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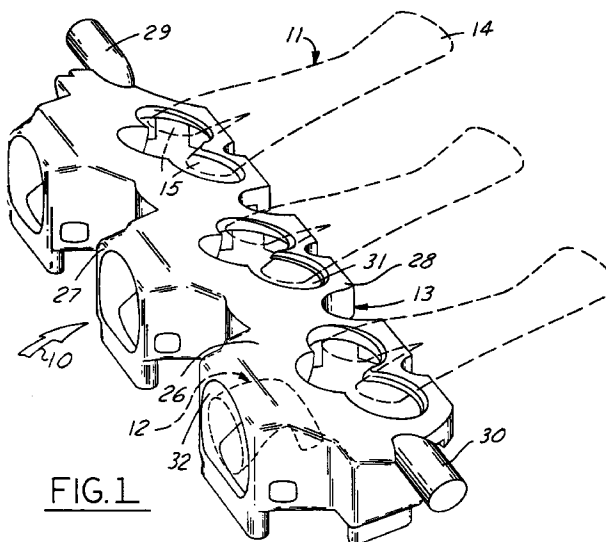
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(54) Rapidly forming complex hollow shapes using lost wax investment casting

(57) A method of repetitively forming rapid prototype metal castings that are fully durable and functional metal parts of a complex shape, comprising the steps of: (a) making an assembly (10) of resin-bonded particulate cores (11,12,13) spaced from each other, one core arcuately encompassing at least one end of another core to define at least one hidden space (31,32) therebetween; (b) making an easily machined die set (18) to receive and support said assembly (10) of cores in spaced relation for defining a casting cavity (34) around and between said cores, including said at least one hidden space (31,32); (c) injecting fluidised wax into said cavity (34) under a controlled sustained pressure to fill said cavity without entrapping gases and to form a wax pattern (37) for the casting; (d) using said wax pattern (37) with said assembly (10) of cores therein to form a shell mould (40) thereabout and thence draining the wax from the mould to permit a metal casting (43) to be formed in place of the wax pattern (37) with the assembly (10) of cores still in place, and (e) removing from the casting all of the particulate cores (11,12,13) in said casting by reversing the bond between said core particles to form a collection of particles that is freely flowable under gravity.



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Description

[0001] This invention relates to rapidly fabricating a run of functional durable parts having hollow complex interiors, and more particularly to making such parts using easily formed and easily removable resin bonded sand or salt cores.

[0002] Non-durable plastic prototypes of complex parts have become commonplace; techniques such as stereolithography or cubital prototyping have been used where a non-functional plastic part is fashioned but limited in what can be done with such plastic part. Such plastic parts can be used to evaluate aesthetic aspects or fit and assembly of the design, but cannot be subjected to evaluation tests that require harsh operating conditions or high temperatures such as that needed to evaluate an internal combustion engine head or block.

[0003] Attempts have been made to rapidly make fully functional durable cast parts of complex interior shape by forming the pattern in sections. An example is stratiform or laminated machining of sectioned wax or foam slabs to produce a fugitive pattern when the slabs are assembled together. Although this approach is highly advantageous for making a limited number of castings, it lacks the speed and integrity of a unitary pattern and becomes economically disadvantageous when more than about four castings of the same design must be made.

[0004] The ancient and well known lost wax investment method avoids sectioning by deploying a unitary wax pattern about which a layered shell mould is formed. Wax is drained from the completed mould and the mould then used to form a metal casting. It is difficult to accommodate the lost wax investment method to the making of complex hollow castings having hidden thin walls, and as a result, is limited to the making of hollow articles of relatively simple configuration, such as vases, air foil shapes (turbine blades), or golf club heads. For such shapes, fused ceramic cores have been found beneficial because of the need to increase core strength so as to withstand the hydrostatic pressures of the injected wax. Ceramic cores are slower to fabricate because of the need for more steps, and are also slower to remove because of the need to dissolve the core material by chemical means which usually leave some core residue, something which cannot be tolerated in engine parts.

[0005] According to the present invention, there is provided a method of repetitively forming rapid prototype metal castings that are fully durable and functional metal parts of a complex shape, comprising the steps of: (a) making an assembly of resin-bonded particulate cores spaced from each other, one core arcuately encompassing at least one end of another core to define at least one hidden space therebetween; (b) making an easily machined die set to receive and support said assembly of cores in spaced relation for defining a casting cavity around and between said cores,

including said at least one hidden space; (c) injecting fluidised wax into said cavity under a controlled sustained pressure to fill said cavity without entrapping gases and to form a wax pattern for the casting; (d) using said wax pattern with said assembly of cores therein to form a shell mould thereabout and thence draining the wax from the mould to permit a metal casting to be formed in place of the wax pattern with the assembly of cores still in place, and (e) removing from the casting all of the particulate cores in said casting by reversing the bond between said core particles to form a collection of particles that is freely flowable under gravity.

[0006] The present invention provides rapid fabrication of complex hollow metal castings, such as engine heads, blocks, manifolds and transmission cases. This invention has an advantage that it provides a method for rapidly making up to 100,000 castings of a complex hollow part using the same aluminium die sets, the produced parts being fully durable and functional parts with the method combining the rapid core making and core removal capabilities of resin bonded sand or salt cores and the rapid pattern making capabilities of the lost wax investment casting technique.

[0007] This method allows for extreme ease and economy for modifying the interior flow characteristics of an engine head without need for changing the exterior shape of such head, leading to nimble manufacturing of engine families.

[0008] The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a perspective view of an assembly of bonded particulate cores utilised in the process;

Figure 2 is a plan-like perspective view of a die set containing the core assembly of Figure 1, with some of the cores removed for better illustration and with the top part of the die removed;

Figure 3 is an exploded perspective view of the die set and core assembly of Figure 2;

Figure 4 is a sectional elevational view of the structure of Figure 2 taken substantially along line 4-4 thereof;

Figure 5 is a perspective view of the completed wax pattern of the casting resulting from injection of wax into the die set of Figure 4, the wax pattern being shown in a position for coating various layers of ceramic therearound to form an investment mould; Figure 6 is a sectional view of the wax pattern showing how the various layers of the investment shell mould are built up and how the wax is drained and replaced by molten metal;

Figure 7 is a perspective view of the metal casting after the wax pattern has been drained and replaced by metal showing how the particulate cores are removed; various openings are shown through which the particulate sand or salt cores can

flow outwardly from the casting upon receiving heat treatment that not only treats the metal of the casting but reverses the bond between the particulates of the cores;

Figure 8 is a plan view of the die set for making the wax pattern showing one exhaust core and one intake core in place; and

Figures 9-13 are sectional views taken along their respective lines shown in Figure 8.

[0009] The process of this invention does not require expensive repetitive machining of several slabs or laminations each time a single pattern is to be made, as in stratiform rapid prototyping (best suited cost-wise to making three or less prototypes) and does not require machining eight or more sets of steel dies to create moulds for each exterior or interior sand core characteristic (best suited to making hundreds of thousands of castings to justify the cost). The process herein described allows for faster and easier economic fabrication of 4-40,000 (even up to 100,000) castings by requiring machining of fewer die sets from aluminium metal or equivalent material; the die sets are limited to four: three for making non-fused resin bonded core elements, and one for making the wax pattern. This process combines the faster core making capabilities of particulate bonded cores and the repetitively faster pattern making of the lost wax investment technique.

[0010] As shown in Figure 1, an assembly or family 10 of particulate bonded cores is formed to define passages within an internal combustion engine head; the assembly here consists of three intake cores 11, three exhaust cores 12 and an annular water jacket core 13. The assembly is unique because it does not comprise fused ceramic cores normally required to withstand the hydrostatic forces of fluid wax, but rather bonded particulate salt or sand cores capable of withstanding the controlled injected wax of this invention as well as molten metal. The intake passage core 11 is shown as having an enlarged common intake end 14 and a bifurcated end 15 to define two intake ports; such core, as well as the exhaust cores, are formed by blowing particles mixed with resin binder into a two-way two-piece die set that defines the core shape. The formed cores, when cured, will have a modulus of rupture of 2500-3200 psi, a bulk density of about 1.92 g/cc, and a porosity of about 26%.

[0011] As a second step of the process, a die set 18 is made to define a pattern or casting cavity 34 around the core assembly 10 (see Figures 2-4 and 8-13). Die set 18, as well as the die sets for the cores, are made of aluminium or other material that is easily machined. The exhaust passage core 12 is a curved single body having an outlet end 16 designed to be keyed into the die side part 20 of die set 18 for supporting such end and has another core end 17 designed to be supported on the base die part 19 on a wall 25 that defines the shape of the combustion chamber. Figure 2 illustrates how one of

the intake cores 11 is supported on the die set 18 (the die set 18 being comprised, as shown in Figure 3, of a base part 19 left side part 20, a top part 21a, another top part 21b, and end parts 22, 23). The other end 14 of such core is keyed at 28 into a groove formed into both side and base die parts.

[0012] As shown in Figures 1-3 and 11-13, the annular water jacket core 13 has a primary longitudinally extending wall 26 which extends between the rows of intake and exhaust cores; annular webs or walls 27, 28 extend from wall 26 and wrap around such respective cores while spaced therefrom. Core walls 27 are much thicker than walls 28 because they define water channels adjacent the exhaust port which demands greater heat extraction. The ends of water jacket wall 26 have core extensions 29, 30 to define passages that connect the water jacket to a fluid circulating system. Core 13 thus provides annular walls around each intake and exhaust core, but in spaced relation. The space therebetween can be quite thin - as little as 3-4 mm. Note how cores 11 and 12 have one end within and arcuately encompassed by the annular webs 27 or 28 and have another end that curvingly projects around and to the outside of such web walls. This creates a spaced relationship that defines hidden spaces or gaps 31 and 32 therebetween. Such thin spaces promote increased heat transfer to the water jacket when replaced by metal, such as aluminium, in the final casting. Such thin spaces have heretofore presented a difficult problem to accurately form with pattern material.

[0013] Inlets 33 for injecting hot fluid wax into casting cavity 34 (the cavity 34 being defined between the walls of the heat conductive die assembly 18 and the core assembly 10) is shown in Figure 4 as step three of the process. The cavity 34 also includes spaces 39 opposite the inlets to allow for complete filling by the wax. The interior cavity does not need to have any draft angles or relief tapers incorporated. Hot wax is injected under a controlled injection pressure between 300-500 psi with the wax at a temperature in the range of 130-140°F. The wax is preferably a mineral base pattern wax or any investment casting wax. An injection apparatus 35 is utilised to force the wax into the ingate 36 and through the plurality of inlets 33, which are sized to a diameter of about one half inch. The injection of hot wax is sustained at such pressure for a time period of about 120-240 seconds until all of the wax fills the voids in the cavity 34 without entrapment of any gases. The wax typically will become solidified in a period of 120-300 seconds because of the heat sink provided by the aluminium die assembly. The injection apparatus 35, after appropriate formation of a skin on the wax pattern 37, is removed and the ingate 36 is separated. After the wax pattern 37 has solidified to a sufficient condition, the parts 19-23 of the die set 18 are separated from the wax pattern 37; the wax pattern 37 still retains the bonded particulate cores 11, 12 and 13, which can be seen at the pattern surface where the cores intersect

the exterior of the wax pattern.

[0014] A shell mould 40 is formed about the wax pattern 37 containing the core assembly 10 as step four of the process. The mould 40 is created by multiple dipping of the pattern into a ceramic slurry 38, draining the excess slurry, applying a refractory stucco, and drying or gelling the coating. This is repeated until a shell of about .3 inches or greater is achieved. The slurry preferably consists of a ceramic flour in colloidal silica which forms a layer 41 that is then sprinkled with a fine sand. After drying, the stuccoed silica/ceramic layer mould is then dipped into another ceramic slurry and then into a fluidised bed containing granular molochite to thereby stucco the surface again to form other layers 42. The slurry may be composed of refractory binders and refractory fillers or solids. The refractory binders can be silica sols, ethyl silicate, sodium and potassium silicate and gypsum type plasters. Common refractory fillers that can be used in the process are silica, fused silica, zircon, and aluminium silicate. The stucco, in many cases, is the same type of refractory as the dip coat, but it has a much larger grain size. The stucco is applied to the wet surface of the slurry to provide a mechanical key for the next coating and to minimise the drying stresses in the slurry coating, thus preventing cracking of the coating. The slurries are kept in suspension by use of a continually rotating drum with paddle mixture arrangement or by use of pneumatic prop mixers. The primary coat is most important to ensure that good surface finish and details are obtained; subsequent coats are used to build the shell thickness and strength in order to withstand de-waxing and metal pressures. The stucco is applied either by raining or by using a fluidised bed. In the raining process, stucco particles are allowed to fall in a raindrop pattern using a diffuser. Fluidised beds use a vertical drum with a porous brick bottom; air at low pressure and high volume passes through the brick and up the bed of stucco material. The effect of this air flow is to impart fluid characteristics to the stucco bed allowing the pattern assembly to be immersed in the stucco material as if it were a liquid. Fine stucco is used for the first coating and second coating, while coarser stuccos are used for backup coats.

[0015] Drying of the shell 40 is important; it begins with applying at constant velocity, temperature and humidity to remove the surface binder liquid (a constant rate drying). This is followed by a falling rate drying period which results in capillary transfer of the binder liquid from inside of the shell to the surface. Control of humidity and temperature is important. Temperature control affects pattern expansion and contraction which can cause the shell to crack. Humidity is preferably controlled to 50% and air velocity is controlled to 60-1200 ft/min.

[0016] The wax pattern 37 is removed from the layered shell mould 40 by shock firing, steam autoclaving, or other heating technique, which drains the wax through suitable drain openings 50 in the shell. Once

the wax is removed, leaving the part cavity 34 vacant, molten metal, such as aluminium, is poured into the cavity 34, as part of step four, through a sprue 51, to produce the required cast object, such as the finished cylinder head 43 shown in figure 7.

[0017] Removal (melting) of the pattern 37 is done during the mould firing cycle. The strength of the solid mould must be adequate to withstand the expansion stresses of the wax pattern. As the mould is heated during the firing cycle, the pattern melts and runs out. The wax pattern material then burns off in the firing furnace. Firing is carried out in an oxidised environment so that no carbon is left on the mould surface and may be accomplished by several techniques including autoclaving, flash firing and microwave de-waxing. Shell firing is then carried out after the moulds are de-waxed to increase the mould strength, along with heating and removing of residual pattern material prior to the final operation of pouring the metal. The moulds are heated in an oxidised atmospheric condition to a temperature of 1600-2000°F depending upon specific foundry requirements. Firing and preheat temperatures depend on the shell material and the type of material being poured. Aluminium castings typically are poured at a heated shell temperature of 400-600°F and steel at 1600-2000°F. The metal is poured slowly into the hot shell without causing turbulence. While the shell is heated to a temperature of 400°F, as described earlier, metal (1200°F for aluminium 356) is poured through the gating system to fill up the cavities and the risers. The metal is then left to cool in atmospheric conditions. In the case of a cylinder head, a chill may be used to draw heat away from the relatively large sections of the cylinder head.

[0018] The final casting 43 still retains the particulate bonded cores therein which can now easily be removed as step five by subjecting the casting to a heat treatment cycle; the resin or other bonding agent, holding the particulates together, is reversed so that the sand or salt becomes freeflowing and easily pours from the openings, such as 46-49 of the casting, by gravity (as shown in Figure 7). Such heat treatment may also be employed to concurrently treat the aluminium metal to enhance its metallurgical characteristics. It is important to keep in mind that cleaning the casting of core material is not carried out by use of hammers or salt baths, but rather by simple use of inquiscent water at 62°F that completely dissociates the bonded cores in less than 12 minutes. Hotter or pressurised water will further reduce dissolution time.

[0019] No longer is it necessary to try and inject the ceramic investment slurry into the core spaces, as is sometimes carried out by the prior art, nor is it necessary to utilise fused ceramic cores which are difficult to completely remove from an intricately shaped interior; some residue is usually left therein from a ceramic core which residue cannot be tolerated with engine castings, such as internal combustion engine heads, which critically depend on the internal cavities being clean and in

a totally functional condition. Resin bonded sand or salt-sand mixtures bonded by organic resins can be totally eliminated from such cavities without any residue.

[0020] The described process also promotes economical nimble manufacturing of a family of engine heads or blocks. Only new sets of cores need be made to change the flow characteristics of a head or block, the exterior configuration defined by the pattern die set 18 can remain the same and continue to be used to make up to at least 100,000 wax patterns for different members of an engine family. This is a significant economic breakthrough.

Claims

1. A method of repetitively forming rapid prototype metal castings that are fully durable and functional metal parts of a complex shape, comprising the steps of:

(a) making an assembly (10) of resin-bonded particulate cores (11,12,13) spaced from each other, one core arcuately encompassing at least one end of another core to define at least one hidden space (31,32) therebetween;

(b) making an easily machined die set (18) to receive and support said assembly (10) of cores in spaced relation for defining a casting cavity (34) around and between said cores, including said at least one hidden space (31,32);

(c) injecting fluidised wax into said cavity (34) under a controlled sustained pressure to fill said cavity without entrapping gases and to form a wax pattern (37) for the casting;

(d) using said wax pattern (37) with said assembly (10) of cores therein to form a shell mould (40) thereabout and thence draining the wax from the mould to permit a metal casting (43) to be formed in place of the wax pattern (37) with the assembly (10) of cores still in place, and

(e) removing from the casting all of the particulate cores (11,12,13) in said casting by reversing the bond between said core particles to form a collection of particles that is freely flowable under gravity.

2. A method as claimed in Claim 1, in which said casting is an internal combustion engine cylinder head and the metal casting (43) is comprised of aluminium based material.

3. A method as claimed in Claim 1 or 2, in which said wax is a mineral based pattern wax.

4. A method as claimed in any one of claims 1 to 3, in which, in step (c), the wax is injected under a pres-

sure of 300-500 psi for a time period of about 120-240 seconds.

5. A method as claimed in any one of the preceding claims, in which said particulate core material is comprised of sodium chloride salt or silica sand.

6. A method as claimed in any one of the preceding claims, in which the hidden space (31,32) has a dimension in the range of 3-10 mm and the internal casting cavity is defined with no draft angles or tapers.

7. A method of rapidly forming up to 100,000 castings of one or more complex interior shapes having hidden spaces therein, comprising the steps of:

(a) making an assembly (10) of bonded particulate sand or salt cores (11,12,13), one core of which has annular portions encompassing at least one end of each of the other cores, the other end of said other cores extending over the annular portion to define a hidden space (31,32) therebetween;

(b) making a heat conductive die set (18) to receive and support said assembly (10) of cores in spaced relation for defining a casting cavity (34) around and between said cores (11,12,13,) including said hidden space (31,32);

(c) injecting heated wax into said cavity (34) under a controlled sustained pressure to form a wax pattern (37) of the casting;

(d) forming a shell mould (40) on said pattern containing said cores;

(e) removing said wax to produce an empty casting cavity within said shell mould (40);

(f) pouring molten aluminium metal into said empty cavity to form a metal casting (43); and

(g) removing the shell mould (40) and removing pyrolytically each of the particulate cores from the metal casting (43).

8. A method as claimed in Claim 7, in which different shaped core assemblies are used with the same shaped die set (18) to make a family of castings having the same exterior configuration, but a different interior configuration depending on the core assembly deployed.

9. A method as claimed in Claim 7, in which in step (g) said particulate cores (11,12,13) are removed by subjecting the casting to a heat treatment cycle to reverse the resin bond between said particles to form a freely flowable sand or salt collection that drops out of the casting through openings (48,49) in the casting (43) under the influence of gravity.

10. A method as claimed in Claim 7, 8 or 9, in which one or more of the particulate cores (11,12,13) are formed of a salt and sand mixture bonded by organic resins.

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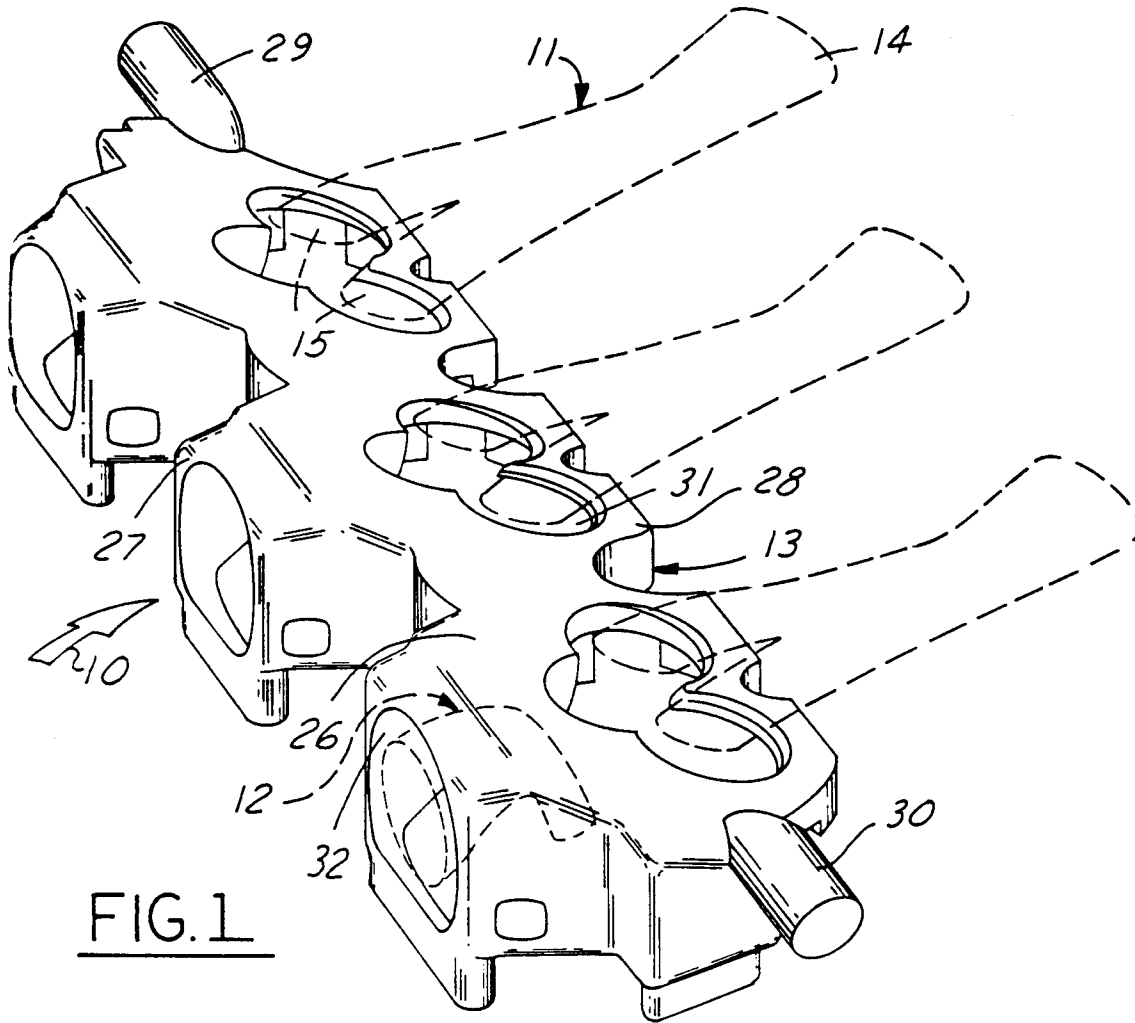


FIG. 1

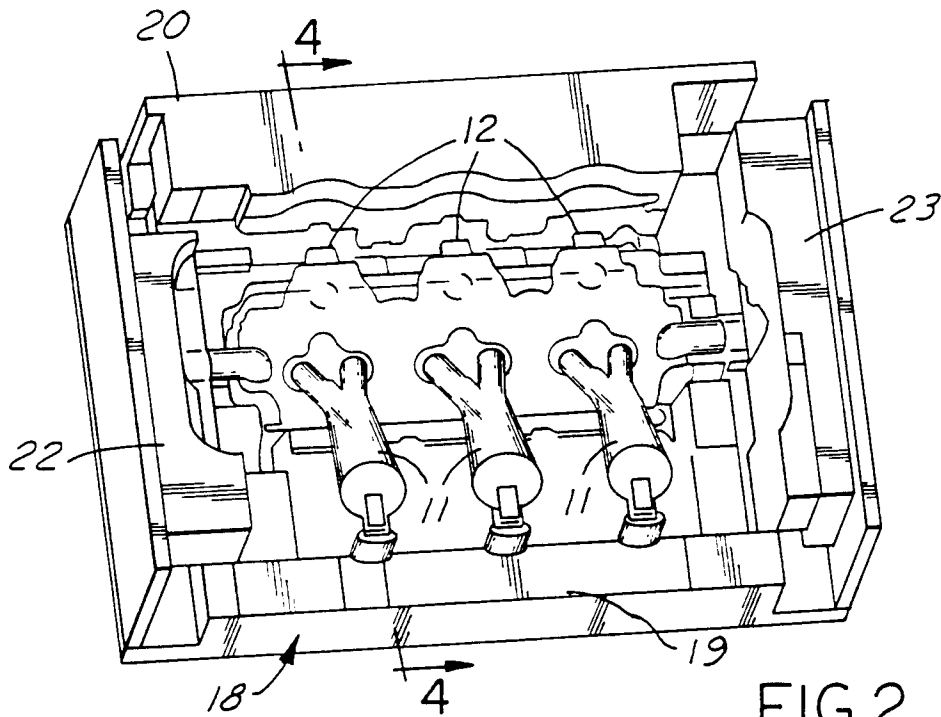


FIG. 2

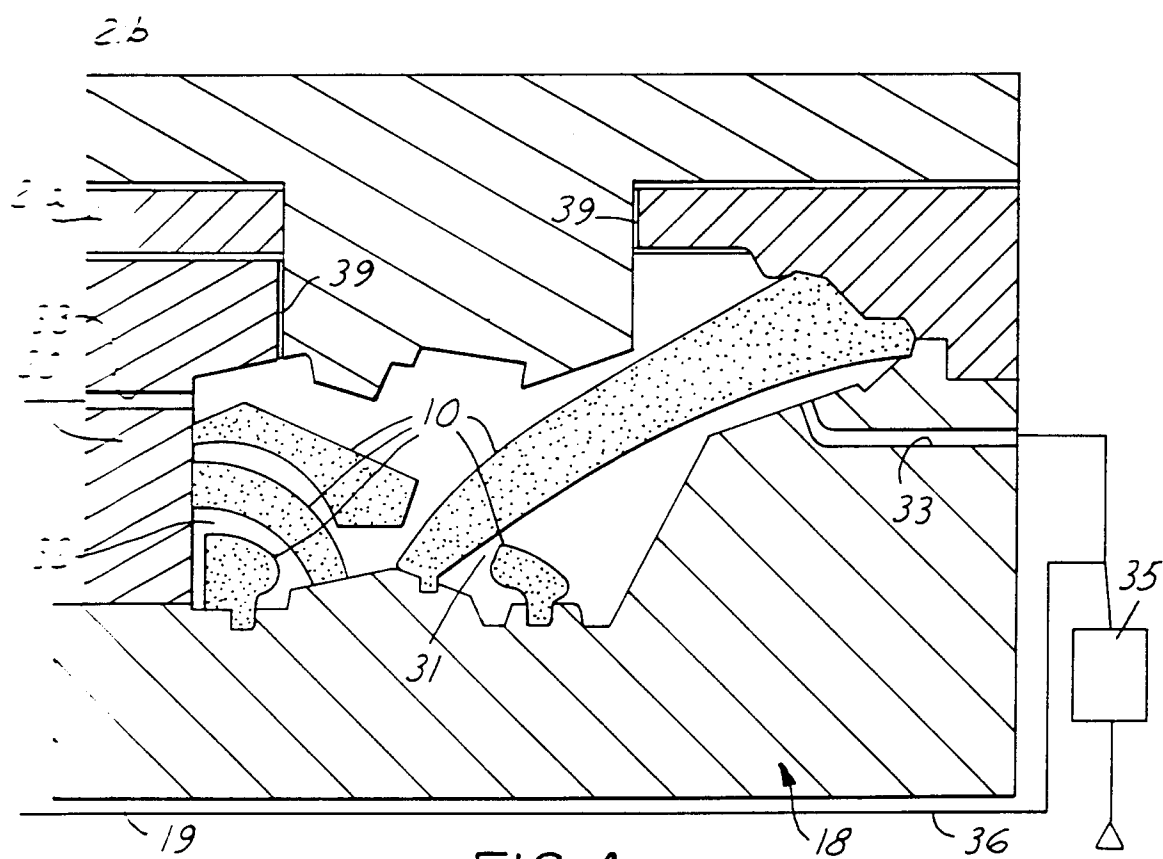
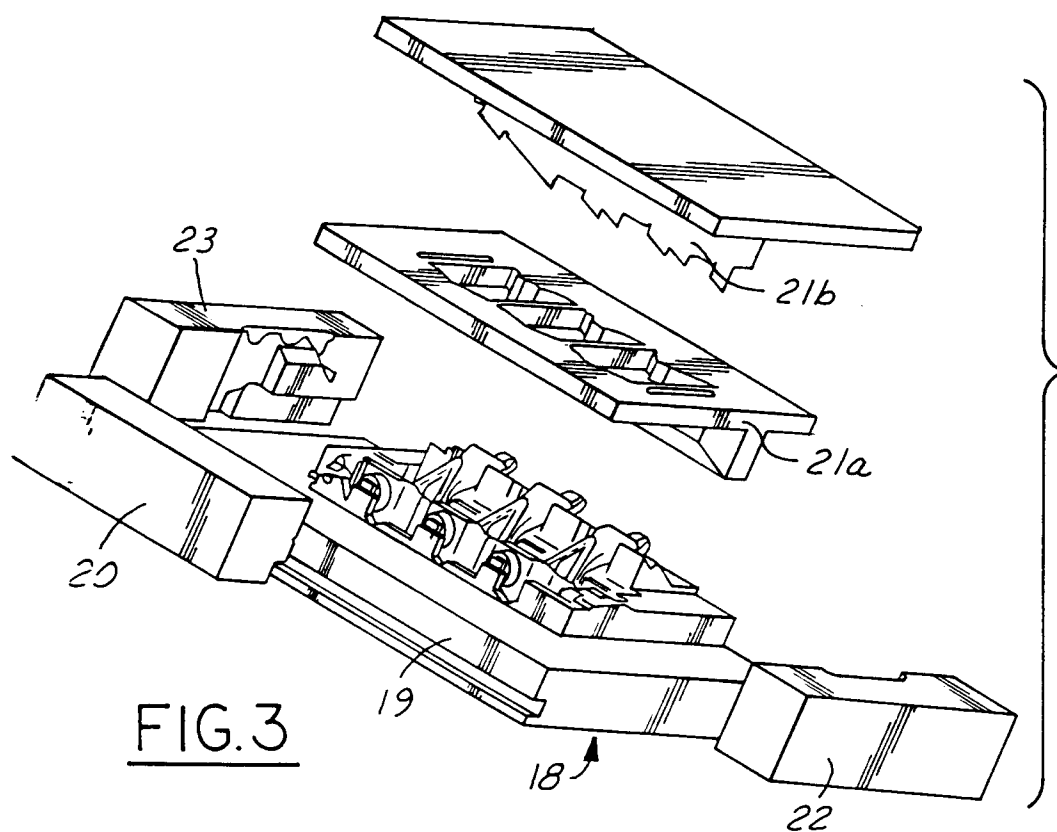


FIG. 4

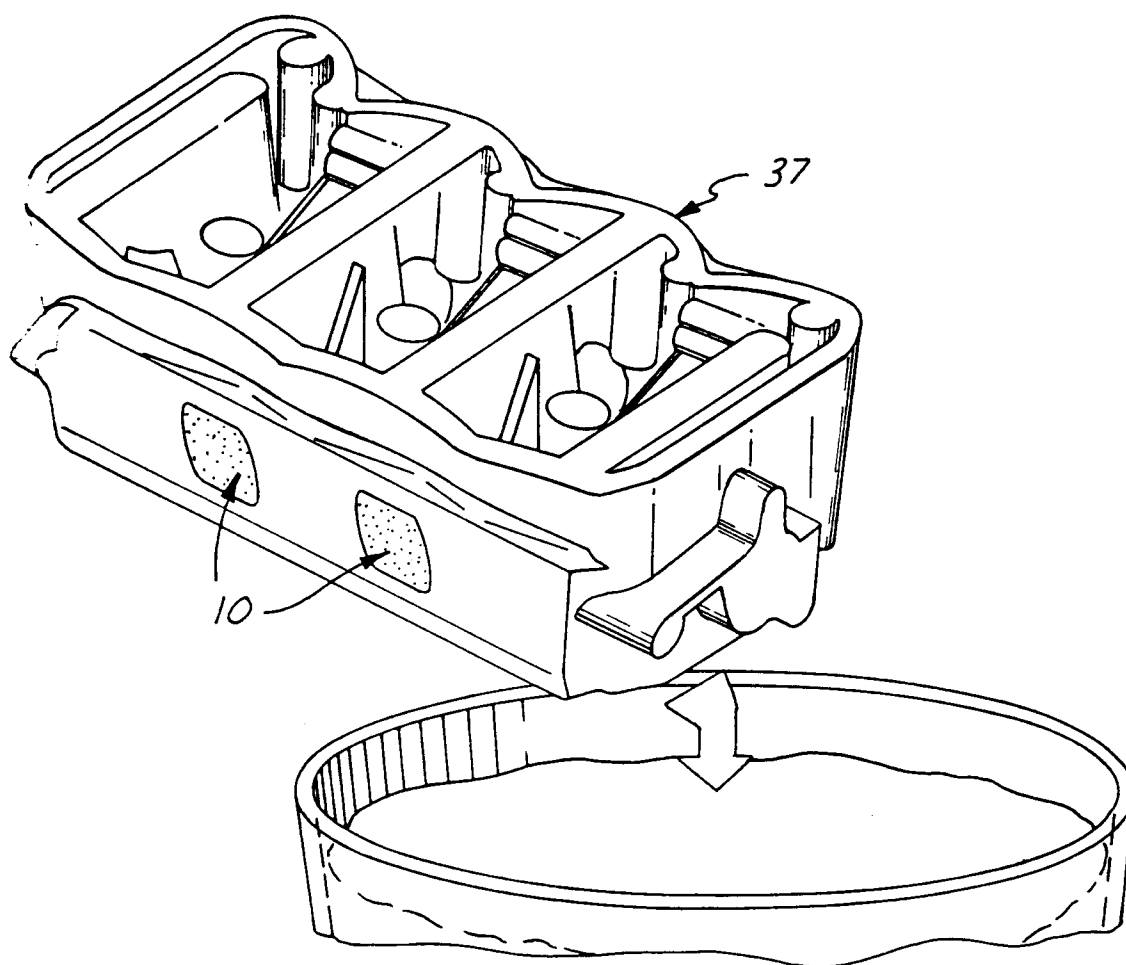


FIG. 5

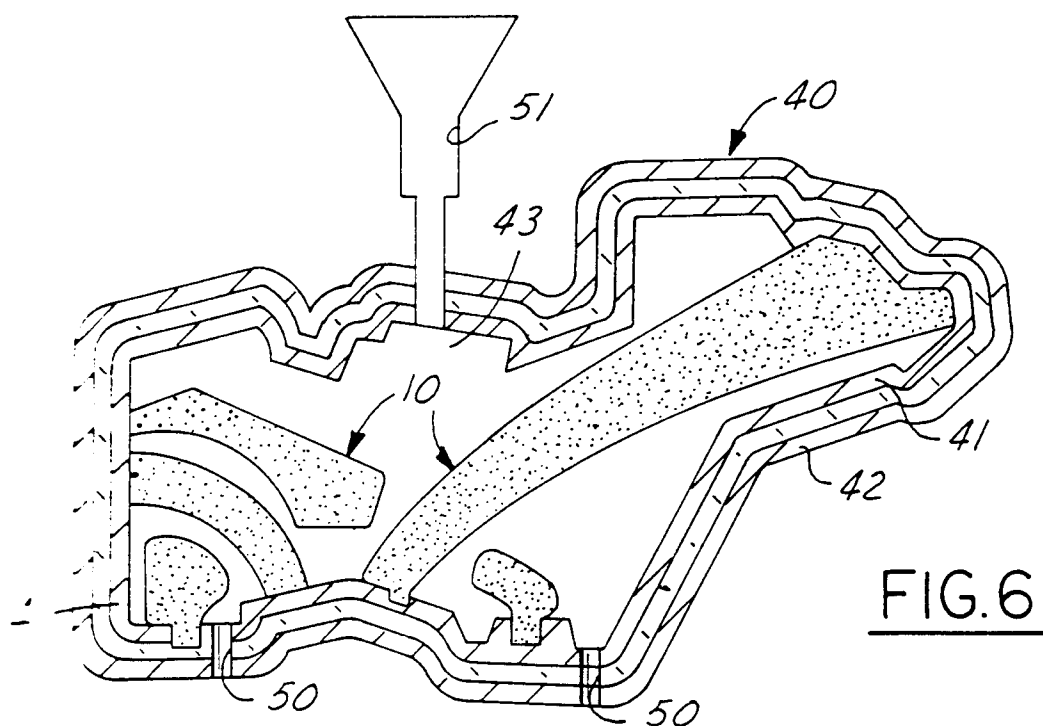
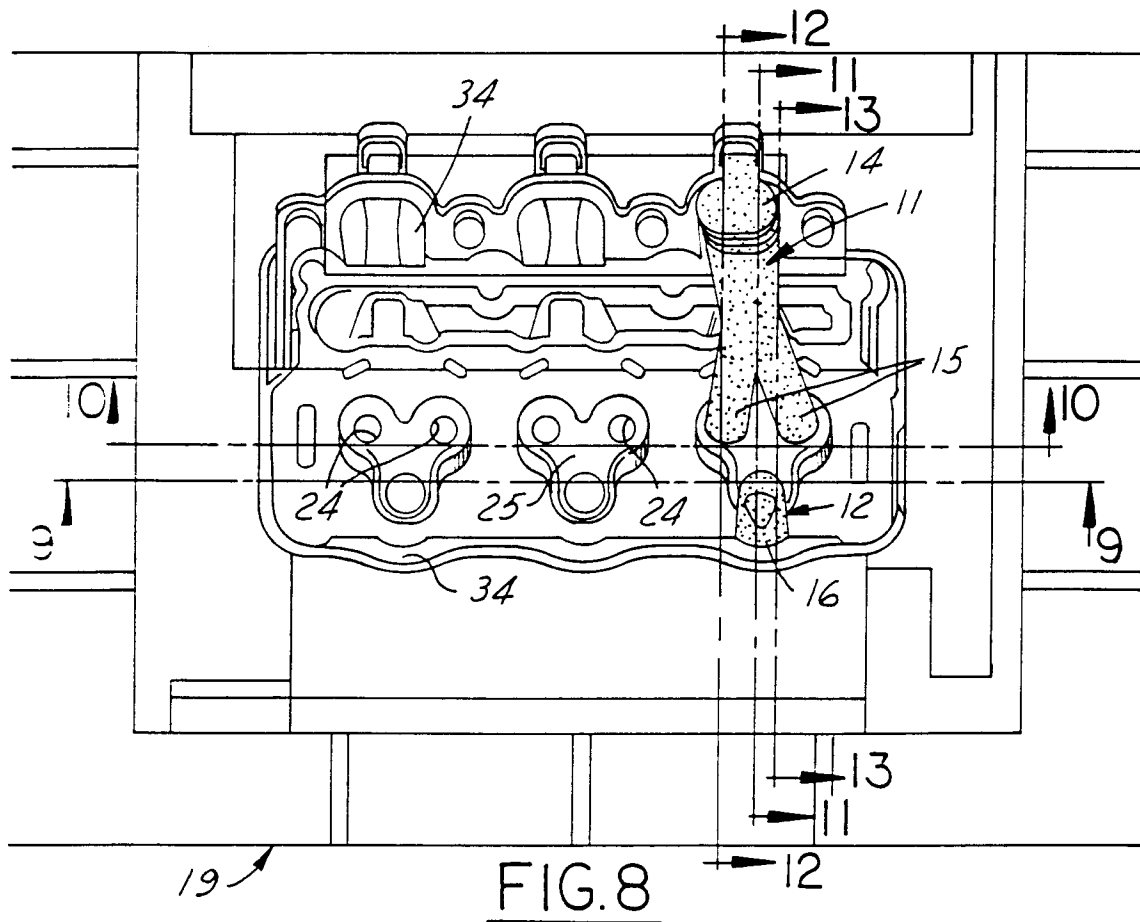
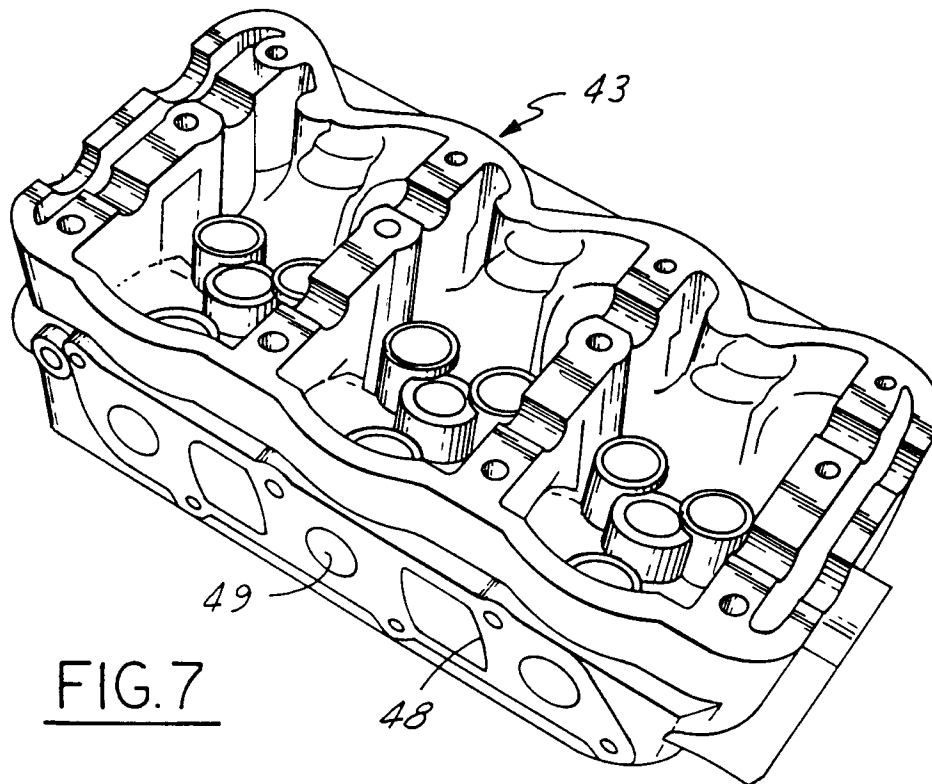
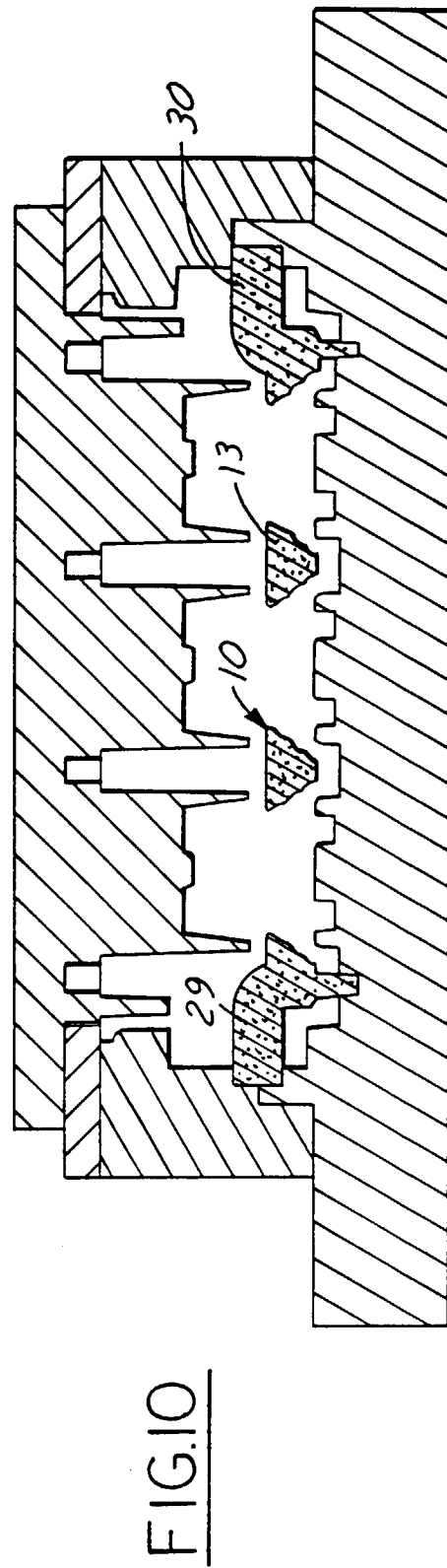
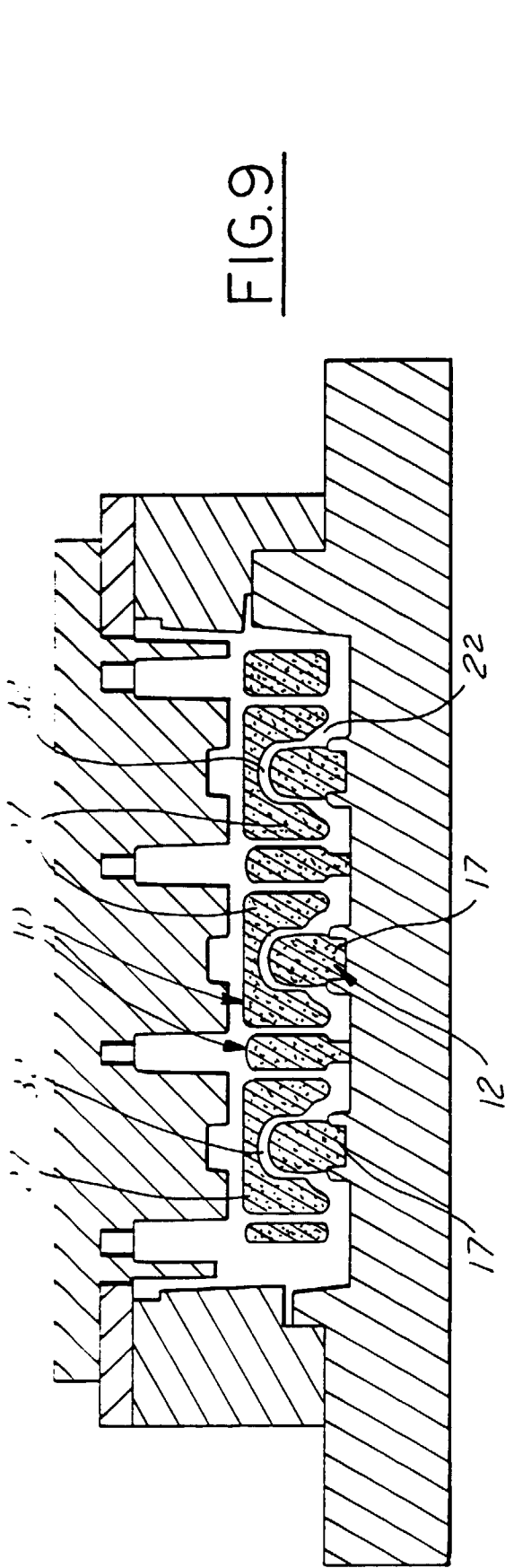
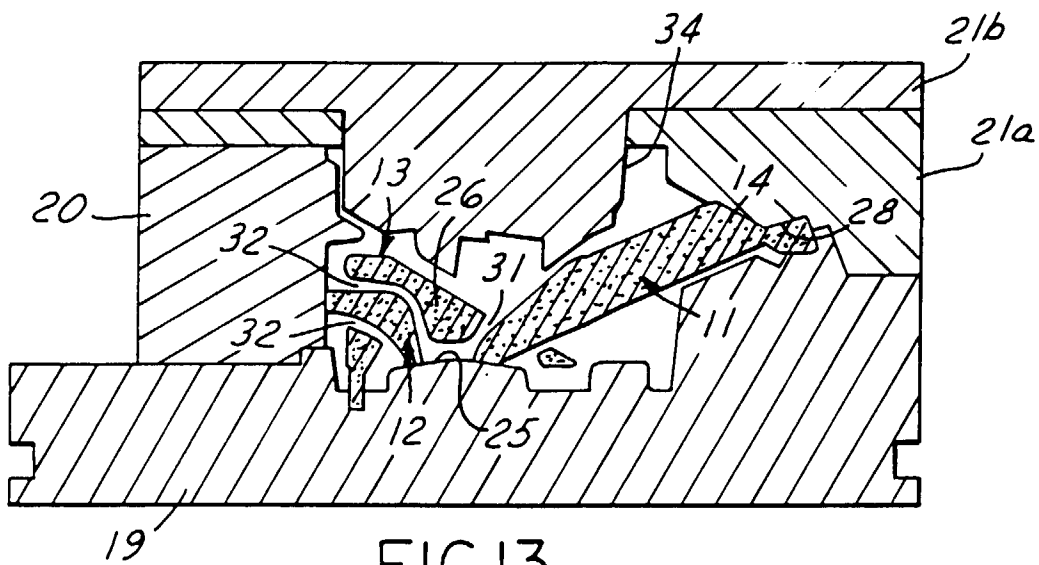
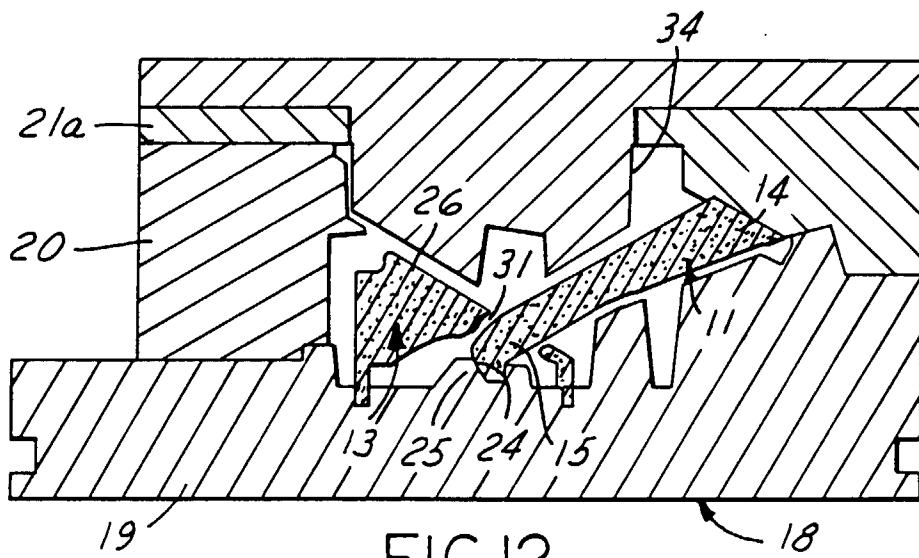
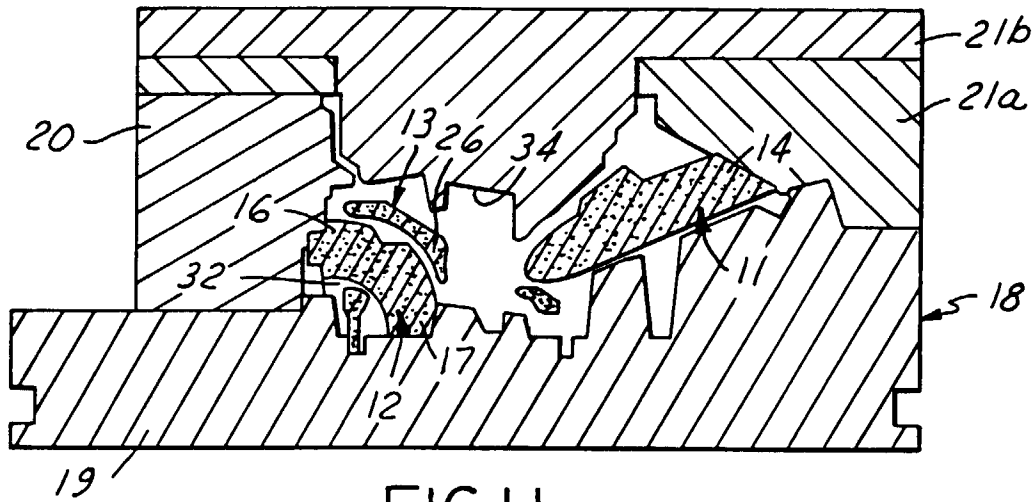


FIG. 6









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EUROPEAN SEARCH REPORT

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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