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Effect of Reinforcing PMMA Denture Base Material by Stainless Steel 316L Wires on Flexural Strength

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A B S T R A C T

A stainless steel 316L (SS316L) wires reinforcing heat cure PMMA matrix samples were prepared for dentures applications. Mechanical scratching and electrochemical anodizing for PMMA denture base supported by wires of SS316L were used as straightforward and low-cost outside layer pretreatments. The two pretreatments were used to improve the flexural strength of PMMA denture bases. The mechanical scratching process acts to scratch the surface of stainless-steel wires by mixing the wires with silicon carbide powder inside a rotating Pyrex container. The pretreatment time was varied to be 60, 90, and 120min. The anodizing solution, containing ethylene glycol (EG) with $HClO_4$ acid, was used with a 15V supply and a graphite rod as a cathode in the anodizing process. A variation in the pretreating time to be 15, 20, and 30min for the electrochemical anodizing process was included. A scanning electron microscope was utilized to examine the morphology of surfaces of the SS316L wires, which showed various morphology natures. The mechanical flexural strength test was conducted for all samples statistically to check the results. The flexural strength test results of the composite sample groups of PMMA reinforced with the scratched surface for 90 min stainless steel wire 316L presented the highest flexural strength value (113 MPa) with a 66% increment. All results proved that reinforcing PMMA by ss 316L are enhancing the flexural strength by comparing the results with previous works and pointing to the activity of the used scratching process.

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1. Introduction

Polymethyl methacrylate (PMMA) has acquired great approval for several dental implementations due to its unparalleled properties like soft density, aesthetics, cost-effectiveness, simplicity of modification, and demanded physical and mechanical properties [1-7]. Despite that, PMMA resin has some disadvantages like denture fracturing because of water sorption and low flexural and impact strength [8]. The weakness of the mechanical parameters resulting in prosthetics are unable to sustain its properties for an extended period. It is time to subject acrylic resin which is used as a foundation for dentures to a variety of enhancing modifications. The previous researches have led to a variety of modifications that have helped to resolve and enhance its properties like its impact and flexural strength. Masticatory forces that occur during intra-oral activity results in exhaustion [9, 10].

Over the last few decades, efforts were made to upgrade mechanical and biological properties to create the ideal denture. Dentures should have excellent bio harmony in the humane mouth setting, perfect match with the actual tooth look, good Young modulus, good toughness, high flexural strength, strong linking with an artificial tooth, and reform potential [11, 12]. The previous studies, for example, have shown that PMMA materials improved when reinforced with a variety of fibers [13-15]. The addition of epoxy resins, polyamide, or butadiene styrene to PMMA-based bio composites has also been reported to increase PMMA impact strength [16-21]. Various approaches to prevent or reduce the incidence of fractures are described in the literature [17, 22-25], like chemical variations in acrylic resin [26], inner including of metallic materials [27], effective fracture prohibition, and embedding of polyethylene or fibre glass and fibre carbon [28-30]. The flexural strength of PMMA reinforced by E-glass fibers was 91.14 MPa [31]. Metal mesh-reinforced Polymethyl methacrylate has a flexural strength of 87.68a (89.84±13.70) MPa [32]. This study objects to make a reinforced PMMA via surface treated stainless steel wires as a biomaterial for various dental applications, using an easy and low-cost surface treatment process, aiming to furthermore PMMA's denture properties improvement. The novelty of this study is to use stainless steel 316L wire with this thickness for supporting polymethyl methacrylate by this easy low-cost mechanical treatment and with new conditions of the anodization treatment.

2. Experimental Procedure

Polymethylmethacrylate PMMA (PMMA, MMA, SpofaDental a.s., ISO 1567:1988, Czech) was used as the matrix for denture material preparation. PMMA was reinforced by wire of SS316L provided by MOST FX 316L, Warszawa-Poland with a diameter of 0.8mm. The first step in denture preparation was cutting Steel 316L wire into several segments with a length of 65mm. Then, the wires were washed using ethanol and then distilled water before sandblasting. Two pre-treatments on SS316L wires were used, a scratching process and an electrochemical anodizing process. The scratching process was done by using silicon carbide powder having a particle size of 0.2-0.7mm. The scratching process was done by mechanical technique in a Pyrex cylinder having a length of 10cm and a base diameter of 4cm. The container was strongly fixed to an electric motor that provides the rotation as in Fig. 1 A and B. The wires and SiC were mixed inside the container by rotational motion at 200 rpm for different times 0, 60, 90, and 120min. Anodizing process was established by using Ethylene glycol (Merck KGaA, Germany) electrolyte with 5% perchloric acid ($HClO_4$) provided by Hi-ARTM/ACS-HiMedia Laboratories Pvt. Ltd, India) in a 100mL beaker to perform the anodization on SS316L wire surface at 15 V for 15, 20, and 30 minutes. As a cathode, a graphite rod with a length of 77mm and a diameter of 1.8mm was utilized. Fig. 2 showed the anodizing system of Ethylene Glycol electrolyte with 5% Perchloric acid. A dental stone flask with dimensions of 65×10×3 mm^3 was employed to fabricate the sample. The dough was placed instantly in the flask cavity. The ratio of PMMA powder to monomer liquid was held at 9g / 3.6mL mixed until reaching the dough. To make the pure denture material (PMMA without reinforcing) G, PMMA was put in the mold directly. The treated and untreated wires were soaked in the monomer fluid directly before putting them in the dough. The supported specimens with untreated and treated wires are denoted by G_0, GM_{60}, GM_{90}, and GM_{120} for scratching samples and GE_{15}, GE_{20}, and GE_{25} for anodizing samples where the subscript numbers represent the treating times, i.e. 60, 90,120, 15, 20, and 25min. Only one wire in dough per sample was utilized. A 0.5 Ton press force was applied to the flask. The process was performed by rising the water flask temperature to about 100°C for 60 min. After that, the samples were smoothed by grinding paper with grade sizes 400, 600, and 1000. Fig. 3 illustrates prepared PMMA samples.

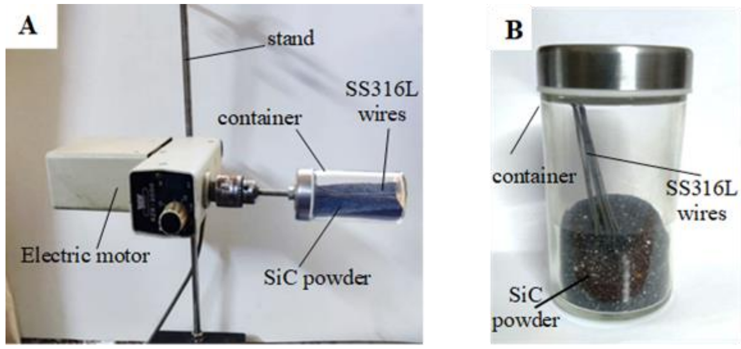

Figure 1: (A) system of mechanical treatment, (B) SS316L wires, and SiC powder in the scratching container.

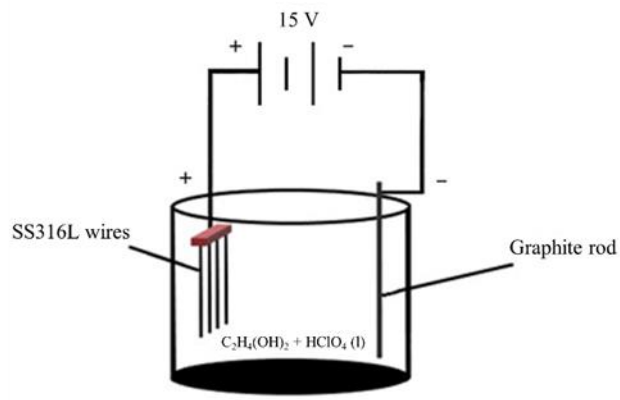

Figure 2: Show the anodizing system of Ethylene Glycol electrolyte with 5% Perchloric acid.

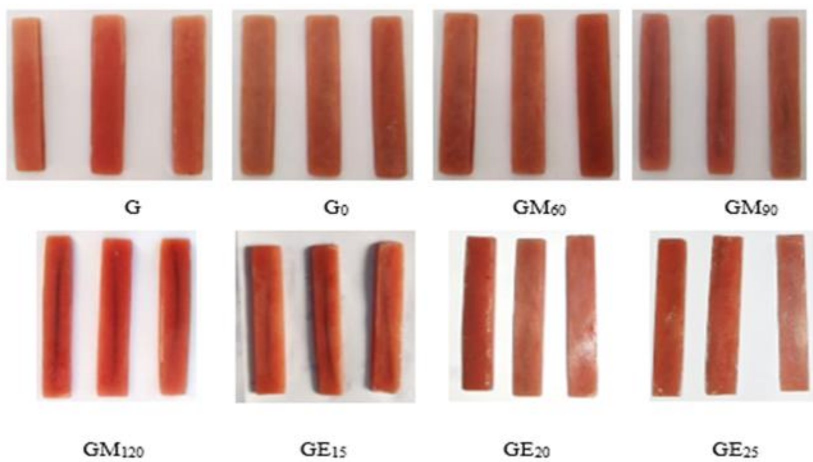

Figure 3: PMMA Sample images according to samples' notation.

The morphology of treated stainless steel 316L wires was investigated using scanning electron microscopy (SEM) (Inspect S50). The mechanical flexural strength test was performed using Instron flexural testing (Instron Company, 1195, canton mass, CHINA), as shown in Fig. 4. Every sample was clamped to a bending fixture made up of two parallel strands separated by (50mm). The full-scale load was set at 20kN. The load was applied at a crosshead speed of 500mm/min using a rod placed between the strands and deflected until the fracture occurred. Eq. (1) was used to calculate the flexural strength in MPa.

$$F.S. = 3PL \, / \, 2bd2 \tag{1}$$

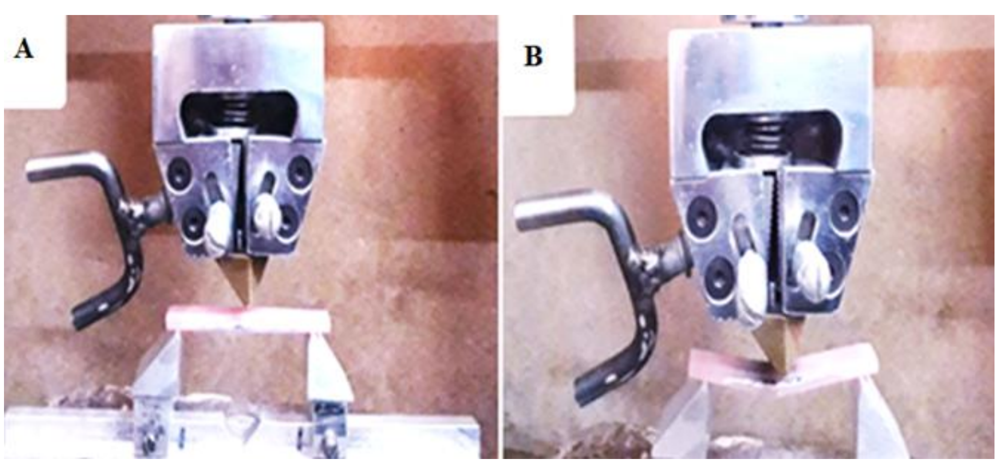

Figure 4: Flexural strength test instrument: A: The sample in test B: Sample after test.

Here, F.S. denotes the Flexural strength in MPa, P is the Maximum load in (Newton), L is the Span distance (mm), b is the specimen width (mm), and d is the specimen thickness (mm). Each group had four samples for testing to find the average value of four readings.

3. Results and Discussion

3.1. Morphological Analysis

SS316L wire surfaces were investigated morphologically to show the influence of scratching operation on the shape and sizes of scratching traces. Figure 5 displays the resulting SEM images for the unprocessed and processed SS316L wires. The image (a) has a wire having a soft surface with a small surface area that the originally existing grooves are a small number and have low dimensions, besides their distribution is disordered. The scratch method influence is shown in pictures (b), (c) and (d) obviously on the treated surfaces of the stainless steel 316L wires. Here, a plain rising in the number of grooves and their dimensions. As a result, the wire surface area is enlarged progressively as the treating period of container rotation is increased. The produced pores have low depth and various sizes besides they are distributed somewhat more uniformly than the untreated ones. It is thought that bores are produced as a result of a crossing of more than one groove. The action of treating time on the groove shape and dimensions is illustrated in Table 1. Here, the statistical procedure was conducted on the picked images for the prepared samples.

Table 1: Statistical for the surface groove on SS316L wire surfaces by scratching process.

Sample image	Scratch period (min)	Number of Grooves ($104\ \mu m^2$)	Groove length (µm)	Groove width (µm)
(a)	0 (untreated)	3	30	0.5
(b)	60	5	50	12
(c)	90	5	60	35
(d)	120	10	60	40

The statics show a generally rising in grooves density on the surface as treating time is getting longer. In addition, the groove dimensions mostly are also growing. It is important to mention that the groove dimensions are depended on the dimension and the shape of the SiC particles, in turn, smaller grains will generate a different trace. Fig. 5 shows the SEM images of the SS316L wire surfaces processed by the anodizing method. The pictures (a), (c), and (e) are belonging to anodizing times for 15, 20, and 30min respectively. The treating time of 15min, the GE_{15}, is not sufficient to produce any obvious voids by the anodizing process.

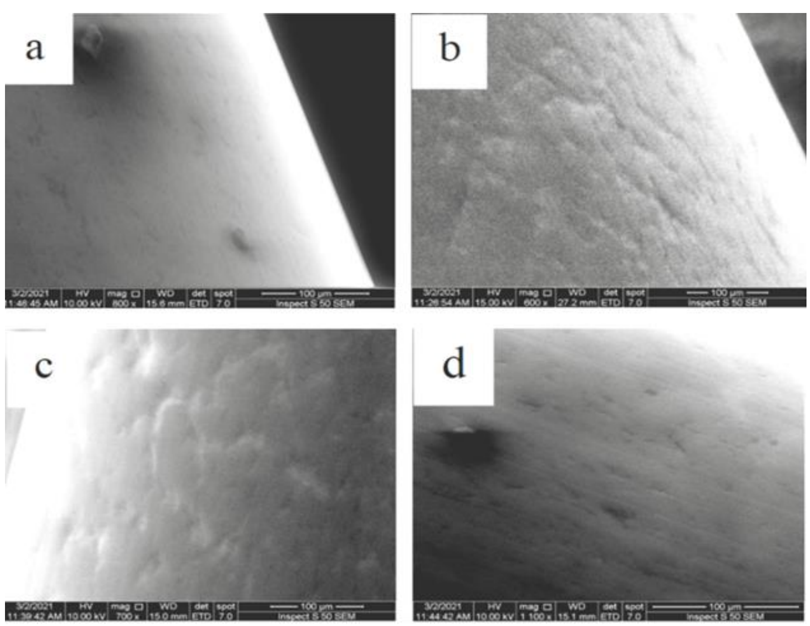

Figure 5: Scanning electron microscope images of untreated (a) and treated (b to d) scratched stainless steel 316L wire surfaces.

Here, the reaction time for producing remarkable voids is simply starting on the wire surface. The observer may recognize a “rippling” on the wire surface concerning the surface of the reference wire in Fig. 6(a) and the enlarged one in Fig. 6(b). These ripples are expected associated with metal oxides (especially iron oxides) produced on the wire surface. These ripples create plateaus and bulges as shown in the image (c) [33], a plain porosity on the wire surface can be visible with the anodizing period growing as shown in the image (e) accompanied by removing oxides and inducing the anodizing process. The investigator can specify two pore sizes in the image (e), ones associated with nano size (<200nm), which appeared as dots and larger ones that appeared as black spots (>2μm). It is believed that some irregularity in the applied electric field and current density may create a such large variance in the voids size distribution.

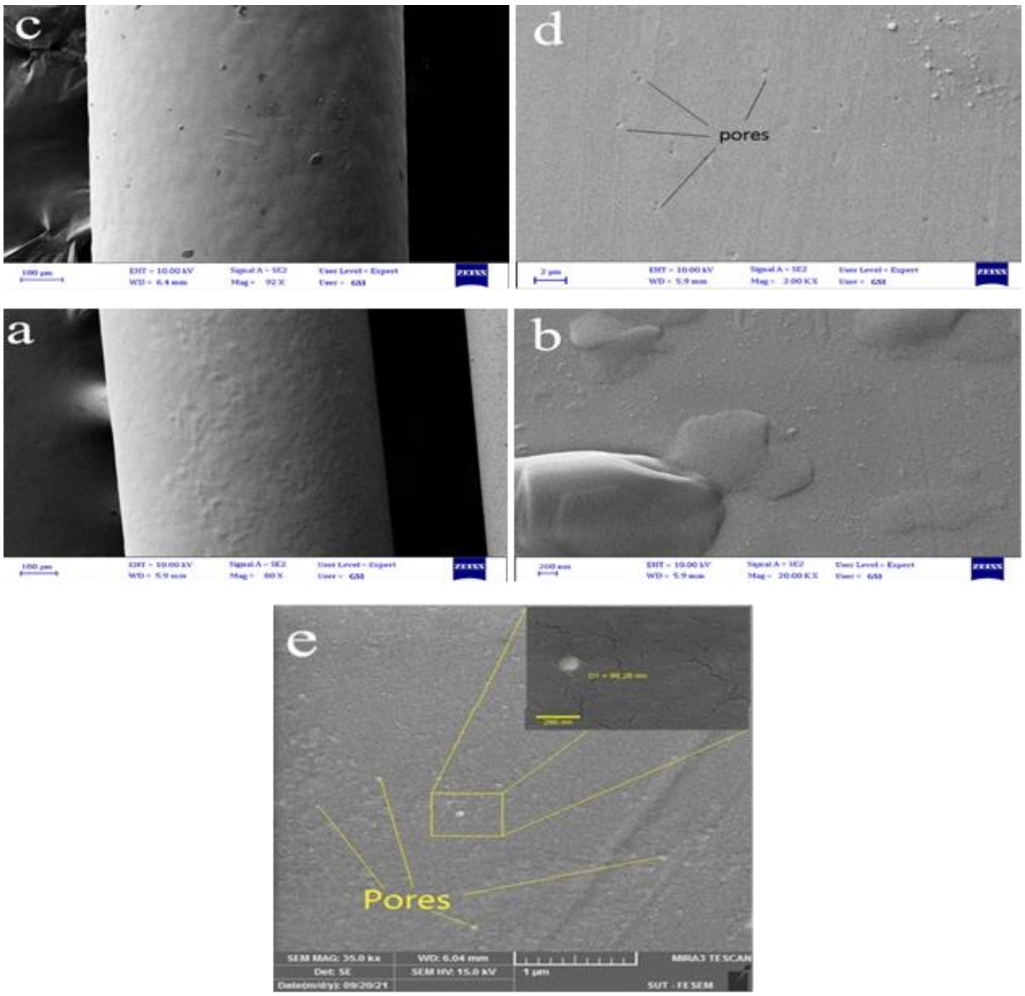

Figure 6: SEM images of anodized SS316L (a) and (b) for 15min, (c) and (d) for 20min, and (e) for 30min.

3.2 Flexural Strength Test

The Instron flexural strength test was performed for PMMA denture base acrylic resin samples. Table 2 and Fig. 7 show the values of the flexural strength test of denture base acrylic resin samples, which were reinforced with a single SS316L wire scratched by SiC powder at different times (0, 60, 90, and 120 min) and anodized SS316L wire at times of 15, 20, and 25 min. A study by Johnston et al shows that 68% of acrylic resins dentures break within a couple of years after fabrication [34]. In the Table, one can also compare the samples having the treated wire with the reference PMMA samples that have the untreated wire, sample G_0, and the sample with no wire, (pure) sample (G). The value of the flexural strength for the sample (G) was (68 MPa). This value is somewhat considered a low value, it could be improved by using untreated SS316l wire, the sample (G_0) shows a (7.35%) increment in flexural strength value. This increment indeed was due to the mechanical properties of the SS316L wire compared to the flexural strength of PMMA. When a wire of the mechanical treatment of a 60min was used, the sample (GM_{60}), a noticeable increment in the flexural strength of (20.59%) was observed compared to the unsupported samples (G). the 90min scratching SS316L wire, the sample (GM_{90}), continue raising the value of F.S to the maximum value (113 MPa) due to this treatment, as shown in Fig. 7. The effect of the modification, which took place on the surface of the SS316L wires, on the resist breakage was evident in this increasing percentage. Then after, the flexural strength decreased significantly for the sample (GM_{120}). If the mechanical treatment continued for 120 min, the number and dimension (width and depth) of grooves increased as shown in Figure 5d affecting the SS316L wire properties by producing the holes and undesired traces. This factor leads to a weak wire and in turn a weak denture material as a whole. The flexural strength test was carried out on the PMMA samples reinforced by anodized SS316L wires. Sample (GE_{15}) showed a significant improvement compared to the sample (G_0) and (G) due to the formation of ripples on the surface of the wire as shown in Fig. 6 a and b, which led to an increase in the bonding between the surface of the wire and PMMA. Sample (GE_{20}) showed a slight improvement compared to sample (GE_{15}), with an increment (21%) compared to sample (G0). Returning to Fig. 6 c and d, here, the surface pores began to be formed on the surface of the SS316L wire, which helps to increase the bonding strength between the treated wire and the PMMA. Sample (GE_{25}) the fracture toughness reached the greatest value for this treatment, with an increase of (47%) compared to the unsupported samples (G). This is due to an increase in the number of pores, as shown in Fig. 6 e. The more pores, the increase the bonding surface area between the wire and the PMMA material. Subsequently, this leads to raising the strength of the composite material with a good load distribution from PMMA material to the SS316L wire.

Table 2: The measured flexural strength (F.S.) for the prepared dentures.

Group no.	Mean (MPa)	Min (MPa)	Max (MPa)	SD
G	68	67	69	1.00
G_0	73	71	74	2.33
GM_{60}	82	80	84	4.00
GM_{90}	113	112	115	2.33
GM_{120}	60	58	62	4.00
GE_{15}	80	78	83	6.33
GE_{20}	82	80	84	4.00
GE_{25}	100	99	103	4.33

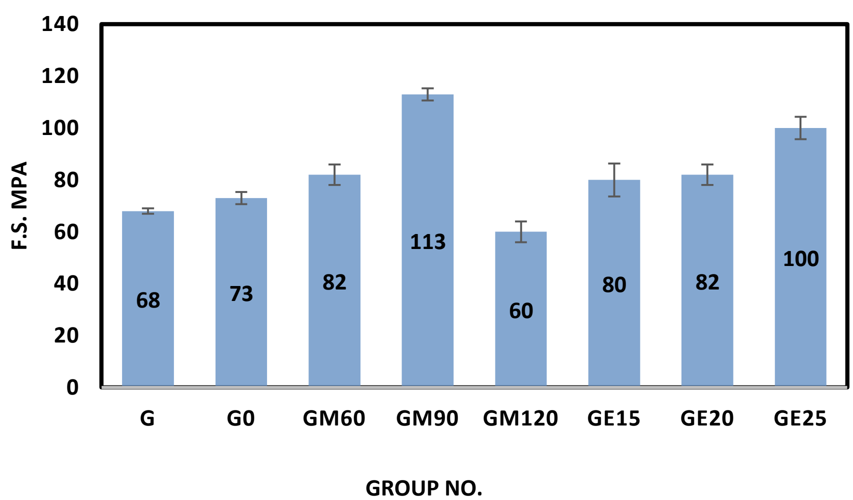

Figure 7: The flexural strength test values of denture base acrylic resin PMMA reinforced with scratched and anodized SS316L wires.

4. Conclusions

This study is depending on reinforcing the stainless steel 316L wire for PMMA as denture applications. Choosing this wire was based on its biocompatibility and reliable well known mechanical properties. The used wire was lower in thickness compared to the literature but showed comparable results. A simple, low cost and available method was adopted for scratching the wire surfaces that gives a notable enhancement to impact strength. The used wire and the proposed wire treating method are active in the preparation and improving the reinforcing denture.

Conflict of Interest

The authors declare that they have no conflict of interest.

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