Original Article

Weld Characteristics of Orthodontic Archwire Materials

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Abstract: Welding attachments to archwires can produce change in their physical as well as mechanical properties. This study evaluated three archwire alloy materials—stainless steel, Beta titanium, and Timolium for their weld characteristics. The study was divided into tensile-shear test using instron universal testing machine, surface evaluation with the help of scanning electron microscope, and metallographic examination with optical microscope. Six specimens were used for evaluation of each parameter. Increased strength in tensile-shear test and smooth surface and characteristic nugget formation in scanning and optical micrographs, respectively, clearly indicated superior weld characteristics for Beta titanium alloys when compared with the other two archwire alloys. Stainless steel was found to be intermediate in nature, whereas Timolium exhibited poor weld characteristics. (*Angle Orthod* 2004;74:533–538.)

Key Words: Archwires; Beta titanium; Metallography; Timolium; Welding

INTRODUCTION

Archwires form the basic unit of orthodontic mechanotherapy through which optimum force for tooth movement can be effectively delivered and managed. The required force is delivered through various force delivery systems like elastics, elastomeric chains, and coil springs with the help of power arms on brackets or attachments welded on archwires.[1,2] Various loop configurations, either made or welded to the archwire, can also be used for this purpose.[3]

Welding of attachments to the archwire for proper force delivery has always fascinated the clinicians by its ease of force application as well as transfer of point of force application toward the center of resistance of tooth. This made the researchers in this field concentrate on developing an archwire alloy with superior weld characteristics, which led to the introduction of titanium-based archwire alloys especially Beta titanium. A new entry into the arena of titanium-based alloys is Timolium™, an α-β alloy with titanium, aluminum, and vanadium as its components. This alloy has a smooth surface texture, less friction at the archwire-bracket interface, and better strength than existing titanium-based alloys.[4,5]

Welding can be defined as the process by which the surfaces are joined by mixing, with or without the use of heat.[6] Orthodontic spot welders use the resistance welding technique by using high-amperage low-voltage electricity. Welding is preferred to soldering to prevent changes in the physical properties of the components being joined.[7] The heat generated in welding is of great magnitude so as to cause melting at the interface. The copper electrodes in spot welders have a low resistance, and the alloy wires used for making archwires have a greater resistance. Because of this differential resistance, essentially all the heat generated by the current flow is contained in the welded area.[6] Because sufficient heat is generated at the weld mate-weld mate interface, the alloy components soften, flow, and fuse together under the influence of mechanical pressure, forming a weld nugget. A satisfactory welded joint is the one that is strong, has not undergone oxidation, and has not been compressed during fusion.[8]

Although various studies have been conducted on orthodontic spot welding[1,2,9], most were aimed at finding the proper voltage setting of the resistance spot welder (RSW). These approaches have omitted the most important aspect, the weld characteristics of the alloy wires used. This study was aimed at evaluating the two most commonly used orthodontic archwire alloys, stainless steel and Beta titanium, and the newly introduced, Timolium, for their weld characteristics. The basic study design was to evaluate the alloy archwires for

- weld-joint strength;
- surface characteristics of the weld area;
- microstructural changes at the weld area.

MATERIALS AND METHODS

Beta titanium (Ormco Corporation, Glendora, Calif), stainless steel (Ormco Corporation), and Timolium (TP

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Accepted: September 2003. Submitted: July 2003.

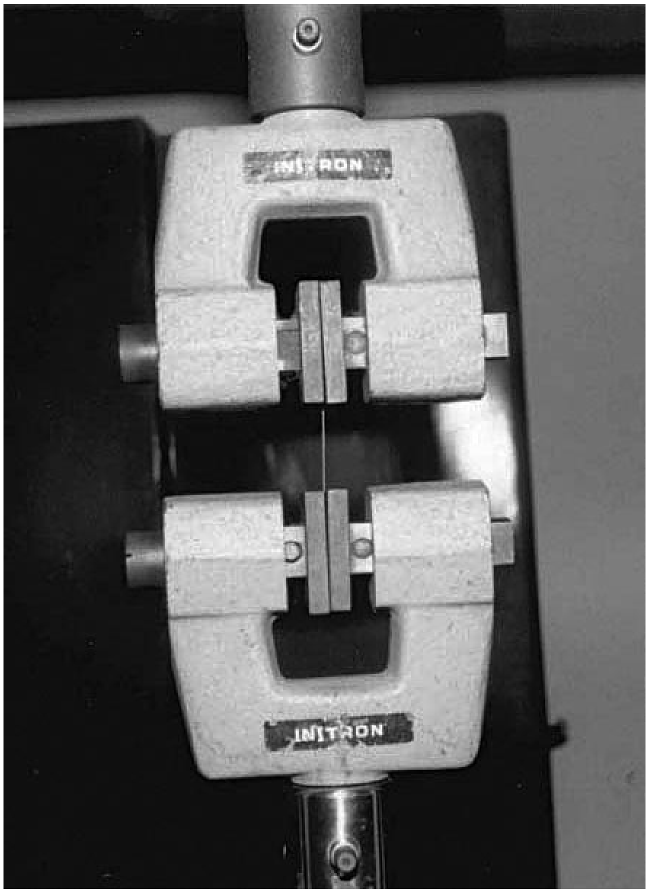

FIGURE 1. Setup for tensile-shear test with welded wire specimen in place.

Labs, Indianapolis, Ind) preformed archwires of size 0.017 × 0.025 inches were obtained. The welding apparatus used was a Rocky Mountain Orthodontics 660 (RM 660) with point-to-point electrode configuration. The optimal voltage setting of the RSW was standardized as 2 as per the reports of the previous studies done in this regard.[1,2,3]

Tensile-shear test for weld joint strength

Six archwire specimens from each of the archwire alloy materials were welded in straight lengths and subjected to tensile-shear loading[10] in an Instron universal testing machine (Model number 1195, Instron Corporation, Canton, Mass). The wire length between the cross-heads of the machine was standardized as 40 mm (Figure 1). The full-scale load was set at 1,000 N with a cross-head speed of one mm/minute. The load taken to break the weld joint divided by the cross-sectional area of the weld surface gave the value for joint strength in N/mm^2.

Statistical analysis

The values obtained were tabulated and entered into SPSS ver. 10, a computer-based statistical program through which the means and standard deviations were calculated. Analysis of variance (ANOVA) was then performed to find the level of significance between the values obtained from the wire samples.

Surface characteristics of the weld joint

This parameter was evaluated using scanning electron microscopy (SEM)—JEOL JSM 5600LV. The wire samples were welded together in a "+" design, mounted on silver studs, and placed in vacuum chamber. The accelerating voltage, angle of fit, and aperture were adjusted to optimize the quality of the micrograph. Representative micrographs of each archwire alloys were obtained at 100× magnification.

Metallographic examination

The microstructural changes in the weld area were evaluated with the help of an optical microscope (LEITZ Metalloplan Microscope). The whole procedure was performed following American Society for Testing and Materials (ASTM) standards. The straight-length samples welded were mounted on Bakelite with the help of metallographer's mounting press (hot mounting). The mounted specimens were then subjected to a leveling process with the help of different grades (coarse to fine) of silicon carbide paper and polished with alumina powder on a polishing buff. The highly polished reflective surface thus obtained was etched with the help of aqua regia ($HCl:HNO_3$ in ratio of 1:3) for stainless steel and HNO_3 and hydrofluoric acid mixture for Beta titanium and Timolium. The specimens were washed thoroughly in running water, dried, and then examined under a reflected light microscope. Representative micrographs were taken under different magnifications to evaluate the microstructural changes at the welded area.

RESULTS

Strength of weld joint

The values (in N/mm^2) needed to break the wire at weld joint of the alloy wires tested (Table 1) clearly indicated the superior strength of the weld joint of Beta titanium wire when compared with other two alloy wires—stainless steel and Timolium. Statistical analysis (ANOVA at 95% confidence level, significant at $P < .05$) performed with the data clearly indicated a 34% and a 27% higher strength for Beta titanium archwire samples than for Timolium and stainless steel, respectively. Comparison of stainless steel and Timolium revealed statistically insignificant result. Statistical results are tabulated in Table 2.

The rank order of wires in descending order of their mean values for strength on tensile evaluation of weld joint was: Beta titanium > stainless steel > Timolium.

The graphical representation of data obtained through tensile evaluation is shown in Figure 2.

TABLE 1. Tensile-Shear Strength of Weld Joint of Wire Specimens (N/mm^2)

Sample Number	Group I, Stainless Steel	Group II, Beta Titanium	Group III, Timolium
1	366.51	462.96	308.64
2	385.80	501.54	347.22
3	385.80	482.25	347.22
4	347.22	424.38	385.80
5	366.51	443.67	347.22
6	327.93	462.96	327.93
Mean ± SD	363.29 ± 22.55	462.96 ± 27.28	344.00 ± 25.63

TABLE 2. ANOVA Results[a]

Source of Error	Sum of Squares	Degree of Freedom	Mean Squares	*F* Value
Between groups	48911.01735	2	24455.5508	38.40
Within groups	9550.67165	15	636.71	
Total	58461.689	18		

[a] 5% allowance value = 39.48.

Surface evaluation

The scanning electron micrographs of the welded area of each of the alloy wires are shown in Figure 3. Weld surface of Beta titanium exhibited smooth flow of the melted alloy with an almost intact weld interface. There was crack propagation from the point of electrode contact of the RSW on the wire surface along with little amount of flocculation of the melted alloy (Figure 3a). The surface of the stainless steel wire exhibited cracks and peeling of the surface layer, indicative of the poor heat tolerance of the alloy. The surface of the welded area was filled with irregularities, and poor flow of the material was very well evident (Figure 3b). Timolium exhibited a smooth and symmetrical flow of the melted alloy, less surface distortions, and an intact weld interface (Figure 3c).

Metallographic examination

Micrographs of the weld joint obtained through optical microscope are shown in Figures 4 through 6. The common microstructural change observed in the alloy wires was a change in linear/fibrous arrangement of grains in the parent metal to a columnar pattern in the weld area, ie, there was a change of the alloy from a wrought structure to a cast structure. Beta titanium wire exhibited a small weld area with characteristic nugget formation (Figure 4a). A wide area of demarcation was evident at the margins of the weld nugget (Figure 4b), indicating a gradual change from wrought to cast structure. There were no observable porosities at the joint surface. Stainless steel wire also exhibited characteristic nugget formation (Figure 5a) with no porosities on the weld surface. The demarcating zone from wrought to cast structure was very well evident (Figure 5b), and the deformation observed on the surface of the wire where the electrode of the RSW made its contact indicated poor heat tolerance of the wire. The weld joint of Timolium exhibited a widely distributed weld area with lack of nugget formation (Figure 6). No magnified view was obtained because the specimens lacked characteristic weld nugget formation. The melting of the alloy was unable to cover the whole area, showing very wide gaps. In addition, there were porosities at the center of the joint.

DISCUSSION

Resistance spot welding involves joining of metals with simultaneous application of pressure and current. Resistance to the flow of current at the weld mate-weld mate interface results in nugget formation, which helps to join the material. Strength testing is an important aspect of any weldability study.

Static tensile-shear test is the most preferred laboratory method to evaluate joint strength at a weld area because of its simplicity.[11] The present study used the tensile-shear test to evaluate three archwire alloy materials—Beta titanium, stainless steel, and Timolium—for weld joint strength. The limitation in this study was the inability to locate the area of failure, whether in the melted zone or in the heat-affected zone. The results clearly indicated a higher strength for Beta titanium archwires with the capability of tolerating a

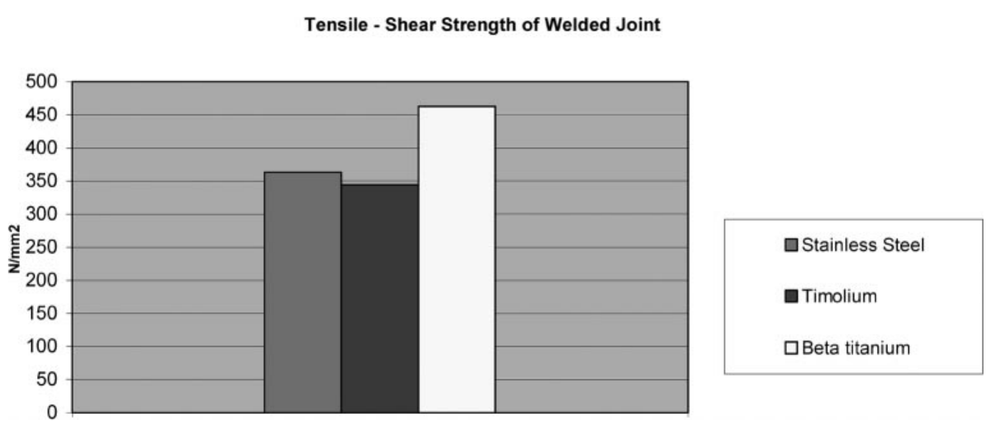

FIGURE 2. Tensile-shear strength of weld joint for archwire alloys.

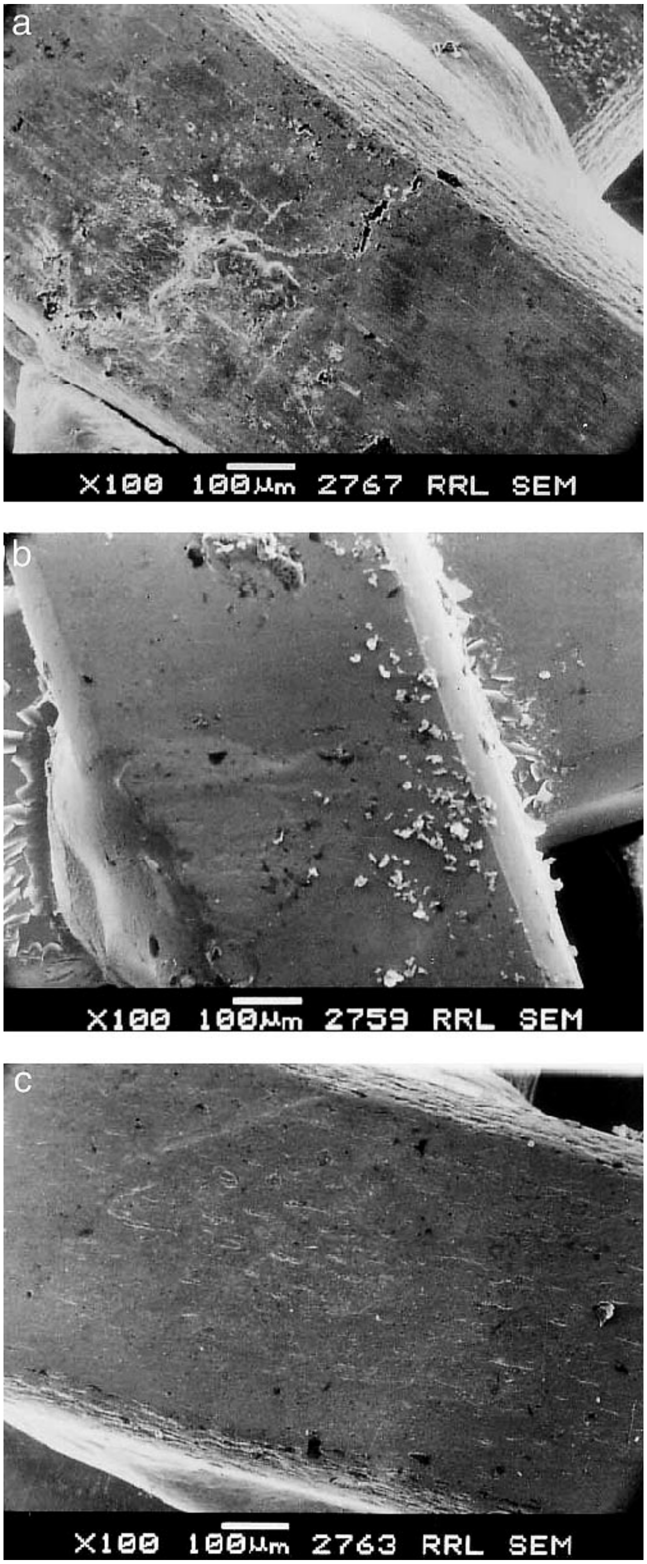

FIGURE 3. Scanning electron micrograph for surface evaluation. 100× magnifications. (a) Beta titanium. Note the crack propagation from point of electrode contact. (b) Stainless steel. Note peeling off of surface layer. (c) Timolium. Note smooth flow on both edges of weld area.

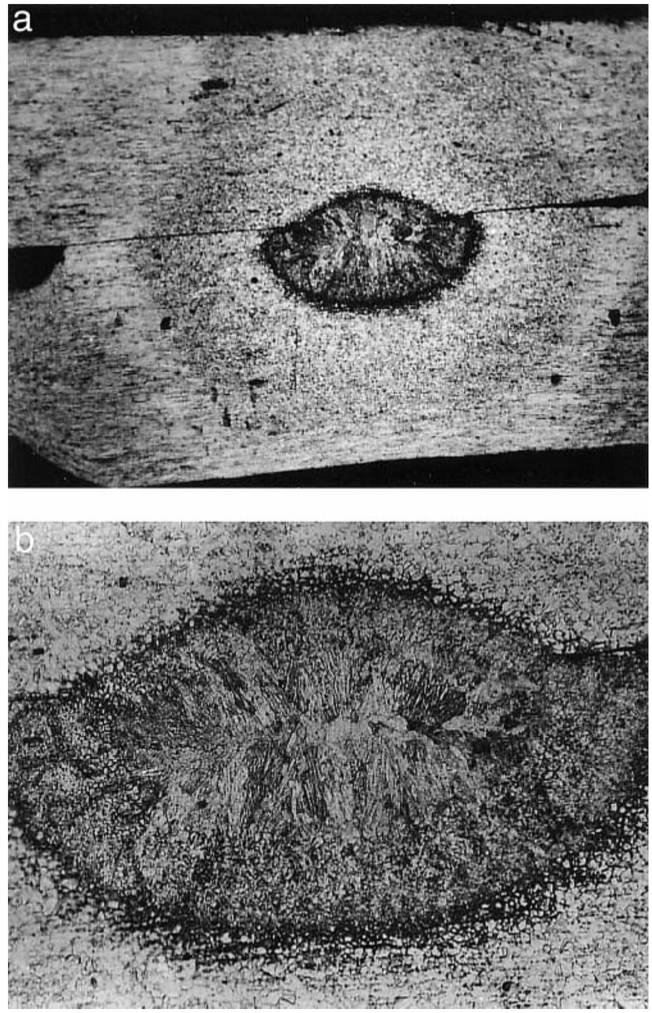

FIGURE 4. Optical micrograph to evaluate microstructural changes in Beta titanium. Note the characteristic nugget formation and change from wrought to cast structure at weld area. (a) 60× magnification. (b) 200× magnification.

greater amount of orthodontic force before failure. Stainless steel was next in strength values, reinforcing the findings of previous literature[12] that stated the need for solders to improve strength at the weld joint. Timolium exhibited very low values on the tensile-shear test when compared with the other two alloys.

Surface evaluation with SEM forms an important method of analyzing external features of the weld joint.[9] Evaluation of Beta titanium wire revealed crack propagation from the point of electrode contact toward the edge, leading to weakening of the joined structure. Peeling of the surface layer with poor surface characteristics was found on specimens of stainless steel. Timolium, with proper flow of weld flash uniformly on both sides, had better surface properties on surface evaluation.

The nugget formation and change in microstructure due to localized heating at the weld mate-weld mate interface were studied with the help of a metallographic examination

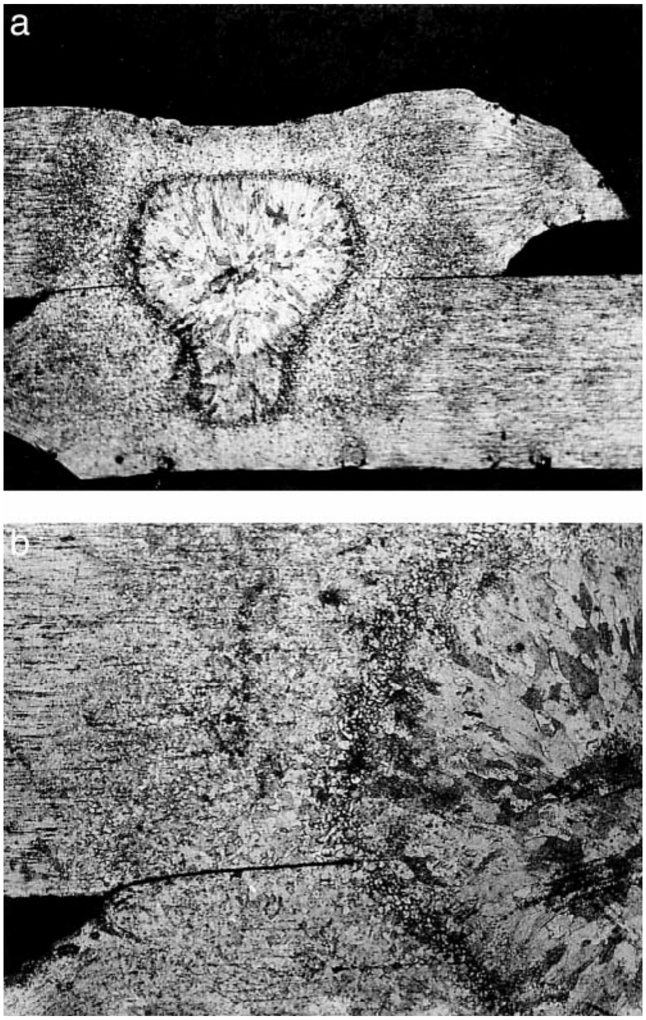

FIGURE 5. Optical micrograph to evaluate microstructural changes in Beta titanium. Note nugget formation and wide structural changes. (a) 60× magnification. (b) 200× magnification.

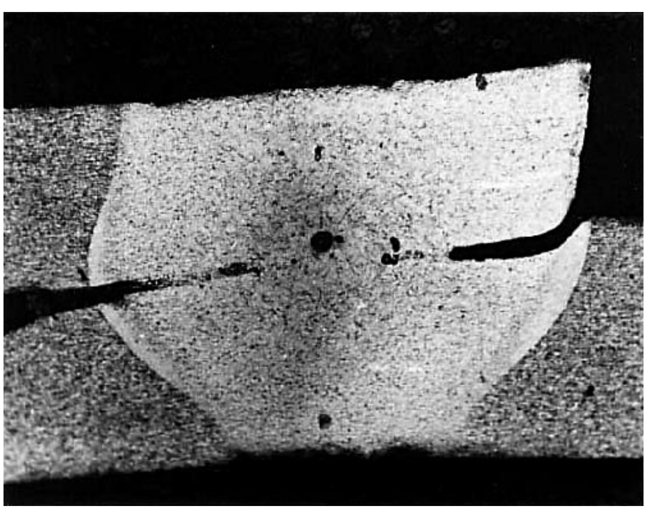

FIGURE 6. Optical micrograph to evaluate microstructural changes in Timolium. Note wide melted zone and voids in the welded area.

with an optical microscope, following appropriate ASTM standards. The characteristic weld nugget formation was very evident in specimens of Beta titanium and stainless steel archwires, but Timolium lacked this feature. The metallographic findings with Beta titanium wires were in concordance with the strength and surface evaluation. The microstructural changes were limited to a small area indicating less change in structure of the parent metal and producing minimal change in the properties of the alloy, even after subjecting it to high-amperage electric current from RSW. The poor heat tolerances of the stainless steel specimens were evident from their deformed top surface and extensive transformation from wrought to cast structure. Timolium exhibited very poor metallographic features with wider area of melting and porosities/voids at the weld area. This finding is in concordance with the very low-strength values on tensile-shear evaluation and can be attributed to the alloying elements like aluminum and vanadium.[4]

CONCLUSIONS

Weld characteristics of three alloy archwires were evaluated with the help of tensile-shear test, surface evaluation, and metallographic examination. Beta titanium with superior strength, better surface characteristics, and metallographic features was ranked superior to the other two archwire alloys. Stainless steel with its intermediate values for strength and characteristic nugget formation was ranked second for its weld characteristics. Timolium was poor in its weld characteristics with large voids and wide gaps at the welded area.

ACKNOWLEDGMENTS

We thank the team at Regional Research Laboratory (RRL), Trivandrum, Kerala—Dr Peter Koshy, Dr Prabhakar Rao, Mr K. Sukumaran, Mr SGK Pillai, Mr KK RaviKumar, and Mr MR Nair—for the facilities extended, immense help, encouragement, and proper guidance throughout the course of this study.

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