Comparison of certain mechanical properties including deflection fatigue resistance of Cobalt Chromium alloy & Nylon tooth colored clasping materials

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ABSTRACT

Background: This study was conducted to test & compare the mechanical properties including the ultimate tensile strength, yield strength, modulus of elasticity, ductility & deflection fatigue resistance of Cobalt Chromium alloy samples, Flexite Supreme samples & commercially available Nylon samples, thus evaluating efficiency & life time expectancy of these materials.

Materials and methods: A reproduction mold was made from addition silicon reproduction material to produce wax patterns of standardized measures, these sacrificial patterns were used to produce fifty samples of each of the three materials (a total of 150 samples). These specimens were tested by tensile testing machine and deflection fatigue resistance machine.

Results: The tested materials expressed differences in their mechanical properties that were highly significant in all comparisons.

Conclusions: Cobalt Chromium alloy, aside from its poor aesthetic, performs better in shallow deflection and have a reasonable life expectancy. Flexile supreme is more aesthetically acceptable, with better performance and longer life expectancy. Commercial nylon is with poor quality rendering it unusable.

Keywords: deflection fatigue, tensile strength testing, Cobalt Chromium, Flexile supreme.

INTRODUCTION

The removable partial denture must have retention to resist reasonable dislodging forces. Primary retention of a removable partial denture is accomplished mechanically by placing retention elements on the abutment teeth (1).

A direct retainer is any unit of a removable dental prosthesis that engages an abutment tooth in such a manner as to resist displacement of the prosthesis away from basal seat tissue. This may be accomplished by frictional means, by engaging a depression in the abutment tooth, or by engaging a tooth undercut lying cervically to its height of contour (2).

There are two basic types of direct retainers. One is the intracoronal retainer, which is cast or attached totally within the restored natural contours of an abutment tooth. The other type of a retainer is the extra coronal retainer, which uses mechanical resistance to displacement from components placed on or attached to the external surface of an abutment tooth (1). The extra coronal or clasp direct retainer is used more frequently than attachment (3).

The problems of clasp arm include poor aesthetics and fracture of clasp arm (1). The application of nylon like materials in the fabrication of dental appliances has been seen as an advance in dental materials. These materials generally replace the metal, and pink acrylic denture used to build the framework for standard removable partial dentures (4). A nylon that is suitably stiffened could be extremely useful in the treatment of those patients for whom acrylic prostheses are not suitable. This would include patients who demonstrate repeated fracture of dentures and those that show tissue reactions of a proven allergic nature (5). Flexite Company developed and patented the first tooth color clasps known. This product made of a nylon material (6).

Fatigue testing which is subjecting a test sample to rapid cycling at a given stress until failure occurs is considered one of the basic testing procedures used to provide data for metals and alloys comparison (7), in addition fatigue is responsible for 90% of all service failure (8). The retentive clasp arms are the parts of removable partial denture most frequently damaged (9,10) since clasps in clinical use are subjected to cyclic bending during insertion, removal of partial dentures and also during mastication (7).

MATERIALS AND METHODS

Tensile strength test: an analog of the specific shape and dimensions of the sample required (according EN.ISO. 527-2: 1993) was made from galvanized steel and used for molding a silicon mold to produce standardized wax patterns from which samples were made. Thirty samples were dedicated for this test. Ten samples of Flexite supreme; group A (Flexite USA) & ten of the best.
commercial nylon; group B (made in China) were injected using a thermoplastic injection system (KCX-09A, China). The same wax patterns were used for casting ten Co-Cr samples. All Cobalt Chromium samples were checked for unforeseen impurities that may have been hidden below the outside surface (figure 1). The samples were seated individually on the X-Ray machine (Diamax Digivision, Planmeca, Finland) at a distance of 10 cm. between the sample to be tested and the radiographic cone was achieved using the film holder. The X-Ray machine was set to 70 KV, 10 MA and the exposure time was 0.6 seconds (11-13). All samples that are proven to have air bubbles or cracks in the testing area (the area of constriction & not the handles) were discarded.

Figure 1: Cropped picture showing a void in the testing area of the sample. Samples showing a defect under X-Ray were discarded.

The nylon samples were tested using a tensile testing machine with jaws designed to grip polymer samples (figure 2). The metal samples were tested with a tensile testing machine with jaws designed to grip metal samples (figure 3). The test was completed by loading the samples till failure in tension with a head speed of 20mm. per sec. The values of the tensile strength were calculated for each test specimen as the force at failure divided by the cross sectional area according to the following formula:

\[
\text{Tensile strength} = \frac{F}{A} \text{ (N.)/} \text{A (mm.²)}
\]  

F: Force at fracture  
The modulus of elasticity (E), were determined using the method of comparing two different points on the stress strain curve and then applying the following formula:

\[
E = \frac{\delta_2 - \delta_1}{\varepsilon_2 - \varepsilon_1}
\]  

\(\delta_1\): stress on the first point  
\(\delta_2\): stress on the second point  
\(\varepsilon_1\): strain on the first point  
\(\varepsilon_2\): strain on the second point

**Deflection fatigue resistance test:** the same procedures for the production of samples were followed to produce the 120 samples required for this test (40 samples of each material). The shape and dimensions of the samples were prepared according to (ASTM E647/1988). The test was carried out by screwing the grip of the testing machine (HSM20, HI-TECH EDUCATION, England). The deflection values (0.25mm.;0.5mm.; 1mm.; & 2.1 mm.) were obtained from the monogram provided with the manual of the machine. In a dental appliance, stress reversal is unlikely to occur & the structure will be stressed in one direction & allowed to return to zero in each cycle (15) & (16) & in this study, this stress cycle was used. Each sample was marked in the center of its length. The deflections of 0.25mm, 0.5mm, 1mm, and 2.1mm were measured at this point for all the samples by a dial gauge with an extended spindle whose tip was applied to the central point in the upper surface of the sample (13) & (17). After a sample had been setup in the testing machine, the sample was fatigued until fracture or permanent deformation occurred (figure 4 & 5).

Figure 2: A polymer specimen clamped by the jaws of the testing machine after the test is over by failure in tension.

Figure 3: A metal specimen clamped by the jaws of the testing machine after the test is over by failure in tension.
RESULTS
Stress strain curves of the materials were plotted demonstrating the behavior of the tested material in tension and as follows:
1. Co-Cr alloy is stiff, brittle but strong (figure 6).

\[\text{Fig. 6: Stress strain curve of the mean value of (Co-Cr) samples under tension.}\]

2. Flexite supreme: flexible, ductile and strong (fig. 7).

\[\text{Fig. 7: Stress strain curve of test group A (Flexite supreme) samples under tension.}\]

3. Commercial nylon: stiff, ductile and weak (fig. 8).

\[\text{Fig. 8: Stress strain curve of test group B (commercial Nylon) under tension.}\]

For the ultimate tensile strength, yield strength and modulus of elasticity Co-Cr had the highest mean values, respectively: 614.14 MPa; 337.84MPa & 120.794MPa. While for the elongation of breakage it had the lowest mean value of 9.83 %.

For the ultimate tensile strength, yield strength and modulus of elasticity Flexite supreme had the following mean values respectively: 152.2MPa; 148.17MPa & 10.4778 MPa. While for the elongation at breakage it had the highest mean value of 198%.

For the ultimate tensile strength, yield strength and modulus of elasticity the commercial nylon had the lowest mean values, respectively: 45.81MPa; 34.73MPa & 5.6153MPa. While for the elongation at breakage it had the lowest mean value of 173.64 %.

Multiple group comparisons of mechanical properties:
By conducting Fisher's least significant difference test (LSD), to obtain an understanding of the multiple statistical comparisons among groups. The results were found to be as follows:
When comparing the Co-Cr with Flexite supreme test group for yield strength, ultimate strength, modulus of elasticity and elongation at breakage the results revealed a statistically high significance.

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Comparing Co-Cr with commercial Nylon test groups for yield strength, ultimate strength, modulus of elasticity and elongation at breakage the results revealed a statistically high significance.

Table 1: Fisher’s least significance difference (LSD) analyzing multiple comparisons between groups

<table>
<thead>
<tr>
<th>Yield Strength</th>
<th>Mean Difference</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-Cr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>189.67000</td>
<td>.86026</td>
<td>.000</td>
</tr>
<tr>
<td>B</td>
<td>303.11000</td>
<td>.86026</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>113.44000</td>
<td>.86026</td>
<td>.000</td>
</tr>
<tr>
<td>Ultimate Tensile strength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-Cr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>461.94000</td>
<td>.57241</td>
<td>.000</td>
</tr>
<tr>
<td>B</td>
<td>568.33000</td>
<td>.57241</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>106.39000</td>
<td>.57241</td>
<td>.000</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-Cr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>110.31600</td>
<td>.29820</td>
<td>.000</td>
</tr>
<tr>
<td>B</td>
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<td>.29820</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>4.86250</td>
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<td>.000</td>
</tr>
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<td>Elongation</td>
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</tr>
<tr>
<td>Co-Cr</td>
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<td></td>
<td></td>
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<tr>
<td>A</td>
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</tr>
<tr>
<td></td>
<td>-106.39000</td>
<td>.41083</td>
<td>.000</td>
</tr>
</tbody>
</table>

LSD *. The mean difference is significant at the 0.05 level.

Table 2: mean value of cycles required to fracture or permanently deform a sample.

<table>
<thead>
<tr>
<th>Material</th>
<th>0.25 mm. deflection</th>
<th>0.5 mm. deflection</th>
<th>1.0 mm. deflection</th>
<th>2.1 mm. deflection</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>21272587.5</td>
<td>12128790.7</td>
<td>7818114.4</td>
<td>3193095.6</td>
</tr>
<tr>
<td>B</td>
<td>18795881.1</td>
<td>10673335.7</td>
<td>6108554</td>
<td>3045619.7</td>
</tr>
<tr>
<td>Co-Cr</td>
<td>32210.4000</td>
<td>13346.9</td>
<td>865.7</td>
<td>527.6</td>
</tr>
</tbody>
</table>

Figure 9: A histogram demonstrating a comparison of the mean values of the number of cycles required to fracture or deflect a sample under deflection for the (Co-Cr), test group A (Flexite supreme) and test group B (Commercial Nylon).

Deflection fatigue resistance test results showed that Flexite supreme had the highest mean value at all deflections while the Co-Cr had the lowest mean values and as shown in table 2 & figure 9. Comparing the two test groups for yield strength, ultimate strength and elongation at breakage recorded a high statistical significance. Comparing the two test groups for modulus of elasticity the results revealed a statistically highly significant, and as shows in the (table 1).

DISCUSSION

1. Mechanical properties: The Co-Cr group registered E & yield strength, which are a poor feature concerning clasp design (18). While the Flexite supreme registering yield strength and modulus of elasticity that are lower than those of Co-Cr and higher than that of the commercial nylon, they might represent the ultimate choice of a material that can flex out of deeper undercut; thus minimizing the amount of tooth preparations and the otherwise unnecessary loss of healthy tooth structure, enhancing retention of a removable partial denture & minimizing the amount of stress excreted on the abutments. The amount of stress required to produce the necessary retention in Flexite Supreme Nylon clasps is delivered through the increase of bulk of the clasp, noting that such an increase wouldn’t overload the prosthesis weight; hence Nylon low density compared to most base metal alloys; nor affect the aesthetics of the patient; hence the tooth colored or gingiva colored clasp. The commercial nylon (made in china) proven to be not functional because of the weakness of the material, and lower modulus of elasticity which would require building a clasp of non acceptable bulk to compensate for its inherent weakness and generate enough strength to retain a RPD (19).

This behavioral difference between metal and polymer could be attributed to the difference in the microstructure level. Metals have small building blocks that are well arranged and highly organized in a dense uniform pattern thus give a rather predictable mechanical behavior in temperatures lower than that of melting point, while that are made up of large strains of polymer molecules, the smaller molecule of polymers can be thousands of times larger than that of any naturally occurring molecules of metal alloys. Plus the fact that polymers have different sizes of molecules contributing to its’ structure. These building blocks of polymers are arranged as areas of well organized molecules (the crystalline state) surrounded by areas of curved, twisted & entangled polymer molecules (amorphous state). The amorphous state is responsible for the freedom in movement in any direction of the polymer in temperatures that are considerably lower than that of melting temp (20).

Deflection fatigue: The results of this study for Co-Cr alloy revealed that the possibility of having a Co-Cr clasp that is subjected to cyclic bending without failure fracture is unlikely to take place even in the minimum deflection of 0.25mm which is in agreement with previous clinical
observations (10) & other fatigue testing (14,21,7) & (17). This can be attributed to the mechanical properties of the alloy, mainly the E: the proof stress (yield strength) & the elongation values. To explain the results of this study, it seems important that the E of the metals should be considered along with the yield strength (proof stress) property (23). Co-Cr alloys have a high E which is a poor feature concerning clasp design but they do have a good proportional limit (18). Retentive clasp arms are required to have adequate elasticity to deflect out of the retentive undercut, adequate stiffness to produce retention & adequate strength to resist accidental damage (23). The other mechanical property that may affect the fatigue resistance of a clasp is the ductility of the material which is usually expressed by the elongation values, the ductility of Co-Cr alloy is considered low (brittle material). Co-Cr clasps are more likely to fracture if bent (24), also increased ductility of Co-Cr alloy improved the resistance to fatigue (25).

Differences between the materials (Co-Cr alloy & Flexite supreme & commercial Nylon) in deflection fatigue.

The difference in the behavior of the samples of the three materials at 0.25mm. & 0.5mm. D and the statistically high significance can be related to the difference in mechanical properties, especially the yield strength, which determines the amount of stress that can build up in the sample (clasp) when deflected. The high yield strength of Co-Cr alloy means that the stresses generated due to deflection can easily pass there proof stress to cause damage or permanent deformation. While the lower yield strength of the Flexite supreme improved the resistance to fatigue (25).

REFERENCES