Tensile properties of general purpose stainless steel wire formed for orthodontic use

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Abstract

Objective: The purpose of this study was to determine the tensile properties of type 304 general purpose round stainless steel wires (sizes 0.016", 0.018", and 0.020") before and after being formed to archwires, and to explore the applicability of type 304 general purpose round stainless steel archwires for orthodontic use.

Materials and methods: Samples were divided into 2 groups: Group I – Type 304 general purpose stainless steel wires without forming and Group II – Type 304 general purpose stainless steel wires which were formed into archwires using a universal testing machine equipped with a forming device. For both sample groups, 12 wires for each of the 3 sizes: 0.016", 0.018", and 0.020" were subjected to tensile test. All specimens were tested using a universal testing machine equipped with an extensometer at gauge length 12.5 mm. The data of tensile strength, 0.2% proof stress, elongation, and elastic modulus were statistically analyzed using One-way ANOVA and Tukey's multiple comparison test at 95% confidence interval.

Results: Both as-received and after forming, the highest values of the tensile strength, 0.2% proof stress, and elastic modulus were 0.016" followed by 0.020" and 0.018", while the highest values of the elongation was 0.018" followed by 0.020" and 0.016". The 0.2% proof stress of the type 304 general purpose round stainless steel wires significantly increased after forming into archwires ($p<0.05$), while no significant changes in tensile strength, elongation, and elastic modulus were observed after forming into archwires ($p>0.05$).

Conclusion: The proof stress of type 304 general purpose round stainless steel wires increased after forming into archwires. However, tensile strength, elastic modulus, and elongation were found to be unchanged. [Based on the evaluated tensile properties, tensile strength, proof stress, and elastic modulus of general purpose round stainless steel archwires in this study can be acceptable to use in orthodontic treatment, while elongation should be improved by the annealing heat treatment.]

Key words: archwires, elastic modulus, elongation, orthodontic, stainless steel, tensile properties

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Introduction

Orthodontic wires are used to apply force to teeth and move them into proper occlusion. The elastic behavior of wire material is important in determining orthodontic tooth movement.[1] Austenitic stainless steel is one of the popularly used materials in orthodontic treatment because of its sufficient mechanical properties such as soldering and welding ability, good corrosion resistance and low cost.[2-4] Stainless steel orthodontic wires are of types 302 and 304 austenitic stainless steels which are the same types as the general purpose stainless steel wires.[1,3,5] Therefore, it is implied that the properties of general purpose stainless steel wires should be similar to stainless steel orthodontic wires. Anuwongnukroh et al[6] demonstrated that the properties of type 304H general purpose stainless steel wire are comparable to stainless steel orthodontic wire, while a stainless steel orthodontic wire is more expensive than a general purpose stainless steel wire.

Nowadays, Thailand imports stainless steel orthodontic archwires which are somewhat expensive. If general purpose stainless steel wires can be produced as archwires and the properties are suitable for orthodontic use, it could reduce the need for costly imports. Mechanical properties are important properties for selecting archwire to a particular treatment and must be determined by utilizing both the tensile testing and the bending testing.[7-9] Bending properties of general purpose stainless steel archwires were studied, and the results supported that the bending properties were acceptable to use in orthodontic treatment.[8] However, tensile properties have not been studied.

The purpose of this study was to determine the tensile properties of type 304 general purpose stainless steel wires after being formed as archwires, and to explore the suitability of type 304 general purpose round stainless steel archwires for orthodontic use.

Materials and Methods

Three sizes (0.016", 0.018", and 0.020") of type 304 general purpose round stainless steel wire (P.Thaidamrong, Bangkok, Thailand) were used in this study, and the composition of these wires is shown in Table 1.

Specimen preparation

Twelve as-received type 304 general purpose round stainless steel wires for each of the three sizes 0.016", 0.018", and 0.020" were subjected to tensile test, and the other 12 as-received type 304 general purpose round stainless steel wires of each size were formed into archwires using a universal testing machine (Instron Model 5566, Instron Corp., Buckinghamshire, UK) equipped with a forming device under forces of 380 N, 470 N, and 550 N, respectively as shown in Figure 1. For the formed archwires, specimens from the straightest section were used for tensile test. All specimens, 45 mm in length were tested for their tensile properties at gauge length 12.5 mm as shown in Figure 2.

Table 1 Composition of type 304 general purpose round stainless steel wires used in this study

Size	Composition (%)							
	C	Si	Mn	P	S	Ni	Cr	Fe
0.016"	0.072	0.40	1.26	0.027	0.0011	8.03	18.42	Balance
0.018"	0.040	0.43	1.92	0.027	0.0083	8.00	18.34	Balance
0.020"	0.075	0.42	1.31	0.026	0.0017	8.03	18.46	Balance

Measurement and data analysis

Tensile properties were measured using a universal testing machine equipped with an extensometer (Extensometer 2620-602, Instron Corp., Buckinghamshire, UK) at a cross-head speed of 1 mm/min. A load-extension curve was recorded on a chart for each specimen. Tensile strength, 0.2% proof stress, elongation, and elastic modulus were determined from the recorded chart. The data of tensile strength, 0.2% proof stress, elongation, and elastic modulus were statistically analyzed using One-way ANOVA and Tukey's multiple comparison test at 95% confidence interval.

Figure 1 Forming general purpose stainless steel wire to archwires.

Results

Mean values and standard deviations for tensile strength, 0.2% proof stress, elongation, and elastic modulus, as well as the statistical differences between the mean values are shown in Table 2.

Tensile strength

Tensile strength of the type 304 general purpose round stainless steel wires ranged from 1,968 to 2,113 MPa for as-received, and

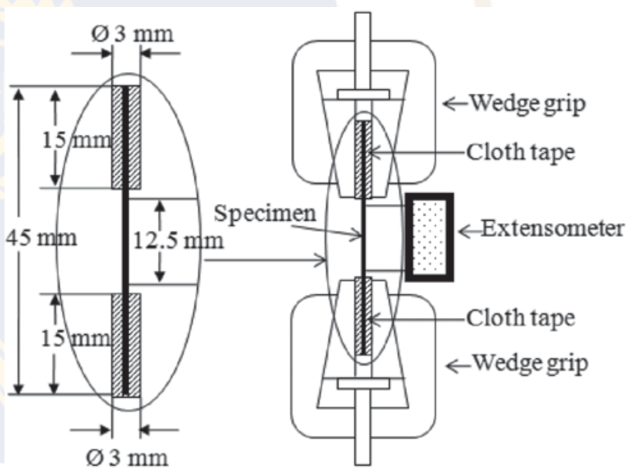

Figure 2 Diagram of specimen setup for tensile test.

Table 2 Tensile strength, 0.2% proof stress, elastic modulus, elongation and comparison between means

Group	Size	Tensile strength (MPa)	0.2% proof stress (MPa)	Elastic modulus (GPa)	Elongation (%)
As-received general purpose stainless steel	0.016"	2,113 (55) a	1,944 (14)c	179.9 (3.9) g	0.32 (0.08) i,j
	0.018"	1,968 (51) b	1,777 (31) d	164.3 (1.7) h	0.41 (0.09) i
	0.020"	2,085 (56) a	1,915 (32) c	164.6 (4.6) h	0.36 (0.10) i,j
Formed general purpose stainless steel	0.016"	2,134 (60) a	2,091 (28) e	180.9 (4.3) g	0.27 (0.06) j
	0.018"	2,017 (49) b	1,922 (28) c	165.3 (3.5) h	0.35 (0.09) i,j
	0.020"	2,091 (55) a	2,007 (26) f	165.9 (4.8) h	0.31 (0.07) i,j

Standard deviations in parentheses

Average values with the same letters at the right-side of the standard deviation are not significantly different at p>0.05.

2,017 to 2,134 MPa for after forming. The highest value was 0.016" followed by 0.020" and 0.018". The statistical differences between the mean showed that for both groups, the tensile strength of 0.018" was significantly lower than the other sizes (p<0.05), while no significant difference was found for tensile strength between 0.016" and 0.020" (p>0.05). For each size, no significant differences were found in tensile strength between as-received and after forming (p>0.05).

0.2% proof stress

0.2% proof stress of the type 304 general purpose round stainless steel wires ranged from 1,777 to 1,944 MPa for as-received, and 1,922 to 2,091 MPa for after forming. The highest value was 0.016" followed by 0.020" and 0.018". The statistical differences between the mean showed that significant differences in the 0.2% proof stress were found among all three sizes after forming, and the highest value was 0.016" followed by 0.020", and the lowest value was 0.018" (p<0.05). For as-received wires, 0.018" had a significantly lower 0.2% proof stress than the other sizes (p<0.05), and no significant difference was found in 0.2% proof stress between 0.016" and 0.020" (p>0.05). 0.2% proof stress of after forming wires was significantly higher than as-received wires for each size of sample (p<0.05).

Elastic modulus

Elastic modulus of the type 304 general purpose round stainless steel wires ranged from 164.3 to 179.9 GPa for as-received, and 165.3 to 180.9 GPa for after forming. The highest value was 0.016" followed by 0.020" and 0.018". The statistical differences between the mean showed that both in as-received and after forming, the elastic modulus of 0.016" was significantly higher than the other sizes (p<0.05), while no significant difference was found in elastic modulus between 0.018" and 0.020" (p>0.05). For each size, no significant differences were found in elastic modulus between as-received and after forming (p>0.05).

Elongation

Elongation of the type 304 general purpose round stainless steel wires ranged from 0.32 to 0.41 % for as-received, and 0.27 to 0.35 % for after forming. The highest value was 0.018" followed by 0.020" and 0.016". The statistical differences between the mean showed that no significant differences were found in elongation among all the three sizes for both groups (p>0.05), and no significant differences were also found in elongation between both groups for each size of sample (p>0.05).

Discussion

The present study investigated the tensile properties of the type 304 general purpose round stainless steel wire sizes 0.016", 0.018", and 0.020" before and after forming as archwires, and to explore the suitability of type 304 general purpose round stainless steel archwires for orthodontic use.

The results of this study showed that the proof stress of the type 304 general purpose round stainless steel wires increased after forming into archwires, and the increase in proof stress may be caused by the dislocation in the crystal structure of wires during forming.[10] Tensile strength and proof stress of size 0.018" were lowest which may be attributed to the carbon content which was lower than the other sizes (Table 1). It has been reported in a study for manufacturing technology[11] that carbon plays an important role in increasing the strength and hardness of the steel. The elastic modulus and proof stress of size 0.016" were higher than those of the other sizes. The probable reason was that size 0.016" was the smallest which underwent the higher percentage reduction of the wire drawing than the other sizes. The increase in percentage reduction of the wire drawing is responsible for the increase in the strength and stiffness.[10,12,13] Moreover, the results of a study by Filho et al[14] showed that strength and hardness of stainless steel wire (SEW 410 Nr.14517) increased with increased percentage reduction.

According to the literatures on dental materials,[1,2,15] tensile strength, yield strength, elongation, and elastic modulus of stainless steel orthodontic wires were 2,100 MPa, 1,100-1,500 MPa, 1-6%, and 160-180 GPa, respectively. In comparison to these stainless steel orthodontic wires, tensile strength (2,017-2,134 MPa) and elastic modulus (165.3-180.9 GPa) of the three archwires in this study had similar values, and proof stress (1,922-2,091 MPa) had higher values, while the elongation (0.27-0.35%) had lower values.

Although these archwires had low elongation, this property may be improved by the stress-relieving heat treatment.[13] Therefore, annealing heat treatment of these archwires should be done in further studies because annealing heat treatment removes the residual stress in cold forming.[13,16] Stress relief is responsible for the increase ductility of stainless steel wire after it has been cold worked.[13]

In conclusion, the proof stress of the type 304 general purpose round stainless steel wires increased after forming into archwires but the tensile strength, elastic modulus, and elongation were found to be unchanged. Based on the evaluated tensile properties, tensile strength, proof stress, and elastic modulus of general purpose stainless steel archwires in this study can be acceptable to use in orthodontic treatment, while elongation of these archwires was lower than stainless steel wires for orthodontic use. Although our pilot forming archwires had somewhat low elongation, but this property may be improved by the annealing heat treatment.

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International Abstract

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Effect of CPP-ACP paste on dental caries in primary teeth: a randomized trial.

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Abstract

This clinical trial tested the effect of daily application of 10% w/v calcium phosphopeptide-amorphous calcium phosphate (CPP-ACP) paste for 1 yr when added to regular toothbrushing with fluoridated toothpaste to prevent dental caries in pre-school children. High-caries-risk children aged 2½ to 3½ yrs in a suburban area of central Thailand were assigned to receive either CPP-ACP (n = 150) or a placebo control (n = 146) in addition to fluoridated toothpaste. The International Caries Detection and Assessment System (ICDAS) was recorded at baseline, 6 mos, and 1 yr. At 1 yr, a significant increase in mean numbers of enamel and dentin caries lesions, as well as dmfs, was found in both groups ($p < 0.001$). No significant difference was observed between groups on these 3 outcome measures (p = 0.23, 0.84, and 0.91, respectively). The odds of enamel caries lesion transitions to a state of regression or stability, compared with progression from baseline, was also not different between groups [OR = 1.00, 95% CI (0.86, 1.17)]. This trial found that daily application of 10% w/v CPP-ACP paste on school days for 1 yr, when added to regular toothbrushing with a fluoride toothpaste, had no significant added effect in preventing caries in the primary dentition of these pre-school children (ClinicalTrials.gov number CT01 604109).

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The effectiveness of xylitol in a school-based cluster-randomized clinical trial.

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Abstract

OBJECTIVE:

The purpose of this double-blind, cluster-randomized clinical trial was to examine the effects of xylitol gummy bear snacks on dental caries progression in primary and permanent teeth of inner-city school children.

METHODS:

A total of 562 children aged 5-6 years were recruited from five elementary schools in East Cleveland, Ohio. Children were randomized by classroom to receive xylitol (7.8 g/day) or placebo (inulin fiber 20 g/day) gummy bears. Gummy bears were given three times per day for the 9-month kindergarten year within a supervised school environment. Children in both groups also received oral health education, toothbrush and fluoridated toothpaste, topical fluoride varnish treatment and dental sealants. The numbers of new decayed, missing, and filled surfaces for primary teeth (dmfs) and permanent teeth (DMFS) from baseline to the middle of 2nd grade (exit exam) were compared between the treatment (xylitol/placebo) groups using an optimally-weighted permutation test for cluster-randomized data.

RESULTS:

The mean new d(3-6)mfs at the exit exam was 5.0 ± 7.6 and 4.0 ± 6.5 for the xylitol and placebo group, respectively. Similarly, the mean new D(3-6)MFS was 0.38 ± 0.88 and 0.48 ± 1.39 for the xylitol and placebo group, respectively. The adjusted mean difference between the two groups was not statistically significant: new d(3-6)mfs: mean 0.4, 95% CI -0.25, 0.8), and new D(3-6)MFS: mean 0.16, 95% CI -0.16, 0.43.

CONCLUSION:

Xylitol consumption did not have additional benefit beyond other preventive measures. Caries progression in the permanent teeth of both groups was minimal, suggesting that other simultaneous prevention modalities may have masked the possible beneficial effects of xylitol in this trial.