AN IN VITRO COMPARISON OF SHEAR PEEL BOND STRENGTH AND FAILURE LOCATION OF ADHESIVES USED FOR CURRENT INDIRECT BRACKET BONDING TECHNIQUES

Authors’ Name:

Maj Vishal Siwach*, MDS, Surg Capt Sandeep Sharmab, MDS,
Lt Col Jaideep Senguptac

* Maj Vishal Siwach, MDS, Graded Specialist, Military Dental Centre Khadakwasla

b Surg Capt Sandeep Sharma, MDS, Classified Specialist, INHS Ashwani Mumbai.

c Lt Col Jaideep Sengupta, MDS, Classified Specialist, AFDC, New Delhi.

* Corresponding Author: Maj Vishal Siwach*, MDS, Graded Specialist, Military Dental Centre, Khadakwasla - 411 023, Pune. Ph: 020-25206774

Abstract

The aim of this in-vitro investigation was to measure the shear peel bond strength of three commercially available orthodontic bonding agents using two most widely used indirect bonding techniques: (indirect-1) introduced by Cohen and Silverman and (indirect-2) as described by Thomas. Eighty extracted human maxillary premolars were divided equally into four groups. First two groups were bonded with stainless steel brackets by indirect-1 technique utilizing Transbond XT- 3M Unitek, and Fuji Ortho LC - CC Corp. respectively. Indirect - 2 technique was used for groups III and IV using the above mentioned adhesives along with Sondhi Rapid Set - 3M, Unitek. Actual chairside procedures were simulated with regard to timing and manipulation of adhesives and attachments. Brackets bonded by these two methods of application were subjected to shear peel bond strength tests using universal testing machine. Mean shear bond strengths were 13.41 ± 5.45 MPa, 9.05 ± 2.36 MPa, 13.19 ± 4.64 MPa and 8.67 ± 1.69 MPa respectively for groups I, II, III and IV respectively. A one-way analysis of variance showed no significant difference in shear peel bond strength of the two adhesives when bonded with either of the indirect bonding technique. Furthermore, a Weibull analysis showed all four groups tested provided over a 90% survival rate at normal masticatory and orthodontic force levels. For each tooth, an Adhesive Remnant Index (ARI) score was determined. Group III & IV (Indirect-2) was found to have a significantly lower ARI score (P<.05) compared with groups I and II.

INTRODUCTION

Preadjusted appliances demand a high degree of precision in bracket placement. With Preadjusted brackets, the position of the bracket on the crown determines final tip, torque, height and rotation of the tooth [1]. Poor bracket positioning can render even the most customized prescription ineffective. Several devices and methods have been tried to make the task of attachment of orthodontic appliances easier and more precise.
Commonly used indirect bonding techniques are: An indirect technique (indirect-1) introduced in 1972 by Cohen and Silverman [2,3] in which the brackets positioned on the study casts with a water soluble adhesive are transferred to the mouth with a custom tray, and a more recent development [4] introduced by Thomas (indirect-2), wherein the bracket is positioned on the patient's study cast with filled resin. The bracket is then transferred to mouth with a custom tray and bonding is facilitated by unfilled liquid sealant that is applied to precured resin at the bracket base and the prepared tooth surface.

The advantages and disadvantages of bonding indirectly as compared with direct bonding have been discussed by numerous authors [5,6,7]. Often listed advantages of indirect system are the following: accuracy, increased office efficiency and improved patient comfort.

Despite these advantages, less than 10% of orthodontists use indirect bonding techniques. One of the reasons for this is the difficulty in achieving consistent and predictable adhesion to teeth [8].

Most studies on indirect bonding have used bonding materials originally developed for direct bonding or for dental restorative purposes [2,3,4,8,9,10]. Recently several products have been introduced that are specifically designed for indirect bonding [11].

In the present study, in addition to light-cured composites (Transbond XT-3M Unitek) and a fluoride-releasing resin-modified glass-ionomer adhesive (Fuji Ortho LC - CC Corp., Tokyo, Japan) for bonding, a recently introduced rapid setting chemical cured sealant (Sondhi Rapid Set - 3M,Unitek) specifically designed for indirect bonding is also considered.

The purpose of this in-vitro investigation was to measure the bond strength of the above mentioned commercially available adhesives using two most widely used indirect bonding techniques and to assess the amount of residual resin on the tooth surface after debonding. There is limited information available on bond strengths with these materials.

**MATERIALS AND METHOD**

This study attempts to follow the standard technique for shear bond testing as suggested by Fox et al [12] as much as possible. For the in vitro study eighty human maxillary first premolars extractedatraumatically for orthodontic treatment were collected. Tissue tags if any were removed from all teeth prior to autoclaving these at 127°C for 20 minutes. The teeth were then stored in water at room temperature.

**Working Model Preparation**

All the teeth were randomly divided into four groups, numbered I to IV. 10 sample teeth from each group were arranged in an ovoid archform simulating mild malocclusion in modeling putty. Alginate impression of the teeth setup was taken and the teeth were transferred in the impression. This impression was then poured in dental stone thus giving one sample arch. Two such sample arches were made from teeth of each group, thus yielding a total of eight arches for four groups. A replica of each sample arch was made in dental die stone with an accurate alginate impression. Teeth in the two sample arches of each group were numbered from 1 to 20.

All the diestone models were checked for any void or bubble and were dried in oven for one hour at 250°C. For the Grp I & II, Indirect - 1 technique was used whereas for group III & IV Indirect-2 technique was used.

For groups I & II, the stainless steel miniature twin upper bicuspids .022 brackets (3M Unitek) with a surface area of the bracket base mesh 8.423 mm2 were placed on the diestone models with water soluble glue (Fevicol) at the long axis of each tooth and in the middle of facial surface 4 mm from the occlusal surface. The adhesive was allowed to set for 1 hour before the construction of transfer tray.

For groups III & IV the diestone models were coated with a thin layer of separating medium (diluted cold mould seal). The brackets were then placed on the teeth as in groups I to II using Transbond XT (3M Unitek) light cure resin and Fuji Ortho LC (CC Corp., Tokyo, Japan) as the adhesive for the group III and IV respectively. Each tooth was then cured for 20 second from the occlusal and 20 sec from gingival using the Setelec LC unit.

Thus 80 brackets were placed on the marked buccal surface of teeth on the diestone models using 3 different adhesives (Table: I).

**Transfer Tray Fabrication**

Transfer trays were fabricated over the bracketed diestone model on the Ministar (Schue-Dental, Germany). Initial tray was up of the Copyplast 1 X
125 mm (Schu-Dental, Germany) which was overlaid with Bioacryl 1 X 125 mm (Schu-Dental, Germany) as per manufacturer instructions. The bracketed diestone model along with the trays was then soaked in warm water for 30 minutes. The trays were then removed from the models and were separated. Any excess tray material was trimmed with a crown and bridge scissors. The hard outer shell was trimmed away from all height of contours. Similar procedure was carried out for the rest of the bracketed diestone models, finally yielding 8 pairs of transfer trays.

The custom bases of the brackets for groups III & IV were again light cured for 5 sec each to ensure complete curing of the resin. The trays were then cleaned in ultrasonic cleaner (*USG 4000*, Ultraschall, Dentaum, Germany) for 5 minutes. For groups I & II trays most of the water soluble adhesive dissolved away from the bracket bases and any remaining adhesive was cleaned with liquid soap, warm water and brush. The adhesive custom bases of the Group III & IV were lightly sandblasted with fine Aluminum oxide particles of the size of 50 µm, ("Korostar", Bego, Germany). Finally acetone was applied to bracket bases of all the groups to remove any residual film and these were air dried. The indirect bonding procedure was performed 7 days after fabrication of transfer trays [1].

**Indirect Bonding Procedure**

A thorough prophylaxis, utilizing a rotary cup and oil free pumice paste was done for all teeth for 10 sec each. The teeth were then rinsed in water and air dried. Preparatory to bonding each tooth was etched with 37 percent phosphoric acid (ScotchbondTM, 3M) for 30 seconds and then rinsed thoroughly with water followed by drying with warm air.

For Group I the prepared teeth were then coated lightly with Transbond XT light cure primer (3M Unitek) and the brackets in the transfer trays were loaded with light cured composite (Transbond XT, 3M Unitek). For Group II just before bonding, enamel surface of each sample tooth was moistened with water with the help of cotton roll and then coated with Fuji Ortho LC primer. The bracket bases were coated with mixed Fuji Ortho LC adhesive. The trays were then seated onto the teeth and were held with firm pressure. Each tooth was cured for 40 seconds (10 sec each from one surface) The trays were then removed from lingual to buccal side one after the other.

For Group III & IV prepared teeth were coated lightly with Resin A of Sonlhi Rapid Set, (3M, Unitek) and the resin pads in the indirect bonding tray with Resin B. The trays were then positioned over the teeth with a hinge motion and then equal pressure was applied to the occlusal and buccal surface of all teeth for next 30 seconds with fingers. The trays were peeled using a scaler from lingual to buccal.

The specimens from all groups were then stored in distilled water for 7 days. In case of a bracket failure upon removal of the tray, the adhesive was removed from the tooth surface with a finishing bur and the base of the bracket was cleaned with a scaler and sandblasted. Then the bonding procedure was repeated. Only two brackets required rebonding by this method. This number was considered insignificant and not taken into account for statistical analysis.

**Debonding Procedure**

The brackets were debonded with a shear load by means of Hounsfield machine set at a crosshead speed of 1 mm/minute with load cell of 300 N. Each specimen was mounted in a specially designed jig so that the shearing blade was positioned above the bracket and adhesive interface to produce a shear peel force parallel to the bracket base in an occluso-gingival direction (Fig. 1). The load at failure was recorded in Newtons. After debonding, specimen's substrate surfaces were examined under stereomicroscope (Nikon Stereoscopic Microscope, SMZ-10, JAPAN) with IO X magnification and an Adhesive Remnant Index (ARI) [13] with modification by Lalani et al [14] for enamel fracture was determined which is as follows:

0: Indicates no adhesive left on tooth surface.

1: Indicates less than 50% of adhesive on the tooth surface.

2: Indicates more than 50% of adhesive on tooth surface.

3: Indicates 100% adhesive on tooth surface along with the impression of bracket base.

EF: Indicates enamel fracture.

The ARI score for the entire sample was assessed by the same operator.

**STATISTICAL ANALYSIS**

The shear peel bond strength values were converted into Megapascals (MPa) units by dividing Shear Load
in Newtons (N) by bracket base mesh area (8.423 mm2). Bond strength of the four groups were subjected to one-way Analysis of Variance (ANOVA) test, with post hoc Tukey test (P < .05). A Weibull analysis was performed: the weibull modulus, characteristic bond strength, correlation coefficient, and stress at 5% and 90% probability of failure were calculated. A Kruskal-Wallis nonparametric test was used to determine whether there were any significant difference in the ordinal ARI values at P < .05. The statistical analyses were performed using SPSS 12.0.1 for windows (SPSS Inc, Chicago, Ill).

RESULTS
The mean shear peel bond strength, standard deviation and parameters of the Weibull analysis (modulus, characteristic bond strength, correlation coefficient, and stress at 5% and 90% probability of failure) are given in table: II and III. Table: IV shows the Weibull distribution of the probability of failure at certain shear stress level for the different groups.

The analysis of variance demonstrated that there were significant differences in shear bond strength between the groups investigated (P < .001, F = 27.224). The Tukey tests revealed that mean shear bond strengths for Group I and III and Group II & IV were not significantly different from each other.

The table V shows comparison of ARI scores among four groups with their frequency distribution. A Kruskal-Wallis test showed a significant difference in ARI existed between the groups (X2 = 19.22, P < .05).

DISCUSSION
Indirect bonding, in various forms, has been practiced for several years [5] and seems to be gaining widespread acceptance among orthodontists, due to improvement in bracket base design, adhesive technology, and transfer tray materials [15].

The majority of reports on indirect bonding procedures have been technique-oriented. Very few studies have quantified bond failures from indirect bonding procedures [1, 6, 10, 11, 16-22].

Several factors can make bond strength comparisons amongst in vitro tests and between in vitro and in vivo studies difficult [7]. It must be taken into account that in vitro bond failures occur under static loading whereas in vivo bond failures occur under variable cyclic loading. Direct extrapolation from in vitro bond strengths to conclusions regarding bond failure rates under clinical conditions may be erroneous. However, in vitro tests still provide an insight on the performance of two different systems intended for the same application. Hence this study was carried out to measure the shear peel bond strength of the two most widely used light cure adhesive systems (Transbond XT (3M Unitek) and Fuji Ortho LC (GC group) used in current indirect bonding techniques [3, 4]. A thorough search of literature and available public domain resources revealed no reference or study in which this combination of bonding adhesives and techniques has been tested in this manner.

The mean shear bond strength for light cure resin (Transbond XT) and light cure resin reinforced glass ionomer cement (Fuji Ortho LC) bonded in Indirect-1 mode was found to be 13.41 ± 5.45 MPa and 9.05 ± 2.36 MPa respectively. The mean shear bond strength of the above mentioned adhesives in Indirect-2 technique along with Sondhi Rapid set resin was found to be 13.19 ± 4.64 MPa and 8.67 ± 1.69 MPa respectively.

The mean shear bond strengths for four groups ranged from 8.47 to 13.84 MPa and were above clinically acceptable levels of 5.9 - 7.8 MPa suggested by Reynolds [24]. At 0.01 level of significance, there were no differences between mean shear peel bond strengths for either of the two application methods tested. This finding is in general agreement with the findings of the studies of Sinha et al [7] and Shiau et al [17, 25]. In general, inter-study comparison of bond strength measurements is complicated by a variety of materials and methods that have been used in bond strength studies [12]; including variations in tooth type, storage conditions, method of debonding, analysis of the results, and the selection of products for comparison [26].

Regarding group III, the finding agrees with several previous publications [18-23]. No published data of shear peel bond strength is available for brackets bonded with Transbond XT in Indirect-1 mode and for Fuji Ortho LC in both Indirect-1 & 2 modes. Klocke et al, Milne et al and Hocevar et al [6, 11, 16] found no significant difference in shear peel bond strength of the brackets bonded in direct and indirect-2 (Thomas technique) techniques with two paste chemical cure adhesive at 0.05 level of significance. If we apply this same finding to the present study then mean shear peel bond strength of Transbond XT (13.41 ± 5.45 MPa, 13.19 ± 4.64 MPa) are comparable with the results of Klocke et al (13.88 ± 2.33) [11], who used the same
adhesives in direct mode in a similar experimental design. Shear peel bond strength of Fuji Ortho LC in the present study (9.05 + 2.36 MPa, 8.67 + 1.69 MPa) when compared with the findings of Bishara et al., Newman et al and Movahhed et al [23,27,28] (7.3 + 1.9 MPa, 7.92 + 2.27 MPa, 9.6 + 1.6 MPa) of the same adhesive but utilizing 10% polyacrylic acid as etchant are also almost similar. The fact that both groups with Fuji Ortho LC exhibited lower bond strengths suggests that the reason for this is related to the bracket base resin reinforced glass ionomer system.

But for the interpretation of the results of bond strength measurements, mean values are of limited use for the clinician [26]. A survival analysis, eg, Weibull analysis, may be more appropriate to indicate the clinical performance because it outlines the probability of failure at a certain force level [12]. The Weibull equation depends on two parameters [29]:

(i) The Weibull modulus. A high Weibull modulus indicates a close grouping of the fracture stress values indicating a more predictable system and, therefore a more clinically reliable system. In the present study Group IV has the highest Weibull modulus of 7.04 while Group III has the lowest value of 2.99 (Table. III). This difference implies more clinical predictability with Fuji Ortho LC in Indirect-2 mode than with Transbond XT in Indirect 2 mode. Similar results are found with the indirect-1 technique.

(ii) The characteristic level. This refers to the shear peel stress at which 63.2 per cent of the samples fail. The higher the characteristic level the higher the bond strength of a bracket-bonding system [29]. In the present study, Group III has the highest characteristic bond strength of 15.16 MN.m-2 while Group IV has the lowest value of 9.01 MN.m-2 (Table. III). This indicates higher shear peel bond strength achieved with Transbond XT in both the Indirect 1 and 2 techniques.

Hobson et al [30] proposed the calculation of probability of failure at clinically sufficient bond strength level of 8 MPa as recommended by Reynolds [24]. Table: IV shows considerable chance of bond failure for groups II and IV when shear stress approaches the abovementioned level of 8 MPa despite having a mean shear peel bond strength of 9.05 + 2.36 MPa and 8.67 + 1.69 MPa respectively. Littlewood et al [31,32] emphasized that lower values of the bond strength distribution govern the likelihood of clinical failure. Littlewood et al [31] suggested using the 5% chance of failure as a more appropriate level to assess bond strength. According to these authors, the bond strength of a material with a 5% chance of failure should be at least 5.4 MPa. In this study, this requirement was met by all the groups (Table. IV) with group III showing the highest value of 5.9 MPa. The fact that both groups with resin reinforced glass ionomer cement exhibited lower bond strengths suggests that reason for this may be related to the custom base composite.

The frequency table of ARI score are presented in (Table V). A lower score indicates a diminished amount of resin remaining on the tooth surface after debonding of the bracket. One-way analyses of variance indicated significant differences (p < 0.01) among the groups. Both Transbond XT and Fuji Ortho LC had significantly lower ARI scores (p < 0.05) for the indirect-2 technique as compared with the indirect-1 technique. The differences in ARI score clearly demonstrated that the indirect-2 technique had the most desired results. This experiment demonstrated that apart from type of bracket base, debonding technique used, and the adhesive type [7], the bonding technique plays a part in determining the ARI score. Our finding is consistent with results obtained by Hocevar et al and Sinha et al [7,16]. This may be due to the fact that the resin is precured to the base of the bracket and, hence, the weak link in the bonding system may be at the precured filled resin-tooth surface interface, the failure occurring within the unfilled resin. The high frequency of score 3 in group II indicates a weak bond between bracket base and adhesive. For the other groups, infrequent occurrence of an ARI score of either 0 or 3 suggested that adequate mechanical retention was present between the adhesive and bracket base and between the adhesive and enamel and that the weak link was within the adhesive itself.

The frequency of enamel fracture at debond was 15% for Group I, 10% for Group II, 5% for Group III and 20% for Group IV. Retief [33] reported that the lowest bond strength at which fracture within the enamel at debond occurred was 9.7 MPa. The shear debond stress resulting in enamel fracture for the groups in this investigation ranged from 4.81 MPa to 23.21 MPa. However the facts that enamel fracture at debond is present in all the four groups cannot be explained solely by bond strength at the interfaces, and therefore other factors may be responsible [34]. Zachrisson et al [9] found that between 7.8% and 10.2% of zones on premolars had enamel cracking in vivo before orthodontic treatment, increasing to 12.2% to 20.5% after debonding. In a study carried out by Rix et al [35]

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using 16X magnification, enamel cracks were found in 46.7% of zones in the sample of 160 premolars, suggesting that the extraction process may have resulted in more extensive enamel cracking than is expected in in-vivo premolars.

SUMMARY AND CONCLUSION
The combinations of bonding adhesives and techniques used in this study had not been tested in this manner under the same testing conditions. All combinations of bonding adhesives and techniques resulted in bond strengths sufficient to withstand functional stresses under orthodontic and masticatory [7] forces. The differences in the ARI score clearly demonstrated that the indirect-2 technique had the most desired results. Bond strengths are technique sensitive, and the same bond materials can yield different results in varying experimental conditions. Further, remnants of resin on debonding after shear testing may be different than those after clinical debonding. This study may have clinical interest because it evaluated bond strengths of two commercially available light cure bonding materials employing most widely used indirect bonding techniques and assessed the amount of residual resin on the tooth surface on debonding. However, laboratory results cannot be extrapolated to clinical environment, hence, clinical studies need to be performed to yield more clinically meaningful results.

The following conclusions were drawn
1. Transbond XT displayed significantly higher shear peel bond strength than Fuji Ortho LC in both indirect-1 & 2 techniques; although bond strengths for both adhesives were clinically acceptable. Fuji Ortho LC is a more reliable bonding system than Transbond XT at low shear stress values up to 6 MPa, but its probability of failure increases sharply beyond stress value of 6 MPa.

2. No significant difference was found in shear peel bond strength of the two adhesives when bonded with either of the indirect bonding technique.

3. The indirect-2 technique had significantly lower ARI score compared with the indirect-1 technique, therefore requiring little or no cleanup after debonding.

REFERENCES
13. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch


### TABLE I: GROUP DISTRIBUTION ALONG WITH ADHESIVES USED

<table>
<thead>
<tr>
<th>Group</th>
<th>Sub Group</th>
<th>Adhesive For Laboratory Setup</th>
<th>Adhesive / Unfilled Sealent for Bonding to Teeth</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>1,2</td>
<td>Fevicol</td>
<td>Transbond XT</td>
</tr>
<tr>
<td>II</td>
<td>3,4</td>
<td>Fevicol</td>
<td>Fuji Ortho LC</td>
</tr>
<tr>
<td>III</td>
<td>5,6</td>
<td>Transbond XT for custom base</td>
<td>-</td>
</tr>
<tr>
<td>IV</td>
<td>7,8</td>
<td>Fuji Ortho LC for custom base</td>
<td>Sondhi Rapid Set</td>
</tr>
</tbody>
</table>

### TABLE II: MEAN SHEAR BOND STRENGTH

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Mean (MPa)</th>
<th>Std. Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Group Difference</th>
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<tbody>
<tr>
<td>I</td>
<td>13.41</td>
<td>5.45</td>
<td>6.23</td>
<td>23.21</td>
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<tr>
<td>II</td>
<td>9.05</td>
<td>2.36</td>
<td>6.09</td>
<td>14.83</td>
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<td>III</td>
<td>13.19</td>
<td>4.64</td>
<td>4.81</td>
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<tr>
<td>IV</td>
<td>8.67</td>
<td>1.69</td>
<td>6.33</td>
<td>11.52</td>
<td>B</td>
</tr>
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*: Groups with the same letters are not significantly different from each other (Tukey, P < .05)

### TABLE III: WEIBULL PARAMETERS OF DIFFERENT GROUPS

<table>
<thead>
<tr>
<th>Group</th>
<th>Weibull Modulus</th>
<th>Correlation Coefficient</th>
<th>Characteristic Bond Strength</th>
<th>Stress At 5% Probability Of Failure</th>
<th>Stress At 90% Probability Of Failure</th>
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<tr>
<td>I</td>
<td>3</td>
<td>.97</td>
<td>15.42</td>
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<td>IV</td>
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<td>.93</td>
<td>9.01</td>
<td>5.9</td>
<td>10.14</td>
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### TABLE IV: PROBABILITY OF FAILURE (%) OF DIFFERENT GROUPS AT FOLLOWING STRESS LEVELS (in MPa)

<table>
<thead>
<tr>
<th>Probability of Failure in %</th>
<th>5.9</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>26</th>
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<tbody>
<tr>
<td>Group I</td>
<td>5</td>
<td>12.95</td>
<td>23</td>
<td>37</td>
<td>52</td>
<td>67</td>
<td>79</td>
<td>88</td>
<td>94</td>
<td>97</td>
<td>99</td>
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<tr>
<td>Group II</td>
<td>6</td>
<td>26.83</td>
<td>59</td>
<td>88</td>
<td>98</td>
<td>99</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Group III</td>
<td>5</td>
<td>13.7</td>
<td>24</td>
<td>39</td>
<td>54</td>
<td>69</td>
<td>81</td>
<td>89</td>
<td>95</td>
<td>98</td>
<td>99</td>
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<td>87</td>
<td>99</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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### TABLE V: FREQUENCY DISTRIBUTION OF ARI SCORE FOR EACH GROUP

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<tr>
<th>SCORE</th>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>TOTAL</th>
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</thead>
<tbody>
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<td>2</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>GROUP II</td>
<td>1</td>
<td>8</td>
<td>3</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>GROUP III</td>
<td>3</td>
<td>16</td>
<td>1</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>GROUP IV</td>
<td>2</td>
<td>15</td>
<td>3</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8</td>
<td>51</td>
<td>12</td>
<td>9</td>
<td>80</td>
</tr>
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</table>

**Fig. 1**: Specimen Mounted on a Specially Designed Jig to produce a sheer force parallel to the Bracket base.