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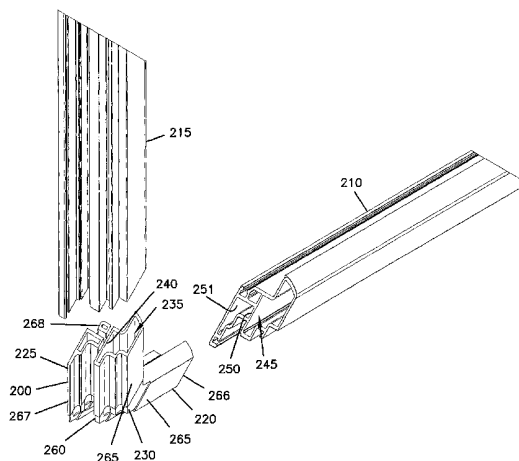
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(54) Title: IMPROVED METHOD FOR FORMING INTERNALLY BONDED JOINT STRUCTURES, JOINT STRUCTURES SO FORMED, AND APPARATUS THEREFORE



(57) **Abstract:** A method for forming an internally bonded adhesive joint is described herein including the step of inserting a first portion (220) of an insert (200) into a hollow region of a first lineal member (210) and inserting a second portion (225) of an insert (200) into a hollow region of a second lineal member (215) to form an unbonded joint assembly (300), where the insert (200) includes at least one adhesive flow channel (230). The unbonded assembly (300) includes an injection port (310) and an adhesive receiving volume is defined by the interior walls of the lineal members and the flow channel (230). The method also includes the step of injecting liquid adhesive into the injection port (310) and into the adhesive receiving volume at a flow rate of at least 15 grams per second. The use of higher temperatures and greater pressures than previously used in a method for forming an internally bonded adhesive joint is described. An internally bonded joint structure is described having an overlap shear stress exceeding 500 pounds per square inch of internally bonded joint surface as measured using a pull test. Preferred insert geometries and an apparatus for forming an internally bonded joint structure are described.



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**Improved Method For Forming Internally Bonded Joint Structures,
Joint Structures So Formed, And Apparatus Therefore**

5 This application is being filed as a PCT International Patent Application in
the name of Andersen Corporation, a U.S. national corporation and resident,
(Applicant for all countries except US), Michael L. Doll, a U.S. resident and citizen
(Applicant for US only), and Yuli Kornblum, a U.S. resident and citizen (Applicant
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10 **Field of the Invention**

The invention relates to internally bonded adhesive joints having structural
strength. The invention extends to an improved method for forming the joint and to
apparatus capable of generating the temperatures, flowrates and/or pressures within
the unbonded joint assembly necessary to form an internally bonded joint having the
15 strength and durability required for structural applications.

Background of the Invention

The joinery of two components to form a reliable assembly structure is an
important technology having a variety of applications in construction and
20 fenestration. Where a portion of each member to be joined is hollow, a key or insert
structure may be used. The hollow members, having at least a hollow portion, are
joined by inserting a portion of the key or insert structure into the hollow portion of
each of the hollow members. The joint is usually formed by enclosing at least a
portion of the key or insert inside the members that come into contact at a joint line.

25 The key or insert structure can be held in place solely by mechanical forces
arising from the interaction between the insert or key and the internal parts of the
hollow member. The surface of the key and the internal structure of the hollow
members can be raised or ribbed in appropriate locations such that the interaction
between the key and the hollow member locks the key in place. In order to create a
30 joint strong enough for construction or fenestration applications, it is conventional to
use some type of additional fastener component in conjunction with an enclosed key

or insert structure for forming secured joints. Such fasteners can include bolt structures, screw fasteners, nails, staples, or other joinery components.

The prior art also recognizes that such joints, particularly corner joints using a corner key or corner insert, can be used to join hollow members at a 90° angle, can
5 also include a sealant in combination with the insert or key in the corner assembly. The sealant typically prevents the penetration of water or atmospheric moisture into the joint or into the hollow member to ensure the long-term integrity of the window.

The use of adhesives to secure the insert or key in the joint has also been described in the prior art. However, the adhesive prior art often suggests the
10 necessity for the use of a fastener such as a screw, staple or nail to ensure joint integrity during the curing stage of the adhesive or to ensure that the adhesive/fastener joint is of sufficient integrity to satisfy mechanical loads during assembly, installation and useful life.

Some examples of structural applications for joint structures include window
15 frames, window sashes, and walls, ceilings and floors of buildings. Structural applications require that a joint can withstand pressures of at least 1000 psi.

Previously filed patent application U.S. Serial Number. 09/301,469 ('469 application) filed April 28, 1999, and entitled, *ASSEMBLY STRUCTURE AND METHOD INVOLVING INSERT STRUCTURE WITH INLET PORT, ADHESIVE CHANNEL PORTION AND*
20 *ADHESIVE BONDING AREA*, discloses internally bonded joint structures and addresses some of the above-mentioned problems. The joint structure disclosed by the '469 application is assembled prior to application of liquid adhesive to predetermined internal surfaces of the unbonded assembly by injecting adhesive into the assembly through an injection port.

25 Another example of a key or insert used with adhesive is found in French Patent No. 2,759,111. French Patent No. 2,759,111 relates to a right-angle joint bracket used for assembling two hollow sections to form two consecutive sides of a frame. The joint bracket of French Patent No. 2,759,111 includes a raised border along the perimeter of each arm of the joint bracket.

30 In creating a strong adhesive bond, it is important that the adhesive thoroughly coats and wets the surfaces to be adhered. Pressure applied to two adherends also helps form a stronger bond by increasing the wetted area, as when a

clamp is used to apply pressure. In a corner key joint structure joining hollow structural members, the adherend surfaces are hidden within the joint before the adhesive is applied. Therefore, it is very difficult to ensure that the adherend surfaces are coated with adhesive. Also, it is not possible to apply direct pressure against the two adherend surfaces inside the joint structure. Accordingly, improved joint structures and methods and machines for forming internally bonded joint structures are needed.

Brief Description of the Drawings

The invention may be more completely understood by considering the detailed description of various embodiments of the invention that follows in connection with the accompanying drawings in which:

Fig. 1 is a top view of one embodiment of an insert of the present invention shown with linear members to be joined to form a window component.

Fig. 2 is a perspective view of another embodiment of an insert of the present invention shown with linear members to be joined.

Fig. 3 is a perspective view of a joint structure including the insert and linear members of Fig. 2.

Fig. 4 is a perspective exploded view of an apparatus for assembling joint structures including devices for injecting adhesive.

Fig. 4A is a perspective view of the apparatus of Fig. 4 with the hose attached to the melt tank and the hand held injector.

Fig. 5 is a cross-sectional view of a nozzle used to inject adhesive according to the present invention.

Fig. 5A is a cross-sectional view of a nozzle before modifications made to provide the nozzle of Fig. 5.

Fig. 6 is a cross-sectional view of another nozzle used to inject adhesive according to the present invention.

Fig. 6A is a cross-sectional view of a nozzle before modifications made to provide the nozzle of Fig. 6.

Fig. 7 is a perspective view of yet another embodiment of an insert of the present invention shown with linear members to be joined, where the insert is designed to be used with larger linear members.

Fig. 8 is a top view of yet another embodiment of an insert of the present invention for use with linear members having a simple rectangular cross-section.

Fig. 9 is a cross sectional view of another embodiment of an insert of the present invention.

Fig. 10 is a top view of yet another embodiment of an insert of the present invention for use with larger linear members having a simple rectangular cross-section.

Fig. 11 is a perspective view of another insert for use with a casement window sash, where the insert includes an injection port.

Fig. 12 is a top view of a material sample with a flat channel used for testing the injection methods of the present invention.

Fig. 13 is a side view of the material sample with the flat channel cavity of Fig. 12 topped by a flat member, defining a flat channel cavity for testing the injection methods of the present invention.

Fig. 14 is a chart showing adhesion strength plotted against flow distance for a flat channel cavity of 1" x 0.06" x 12", for adhesive injections in the flat channel cavity of Figs. 12 and 13 using four different adhesive flow rates.

Fig. 15 is a perspective view of an unbonded joint assembly before it is injected with adhesive.

Fig. 16 is a perspective view of the unbonded joint assembly of Fig. 15 with a containment unit over the injection port.

Fig. 17 is a perspective view of the joint assembly of Fig. 15 where a hand-held injector of an injection apparatus is in position for injection into the containment unit.

Fig. 18 is a perspective view of a clamping mechanism that is used to prevent deflection of the lineal member when adhesive is injected into a joint assembly.

Fig. 19 shows a top view of a containment unit including an injection port positioned on an unbonded joint assembly.

Fig. 20 shows a top view of a clamping arrangement for use with the present invention.

While the invention is amenable to many modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiment described. On the contrary the intention is to cover all modifications equivalents and alternatives following within the spirit and scope of the invention as defined by the appended claims.

Summary of the Invention

10 Inserts may be used to join various members together, such as joining components of a window frame. An insert is positioned within a hollow region of a first member and also within a hollow region of a second member to form a joint assembly. Adhesive may then be injected into the interior of the joint assembly to form an adhesively bonded joint assembly. The present invention relates to the
15 difficulties of forming a sufficiently strong adhesively bonded joint assembly. The application of adhesive at higher temperatures and greater pressures than previously contemplated improves the strength of the joint considerably. Improved insert geometries are also described herein which result in improvements in the strength of an adhesively bonded joint assembly. In addition, an improved apparatus for
20 forming joint structures using an insert is described.

A method for forming an internally bonded adhesive joint is described including the steps of inserting an insert into a first lineal member and second lineal member to form an unbonded joint assembly. The insert includes at least one adhesive flow channel. The unbonded joint assembly includes an injection port. An
25 adhesive receiving volume is defined by the interior walls of the first and second lineal members and the flow channel. The method also includes the step of injecting liquid adhesive through the injection port into the adhesive receiving volume at a flow rate of at least 15 grams per second. Alternatively, the adhesive injecting step may occur at a flow rate of at least 17 grams per second, at least 25 grams per
30 second, or at least 30 grams per second. The adhesive may have an exit temperature of at least 200°C during injection.

According to one embodiment, the flow channel is adjacent to the injection port and has an aspect ratio of flow channel width to flow channel depth of at least 16. The width of the flow channel may be about one inch and the depth of the flow channel may be about 0.06 inch.

- 5 During the injection of liquid adhesive, the pressure at the injection port may be monitored and the injection may be stopped when a desired pressure value is detected. The timing of the injection of liquid adhesive may also be performed so that the injection is stopped when a desired time has elapsed.

- An internally bonded adhesive joint structure is described including first and
10 second polymeric lineal members including hollow regions at least at the end portions thereof, an insert including at least one adhesive flow channel, where the insertion of the insert into the hollow regions of the lineal members forms an unbonded joint assembly having at least one injection port, and an adhesive filling an adhesive receiving cavity of the unbonded joint structure, where the adhesively
15 bonded joint structure may provide an overlap shear stress as measured using a pull test that exceeds 1,000 pounds per square inch, 1,500 pounds per square inch, 2,000 pounds per square inch, or 2,500 pounds per square inch of internally bonded joint surface.

- The internally bonded adhesive joint structure may include a hot melt
20 adhesive such as a polyamide or polyethylene-co-vinyl alcohol. The adhesive may chemically cross link upon solidification.

- The flow channel of the insert may have an area to volume ratio less than 0.5 reciprocal meters or 5 reciprocal meters. The insert may include freeze-off regions adjacent the flow channel where the freeze-off regions have an area to volume ratio
25 greater than 2.5 reciprocal meters or 5.0 reciprocal meters. According to one embodiment of the present invention, an internally bonded adhesive joint structure may include an insert having a plurality of separate pieces. The insert defines at least one adhesive flow channel and a pan and the insertion of the insert into the hollow regions of two lineal members forms an unbonded joint assembly. Adhesive
30 may fill the adhesive receiving volume of the unbonded joint structure. The use of an insert including multiple separate pieces may be helpful for accommodating lineal members that have internal walls.

According to the present invention, an apparatus for forming an internally bonded joint structure may include a clamping device for holding an unbonded joint assembly, a device for pressurizing solidifiable adhesive in a liquid state, an adhesive injector for injecting adhesive through an injection port, and a pressure sensor for detecting the adhesive pressure at the injection port during injection. The apparatus may also include means for melting hot melt adhesive, means for positioning the first and second lineal members and insert, and means for sequencing the positioning of the first and second lineal members and insert. The apparatus may also include a device for sequencing the clamping of the positioned lineal members and insert.

Detailed Description of Various Embodiments

Insert technology has been used for many years in various industries to connect various components, such as the components of a window frame. Previously filed patent application U.S. Serial Number. 09/301,469 ('469 application) filed April 28, 1999, and entitled *ASSEMBLY STRUCTURE AND METHOD INVOLVING INSERT STRUCTURE WITH INLET PORT, ADHESIVE CHANNEL PORTION AND ADHESIVE BONDING AREA*, incorporated herein by reference, discloses internally bonded joint structures. The joint structure disclosed by the '469 application is assembled prior to application of liquid adhesive to predetermined internal surfaces of the unbonded assembly by injecting adhesive into the assembly through an injection port.

Generally speaking, when two surfaces are adhesively bonded, pressure is applied to force the adhesive into intimate contact with bonding surfaces because the adhesive does not spontaneously wet (spread over) the surfaces as described in more detail herein below. In a simple example, glue is applied to the surfaces to be bonded, which are then pressed together using a clamp, vice, or application of weight. This applied pressure forces the adhesive to flow over the surfaces and into micro-cracks and/or pores existing on the surface when viewed on a microscopic scale. As shown below, the bonding force decreases with the square of the distance between the surfaces. Consequently, the use of pressure to urge the adhesive and bonding surfaces into intimate proximity can result in much improved bond strength.

Where a joint is made using an insert and adhesive, as described in the '469 application, the internal surfaces of the lineal members are bonded to the external surfaces of the insert. During assembly of the joint, the surfaces to be bonded are hidden within the joint, and are not accessible for pressing together with a typical clamping device. Therefore it is more difficult to ensure that an adhesive bond will form between the internal surfaces of the lineal members and the external surfaces of the insert.

Another difficulty with adhesive insert structures arises because the cavity that receives the adhesive may vary in size, shape and volume. Different insert designs result in different cavity shapes and sizes. Even for the same insert design, the volume of the same basic cavity varies randomly because of the random tolerance accumulation due to the lineal member, insert, and assembly tolerances. In some joint structures, the volume of the cavity can double within the allowable tolerances. Another difficulty with joint structures formed with inserts is that upon injection of the adhesive, the cavity walls and/or the insert may deflect because of the adhesive's heat or pressure, thus creating new leak paths for the adhesive.

To address these concerns, the inventors of the present application have conducted experimental work to study and enhance lineal connection with an insert or corner key using injected adhesive. The study concentrated on the time, temperature, and flow distributions of the adhesive as it was injected into a channel formed by the insert and lineal walls.

The inventors have found that applying adhesive at higher temperature and greater pressures than previously used improves the strength of the joint considerably. It is believed that high temperature adhesive application more effectively dislodges, dissolves, or desorbs surface contaminants from the bonding surfaces especially adsorbed air and moisture. Increased pressure urges the molecules of the adhesive and surface into closer proximity thereby increasing the strength of the adhesive bond.

Also, an improved apparatus for forming joint structures using an insert is described herein. Preferred insert geometries are also described. A joint having

structural integrity can be formed with an adhesive bond without the need for a mechanical fastener such as a screw, nail or staple.

The insert structure, joint assembly structure, joint assembly method and apparatus for joint assembly of the invention can be used to join virtually any partially hollow member to a second similar or dissimilar partially hollow member in virtually any process involved in commercial or household construction. Not only can the inventions be used in the manufacture of fenestration components including windows and doors, the insert components can be used in any joinery aspect of any construction. The inserts can be used in primary framing by joining either extruded or metal hollow profiles into load bearing and partition wall framing. The insert structures can be used in forming roof trusses, floor substructures, concrete mold preparation and any other aspect of such construction adaptable to adhesive based assembly.

Fig. 1 illustrates one particular application of the present invention for forming joint assemblies 10, where four linear members, also known as lineal members or lineals, are shown with four inserts 20 for assembling a window component. Each joint structure 10 includes a first linear member 12, a second linear member 14, and the insert 20. As illustrated in Fig. 1, the joint structures 10 of the present invention may be used to join four linear pieces in a rectangular product, such as a window sash.

Fig. 2 shows a different embodiment of an insert 200 of the present invention, used to join first and second linear members 210, 215. The insert 200 is shaped to match the interior profile of the linear members 210, 215. The insert 200 includes a first leg 220 corresponding to a first linear member 210 and a second leg 225 corresponding to a second linear member 215. The insert also includes a flow channel 230 at the joint line between the first leg 220 and second leg 225. The insert 200 has a hollow interior 235 and may have some interior walls 240 within the hollow interior 235.

Generally, linear members to be joined using an insert of the present invention include at least a hollow portion at their ends to receive the insert, and may be hollow throughout their length. Some linear members are substantially hollow

but include internal walls. For example, linear member 210 of Fig. 2 has a hollow interior 245 that runs along the length of the linear member 210. Linear member 210 also includes interior walls 250 and internal surfaces 251 that interact with the insert 200. Second linear member 215 also includes a hollow interior and interior walls in this embodiment that are not shown in Fig. 2.

In order to accommodate the interior walls of a lineal member, an insert may be made of multiple pieces. For example, the insert 200 of Fig. 2 is actually composed of three separate pieces: a first insert piece 266, second insert piece 267 and third insert piece 268. Interior walls provide beneficial properties to linear members such as improved rigidity, strength, insulation properties and weight. Accordingly, an insert design that can accommodate interior lineal walls is advantageous. The separate insert pieces 266, 267 and 268 may be incorporated into an unbonded joint assembly as separate components.

A multi-piece insert or corner key is appropriate for use with linear members having interior walls or having complex profiles where molding a single appropriately shaped insert would be difficult. Single piece inserts are appropriate for more simple linear member profiles.

In use, first and second legs 220, 225 of insert 200 are pushed into the hollow interior end portions of the first and second linear members 210, 215, respectively, to form an unbonded joint assembly. The unbonded joint assembly includes the first and second linear members and the insert, which is not visible in the embodiment of Fig. 2. However, some other insert designs, discussed in more detail herein, include a portion that is visible in the joint assembly. An example of an unbonded joint assembly 300 made of the components of Fig. 2 is shown in Fig. 3. An injection port may now be formed in one or both of the first and second linear members. The injection port is preferably formed at a joint line where the first and second linear members meet, with part of the port in each linear member. Injection port 310 is formed at the joint line 312. Many other locations for the injection port are possible. The injection port may be formed by drilling or other methods known in the art. In the alternative, the injection port may be formed in a linear member or members before the unbonded joint assembly is assembled. The injection port and the adhesive injection process will be discussed in more detail herein.

Now referring to Fig. 2, the linear members pictured are the components of a casement window sash. The flow channel 230 is a recessed portion of the insert 200 that is present around the central portion 255 of the insert, where the first and second legs 220, 225 meet. Flow channel banks 265 are adjacent to the flow channel 230.

5 The flow channel is sized to allow adhesive to flow around the exterior surface of the insert at the joint line. The flow channel 230 width is preferably about 0.8 to 1.2 in., more preferably about 0.9 to 1.1 in., more preferably still about 0.95 to 1.05 in., where the channel width is 1 in. in the most preferred embodiment. The flow channel depth is preferably about 0.5 to 0.7 in., most preferably about 0.06 in. An
10 insert 200 for use with a casement window sash typically has a flow channel encircling the insert so that each of the lineals is sealed from the outside environment by the adhesive in the flow channel. The first and second legs of the insert 200 preferably extend at least one inch beyond the edge of the main flow channel. The banks 265 serve as a freeze-off area for the adhesive, as will be
15 discussed in greater detail herein. The rationale behind the geometry of insert 200 and other inserts of the present invention will now be discussed.

Preferred Geometry for Insert Flow Path

The inventors of the present invention have discovered important principles
20 for structuring an insert to be used with hot melt adhesive for creating a strong joint assembly, capable of use in structural applications. A detailed analysis of the factors determining the strength of adhesively bonded joints in general shows that the strength of adhesive joints is determined by a complex interaction of joint geometry and properties of the materials used in its construction. Also to be considered are
25 contaminants trapped within the roughness of the surfaces of lineals and inserts comprising the joint structure (for example adsorbed air and moisture) that are displaced or dissolved in the adhesive during the bonding event.

The technical literature describes why measured adhesive joint strengths (using peel or shear tests) are a factor of ten (10) lower than those calculated from
30 the thermodynamic work of adhesion between the adhesive and adherend (in the instant case the surface of the lineals and inserts). J.C. Berg, *Surface and Colloid Science* (University of Washington, 1998) (pages II-19 through II-27), the disclosure

of which is hereby incorporated by reference, notes the relationship that exists between wetting and adhesion. Generally adhesion refers to the strength of the bond between two solids as measured by some mechanical test. The values obtained depend on the method and conditions of the disjoining event that takes place during measurement. In addition contamination, roughness and mechanical interlocking of the surfaces, electrostatic effects, residual stresses, and adhesive rheology also affect the measured strength. Wetting, on the other hand, can be tied to thermodynamic work of adhesion by measurement of the contact angle between adhesive and adhered. Out of this analysis emerge two (2) important thermodynamic criteria for the optimization of contact adhesion: (1) an adhesive that "spreads" on the adherend (zero contact angle), and (2) adherend surfaces that maximize the work of adhesion. In practice, it is difficult to select adhesives having zero contact angle. A more practical approach is to choose from those that minimize the contact angle. The various components contributing to the work of adhesion can be estimated by measuring the contact angles of probe liquids of varying polarity, acidity, and hydrogen bonding potential against the adherend surface. U.S. Patent No. 5,948,524 discloses Advanced Engineering Resin and Wood Fiber Composite materials useful in forming the lineal members of the present invention. The disclosure further teaches that the resin used to form the composite has a surface energy greater than 40 dynes per centimeter which is defined in ASTM D724-89 as revised. The method used to measure the surface energy using probe liquids is explained in the paper by Owens et al. "Estimation of the Surface Free Energy of Polymers", *Journal of Applied Polymer Science*, Vol. 13, pp 1741-1747 (1969), which is hereby incorporated by reference. This method has become a standard method for quantifying surface energy and supplements the approaches of Zisman, Fowls, Good-Garifalco, and Drago as discussed in the references cited above and elsewhere.

A.W. Adamson, *Physical Chemistry of Surfaces*, (J. Wiley & Sons, Fifth Ed., 1990)(pages 385-420 and 482-487), the disclosure of which is hereby incorporated by reference, shows how the thermodynamic treatment can be extended to calculate the force required to separate two parallel plates (adherends) joined by a liquid adhesive bridge of constant volume. The calculated force is directly proportional to the surface energy and inversely proportional to the square of the distance separating

the plates (neglecting edge effects) as described in detail by Adamson equation XII-32 (*Id.*, page 484). Thus the adhesive bonding force is maximized when the adhesive film is made as thin as possible. This treatment assumes that the adhesive film is continuous covering over the cracks and asperities of rough surfaces of the adherends existing on the molecular scale.

Since zero contact angle and spontaneous spreading are not achieved, forced spreading is required to apply the adhesive and pressure is helpful in forcing adhesive over the surface and into voids displacing most of the adsorbed air but trapping some micro bubbles within the surface pores as the adhesive film spreads over the adhered as shown by Adamson in Figure X-3 (*Id.*, page 388). This results in incomplete contact between adhesive and adherend (disruption of the continuous adhesive film required above) explaining in part why the joint strengths fall short of their calculated values. Adhesive joints fail by the release of stored elastic energy and the work of crack propagation (Griffith-Irwin Criteria) at the adhesive-adherend interface (adhesive failure) or within the adherend bulk phase (cohesive failure). If the trapped micro bubbles are substantially coplanar, a crack can easily propagate from bubble-to-bubble and the interface essentially "unzips". Rough adherend surfaces which effectively smear the adhesive-adherend interface into relatively thick regions of adhesive and adherend (also called boundary layers or interphase regions) keep the trapped air bubbles from becoming coplanar and are beneficial in combating the "unzipping" type failures.

In the context of the instant invention, a high-pressure adhesive injection system is used to form the internally bonded joint structure. As described above, in general the adhesives and adherends will be chosen to minimize the contact angle there between, but in general the contact angle will not be zero and the adhesive will not spontaneously spread over the adherend. Pressure drives the adhesive flow required by the non-spontaneous spreading process as adhesive flows from the injector through the injection port, flow channels, into the adhesive regions of the joint structure. If the flow is considered laminar, the Hagen-Poiseuille flow profile developed will depend on the pressure drop, adhesive viscosity, and channel geometry (width, height, length, number & severity of the bends or restrictions in the channel). The preferred adhesive for practicing the invention is a crystallizable, hot

melt adhesive. Preferred adhesives for use in the invention are more accurately described as visco-elastic materials that exhibit both solid and liquid like properties as opposed to an ideal crystalline solid which under goes a phase transition at the melting point to become a liquid. The pressure driven spreading of a visco-elastic adhesive over an adherend is a hydrodynamic event and it is the dynamic contact angle that determines the shape of the adhesive wave front as it advances over the adherend both displacing and trapping adsorbed air. Important considerations in analysis of the dynamic equilibrium are concentration gradients, thermal gradients, and hydrodynamic behavior in the contact zone as discussed by Stokes and Evans, *Fundamentals of Interfacial Engineering*, (J. Wiley-VCH, 1997)(pages 360-374 and 454-456), the disclosure of which is hereby incorporated by reference. The adhesive is injected into the inventive joint structure at high temperature where it behaves like a viscous liquid. As the adhesive temperature drops its viscosity sharply increases and at constant pressure the adhesive flow within the joint drops abruptly and spreading of adhesive over the surface of insert and lineals (adherends) ceases. To reduce this undesirable temperature drop and viscosity increase of the adhesive, channel geometry within the joint is designed to minimize heat transfer from the hot adhesive to the cool surfaces of the insert and lineals. Consequently, surface area to volume ratio is minimized in the injection port and adhesive flow channel and maximized at the edges of adhesive receiving volume that form the freeze-off flow directing barriers as discussed in further detail elsewhere herein.

The adhesive used with the present invention is preferably a compound that is injected at a relatively high temperature, as discussed in more detail below. The thermal process of hot melt adhesive injection into a room temperature cavity is known as "transient heat transfer". The adhesive's flow, temperature and state vary with time and location. This situation is significantly different than injection under steady state conditions, where the adhesive and the adhesive receiving cavity are near the same temperature. In the transient case, the hot adhesive transfers heat to the cavity walls. The state of the adhesive depends on the local flow and the local temperature. If the adhesive flow is too slow and loses considerable heat to the cavity, the adhesive may solidify prematurely.

In a transient heat transfer situation, the thermal mass and thermal diffusivity of the adhesive are important. The thermal diffusivity is defined as the thermal conductivity divided by the product of density and the specific heat. The injection situation includes two main regimes: a fast transient, when the flow is initially
5 injected into the corner, and a slow transient, after the initial rise in temperature. The situation in the fast transient is much more complicated than the situation in the slow transient.

The temperature loss (heat transfer) of the adhesive depends on the thermal properties of the linear members, the insert and the adhesive. Heat transfer is also
10 dependent on the geometry of the flow channel, specifically, on the local area to volume ratio of the adhesive as it fills the various volumes of the cavity. A large adhesive surface area will result in a large area to volume ratio that maximizes heat transfer and therefore results in a rapid temperature drop. A narrower flow channel provides a larger adhesive surface area compared to the volume of the flow.
15 Therefore, in a narrow flow channel, the adhesive may increase in viscosity, slow and solidify. This situation is not desirable in the main flow channel, which has to deliver the adhesive to the various locations of the adhesive receiving cavity. The main flow channel must be wide enough and deep enough to provide a low local surface area to volume ratio so that the adhesive can adequately transmit the pressure
20 required for spreading as it transits the entire flow channel.

However, a large local area to local volume ratio is desirable at the edges of the flow channel. On the banks of the main flow channel, or the area on the insert just adjacent to the main flow channel, it is desirable to allow the adhesive to solidify quickly. Solidified adhesive on the banks of the main flow channel acts as a
25 channel wall, so that the adhesive creates its own flow cavity. Therefore, when designing the flow channels, it is desirable to have one main flow channel that is wide enough and deep enough to have the flow fill it very fast. At the banks of the flow channel, the distance between the insert and the interior surfaces of the linear member should be as small as possible, so the flow will solidify quickly and create
30 its own flow cavity surrounding the main channel. However, there should be some distance between the insert and the interior surfaces of the linear member so that

adsorbed air and air within the adhesive receiving cavity can escape as the adhesive is injected without compressing and thus causing back pressure opposing the adhesive flow.

As a result of the local area to volume considerations, it is preferable that the local area to volume ratio is minimized. The channel should be structured so that it is possible for adhesive to traverse the channel without solidifying. A straight channel of 1" by .06" by 12" was tested, as discussed in relation to Fig. 14, and provided excellent bond strength, especially at the higher flow rate of 28 g/s.

10 Process of Adhesive Injection

Faster injection results in high pressure in the joint therefore improving joint strength. It is desirable to achieve the highest pressure possible without breaking or damaging the linear members or the insert. The adhesive injector should have a strong mechanism to propel the adhesive flow and the injector should be set to a high flow rate. In this patent application, the term flow rate refers to the flow rate achieved when the injector is freely releasing adhesive and is not restricted in any way. The adhesive receiving cavity may apply pressure against the adhesive output so that the flow rate set on the injector is not actually achieved by the injector.

The steps for formation of an adhesively bonded joint assembly of the present invention will now be discussed. A portion of the insert is pushed inside of a hollow portion at the end of one linear member. The other portion of the insert is pushed inside of a hollow portion at the end of a second linear member. During the formation of a four sided frame or sash component, the four sides may be brought together with four inserts, as illustrated in Fig. 1.

The linear members may be assembled entirely by hand, clamped into an assembly for assisting with proper alignment, or joined using any other method known in the prior art. In a preferred method where the linear members are being joined to form a window sash or frame, the members, inserts and any other components may be placed in position around a sheet of glass, a preassembled insulated glass unit having argon gas filling or dry air filling, or other glazing units. The inserts may be fitted into the interiors of the linear members by hand. The

window sash, now fitted together, is placed into a clamp assembly and the clamps are tightened. The clamps may exert a force against the joint assembly to ensure that the inserts and linear members are firmly in place and are aligned. The applied force may act against each joint assembly in a direction at 45° to both of the linear

5 members. The same force should be applied to each of the four inserts in a window sash assembly to ensure proper alignment. Preferably, the clamp also supports the surfaces of the linear members when adhesive is injected into the joint assembly to prevent the linear members from deflecting in response to the pressure of the adhesive. A deflection of the linear members moves the surfaces to be bonded

10 farther apart, reducing the likelihood of a strong bond. Preferably, the clamp will firmly support the exterior surfaces of the linear members and will follow the profile of the linear members to brace against deflection of the linear member walls.

One example of an unbonded joint assembly that is clamped and ready for adhesive injection is shown in Fig. 15 and Fig. 18. Another clamping configuration

15 is shown in Fig. 20. In a preferred clamping device, the clamp would support the exterior wall of the linear members by following the linear member wall.

After clamping the unit, the injection timer is set to the desired time in preparation for injecting the adhesive and the injector, which may be hand-held, fixed, or moved automatically is positioned at the injection port. Because it is a goal

20 of the invention to inject the adhesive under pressure, it is possible that the adhesive may not only enter the injection port when injected, but may also escape to the outside environment. A good seal between the injector nozzle and the inlet port, whether the inlet port is defined in the insert or in the linear members, is important. When the inlet port is formed in polymer and wood composite linear members, the

25 hot injection nozzle may melt the linear members. To address the issue of a good seal with the injection port, a containment device may be used in between the injector nozzle and the injection port.

Fig. 15 shows an unbonded joint assembly 1500 including first and second lineal members 1510 and 1520 and insert 1530 including an injection port 1540.

30 The first and second lineal members 1510, 1520 meet at a joint line 1550. The insert 1530 includes a visible portion 1560 that is visible in the joint assembly 1500 and defines the injection port 1540. The joint assembly 1500 is held in a clamping

apparatus 1570. Fig. 16 shows the unbonded joint assembly 1500 with a containment unit 1600 in place over the injection port 1540. The containment unit 1600 includes an injection port 1610. Fig. 17 shows an adhesive injector 1700 with its nozzle inserted into the injection port 1610 of the containment unit 1600.

5 A containment unit for use with the present invention is preferably made of a material that will not stick to the adhesive. For example, Teflon brand material and polypropylene will not stick to many adhesives. The best choice of material for the containment unit depends on the adhesive. The surface of the containment unit that fits against the joint assembly should be constructed to follow the wall of the joint
10 assembly. The injection port of the containment unit is preferably sized to be slightly smaller than the injection nozzle diameter, so that a tight fit is created between the injection nozzle and the containment unit. The containment unit material at the injection port preferably flows or softens slightly when in contact with the injection nozzle, further enhancing the seal between the injection nozzle and
15 the containment unit.

 The adhesive nozzle is activated and adhesive is injected into the joint assembly for the designated amount of time set on the timer. After adhesive injection, the adhesive is allowed to cure for a few moments and the clamp is then released so that the joint assembly may be removed. The appropriate time for
20 allowing the joint assembly to cool after injection will depend on the specific adhesive that is used and the geometry of the joint assembly. The containment device prevents back flow of adhesive and therefore helps to establish the necessary pressure in the adhesive receiving cavity.

 Fig. 19 shows a top view of a containment unit including an injection port.
25 Fig. 20 shows an example of a clamping arrangement for use with the present invention. The containment units may be a separate piece or may preferably be attached to the injection nozzle.

Machinery for Adhesive Injection

Figs. 4 and 4A show an adhesive injector apparatus or hot melt machine 400 that may be used with the present invention, including a control box 405, a melt tank 410, a timer 415, a hose 420, a hand-held injector 425 and an automatic injector 430.

5 A motor 435 and a gear pump 440 are located underneath a chassis 445. The hose 420 supplies hot adhesive from the melt tank 410 to the injector 425 or 430 and also connects the control box 405 to the injector 425 or 430.

The preferred hot melt machine for use with the present invention is capable of a volume flow rate of at least about 15 g/s for adhesive with a viscosity of 6000
10 cps, more preferably at least about 20 g/s and most preferably at least about 28 g/s. However, it is even more preferable that the hot melt machine can achieve flow rates of 50 g/s or more, preferably 100 g/s. The preferred adhesive injection is preferably capable of heating the adhesive to 210°C, more preferably 230°C. Further it is desirable that the injector has a timer for regulating the flow of adhesive and has a
15 gear pump capable of producing at least 2600 psi.

One example of a hot melt machine that is preferred for use with the present invention is a Proflex injector made by Hot Melt Technology, 1723 West Hamlin Road, P.O. Box 67, Rochester, MI 48309, which was modified for better performance with the present invention. The Proflex injector is capable of a volume
20 flow rate of 17 cc (17 g/s) with a 1/6 HP motor, and can reach temperatures of 230° C. A timer was added to the Proflex injector to control injection time.

The Proflex injector was modified to replace the 1/6 HP 85 RPM motor with a 1/3 HP 170 RPM motor. With the new motor, a higher flow rate of 31.5 g/s could be achieved where the tank temperature was 418°F, the hose temperature was at 427
25 °F and injector temperature was at 433°F. It should be noted that the actual adhesive temperature is typically about 15-25°F below the temperature setting of the hot melt machine, depending on the flow rate and the time between different injections.

Also, the original nozzles of the Proflex injector were modified to allow a better flow rate, prevent the collapse of the injection port, and enhance joint
30 pressurization by preventing back flow from the injection port. When the original nozzle was used, it was sized to be placed adjacent to but outside of the inlet port.

Because the nozzle is at a very high temperature, the material defining the injection port tended to melt when the original nozzle was used, collapsing the injection port so that the material flowed into the adhesive receiving cavity, obstructing communication with the flow channel. The modified nozzle of Fig. 5 was designed to replace the original nozzle of Fig. 5A. The modified nozzle of Fig. 5 accommodates the faster injection rates required by the present invention by providing a larger interior flow area cross-section. The modified nozzle of Fig. 5 also allows the nozzle to be placed partially within the injection port of the joint assembly rather than adjacent to the injection port. The modified blunt nose nozzle shown in Figure 5 may be used with most insert designs of the present invention.

The modified extended blunt nozzle shown in Fig. 6 is especially suited for an insert where the inlet port or injection port on a particular insert embodiment could not be made large enough to accommodate the nozzle of Fig. 5 and an extended nozzle is required because the preferred site for the injection is deeper within the joint assembly than can be reached by the nozzle of Fig. 5. The modified nozzle of Fig. 6 was designed to replace the original nozzle shown in Fig. 6A.

Insert Designs

Several alternative insert designs and insert features will now be described.

Fig 7 is a perspective view of an insert and two linear members similar to Fig. 2, but where the linear members are larger and the insert is designed for use with the large linear members. Insert 700 has a profile similar to insert 200 of Fig. 2. Linear members 710 and 715 may be joined together using insert 700 by receiving the legs 720 and 725, respectively, of the insert 700. A central flow channel 730 is defined in the insert 700 at the joint line of the first and second legs 720, 725. The insert 700 defines a hollow interior 735 and includes some interior walls 740. Linear members 710 and 715 include interior walls 750 and define a hollow interior 745 for receiving the insert 700. The linear members 710, 715 include interior surfaces 751 that interact with the insert 700. Along a central portion 755 of the insert, where the legs 720 and 725 meet, an inlet port will be formed in the linear members corresponding to location 760 on the insert 700. Flow channel banks 765 are adjacent to the main flow channel 230.

Additional adhesive flow channels 770 and 775 are defined in the first and second legs of the insert 700 respectively. Additional inlet ports will be formed in the first and second linear members to allow injection of adhesive into flow channels 770, 775. For flow channel 775, the injection port will correspond to location 780
5 on the insert. By supplying adhesive to the adhesive flow channels 770 and 775 in addition to the main flow channel 730, the strength of the joint is improved.

The interior walls 750 of the linear members 710, 715 are accommodated by the insert 700 being composed of three separate pieces: first insert piece 781, second insert piece 782, and third insert piece 783. The interior walls 740 of the insert 700
10 actually separate the insert into its three distinct pieces. As discussed above, interior walls of the linear members are preferred for many reasons. As a result, it is advantageous for an insert design to accommodate the interior walls of the linear members, as accomplished by the insert 700 of Fig. 7.

Fig. 8 is a top view of an insert 800 within first and second linear members
15 810, 815, where the top part of the linear members is cut away to reveal the insert 800. Insert 800 is designed for use with linear members having simple square or rectangular profiles. A first leg 820 of the insert fits within the first linear member 810 and a second leg 825 of the insert fits within the second linear member 815. A flow channel 830 is defined in a central portion 855 of the insert 800 for receiving
20 adhesive. An injection port 862 is defined by the first and second linear members 810, 815, corresponding to location 860 on the insert. Banks 865 are adjacent to the flow channel 830.

Fig. 9 is a cross-section of another insert 900 of the present invention, where first and second linear members 910, 915 fit over first and second legs 920, 925. A
25 flow channel 930 is defined in the insert 900 for receiving adhesive at a central portion 955 and banks 965 are adjacent to the flow channel 930. An injection port 962 is defined by the first and second linear members 910, 915, corresponding to location 960 on the insert. Near the injection port 962, the insert 900 has a flattened portion 932.

30 Ribs 972 are present within hollow interior 935 for providing additional structural support to the insert 900. As adhesive is injected into the injection port 962, significant pressure is placed on the insert. Ribs 972 strengthen the legs of the

insert, so that they will be less likely to deflect away from the interior surfaces of the hollow linear members 910, 915.

Fig. 10 is a top view of an insert 1000 within first and second linear members 1010, 1015, where the top part of the linear members is cut away to reveal the insert 1000. Insert 1000 is designed for use with linear members having simple square or rectangular profiles, similar to insert 800 of Fig. 8, but insert 1000 is designed for use with larger linear members where additional flow channels improve the strength of the joint assembly. A first leg 1020 of the insert fits within the first linear member 1010 and a second leg 1025 of the insert fits within the second linear member 1015. The linear members have interior surfaces 1051 that interact with the insert 1000.

A central flow channel 1030 is defined in a central portion 1055 of the insert 1000 for receiving adhesive. A central injection port 1062 is defined by the first and second linear members 1010, 1015, corresponding to location 1060 on the insert. Banks 1065 are adjacent to the flow channel 1030.

Insert 1000 also has first and second side supplemental flow channels 1070, 1072 that are defined in the first and second legs 1020, 1025 of the insert, respectively. First and second side injection ports 1074, 1076 are defined in the first and second linear members 1010, 1015, respectively, near the first and second supplemental flow channels 1070, 1072. Flow channel banks 1078, 1080 are adjacent to the first and second supplemental flow channels 1070, 1072.

In the embodiment shown in Fig. 10, the width of the central flow channel is preferably about 0.60 inches. The first and second side flow channels 1070, 1072 are preferably about six inches from the center of the insert. The first and second side flow channels 1070, 1072 preferably have a width of about 0.50 inches.

Fig. 11 shows a perspective view of an insert 1100 for use with a casement window sash shown with linear members 1101. In contrast to the inserts shown in Figs. 2 and 7-10, the insert 1100 includes a visible portion 1102 that is visible in the bonded joint assembly. A rout 1104 in the linear members allows the presence of the visible portion 1102. The visible portion 1102 defines an injection port 1105. The insert 1100 also includes a flow channel 1107. The linear members have interior surfaces 1151 that interact with the insert 1100.

The insert 1100 is not a preferred insert design because its shape makes it more likely to deflect when adhesive is injected into the joint assembly compared to insert designs that are more supported and reinforced. However, insert 1100 illustrates an example of an insert including a visible portion that defines an injection port.

Typically, the clearance C between the insert and the interior surface of each linear member will be about 0.03 inches or less, more preferably about 0.02 inches or less. The clearance C between the banks of the flow channel and the interior surface of the linear member should be small enough to provide a relatively high local area to volume ratio for the adhesive flow so that the banks serve as an adhesive freeze-off area. However, C should be large enough to allow bleed out of air within the adhesive receiving cavity of the joint assembly.

Generally, there are advantages to an insert that is completely enclosed within the linear members that it joins. Where a portion of the insert is visible, there are additional paths for adhesive to leak out of the joint assembly. Also, a completely enclosed insert presents a more uniform aesthetic appearance.

Each joint assembly defines an adhesive receiving cavity or volume in the spaces between portions of the insert and the internal surfaces of the linear members. The adhesive receiving cavity will primarily be adjacent to the insert's flow path or flow paths and its flow path banks that serve as a freeze-off area.

Alternate Angle Construction

While examples of right angle corner joint constructions have been described, the insert of the present invention may also be used to form a joint of various other angles, including a straight joint structure. Linear members to be joined in a straight joint structure may have an end cut at a 90° angle. In addition, the joint structure of the present invention may be used to connect members that are not entirely linear, as long as at least a portion of the member to be joined is capable of receiving an insert. For example, an arched member may be joined to a horizontal or vertical member according to the present invention.

Materials and Preparation of Linear Members

The composition and requirements of the components of the joint structure of the present invention will now be discussed. Before assembly of a joint structure, the linear members are cut to the proper length. The ends of the linear members may be prepared for joining by cutting the ends at a specified angle. For example, if the linear members will define an angle of 180° after assembly, the ends of the linear members will be cut at a 90° angle to the length. If a 90° angle will be formed between the two linear members after assembly, the ends of the linear members may be cut at a 45° angle, as shown in Fig. 2. However, it is also possible to assemble linear members at a 90° angle where the ends of the linear members are cut at a 90° angle. These types of joint assemblies are known as M&T joints. End geometry for each linear member may be designed depending on the particular joint configuration and linear member profile.

Possible methods of cutting the linear members include a power miter box, a contractor table saw, a radial arm saw or a tenoner modified by replacing blades with face mills and the drive chain with a servo-driven ball screw. In addition, many other methods of cutting are known in the art and may be applicable to the present invention. The dimensional tolerances of each method should be tested with the particular machinery that is used.

The present invention may be used with linear members of many different types of material. The invention is especially suited for use with linear members made of a composite material of wood and polymer. Examples of a wood and polymer composite that may be used with the present invention are described in U.S. Patent Nos. 5,406,768 and 5,948,524, the disclosures of which are hereby incorporated by reference in their entirety. In addition, the methods of the present invention may be used to join linear members of metal, plastic, vinyl, wood, fiberglass, other materials or composites thereof.

In order to form the joint assembly of the present invention, the ends of the linear members will be capable of receiving the insert. These linear members may be hollow, partially hollow, or hollow only at the ends. Extruded linear members may be used with the present invention, which are generally hollow but may include ribs or interior walls within the profile to add strength to the member. In some

cases, portion of the ribs may be removed to accommodate the insert, or the insert may be designed to fit within the ribs.

Inlet Port Formation

5 The inlet port may be formed as a part of the insert where a portion of the insert including the injection port will be visible in the joint assembly, as in Figs 11 and 15-17, or as an opening in one or more of the linear members. Where the inlet port is in a linear member, as in Figs. 2 and 7-10, the inlet port may be formed in either or both of the linear members to be joined to give access to the channel or
10 channels of the insert. The placement of the inlet port may be chosen after considering the adhesive flow path, so that the adhesive will be able to reach all channels and pans where bonding is required.

For the embodiment of the insert illustrated in Figs. 2, the inlet port may be located on the linear member joint line, corresponding to location 260 on the insert.
15 The inlet port may be formed in a linear member using a hand held jig, or other machinery that is known in the art. The inlet port of this embodiment is preferably precisely located over the channel, and will be formed only in the linear member or members, not penetrating into the insert. The diameter of the port is preferably chosen to be large enough to allow easy insertion of the nozzle and easy injection of
20 the proper adhesive amount at the appropriate flow rate. The port may be approximately 1/8 to 1/2 inch in diameter, or more preferably about 1/8 to 1/4 inch, and most preferably 3/16 inch in diameter.

Generally, an injection port or inlet port formed at the joint line of the two linear members is preferable to an inlet port defined in the insert. Where an inlet
25 port is defined in the insert, the insert has a visible portion that is accommodated by a rout or cut in at the joint line of the linear member. The interface of the visible portion with the linear members provides opportunities for adhesive leaks that may prevent adequate pressurization of the adhesive receiving cavity.

Design of Insert

30 When the dimensions of the insert are determined, a designer preferably considers the manufacturing tolerances of the profile of the linear members that will

be joined. The insert should be designed to easily fit within the linear member, considering the possible variances in wall thickness. For example, in some cases where the method of U.S. Patent No. 5,406,768 is used to produce linear members, wall thickness can vary by 0.020 inch. The insert dimensions may account for this
5 type of variation.

Another consideration when designing the insert is the clearance between the insert and the interior walls of the linear members. The designer may allow for sufficient clearance for ease of assembly, but also consider alignment, required adhesive flow and required adhesive distribution.

10

Materials for the Insert

The insert may be made of materials known in the art that can withstand the stresses and deformations induced during assembly, shipment, installation and use of the finished product into which it is incorporated. Modeling may be employed to
15 determine the stresses that the insert will need to withstand, and then a range of appropriate materials can be investigated. For many uses, polymers have sufficient tensile yield strength and toughness to function as an insert. Polymers that can be injection molded allow for a preferred method of manufacture. Some examples of polymers that may be used include injection molding grade PVC, ASA plastic, ABS
20 plastics and Valox made by General Electric, Nylon 66, and other engineering resins. For a window sash application, a PVC marketed as VISTELTM 9121 available from CONDEA Vista Co., Houston, TX 77079 has performed favorably. These materials are provided as examples that may be applicable to a specific insert application, but many other materials may also be appropriate. Preferably, the
25 manufacturing tolerances of the insert are also considered when determining the dimensions of the insert.

The melting temperatures of the adhesive and insert material should also be considered when selecting a material for the insert. PVC for example has a very high melting point and is therefore suitable for use with adhesives with high melting
30 points.

Flowable Hot Melt Adhesive

In forming the bonded joints of the invention, a flowable hot melt adhesive is typically introduced into a port at the joint. The adhesive is fluidly communicated to the channel or channels and to the adhesive receiving cavity or volume. The

5 preferred adhesive for use in this invention is a hot melt adhesive that is introduced into the joint at high temperature of 210°C or higher. After introduction into the joint area, the adhesive solidifies either by cooling or through a curing or crosslinking reaction forming a tough reliable bond. Preferred adhesives form a rigid structural bond between the insert or key and the hollow members. Further, the

10 resulting structure should have sufficient strength to prevent failure in a cleaving mode destruction test and in a hanging mode destruction test. Further, the adhesive should also provide a sealing function to prevent air or water infiltration into the interior of the hollow members. The adhesive should be sufficient to maintain an adequate structural bond while being exposed to extremes of other conditions

15 including vibration, shock, temperature, insolation and humidity. Both relatively high temperature thermoplastics and curable thermosetting adhesives can find use in the application. Preferred adhesives have a relatively high melting point, typically greater than about 220°C. Such a high melting point allows for efficient application but obtains a high melting point bond that resists the effects of high temperature

20 during periods of intense insolation, particularly in semi-tropical and tropical locations. A high softening point of 150°C or more is preferred for this reason. Preferred hot melt adhesives comprise a polyamide adhesive that is manufactured typically by the reaction of a dibasic acid and a diamine compound. Such polyamides often have a melting point that ranges from about 160°C to 220°C.

25 Dibasic acids typical for manufacturing such polyamide adhesives include dimeracid (dimerized fatty acids), dodecanedioic acid, sebacic acid, azelaic acid, adipic acid and aromatic acids such as terephthalic acid and naphthlendioic acid. These acids can be reacted with amines such as ethylenediamine, hexamethylenediamine, diethylenetriamine, triethylenetetramine, dipiperidylpropane,

30 polyoxypropylenediamine and other amino acids and lactam such as caprolactam, 11-aminoundecanoic acid, dodecalactam and others. The resulting adhesives are characterized by a sharp melting point, excellent adhesion to composite substrates,

excellent color with low odor, good moisture vapor barrier properties, good chemical and oil resistance and strong structural bonding. The polyamide material can be combined with additives such as tackifying resins, plasticizers and others including rosin tackifiers, dimerized rosin tackifiers, rosin ester tackifiers, rosin phenolic
5 tackifiers, ketone resins, modified phenolic resins, malaic resin tackifiers, and plasticizers including para-toluenesulfonamide, n-ethylparatoluenesulfonamide, n-cyclohexylparatoluenesulfonamide, triphenylphosphate, tributylphosphate, phthalate esters, castor oil and other known materials. Use of these additives also tends to enhance the visco-elastic rheological behavior of the adhesive.

10 Two or more part reactive or self-curing hot melt adhesives can also be used in the invention. Such adhesives are typically derived from two or more parts. Each part is melted and then combined in an applicator or glue gun that combines the hot melt streams at an appropriate volume ratio and applies the mixed homogeneous adhesive to the appropriate location in the joint area. The materials are formulated
15 such that the melting points will be sufficiently high to provide good green strength within the joint upon cooling. Green strength is bond strength that occurs after the material is cool but before final crosslinking or curing reactions are complete. Green strength is an important adhesive characteristic for facilitating a rapid assembly method. With the preferred adhesive choices, such as Bostic's 4240 adhesive, and
20 using the methods of the present invention, it is possible to achieve up to 80% green strength. Preferred hot melt adhesives in this area include epoxy and polyurethane adhesive materials. Epoxy adhesives typically operate by reacting an oxirane or epoxy group in an epoxy part with a compound having an active hydrogen compound typically an amine mercaptan carboxylic acid or hydroxyl or other similar
25 compound having a reactive or active hydrogen moiety. Typical epoxy resins include bis-phenol A epoxy resins, epoxy novolak resins, high performance epoxy resins based on largely aromatic materials, flexible chain - long chain aliphatic epoxy resins, typically ether or ester based groups, and others well known in the art. Typical curing agents for crosslinking with the epoxy or oxirane groups include
30 mercapto compounds or polysulfides, amines, aliphatic amines, cycloaliphatic amines, aromatic amines, polyamides, dicyandiamide and others. Often, epoxy adhesives contain catalysts, diluents, fillers, elastomeric modifiers, and other

materials. Further, polyurethane (isocyanate compound based) curable adhesives can also be used in the invention. The polyurethane adhesives are typically based on toluene diisocyanate (TDI), diphenylmethane-4,4'-diisocyanate (MDI), polymethylenepolyphenylisocyanate (PAPI) and triphenylmethanetriisocyanate (Desmodur R) materials. Such reactive isocyanate compounds often are reacted with various polyester and polyether based glycols which react and crosslink to form a hard reliable joint. Polyurethane adhesives can be effective because the use of higher functionality polyurethanes can cause extensive crosslinking and high strength bonding. Further, polyurethanes can form good high green strength bonds when appropriately formulated. Polyurethane adhesives can also be formulated with a variety of ingredients including polymeric materials to provide increased green strength, tackifiers and plasticizers as described above to improve the initial bond strength and flexibility of the adhesive material. Further, the adhesive can be combined with fillers and other materials for viscosity adjustment and stability.

Both epoxy and polyurethane adhesives have to be used carefully. The adhesives should be mixed and applied virtually instantaneously to avoid problems caused by the adhesive crosslinking and bonding within the application equipment. The viscosity of the hot melt thermoplastic or hot melt epoxy or polyurethane curable adhesives should remain between 700 and 30,000 cP, preferably between 7500 and 2000 cP at the application temperature. Preferred application temperatures typically range from about 120°C to 220°C using preferred application equipment.

The modulus and elongation characteristics of the cured adhesive in the bond becomes important to obtain rigidity in the resulting assembly. The bond is typically tested in two modes. In a tensile mode where the joint is pulled apart by suspending the joint and applying a measured force to separate the joint at the joint line. Secondly, a cleavage type test can be applied to estimate the strength of the adhesive as the force is applied to the structure in a torsional mode around the adhesive joint. Both these properties are important for maintaining an adequate structural joint. The behavior of the joint under tensile stresses in an operating temperature range is important for maintenance of integrity and shape of the sash at relatively low temperature (below 40°C) and at relatively high temperature greater than about 80°C to model common temperatures resulting from high insolation rates.

The bond should be able to maintain the sustained load at high temperature of greater than 15 pounds in a tensile mode and to survive at temperatures cycled between -30°C and 82°C. Tensile strength of 500 psi is adequate for some structural applications. Tensile strength of 1000 psi over a long product life is more desirable in a joint assembly for structural applications in construction. Tensile strengths of 1500 psi and 2000 psi are still more preferable. These joint strengths can be achieved in an adhesively bonded joint structure with the preferred adhesive according to the present invention. Accelerated testing procedures can be used for predicting the long-term performance and structural integrity of a joint assembly. Examples of preferred adhesives for use in the structures of the invention include 3M's curable isocyanate adhesive TE030 and Bostic's thermoplastic copolyamide 4240 adhesive.

Experimental Results for Flow in a Flat Channel

Experiments were conducted to test the adhesion of PVC material to a wood and polymer composite material (Fibrex TM material). Adhesive was injected into a flat channel in a PVC block topped by a board made of the composite material and then the strength of the adhesive bond was tested at several data points along the length of the channel.

Fig. 12 shows a top view of a PVC board 1200 with a flat channel 1210 used in the experiments. The channel depth was 0.06" deep, channel width (cw) was 1" and channel length (cl) was 12". A flat composite board was placed on top of the PVC channel, and clamped securely in place. Fig. 13 shows a cross sectional view of the experimental set up, with the composite board 1300 clamped into place on top of the channel 1210 in the PVC block 1200.

At the end of the channel, a port was formed to allow the injection of adhesive into the channel. The composite board 1300 and the PVC block 1200 were clamped along the length of the channel, so that adhesive would not leak from the sides of the channel 1210.

The adhesive injector used with the experiments was a Proflex injector modified to have a 1/3 HP 170 RPM motor and a timer. Adhesive was injected into

the flat channel cavity at varying flowrates. After the adhesive had cooled, the bonded structure was cut into one inch strips. A pull test was conducted on each strip of composite material bonded to the PVC block using an Instron Corporation Series IX Automated Materials Testing System equipped with a 5 kiloNewton load
5 cell. The test strips were securely clamped into the Instron device. The pull test measured the extensional force required to pull the composite board off of the PVC block.

Fig. 14 shows the adhesion strengths in psi as determined by a pull text at several data points along the length of the channel. Shear strength was plotted
10 against distance in the cavity for four different flow rates: 28 g/s, 20 g/s, 14 g/s and 8 g/s. At 28 g/s, the pull test conducted at the first four data points at less than 5 inches down the cavity resulted in failure of the composite board before the adhesive bond failed. Even at distances in the cavity of greater than five inches, the adhesive strength for 28 g/s was significantly improved compared to a flow rate of 20 g/s or
15 slower. The adhesive strength improved at all cavity distances as the flow rate increased.

The various embodiments described above are provided by way of illustration only and should not be construed to limit the invention. Those skilled in the art will readily recognize various modifications and changes that may be made to
20 the present invention without strictly following the exemplary embodiments and applications illustrated and described herein and without departing from the true scope of the present invention that is set forth in the following claims.

What is claimed is:

1. A method for forming an internally bonded adhesive joint, the steps comprising:
 - (a) inserting a first portion of an insert into a hollow region of a first lineal member and inserting a second portion of an insert into a hollow region of a second lineal member to form an unbonded joint assembly, the insert comprising at least one adhesive flow channel, the unbonded joint assembly including an injection port, wherein an adhesive receiving volume is defined by at least the interior walls of the first and second lineal members and the flow channel; and
 - (b) injecting liquid adhesive through said injection port into said adhesive receiving volume, wherein said adhesive injecting step occurs at a flow rate of at least 15 grams per second.
2. The method of claim 1 wherein the adhesive has an exit temperature of at least 200°C during injection.
3. The method of claim 1, wherein the flow channel is adjacent to the injection port and has a width and a depth, wherein the aspect ratio of the flow channel width to the flow channel depth is at least 16.
4. The method of claim 1, wherein the width of the flow channel is about 1 inch and the depth of the flow channel is about 0.06 inch.
5. The method of claim 1, wherein said adhesive injecting step occurs at a flow rate of at least 17 grams per second.
6. The method of claim 1, wherein said adhesive injecting step occurs at a flow rate of at least 25 grams per second.
7. The method of claim 1, wherein said adhesive injecting step occurs at a flow rate of at least 30 grams per second.

8. The method of claim 1, wherein said unbonded joint assembly and said liquid adhesive are at substantially the same temperature during bonding and said adhesive solidifies by chemically cross-linking.
9. The method of claim 1 wherein the step of injecting liquid adhesive further comprises monitoring pressure at the injection port, wherein injection is stopped when a desired pressure value is sensed.
10. The method of claim 1 wherein the step of injecting liquid adhesive further comprises timing the injection of liquid adhesive, wherein the injection is stopped when a desired time has elapsed.
11. An internally bonded adhesive joint structure comprising:
 - (a) first and second polymeric lineal members including hollow regions at least at the end portions thereof,
 - (b) an insert comprising at least one adhesive flow channel, the insertion of said insert into said hollow regions forming an unbonded joint assembly having at least one injection port; wherein an adhesive receiving cavity is defined by at least the interior walls of the first and second lineal members and the flow channel; and
 - (c) an adhesive filling the adhesive receiving cavity of the unbonded joint structure, wherein said adhesively bonded joint structure provides an overlap shear stress exceeding 500 pounds per square inch of internally bonded joint surface as measured using a Pull Test.
12. The joint structure of claim 10, wherein said adhesively bonded joint provides an overlap shear stress exceeding 1000 pounds per square inch of internally bonded joint surface as measured using a Pull Test.

13. The joint structure of claim 10, wherein said adhesively bonded joint provides an overlap shear stress exceeding 1500 pounds per square inch of internally bonded joint surface as measured using a Pull Test.

14. The joint structure of claim 10, wherein said adhesively bonded joint provides an overlap shear stress exceeding 2000 pounds per square inch of internally bonded joint surface as measured using a Pull Test.

15. The joint structure of claim 10, wherein said adhesively bonded joint provides an overlap shear stress exceeding 2500 pounds per square inch of internally bonded joint surface as measured using a Pull Test.

16. The joint structure of claim 10, wherein said adhesive is a hot melt adhesive.

17. The joint structure of claim 16, wherein said hot melt adhesive further comprises polyamide.

18. The joint structure of claim 16, wherein said hot melt adhesive comprises polyethylene-co-vinyl alcohol.

19. The joint structure of claim 11, wherein said adhesive chemically cross-links upon solidification.

20. The joint structure of claim 11, wherein said channel has an area-to-volume ratio less than 0.5 reciprocal meters.

21. The joint structure of claim 11, wherein said channel has an area-to-volume ratio less than 5 reciprocal meters.

22. The joint structure of claim 11, the insert further comprising freeze-off regions adjacent the flow channel, the freeze-off regions having an area to volume ratio greater than 2.5 reciprocal meters.

23. The joint structure of claim 11, the insert further comprising freeze-off regions adjacent the flow channel, the freeze-off regions having an area to volume ratio greater than 5.0 reciprocal meters.

24. An internally bonded adhesive joint structure comprising:

- (a) a plurality of polymeric lineal members including hollow regions at least at the end portions thereof and at least one internal wall;
- (b) an insert comprising at least one adhesive flow channel and a pan, the insertion of the insert into the hollow regions forming an unbonded joint assembly having at least one injection port, the unbonded joint assembly defining an adhesive receiving volume at least the flow channel and pan defining an adhesive receiving volume, and wherein the insert further comprises a plurality of separate pieces; and
- (c) an adhesive filling the adhesive receiving volume of the unbonded joint structure.

25. An apparatus for forming an internally bonded joint structure comprising:

- (a) a clamping device for holding an unbonded joint assembly, where the unbonded joint assembly comprises first and second lineal members, an insert received within hollow end portions of the first and second lineal members, and an injection port, wherein surfaces of the insert and internal surfaces of the lineal members define an adhesive receiving volume;
- (b) a device for pressurizing a solidifiable adhesive in the liquid state;
- (c) an adhesive injector for injecting adhesive through the injection port; and
- (d) a pressure sensor for detecting the adhesive pressure at the injection port during injection.

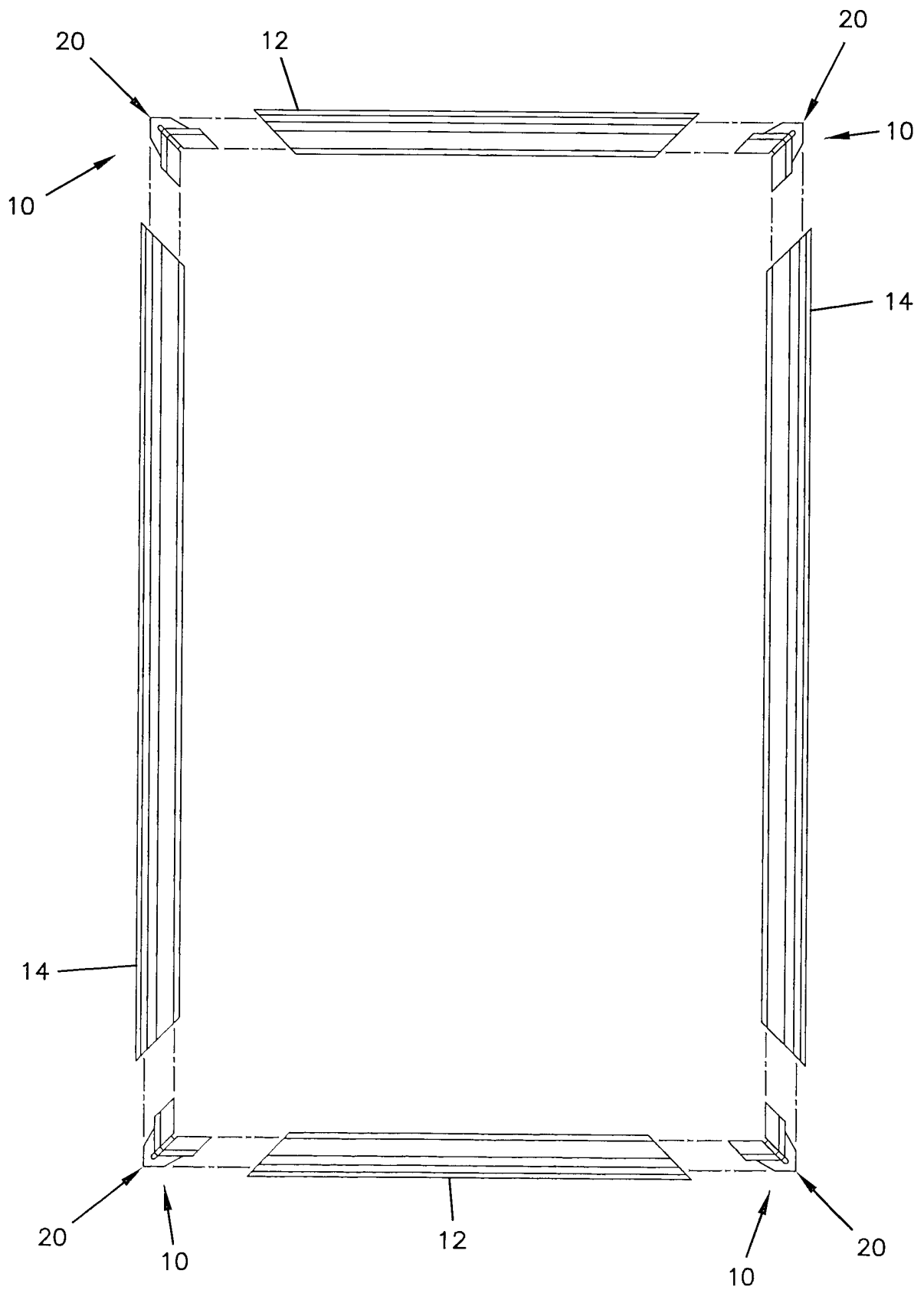
26. The apparatus of claim 25, further comprising means for melting hot melt adhesive.

27. The apparatus of claim 25, further comprising means for positioning the first and second lineal members and insert.

28. The apparatus of claim 27, further comprising means for sequencing the positioning of the first and second lineal members and insert.

29. The apparatus of claim 27, further comprising means for sequencing the clamping of said positioned lineal members and insert.

FIG. 1



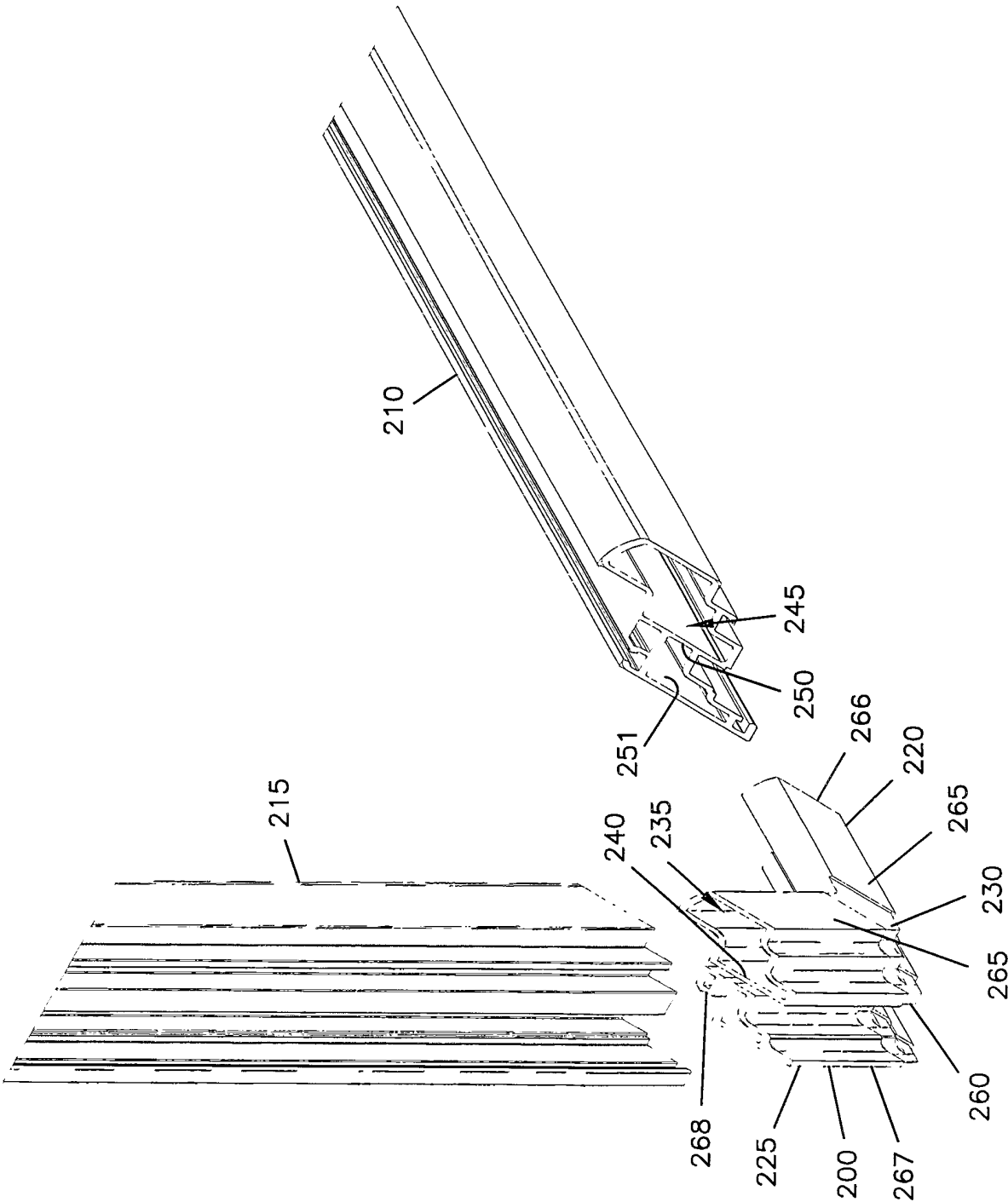
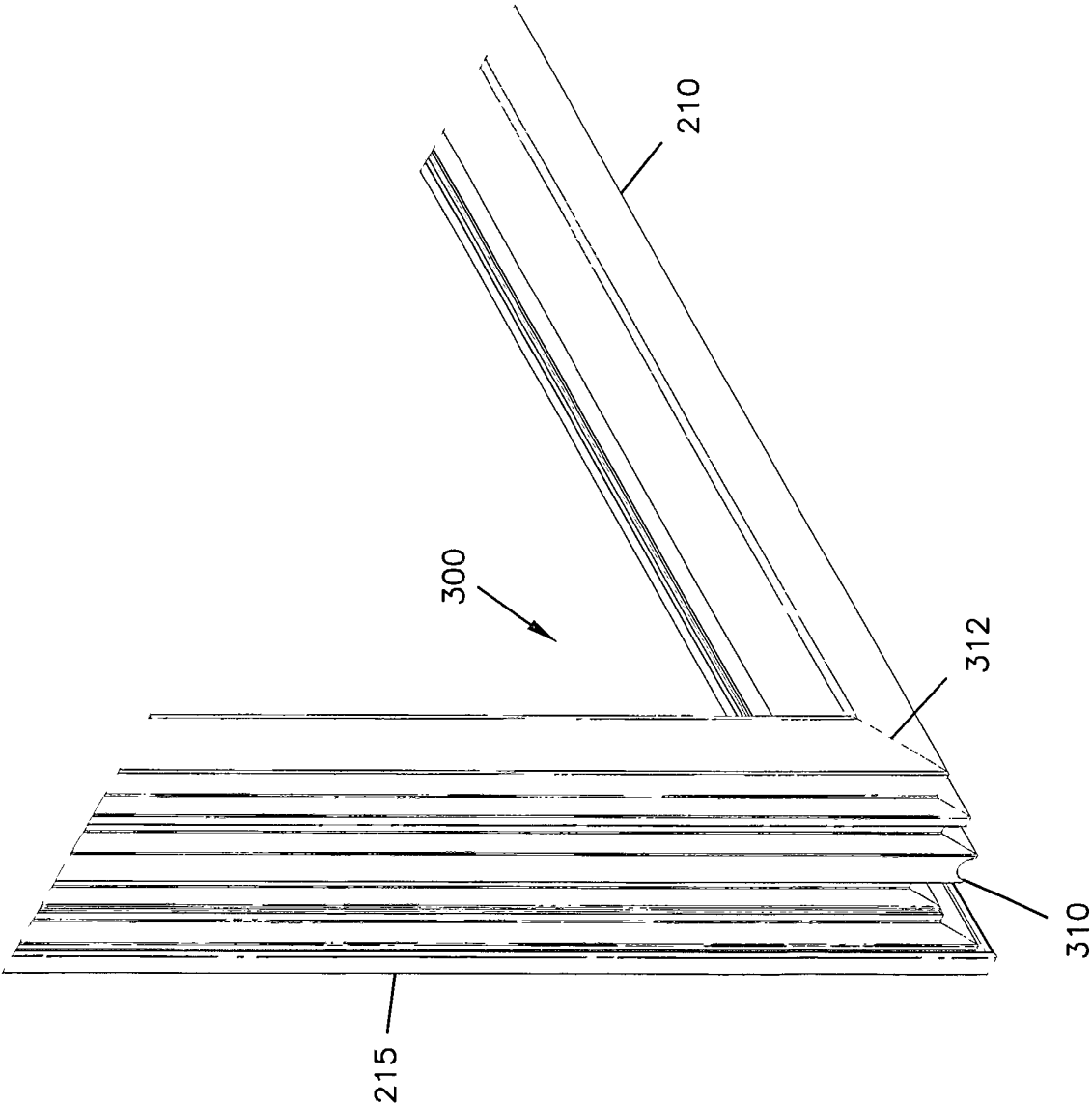


FIG. 2

FIG. 3



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FIG. 4

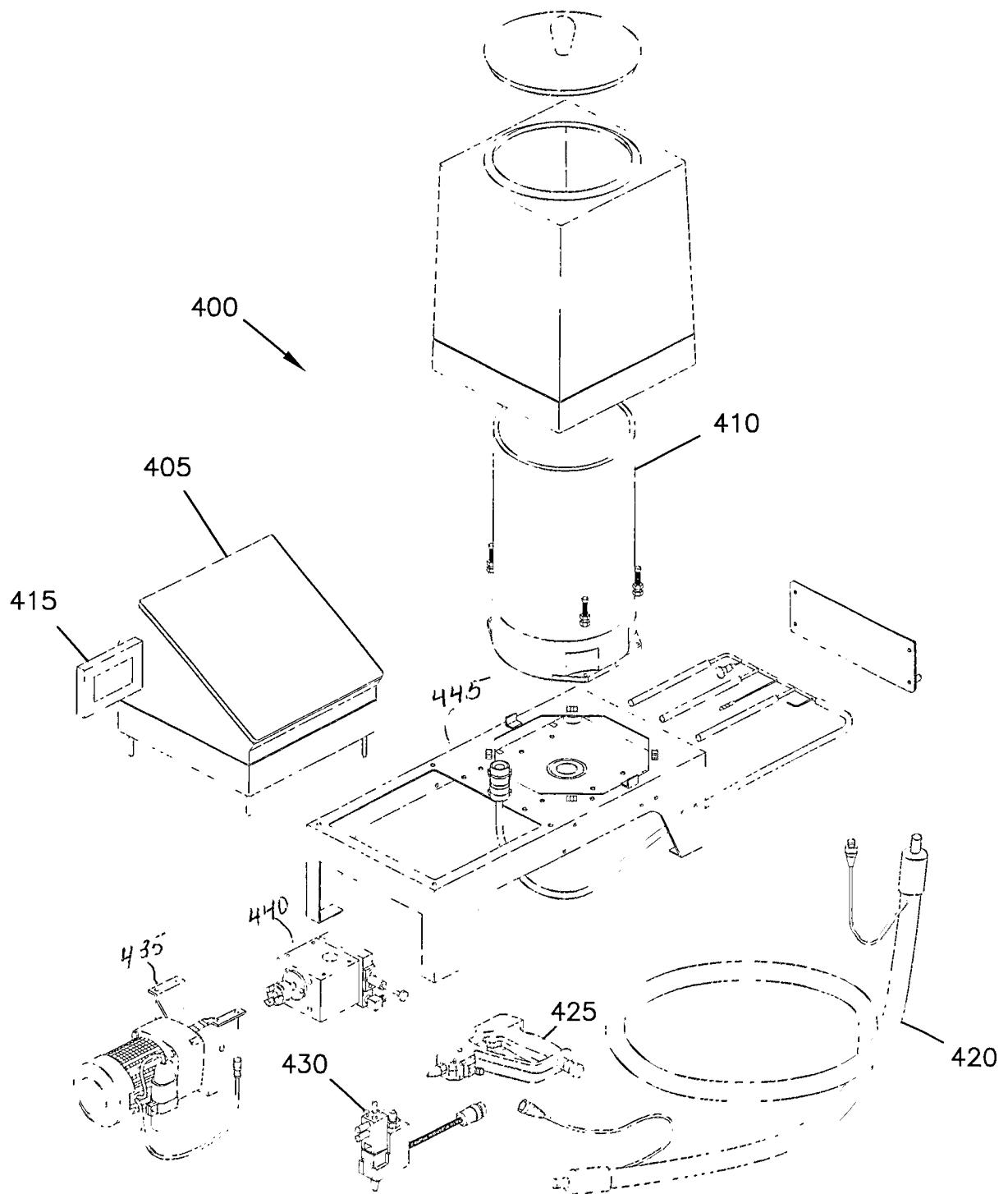
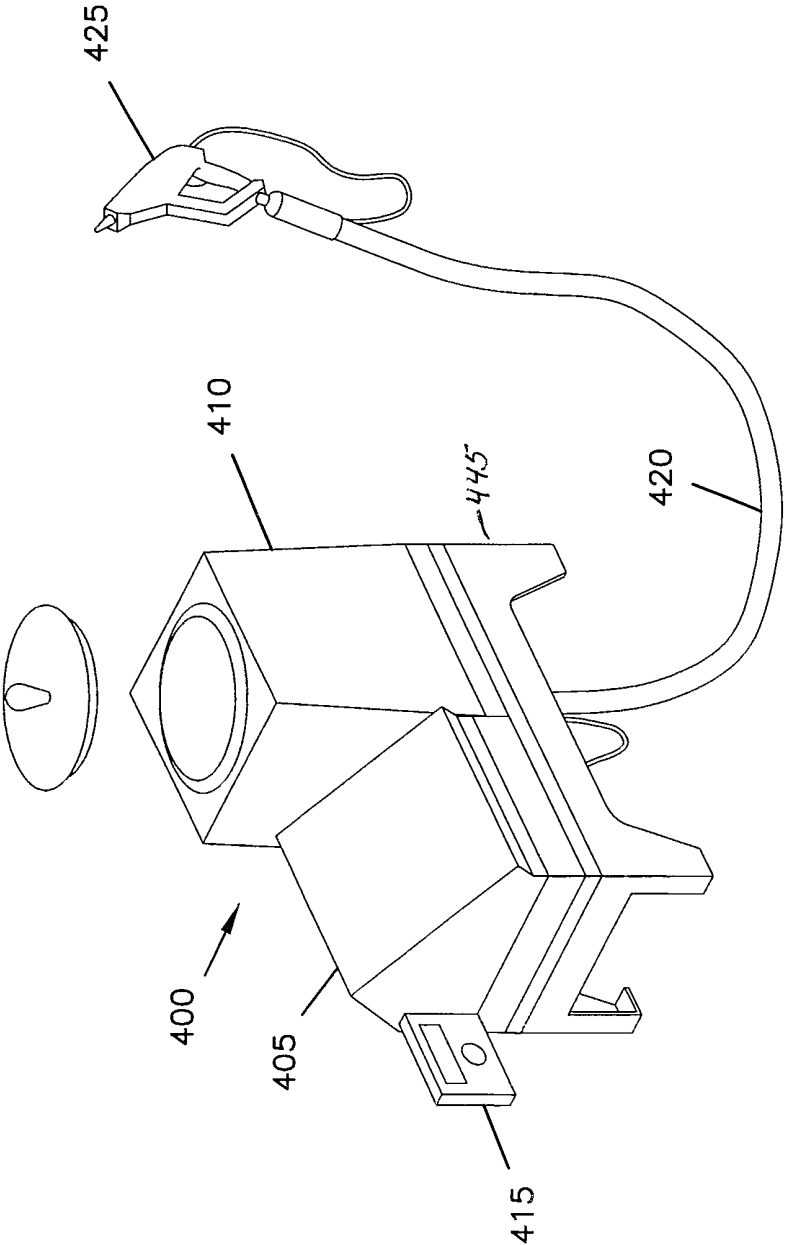


FIG. 4A



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FIG. 5A

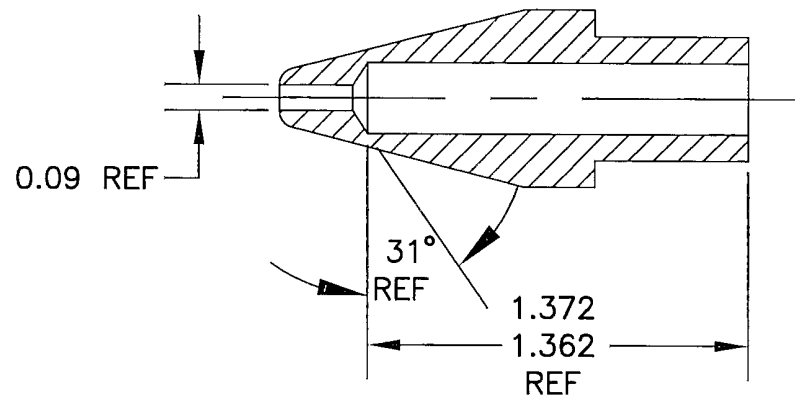


FIG. 5B

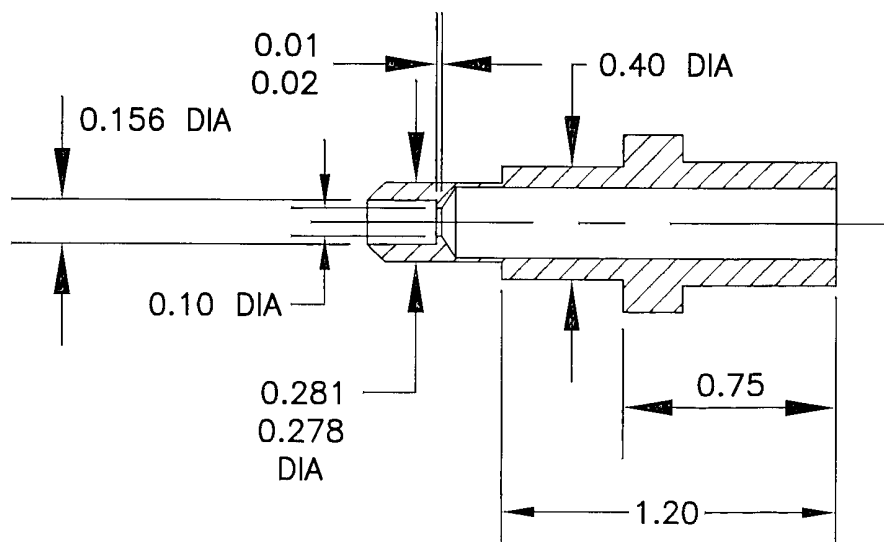


FIG. 6A

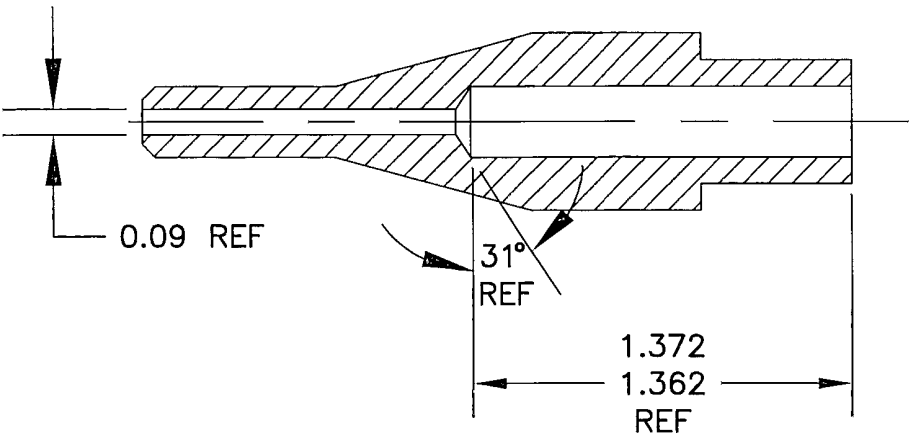
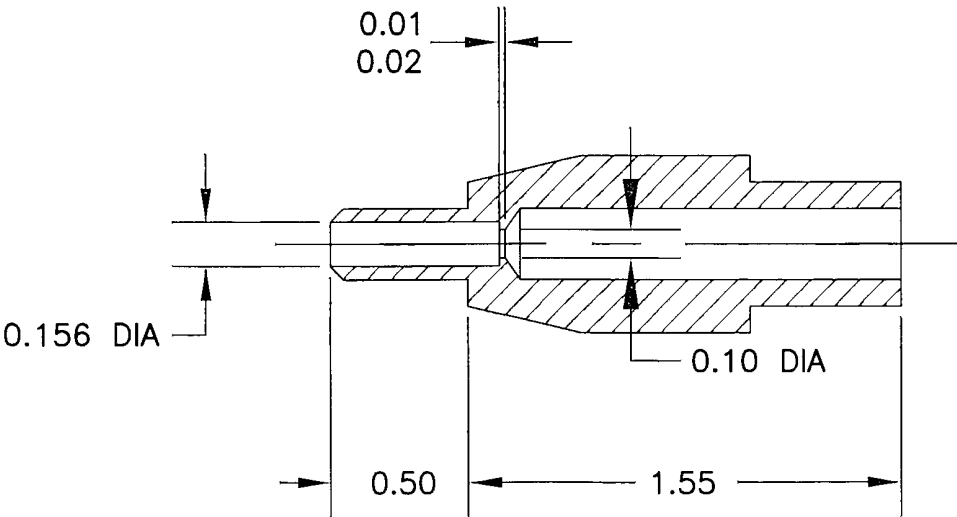


FIG. 6B



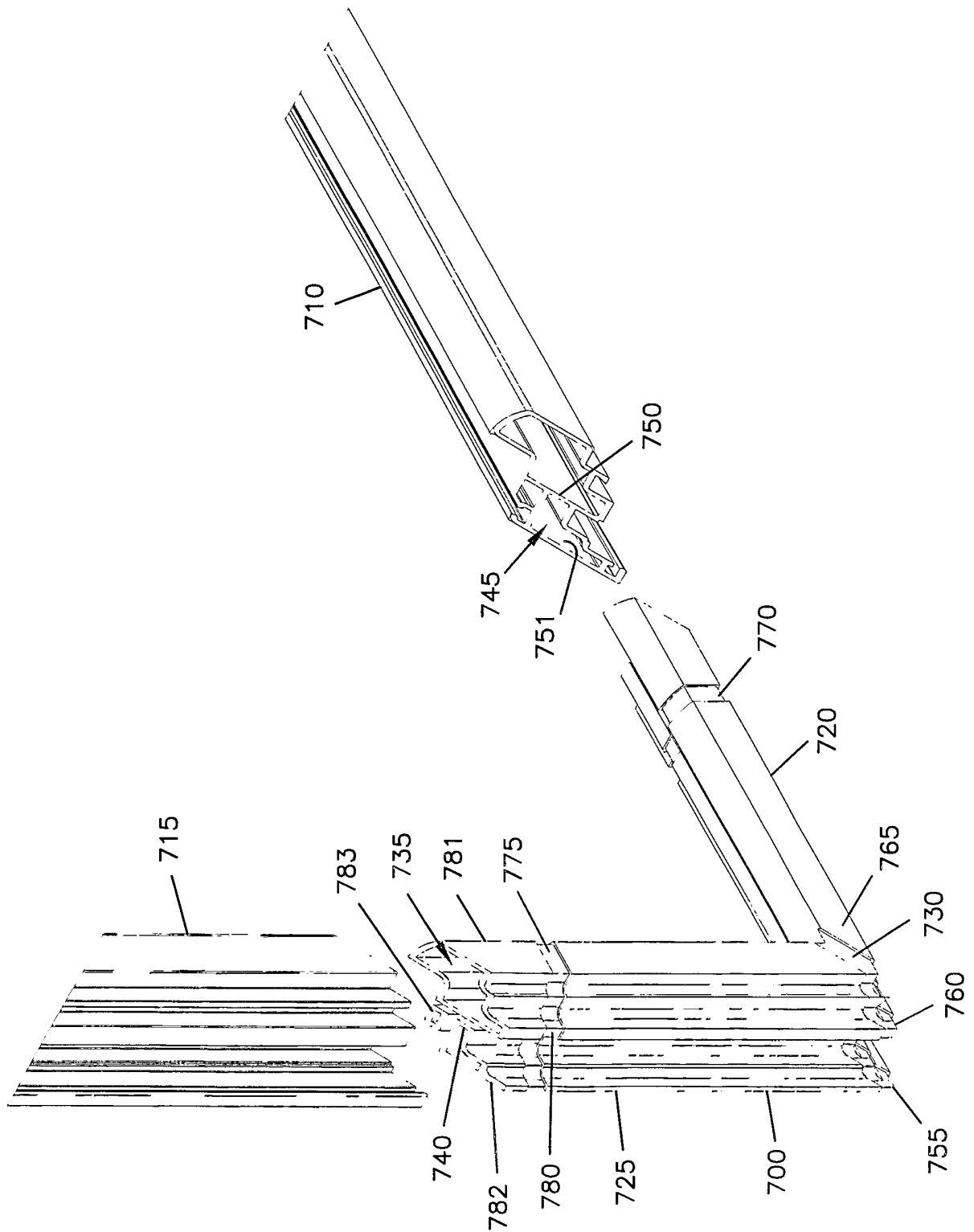
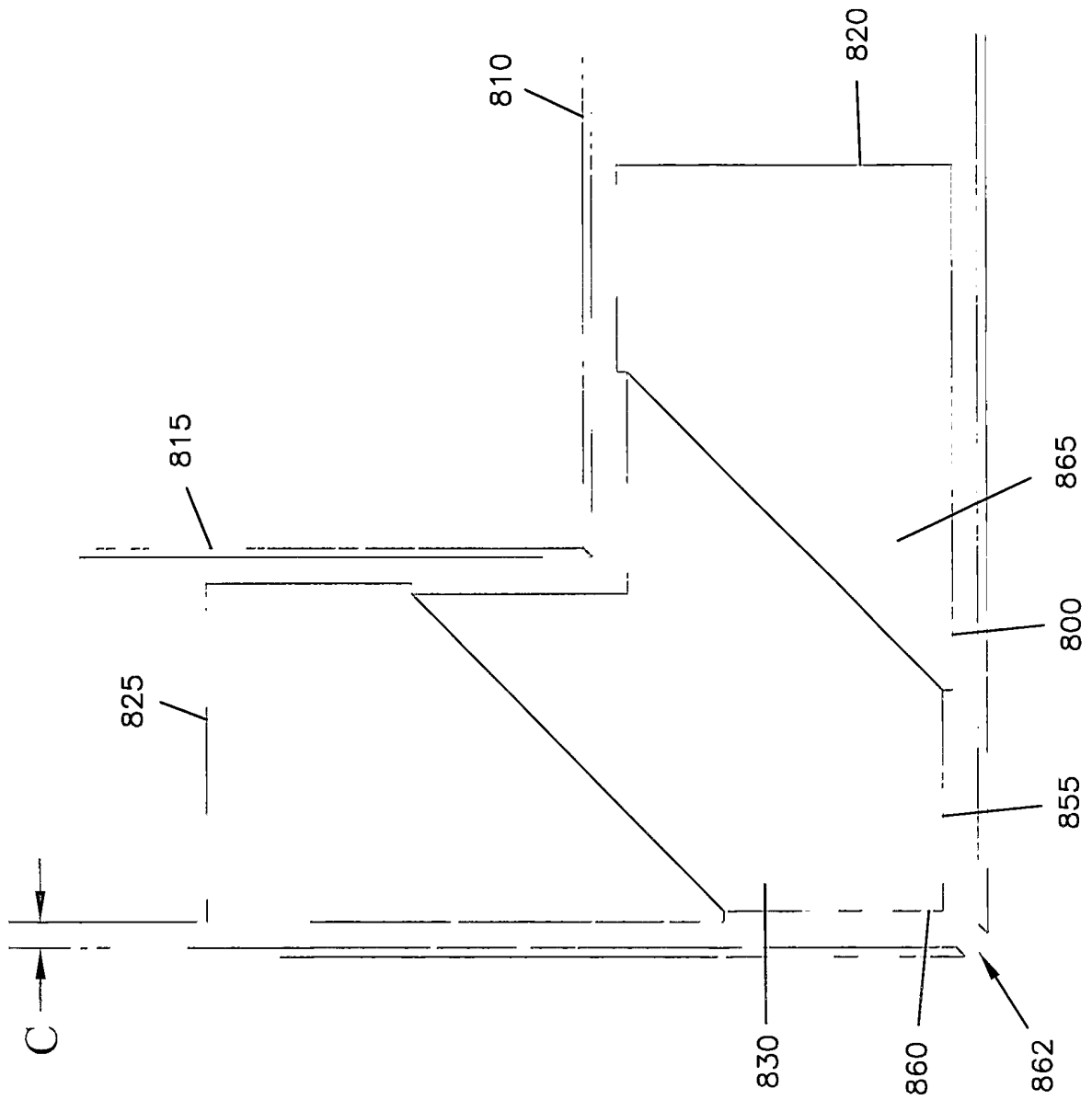


FIG. 7



8 F/G.

FIG. 9

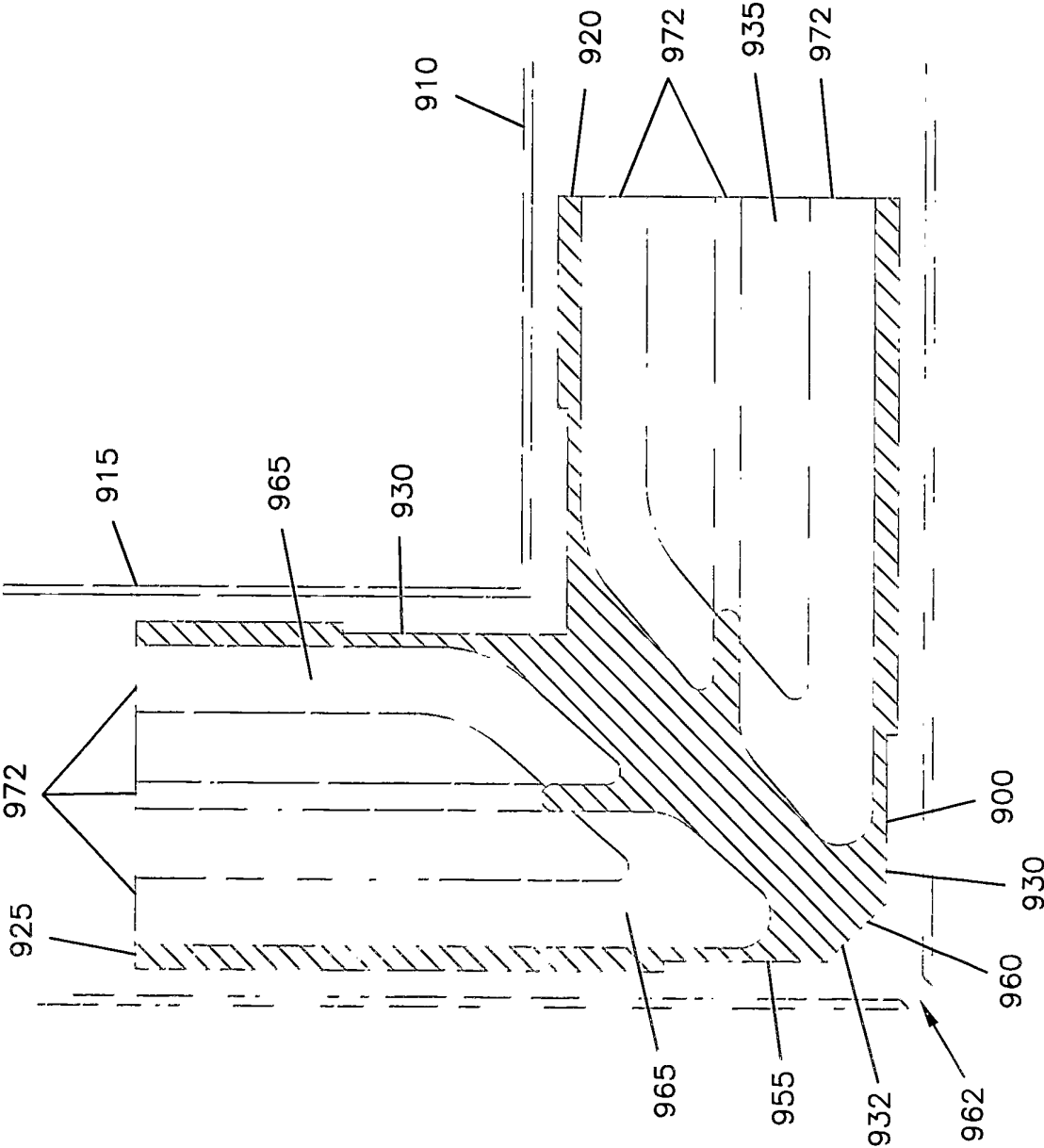
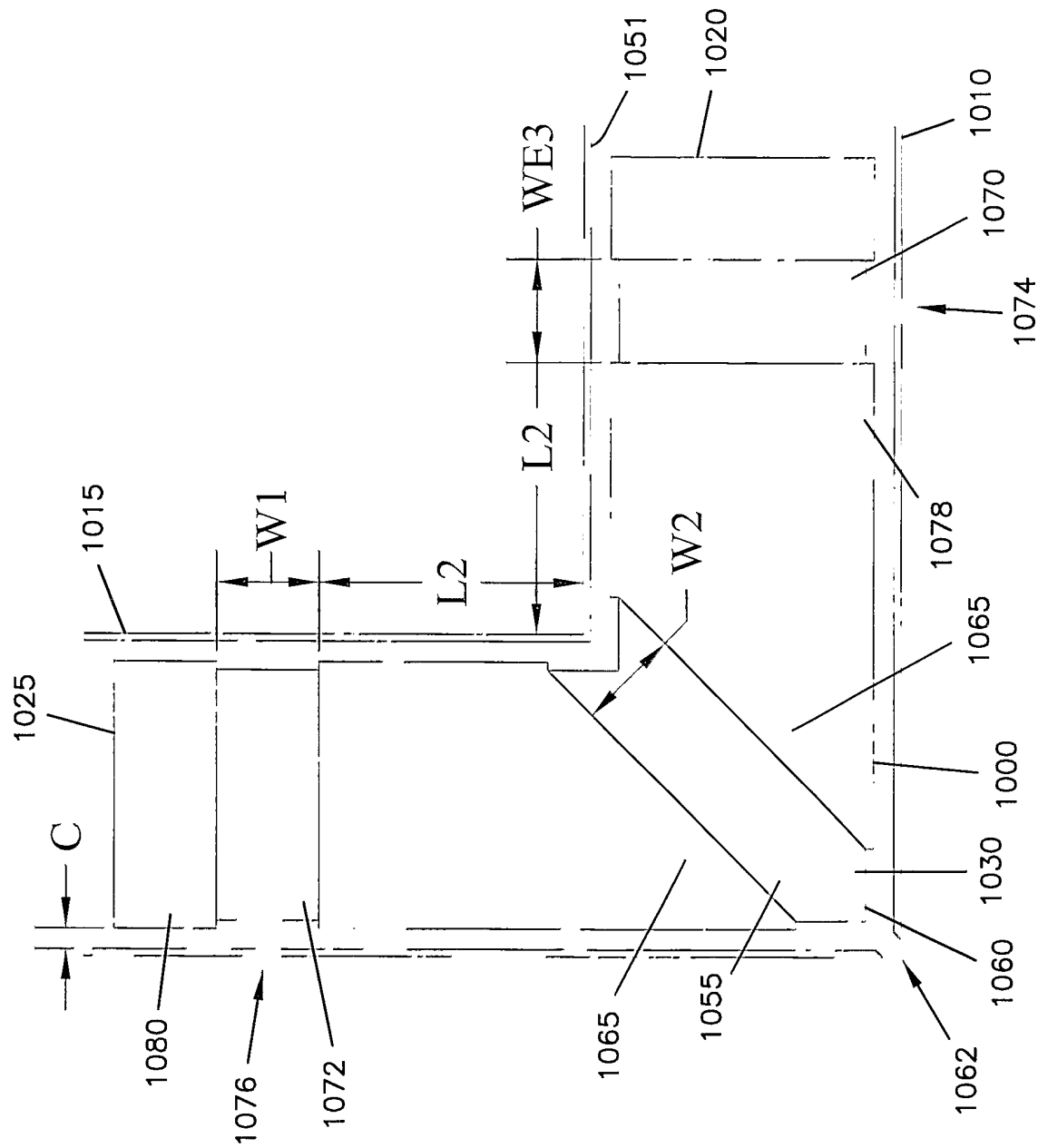


FIG. 10



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FIG. 11

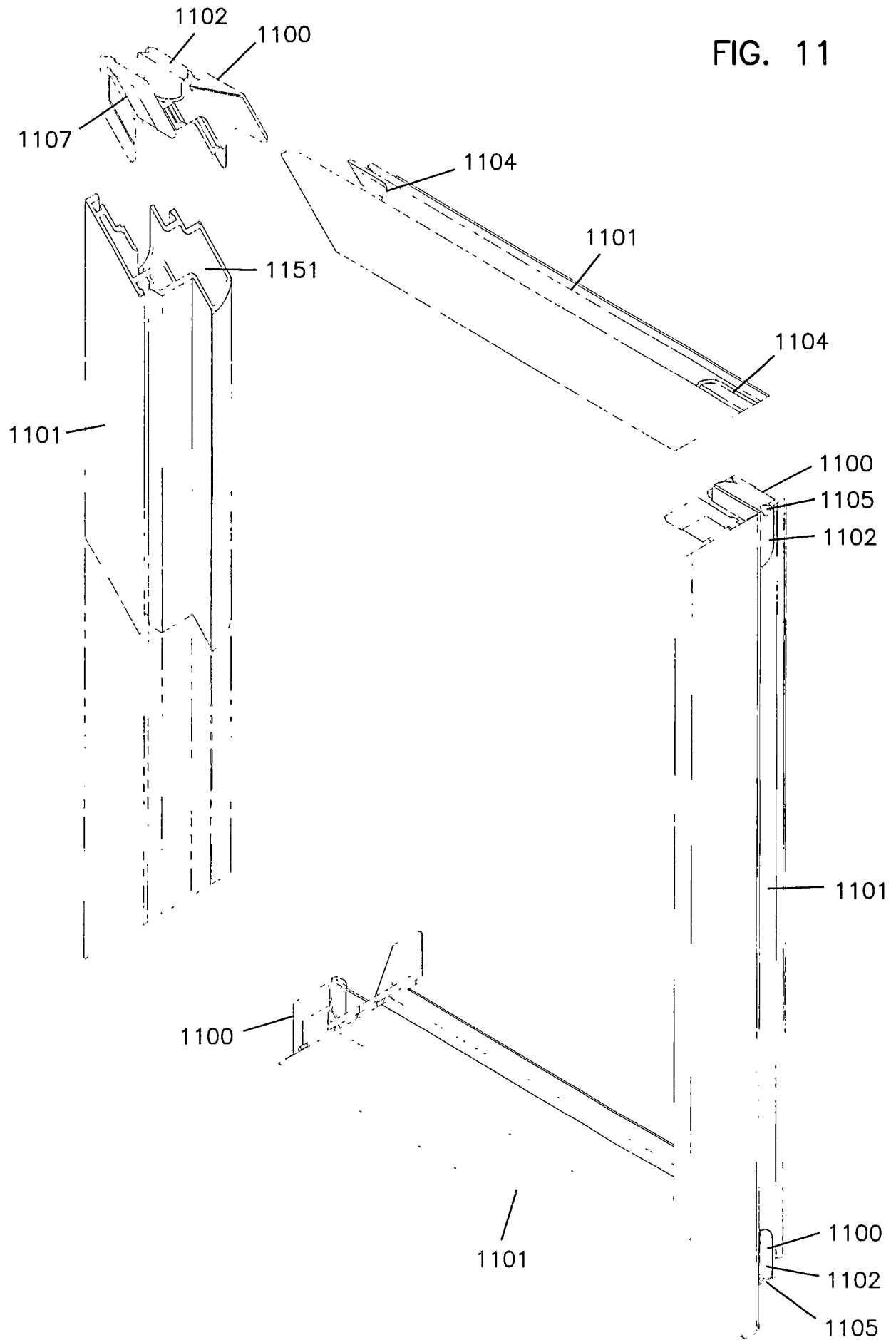


FIG. 12

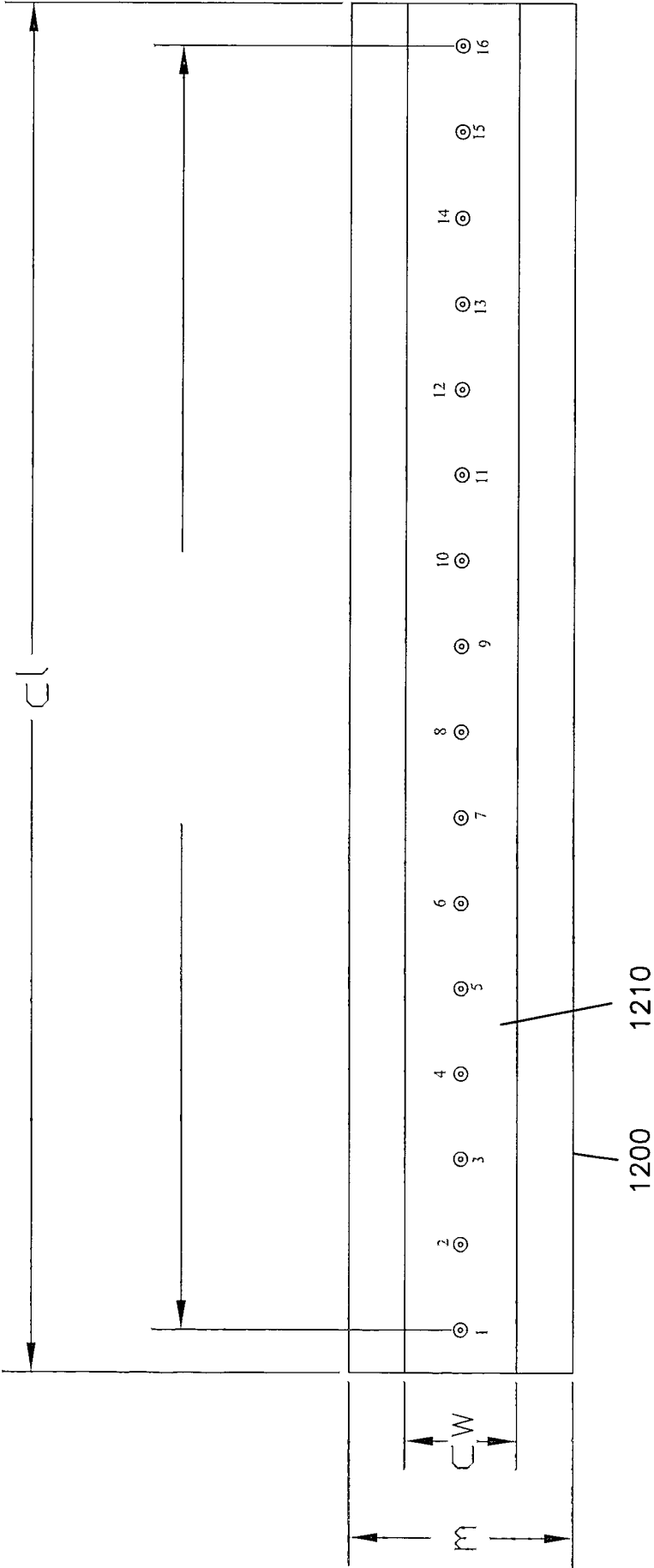


FIG. 13

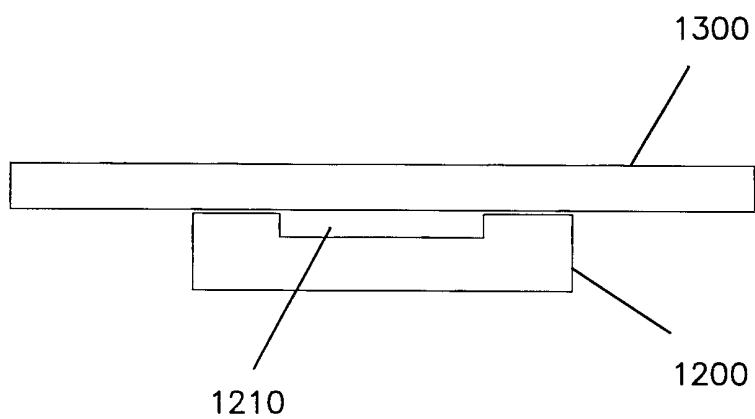


FIG. 14

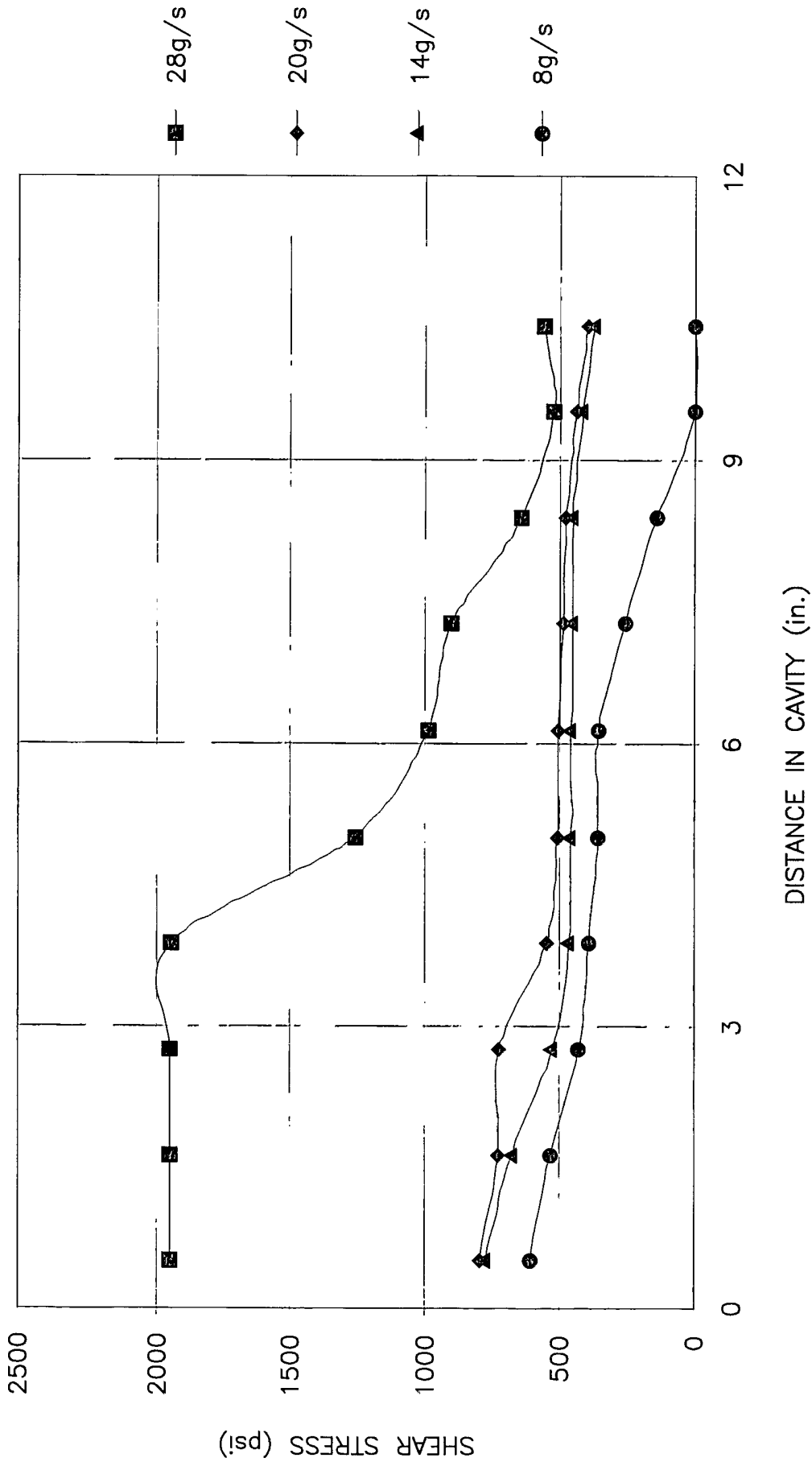


FIG. 15

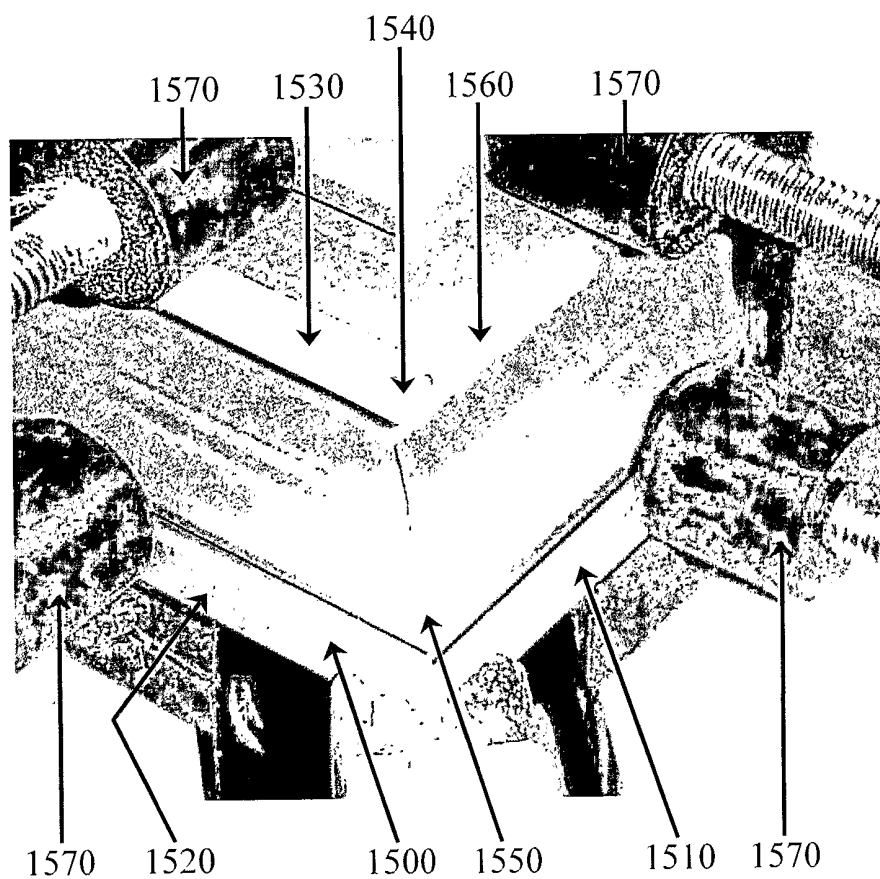


FIG. 16

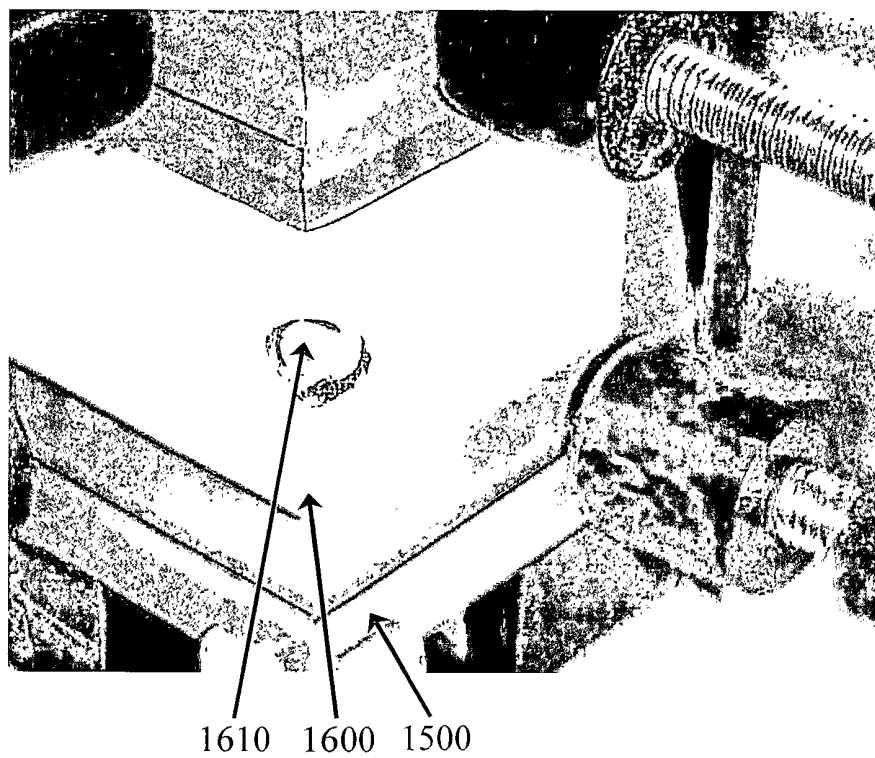
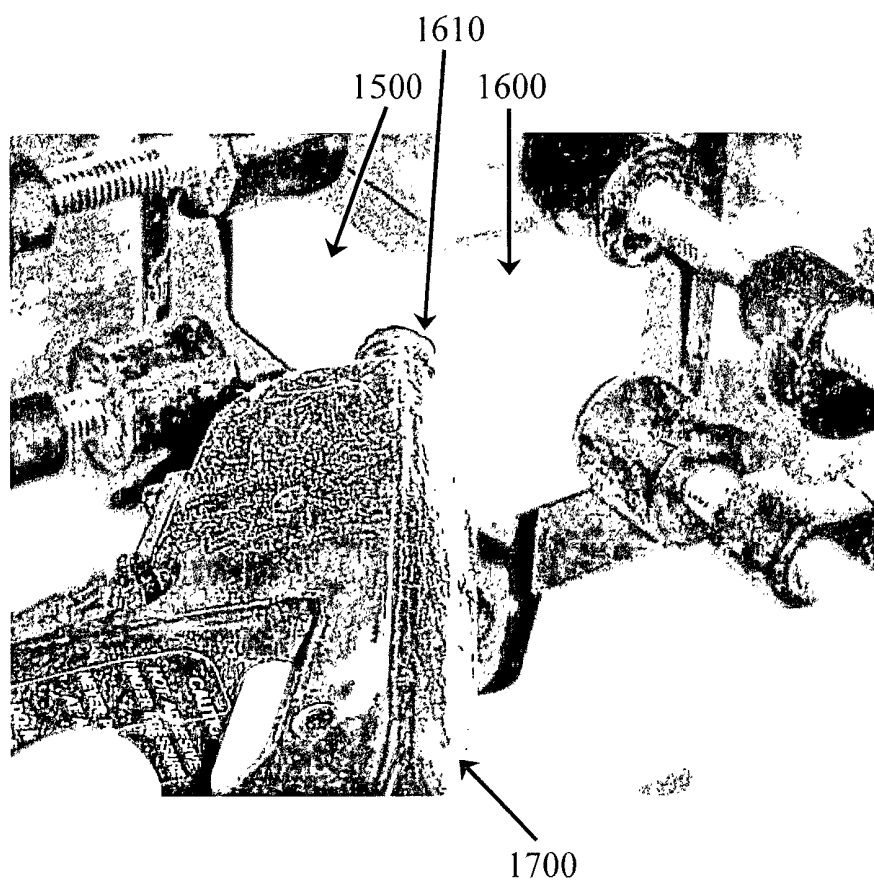


FIG. 17



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FIG. 18

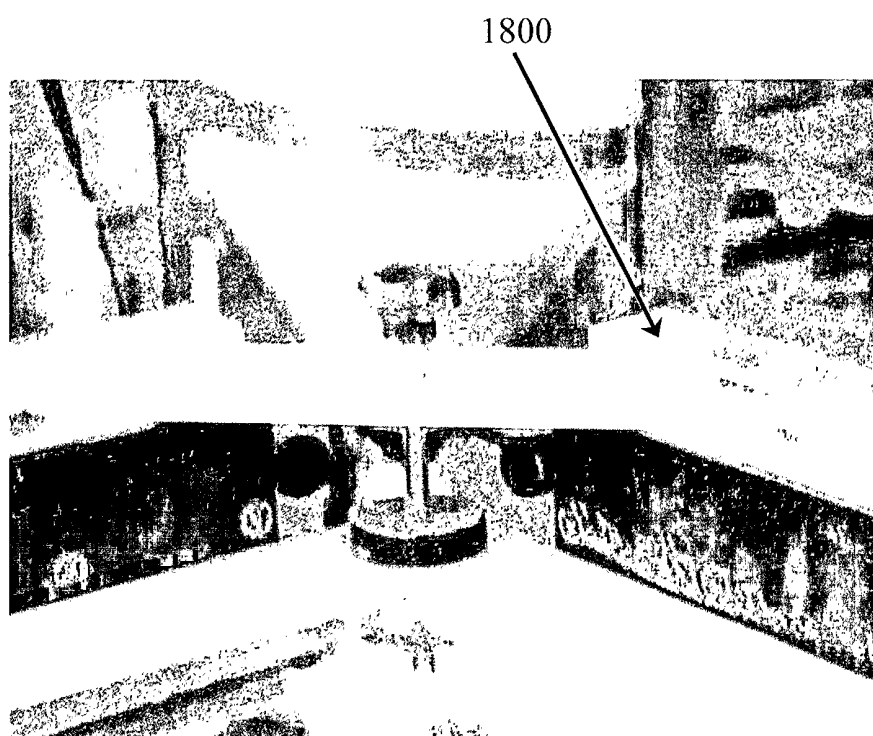
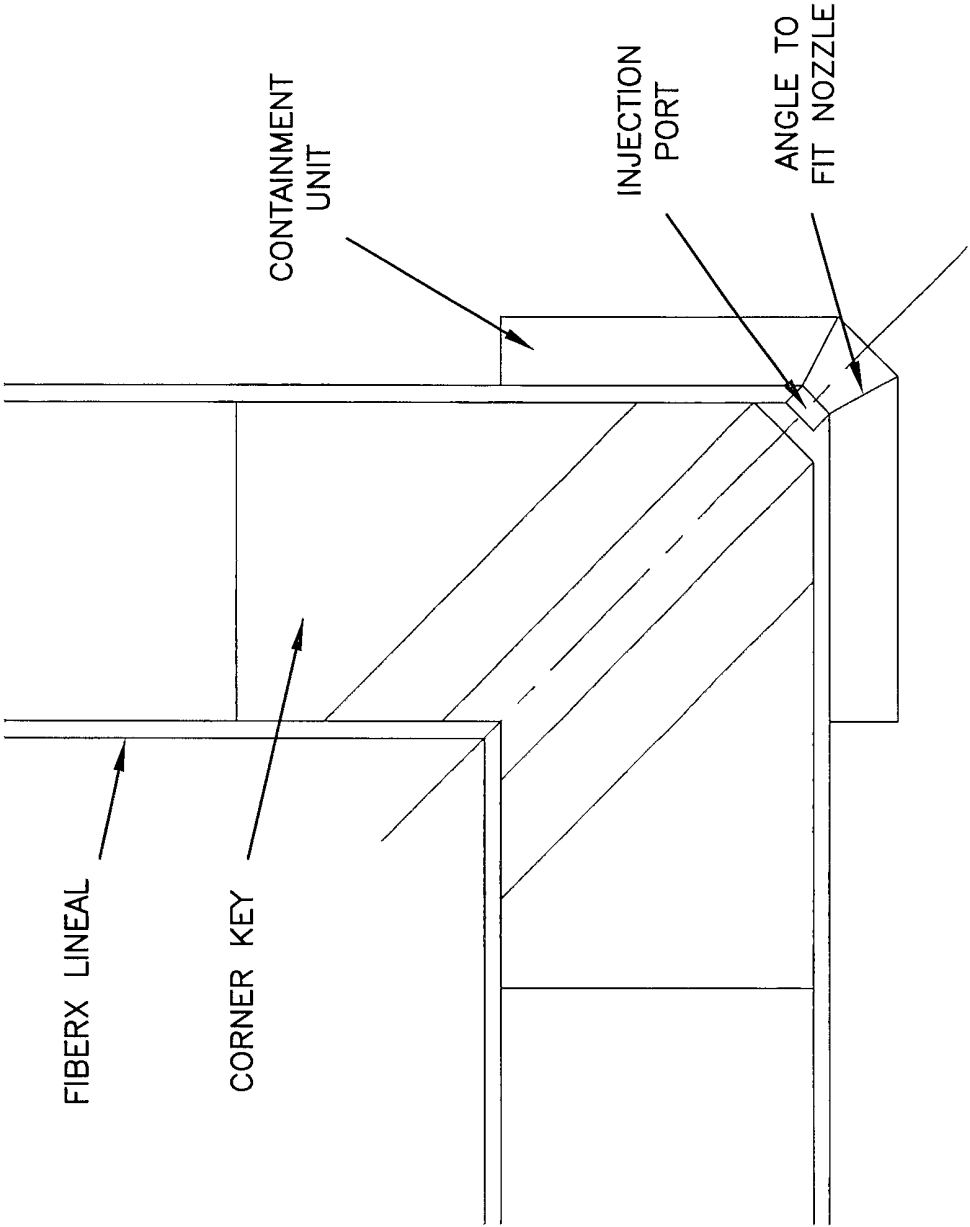


FIG. 19



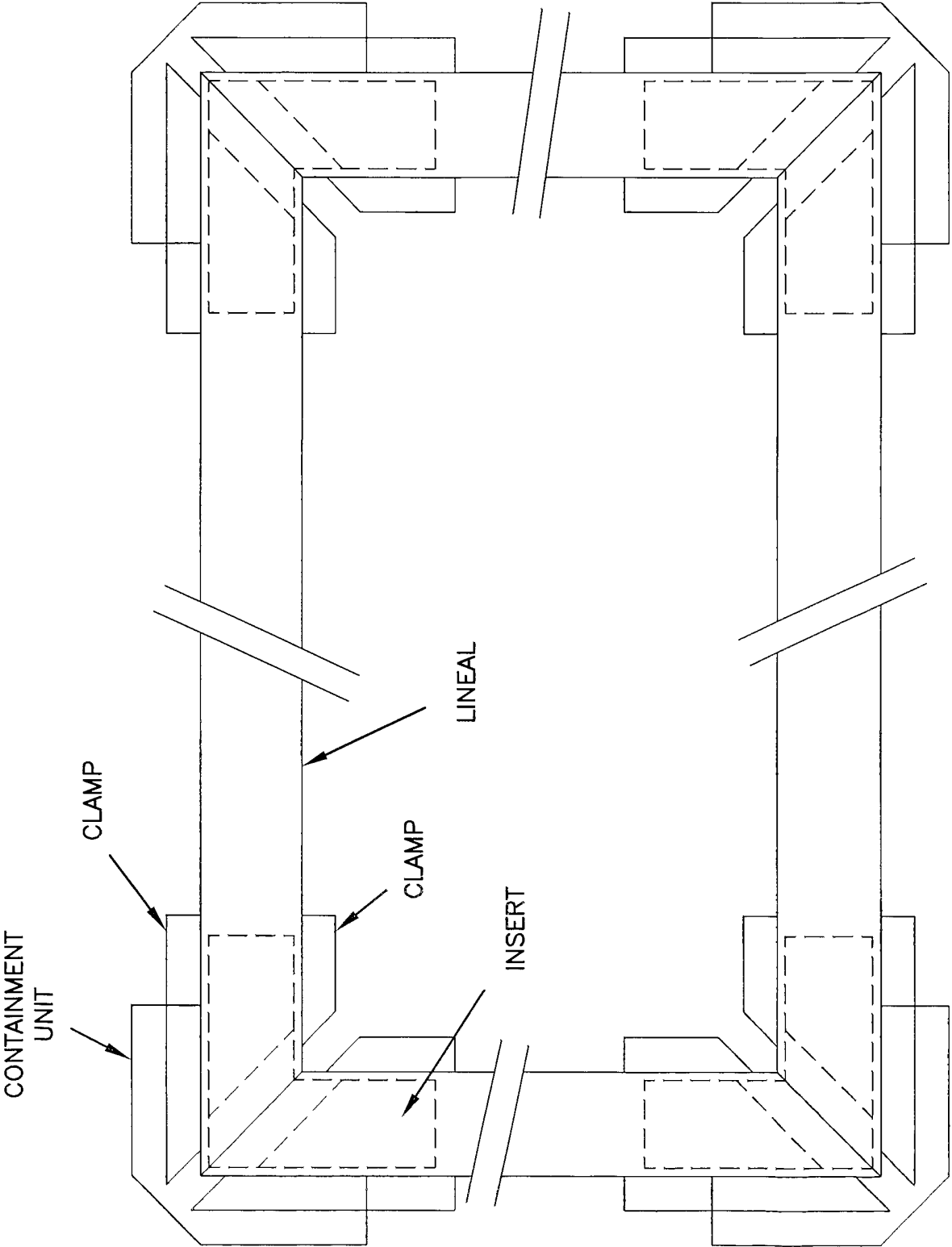


FIG. 20