The effect of adhesive base design of three well used stainless steel orthodontic molar brackets. An *in vitro* comparison of shear bond strengths

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The majority of todays fixed appliances are routinely bonded from second molar to second molar with a great deal of success (Tsibel and Kuftinec 2004). Thus, it would appear as though orthodontic treatment is moving away from using molar bands to bonding as techniques, bonding agents and the adhesive bracket bases evolve and improve.

Enamel etching is an accepted procedure even though there is enamel decalcification and loss (Flores *et al* 1999, Hosein *et al* 2004). Little has changed in the composition of the adhesive composite resins, because of the consistant reliabilty of the bond achieved. The majority are still a mixture of bis-GMA (Bisphenylglycidal-methacrylate) diluted with a less viscous acrylate (Matasa 2003a, Aljouni *et al* 2004). Both the enamel and the bracket base bond to the bonding agent by means of mechanical retention. (Sharma-Sayal *et al* 2003)

The variables associated with shear bond strength are amongst others the size, design and surface treatment of the adhesive surface of the brackets (Bishara *et al* 1999a, Sharma-Sayal *et al* 2003). In the attempt to improve bond strength the bracket adhesive pad has been a focus of development (Matasa 2003a). There are many variations in the adhesive surface design of stainless steel orthodontic brackets. Manufacturers claim their own unique ‘in house’ adhesive surface design, trademarks and/or patents but at the same time provide very little information regarding the dimensions of these bases (Matasa 2003a). The demands of an aesthetically conscious society and the refinement of bracket base design has allowed manufacturers to decrease the size of the bases, without sacrificing bond strength (cucu banks cozza). The adhesive surface size has been reduced by 75% in recent years (Matasa 2003a). The size of the base is important because of the oral hygiene ramifications, bond strength and aesthetic considerations (Sharma-Sayal *et al* 2003 (Sperber *et al* 1999, Tsibel and Kuftinec 2004, Millett and Mc Cabe 1996, Gillgrass *et al* 2001).).

Since the inception of bonding, it has been the bracket base/adhesive agent interface that has been the weak link in orthodontic bonding (Sharma-Sayal *et al* 2003). Seventy five percent of brackets with a simple foil mesh base undergo bond failure at the bracket adhesive interface (Sorel *et al*

2002). Presently most stainless steel attachments use a fine mesh of sorts (Wang *et al* 2004).

The mesh based brackets with larger mesh spaces (apertures) provided a greater shear bond strength than did bases with smaller mesh apertures. The number of openings per unit of area of the bracket base is determined by the wire diameter and the mesh spacing. For resin to penetrate the base effectively air needs to be able to escape and this is determined by the free volume between the mesh and the bracket base (Sharma-Sayal *et al* 2003).

The two areas in which improvements have taken place are in the design of the mesh as well as bond enhancing metal surface treatments (Matasa 2003b, MacColl *et al* 1998). The various types of treatment have entailed micro-etching, sandblasting, polymer coating or spraying with fine particles of molten metal (Matasa 2003a, MacColl *et al* 1998). There are still further possibilities for improving base retention by incorporating a wetting agent, thus facilitating better penetration of the adhesive. Bis-GMA is a hydrophobic non-polar compound with a hydrophilic-lipophilic balance of +7.4 and does not penetrate the highly polar surfaces (hydrophilic) of etched enamel or oxide covered attachments. To counter this chemical effect, pressure application to the attachment prior to polimerisation is of utmost importance in order to ensure maximum penetration of adhesive into the mesh of the bracket pad (Matasa 2004). As far as the mesh design is concerned Matasa (2003a) claimed that the mesh number and the wire diameter of the mesh are the most important influencing factors. *Mesh number* is the number of openings per lineal inch measured from the centre of the one strand to the next. The mesh *wire diameter* is also important in that if it is to thin it could break, whilst if too thick it could limit sufficient amounts of adhesive penetration. The size of the *aperture* in the mesh plays a role in that it can prevent the coarser particles of the adhesive from penetrating the mesh. Currently the trend is for a less dense mesh to be used so as to ensure a larger aperture or open area in the base (Wang 2004).

Certain bracket/adhesive combinations exhibit greater shear bond test results. This is thought to be as result of the fact that the base design enhances or restricts adhesive penetration and or light exposure. The distribution of certain resins within a certain base design may better resist debonding because of a more favourable stress distribution (Knox *et al* 2000). Mesh design affects stress distribution at debonding mainly by influencing the flexibility of the base of the bracket (Knox *et al* 2001). Double mesh bases showed less stress in the superficial mesh as opposed to the deeper mesh layer thus allowing increased flexibility of the base, when compared to single mesh designs. Wire diameter and mesh spacing of the single mesh brackets affect the size and location of the stresses both adhesively and cohesively. Single and double mesh bases have similar bond strength and bracket failure modes (Bishara *et al* 2004b).

(Cucu *et al* 2002 Banks and Macfarlane 2007) claimed that there is no apparent relationship between the size of the adhesive pad and bond strength. Cozza *et al* 2006) demonstrated that retentive surface enlargement improved adhesion but also increased the risk of fracture at the bracket/adhesive interface because of surface variability. This substantiated the finding of MacColl *et al* (1998) that shear bond strength was independent of the base size once the surface area of the bracket exceeded 7mm^2. Their tests showed that the site of bond failure was mostly at the adhesive bracket interface. However their clinical observations show bond failure to occur usually at the enamel adhesive interface (Cucu *et al* 2002). This suggests that factors such as moisture contamination play a large part in the bond failure of the orthodontic brackets in clinical practice.

Normal orthodontic forces applied to the brackets are estimated to produce stresses in the region of 3 to 7.8 MPa. For an adhesive system to have a clinically acceptable performance *in vitro* should be between 6 and 8 MPa (Clarke *et al* 2003, Webster *et al* 2001). Environmental forces increase these stresses, particularly in the molar region (Swanson *et al* 2004). Bishara *et al* (2003) stated that forces as a result of chewing increased the further posterior the teeth are situated in the mouth. Sonneson and Bakke (2005) using a load transducer found pre-orthodontic thirteen year old children to have a maximum mean bite force of 362 Newtons in the molar region. This value was obtained by testing the bite in 88 sequentially admitted pre-orthodontic children.

Methodology

The aim of this study was to comparatively assess the effect that stainless steel molar bracket base size and design has on shear bond strength. This was achieved by using three different maxillary molar brackets each in combination with three different adhesive resins.

Sixty maxillary molar stainless steel orthodontic brackets from each of three different manufacturers were obtained. These were Optimesh XRT (Ormco, Orange, CA92867. U.S.A.) Lot: 06D238D, Victory Series (3M Unitek, Monrovia, CA 91016. U.S.A.) Lot 998186100 and Bondable molar attachment. (GAC, Bohemia, NY 11716. USA.) Lot B375

The three adhesive resins used to bond each of the brackets were Transbond XT (3M Unitek, Monrovia, CA 91016. U.S.A.), Enlight (Ormco, Orange, CA92867. U.S.A.), Sure Ortho Light Bond (Sure Orthodontics, Geneva. Switzerland).

One hundred and forty four upper extracted human molar enamel specimens were selected according to a selection protocol. Teeth with caries affecting or undermining the buccal enamel were excluded. As were teeth exhibiting fluorosis or enamel damage as result of the extraction process. The enamel was inspected at ten times magnification for any signs of enamel damage.

The selected teeth were prepared for bonding and were sectioned in such a way as to remove the roots this was done by means of a water cooled high speed turbine handpiece. The sectioned crowns were stored in water at four degrees centigrade with a few crystals of thymol added (as an anti-bacterial agent). The teeth were randomly assigned to three groups, one group (forty eight specimens) for each of the bracket groups. Each group of these assigned teeth was then divided into three groups of sixteen teeth each and bottled (9 bottles) separately. Each of these bottles was labeled with the assigned bracket/adhesive resin combination. This was done with a view to ensure that sixteen brackets of each manufacturer would be bonded with the each of the three adhesive agents (16x3x3 combinations). Each enamel specimen was then checked in order to identify any unacceptable morphology of the buccal surface of any of the enamel specimens. This was done by placing an example of its assigned bracket with its base positioned in the prescribed position on the buccal enamel. If there was any doubt regarding the closeness of the 'fit' of the base to the tooth, the tooth was excluded from any further testing and another specimen was assessed and used if found to be suitable. This was done in an attempt to minimise the variation of the thickness of the adhesive layer as much as possible.

All the enamel specimens were gently polished (for 10 seconds) with a oil free, fluoride free pumice solution to clean the enamel thus simulating the removal the pellicle as in the clinical scenario.

All the brackets to be bonded with the same bonding agent, were bonded in one session by the same operator. Each of the three adhesive resins was used in accordance with the instructions of their manufacturer. The bracket was positioned on the buccal surface of each tooth, by means of bracket tweezers, and then a force of four hundred grams was applied by means of a Dontrix gauge (American Orthodontics, Sheboygan, Wisconsin, WI53081. U.S.A.) to ensure a consistently close fit between the base and enamel surface, as well as maximal penetration of adhesive into the mesh design. Prior to light curing the excess adhesive agent was removed from around the base of the bracket with a sharp probe.

The adhesive resin on each bonded tooth was light cured for thirty seconds (10 seconds from a mesial direction, 10 seconds from an occlusal direction and 10 seconds from distal of the bracket) with the exit portal of the light curing as close as possible to the bracket. A standard standard tungsten quartz halogen curing light (Optilux 501, Demetron Research Corporation) was used to cure the bonding agents. A light intensity range of between 440 and 480 mW/cm^2 was used. The intensity of the curing light was checked after every 8 exposures with a Dentsply light intensity meter (Cure Rite Meter, Dentsply, Caulk.) to ensure this consistent intensity. Each bonded specimen was placed back into the water/thymol solution in its designated bottle and stored for twenty four hours at room temperature and the exposed to a temperature cycling procedure. This entailed each specimen being exposed to 500 cycles of heat and cold. The specimens were exposed to a temperature high of 55^o C as opposed to a low of 5^o C, in cycles of 15 seconds with a dwell time of 30 seconds (Saayman *et al* 2005, Grobler *et al* 2007a).

Following the temperature cycling the enamel specimens were stored in their respective adhesive/bracket combination groups. The bonded enamel specimens were then embedded in plastic cups with cold curing acrylic resin. The specimens were positioned by means of a jig in such a way that the entire buccal enamel surface stood proud of the embedding material and the plastic cup in such a way that the bracket/enamel interface was positioned at ninety degrees to the long axis of the plastic cup.

The specimens were clamped to the base of the Zwick Universal testing machine (Matterialprufung, 1446, Germany). A shear load was applied in an occluso-gingival direction to the attachment, with the debonding force parallel to the bracket/adhesive interface. This load was applied by means of a knife-edged rod at a crosshead speed of 0.5 mm per minute. Shear bond strengths were registered in Newtons to be converted and expressed in mega pascals (MPa).

Each of the three brackets had their contact surface area measured individually making use of a reflex microscope (Prior S2000 Reflex Microscope, 9 Whitehall Park, London. N19. No 001).

The mesh wire diameter of each bracket was measured in microns using the Zwick/Roell ZHV microhardness tester (Indentec hardness testing machines limited, West Midlands, DY9 8HX). The aperture dimensions were also measured using the same apparatus and the open space or aperture area was calculated. Each bracket was measured randomly in five locations for both mesh strand thickness and for the size of the open spaces or apertures.

Results

Table 1:

Comparison of bracket base mesh dimensions

	Bracket bases		
	3M	**GAC**	**Ormco**
Mesh aperture size (μm)	208.6 x 205	225.1 x 218.9	140.5 x 141
Aperture area (μm^{2})	42640	49500	19600
Average thickness of the mesh strands (μm)	115.5	113.5	126.5

Table 2:

The average bracket base contact surface area size.

Bracket make	***3 dimensional surface area***
GAC	26.20mm^{2}
3M	25,05mm^{2}
Ormco	20,90mm^{2}

Table 3:

Pivot table of shear bond strengths (average, standard deviation, minimum and maximum) of each bracket/adhesive resin combination in Newtons.

	3M			GAC			Ormco			All groups
	Enl	SB	Tb	Enl	SB	Tb	Enl	SB	Tb	
Count	16	16	15	16	16	16	16	16	16	143
Average	245.6	272.2	294.9	242.2	306.1	272.6	121.5	159.2	147.1	228.6
Standard deviation	56.1	62.8	70.8	67.3	43.0	54.5	20.4	72.5	55.2	85.8
Minimum	117.7	151.9	138.3	112.3	244.8	104.2	77.2	75.6	82.3	75.6
Maximum	347.1	371.6	399.4	357.2	382.9	333.9	154.0	359.8	294.6	399.4

Table 4:

A pivot table of shear bond strength expressed in MPa (average, standard deviation, minimum and maximum).

	3M			GAC			Ormco			
	Enl	SB	Tb	Enl	SB	Tb	Enl	SB	Tb	
Count	16	16	15	16	16	16	16	16	16	143

Average	9.8	10.9	11.8	9.2	11.7	10.4	5.8	7.6	7.0	9.3
Standard deviation	2.2	2.5	2.8	2.6	1.6	2.1	1	3.5	2.6	3.1
Minimum	4.7	6.1	5.5	4.3	9.3	4	3.7	3.6	3.9	3.6
Maximum	13.9	14.8	16.0	13.6	14.6	12.7	7.4	17.2	14.1	17.2

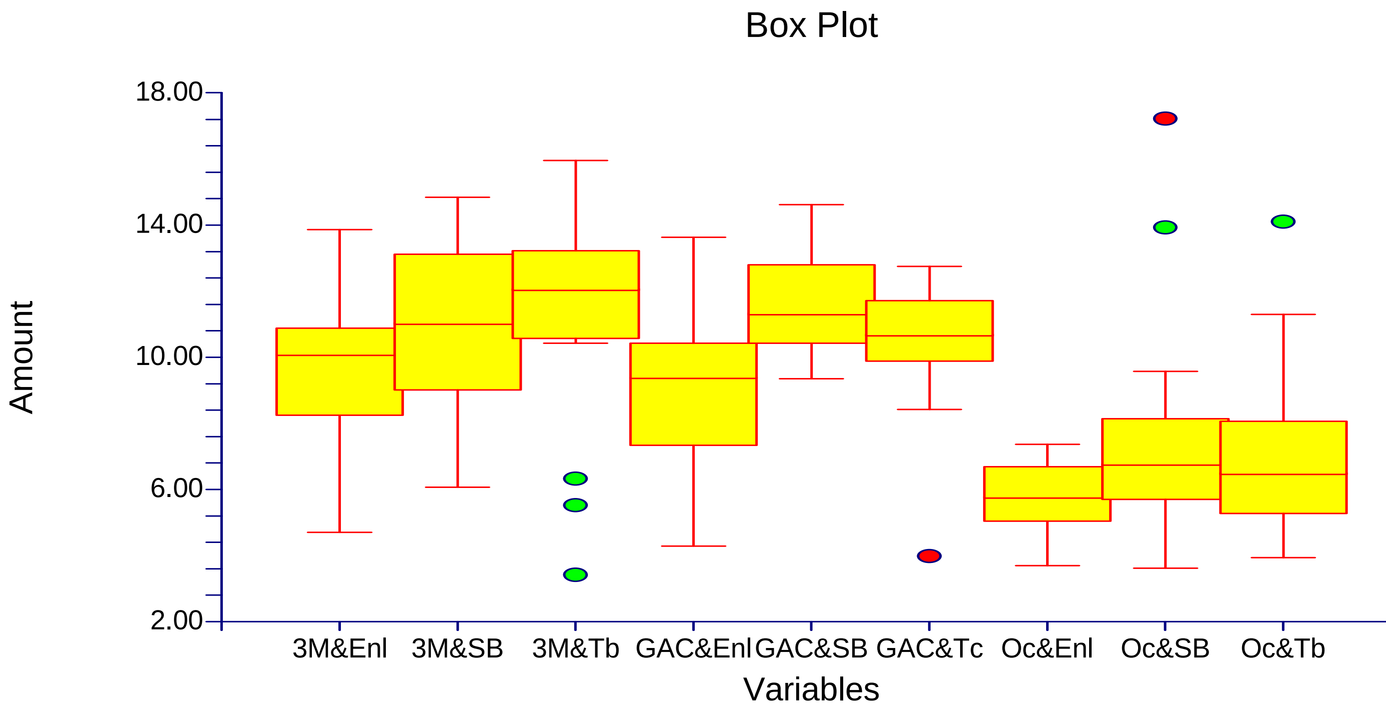

Figure 4.3a:

A box plot showing the shear bond strengths in MPa (Amount), of each bracket/adhesive combination (variables).

Each box represents (the interquartile area) 50% of the readings for each combination.

The red line in each box represents the median of each combination.

The green and red dots are representative of extreme values obtained.

Discusion

The Ormco brackets have a smaller contact surface area than the other two brackets. Some authors claim that a reduced bracket base contact surface size does not significantly affect the shear bond strength (Cucu *et al* 2002, Matasa 2003a, Banks and Macfarlane 2007). However Sarma-Sayal *et al* (2003) stated that a smaller bracket base size is an important variable that could affect bond strength, other variables are the base design, any treatment applied to the base of the bracket, the adhesive used and intra oral factors like the position in the mouth and the depth of the bite(Banks and Macfarlane 2007).

In table 1 the microscopic inspection of the base revealed that the diameter of the mesh wire was greater on the base of the Ormco bracket (126.5 microns) than on the GAC bracket (113.5 microns) and the 3M bracket (115.5 microns). The area of the aperture of the Ormco Optimesh brackets, when calculated, was less than half the size of the aperture of either of the other two bases (table 1). The average aperture size of the Ormco bracket measured 140.5 x 141 microns (19600 μm^2). The GAC bracket aperture was larger at 225.1 x 218.9 microns (49500 μm^2), and that of the 3M Unitek bracket measured 208.6 x 205 microns (42640 μm^2).

The mesh number per lineal millimetre also showed a significant difference. The Ormco bracket base showed 4 openings per lineal mm. Both the 3M GAC bracket bases showed 3 openings per lineal mm.

The other important difference in the design of the adhesive surfaces of the bases evident on microscopic investigation was that the 3M brackets (figure 2) displayed a single mesh design with the mesh crisscrossing the base diagonally from corner to corner. The entire base had an even mat finish as a result of micro-etching. The GAC brackets (figure 3) displayed a double mesh structure on the base which they claim will enhance the bond at the adhesive bracket interface as well as serve to reduce the amount of residual adhesive left on the enamel. The bracket construction (GAC US patent 4889485) is such that the mesh material becomes thicker, the apertures wider and the surfaces rougher toward the adhesive/bracket interface. The entire base had an even mat finish as a result of sandblasting. The stated intention of this design is to reduce the amount adhesive left on the enamel after debonding. The Ormco bracket (figure 1) surface displayed a single mesh layer. The main feature of this adhesive pad was the size of the apertures which were visibly smaller than the mesh of the other two brackets. The surface of the mesh appeared to be shiny and smooth whilst the ‘ceiling’ of the aperture had a rough and irregular mat surface. The base is coated with a special Ormco treatment the so-called ‘Optimesh XRT’ coating.

As can be seen in figure 1 the Ormco brackets combined with any of the three adhesive resins displayed considerably lower shear bond strength. This decreased shear bond strength of all three Ormco bracket/adhesive resin combinations is so substantial that it is statistically significant. Using the Regular Kruskal-Wallis multiple-comparison z-value test all three of the Ormco bracket/adhesive resin combinations were shown to be significantly different from any combination of adhesive with either of the other 2 brackets in this study. This test shows the medians to be significantly different in all cases where z-value is greater than 1.9600.

These differences were highlighted and confirmed by the Kruskal-Wallis one-way analysis of variance on ranks. This test showed that all the Ormco bracket/adhesive resin combinations were significantly different in terms of the average rank, the z-value, the median, the mean and the effect, in both cases of force applied (Newtons) and stress units calculated (MPa).

The Tukey-Kramer multiple comparison test confirmed that all three mean values of the Ormco bracket/adhesive resin combinations were significantly different from the other groups, using the force (Newton) values.

The GAC bracket was associated with 18 incidents of enamel damage. It was the only bracket to remove all the adhesive resin from the enamel surface in 4 instances. On the contrary the Ormco brackets had no incidence of enamel fracture and most debonding occurred at the bracket adhesive interface. These findings could only be interpreted as being the result of the contact surface design.

Conclusions

- The Ormco brackets combined with any of the adhesive resins showed significantly lower bond strengths when compared to the combinations with either of the other two brackets.
- The shear bond strengths of the three adhesives investigated in this study were all within close range of one another, with Enlight consistently displaying the weakest shear bond strength of the three. This was found with each of the three brackets used in this study.
- The overall relatively poor performance of the Ormco brackets with all the adhesives can only be ascribed to the contact surface size and design of these brackets.
- A thicker mesh wire and a smaller mesh aperture lead to a lower shear bond strength confirming the findings of Matasa (2003a).

<u>Clinical significance:</u>

- The GAC and 3M Unitek brackets combined with any of the adhesive resins tested could be successfully employed in the molar region. With maximum shear bond values being almost equal to the maximum bite force of 362 Newtons in the molar region (Sonneson and Bakke 2005). Careful positioning of the brackets with regard to the bite in the molar region is mandatory, as well as patient dietary counseling in order to achieve this success. Few authors reveal whether molar brackets were protected from the forces of the occlusion or not (Banks and Macfarlane 2007). The high *in vivo* failure rate maybe as a result of the occlusal forces acting directly on the attachment or that the patient made no dietary adjustments with regard to the presence of the brackets. Therefore successful molar bonding depends on a combination of case selection, patient compliance and operator skill.
- The Ormco brackets delivered significantly weaker bond strengths, with all three adhesives which indicate that these brackets may not be a suitable choice for direct bonding in the molar region as it has been shown that *in vivo* bond strengths are lower than *in vitro* bond strengths (Pickett *et al* 2001, Banks and Macfarlane 2007)
- The base design of brackets play a role in the shear bond strength of orthodontic adhesives. In the case of molar bonding this could be considered as important as any other aspect deemed important in the bracket design.

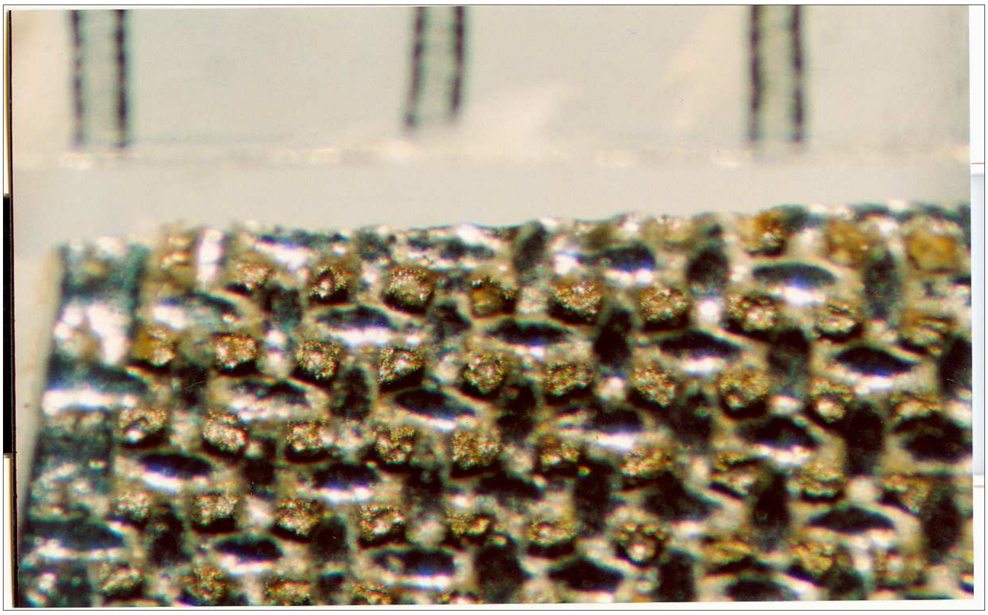

Figure 2

The single mesh base of the Ormco bracket with a millimeter scale at the top of the photograph (62.5 X magnification).

Figure 3

The single mesh base of the 3M bracket with a millimeter scale at the top of the photograph (62.5 X magnification)

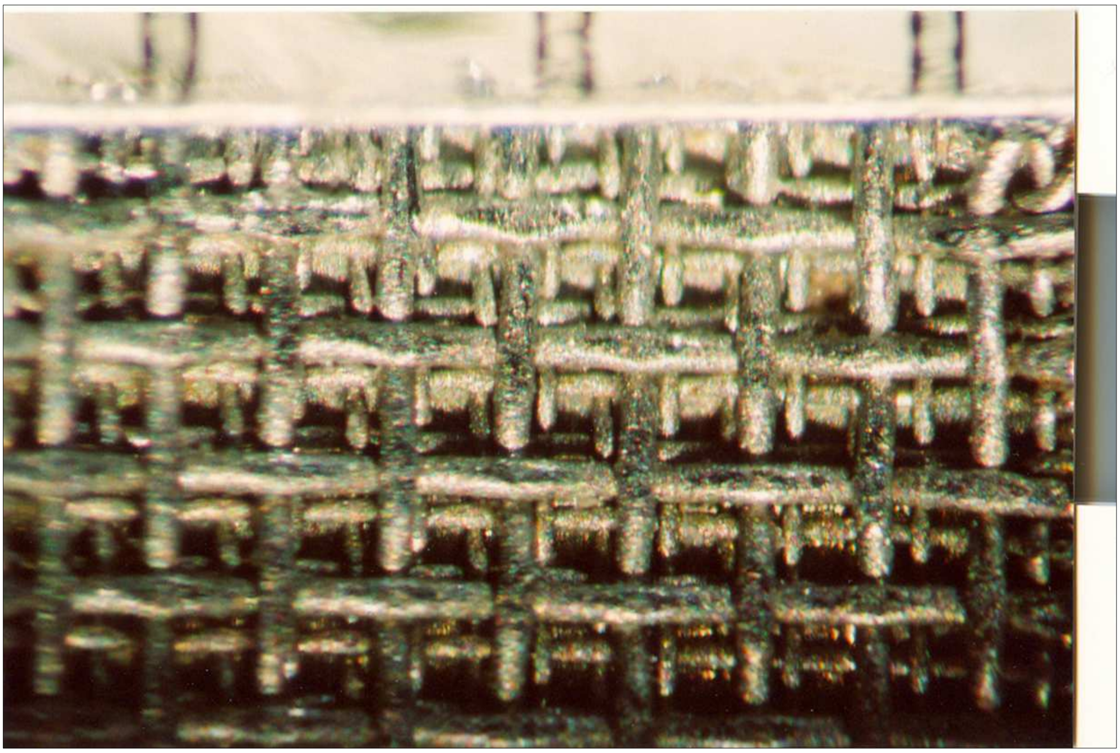

Figure 3

The double mesh base of the GAC bracket with a millimeter scale at the top of the photograph (62.5 X magnification)