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Orthodontic Bracket Friction Affected by Design Selection, Material and Manufacturing Process

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Abstract. One of the problems in orthodontic treatment is friction. Some of the factors that support friction are archwire material, archwire dimensions, bracket material, surface roughness, type of ligation, environmental humidity, and bracket position, angulation angle between bracket and wire, changes in the surface of the archwire and bracket. The aim of this study is to analyse the difference in friction between the two branded bracket designs and a new patented bracket (patent no. IDP000069597). The production method for this new bracket is different, however, uses the same material of 17-4 PH stainless steel. There are three groups in this research, one sample of bracket each from two different branded and one sample of a new bracket design. All three groups were tested for microstructure, then tested for measurement of friction between bracket slots and archwire. The microstructure of the two branded brackets has a martensitic phase that is not as dense as the new bracket, which is due to the different manufacturing method processes. The two branded brackets use the metal injection molding method, while the new brackets use the investment casting method. The friction test results show that there are significant differences between the three groups of brackets. One of the branded brackets (A) has the lowest friction, but branded bracket (B) does not have different friction with the new bracket. Differences in design and manufacturing methods of orthodontic bracket affect the friction between orthodontic brackets and archwires even though they use the same material.

Introduction

Friction between the orthodontic bracket and the archwire is a factor that is still a concern in fixed orthodontic treatment. Friction occurs in every tooth movement when orthodontic forces are applied. Friction can be divided into two types, i.e. static friction which is the needed to move the tooth, and kinetic friction which is the friction that restrains the movement of the tooth. The coefficient of static friction is always higher than the coefficient of kinetic friction. Static friction is more important because it serves in tooth movement as the tooth moves along the archwire. Movement occurs when there is a reaction between the archwire and the surrounding biological tissue, so that the tooth adapts to uprighting the root through the alveolar bone. The occurrence of friction can be influenced by the bracket design, archwire type, and the type of ligation method [1]. The friction formula is friction = μ x F, where μ is the coefficient of friction and F is the force when the surfaces of the archwire and bracket are in contact with each other. In order to allow tooth movement, the applied force must be greater than the static friction, which is 50% of the total force applied to the teeth. A large amount of force will be required in situations that causes a high friction. The contact between the bracket and the archwire as well as the choice of materials and surface roughness are factors that influence the occurrence of friction. Friction affects the movement of tooth from the horizontal, vertical, and the combination of the two directions. In horizontal movement, friction is caused by the wire or elastomer binding. In vertical movement, friction is caused by binding and notching. Finally, the combination of vertical and horizontal movements is a crucial situation [2].

The choice of archwire determines the efficiency of tooth movement and also affects the length of treatment. The occurrence of friction is caused by two factors, i.e. mechanical and chemical factors, including the ligation method. This friction may cause the applied force decreased by 12%-74%. Static friction is caused by bracket material, surface roughness, ligation method, humidity, and wrong bracket position. The occurrence of binding and notching depends on the dimensions of the archwire along with the characteristics of the surface. The combination of static friction, binding, and notching will affect tooth movement [3]. Tooth movement begins when the applied force produced static friction. Binding effect appears when the force is increased and the wire starts to touch the corner of the bracket. Notching effect occurs when there is a plastic deformation of the wire, causing tooth movement to stop [3]. The different shape of the bracket slot design also gives different reactions when the archwire comes into contact with the bracket slot [4].

The fabrication method of orthodontic brackets can be done by casting, milling, and metal injection molding (MIM) methods. The casting method used a process in which the metals is melted and then poured into a mold until it cooled down and become solid. However, this method has a high production cost as it wasted a lot of material used on runners and sprues construction. Meanwhile in milling or machining method, it used cutting tools to fabricate brackets that follows the design. This method is suitable to fabricate supporting components such as a hook. However, when this method is used to fabricate brackets, it is also not economical due to a lot of material is wasted [5]. The MIM method is a method that uses metallurgical powders combined with binders (wax, thermoplastic resins), lubricants, and dispersants until it reached a homogeneous substance, referred to as feedstock. The feedstock is then injected with an injection machine into a mold that has been adjusted to account for shrinkage in the heating process in the next stage. The results of the injection (green parts) then go through the debinding/heating stage to remove the binder, while through the heating process the green part turns into the brown part. The final stage is sintering process which is carried out in a furnace with a high temperature in a vacuum environment, which will remove the remnants of the binder. The final product will achieve the desired geometry [6].

This problem becomes an interesting thing to analyse, especially the unclear friction that was caused by different bracket designs, material selection, and manufacture methods. This study aims to analyse the difference in friction occurred between the two branded bracket designs (A and B) with a new bracket (N) with patent number IDP000069597. The fabrication method of the new bracket is different, although it uses the same material, namely the 17-4 PH stainless steel.

Materials and Methods

Two samples of branded brackets and one sample of new bracket designs were tested for microstructure with Microscope-Olympus BX41M-LED based on the ASTM E3 and ASTM E 407 standards., while the friction measurement between bracket slots and archwire was conducted by using the Instron 5900 Tensile test. The sample brackets of each group were attached to a steel plate with a self-curing adhesive; 0.019 x 0.025 inches rectangular archwires were cut with a length of 5 cm. The orthodontic brackets and the archwires were secured by a 6 cm long, 0,08-inch diameter ligature wire. The maximum frictional forces between brackets and archwires will be recorded in Newton units when a 4 mm shift of the archwire at a speed of 10 mm / min occurred. The measurement data of the friction test was then statistically analysed. The Sahpiro-Wilkinson normality test was performed and the results showed that the the data was normally distributed. Comparison test using the one-way ANOVA was performed along with the Post Hoc LSD test should there be a significant difference in ANOVA test.

Results and Discussion

The results of the one-way ANOVA test (Table 1) showed a p-value of 0.001, indicating that there are significant differences in friction between the three groups of orthodontic brackets. After that, the Post Hoc LSD test (Tables 2) showed that the bracket which has the lowest frictional value was the orthodontic bracket A, and the difference with the new bracket (N) and B bracket were significant. Meanwhile, the frictional value between new bracket and B bracket was not significantly different. The results of this friction test showed that the new bracket can achieve a friction that is equivalent to the branded bracket (B).

Table 1. Frictional Differences Comparison between Three Orthodontic Bracket Groups

Samples	Group	N	Mean ± SD	p-value
Orthodontic Bracket	N	10	1.1700 ± 0.29390	0.001*
	B	10	1.3680 ± 0.49763	
	A	10	0.6690 ± 0.34272	

One-way ANOVA test; Sample N: New Orthodontic Bracket; Sample B: Branded Orthodontic B Bracket; Sample A: Branded Orthodontic A Bracket.

Table 2. Multicomparison Analysis of Frictional Differences between Three Orthodontic Bracket Groups

Samples	Mean Difference	CI (95%) Min	CI (95%) Max	p-value
N vs A	0.501	0.1450	0.8570	0.008*
N vs B	-0.198	-0.5540	0.1580	0.264
B vs A	0.699	0.3430	1.0550	0.000*

Post Hoc LSD test; Sample N: New Orthodontic Bracket; Sample B: Branded Orthodontic B Bracket; Sample A: Branded Orthodontic A Bracket.

One possible cause for the difference found was the imperfect geometry of the N bracket produced by the casting process (Fig. 1). The wing component has a design that aims to reduce the frictional force from the pressure exerted by the wire ligation. When force is applied to the archwire with an acceleration of 10 mm/min, it is analogous to the magnitude of the Applied Force (F_A), however if the frictional force (F_F) has the same value, it means that no movement will occur ($F_E = F_A - F_F$). As long as there is still frictional force (F_F), the effective force (F_E) will always be smaller than F_A, therefore the mechanical sliding process in orthodontic treatment can occur if F_F is smaller than F_A [7].

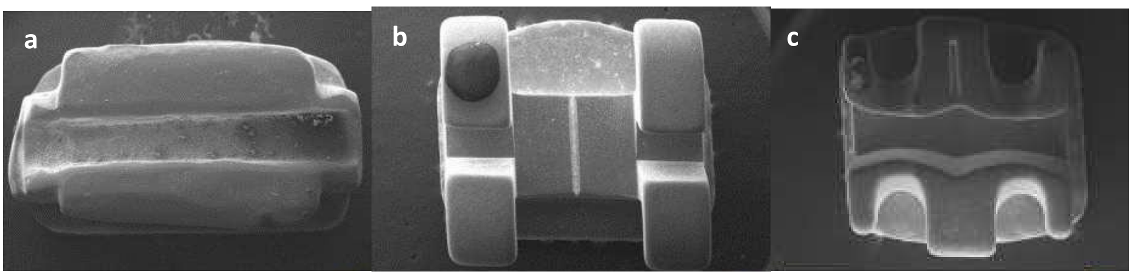

Figure 1. a. New Bracket (N); b. A Bracket (A) [8]; c. B Bracket (B) [8]

Based on the results of the F_F data of the new orthodontic bracket (1.17 N), it is shown that this result is greater than F_F of the A bracket (0.67 N), and smaller than the B bracket (1.37 N). The B Bracket has an unconventional design consisting of three (3) wings, so that the slot wall touches the archwire when it shifts, compared to the A Bracket. The new orthodontic bracket design actually has the characteristic of achieving lower F_F compared to the B and A Brackets, however the investment casting results showed unfilling defects, causing an imperfect geometry of the wing. Even though the slot wall of this new design is wider and thus touches the archwires surface more, the wire ligation pressure can be slightly reduced by the additional imperfect wing so that the resulting F_F can be smaller than the B bracket [7]. The microstructure of the two branded brackets has a martensitic phase that is not as dense as the new bracket, which were caused by the different manufacturing method processes. The two branded brackets used the metal injection molding method, while the new brackets used the investment casting method. The branded bracket (A) has a less dense martensitic phase than the new bracket, and the bracket (B) has a semiaustenitic phase (Fig. 2).

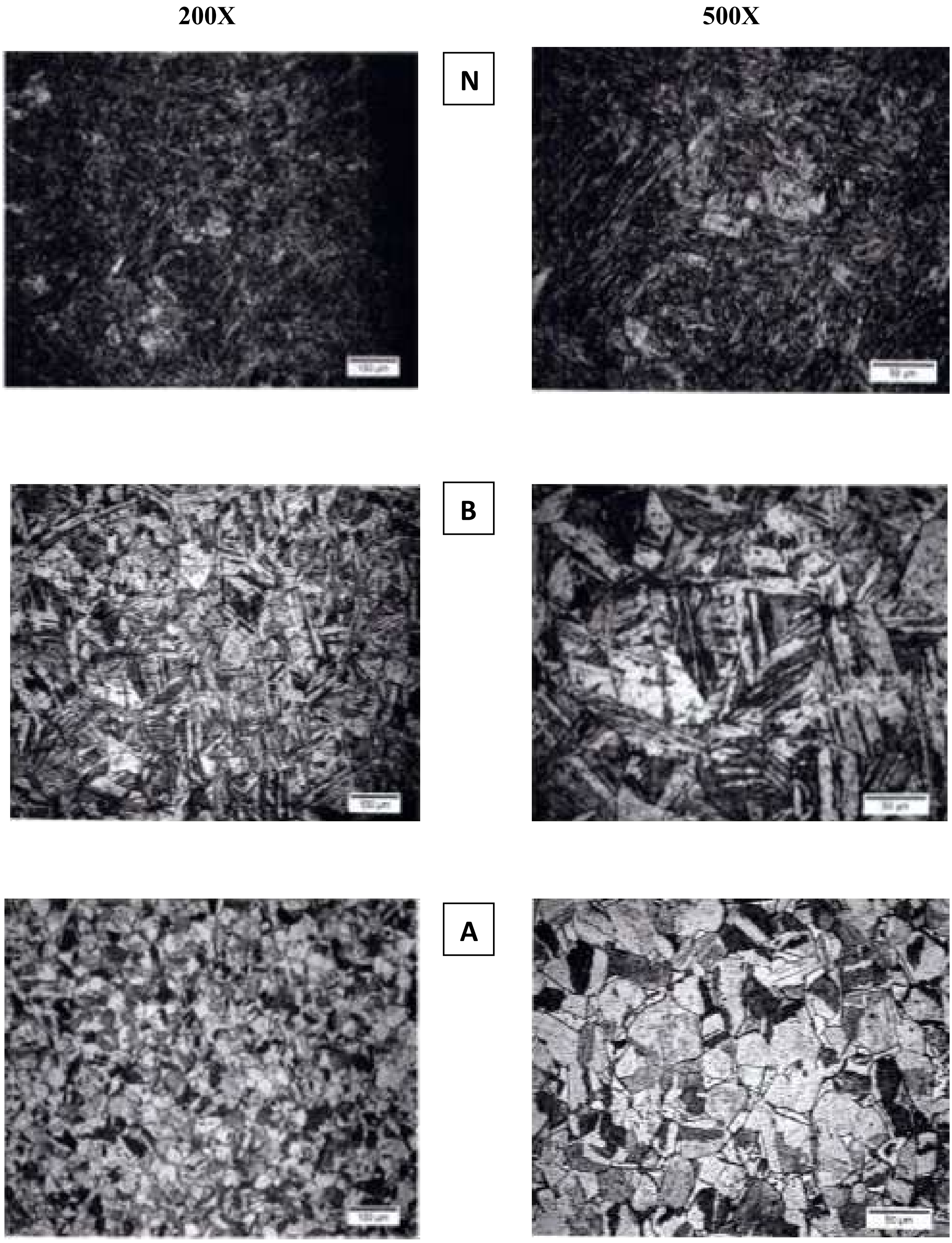

Figure 2. Microstructure Images of N, B, and A Orthodontic Brackets, with the Magnification of 200X and 500X.

There are two things that cause unfilling defects in new orthodontic brackets, namely cold shut and misrun. Cold shut occurs when the flow of the two different metals cannot blend properly while misrun occurs due to the inability of the molten metal to fill the narrow and distant mould space, a characteristic that can be seen on the new orthodontic bracket, especially on the edges of the bracket body which is round and smooth. Both of these characteristics are caused by intermittent casting time, slow casting process, low melting temperature, improper metals composition, lack of fluidity in molten metal, mould design errors, and ingate design errors. To resolve these problems, it can be done either by using the proper temperature during the casting process, modifying the mould design, or by modifying the ingate system [9,10]. The low temperature may cause a non-optimum solidification, thus higher temperatures are needed to increase the metal fluidity in order to be able to fill the narrow and distant areas. A proper adjustment of the temperature during the casting process can prevent cold shut effect. A slow casting time reduces the flow of molten metal, thereby limiting its ability to fill any narrow and distant spaces, while a short casting time may cause air to be trapped in the mould chamber, resulting in holes and pores. A proper setting of the casting time will reduce the occurrence of cold shut [10]. Any differences in the results between the three brackets are due to differences in the design, manufacturing methods, and the manufacturing process of each orthodontic bracket [3, 11].

Conclusions

In order to acquire an orthodontic bracket with light frictional forces, it is necessary to choose the right material. The MIM method is a proper and economical manufacturing method; this method could also achieve light frictional forces of the bracket. In addition to materials and manufacturing method, the design factor also supports to reduce the friction between brackets and archwires in orthodontic treatment.

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