which molten alumina **24** is drawn. The melt **24** is drawn from the crucible **22** through the capillary **34** to the top surface **28** of the die **26**, where it spreads out and completely covers the said top surface **28** with a film of molten alumina. However, because molten alumina and molybdenum or iridium have the appropriate wettability relationship, the molten alumina film stops at the edge of the surface **28**. Therefore, alpha-alumina crystal grown or pulled from this film of molten alumina assumes a cross-sectional configuration substantially exactly the same as the configuration of the top surface **28** of the die **26**. Thus, the rod **30** (which had been started by a seed crystal, as in the Czochralski process) pulled by a pulling mechanism **36** from the film of molten alumina on the top surface **28** of the die **26** will have a cross-sectional configuration substantially identical to the configuration of the top surface **28** of the die **26**.

The crystal orientation of the growing rod may prove to be important (at least economically, and perhaps also from a performance standpoint) in the practice of the invention. In the case of crystalline alpha-alumina, the crystal orientation can be defined with referenee to the C axis of the crystal. (The C axis is perpendicular to the plane which contains the simplest arrangement of atoms in the crystal unit cell. Stated another way, the C axis is perpendicular to the plane which contains the a_1 and a_2 axes.) The minimum amount of strain developed in the growing crystal will occur if the C axis is found in a plane perpendicular to the longitudinal axis L of the rod **30** (see FIG. **7**). This may prove to be the optimum crystal orientation in some cases. (As is known in the art, the growing crystal will assume the crystal orientation of the seed crystal.)

In other cases, however, it may be preferred to orient the C axis an angle α from the longitudinal axis L of the rod **30** (FIG. **7**) such that the C axis is found in a conical surface formed by pivoting the C axis 360° around any point of intersection between the C axis and the longitudinal axis L, with the angle between L and the C axis being α. In this case, the angle α is between 30° and 60°. The reason for orienting the crystal in this way is to minimize chipping of the crystalline alpha-alumina during machining.

Regardless of the crystal orientation of the rod **30**, it is preferred to anneal the rod **30** prior to machining so as to relieve stresses in the crystal to minimize the chances of breakage during machining. A typical annealing cycle would be to heat the rod **30** from room temperature up to 1850° C. at an even rate for about 12 hours, to maintain the rod **30** at 1850° C. for 4 to 6 hours, and to then cool the rod **30** down to room temperature at an even rate for 18 to 24 hours.

The crystalline alpha-alumina rod **30** is cut into individual blanks **38** (FIG. **8**), each of which is machined into a bracket. FIGS. **1–4** are various views of an orthodontic bracket **40** made completely of crystalline alpha-alumina. The bracket **40** is made from the blank **38** by a series of cutting, grinding, and polishing steps, using known techniques for machining crystalline alpha-alumina. A diamond cutting wheel or an abrasive slurry wire saw may be used to cut out the archwire groove **42** and the "saddle" **43** of a double wing bracket (such as is shown in FIG. **1**). A single wing bracket **41** is shown in FIG. **15**. Edges may be beveled by grinding, and corners rounded off by polishing, by known techniques. After machining, another annealing step under the conditions suggested above is recommended to relieve stresses induced by machining.

As is shown in the drawings, the tooth contacting surface **74** of the bracket is contoured to match the curved surface of a tooth. This contour is machined by a conventional grinding procedure.

In alternative embodiments, the most critical load bearing portions of the bracket are made of crystalline alpha-alumina, while the remainder is made of another transparent material, such as polycarbonate or polysulfone plastic, that is less expensive, easier to work, and easier to bond to the tooth. FIG. **10** shows one such alternative embodiment, wherein the bracket **44** is made predominantly of transparent plastic **46** (e.g., polycarbonate), but wherein the archwire groove has a crystalline alpha-alumina liner **48** cemented therein by an adhesive in accordance with this invention. In another embodiment, shown in FIG. **11**, the bracket **50** has a transparent plastic base **52** cemented to a crystalline alpha-alumina body **54** by an adhesive in accordance with this invention. In both of these alternative embodiments, the crystalline alpha-alumina portions can be made by a modification of the method described above, starting with a crystalline alpha-alumina rod of appropriate shape made by the EFG process.

As was indicated above, bonding a crystalline alpha-alumina bracket to the tooth (or to a plastic base or to any other substrate) is not a straightforward matter. Crystalline alumina has a high surface energy, and many of the ordinary orthodontic cements (which are usually acrylic resins) will not adhere well enough to crystalline alpha-alumina to be useable without taking steps to enhance the adhesion. One means of enhancing the adhesion of a crystalline alpha-alumina bracket to the tooth is illustrated in FIGS. **13** and **14**, in which a bracket **56** is shown that has an undercut or keyway **58** in the bottom or tooth-contacting surface **74** of the bracket **56**. Orthodontic cement filling the keyway **58** will have enhanced mechanical adhesion to the bracket **56** because of the undercut portion. This bracket **56** can be made by a method analogous to that described above, starting with the EFG process using a molybdenum die **60** having a top surface shaped as shown in FIG. **12**.

This invention provides another means of enhancing the adhesion of cements such as acrylic resins to a crystalline alumina bracket by altering the surface of the crystalline alumina in such a way as to increase the strength of the adhesive bond between the crystalline alumina and the cement. It is known, for instance, that a wide variety of silicone coupling agents can be used to enhance the adhesive force between siliceous substrates and a wide variety of thermosetting plastics. However, such known technology may not be adequate in the present case, because the known coupling agents may not enhance the bond of acrylic cements to alumina to the strength required in an orthodontic application. The lack of availability of adequate coupling agents for alumina is circumvented in accordance with this invention by coating the crystalline alumina surface that is to be in contact with the cement with a thin coating (usually thinner than about 10,000 angstroms, and preferably, up to about 1,000 angstroms) of a siliceous material such as silica, and then using silicone coupling agents to enhance the bond of that surface to the cement, in a manner analogous to that which is presently known. Examples of means for coating the crystalline alumina surface with a siliceous material are cathode sputtering, plasma deposition, and electron beam evaporation, all of which are known techniques, especially in the semi-conductor