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# TRIBOLOGICAL PERFORMANCE OF COMPOSITE RESIN TREATED BY CONTINUOUS AND PULSED LIGHT CURING

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## ABSTRACT
**The present work investigates the effect of continuous and pulsed light curing methods on the tribological properties of composite resin dental restorations. The objectives are to give specific information to the dentists to ensure durable restoration when applying light curing.**

**It was found that pulsed light cured specimens showed lower friction and wear than that detected for continuous light curing. Besides, friction coefficient displayed lower values in water wet sliding than that observed in dry sliding. Wet sliding showed higher wear than dry sliding, where pulsed light cured specimens showed lower wear than continuous light cured ones. In addition, pulsed light cured specimens generated lower voltage than the continuous light curing. Sliding of composite resin on bovine teeth revealed that continuous light cured specimens showed higher friction coefficient than pulsed treated ones. Light pulsed cured specimens generated higher voltage than that measured for continuously cured ones. It seems that pulsed curing allowed longer time during curing process that facilitates the free monomers to be linked to other ones, forms longer polymer chains and increases the degree of polymerization.**

## KEYWORDS
**Composite resin, continuous, pulsed, light curing, triboelectrification, friction coefficient, wear.**

## INTRODUCTION
**The chemically activated composite resin had several disadvantages such as inducing air bubbles into the resin during mixing and longer working time due to the slow polymerization reaction, [1, 2]. Therefore, light-activated composite resin is extensively used for teeth restoration. There are several types of light curing methods. It was recommended that light curing intensity should be gradient within the**

**composite to get faster polymerization closer to the light source, [3]. In the uniform continuous curing, the light of constant intensity is applied to the composite resin for a specific period of time. While, the step cure treatment, firstly low energy light is applied, then is stepped up to higher intensity, [4 – 6]. Pulsed curing light uses low intensity light to initiate slow polymerization. Then increasing the intensity of the next curing cycle provides the required energy for enhanced polymerization, [7]. The pulse delay cure includes application of single light pulse followed by a short pause and then by a second pulse of greater intensity and duration of exposure. In the start, the slow polymerization allows shrinkage to start until the composite becomes rigid. then the second pulse of greater intensity provides the composite of the final stage of polymerization, [8].**

**Adhesive teeth restoration depends on composite resin, [9]. The volumetric shrinkage is the drawback of the polymerization of the resin matrix, [10]. Volumetric shrinkage is caused by polymerization that influences the elastic modulus, [11, 12]. The stress residuals after polymerization causes microleakage, [13 - 17]. It was proved that preheating of composite resins modified the monomer mobility and polymerization rate, [18 - 20]. Besides, the polymerization stress increases as the time of light exposure increases, [21, 22].**

**The durability can be increased by the perfect polymerization of resin composites. The polymerization consists of activation, initiation, propagation and termination reactions, [23 - 29], where the free radicals are released to initiate polymerization in activation. Then free radicals are linked to other monomers forming polymer chains. The propagation means that new monomers are added to the polymer chain. The termination phase is the end of the end of the reaction. The degree of polymerization increases as the number of monomers in the chain increases, [30 - 32]. Better polymerization is favorable for good composite restoration.**

**Polymerization is the process that the monomers are linked together to form long chains of monomers forming the polymers. The monomers consist of carbon-carbon double bonds (C=C). The other atoms can be linked to the carbon atoms through the C=C double bonds. The polymerization process includes four reactions. The first is the activation process where the free radicals are released to start polymerization, [33]. The second is the propagation, [34], where the activated monomers can be linked to other monomers to form polymer chains, [35], and new monomers are added to the polymer chain. This process continues until there are no more free radicals left in the environment (36). During the propagation stage, new monomers are added to the growing polymer chain. Then the termination process happens when the reaction ends [37]. As the number of monomers are added to the chain increased, the degree of polymerization increased. Enhanced polymerization is essential in composite resin due to the developed mechanical properties and strong adhesion to the tooth cavity, [38]. It was revealed that as the degree of polymerization increased, the surface hardness increased, [39].**

**Light-activated polymerization is extensively used for polymerization of dental composites because the dentists can control their working time. The exposure time of the curing light controls the polymerization of the composite resins and bonding agents. Several types of polymerization protocols were introduced to increase the degree of polymerization and mitigate polymerization shrinkage, [40]. The first is the continuous type where the light power remains constant in different intervals such as 20, 40 and 60 seconds. The second type is the soft-start one, where low light intensity is used and gradually increased. This process extends the time for the composite to flow to the surface.**

**Recently, accelerated wear tests were performed at different loads to study wear resistance and friction coefficient of resin composite restorations. Incremental layers of composite treated by continuous and pulsed light curing modes were tested, [41]. It was found that applying composite resin in two and three layers showed relatively lower wear rather than bulk-fill. The effect of curing techniques on electrification of the composite resin was investigated, [42]. Simulation of the oral masticatory condition was carried by sliding the composite resin on bovine teeth, [43]. It was revealed that test specimens of two layers showed the highest friction at dry sliding. In addition, specimens of bulk-fill showed the highest voltage, while specimens of layers displayed the lowest voltage.**

**The objective of the present study is to study the influence of continuous and pulsed light curing modes on the tribological properties of composite resin dental restorations.**

## EXPERIMENTAL

**The composite resin was treated by continuous and pulsed curing light. The tested specimens were prepared in form of cylindrical pin of 12 mm and 6 mm diameter. Light curing was applied for 20 seconds on the top surface of the specimens. Three groups of experiments were carried. The first group was performed to evaluate the wear resistance of the tested specimens through accelerated abrasive wear at 1.5 m/s sliding velocity for 30 seconds at 8, 10 and 12 N load. The second group was performed at reciprocating motion of 40 mm stroke of 30 strokes per minute, where the counter surface was abrasive paper at 2, 6 and 10 N load. While the third group was carried out with the same arrangements of the second group but the counter surface was replaced by piece of bovine tooth of 25 × 12 $mm^2$ surface area. Friction coefficient (μ) was determined by dividing friction force on applied load where friction force was recorded by load cell. The composite resin pin was assembled in steel cap as the first terminal while the steel substrate under the abrasive paper or bovine tooth as the second terminal to measure the voltage by digital voltmeter of ± 0.1 mV accuracy. The details of measuring voltage are shown in Fig. 1. Wear was evaluated by the weight loss after test by electronic balance of ± 1.0 mg.**

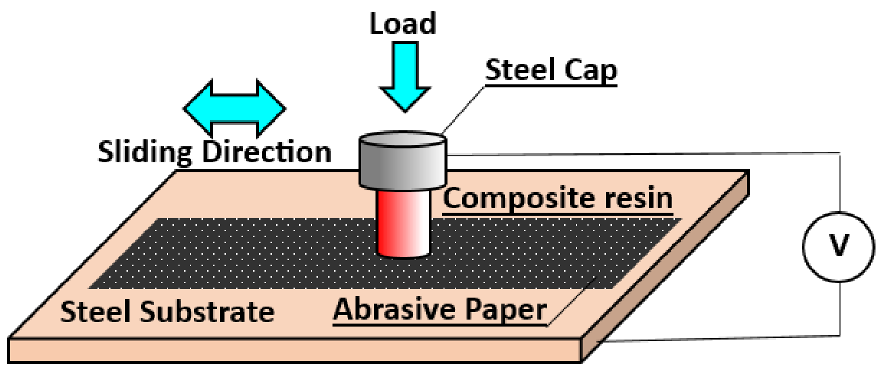


Fig. 1 Details of the wear tester.

**RESULTS AND DISCUSSION**

The comparative friction behavior displayed by the sliding of the composite resin of the first group that treated by continuous and pulsed curing light is shown in Fig. 2. It is seen that specimens treated by pulsed curing light showed relatively lower friction than that observed for continuous curing mode. This observation confirmed the ability of pulsed curing to decrease friction.

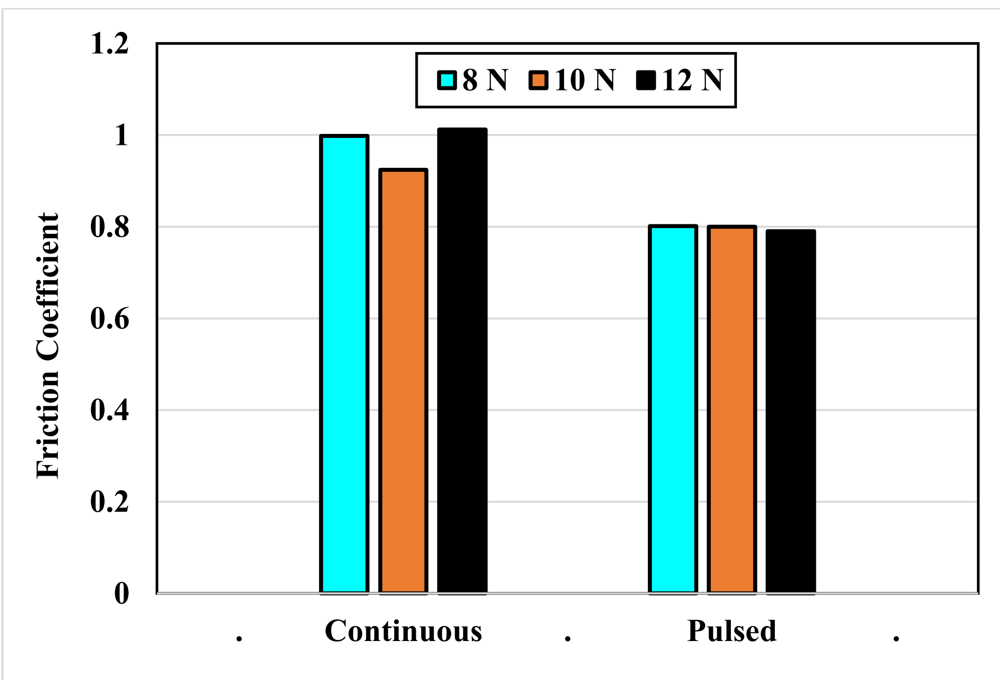


Fig. 2 Friction coefficient displayed by the sliding of test specimen prepared by continuous and pulsed curing light (group I).

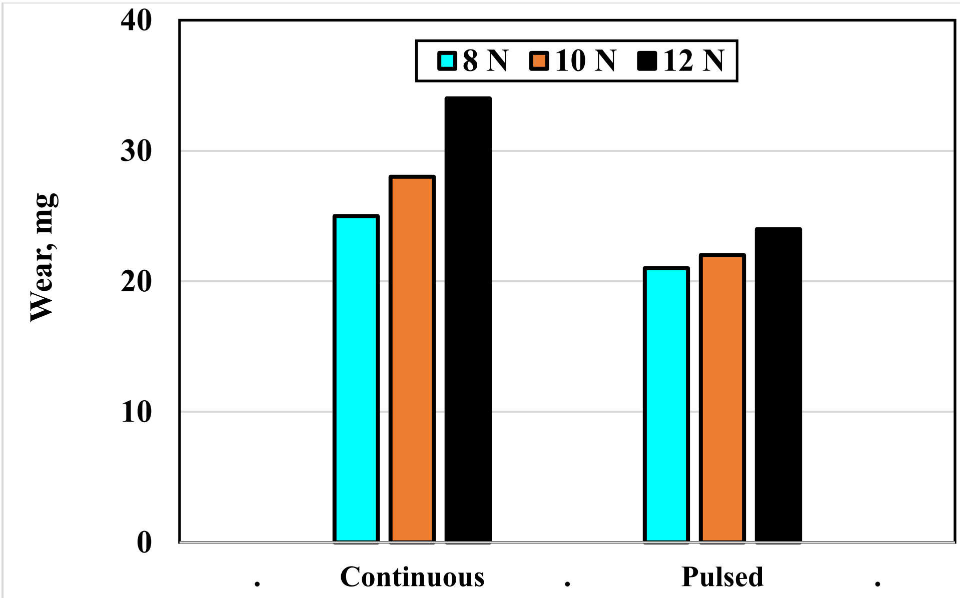


**Fig. 3 Wear displayed by the sliding of test specimen prepared by continuous and pulsed curing light (group I).**

**Wear increased with increasing the applied load, Fig. 3. Specimens treated by pulsed light displayed lower wear values than that cured by continuous light. The wear reduction revealed that pulsed light treatment enhanced the degree of polymerization and increased the crystallinity of the composite resin. It seems that pulsed curing offered longer time in curing process allowing the free radicals to be linked to other monomers forming longer polymer chains and developing the degree of polymerization and consequently the mechanical property and wear resistance increased.**

**In the experiments of the second group, the friction coefficient displayed by the test specimens at dry sliding is illustrated in Fig. 4. Test specimens prepared by continuous curing displayed higher friction than pulsed ones. Friction coefficient gradually decreased as the applied load increased due to the heat accompanied to sliding at higher loads. A polymeric layer of low shear strength was formed on the sliding surface due to the heat rise and consequently friction coefficient decreased. Water wet sliding displayed lower values than that observed in dry sliding, Fig. 5. The wear of the test specimens at dry and water wet sliding conditions is illustrated in Fig. 6. It is shown that wet sliding displayed higher wear than dry sliding. It seems that the water removed the worn particles of composite resin adhered in abrasive paper then the silicon carbide particles became more abrasive. Besides, specimens treated by pulsed light showed lower wear than that cured by continuous light.**

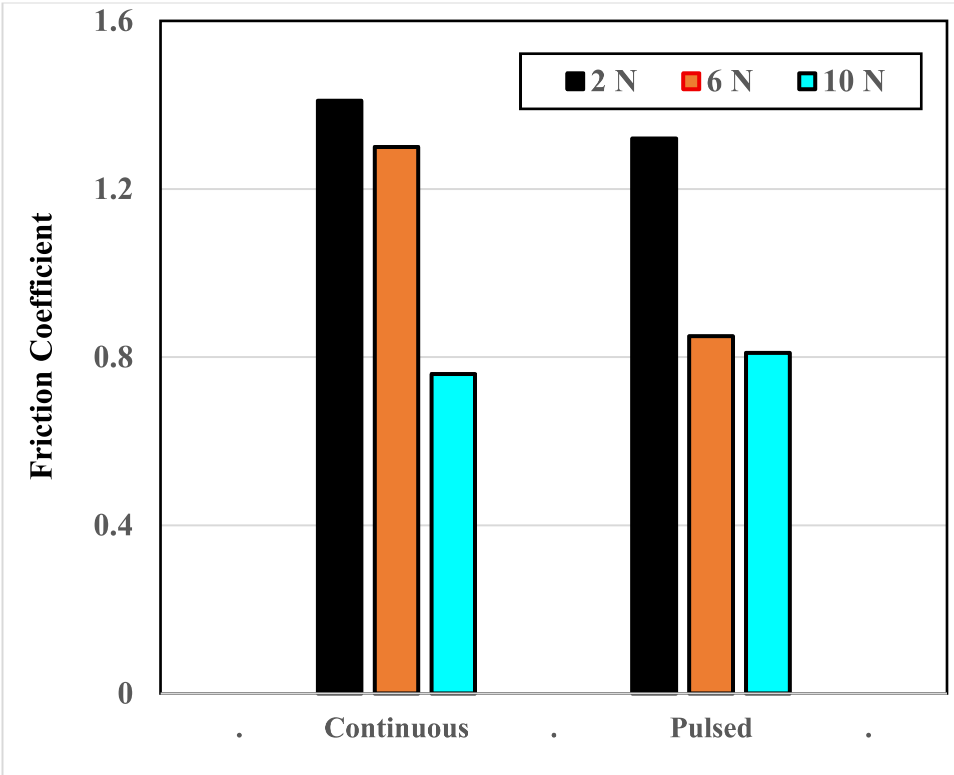


**Fig. 4 Friction coefficient displayed by the dry sliding of test specimens (group II).**

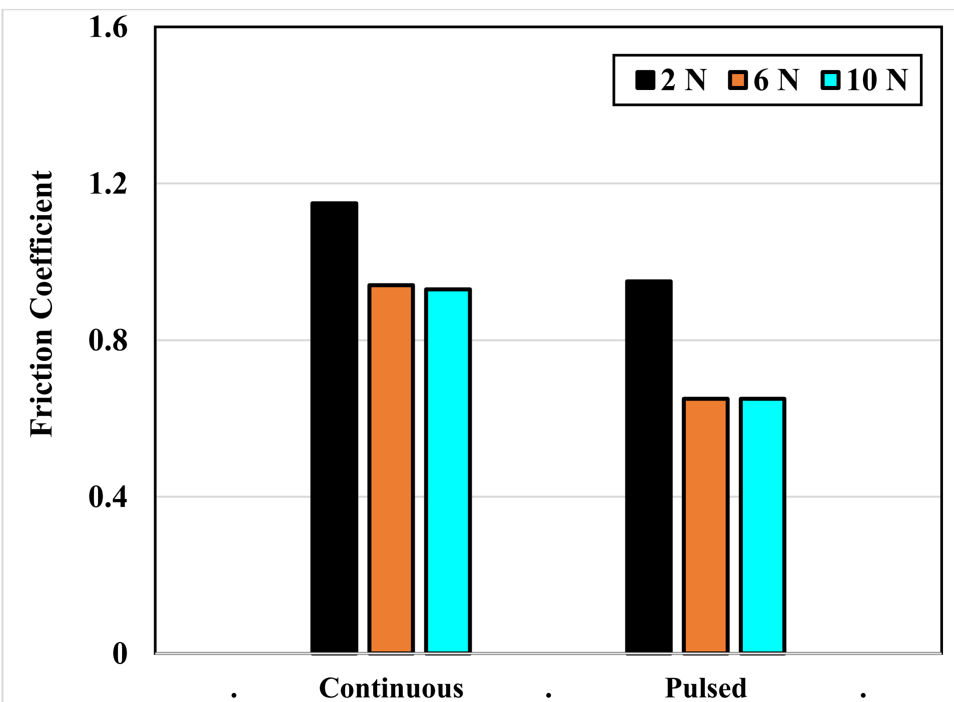

**Fig. 5 Friction coefficient displayed by the water wet sliding of test specimens (group II).**

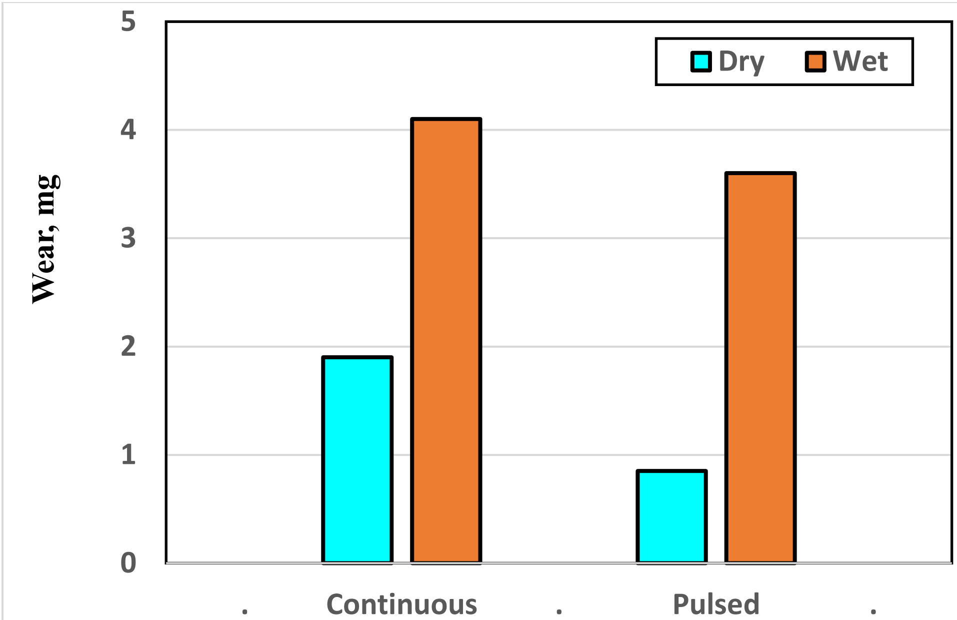


**Fig. 6 Wear displayed by the sliding of test specimen (group II).**

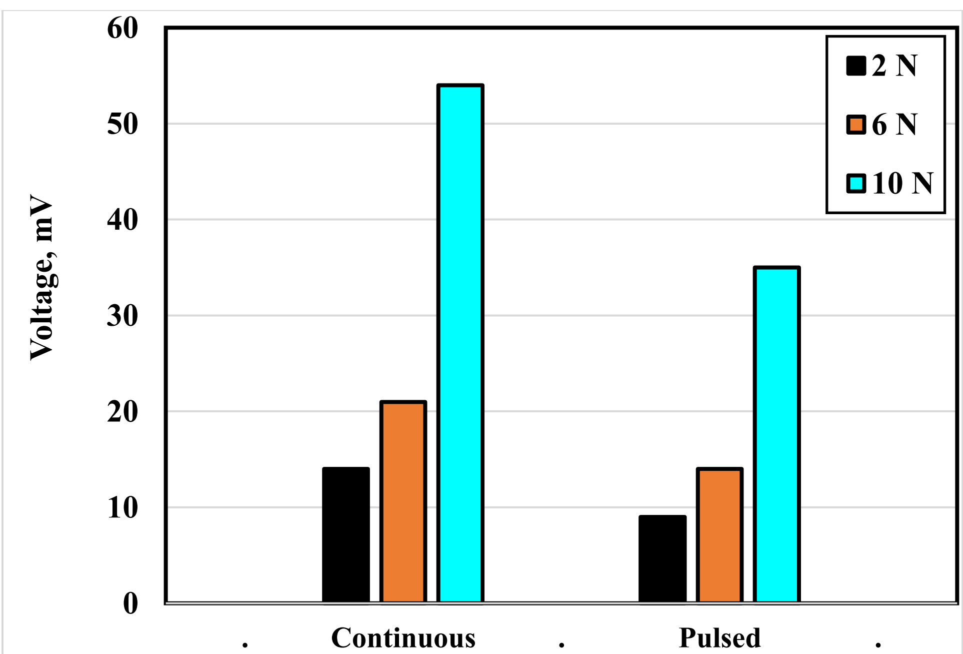


**Fig. 7 Voltage generated from the dry sliding of the test specimens (group II).**

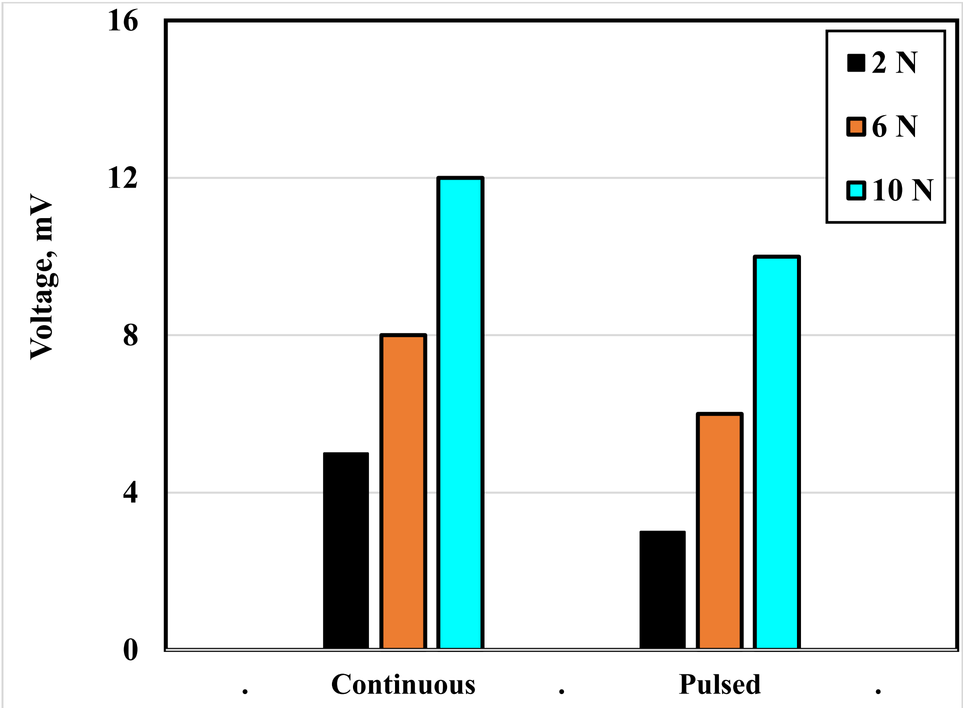


**Fig. 8 Voltage generated from the water wet sliding of the test specimens (group II).**

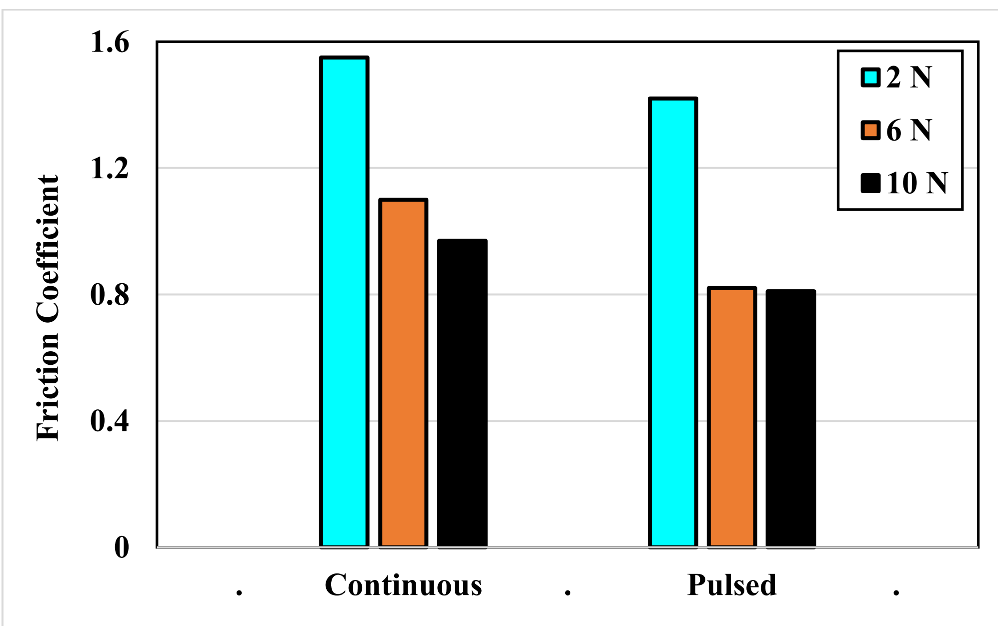


**Fig. 9 Friction coefficient displayed by the dry sliding of test specimens (group III).**

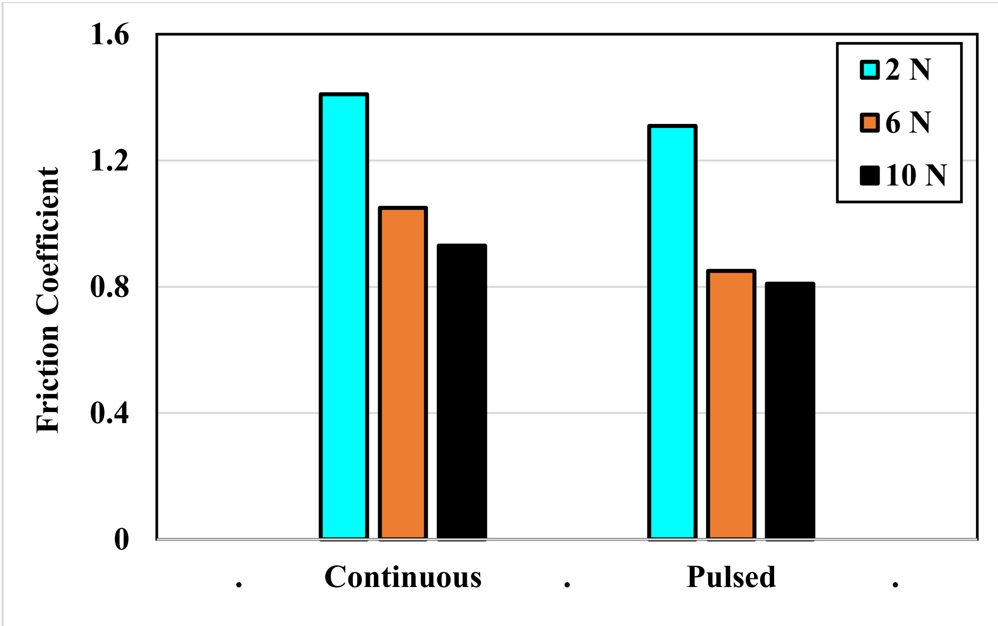


**Fig. 10 Friction coefficient displayed by the water wet sliding of test specimens (group III).**

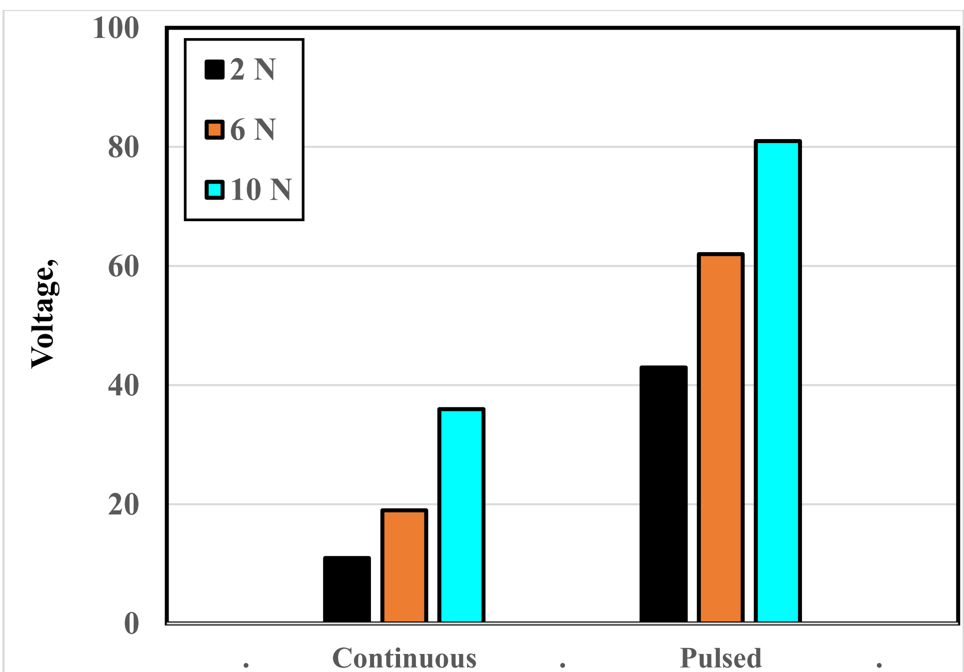


**Fig. 11 Voltage generated from the dry sliding of the test specimens (group III).**

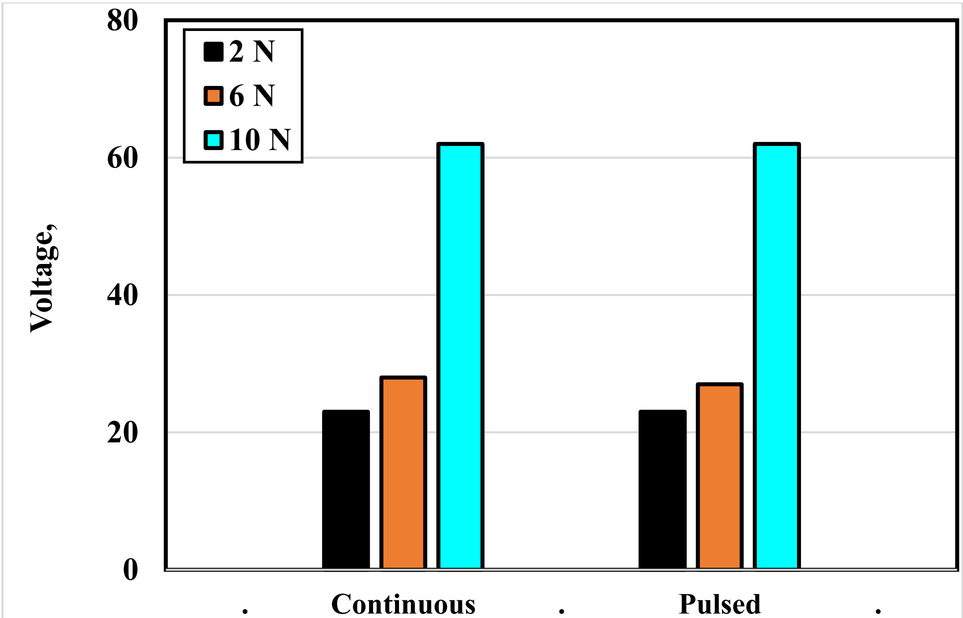


**Fig. 12 Voltage generated from the water wet sliding of the test specimens (group III).**

**It is necessary to measure electrostatic charges (ESC) generated from the sliding of composite resin restoration on teeth. It is found that human teeth generate ESC through the piezoelectric effect due to the mechanical stress, where dentin generates higher ESC than enamel. Added to that, electric current can be generated from amalgam fillings due to galvanism. Besides, electric toothbrushes induce electric currents in teeth through the electromagnetic fields. The generation of ESC in the mouth from the sliding of dissimilar materials of dental restorations on each other can act as oral galvanism in the medium of saliva and influence the human health.**

**Voltage generated from the tested specimens slid on dry and wet abrasive paper increased with increasing the applied load as result of the increase of the contact area, Figs. 7, 8. Besides, at water wet sliding, Fig. 8, voltage decreased due to the presence of water that conducted the voltage generated on the two sliding surfaces. Pulsed light cured specimens generated lower voltage than that measured from the sliding of the continuous light cured specimens.**

**In the third group where the composite resin slid on bovine tooth, friction coefficient displayed by the composite resin treated by continuous curing light was higher than that observed for pulsed treated test specimens at dry and water wet sliding, Figs. 9 and 10 respectively. At water wet sliding, friction showed slight decrease compared to the dry sliding.**

**Voltage generated from the sliding of composite resin on bovine tooth are shown in Figs. 11, 12, at dry and water wet sliding respectively. The dry sliding of the test specimens cured by continuous light, Fig. 11, showed lowest voltage values compared to that cured by pulsed light. Water wet surfaces displayed the same voltage values, Fig. 12, for continuously and pulsed light cured specimens.**

## CONCLUSIONS

**1. Pulsed light cured specimens showed lower friction and wear than that detected for continuous cured ones. Friction coefficient in water wet sliding displayed lower values than that observed in dry sliding.**

**2. Wet sliding displayed higher wear than dry sliding, where pulsed light cured specimens showed lower wear than that observed for specimens treated by continuous light.**

**3. Pulsed light cured specimens generated lower voltage than the continuous light cured ones.**

**4. When the composite resin slid on bovine tooth, continuous light cured specimens showed higher friction coefficient than pulsed cured ones. In the presence of water, friction showed slight decrease compared to the dry sliding.**

**5. Pulsed cured specimens generated higher voltage than that measured for continuously cured ones, while water wet surfaces displayed the same voltage values.**

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