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İSTANBUL YENİ YÜZYIL UNIVERSITY

HEALTH SCIENCES INSTITUTE

DEPARTMENT OF ORHODONTHICS

EVALUATION OF SHEAR BOND STRENGTH OF REBONDED ORTHODONTIC BRACKETS AFTER DIFFERENT RECYCLING METHODS

MASTER OF THESIS

USAMA IBRAHIM BSHAYA

Supervisor

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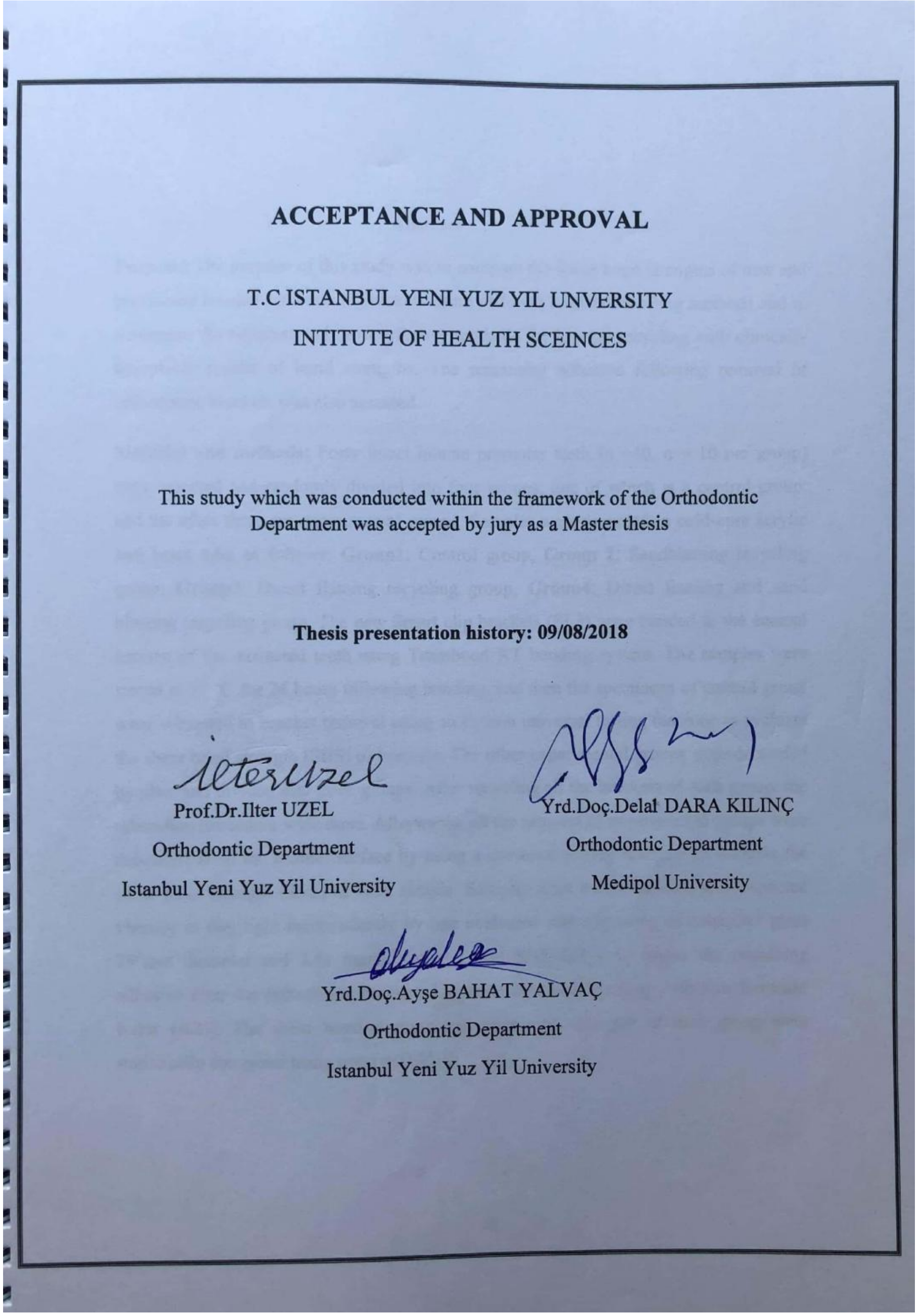

ACCEPTANCE AND APPROVAL

T.C ISTANBUL YENI YUZ YIL UNVERSITY
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This study which was conducted within the framework of the Orthodontic Department was accepted by jury as a Master thesis

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Abstract

Purpose: The purpose of this study was to compare the shear bond strengths of new and previously bonded orthodontic brackets using different bracket recycling methods and to determine the simplest and most effective methods for bracket recycling with clinically acceptable results of bond strengths. The remaining adhesive following removal of orthodontic brackets was also assessed.

Material and methods: Forty intact human premolar teeth (n =40, n = 10 per group) were selected and randomly divided into four groups, one of which is a control group, and the other three are experimental groups. Samples were mounted in cold-cure acrylic and brass tube as follows: **Group1**: Control group, **Group 2**: Sandblasting recycling group, **Group3**: Direct flaming recycling group, **Group4**: Direct flaming and sand blasting recycling group. The new Smart clip brackets (SL3) were bonded to the enamel surface of the extracted teeth using Transbond XT bonding system. The samples were stored at 37 ˚C for 24 hours following bonding, and then the specimens of control group were subjected to bracket removal using an Instron universal testing machine to evaluate the shear bond strength (SBS) of brackets. The other experimental groups were debonded by plier and divided into three groups. After recycling all the brackets of each group, the rebonding procedure were done. Afterwards, all the samples of experimental groups were debonded from the enamel surface by using a universal testing machine to evaluate the shear bond strength (SBS) of each sample. Samples were then examined and inspected visually in day light independently by one evaluator with the using of magnifier glass 75°mm diameter and 2.5x magnification (No: SBR-227), to assess the remaining adhesive after the orthodontic brackets had been removed by using Adhesive Remnant Index (ARI). The shear bond strength and remaining adhesive of each group were statistically compared using t-test $p<0.05$.

RESULT: The control group with new brackets had significantly highest value of shear bond strength **(17.7670)** when compared with other experimental groups, followed by direct flaming / sandblasting technique **(15.5644)**, then sandblasting technique **(10.4908)**. However, the lowest value of shear bond strength had been scored in the group of direct flaming technique **(5.6430)**.

The mean residual adhesive of control group **(1.40)** had showed significant difference of mean ARI value when compared with the second and third groups **(2.90) (p=0.002)**, **(2.60) (p=0.034),** respectively. On the other hand, the mean ARI of control group did not show significant difference when compared with group four **(1.10) (p=0.323)**.

Conclusion: The null hypothesis of the study was rejected. It was concluded that the new premolar smart clip metal brackets had highly SBS values compared with recycled ones. The brackets that had been flamed / sandblasted were higher in SBS than those were recycled either by sandblasting only or flaming only. Recycling by flaming can lead to significantly lower SBS, because of decreasing corrosion resistance which can lead to softening of bracket metal. Bracket recycling with sandblasting is considered the simplest, fastest and more efficient technique, which reduces the working time and cost as well as can provide comparable and adequate SBS that meets the clinical requirements needed with less changes in the physical properties of the recycled brackets.

The brackets with high SBS showed higher frequency of scores 0 and 1 with less adhesive remained on teeth surfaces, whereas the bond failure of less SBS brackets occurred at bracket-resin interface with predominant ARI score 2 and 3 with excessive amount of adhesive remained on teeth surface.

Key Wards: Shear bond strenght, Bracket recycling, Reconditioning, Debonding, Rebonding, Sand blasting, Direct flaming.

Dedication

This work of master thesis is dedicated to:

My parents

IBRAHIM & NAEEMA

Who were always being the source of my hope, passion and enthusiasm

by their wishes, encouragment and support to achive my goals.

To my wife SARA who stood by me along with my postgraduate educational gourney and life.

To my children ARIEN & IBRAHIM.

To my brothers and all of my family and friends who alwayes wishes to me

a bright future.

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It is a pleasant moment to express my thanks to all who contributed and helped this research study to succeed which made deep impression on me.

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Life would not be easy without constant care and support. Therefore, I wish to express my deepest gratitude to my parents, wonderful brothers, family and friends who always believed in me and support me throughout hard times.

I would like to offer heart filled gratitude to my wife and my children for their love and encouragement, also for being my life companion.

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List of symbols and abbreviations

H3PO4:	Phosphoric acid
GIC:	Glass Ionomer Cement
RM- GIC:	Resins modified glass ionomer cement
HEMA:	Hydroxyethyle Methacrylate
SL3:	Slef ligating bracket system
SHR:	Specimen holder ring
SBS:	Shear bond strength
ARI:	Adhesive Remnant Ring
min:	Minute
sec :	Second
Cm:	Centimeter
mm2:	Millimeter square
µm :	Micrometer
MPa:	MegaPascal
PSI :	Pounds per Square Inch
KG :	Kilogram
N :	Newton
ANOVA :	Analysis of variance
p :	Level of statistical significance
(˚):	Degree
(%):	Percentage
AL2O3	Aluminum oxide

1- LITERRATRURE REVIEW

1.1 Introduction and history of orthodontic bonding

Generally, brackets and tubes are devices used to transfer the applied forces to the teeth. Fixed orthodontic treatment was previously performed by welding of orthodontic brackets to stainless steel bands which were cemented to all teeth. This procedure was impractical and took long chair time work (1). In addition, it could harm and damage the periodontal or/and dental tissue in case of less oral hygiene care. Using molar tubes lead to less declassification that could occur beneath the bands. (2)

Bonding of orthodontic attachments is widely used nowadays, not only in fixed appliances but also with removable appliance (Betteridge, 1979) (3) and became universally applicable technique in orthodontics in the nineties of the last century (Fox, McCabe and Buckley, 1994) (4).

In orthodontics, continuing efforts have been performed to influence the technical procedures in order to decrease the cost of treatment and save the operative time. In 1955, Buonocore introduced the acid etch bonding technique, where the concept of enamel- resins bonding has been developed in dentistry fields as well as orthodontics (1).

Many researchers have mentioned the advantages of direct bonding of orthodontic attachments to the tooth surface such as; Aesthetically superior, simpler, faster (save time), less discomfort for the patient (no band seating and separation). arch length is not increased by band material, allowing more precise bracket placement, more hygienic than bands (better access for cleaning), partially erupted or fractured teeth can be controlled, caries risk under loose bands is eliminated, there are no band spaces to close at the end of treatment, brackets may be recycled (further reducing the cost), lingual brackets invisible braces can be used when the patient rejects visible orthodontic appliances, attachments may be bonded to fixed prosthetic bridgework when the bridge is not made from metal, decreased incidence of gingival irritation with bonding, and debonding is easier after treatment completion (7-16).

This etching technique has greatly increased the mechanical bonding between the enamel surface and adhesive material, providing optimal bonding of orthodontic attachments to enamel surface, which influence the placement procedure of brackets and widen the perspectives in Orthodontics (5), where the quality and design of brackets have been developed by the manufacturers to improve treatment quality (6).

The bonding material should penetrate the surface of enamel to be dimensionally stable and obtain adequate bond strength (17). The idea of etching technique as Bounocore proved in 1955, after the enamel being etched by acid, the surface area is increased as a result of roughening the outer layer by dissolving enamel menials, to create an irregularities and remove the smear layer. This will help the adhesive fluid component to penetrate the pores and form micromechanical retention after polymerization (1).

Reynold (1975) stated that the shear bond strength of orthodontic attachments should be high enough to be able to withstand the applied forces during treatment and keep attached to teeth surface, meanwhile providing easy debonding without harming the enamel surface. He has also reported that the optimal bond strength value ranged between 6 to 8 MPa which is adequate to resist orthodontic treatment forces (18).

The most frequent problem happening in orthodontics practice is bracket failure which is an economic disadvantage and may also cause stress and delay in course therapy. The oclusal forces (patients applied inappropriate force by mistake to the bracket), poor bonding technique, and low retentive bracket base are the main factors of bracket failure (19) (20). Clinicians are commonly faced with the decision of what to do with broken or incorrect positioned brackets that require repositioning during treatment. Currently, interest in the reconditioning of metallic direct bonding orthodontic brackets has increased either because of economic reasons or to reduce chair time work (21).

There are several methods used for bracket recycling, which could be performed not only in specialized companies (commercial recycling), but also in dental practice (in- office recycling) (22).

1.2 Enamel

1.2.1 Enamel composition and morphology

Fully formed enamel is the hardest substance in the human body, consisting of 96% mineral mainly in the form of hydroxyapatite and 4% water and organic material. The enamel does not contain collagen, as found in other hard tissues like dentine and bones, but it rather contains two unique classes of proteins: amelogenins and enamelins (23).

Enamel is a brittle substance. Although the hardness is comparable to that of mild steal, the underlying layer of more resilient dentin is necessary to maintain its integrity (23). The normal color of enamel differs from light yellow to gray (bluish) white. Since enamel is semitranslucent, the color of dentin underneath strongly affects its appearance. On the edges of the teeth where there is no underlying dentin, the color of enamel sometimes has white or slightly transparent tone, which can be easily seen on the upper incisors (23). The enamel thickness varies from a maximum of approximately 2.5mm over the cusps to a feather-edge at the cement-enamel junction (23).

When viewed in transverse section, the striae of Retzius appear as a series of dark lines extending from the dentino-enamel junction toward the outer surface of enamel, where they end in shallow furrows known as perikymata (23). The ameloblasts are destroyed after the maturation phase and before the eruption of the tooth, which cause the enamel to be non-generative

1.2.3 Enamel structure

The fundamental organizational unit of enamel is called an enamel rod, formally known as enamel prisms, measuring 4-8 microns in diameter. The enamel rod is a mass formed by long and closely packed crystals of hydroxyapatite in a structured pattern (23). When seen in cross section, enamel rods appear similar to a keyhole, where its head is directed toward the crown, and its bottom is directed toward the root (23).

Understanding the direction of enamel is very crucial in restorative dentistry, since enamel has to be supported by underlying dentine, otherwise it will be susceptible to break. Enamel rods are generally oriented at right angle to the dentin, with a slight divergence toward the root in the cervical third of permanent teeth (23).

The area that surrounds the enamel rod is referred to as interrod enamel. Both rods and interrod enamel are identical in composition, and they only differ in the orientation of their crystals. The rod sheath is the boundary where the crystals of both enamel rods and interrods meet (23).

1.2.2 Enamel Development

Tooth development stages are generally recognized as the Bud stage, the Cap stage, the Bell stage and the Crown stage. Enamel formation occurs in crown stage (also known as calcification stage) (23).

After the establishment of dentin, the ameloblasts begin to form enamel in a process called amelogenesis. Amelogenesis is a complex process, but can be basically divided into two phases: the first phase, known as the Secretory phase, where proteins and organic matrix form a partly mineralized enamel, and the second phase, Maturation phase, where further mineralization of enamel is taking place (23).

1.2.4 Bonding to enamel

Direct bonding to enamel has always been a challenge to clinician in dental practice. Many clinical techniques with different types of bonding materials were attempted to reach and find the best and optimal bond strength value.

Adequate orthodontic bonding is based on three main components: bonding of material itself (bond strength, material composition), tooth surface (morphology, surface preparation), and orthodontic base attachment characteristics (mechanical and material properties) (24)(25). There are a variety of resins available to be used in orthodontics such as chemically, light activated, and filled resins and other cements.

A sufficient marginal seal and less bonding material around the bracket to avoid caries or white spot lesion with high of SBS are the aims of direct orthodontic bonding.

Direct bonding of orthodontic attachments to enamel surfaces has become widely used clinically in orthodontics since it was developed in 1955 by Buoncore (1). The bond strength of attachments should be adequate to withstand the masticatory forces as well as stress generated from the heavy arch wires. However, the bond strength between the enamel and the orthodontic bracket might be affected by several factors such as acid etching technique (concentration, length of etching time), composition of the adhesive, bracket base design, the oral environment, in addition to the skill of the clinician (26).

1.3 Tooth surface preparation and conditioning

1.3.1 Prophylaxis

Cleaning the tooth surface is necessary in order to receive bonded (direct & indirect) restorations. Removing the discoloration and plaque accumulation before enamel etching could be done using dental prophylaxis (pumice powder or paste) with a brush or rubber cup in low speed handpiece, which is the most common technique. However, many other faster and more efficient prevention techniques, such as airflow and bicarbonate jet polishers could be used, but they may harm tissues and contaminate surfaces.(27)(28)(29)(30) (31).

Pus and way, (1980); Thompson and Way, (1981) have concluded that enamel could be abraded as much as 10 µm after initial prophylaxis using bristle brush for 10 to 15 seconds, whereas only 5 µm from the enamel might be lost when a rubber cup is used (32)(33).

The tooth surface is covered by a protein film known as pellicle, which is shapeless, organic, without cells. It is necessary to remove the invisible acquired pellicle even in patients with good oral hygiene, which covers cleaned tooth surfaces in a few minutes. (34). This acquired pellicle is important, especially in enamel demineralization/re-mineralization process (35)(36). In clinical terms, it has been revealed that the effectiveness ability of acquired pellicle to protect the tooth surface is unknown, as well as dental surface response to acid exposure (37).

1.3.2 Enamel surface conditioning / Etching

Enamel surface etching technique firstly introduced by Bounocore in 1955, by using weak acid such as phosphoric acid (H_3PO_4), with a concentration of 85 % for 30 seconds to improve the retention between enamel and acrylic resins. The application of acid etching technique was aimed to roughen the surface with microscopic irregularities in enamel surface to form mechanical resin tag that interlocks between enamel and adhesive (Buonocore, Matsui & Gwinnett., 1968) (38). This process has resulted in an increase of surface area for the mechanical attachment (Buzzitta, Hallgren & Powers., 1982) (39).

The effect of acid etching can vary depending on duration of etching on enamel surface, type of etchant used, and condition of enamel surface, which are considered as an important variables (40).

Acid etching technique can form three types of patterns: type I, in which enamel rods are predominantly dissolved; type II, in which the area around the enamel rods is dissolved, and type III in which there is no evidence left of enamel rods. The most favorable pattern is type I, whereas type III is the least. The reasons behind the differences between the patterns are unknown, but is most commonly related to differences in enamel crystals orientation (41).

Bonding of resin material to the teeth surface is generally based on the changes on enamel surface due to acid treatment, which include removing of smear layer, presence of micro porosity and increasing the permeability. The micro mechanical retention plays a major role in bonding after penetration of polymerizable monomers into the interprismatic spaces to form enamel resin tags.

Many studies have concluded that resin tags penetration depth ranges between 8 and 15 microns to reach a maximum length up to 50 microns(42), whereas the surface area of enamel lost varies between 10 to 30mm. On the other hand, about 55.6mm of enamel surface could be lost as a result of cleaning procedure after debonding (43).

Like other conceptual and technological innovations, the procedure was introduced in dentistry ahead of its time and after 10 years the bonding mechanism was described (44).

1.3.3 Etching time and concentration of etchant

Although the acid etch application is a widely used technique in dental practice, the optimal duration of acid application and concentration still remain highly controversial among the researchers. The inventor of acid etching technique, Bounocore in 1955, recommended to use 85% phosphoric acid for 30 sec (45), but this time was increased at the time of first clinical use in 1960 to 60 sec (44)(46).
Silverstone, 1974 and Retief., (1974) in their investigations found that using acid etch with a concentration of 20-50% for 1 to 2 minutes produced the most retentive condition.(47)(48) .

The duration of etching time was reduced again in 1980 to 30 sec, and the appliction is still used until today(49)(50). Some researchers suggested to decrease the etching time to 15 sec when the concentration of phosphric acid between 32% to 40% is used (51). Legler *et al* (1989) evaluated the effects of duration and concentration of phosphoric acid on shear bond strength of an orthodontic bonding resin. His findings showed phosphoric acid concentration did not significantly affect the SBS, whereas the duration of etching had a significant effect on the bond strength (52).

Wang and Lu., (1991) in their study compared the bond strength after using the same concentration of phosphoric acid 37% with different etching time 15-, 30-, 60-, 90-, and 120 seconds. They found that a good retention is obtained when using 15 sec etching time, which is suggested for teenage patient to decrease enamel loss and to save operative time. Some enamel fragments were found in etching time group over 30 sec. The size of fragment was proportionally increased with increase of etching time (53).

Hermsen and Vrijhoef., (1993) compared two types of etching solution, 10% aleic acid and 35% phosphoric acid, and concluded that in less enamel loss with same enamel surface structure to phosphoric acid, with etching time 15 to 120 seconds (54). In 1998, MacColl and coworkers achieved a high shear bond strength using 10% aqueous maleic acid, compared to 37% phosphoric acid gel and 37% phosphoric acid aqueous solution. The study, however, did not show a significant difference between the three acids (55).

The application of 30% to 60% acid concentration for 30 to 60 seconds are the most extensively used concentrations of phosphoric acid in dentistry. (Newman, 1965; Retief, 1974a; Retief,1974; Bryant et ai,1987; Surmont *et a/.,* 1992*;* MacCoII *et al 1*998). (7)(55)(56)(57)(58)(59). (Retief, 1974) had stated that 30% to 50% of acid concentration had recorded the highest bond strength value (57).

1.4 Adhesives

1.4.1 Orthodontic cements and adhesives

Since the introduction of direct bonding in orthodontic treatment, bonding of orthodontic brackets to dental surface has been an important issue. The use of resin and hybrid resin-cement is getting more popular, because they offer better physical properties. (60)

Composite resin is one of the most widly used adhesives in orthodontic practice because of its handling, simplicity and adequate bonding strength. On the other hand, bonding of resins to tooth surface takes place only by mechanical interlock, as they require moist free field and their anticaries effect is limitid because of the insufficient release of fluoride.

Resin-modified glass ionomer cements are the most recent generation of glass ionomer cements. They outclass the composite resins in terms of their renewable fluoride release properties, as well as their ability to provide adequate bonding in moist field. Superior bonding strength is also provided by chemical bonding in addition to micromechanical lock with tooth surface irregularities (60).

1.4.2 Ideal Requirements Of Orthodontic Adhesive

Orthodontic adhesives should provide bracket stability for the whole treatment duration and enable easy removal of brackets without damaging the tooth structure or causing notable discomfort to the patient(61)(62). The adhesive should be non-irritant. While positioning brackets, the adhesive working time should be long enough and the setting time should be as short as possible for more patient comfort. Its application should be easy, curing should be convenient, and has the qualityof fluoride release (63).

1.4.3 Glass ionomer cement

Glass ionomer cements were introduced in 1972 by Wilson and Kent as a material for restorative treatment, and later used as a cement. The first generation Of GICs consists of aluminosilicate glass powder and an alkenoate acid liquied, setting reaction of GICs considered acid base reaction. The second generation of GICs combined a freeze-dried acid powder in addition to glass and distilled water (64). The original glass ionomer cements (GICs) were brittle and water-based substances which set by acid-base reaction between a polyalkenoic acid and fluroaluminosilicate glass materials. To enhance their physical properties, metal particles (silver or gold) were added, (ceramic, metal) were fused resulting in a cermet, or the addition of amalgam alloy particles (admix) (65).

However, handling proprties and accurate dispensing of the liquid component are difficult because they are prone to be affected by moisture during the setting reaction. The encapsulated cements are a better option, but are more expensive and wastage of material is probable (64).

1.4.4 Zinc poly-carboxylate cement

Polycarboxylate cement is obtained by the reaction of zinc oxide and a polycarboxylate acid solution. A chemical bond between the cement and the tooth results from the chelation of the carboxyl groups to the calcium of the tooth.

Mixing the zinc oxide powder into the viscous polycarboxylate acid is difficult to control (66).

In the early 1970s zink polycarboxylate cements were utilized in orthodontic treatment inspite of their short working time, weak bonding strenght, solubility and high viscosity (64).

1.4.5 Zinc-phosphate cement

Zinc phosphate cement is produced by the reaction of zinc oxide and phosphoric acid solution. It is one of the oldest cements and has been used to a large degree as band cement in the recent decades (67).

The technique of mixing the powder into liquid is sensitive. Preferably, during mixing of zinc phosphate cement it should be kept cool and mixing of the cement components must be made properly to ensure an optimum acidic base, resulting in satisfactory physical properties including the relatively dimensional stability and the low solubility in oral fluids (66)

Zinc-phosphate has high compressive strength, but its tensile strength is low and its solubility is high, leading to demineralization and micro-leakage (64).

1.4.6 Resin modified cement

After presenting high powder:liquid ratio of liquid materials, the employment of "metal reniforced" GICs has declined.

In early 1990s alterations was made to the conventional GICs in the form of resin modified' GICs (RM-GICs). This took place through the addition of water soluble resin to improve the physical charecteristics and minimize the sensitivity of the water balance of conventional GICs(63). Resin modified glass ionomer cement has the features of good adhesion to the tooth, fluoride release and fast setting by visible light. (68)(69).

In addition to the chemical bonding of RM-GICs, resin monomers produce a micro-mechanical interlock through surface irregularities penetration following polymerization (66).

1.4.7 Resins

Epoxy resin was first used for bonding stainless steel brackets to tooth surface by Newman in 1965. Resin cements are mainly low viscosity flowable composites. They are composed of resin monomers and inert fillers (67). Single-component resins are light activated, so there is no need for mixing thus making them more regularly utilized. (66).Chemically cured systems are available as powder and liquid or as two pastes. Dual cure systems use both chemical and light cure mechanisms.

Resin cements do not have any fluoride release potentials and they are insoluble in oral fluid. The mechanism of resin bonding to enamel and brackets is by mechanical interlock. Multiple factors affect the bond strength between enamel and brackets. These include the enamel conditioners used, concentrations of acid, etching time, the primer, bracket material, base design and oral environment (67).

1.4.8 Compomers

Compomers, also known as polyacid –modified composite resins, are a single container systems composed of aluminosilicate glass, carboxyl modified resin monomers and light cure conventional resin monomers. Reaction does not occur within the packaged container due to the absence of water from the composition.(66). This composition is sensitive to moisture and packed in containers which are moisture proof.

Light curing of the acidic monomers changes the material to become rigid causing it to set. Fluorides are released from aluminosilicate glass as a result of acid-base reaction that takes place when the material absorbes water from the saliva. Mechanical interlock is the main mechanisim of bonding to the tooth surface. Prior to bonding, tooth surface must be dry and surface treatments are required(67).

1.4.9 Three-step adhesive (total etching system)

Before placing the composite, these systems require acid etching of enamel and dentin, rinse and dry, use of a primer and adhesive.

Bonding of adhesive resin is achieved when the hydrophilic tooth surface is transformed into hydrophobic surface by primers (70).

Complete tissue infiltration can be achieved if such tissues have been previosuly wetted. Since volatile organic materials, such as ethanol and acetone found in adhesive systems, remove the remaining water, this enables the penetration of micropores of etched enamel to reach the nano-spaces in the collagen network of dentin.

Hydroxyethyle methacrylate (HEMA) and Polyalkenoic acid are the main components of water-soluble primers. The steam pressure of water is much higher than HEMA, so it is retained on the applied surface, as the solvent, water, evaporates in the drying phase. The mechanism of action is based on the fact that water evaporates after application and the surface is air-dried, thus increasing the hydroxyethyle methacrylate concentration.

The final step, is the application of the hydrophobic bonding agent, which will chemically bond with the composite resin.

One of the advantages of a three-step system is the ability to achieve strong bond to tooth structure. The main disadvantage is that the technique has many clinical steps which makes it very sensitive. There is also a risk of over-wetting or over drying the dentin after the acid etching. The bond-strength value of these adhesives have reached nearly 31 MPa (71)(72).

1.4.10 Two-step adhesive

This technique is considered more sensitive. The priming step does not occur independently, so wet tissue should be kept in the dentin case to prevent the demineralization collagen from collapse, thus preventing the infiltration of incomplete adhesive. However, it is very difficult for the doctor to reach the optimum degree of moisture, which is why the technique is a sensitive system (73).

The clinical technique of this system is simplified, to some extent, to reduce the working time. Two procedures are described as follows. First, the primer and adhesive come together in one package and comes separately. The main drawback of this system is acid rinse with water and then dry. However, the dentin must remain wet after etching, which is difficult to standardize clinically given the lack of stability of the demineralized matrix (73).

The primer now has monomers acid etching agent, thus preparing dental tissues for adhesion. The main advantage of this system is elimination of rinse phase, also the surface of dentin is already ready to receive adhesive agent (73).

1.4.11 One Step All-in-One Adhesives

These systems combine three functions of acid etching, priming and adhesion in one stage. The main advantage is that they are easy to apply and there is no need for surface rinsing, only drying is necessary for uniform spreading of the product before polymerization (74).

Technology of adhesive system is simplified, making it possible to maintain acidic water monomers, organic solvents and water in one solution.

The components necessary to activate the process of dentin are demineralized before running the system (75). Solvents such as acetone or alcohol are retained in solution, but once dispensed the solvent evaporation begins leading to separation phase with multiple drops formation and oxygen inhibition. There is also a lower degree of conversion, which enhances the hydrolytic dig bond regeneration systems in restorative dentistry, affecting the ability of bonding in the adhesive interface (76)(77).

1.5. Bracket design and bond strength

1.5.1 Bracket material and base design

Maijer and Smith.,(1981) mentioned that plastic based, ceramic based, and metal based (stainless steel) attachments are the three types available for orthodontic brackets (78). The first metal bracket were formed from cold drawn from stainless steel with perforated base (79). Metal brackets do not attach chemically to adhesive, since they rely on mechanical retention for bonding where mesh gauze is the conventional method for providing this retention (78)(80)(81)(82). One of the disadvantages of using metal brackets is presence of corrosion, black and green stains (Ceen and Gwinnett., 1988) (85).

The bracket base design had changed to foil-mesh bracket base with higher bond strength and less tissue irritation and plaque accumulation (78)(80)(81). (Zachrisson and Brobakken., 1978), have stated that perforated metal bases are inferior to Foil-mesh bases (83).

MacColl and coworkers (1998) reported that optimum shear bond strength obtained from bracket with base surface area between 6.82 mm^2 and 12.35 mm^2. The reduction of SBS is affected by the reduction of bracket base area from 6.82mm^2 to 2.38 mm^2 (55). Although there were improvements in aesthetics and hygiene (Maijer and Smith.,1981)(78), the reduction in bracket size provided less base surface area needed for bonding (Cavina.,1977)(84).

1.5.2. Bond strength measurement unit

Fox and McCabe, (1994) reported that there has been a confusion over the appropriate unit used to measure the shear bond strength (4). There are several units used to define the force per unit area required for dislodging the brackets such as newton per millimeter squared, meganewton per meter squared, pascal, and megapascal. As the size of bracket base decreased, newton per millimeter squared and megapascal are preferred units for use.

1.5.3. Bracket bond strength testing

Van Noort *et al.* (1989) and Rueggeberg., (1991) have suggested measurement of bond strengths needs standardization of test procedures, to allow valid comparisons to be made between different bonding agents (86). Also, (Fox *et al*) later in (1994) recommended standardization of bond strength testing (4).

Instron universal testing machine was used for measuring shear bond strength since it is accurate and widespread. This machine is capable of delivering a controlled and measured force to the bonded bracket via its moving crosshead.

Compressive fracture resistance test by universal testing machine is an important method used to measure the shear bond strengths of different orthodontic brackets bonded to extracted teeth. This testing method has several advantages and disadvantages. The major disadvantage is that *in vitro* shear bond strength test does not exactly replicate the clinical situation.

In the mouth there are a combination of forces shear, tensile and torsion directed onto orthodontic brackets, whereas *in vitro* studies the universal testing machine is capable of producing only pure debonding forces (shear, tensile or torsion) not the combination of them. Furthermore, the rate of loading for the machine is constant, whereas the rate of loading for *in vivo* debonding is not standardized. The bond strength of adhesive system (bracket -adhesive – enamel) in orthodontic varies and depends on factors such as the type of adhesive, bracket base design, storage media, enamel morphology, appliance force systems and the clinician’s technique (87)(88).

Despite the limitations of shear bond strength test to be a real representative of bond strength, it remains a clinically relevant method used to compare bonding of different protocols by providing important information on clinical bracket debonding (89).

1.5.4. Ideal bracket bond strength

Direct bonded attachments were obtained to ensure that the orthodontic accessories remain attached to the teeth during treatment time (Millet and Gordon., 1994) (90).

The bracket bond must be able to withstand the forces generated by orthodontic mechanics and by mastication forces during orthodontic treatment. Reynolds reported that the clinically optimal bond strength is about 6 to 8 MPa (18).

On the other hand, the bond strength should not be too high to avoid harm the tooth surface when debonding process is needed at the end of treatment (Carstensen., 1986) (91).

Retief in his study in 1974 had demonstrated that enamel fracture could occur with bond strength as low as 13.5 MPa (56). (Ferguson, Read and Watts., 1984) have mentioned many factors that may influence the bond strength including the nature of the enamel surface, the conditioning procedure, the type of adhesive and the design of the bracket base itself. (82)

1.6 Failure in orthodontics bond

1.6.1 Types of bond failure: Adhesive Vs Cohesive

Attachment failure can occur in two major sites, bracket base/adhesive interface and the enamel/adhesive interface as observed by (O'Brien, Watts and Read,1988) in most of *in vitro* investigations of bond failure (92). The bond failure is defined as adhesive failure on the enamel surface in which resin is dislodge from enamel, cohesive failure in which it occurs in the main core of resin, or combination of both adhesive and cohesive failure (56) (93).

Powers, Kim & Turner., (1997) have stated that if the orthodontists know where the bond failure will occur, they should modify the debonding technique and advice patients to how to take care of their appliances (94).

1.6.2 Adhesive remnant system (ARI)

Artun and Bergland., (1984) have introduced index system known as "Adhesive Remnant Index" (ARI) system (95), which is used for evaluating fracture sites and amount of adhesivea left on the tooth after debonding. The index score ranges from 0 to 3 as follows:

Score 0 =No adhesive left on the tooth.
Score 1 =less than half of the adhesive left on the tooth.
Score 2 = More than half of the adhesive left on the tooth.
Score 3 =All adhesive left on the tooth, with distinct impression of the bracket mesh.

Later, Bishara has modified the index to a five-point scale to quanifiy the amount of material that remains on the surface of the tooth upon bracket debonding as well as the type of bracket bond failure (96).

The modified ARI scores are 1, all adhesive remaining on the tooth surface; 2, >90% of the adhesive remaining; 3, >10% but <90% of the adhesive remaining; 4, <10% of the adhesive remaining; 5, none of the adhesive remaining.

O'Brien; Watts & Read.,(1988) have revealed that the optimal bond failure site is controversial topic (92). Brown.,(1988) and Fox, McCabe and Buckley.,(1994) reported that the ideal site of bonding should be at the enamel/composite interface where less adhesive remains on teeth surface, making it subsequently easy to clean and polish. Clinically it rarely occurs and adhesive left behind on teeth surface has to be removed (4) (98).

1.7. Objective of study

The objective of this study is to compare the shear bond strengths of new and previously bonded orthodontic brackets using different bracket recycling methods and to determine the simplest, fastest and cheapest in-office techniques and most effective method for bracket recycling with clinically acceptable results of bond strengths with minimal changes in the physical properties of the bracket. This would be beneficial for clinical practices in case of unavailability or expensive replacements and, at the same time, would avoid the delays that affect treatment time associated with commercial recycling.

2. MATERIALS AND METHODS

Power calculation 2.1

According to the power analysis result, which was performed to determine the number of samples, the minimum sample size was found to be 9 for each group. The analysis was performed with (G * Power 3.1.9.2) program, and the sample width analysis was performed by taking 0.80 power value (alpha error probability = 0.05). Four groups were used, a total of 40 samples was included, and each group contained 10 samples.

2.2 Materials used in this study

2.2.1 Bonding system

The orthodontic Transbond XT bonding system was used in this research project. The description of manufacturer is shown in **Table 2.1**

According to 3M manufacture brochure, Transbond™ XT Light Cure Adhesive bonds metal and ceramic brackets to teeth surfaces. The properties of product are quick metal/ceramic bracket cure, extended working time which allows precise bracket placement, immediate bond strength, efficient bonding of ceramic and metal brackets, no waste of materials and excellent handling properties where no bracket drift and easy flash clean-up.

The light cure adhesive is available in both syringe and capsule. Capsule type with dispensing gun was used in our research, which provides increased control, easy application, and convenience to the clinician.

Figure 2.1: Gun with capsule light cure adhesive system, Transbond XT, 3M Unitek, Monrovia, California.

Figure 2.2: Capsule light cure adhesive system.

Table 2.1: Description of bonding system.

Bonding Material	Type	Remarks	Manufacturer
Transbond XT	Capsule with gun	Light cure adhesive system	3M Unitek, Monrovia, California

2.2.2 Bracket

Forty premolar Smart clip metal brackets SL3 (3M unitek, Monrovia, California) were used to be bonded to the control and experimental groups. All brackets used in this study were bought from the same company to ensure that all specimens have the same bracket base criteria.

Figure 2.3: Package of Smart clip brackets SL3 (3M unitek, Monrovia, California).

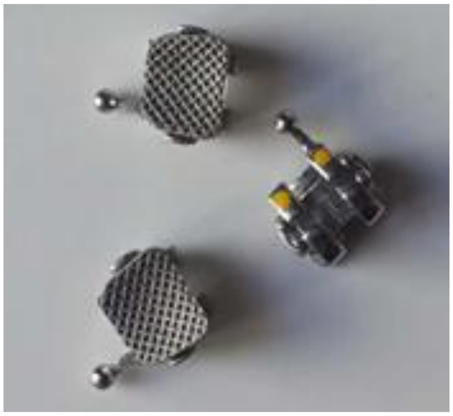


Figure2.4: Smart clip brackets SL3 (3M unitek, Monrovia, California).

2.3 Experimental procedures

2.3.1 Specimen collection and storage

Forty upper and lower premolar teeth were used in this study, which were prepared and randomly separated into 4 groups, and each group contains 10 teeth. These teeth were extracted for orthodontic reasons, mainly in sever crowding orthodontic cases, making them easy to obtain. All of the teeth were collected from the Orthodontic Department of Istanbul Yeni Yüzyil University, Faculty of Dentistry.

The samples were selected carefully. All samples were examined under the normal light conditions for suitability of inclusion criteria.

The criteria of teeth selection and exclusion were as follows:

- Teeth have intact buccal enamel surface.
- All samples have no caries and were not restored.
- No cracks caused by forceps during extraction.
- Teeth have no enamel or other developmental defect.

All the teeth samples, after extraction, were placed in container filled with distilled water and Thymol crystals to inhibit bacterial growth (Sliverstone.,1967) (98). Samples were placed in a dark place at 37°C (Fox et al, 1994) (4).

2.3.2 Specimen preparation for bonding procedure:

Preparation of enamel surface for bracket bonding underwent several steps. The pumice slurry was used to polish the buccal surface of the enamel of the samples with rubber cup and brush for 10 seconds. The samples were then washed by water for 15 second and dehydrated by compressed air for 10 seconds.

.**Figure 2.5:** Polishing buccal surface of teeth.

The labial surface of all control and three experimental groups were prepared by using conventional etching and primer protocol. Adhesive resin material was polymerized with instant of 1600 mm/cm for 20 seconds using an ortholux luminous curing. Adhesive material was allowed to be completely polymerized for 24 hours at 37°.

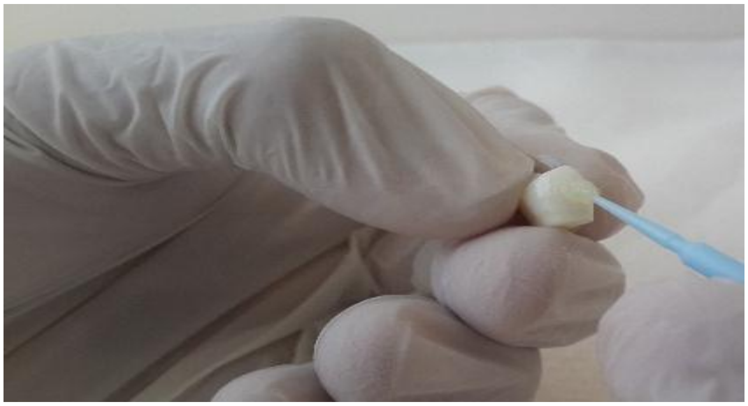
The brackets were bonded to the enamel surface of the extracted teeth. Instructions of the manufacturer were followed for brackets bonding. The first step in applying braces in orthodontic treatments is to roughen the tooth surface by acid etching, where the buccal surface of enamel was conditioned for 15 seconds with conventional 37% phosphoric acid. Afterwards, The etched surface of the enamel was washed with water for 15s and dried with the help of the fingertip compressed air until the etched enamel surface had a white chalky appearance.

The adhesive primer was applied to etched enamel surface followed by a stream of compressed air to ensure that a thin layer of primer remained, then the surface was light cured for 10 seconds.

In the last stage, orthodontic adhesive materials (i.e., Transbond XT composite) were applied on the base of the smart clip brackets to be placed directly to the tooth surface in an ideal position (mesio-distal and occluso-gingival). The brackets were placed in midway mesio-distally then adjusted, so that the bracket slots were 4mm from the cusp tip. Once the bracket was in the correct position, a sufficient pressure was applied to it to force out the excess adhesive, which was removed carefully from around the bracket margin by right angle probe to avoid disturbing the setting of the adhesive. The bonding material were then polymerized using ortholux luminous curing for 20 seconds.

Figure 2.6: Etching gel and Transbond XT Primer.

Figure 2.7: Etching of prepared tooth with 37%phosphoric acid.



Figue 2.8: Apply Transbond XT primer on etched surface.

Figure 2.9: Curing of primer.

Figure 2.10: Apply Transbond XT Composite on the bracket base.

Figure2.11: Placing the bracket in ideal posiotion.

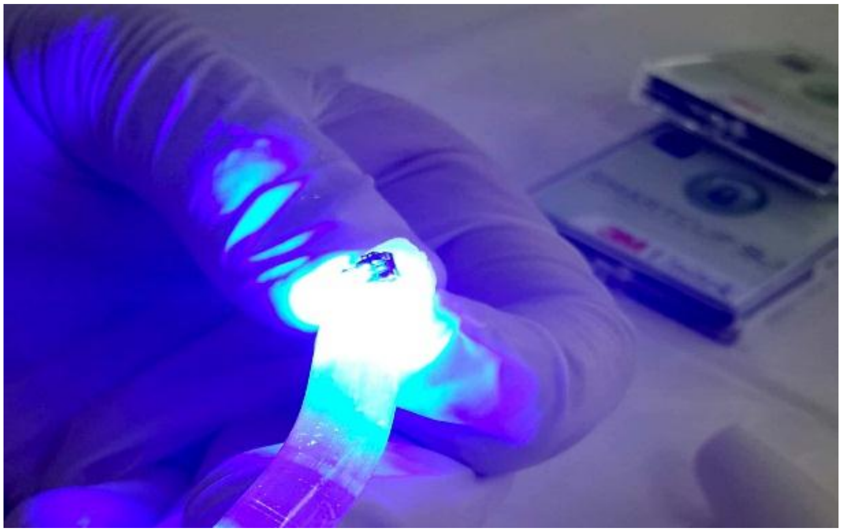


Figure 2.12: Curing of composite after bracket placing on tooth surface.

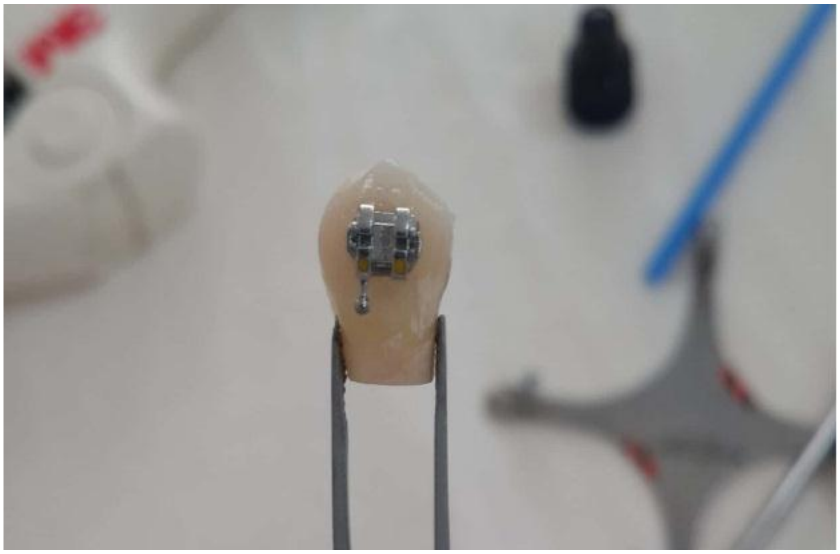


Figure 2.13: Bracket placement on tooth surface.

Table 2.2 Test groups

GROUPS	**– Group 1** **Control group**	**– Group 2** **Sand blasting recycling group**	**– Group 3** **Direct flaming recycling group**	**– Group 4** **Direct flaming & sand bllasting recycling group**
Bonding material	Phosphoric acid (37%) Adhesive primer & Composite : Transbond XT (3M Unite, Monrovia, California)	Phosphoric acid (37%) Adhesive primer & Composite : Transbond XT (3M Unite, Monrovia, California)	Phosphoric acid (37%) Adhesive primer & Composite : Transbond XT (3M Unite, Monrovia, California)	Phosphoric acid (37%) Adhesive primer & Composite : Transbond XT (3M Unite, Monrovia, California)
Bonding technique	Conventional Bracket bonding technique	Conventional Bracket bonding technique	Conventional Bracket bonding technique	Conventional Bracket bonding technique
Bracket	Smart clip SL3 (3M unitek, Monrovia, California)	Smart clip SL3 (3M unitek, Monrovia, California)	Smart clip SL3 (3M unitek, Monrovia, California)	Smart clip SL3 (3M unitek, Monrovia, California)
Debonding technique	Universal testing Machine	Bracket removal plier	Bracket removal Plier	Bracket removal Plier
Recycling method	/	Sandblasting	Direct flaming	Direct flaming & sand blasting
Rebonding	/	Yes	Yes	Yes
Debonding technique	/	Universal testing machine	Universal testing machine	Universal testing machine

2.3.3 Specimen embedding

The roots of all teeth were cut 1mm away from the cement-enamel junction using motorized cutter disc with water coolant source. The cut crowns were placed in self-curing orthodontic acrylic resin in specimen holder rings (SHR). The buccal surface of cut crowns placed parallel to the metal edge of the rings, with at least 1mm of projection supra to the border of the cylinder. Afterwards, the crowns were placed in distilled water to avoid enamel dehydration.

Figure 2.14: Teeth after cutting of roots.

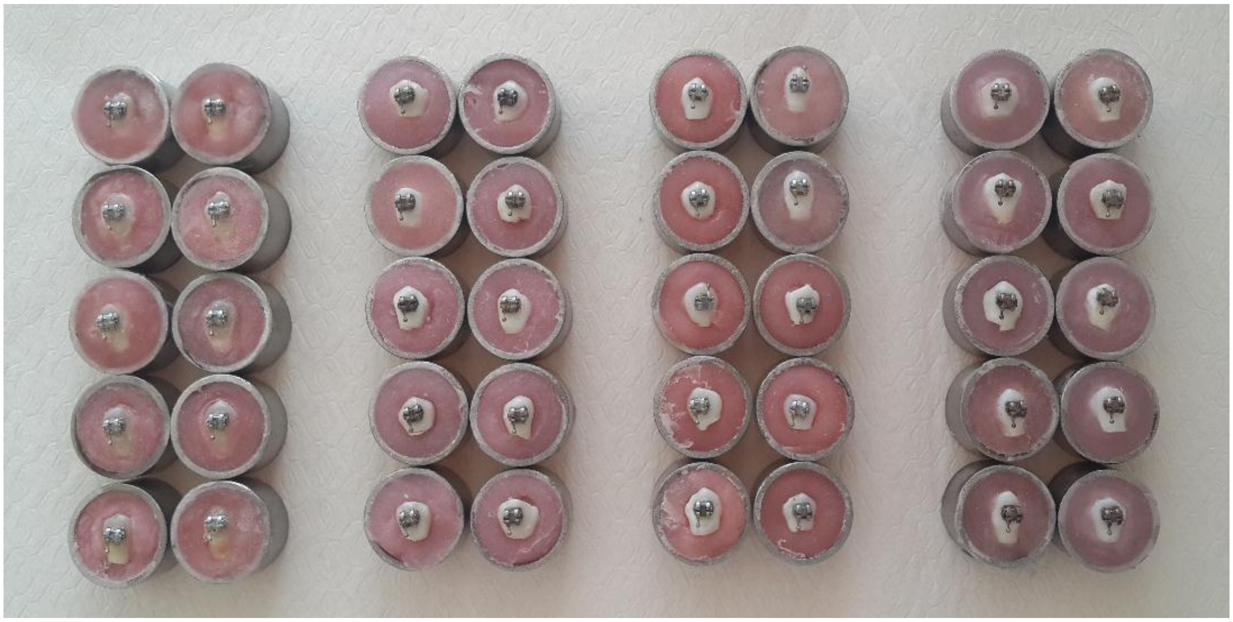
Figure 2.15: Specimen holder rings (SHR).

Figure2.16 a,b : Specimen preparation in the laboratory.

Figure 2.17: Mounting of specimens in acrylic resin.

2.3.4 Groups

The specimens were divided into four groups with 10 samples in each group. One of them was a control group **(Group 1)**. The other three groups were experimental groups which utilized three different bracket recycling techniques; sandblasting recycling technique **(Group 2), d**irect flaming recycling technique **(Group 3)**, direct flaming and sandblasting recycling technique **(Group 4)**.



Gr I **Gr II** **G III** **Gr IV**

Figure 2.18: Control and experimental groups before debonding.

2.3.4.1 Group 1 – Control group

In the control group, new brackets were bonded to enamel surfaces of teeth by using conventional bonding technique. The bonded brackets remained attached to tooth surface until shear bond testing, i.e. no debonding/rebonding procedures were done for bracket recycling. The specimens were then placed in the universal testing machine for brackets debonding to evaluate the shear bond strength (SBS) of new brackets. The teeth surfaces were inspected afterwards using a 75mm diameter magnifier glass with a 2.5X magnification. The amount of remaining adhesive was scored using the modified Adhesive Remnant Index (ARI).

2.3.4.2 Group 2 – Sand blasting recycling experimental group

In this group, the specimens were prepared similarly to group 1. Afterwards, the specimens of group 2 were debonded by bracket removal plier and recycled with sand blasting machine. For sandblasting, a special device was designed and fabricated by researchers (see **Figure (2.21-2.22)** to hold the debonded brackets perpendicular to the etcher tip of blasting machine. The distance between the bracket base and the head tip was fixed at 10mm.

The recycling process was carried out with a sandblasting unit (Starblasting, Star dental medical, Turkey) using 90 μm aluminum oxide abrasive powder.
Each bracket base was sandblasted by micro-particles of aluminum oxide for 30 seconds under five-bar (72.5-psi) line air pressure to remove all the adhesive from the mesh of bracket base.

Figure 2.19 a.b : Debonding procedure using bracket removal plier.

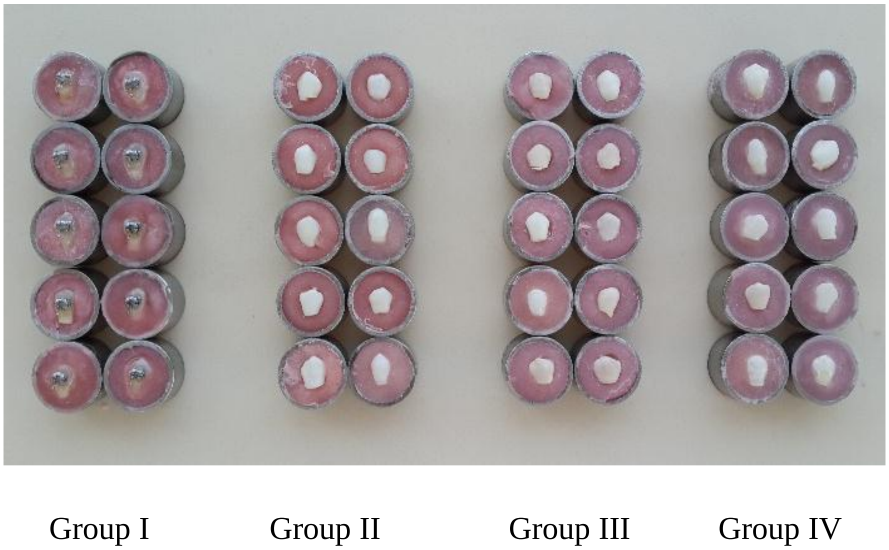


Figure 2.20: Experimental groups after debonding.

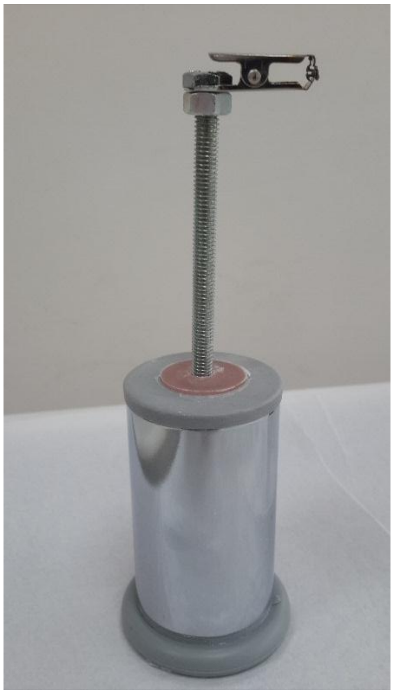


Figure 2.21: Bracket holding apparatus.

Figure 2.22: Holder part of apparatus.

Figure 2.23: Sandblasting machine.

Figure2.24: Pressure used in the test.

2.3.4.3 Group 3 – Direct flaming recycling experimental group

After preparing the specimens of this group similarly to group 1, all the brackets samples were debonded by bracket removal plier and subjected to heat.

The debonded bracket were held with the same holding device that designed to hold the bracket, which was used in group 2.

The heat was directed to the base of the bracket with the help of micro torch, using the non-luminous zone of the flame for 10 seconds until the adhesives on the base of the bracket started to burn and became cherry red, in order to remove the residual resin from the base. Then the bracket was immediately quenched in water at room temperature and dried in an air stream.

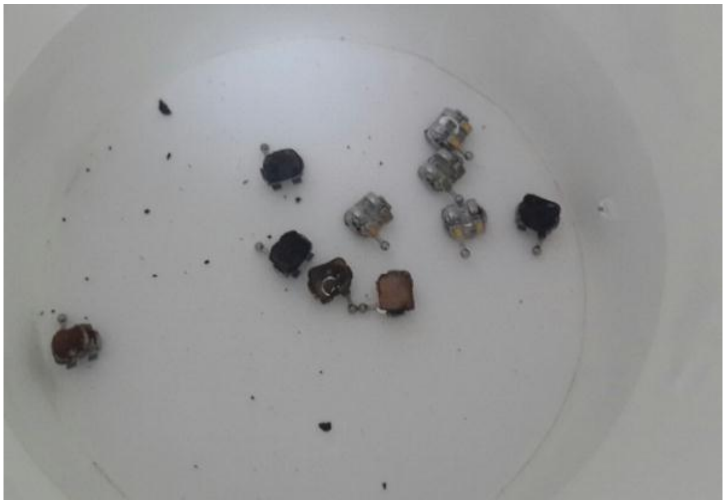
2.3.4.4 Group 4 – Direct flaming & Sand blasting recycling experimental group

Similar to groups 2 and 3, the specimens were prepared similarly to group 1. The brackets were then debonded by bracket removal plier, subjected to heat, and sand blasted with micro-particles of aluminum oxide.

The heat was directed at the base of the bracket with the help of micro torch for 10 seconds, until the adhesives on the base of the bracket started to burn and became cherry red, then the bracket was immediately quenched in water at room temperature and dried in an air stream.

Afterwards, each bracket base was sandblasted by micro-particles of aluminum oxide (90 μm) for 30 seconds under five-bar (72.5-psi) line air pressure to remove the burned adhesive from the mesh of bracket base.

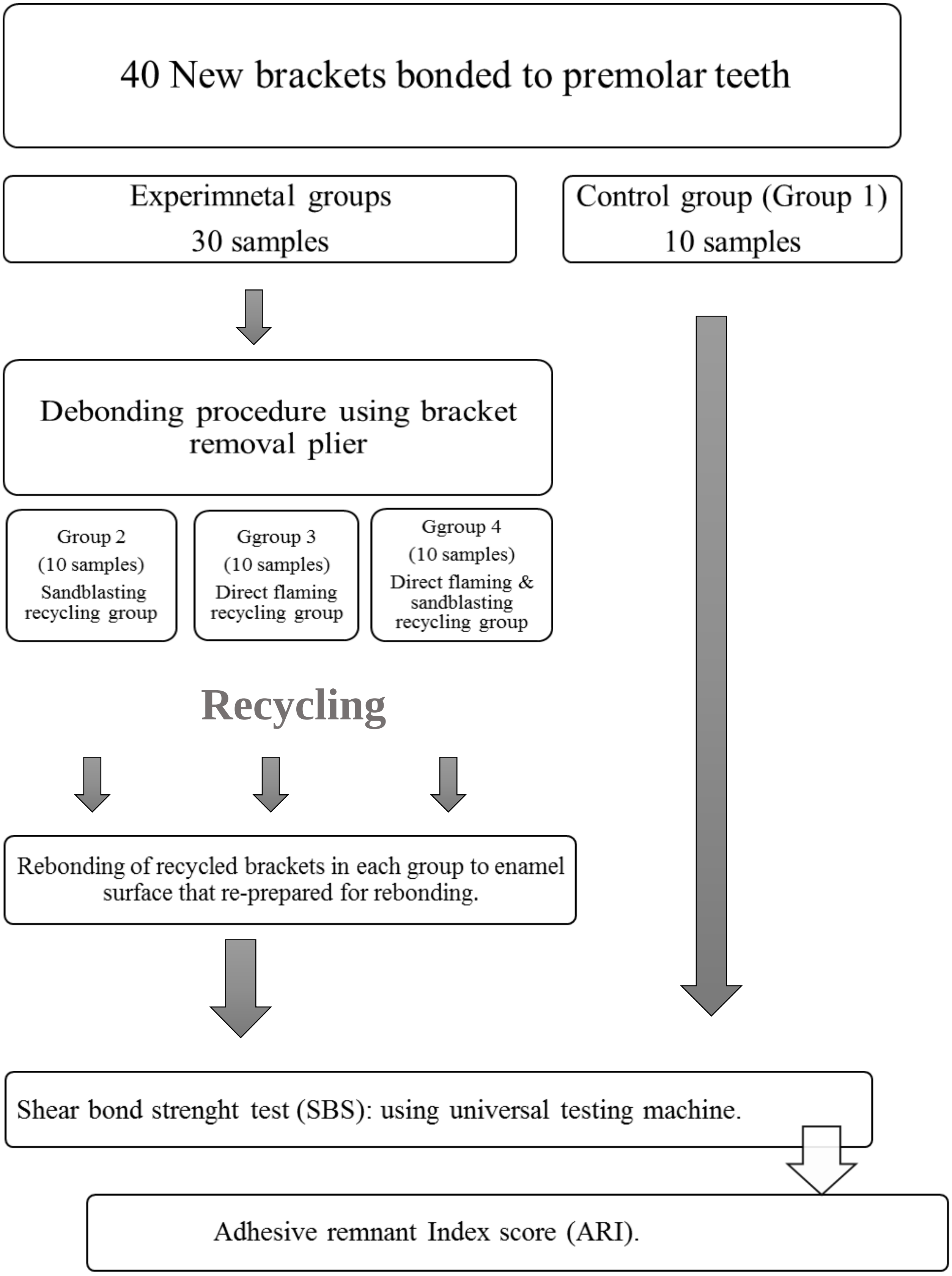
.**Figure 2.25:** Direct flaming of bracket



.**Figure 2.26:** Water bath after direct flaming

After recycling the brackets, each bracket bonded to the enamel surfaces was prepared again for rebonding using the same bonding technique used for the new brackets, as previously described.

Finally, all the samples of experimental groups were subjected to the universal testing machine for brackets debonding to evaluate the shear bond strength (SBS) of the groups. The bracket bases and teeth of three groups were inspected using a 75mm diameter magnifier glass with a 2.5X magnification. The remaining amount of adhesive was scored using the modified Adhesive Remnant Index (ARI).


40 New brackets bonded to premolar teeth
Experimnetal groups
30 samples
Control group (Group 1)
10 samples
Debonding procedure using bracket removal plier
Group 2
(10 samples)
Sandblasting recycling group
Ggroup 3
(10 samples)
Direct flaming recycling group
Ggroup 4
(10 samples)
Direct flaming & sandblasting recycling group
Recycling
Rebonding of recycled brackets in each group to enamel surface that re-prepared for rebonding.
Shear bond strenght test (SBS): using universal testing machine.
Adhesive remnant Index score (ARI).

2.3.5 Preparation of specimens for SBS test

The test permission was signed by the researcher, the supervisor and the director of the laboratory before starting the test. After the specimens were prepared and recycled in the orthodontic laboratory at Yeni Yuzyil University, the test of shear bond strength of this research was done in the laboratory of hard tissue at Yedetepe University. The result of test was received from the laboratory team and sent for statistical analysis.

The shear bond strength was evaluated using Instron Universal Testing Machine, (Model 3345, Instron Inc., Canton, Massachusetts, USA) with a capacity of 5000 Newton. The specimen holder rings (SHR) were mounted in the customized jig in the lower jaw of cross head of the machine. The specimen holder rings were fitted in the cylindrical adjustable hole of the jig, where the rings had the ability to be adjusted in both rotational and in-out direction, allowing the shear forces to be applied parallel to the buccal surface of teeth and bracket base in occluso – gingivally direction.

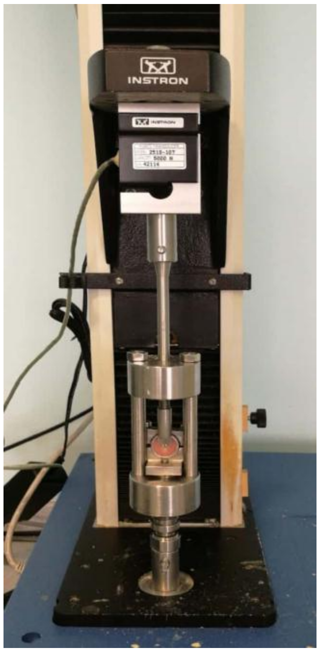


Figure2.27: Instron Universal Testing Machine, (Model 3345, Instron Inc., Canton, Massachusetts, USA).

A rod with a chisel configuration was used for bracket debonding with crosshead speed of 5 mm/ min. This distance was fixed for each specimen; an increase in distance from the tooth would increase the bond strength (Katona, 1997) (99). The load and speed of crosshead at the time of testing procedure were 2Nk load cell and 1.0 mm/min, respectively (Sunna and Rock, 1999) (63).

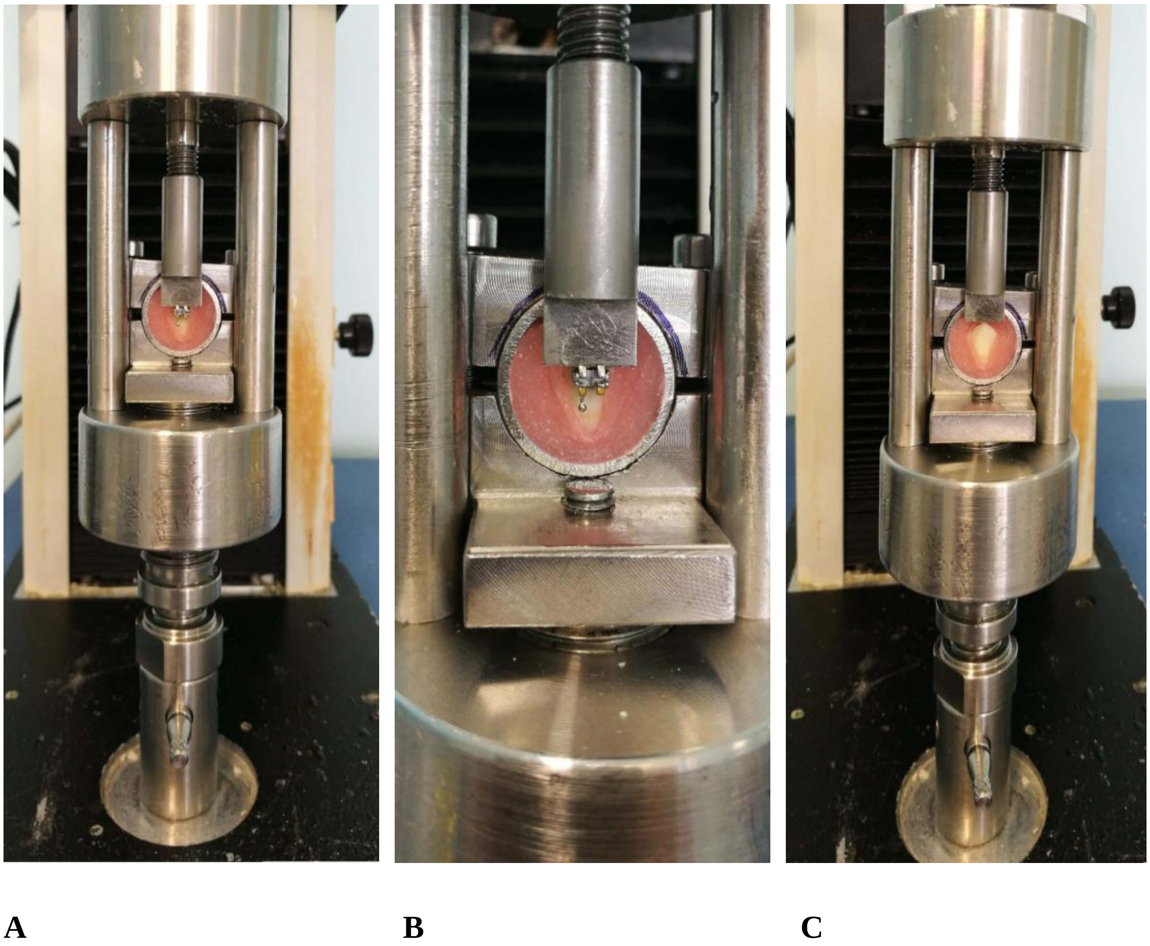
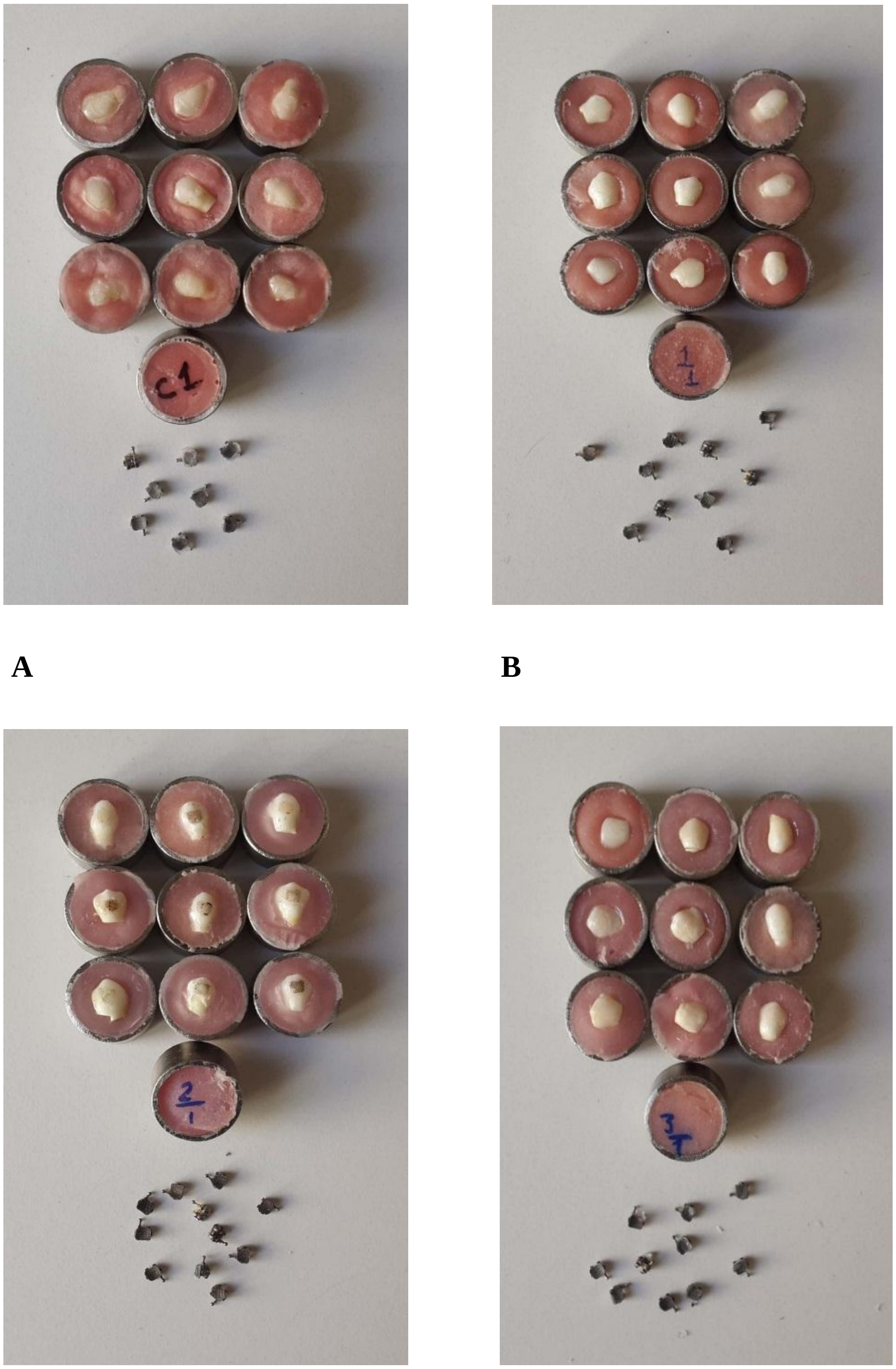


Figure 2.28: Bracket debonding procedure during test using Instron (universal testing machine).

A-B: Specimen in the machine before debonding , **C:** Specimen in the machine after debonding.



A

B

C

D

Figure2.29: Specimens after bracket debonded. **A:** Control group.

B: Sandblasting group, **C:** Direct Flaming group, **D**: Flaming / Sandblasting group.

The Instron machine is connected to electronic reader that records the value of maximum load at failure in Kg and Newton which is necessary to debond and shear off the brackets. Data were subsequently converted into megapascals (MPa) as a ratio of Newton to surface area of the bracket using the following equation:

$$\mathrm{MPa} = \frac{\text{Load (mass) (kg)}}{\mathit{Bracket\ base\ area}}\ X\ \mathit{gravitational\ acceleration\ constant}\ (9.81)$$

1 Kg = 9.81 N

1 MPa = N / mm2

The surface area of bracket base was calculated by taking the average sum of width and length of 10 brackets measurements using digital calipers.

Figure2.30: Digital caliper for measurements.

The term “shear–peel” is more accurate to use than “shear-bond” because the applied force creates tensile stress that tends to peel the bracket away from the tooth (Katona, 1997)(99). The Instron machine is therefore more likely to create shear-peel forces that mimic the clinical situation although never truly represent it (Tavas and Watts, 1979)(100).

2.3.6 Examination of enamel surface and evaluation of fracture sites

After debonding the teeth samples, the bond failure of composite was detected in which the teeth and brackets were examined and inspected visually in daylight independently by one evaluator using a magnifier glass with a diameter of 75mm and 2.5x magnification (No: SBR-227). (Artun, and Bergland, 1984) evaluated the residual index on enamel and bracket using modified Adhesive Remnant Index ARI (Table 2.3) (95).

The ARI scores were used to detect the amount of bonding material remaining on the enamel surface after bond failure. All samples were evaluated by this method.

The ARI scale has a range between 0 and 3, with 0 indicating that no composite remained on the enamel; 1, less than 50% of composite remained on the surface; 2, more than 50% but less than 90% of the composite remained; 3, all of the composite remained on the tooth surface, along with the impression of the bracket.

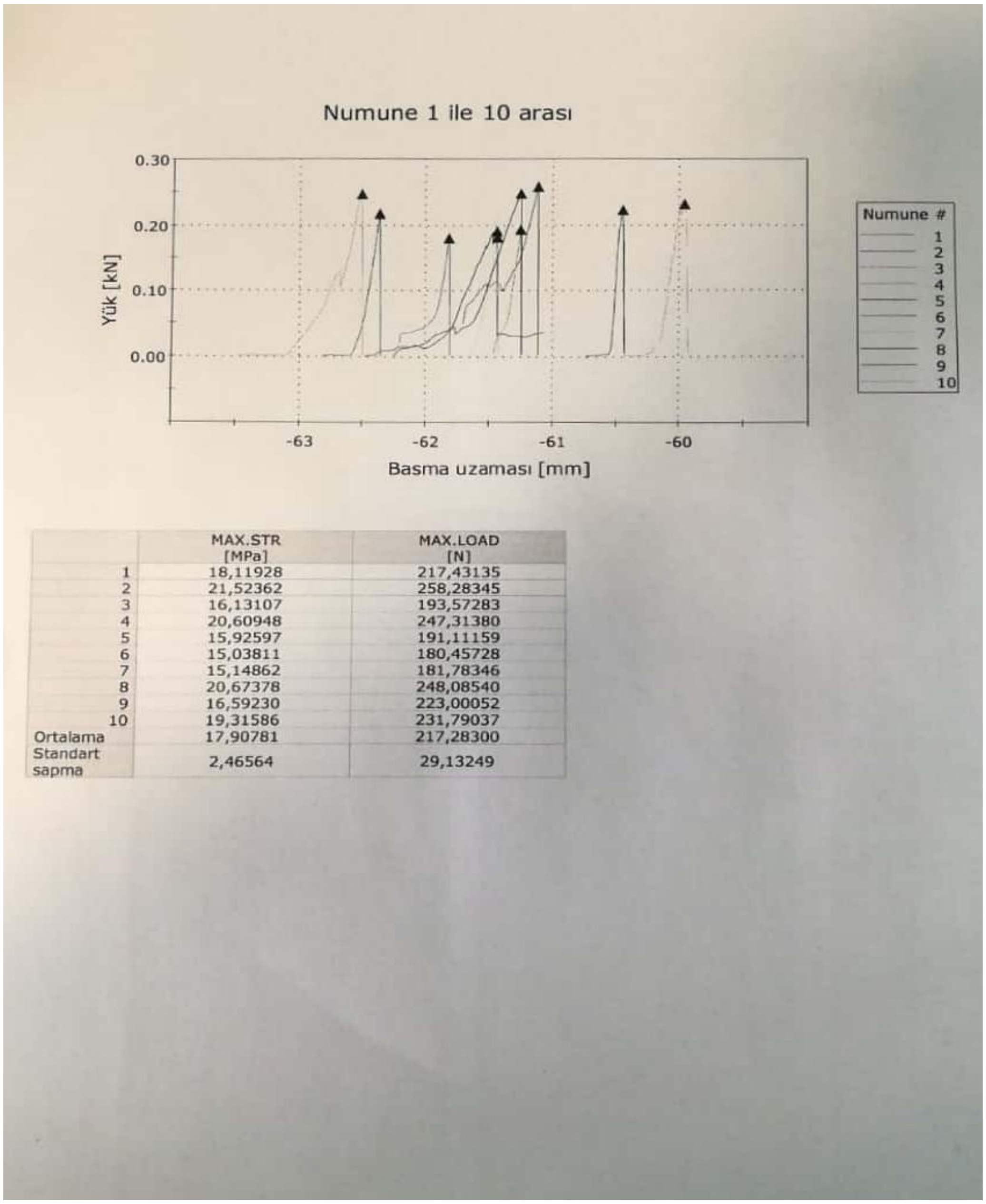
Table 2.3 ARI (Artun and Bergland, 1984)

0	No adhesive left on the tooth
1	Less than half of the adhesive left on the tooth
2	More than half of the adhesive left on the tooth
3	All adhesive left on the tooth, with distinct impression of the bracket mesh

Figure2.31: Distinct impression of the bracket mesh after bracket debonding.

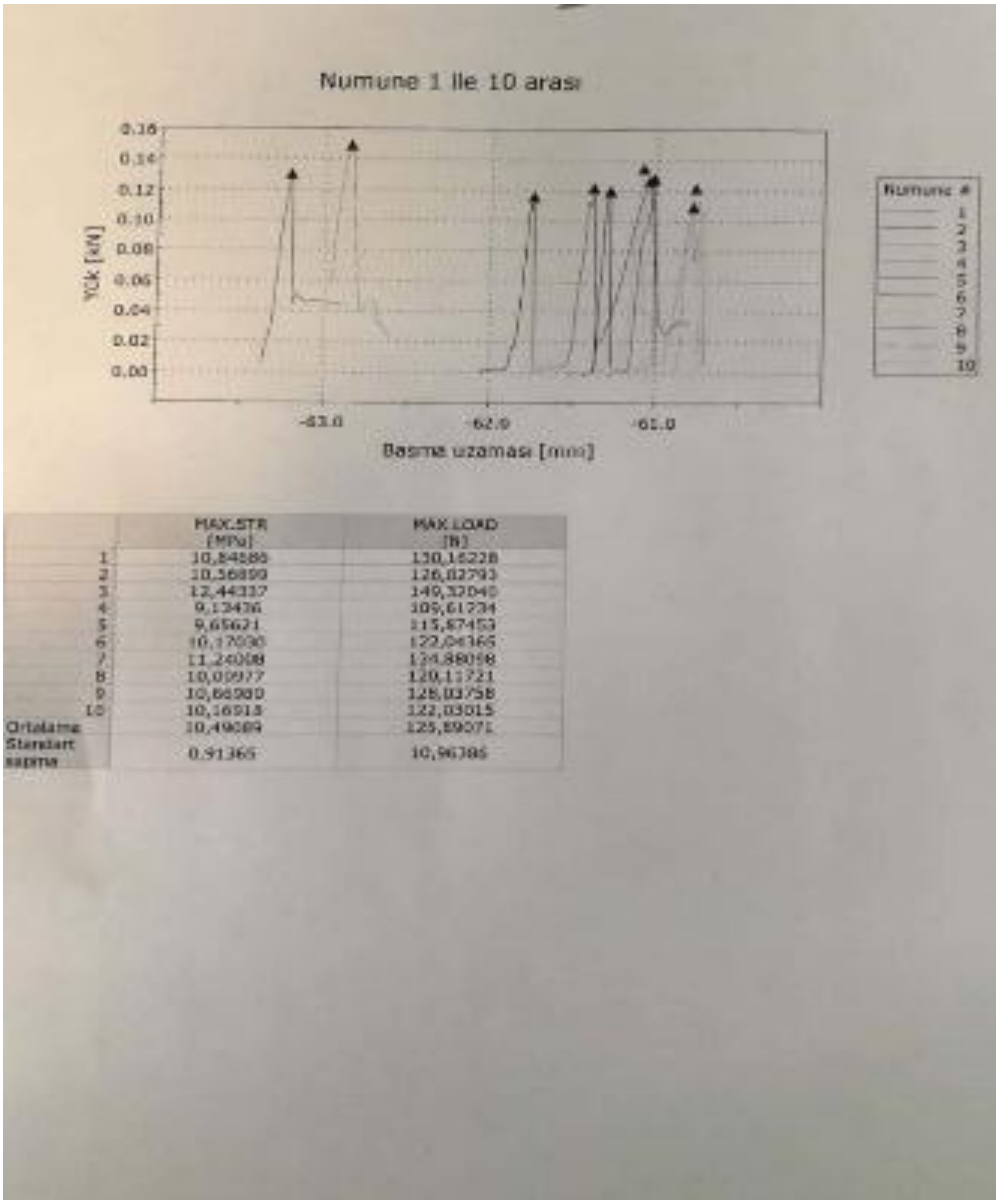
2.3.7 Statistical analysis of the data

Statistical calculations were performed with ANOVA statistical software program for Windows. Student’s t-test was used to assess a statistically significant difference in mean values between test groups, shear bond strength and residual adhesive.



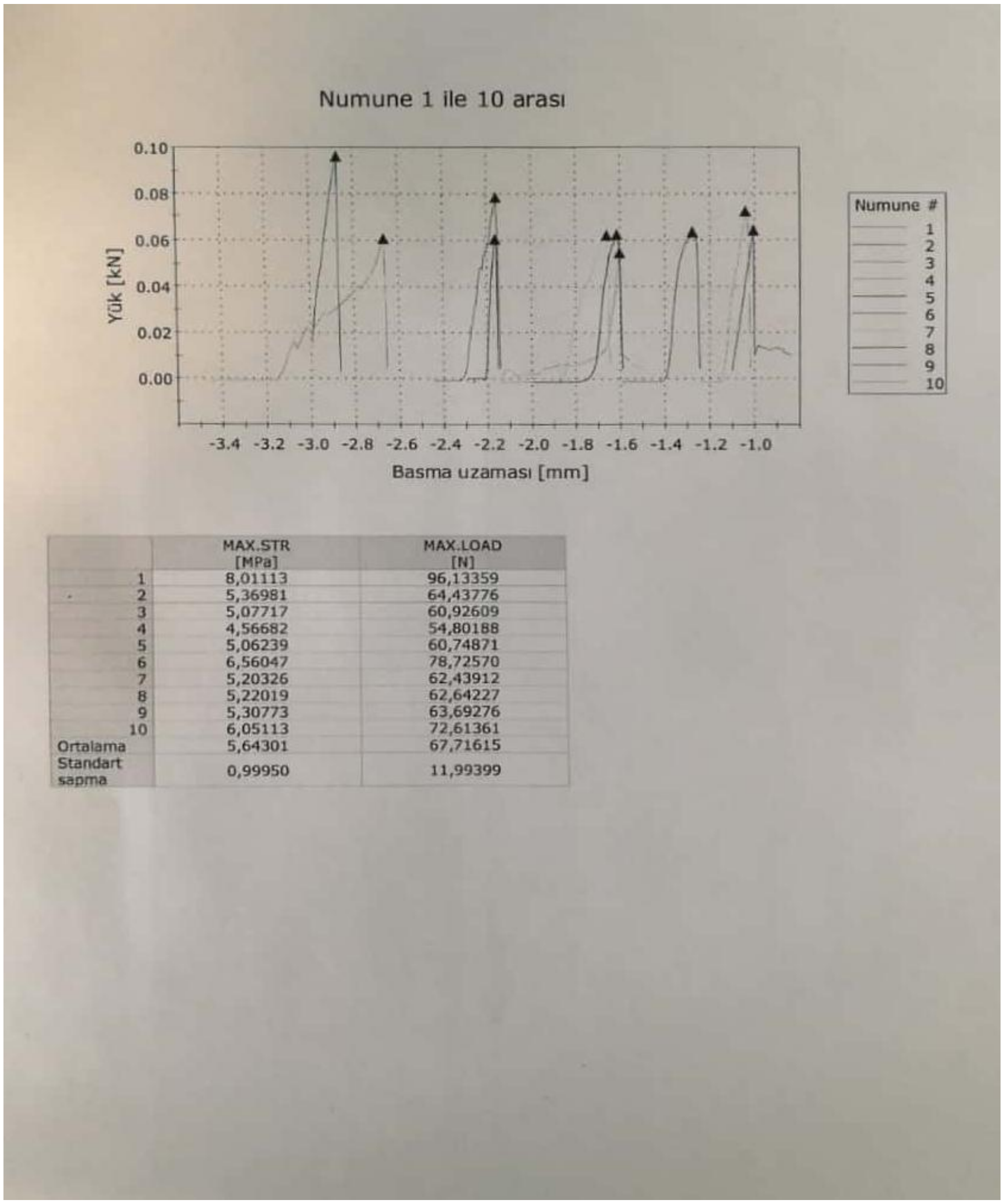
	MAX.STR [MPa]	MAX.LOAD [N]
1	18,11928	217,43135
2	21,52362	258,28345
3	16,13107	193,57283
4	20,60948	247,31380
5	15,92597	191,11159
6	15,03811	180,45728
7	15,14862	181,78346
8	20,67378	248,08540
9	16,59230	223,00052
10	19,31586	231,79037
Ortalama	17,90781	217,28300
Standart sapma	2,46564	29,13249

Figure2.32: SBS test result of Group 1 (Control group).



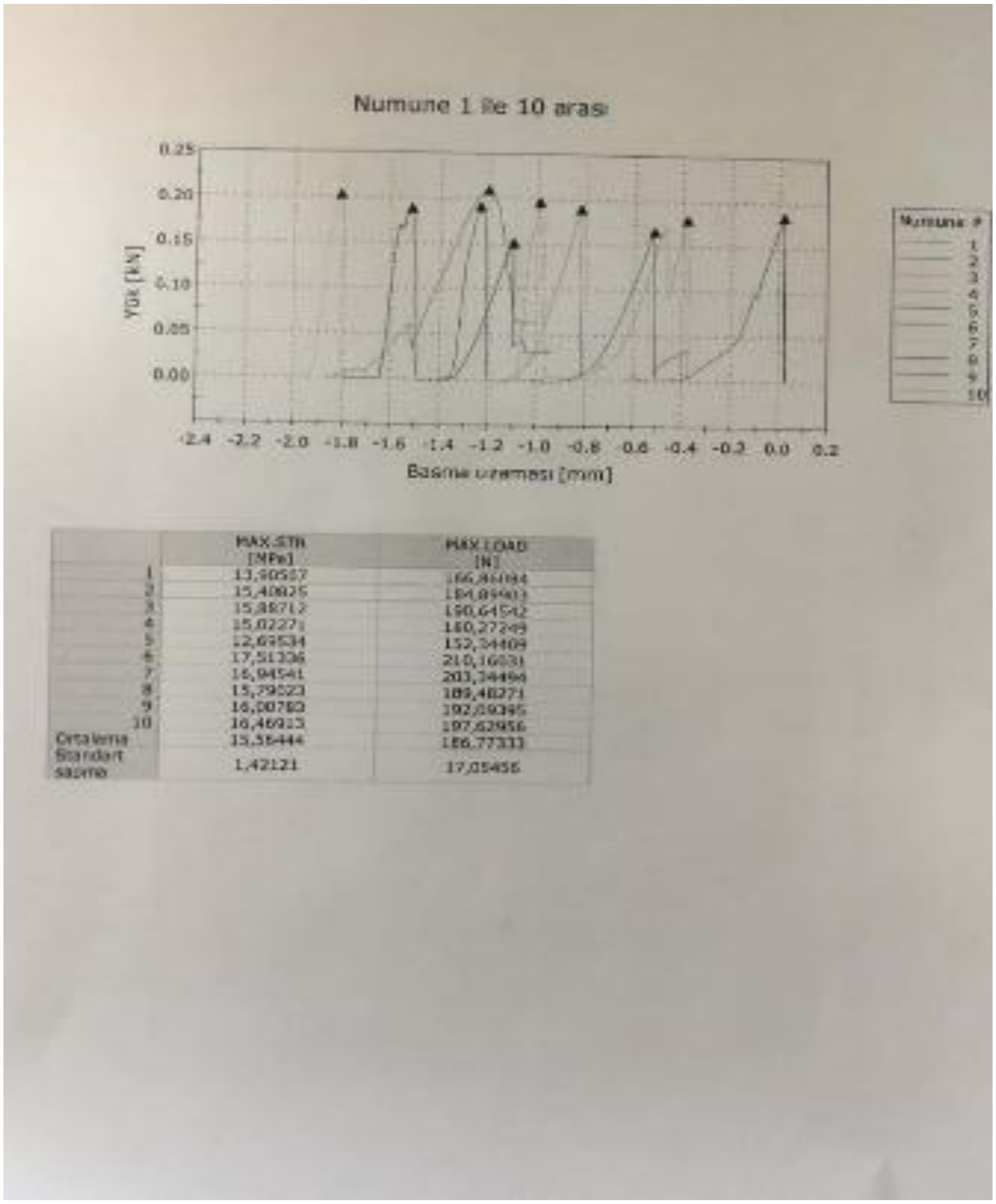
	MAX.STR [MPa]	MAX.LOAD [N]
1	10,84886	130,16228
2	10,56899	126,82793
3	12,44337	149,32040
4	9,13436	109,61734
5	9,65621	115,87453
6	10,17030	122,04365
7	11,24008	134,88098
8	10,00977	120,11721
9	10,66980	128,03758
10	10,16918	122,03015
Ortalama	10,49089	125,89071
Standart sapma	0.91365	10,96386

Figure2.33: SBS test result of Sandblasting group.



	MAX.STR [MPa]	MAX.LOAD [N]
1	8,01113	96,13359
2	5,36981	64,43776
3	5,07717	60,92609
4	4,56682	54,80188
5	5,06239	60,74871
6	6,56047	78,72570
7	5,20326	62,43912
8	5,22019	62,64227
9	5,30773	63,69276
10	6,05113	72,61361
Ortalama	5,64301	67,71615
Standart sapma	0,99950	11,99399

Figure2.34: SBS test result of Direct flaming group.



	MAX.STR [MPa]	MAX.LOAD [N]
1	13,90557	166,86684
2	15,40825	184,89903
3	15,88712	190,64542
4	15,02271	180,27249
5	12,69534	152,34409
6	17,51336	210,16031
7	16,94541	203,34496
8	15,79023	189,48271
9	16,00783	192,09395
10	16,46913	197,62956
Ortalama	15,56444	186,77333
Standart sapma	1,42121	17,05456

Figure2.35: SBS test result of Flaming / Direct flaming group.

3- RESULT

Some descriptive standards:

Table 3.1: Mean shear bond strength of control group and experimental groups:

Groups		N	Mean	Std. Deviation
Shcon	Control group Group1	10	17.7670580	2.41600908
	Group 2	10	10.4908920	.91365584
	Group 3	10	5.6430100	.99949844
	Group 4	10	15.5644450	1.42121387

Table 3.2: Comparison of shear bond strength between control group and experimental group:

The mono-variance analysis was used here because the analysis of the number of groups was more than two and there was no independence between groups.

ANOVA

		Sum of Squares	Df	Mean Square	F	Sig.
shcon	Between Groups	881.161	3	293.720	121.238	.000
	Within Groups	87.216	36	2.423		
	Total	968.377	39			

The value of the statistical significance was found to be less than 0.05 and thus the test was significant between the control and the three groups, ie the averages are different from each other and there is no effect of the control and the other three groups.

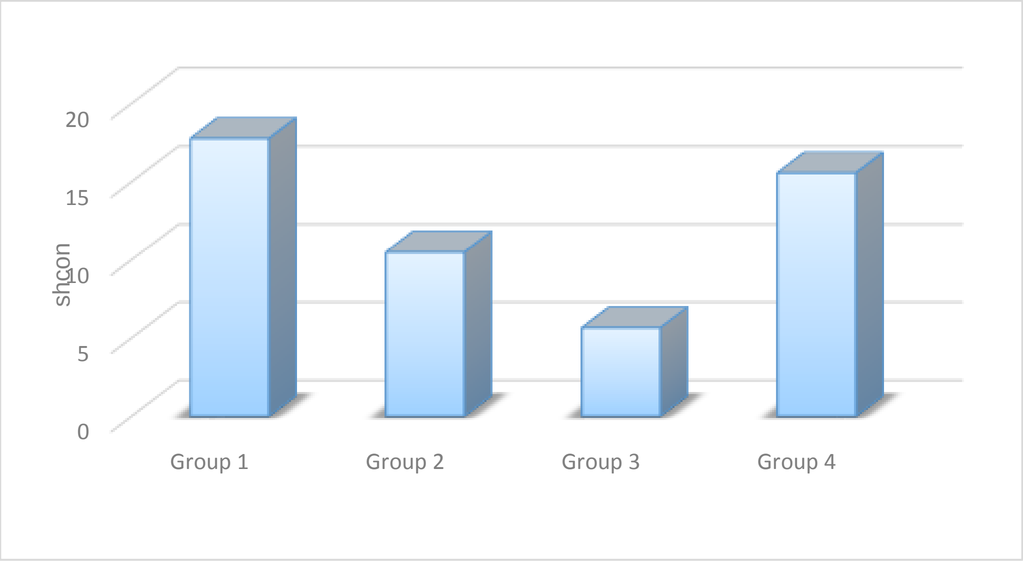


Figure 3.1: Bar graph of averages of shear bond strength in MPa for control group and experimental groups.

Table 3.3: Comparison of shear bond strength between control group and group two:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Shcon	Equal variances assumed	10.273	0.005	8.908	18	0.000	7.27616600	0.81681496
	Equal variances not assumed			8.908	11.523	0.000	7.27616600	0.81681496

Assuming the heterogeneity of the two groups because the value of the statistical significance Sig = 0.005. Smaller than 0.05 and thus the absence of homogeneity is based on the option Equivalences not assumed where the value of t = 8.908 and the statistical significance value is 0.000 which is very close to zero, which indicates the significance of the test and there are significant differences between the control group and group 2 .

Table 3.4: Comparison of shear bond strength between control group and group three:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Shcon	Equal variances assumed	8.905	0.008	14.664	18	0.000	12.12404800	0.82680693
	Equal variances not assumed			14.664	11.993	0.000	12.12404800	0.82680693

Assuming the heterogeneity of the two groups because the value of the statistical significance Sig = 0.008. Is smaller than 0.05 and therefore there is no homogeneity to the alternative variances not assumed where the value of t = 14.664 and the statistical significance value is 0.000 which is very close to zero, which indicates the significance of the test and there are significant differences between the control group and group 3.

Table 3.5: Comparison of shear bond strength between control group and group four:

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Shcon	Equal variances assumed	4.143	0.057	2.485	18	0.023	2.20261300	0.88639431
	Equal variances not assumed			2.485	14.563	0.026	2.20261300	0.88639431

Assuming the homogeneity of the variance of the two groups because the value of the statistical significance Sig = 0.057. Is greater than 0.05 and therefore the homogeneity is based on the option Equivalence equals t = 2.485 and the statistical significance value is 0.023 which is smaller than 0.05 which indicates the significance of the test and there are significant differences between the control group and group 4.

Adhesive remnant index score:

Some descriptive standards:

Table 3.6: Mean ARI (0- 3) of control group and experimental groups:

Groups	n	Mean	Std. Deviation	Std. Error
Control group Group 1	10	1.4000	1.07497	.33993
Group 2	10	2.9000	.31623	.10000
Group 3	10	2.6000	.51640	.16330
Group 4	10	1.1000	1.28668	.40689
Total	40	2.0000	1.15470	.18257

Table 3.7: Comparison of ARI between control group and experimental groups:

The mono-variance analysis was used here because the analysis of the number of groups was more than two and there was no independence between groups.

ANOVA

Cont

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	23.400	3	7.800	9.818	.000
Within Groups	28.600	36	.794		
Total	52.000	39			

The statistical significance was found to be less than 0.05, so the test was significant between the control and the three groups. There were significant differences between the control and the three groups. There was an effect of the control and the other three groups.

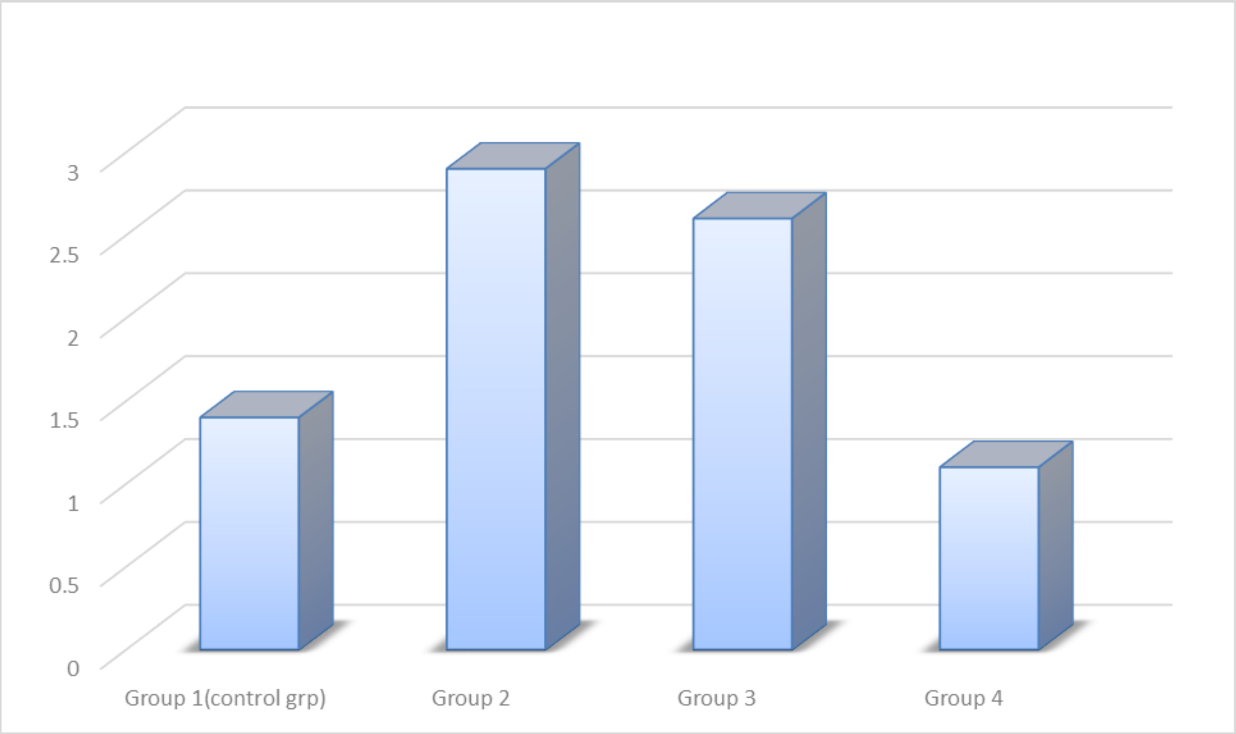


Figure 3.2: Bar graph of averages of adhesive remnant index score (0-3) for control group and experimental groups.

Table 3.8: Comparison of ARI between control group and group two (0-3)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Cont	Equal variances assumed	13.645	0.002	-4.233	18	0.000	-1.50000	0.35434
	Equal variances not assumed			-4.233	10.546	0.002	-1.50000	0.35434

Assuming the heterogeneity of the two groups because the statistical significance value is Sig = 0.002. Less than 0.05 and thus the absence of homogeneity is based on the option Equivalences not assumed where the value of -4.233 = t and the statistical significance value is 0.002 and is very close to zero, which indicates the significance of the test and there are significant differences between the control group and second group.

Table 3.9: Comparison of ARI between control group and group three (0-3)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Cont	Equal variances assumed	5.233	0.034	-3.182	18	0.005	-1.20000	0.37712
	Equal variances not assumed			-3.182	12.944	0.007	-1.20000	0.37712

Assuming the heterogeneity of the two groups because the statistical significance value is 0.034. Sig = is smaller than 0.05 and therefore there is no homogeneity to the alternative variances not assumed where the value of -3.182 = t and the statistical significance value is 0.007 which is very close to zero, which indicates the significance of the test and there are significant differences between the control group and third group .

Table 3.10: Comparison of ARI between control group and group four (0-3)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
cont	Equal variances assumed	1.034	0.323	0.566	18	0.579	0.30000	0.53020
	Equal variances not assumed			0.566	17.448	0.579	0.30000	0.53020

Assuming the heterogeneity of the two groups because the value of the statistical significance Sig = 0.323. Greater than 0.05 and therefore the homogeneity is based on the option Equivalence equals where the value of .666 = t and the statistical significance value is 0.579 which is greater than 0.05, which indicates the significance of the test and there are no significant differences between the control group and forth group.

4- DISCUSSION:

Many extensive investigations have been conducted to study bond strength of orthodontic brackets. Sufficient orthodontic bond should be present to ensure that the brackets remain bonded to the tooth surface along with the orthodontic treatment time, tolerating both orthodontic and orthopedic forces. In addition to that, at the end of treatment all the bonded brackets must be easily removed without any harmful effect to the enamel surface resulting from debonding procedure. (18)

Appropriate seal between the tooth surface and bracket base is a key point for achieving an optimal marginal integrity and decreasing the chance of bracket debonding. Moreover, increasing the tight seal between the bracket-adhesive-enamel will minimize the micro leakage of plaque bacteria while decreasing the demineralization of enamel surface and presence of white spot lesions. (101)(102).

Fixed orthodontic therapy components are plaque-retentive appliances that may lead to formation of caries and maximizing the incidence of enamel demineralization. Efforts are still ongoing to persuade the manufacturers to produce brackets with smaller base surface areas (Glatz and Featherstone,1985), (103).

(Maijer and Smith, 1981) in their study observed that decreasing the size of the bracket base enables the patient to maintain good oral hygiene, as well as improves the aesthetics (78). However, (MacColl *et al* 1998*)* have shown that decreasing the bracket base surface area from 6.82 to 2.38 mm has a great effect on bond strength reduction which affects the bonding of the attachments, hence increasing the debonding rate (55).

On the other hand, damaging of the enamel surface after debonding have resulted from difficulties in debonding because of increased bond strength to enamel (Betteridge, 1979; Carstensen, 1986) (3)(92). Retief (1974) in his work on bond failure has reported that the damage on the enamel could happen with bond strength of 13,5 MPa. However, the current studies have revealed that 11.4 MPa is considered a relatively safe value for debonding force (56).

Many literature have mentioned that the bond strength can be affected by several factors including: the bracket base type and size, tooth surface contour, types of samples (human or animal teeth), types of teeth (incisor, canine, premolar, or molar; young or old permanent teeth, deciduous teeth), etching time, concentrations of etchant, pretreated condition (humidity, temperature, and duration of water bathing), rebonding of tooth surface, recycling of bracket, types of resin and testing speed of the debonding machine (4- 16- 59- 81- 83- 104- 105- 106- 107).

In this study, forty premolar Smart clip metal brackets SL3 (3M unitek, Monrovia, California) were used to be bonded to control and experimental groups. All brackets used were bought from the same company to ensure that all specimens have the same bracket base size where the bracket surface area was determined to be 12 mm^2. In control group, the values of SBS were higher than the magnitude values of SBS achieved by Quick AN. In his study, smaller incisor brackets (Mini Diamond Twin, Ormco Corp, California, USA) were used, whereas we used premolar Smart clip metal brackets SL3 (3M unitek, Monrovia, California) with larger base surface area (20).

It has been shown that different tooth types have a significant impact on bond strengths. Researchers should use only one tooth type and/or equal number of different tooth types in test groups of their studies and, ideally, take this into account (108). In our study, human teeth were used instead of animal bovine or artificial teeth to be as close to natural properties as possible in terms of clinical morphology and tooth architecture. Premolar teeth with similar sizes and shapes were collected to decrease the possibility of variation and errors, as well as because of relative ease of collecting the sample following orthodontics therapeutic extraction.

Many solutions were used as storage media for teeth after extraction. Literature between 1999 and 2002 have indicated that freezing, ethanol, water, chloramine, formaldehyde, thymol, distilled water, and saline solution are the main storage media used for natural human teeth (109). These storage media should provide not only the preservation of the chemical, physical and mechanical properties of extracted teeth, but also avoid dehydration of teeth until further processing. Dehydration of tooth dentine leads to decrease in flexibility and increase in stiffness of dentine. This may affect the results, but may not weaken the strength and toughness of dentine.

In our study, the distilled water was used as a storage media for extracted teeth, which considered as one of the best storage medium among the other solution media used for bond strength studies.

A similar study was done by (Sachdeva *et al.*) has revealed that the shear bond strength results using isotonic saline and distilled water were 6.15 and 7.59 MPa, respectively. These results were comparable to clinical acceptable bond strength of 6-8 MPa (110). Also, (Silva et al. 2006) has shown that using distilled water as a storage media provides less variation in bond strength values, by comparing the effect of the storage time and type of storage on bond strength of extracted teeth (109).

It has been stated by (Kimura *et al* 2004) that preparation of enamel surface provides a great surface energy for bonding (111). In our study, polishing, rinsing with water/ air and dried with a steam of compressed air have been done for teeth preparation. The fluoride free pumice was used for teeth polishing, since the bond strength might be affected by fluor apatite formation resulting from deposition of fluoride in hydroxyapatite on the enamel surfaces, (Aasenden *et al* 1972) (112). Also, it has been reported that the reduction of bond strength of dental resins could be produced by the interference between topical application of fluoride and etching effect of phosphoric acid on enamel surface. (Garcia-godoy *et al* 1991) (115).

In this study, we used a conventional etching with 37% orthophosphoric acid gel for 15s. It has been reported that bond strength of 15s etching when compared to that of 60s etching were 9.38± 4.35 Mpa and 12.15± 4.25 MPa, respectively, which is higher than the required clinical successful orthodontic bonding values 6-8 MPa (114).

Transbond XT light cure adhesive and primer have been used in this study, which are considered as the one of the most popular bonding material in orthodontic clinics.

It has been reported in many studies that Transbond XT light-cured resin has a strong bond strength than that of the self-cured resin of concise. Score 1 was predominance type of bond failure which would help in the resin removal from enamel surface after completion of orthodontic treatment (115)(116).

It has been known that the orthodontic brackets in the mouth are subjected to a combination of three forces: shear, tensile and torsion (88). In our study, only shear force was evaluated using a universal test machine at a crosshead speed of 5 mm/min where shear forces applied parallel to buccal surface of teeth and bracket base in occluso – gingivally direction. The Instron machine is connected to electronic reader to record the value of maximum load at failure in newton, which is necessary to debond and shear off the brackets. Data were subsequently converted into megapascals (MPa) as a ratio of newton to surface area of the bracket (117).

This study was conducted to evaluate the shear bond strength of rebonded orthodontic brackets after different recycling methods, where orthodontic treatments have shown undesirable occurrence of bond failure more frequently (118).

The goal of bracket reconditioning is to clean and remove remnant adhesive composite from the base of the bracket with less damage either to bracket base (retentive mesh) (119) or slot dimensions, providing efficient clinical SBS needed for optimal attachments to withstand the masticatory forces. (Buchwald *et al*), have indicated in their study that some amount of composite resin remained on the bracket base in the form of residual debris after brackets recycling (120).

The bond strength of rebonded brackets depends on several factors such as; the type of bracket used, the use of recycled or new brackets, the type of adhesive system and the frequency of bonding/debonding sequences (24)(121).

The shear bond strength of recycled rebonded brackets has been interesting and controversial topic among professionals (122). (Jones and Andrew) have revealed that ecological conservation and reduction in cost are the main advantages of reusing the debonded brackets. However, decrease in shear bond values between 6-20 % is the major disadvantage (20) (123).

There were many methods available for brackets recycling, either by sending them to commercial recycling companies (Orthocycle co., Esmadent co.) or in office (chair side) recycling methods.

Although specialist recycling companies have been found to be effective in adhesive removal with adequate SBS (124), the commercial method is considered impractical, complex and requires time to send the brackets to the company for recycling. As a result, using new brackets would be more viable option. On the other hand, office technique was established and developed to avoid this delay. Studies have previously conducted and indicated that using office techniques can meet clinical requirements and yield decent results (125)(126).

Therefore, the objectives of this study are to investigate and assess the SBS of the rebonded brackets and to determine the simplest, fastest and cheapest in-office techniques used for bracket recycling. In our study, three techniques were used: sandblasting only, direct flaming/sandblasting and direct flaming only, which were compared to control group with new brackets.

On the light of the result of this study, the control group with new brackets had significantly greatest value of shear bond strength with a mean value of (17.767) among all groups. This result was in agreement with result of (Samir. E. Bishara) (122), who concluded that highest shear bond values are generally achieved after initial bracket bonding. Whereas, the shear bond strength with the values of (10.490) (p=0.00), (5.643) (p=0.00), and (15.564) (p=0.023) were obtained from recycling experimental groups; Group 2, Group 3, and Group 4 respectively.

Sand blasting recycling technique

Sandblasting technique with aluminum oxide air abrasion became preference of clinician for bracket recycling. This technique is considered simple and practical that can be performed in dental practice to avoid wasting time by sending brackets for commercial recycling (127).
The result findings of this group showed a decrease in values of SBS in comparison with control group, which indicated a significant difference between the groups. This result was in accordance with the findings of (Regan *et al.* 1993), who reported significant difference in his results with 41.4 percent of reduction in SBS following the sandblasting technique (128).

However, (Sonis *et al* 1996) have indicated that the result findings of his work show no significant difference in SBS between new and sandblasted brackets. On the contrary, the results of our study have shown that the SBS of new brackets were significantly higher than that of reconditioned brackets (5) (88) (20).

The difference in results between the two studies could be explained by variation in: type of bracket used, sandblasting duration in different studies, aluminum oxide (AL2O3) particle size and distance between etcher tip and base of bracket.
(Willems) has revealed that bracket type has a great effect on the efficiency of sandblasting (19)(129). In our study, we used premolar Smart clip metal brackets SL3 (3M unitek, Monrovia, California), whereas the Sonis has used other type of premolar brackets (GAC International, Inc., Central Islip, N.Y.) (19).
According to (Quick *et al),* recycling brackets at a pressure of 4.5 bar and using aluminum oxide granules 50μm for 15s duration time was enough to remove the remaining compound of adhesives without compromising the strength of the bond (20). However, (Milllett (130) and Aricit) (131) have stated that sandblasting the recycled brackets for an extended duration of time with larger granules leads to decrease in SBS as a result of bracket base damage and distortion. Also, (Neumann *et al* and Rajagopal *et al*) had a great concern of recycling bracket for longer time by sandblasting, as this could lead to harm and damage the area of undercut in the bracket base which may compromise the SBS (132).

In our study, 90 μm aluminum oxide (AL2O3) abrasive powder has been used at pressure of five-bar (72.5-psi) for an extended time duration of 30s. This may obliterate the bracket base mesh by residual adhesive material and alter the definition of retentive area, which could help in explaining the results of our study and the difference in SBS between the groups.

Direct flaming recycling technique

The direct flaming technique in this study has recorded the lowest SBS among all the groups, which is significantly different from the control group. This findings seems to confirm the result of (Kamisetty SK *et la*) (26), and other various earlier studies.

Chetan in his study has shown that heating the bracket base for bonding material removal reduced bracket hardness (133). Removing the adhesive material requires exposure to heat for longer time which is a crucial factor that has a negative effect on bracket material and its microstructure (88). Heat affects mesh strand diameter leading to decline in bond strength as a result of reduction in effectiveness of the retentive parts of the base and their size(6). Moreover, the physical properties of the metal of the brackets might be affected by gas torch used for heating brackets (134). In this study we used gas torch for only 10s for bracket recycling, which was found to be not enough to remove all the remnant of composite, and could lead to obstruct the mechanical retentive area of bracket base (20).

Orthodontic brackets are fabricated from austenitic stainless steel (88) with homogeneous and nongranular microstructure. Exposing the brackets to heat above 400°C leads to chromium carbide precipitate (6) and this in turn makes the brackets more vulnerable to fracture under masticatory forces due to the weakened structure and disintegration of the metal alloy. However, (Buchman) has reported that there was a little clinical importance as a result of reduction on bracket hardness due to heating process (21). Furthermore, it causes discoloration which is inacceptable for most of patients (134) and a decrease in corrosion resistance (132) which are the main disadvantages along with the reduction in bond strength after heating process.

(Huang Tsui-Hsien *et al)* have reported that thermal recycling method makes brackets more susceptible to tarnish and corrosion, which are responsible for bracket failure in the mouth (18). A layer of metal oxide could be produced as a result of the reduction in resistance of corrosion in the bracket. Electro polishing procedure is used in order to remove this layer. (Bishara *et al*) have stated that the possibility of slot widening in the bracket may occur because of electro polishing, which may also lead to damage the brackets under masticatory forces (24)

Direct flaming / sand blasting recycling technique

In direct flaming/sandblasting technique for group 4, the shear bond strength values have been reduced, however they were still the highest BSB values among the experimental groups. The result findings showed a significant difference in comparison with control group. The recycled brackets of this group were manipulated similarly to those of group 2. Apart from that the remnant adhesive material was flamed before sandblasting the bracket.
These findings were inconsistent with the results achieved by (Quick AN, Harris AM, Joseph) who concluded that there was no significant difference in SBS of new bracket and recycled bracket by flaming and sandblasting (20).

In this study the observed decrease in SBS for experimental groups compared to control group was similar to that of some previous studies (128) (136). However, (Regan *et la*) (128) have emphasized that if this reduction was still above the minimum optimal values of SBS with enough bracket bond strength, the reconditioned brackets could be rebonded again, where the acceptable clinical SBS has been defined to be between 6- 8 by (Reynolds IR *et la*) (18).
(Bishara *et la*) have concluded in their study that the highest SBS was generally achieved after first bonding, and shear bond strength could also change as a result of morphological changes in etched surface of enamel after debonding because of composite remnant presence (24).

Adhesive Remnant Index (ARI)

In our study, the mean of residual adhesive of control group was about (1.40), suggesting a significant difference in mean ARI value when compared with the second and third groups, (2.90)(p=0.002 and (2.60)(p=0.034), respectively. These results indicate that failure of bonding occurred more frequently at bracket/resin interface in experimental group 2 and 3. The mode of bracket failure among these groups was favorable with less chance of enamel fracture during the debonding procedure. On the other hand, the mean ARI of control group (1.40) did not show a significant difference compared with fourth group (1.10) (p=0.323).

For enamel surface examination, many methods were used for this purpose including (Brown and Way, 1978) (137) who used a miniaturized Boley gauge for quantitative analysis, (Quick et al., 1992) (137), scanning ruby laser digitizer was used by (Al Shamsi et al., 2007) (138), and non-contacting laser probe or a 3D laser profilometer which was used by (Lee and Lim, 2008) (139).

In our study, the bonding area of teeth was examined and inspected visually in daylight using a magnifier with a 75mm diameter and 2.5x magnification (No: SBR-227) to examine the amount of resin left on the enamel surface after debonding. Afterwards, the qualitative assessment of the tooth surface was provided by ARI scores (95).

For reliability, five specimens from each group were randomly selected and re-examined after a period of 3 days by the same inspector in the same environment of daylight and compared with the previous result of ARI.

Clinically, the results would be undesirable when the bond failure occurred at enamel- resin interface as the risk of enamel damage might happen. However, it is much preferable for the failure to occur at bracket-resin interface because that means less enamel fracture will occur later during deboning process (140) (141).

Based on our investigation, the greatest number of ARI were score 3 and 2, which were recorded for experimental groups 2 and 3. These scores indicate that in both groups the bond failure took place at adhesive-bracket interface and excessive amount of resinthe enamel surface. In clinical terms, however, these results may reduce the chance of enamel damage and fracture at the time of bracket debonding. The removal of residual resin from the enamel surface not only increase the chair time, but also could lead to enamel damage with the use of tungsten carbide burs. (Schuler and Van Waes., 2003) have concluded that tungsten carbide burs caused visible grooves in the line angle +/- cervical areas in 88% of specimens after examined 284 teeth (142).

In control group and group 4 the site of bond failure occurred at enamel – resin interface with predominant score between 0 and 1, i.e., No or less than 50% of resin remained adhere to enamel surface. This proves that the bond between brackets – resin were higher than the bond between enamel- resin interface, which indicated of high SBS of brackets.

5- CONCLUSION

The following conclusion can be drawn from this study:

The null hypothesis of the study was rejected. It was concluded that the new premolar smart clip metal brackets had highly SBS values compared with recycled ones. The brackets that have been flamed/sandblasted were higher in SBS than those recycled either by sandblasting only or flaming only. Recycling by flaming can lead to significantly lower SBS, resulting in a decrease in corrosion resistance which leads to softening of bracket metal. Bracket recycling with sandblasting technique is considered the simplest, fastest and more efficient method that can reduce the working time, minimize the cost and provide comparable and adequate SBS that meets the clinical requirements needed with less changes in the physical properties of the recycled brackets.

The brackets with high SBS showed higher frequency of ARI scores 0 and 1 with less adhesive remained on teeth surfaces, whereas the bond failure of less SBS brackets occurred at bracket-resin interface with predominant ARI score of 2 and 3 with excessive amount of adhesive remained on teeth surfaces.

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APPENDICES:

Table 7.1: Results of SBS for control group and experimental groups:

Group Sample No	Group 1	Group2	Group3	Group 4
1	18.119	10.846	8.011	13.905
2	21.523	10.568	5.369	15.408
3	16.131	12.443	5.077	15.887
4	20.609	9.134	4.566	15.022
5	15.925	9.656	5.062	12.695
6	15.038	10.170	6.560	17.513
7	15.148	11.240	5.203	16.945
8	20.673	10.009	5.220	15.790
9	16.592	10.669	5.307	16.007
10	19.315	10.169	6.051	16.469

Table 7.2: Adhesive remnant scores

Groups Sample No	Group 1	Group 2	Group 3	Group 4
1	1	3	3	1
2	0	3	3	1
3	3	2	3	0
4	0	2	3	1
5	0	3	3	0
6	0	3	3	2
7	2	3	3	1
8	2	2	3	2
9	0	3	3	3
10	3	2	2	3