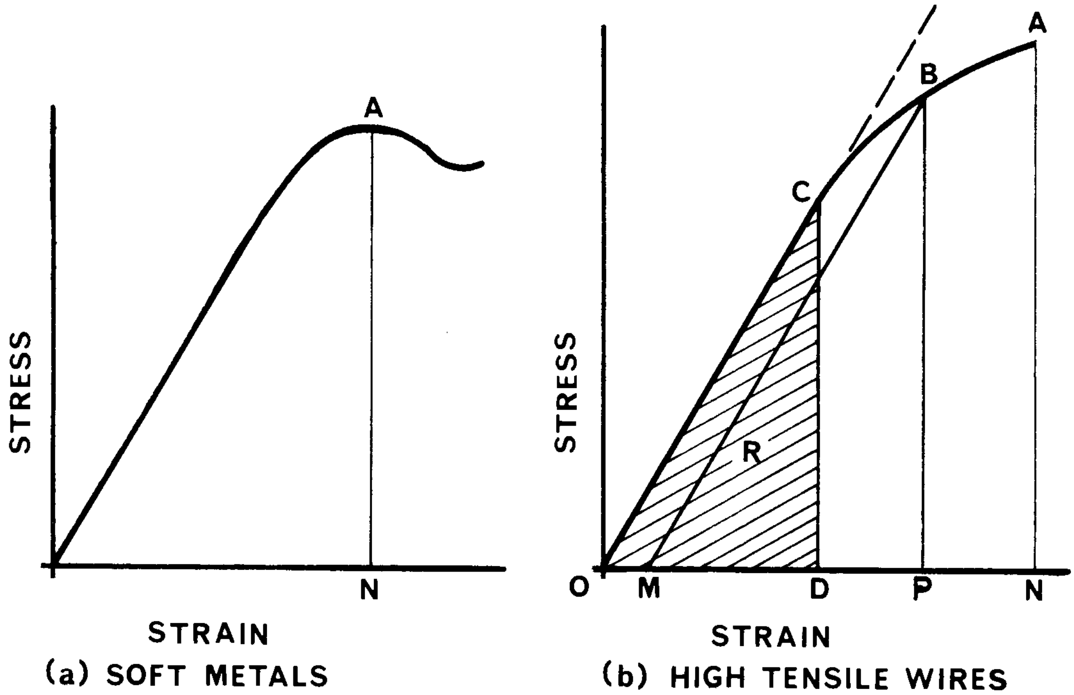
Stress. As a tensile force is applied to the wire the stress, which is the force divided by the original cross-sectional area, increases.

Tensile strength is the maximum force (A) applied up to breaking divided by the original cross-sectional area of the wire.

Strain is the increase in the length of the wire divided by the original length or expressed as a percentage.

Gauge length is the chosen length at which the extensometer (Fig. 1) is set on the wire — in these tests, 10 cm.

Elastic limit or proportional limit is the calculated stress at the point C where the graph ceases to be linear (straight) as in Fig. 2(b). If released at or below this point the wire will return without any set. This is the effective stress for tooth movement.



AN	Tensile Strength
BP	Proof Stress
CD	Elastic Limit
OM	0.1% offset for Proof Stress
OD	Strain at Elastic Limit
ON	Elongation at Break
R	Area = Modulus of Resilience
$\frac{CD}{OD}$	Modulus of Elasticity

Fig. 2: Stress-strain graphs and elastic properties of wires.

Proof stress or yield strength. As the point C at which the graph ceases to be linear is difficult to determine, a line MB is drawn parallel to OC until it reaches the graph at B. The distance OM is made to equal a percentage of the gauge length and in this case it is 0.1%. This point on the graph includes the linear elastic portion and some plastic flow.

Modulus of elasticity is the stress CD divided by the strain OD.

Modulus of resilience is the energy available at the elastic limit per unit volume of material and is equal to the area under the straight portion of the stress-strain curve, that is, one half of CD × OD.

Elongation. The elongation was measured from the graph and is the increase in the gauge length of the wire at the maximum force, that is, AN.

Classification of Wires.

Table 1 shows the classification of wires according to Australian Standard T32, together with the proposed requirements of an almost completed metric revision. None of the wires submitted were classified in this manner nor was a minimum breaking strength claimed, so after testing, the samples were arranged to fit into the AS T32 types A to D and into the revised standard types 1 to 6 according to their tensile strengths.

In the following test, the types for the two standards will be referred to as A(1), B(2), B(3), C(4), D(5) or D(6). The alphabetical classifications will cease when the revision is published. Table 1 shows that, previously, under the old standard AS T32 types B and D covered too large a range whereas the new classification subdivides types B and D, giving a more equal distribution of the classifications throughout the range.

TABLE 1. Comparison between the present classifications contained in Standard AS T32 and the New Revised Standard (as yet unreleased)

AS T32			Revised AS T32 (Not yet numbered)				
Type	Tensile Strength		Type	Tensile Strength			
	MPa	1000 lbf/in^2		MPa Min.	MPa Max.	1000 lbf/in^2 Min.	1000 lbf/in^2 Max.
A	1725-2240	250-325	1	1720	2240	250	325
B	2245-2550	326-370	2	2241	2400	326	348
			3	2401	2550	349	370
C	2555-2690	371-390	4	2551	2700	371	390
D	2695-	391 & over	5	2701	2860	391	415
			6	2870	—	416	—

Test Results

Comparison of Wires 0.016 diameter

Since the largest selection of round wires submitted by all manufacturers was in the 0.016" diameter range and this is the size most used in the light wire technique, comments will first be restricted to these. The samples submitted in this size are shown in Table 2 together with the test results and the classifications into which they

TABLE 2. Properties and classification of 0.016" (0.4 mm) diameter orthodontic wires

Column	1	2	3	4	5	6	7	8	9	10
Property / Sample	Tensile Strength MPa*	Proof Stress MPa*	Proof % tensile	Modulus of Elasticity 1000 MPa*	Modulus of Resilience 1000 Joule	Elong-ation %	No. of Bends to Fracture	Wrapping Test	AS T32 Standard Type	Draft Revised Standard Type
(c) *Low Class*										
Elgiloy Red	2180	1260	58	163.3	1510	3.00	25	Broke	A	1
Rocky Mountain Truchrome	2060	1540	74	164.0	1660	1.68	20	Complied	A	1
Unitek Standard	2220	1600	72	166.0	2448	2.30	23	Broke Failed	A	1
(b) *Medium Class*										
Wilcock Regular	2300	1820	79	165.5	3125	1.79	24	Complied	B	2
Wilcock Regular Plus	2330	1720	74	161.2	3557	2.13	23	Complied	B	2
Remanit Super Spring Hard	2640	2100	80	170.5	4116	1.80	20	Split	C	4
(a) *High Class*										
Wilcock Special	2730	1690	62	182.5	3782	2.31	29	Complied	D	5
Wilcock Special Plus	2750	2180	78	172.0	4256	2.13	24	Complied	D	5
Wilcock Premium	2010	2220	74	180.2	5900	2.20	30	Split at 4X stretch	D	6
Remanit Super Special	2930	2410	82	183.4	4840	2.30	22	Complied	D	6
Spring Hard Unisil	2800	2300	81	176.8	5581	2.02	19	Complied	D	5

*Divide MPa by 6.9 or 7 for approximate 1000 lbf/in^2 values.

fit, according to Australian Standard T32 and to the revised classification.

Masson had not seen Wilcock Premium wire at the time he wrote his thesis (Masson, M.D.Sc. Thesis 1969) nor up to this time, but in a personal communication Wilcock indicated that this wire has been available for five years, but only on special request because of the care required in bending. This wire, from the same type of austenitic stainless steel as his other wires, was produced by a modified technique.

Discussion of Test Results for the 0.016" Wires

Since the tensile strengths (column 1, Table 2) of wires submitted by Rocky Mountain, that is Truchrome and Elgilogy, only fitted into AS T32 Type A or revised Type 1, A(1), classification, and Dentaurum Remanit Super Spring Hard wire into C(4), they will be discussed later.

(*a*) *High Class Resilient Wires*

The AS T32 Type D(5 or 6) wires are the most resilient for the light wire technique, and they are now discussed separately.

Strength. The Wilcock wires are of austenitic stainless steel while apparently the Dentaurum and Unitek wires are of the precipitation hardened type of steel. The tensile strength, proof stress and the ratio P.S./T.S. are shown in columns 1, 2 and 3, respectively. The Dentaurum and Unitek wire show a higher proof stress/tensile strength ratio of 81 and 82 compared with 62, 74 and 78 for the Wilcock wires, but the Wilcock austenitic steel shows a better resistance to fracture by continuous bending (column 7), that is, 24, 29 and 30 bends against 19 and 22. There is little between the elongation figures (column 6) although the figure for Unisil is a little lower.

Modulus of Elasticity. Wires with a low modulus of elasticity are preferable because the force applied during tooth movement will change less than for high values. A comparison for the various wires is shown in column 4. The values are higher for the stronger wires, but this property is basically dependent on composition.

Modulus of Resilience. The energy available for tooth movement for the range of 0.016 wires is shown in column 5. The higher values are to be preferred and these appear in a C(4) wire and all the D(5) and D(6) wires.

Elongation. There is little significant difference in the values as is shown in column 6.

Wrapping Test. The wrapping test is a very severe one. It consists of tightly winding a spiral spring with the wire itself as a mandrel and then stretching the spring as far as possible. Fracture should not occur during making or while stretching to 5 times the total closed length. The results are shown in column 8. In these tests Unisil, Remanit and Wilcock Special Plus and Special complied with the requirements of the standards. The Wilcock Premium reached a stretch of 4x before splitting which is good for such a high tensile strength.

Twisting (*Torsion*) *Test.* The twisting test of AS T32 has been eliminated from the revised standard as it was considered to be too severe since very few high tensile wires show freedom from some form of failure such as reed splitting or a poor fracture pattern because of excessive work hardening which is already at a high level. Wires are not normally subjected to such a stress in orthodontic practice.

Although not recorded in Table 2, the results of the twisting test for the D(5 and 6) class wires were:

Unisil did not twist uniformly, but had a normal fracture.
Remanit wire split spirally during twisting.
Wilcock Special plus wire twisted as specified, but broke with a short spiral fracture.
Wilcock Premium twisted as specified, but split along the spiral.

Summary for High Class Wires

All of these top class wires which have high tensile strength, proof stress and modulus of resilience are ideal for use in the Begg technique. They should maintain their bite opening bend very satisfactorily, particularly where bite opening is of paramount importance. Little trouble should be experienced if these wires are handled correctly. They require smoothly honed pliers without sharp edges or burs, minimum plier pressure and slow bending. However, even with the greatest of care in handling and with good quality control during production, failure can still occur. The smallest flaw in a billet could give rise after drawing to a defective length in a batch of wire and even with a reasonable amount of testing such a length may be missed.

Comparison for the Wilcock wire between the above tests and those conducted by Masson for his M.D.Sc. Thesis in 1969

Table 3 shows the results obtained by Masson at that time. This table shows that most of the wires labelled Special Plus were of the Type C(4) rather than D(5), but in the present series the results showed a very high quality Type D(5 or 6) wire.

The wires for the present tests were provided by the manufacturer, but in order to ascertain whether the quality of wires provided by the manufacturer is maintained, check tests will be conducted later on samples obtained from customers. The results will be published after the tests have been completed.

TABLE 3. Result of radom testing of Wilcock Special Plus Wire. Values obtained for U.T.S. and subsequent classification. Masson 1969

Batch Number	U.T.S. (1000 lbf/sq. in.)	MPa	AS T32 Classification
C. RCC	372	(2565)	Type C
T. ROA.	386	(2660	Type C
B. ROL.	410	(2827)	Type D
O. RCL	386	(2660)	Type C
D. RCC.	388	(2675)	Type C
Re-imported Australian Wire T.P. Lab. 1632	375	(2585)	Type C
T.P. Lab. 1821	386	(2660)	Type C

Accreditation

It must be brought to the notice of orthodontists that no manufacturer makes any specific claims for his wire with respect to tensile or proof stress. The orthodontist usually buys by name as Unitek Unisil, Dentaurum Remanit Super Special Spring Hard, or Wilcock Special Plus and Premium for the top class resilient wires without knowing what their performance is likely to be except from some previous experience.

The ideal envisaged from the orthodontist's point of view and the one which *manufacturers should note,* would be that the labelling of all future orthodontic wire would cover the type of wire according to the specification and the percentage ratio of proof stress to the tensile strength. From these two figures, it would then be possible for the orthodontist to assess the quality of the wire he is purchasing. For example, a Type D(5) wire with an 80% proof stress to tensile strength ratio. This would be an ideal wire for bite opening in the Begg technique.

The onus is on the manufacturer to have his material accredited, but if this is not done, the Australian Society of Orthodontists can procure a range of samples, have them tested and the results regularly published or, if they comply, have them listed on the Australian Dental Association List of Certified Products. The standard has been produced for this purpose.

(b) *Medium Class Resilient Wires*

In the medium category of wires, Table 2, Remanit Super Spring hard falls into Type C(4) which is normal and the Wilcock Regular and Regular Plus into Type B(2). Normally, Regular should be Type B(2); Regular Plus, Type B(3); and Special, Type C(4) so the Regular Plus value is low, but the value D(5) for Special wire is better than would be expected since Special Plus is in the range D(5).

(c) *Low Class Resilient Wires*

From Table 2, the Rocky Mountain Truchrome and Elgiloy Red are Type A(1) wires which is normal. Elgiloy Green, Yellow and Blue, not listed, are softer varieties that can be shaped and then hardened to Red quality. These wires could be used only where very low forces are required as they will deform at higher loads with the necessity of repeated adjustment.

The values for tensile strength for three of the Elgiloy types are:

2180 MPa (316,000 lbs/sq. in.) for the Red
1854 MPa (269,000 lbs/sq. in.) for the Green
1685 MPa (244,500 lbs/sq. in.) for the Yellow

The latter two wires can be formed into the required shape and then heat treated, but when Masson tried to carry out tests on these heat treated wires in his thesis study (1969), the wires were so brittle that he could not hold them in the chuck of the Hounsfield Tensometer.

The same problem would apply should it be necessary to adjust an already formed arch wire which had been heat-treated, the wire would tend to fracture when held with the pliers and force applied to bend it. There is no doubt that many people use this wire and handle it quite satisfactorily, but when such excellent stainless steel wires are now available, it seems unnecessary to go to all this trouble.

There are, however, at the moment on the market, a range of preformed torquing arches made in Elgiloy and, as these require no alteration to their shape to be fitted into position, they give excellent service over a long period of time because of the advantages of being able to form them and then heat treat them for maximum mechanical properties. However, there is still the question of the elastic properties, particularly with the Begg technique.

Application of 0.016" wires

Type D (5 and 6) 0.016 wires are the most suitable for Stage 1 of the Begg technique where maximum bite opening is required. Type C(4) wires are used by some operators, but quicker results and better bite opening are possible with the use of Type D (5 or 6) wires. Type C(4) wires could be used in either the Edgewise or Begg technique where only alignment of the arches is required.

TABLE 4. Tensile strength and proof stress for 0.014", 0.018" and 0.020" diameter wires.

Diameter of Wire in	Material	Tensile Strength MPa*	Proof Stress MPa	AS T32 Type	Revised Type
0.014	Wilcock Special Plus	2760	2020	D	5
	Unisil	2842	2116	D	5
	Remanit Super Federhart	2508	2066	B	3
	Unitek Standard	2311	2046	B	2
	Rocky Mountain Truchrome	2180	1629	A	1
0.018	Unisil	2652	1971	C	4
	Remanit Super Federhart	2561	2057	Low C	4
	Unitek Standard	2266	2002	B	2
	Rocky Mountain Truchrome	2122	1496	A	1
0.020	Unisil	2667	1846	C	4
	Remanit Super Federhart	2622	2257	C	4
	Unitek Standard	2082	1796	A	1
	Rocky Mountain Truchrome	1962	1481	A	1

* Divide MPa by 6.9 or 7 for approximate 1000 lbf/in^2 values.

Comments and Comparison of 0.014" Wires

Samples were submitted in this size by Dentaurum in Remanit Super Federhart, Unitek in their Standard wire and in Unisil. Wilcock makes wires of all types in and above Type B(2). A special plus, D(5), is included. The results of 0.014 wires are shown in Table 4. The 0.014 Unisil and Wilcock wires show a high tensile strength D(5), but the proof stresses of all but Rocky Mountain are of the same order.

It is at present assumed that the high tensile wires are best but properties such as proof stress, modulus of elasticity and modulus of resilience need further investigation This has been done for the 0.016 wires but larger numbers of samples are necessary before conclusions can be reached. All of these wires, apart from Rocky Mountain, could possibly be used with the Begg or Edgewise techniques especially in the making of auxilliary spring attachments (e.g. uprighting springs) but the higher tensile strength wires would be preferred.

Comments and Comparison of 0.018" Wires

Wires of 0.018 diameter were submitted by Unitek in Standard wire and in Unisil, Rocky Mountain in Truchrome, and Dentaurum in Remanit Super Federhart.

Wilcock also makes these wires in all types in and above B(2), but they are not always immediately available. None were submitted.

The results for tensile strength and proof stress are shown in Table 4. Both Unisil and Dentaurum obtained a Type C(4) rating and are the most satisfactory of those tested in this size. In this series, the proof stress of Unisil was lower than to be expected, but apart from Rocky Mountain, all are of the same order. A C(4) rating is possibly the highest available in this size.

Comments and Comparison of 0.020" Wires

Again, wires were submitted by Dentaurum, Unitek and Rocky Mountain, but Wilcock did not submit a sample. The results for tensile strength and proof stress are shown in Table 4. It will be seen that the Unisil and Dentaurum Super Federhart wires have the highest tensile strengths, but the proof stress of Unisil is low compared with Remanit.

Rectangular Wires

Rocky Mountain submitted 0.018" X 0.025" and 0.0215" X 0.028" rectangular wires in Truchrome and Elgiloy Blue and Yellow. They are borderline cases for Types A(1) and less.

Conclusion

A comparison has been made between various wires from four manufacturers. The results show that there is a range of very good quality wires available to orthodontists. However, for selection of the best, further tests on a broader statistical basis are necessary before firm conclusions can be drawn. Such tests are envisaged.

These further tests would be from a random selection of wires obtained from orthodontists rather than those provided by the manufacturers in order to check quality as generally received.

Manufacturers should submit samples to be tested for inclusion in the Australian Dental Association Accreditation scheme so that they can be classified and added to the List of Certified Products.

Summary

A range of orthodontic wires of diameters from 0.014" (0.35 mm) to 0.020" (0.5 mm) from various manufacturers was submitted to the Australian Society of Orthodontists to be tested by the Australian Dental Standards Laboratory to Australian Standard T32 for Resilient Orthodontic Wires.

The test results are compared with the classification of Australian Standard T32 and a draft revision which is almost ready for publication.

Further information including proof stress, modulus of elasticity and modulus of resilience was extracted from the graphs for the 0.016" (0.4 mm) diameter wires.

The results show that a number of high class orthodontic wires are available to orthodontists.

It is strongly recommended that the classification of the revised standard (when it is published), together with the percentage ratio of proof stress/tensile strength be indicated on each package of wire to enable orthodontists to select suitable wires.