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(54) Title: JOINING OF MULTILAYER THERMOPLASTIC PIPES

(57) Abstract: First and second pipes having at least two concentric layers of thermoplastic material are joined to form a pipe assembly. A non-planar mating surface is prepared on the end of each pipe. The pipes are brought into abutment at the mating surfaces to form a joining zone. Each of the mating surfaces is heated and then cooled under compression to solidify the joining zone, thereby forming a weld. Preferably separate heating processes are used to melt and join the separate layers, thereby substantially eliminating the intermingling of the layers, which may be chemically incompatible. A strong, durable joint is effected in a simple and reliable manner. Optionally, a melt flow insert is disposed between the pipes being joined to provide physical separation between the volumes of the different layers that are melted during the formation of the joint.



## JOINING OF MULTILAYER THERMOPLASTIC PIPES

BACKGROUND OF THE INVENTION5 1. Field Of The Invention

This invention relates to the joining of thermoplastic workpieces, and more particularly, to the joining of multilayer thermoplastic pipes and related articles composed of dissimilar materials.

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2. Description Of The Prior Art

Modern thermoplastic, polymeric materials have found widespread and varied manufacturing applications. In many cases, articles composed of suitable thermoplastic materials have been found to be advantageous replacements for metal or thermoset articles previously required. In a given application, mechanical requirements can often be met with a thermoplastic article that is cheaper, lighter, and more robust and durable than a comparable metallic or thermoset article. As a result, thermoplastics are now widely used in a diversity of applications in the marketplace. Use of thermoplastics in various forms of pipes and tubes for conveying fluids, both liquid and gaseous, has proven especially attractive.

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In many cases, the technical requirements for a given piping application are often best satisfied with an item in a form that comprises multiple layers of different thermoplastic materials. The Service requirements for such items impose performance criteria that include thermal, mechanical, and chemical behavior. Tubing must retain its structural integrity in the face of both internal exposure to a fluid or other medium being conveyed, in many instances at substantial pressure, and external exposure to a surrounding environment. In some cases, the required properties are difficult or impossible to satisfy with tubing composed of a single material. For example, the chemical reactivity or corrosivity of a fluid or its temperature (either very high or low) may restrict the feasible choices to certain select materials. However, such materials may have inadequate mechanical and tribological properties. A given material may not have a mechanical strength that is adequate for the desired diameter and length of tubing or may lack abrasion resistance. In many instances a cost-effective alternative is a tubing form having two or more concentric layers. In one such arrangement, the innermost layer is composed of a material that affords the requisite chemical properties such as corrosion resistance, while the outermost is made of a material that has a low coefficient of friction and is robust against mechanical abrasion. Tubing forms having more than two concentric layers are also used in certain specialized applications. For example, an intermediate layer such as a woven fabric layer may provide additional mechanical strength needed to satisfy a pressure requirement.

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However, using a multi-layer tube is viable only if these are reliable means of joining the composite material. Although joints made with auxiliary, mechanically secured Fittings or fasteners are widely known and used, they frequently are found to be difficult to assemble and insufficiently durable for the required service life. In many applications, after initial assembly, joints are disposed in locations that are highly difficult or impossible to access for repair. Accordingly, leak-free, long-term mechanical stability and reliability is essential. Many situations also demand that the joint area not be significantly enlarged in diameter, such as by couplings into which the respective tube ends are inserted and secured. As a result, methods for joining such pipes by direct welding are sought. Solvent welding is a feasible technique in certain instances. Such a process comprises softening the mating ends of the pipes by exposure to a suitable solvent and bringing the ends into mating contact. Thereafter the softened volume hardens to form a welded joint. However, solvent joining can affect the mechanical performance of plastic and weld adversely, causing brittleness or other such problems. In addition, many of the typically used solvents are potentially harmful to both the environment and the workers exposed. Such processes are also not compatible in many cases with multi-layer pipe systems. Furthermore, these layers often are made of chemically incompatible thermoplastics, making joining processes such as conventional thermal or solvent welding difficult or impossible to use. Representative lists of materials and their relative chemical compatibilities are found at pages 462 and 464 of Joining of Plastics: Handbook for Designers and Engineers, edited by Jordan Rotheiser (Cincinnati: Hanser Publishers), which pages are incorporated herein by reference thereto. A joint effected by such processes frequently is far weaker than the underlying material, and the beneficial properties of the respective layers are often lost by admixture of the materials. Such admixture can arise in a number of ways. In some cases, the different materials have substantially different heat softening or melting temperatures, so that heating the composite above the highest of the temperatures is deleterious to the other constituents and may cause them to become so soft that they lose their general shape or properties. In extreme cases, some of the materials would decompose or otherwise chemically react at the temperatures needed to soften the other constituents.

Together these requirements have imposed a persistent need for satisfactory joining methods appropriate for multi-layer thermoplastic materials. Traditional methods entailing arc welding, brazing, soldering, and the use of known mechanical fastening hardware, that are widely practiced for joining metallic workpieces, are generally inapplicable for thermoplastics, which have markedly different thermal and mechanical characteristics.

Hot-plane welding methods are sometimes adequate for making geometrically simple systems. One or both of the workpieces are heated to melt the mating surface. The workpieces are then quickly brought into abutment and joined. However, reliable welding by this method necessitates tight process control and very careful mechanical handling to assure proper mating. Moreover, hot-plane methods are generally applicable only in joining pipes with similar, chemically compatible compositions.

Frictional welding methods used with thermoplastic parts may broadly be classified as vibrational (linear and orbital), rotational/spin, and ultrasonic. In both vibrational and rotational methods the workpieces are brought into mating contact and moved relative to each other in a direction substantially in the plane of the joint surface while being urged together under compressive force. The resulting friction rapidly heats the joint area to cause melting and welding. With vibrational methods the workpieces are moved relative to each other in an oscillatory linear or orbital pattern. The rotational method (spin welding) entails rapidly spinning one of the workpieces and bringing it into contact with its mate. However, spin welding is suitable only for relatively short parts having joint surfaces that are cylindrically symmetrical, and is impractical for tubes or pipes of extended length. In addition, spin welding requires very precise alignment of the parts to get a uniform weld fully encircling the final article, which is essential if high strength or hermetic sealing is required. Such alignment is especially critical for joining multi-layer pipes.

Ultrasonic welding is widely applied for joining thermoplastics, especially for mass production of relatively small articles in which high throughput and speed of welding are advantageous. Amorphous thermoplastics are regarded as most amenable to ultrasonic welding, especially if a hermetic joint is needed. The process is also widely used for semicrystalline, filled, and fiber-reinforced thermoplastics. However, the apparatus for ultrasonic welding and the required disposition of the parts therein generally precludes its use for extended sections of pipe.

Notwithstanding numerous advances in the Field of thermoplastic welding, there remains a need in the art for an economical, efficient welding process for joining multilayer thermoplastic parts, especially pipes composed of incompatible materials.

#### SUMMARY OF THE INVENTION

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The present invention provides an economical, efficient method for joining multilayer thermoplastic pipes to form a pipe assembly.

In one aspect, there is provided a process for joining a first pipe and a second pipe, each of the pipes having an outside surface and an inside surface and being comprised of a plurality of layers of thermoplastic materials. The joining process comprises the steps of. (i) preparing a first non-planar mating surface at one end of the first pipe; (ii) preparing a second non-planar mating surface at one end of the second pipe; (iii) heating the first and second pipes to at least soften the first and second mating surfaces; (iv) bringing the first and second pipes into abutment at the mating surfaces to form a joining zone; and (v) cooling the first and second pipes under compression to solidify the joining zone, thereby forming a weld joining the pipes.

In another aspect, there is provided a pipe assembly, comprising a first thermoplastic pipe with a first non-planar mating surface at one end and a second thermoplastic pipe with a second non-planar mating surface at one end. Each of the pipes has an outside surface and an inside surface and comprises a plurality of layers of thermoplastic materials. The pipes are welded together at a joint with the first and second mating surfaces in abutment.

Advantageously, the process of the invention allows joining of multi-layer thermoplastic pipes wherein some of the layers are chemically incompatible. Intermingling of the incompatible materials, which results in a weak, unreliable joint, is substantially reduced or eliminated. In addition, the process may be employed to join long sections of pipe in a reliable and inexpensive manner. The joint does not require any Fittings or structure that enlarges the pipe diameter in the region of the joint, and does not unduly constrict the bore of the pipes. As a result, joined pipes may be disposed in a wide range of locations, including the offshore oil production industry and in various pipe-in-pipe systems. In many of these applications, the durability, weight reduction, and corrosion resistance of multilayer thermoplastic pipes are essential.

In still another aspect of the invention, a tubular joint insert is used as a melt flow separator in joining two multi-layer thermoplastic pipes. Advantageously, the insert separates the volumes in which the respective layers of the pipes melt to further reduce the likelihood of mixing the materials. Preferably, the insert is composed of a thermoplastic material chemically compatible with the inner welding layer of the pipes being joined. The insert has first and second end sections, a center section, and first and second transition sections between the end sections and the center section. The end sections have an outside diameter substantially equal to the inside diameter of the inner welding layers and the center section has an outside diameter substantially equal to the outside diameter of the inner welding layers. In preparation for welding, the mating surface of the first pipe is placed in abutment with at

least the first end section and the first transition section and the mating surface of the second pipe is placed in abutment with at least the second end section and the second transition section.

- 5 The process of the invention is suited for the joining of pipes composed of a wide variety of polymeric materials, including non-exclusively Acetal, ABS 10 (acrylonitrile/butadiene/styrene), ASA (acrylonitrile/styrene/acrylate), BS (styrene/butadiene block copolymer), block copolymer polyester, braids of paraaramid Fiber (e. g. Kevlar(V braid), MABS (methyl methacrylate/ acrylonitrile/butadiene/styrene), polyamides (e.g. nylons 6, 66, 66/9, 46, 10, 11, and 12 ), PSU (polysulfone), PE (polyethylene), PEX (Cross-linked polyethylene), PP (polypropene), PES (polyethersulfone), POM (polyoxymethylene), PEK (polyether ketone), PEEK (polyether ether ketone), PS (polystyrene), PVC (polyvinyl chloride), PPS (polypropylene sulfide), PTEF (polytetrafluoroethylene) and SAN (styrene/acrylonitrile copolymer).

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#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood and further advantages will become apparent when reference is had to the following detailed description of the various  
20 embodiments of the invention and the accompanying drawings, wherein like reference numerals denote similar elements throughout the several views, and in which:

Fig. 1 is a longitudinal cross-sectional view depicting a section of generally cylindrical pipe composed of inner and outer layers of thermoplastic material and appointed to be joined in accordance with the present invention;  
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Fig. 2 is a longitudinal cross-section view depicting a section of two generally cylindrical pipes in abutting relationship and appointed to be joined in accordance with the present invention;  
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Fig. 3 is a longitudinal cross-section view depicting a section of two generally cylindrical pipes in abutting relationship and appointed to be joined in accordance with the present invention;

35 Fig. 4 is a longitudinal cross-section view depicting two multi-layer pipes having linearly tapered mating surfaces appointed to be welded in accordance with the present invention;

40 Fig. 5 is a longitudinal cross-section view depicting two multi-layer pipes having curvilinearly tapered mating surfaces appointed to be welded in accordance with the present invention;

Fig. 6a is a perspective, three-dimensional, longitudinally cutaway view depicting two multi-layer pipes having toothed mating surfaces appointed to be welded in accordance with the present invention;

- 5 Fig. 6b is a perspective, three-dimensional, longitudinally cutaway view depicting two multi-layer pipes having toothed mating surfaces appointed to be welded in accordance with the present invention;

- 10 Fig. 7 is a longitudinal cross-section view depicting a melt flow separator insert of the invention;

- 15 Fig. 8 is a longitudinal cross-section view depicting cross-sectional view depicting two multi-layer pipes joined with a melt flow separator insert and appointed to be welded in accordance with the present invention; and

- Fig. 9 is a longitudinal cross-section view depicting another melt flow separator insert of the invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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The present invention is directed to the welding or joining of pipes comprised of at least two layers of different thermoplastic materials.

- 25 One embodiment of the present invention, depicted by Figs. 1 - 3, is used to join pipes comprising at least two layers which have relative thicknesses that vary along the length of the pipe. For example, Fig. 1 Shows a pipe 10 with concentric inner layer 12 and outer layer 14, which are composed of different thermoplastic materials and undulate in relative thickness along the pipe length. Preferably, indicia or similar fiducial markings are painted, printed, mechanically or laser etched, molded, or otherwise manifest on the exterior surface of pipes 10 to facilitate preparation and joining of the pipes. The terms "pipe", "duct", "tube", and "tubing" are used interchangeably herein to denote an elongated, generally cylindrical, hollow body typically used to convey fluids, gases, liquids, slurries, or the like. It is preferred, but not essential, that the Body be a right circular cylinder. It further will be understood that the inventive method disclosed herein also comprises joining a pipe to a fitting, valve, flange, or other similar device used in connection with piping systems.
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- Preferably, the amplitude of the undulation of thicknesses of the layers 10, 12 of pipe 10 is sufficient to produce regions in which one of the layers occupies a substantial portion of the pipe thickness, i.e. at least about 80% of the thickness, and more preferably, at least 90% of the thickness, and most preferably, substantially all the thickness, as depicted by Figs. 2 - 3. Mating surfaces of multilayer pipes of the
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types shown in Figs. 1 - 3 are preferably formed at a location along the length at which the relative thickness of the inner and outer sections is substantially similar on both mating surfaces. The pipes may be joined at a point along their lengths where the thickness of one of the layers predominates, i.e. occupies a substantial portion of the total thickness. The selection of which layer predominates is preferably made on the basis of the chemical and mechanical properties that result therefrom.

In the embodiment of Fig. 2, pipes 11 and 13 are prepared with mating surfaces 16 and 18, respectively, with substantially all of the thickness composed of inner layer 12, while pipes 11' and 13' in Fig. 3 have mating surfaces 16' and 18' at which substantially all the thickness is composed of outer layer 14. The pipes depicted in Fig. 2 or 3 are joined to form a pipe assembly by bringing them into aligned, coaxial abutment, heating the mating surfaces to at least soften them, and allowing the resulting assembly to cool to form a welded joint. Advantageously, any melting occurs only in a volume in which substantially all the material is of the type of either inner layer 12 or outer layer 14, so that little or no mixing of the materials occurs. As a result, even pipes with chemically incompatible layer compositions can be joined.

Referring now to Figs. 4 and 5 there are shown two further and related embodiments of the invention. Two generally cylindrical, multi-layer pipes 30, 32 have inner surfaces 31 and outer surfaces 33. The pipes are appointed to be joined at tapered mating surfaces 38, 40. Each pipe depicted has an inner thermoplastic layer 34 and an outer thermoplastic layer 36, which optionally are not chemically compatible. However, in other embodiments (not shown) the pipes may have more than two concentric layers. The mating surfaces 38, 40 of pipes 30, 32 in Fig. 4 are linearly tapered between inside surface 31 and outside surface 33. Pipe 30 tapers radially inwardly from outside surface 33 to inside surface 31, while pipe 32 tapers radially outwardly from inside surface 31 to outside surface 33. That is to say, the inside surface of pipe 30 in the region of mating surface 38 and the outside surface of pipe 30 in the region of mating surface 40 have frustoconical shapes. Mating surfaces 38 and 40 are complementary, so that the mating end surfaces are in contact over substantially their entire area when pipes 30 and 32 are brought into aligned abutment. Fig. 5 depicts pipes 30 and 32 that have curvilinearly tapered mating surfaces, viz. inwardly tapered surface 42 and complementary outwardly tapered surface 44.

Advantageously, pipes having complementary tapered mating surfaces, including those depicted in Figs. 4 - 5, are urged into self-alignment by those mating surfaces. Such alignment is further facilitated in the embodiment of Fig. 5 by forming surfaces 42 and 44 as portions of a spherical surface of substantially the same diameter. By way of contrast, butt joints between pipes wherein both mating surfaces

are planes nominally perpendicular to the pipe axis are more difficult to properly dispose in alignment for welding. Any lateral misalignment of the pipes reduces the surface area of actual contact, and so ordinarily results in a weaker joint. On the other hand, if the two pipes are brought into abutment with their axes 10 not in parallel, collinear alignment, contact between the mating surfaces during welding does not extend fully circumferentially, and leaks often ensue at points lacking contact. Accurate alignment is especially difficult to achieve when joining long pipes which tend to be unwieldy and hard to manipulate with precision. In addition, the geometries of the pipes of Figs. 4 - 5 beneficially increase the contact area over what would be obtained with the perpendicular, planar mating surfaces used in a conventional butt joint. Tapered joints also are found generally to reduce the inadvertent flow of molten material from the joint either inwardly into the bore of the pipes being joined or outwardly to the pipe surface.

Another implementation of the present process for joining multi-layer thermoplastic pipes is shown by Figs. 6a - 6b, which depict pipes 92 and 94 appointed to be joined by welding. The pipes have first and second mating surfaces 93 and 95, respectively. Each mating surface in the embodiment of Fig. 6a has a plurality of axially projecting teeth 96, 98 that further define a plurality of indentations 97, 99 between adjacent ones of the teeth. The teeth and indentations of the two mating surfaces are complementary. While the teeth and indentations shown in Fig. 6a terminate in sharply pointed vertices, other forms are possible, including the generally trapezoidal teeth and indentations shown in Fig. 6b or teeth and indentations having rounded vertices (not shown). When the pipes in any of these embodiments are disposed in axially aligned abutment, the corresponding teeth and indentations of the respective mating surfaces are brought into meshed engagement as depicted by Figs. 6a - 6b and joined to form pipe assembly 90. Mating surfaces having various forms of toothed geometry also provide for higher contact area than in a butt joint, resulting in a joint with improved strength, in both axial, flexural, and torsional directions.

The present invention further provides a process for joining multilayer tubes. As discussed hereinabove, prior art methods for heat joining multi-layer structures have frequently resulted in the simultaneous melting and undesirable intermingling of the various layers which often are chemically incompatible. Preferably, the present method comprises either separate melting of the layers in different steps or techniques for physically separating the distinct layers.

A number of processes are advantageously used to form the present pipe assembly by welding. In some instances, especially those wherein the pipe layers are relatively compatible chemically, simple hot-plate and other non-contact, radiant heating techniques may be used. Hot-plate methods are readily implemented for joints

in which the mating surfaces are planar and perpendicular to the tube axis, such as the structures seen in Figs. 2 - 3. Other geometrically simple mating surfaces, such as the conical surfaces of the tubes of Fig. 4 and the spherical surfaces of the tubes of Fig. 5 may be heated on conformally designed heated surfaces. Hot-plate techniques are generally applied before the workpieces are brought into abutment.

Preferably, separate melting steps are carried out to form the present pipe assembly, whereby intermingling of different layers of the pipes is minimized or eliminated. In one aspect the inner layers 34 are welded using heat resulting from the impingement of radiation, either by radio frequency electromagnetic induction or by laser techniques. Such techniques are usually employed after the workpieces are disposed in position for welding. In the electromagnetic induction technique, a radio frequency absorbing material is either placed on one or more of the surfaces being joined or incorporated in the bulk at least part of the material being joined.

The joint area is exposed to an electromagnetic field of a frequency at which the absorbing material is effective. Energy absorbed from the field generates local heating that causes localized melting and welding of the subject parts. Any conducting or semiconducting material having suitable absorption may be used, including metal powders such as iron. Suitable systems equipment and absorbing materials are available commercially under the tradenames EMABOND and EMAWELD from the Ashland Specialty Chemical/Emabond Company, Norwood, NJ.

Laser techniques are also advantageously used in forming the present structures. Preferably, the material used in outer layers 36 is transparent to light of a preselected wavelength, while inner layers 34 absorb light of the same wavelength. Alternatively, at least a portion of the mating areas of inner layer 34 is coated with an optically absorbing substance, such as carbon black. Welding of the inner layer is accomplished by impinging light generally radially inwardly, through outer layer 36 and onto inner layer 34 in the area appointed for joining. As used herein, the term "light" is understood to mean any electromagnetic radiation having a wavelength ranging from infrared to ultraviolet; "light" is not limited to radiation of wavelengths perceptible to human vision. Preferably, infrared light furnished by either an infrared, filament-type lamp or a laser is used for best effectiveness of welding. It is further preferred that the light be furnished by a laser selected from the group consisting of Nd:YAG, diode, CO<sub>2</sub>, or excimer lasers. In a more preferred implementation, laser light absorbing dyes, such as those disclosed in published International Patent Application WO 00/20157 or otherwise known in the art may be incorporated in one or more inner layers of the pipe.

Still another embodiment of the present invention is depicted by Figs. 7 - 9. Melt flow separator 50, best seen in the cross-sectional view of Fig. 7, is a generally cy-

lindrical, hollow bore tubular insert having end sections 52, 54 and center section 56 with intermediate tapered transition sections 58, 60. Flow separator 50 is used to join pipes 30, 32 as shown by Fig. 8 and preferably is composed of the material of the inner layer 34 of pipes 30, 32 or another material chemically compatible therewith. End sections 52, 54 have an outside diameter substantially equal to the inside diameter of the innermost layer 34 of pipes 30, 32, respectively. Center section 56 has an outside diameter substantially equal to the outside diameter of layer 34. Mating surfaces are prepared at the ends of pipes 30, 32 by removing material from inner layer 34 of pipes 30, 32 to create inner layer mating surfaces 59, 61 and a recess that complementarily accommodates center section 56 and tapered transitions 58, 60 of flow separator 50. Full insertion of the separator brings the ends 62, 64 of outer surfaces 36 of pipes 30, 32 into abutment.

Pipes 30, 32 are joined by fusion welding using flow separator 50. The welding comprises melting operations that (i) join transition regions 56, 58 of separator 50 with inner layer melting surfaces 59 and 61, respectively; and (ii) outer layer melting surfaces 62 and 64.

Advantageously, the configuration of the pipes and flow separator of Fig. 7 separates the abutment region of inner layers 34 and outer layers 36. As a result, welding of the joint can proceed without significant likelihood that melted portions of the pipe layers will admix and degrade the mechanical and chemical properties in the joint. Such separation of the melt regions is especially beneficial for pipes wherein layers 34 and 36 are not chemically compatible. Preferably, inner layer 34 is substantially fully removed from the bore of pipes 30, 32 for a distance extending sufficiently far into the pipes to separate the heat-affected regions near inner layer mating surfaces 59 and 61 from the respective heat affected regions near outer layer melting surfaces 62 and 64. In a related embodiment (not shown), pipes 30, 32 comprise an inner welding layer having a plurality of concentric sub-layers instead of a single inner layer 34. In this embodiment, all of the sub-layers of the inner welding layer are preferably removed a distance extending sufficiently far into the pipes to separate the heat-affected regions near inner layer mating surfaces 59 and 61 from the respective heat affected regions near outer layer melting surfaces 62 and 64.

Optionally the ends of end sections 52, 54 are chamfered to facilitate insertion of flow separator 50 into the prepared ends of pipes 30, 32. Advantageously, the insertion of flow separator 50 insures that the ends of pipes 30, 32 maintain a cylindrical cross section. Thermoplastic pipes are commonly prepared and shipped from the manufacturer as extended lengths wound onto a large spool. Placing the pipe on such a coil winding form frequently is found to cause nominally cylindrical pipe to become elliptically deformed and foreshortened along the axis radial to the coil

winding form. Insertion of flow separator corrects this deformation in the vicinity of the proposed weld and helps to assure proper alignment of the surfaces in preparation for the welding operation.

- 5 A variant of the melt flow separator 50 seen in Fig. 7 is provided by melt flow separator 50' depicted by Fig. 9. A plurality of generally circumferential grooves 68 or similar recesses on the exterior surface of separator 50' provide a location in which absorbent material is disposed. The absorbent material can be either electromag-
- 10 field or optical welding techniques discussed in greater detail hereinabove.

The configuration of Fig. 8 using a melt flow separator is advantageously welded using the aforementioned electromagnetic or optical techniques to join the inner pipe layers. By suitable placement of the absorbing medium either in the melt flow

15 separator or the inner layer, the impinging energy can be localized to largely confine the melting to the volume which effects joining of the inner layers through the melt flow separator. Any melting of the outer layer during the impingement of electromagnetic or optical energy is substantially localized and restricted by the separator, advantageously minimizing or eliminating deleterious intermingling of incom-

20 patible materials.

Having thus described the invention in rather full detail, it will be understood that such detail need not be strictly adhered to but that various changes and modifications may suggest themselves to one skilled in the art, all falling within the scope

25 of the present invention as defined by the subjoined claims.

## Claims

What is claimed is:

- 5 1. A process for joining a first pipe and a second pipe, each of said pipes having an outside surface and an inside surface and being comprised of a plurality of layers of thermoplastic materials, the process comprising the steps of
  - 10 a) preparing a first non-planar mating surface at one end of said first pipe;
  - b) preparing a second non-planar mating surface at one end of said second pipe;
  - c) heating said first and second pipes to at least soften said first and second mating surfaces;
  - 15 d) bringing said first and second pipes into abutment at said mating surfaces to form a joining zone; and
  - e) cooling said first and second pipes under compression to solidify said joining zone, thereby forming a weld joining said pipes.
- 20 2. The process of claim 1, wherein said first mating surface tapers radially inwardly from said outside surface to said inside surface; and said second mating surface tapers radially outwardly from said inside surface to said outside surface and is complementary to said first mating surface.
- 25 3. The process of claim 1, wherein said first and second mating surfaces are linearly tapered.
4. The process of claim 1, wherein said first and second mating surfaces are curvilinearly tapered.
- 30 5. The process of claim 1, wherein each of said first and second mating surfaces has a plurality of axially projecting teeth and a plurality of indentations thereby formed between adjacent ones of said teeth, said teeth and indentations of said respective mating surfaces being complementary, and said pipes are brought into abutment with said teeth and indentations of said respective mating surfaces in meshed engagement.
- 35 6. The process of claim 1, wherein said pipes are heated by bringing each of said mating surfaces into contact with a heated surface having a shape complementary to said mating surface.

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7. The process of claim 1, wherein said pipes are brought into axial abutment prior to said heating step.
- 5 8. The process of claim 7, wherein said heating is effected by radio frequency electromagnetic induction heating and said pipes comprise an electromagnetically absorbing component.
9. The process of claim 8, wherein said absorbing component is present in at least one of said surfaces.
- 10 10. The process of claim 7, wherein said absorbing component is dispersed in at least one of said layers of said pipes.
11. The process of claim 7, wherein said heating is effected by impingement of optical radiation of a preselected wavelength onto at least a portion of said mating surfaces.
- 15 12. The process of claim 11, wherein at least one of said inner layers strongly absorbs optical radiation of said preselected wavelength and said layers radially outward of said absorbing layer transmit optical radiation of said wavelength and said optical radiation is provided by radial impingement of light of said wavelength.
- 20 13. The process of claim 11, wherein said light is provided by a laser or an infrared lamp.
- 25 14. The process of claim 13, wherein said laser is one of Nd:YAG, diode, CO<sub>2</sub>, or excimer lasers.
- 30 15. The process of claim 1, wherein said pipes comprise layers of thermoplastic materials composed of chemically incompatible materials.
16. The process of claim 15, wherein said joint is substantially free from mixing of said chemically incompatible layers.
- 35 17. A pipe assembly, comprising a first thermoplastic pipe with a first nonplanar mating surface at one end and a second thermoplastic pipe with a second non-planar mating surface at one end, each of said pipes having an

outside surface and an inside surface and comprising a plurality of layers of thermoplastic materials and welded together at a joint with said first and second mating surfaces in abutment.

- 5 18. A pipe assembly as recited by claim 17, wherein said welding is carried out by a process comprising the steps of
- 10 a) preparing said first and second non-planar mating surfaces;  
b) heating said first and second pipes to at least soften said first and second mating surfaces;  
d) bringing said first and second pipes into abutment at said mating surfaces to form a joining zone; and  
e) cooling said first and second pipes under compression to solidify said joining zone, thereby forming a weld joining said pipes.
- 15 19. A pipe assembly as recited by claim 17, wherein said first mating surface tapers radially inwardly from said outside surface to said inside surface; and said second mating surface tapers radially outwardly from said inside surface to said outside surface and is complementary to said first mating surface.
- 20 20. A pipe assembly as recited by claim 17, wherein each of said first and mating surfaces has a plurality of axially projecting teeth and a plurality of indentations between adjacent ones of said teeth, said teeth and indentations of said mating surfaces being complementary, and said pipes are joined in abutment with said teeth and indentations of said mating surfaces in meshed engagement.
- 25 21. A pipe assembly as recited by claim 17, wherein said pipes comprise layers of thermoplastic materials composed of chemically incompatible materials.
- 30 22. A pipe assembly as recited by claim 21, wherein said joint is substantially free from mixing of said chemically incompatible layers.
- 35 23. A pipe assembly, comprising:
- a) a first thermoplastic pipe with a first non-planar mating surface at one end and a second thermoplastic pipe with a second non-planar mating surface at one end, each pipe having an inner welding layer with inside and outside diameters and an outside layer; and

- 5           b) a tubular joint insert composed of a thermoplastic material chemically compatible with said inner layer and having first and second end sections, a center section, and first and second transition sections between said end sections and said center section, said end sections having an outside diameter substantially equal to the inside diameter of said inner welding layers, said center section having an outside diameter substantially equal to the outside diameter of said inner welding layers, and said first mating surface being welded in abutment with at least said first end section and said first transition section and said second mating surface being welded in abutment with at least said second end section and said second transition section.
- 10
24. A pipe assembly as recited by claim 23, wherein said inner welding layers comprise a plurality of sub-layers.
- 15
25. A process for joining a First thermoplastic pipe and a second thermoplastic pipe using a tubular joint insert therebetween, each of said pipes having an outside surface and an inside surface and an inner welding layer with inside and outside diameters and an outside layer, the process comprising the steps of:
- 20
- a) preparing a first non-planar mating surface at one end of said first pipe;
- b) preparing a second non-planar mating surface at one end of said second pipe;
- 25
- c) providing said tubular joint insert having first and second end sections, a center section, and first and second transition sections between said end sections and said center section, said end sections having an outside diameter substantially equal to the inside diameter of said inner welding layers, said center section having an outside diameter substantially equal to the outside diameter of said inner welding layers, and being composed of a thermoplastic material chemically compatible with said inner welding layer;
- 30
- d) bringing into abutment said first mating surface with at least said first end section and said first transition section, and said second mating surface with at least said second end section and said second transition section, to form a joining zone;
- 35
- e) heating said first and second pipes and said tubular joint insert to at least soften said first and second mating surfaces and said tubular joint insert

- f) cooling said first and second pipes and said tubular joint insert under compression to solidify said joining zone, thereby forming a weld joining said pipes.

5 26. A pipe assembly, comprising:

- a) a first thermoplastic pipe with a first mating surface at one end;  
b) a second thermoplastic pipe with a second mating surface at one end,  
c) wherein each of said pipes has an outside surface and an inside surface  
10 and comprises at least inner and outer layers of thermoplastic materials, the relative thickness of said layers varying substantially along the length of said pipes;  
d) said pipes are welded together at a joint with said first and second mating surfaces in abutment; and  
15 e) said mating surfaces are formed at locations an the length of said pipes at which the relative thicknesses of the inner and outer layers pipes are substantially the same and the thickness of one of the layers predominates.

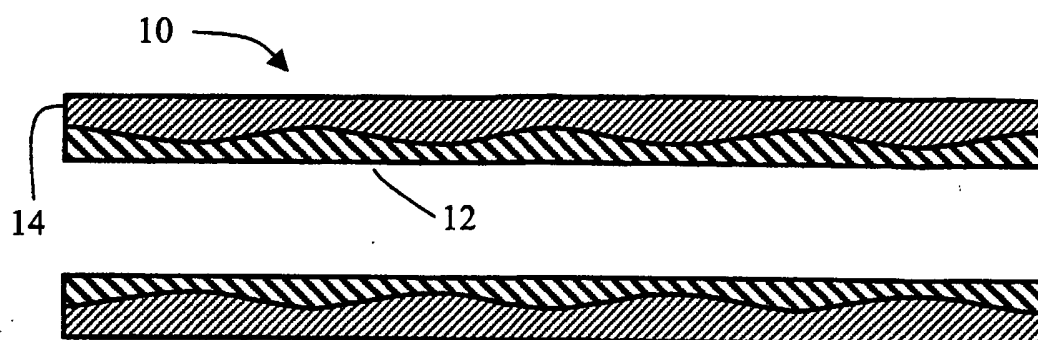
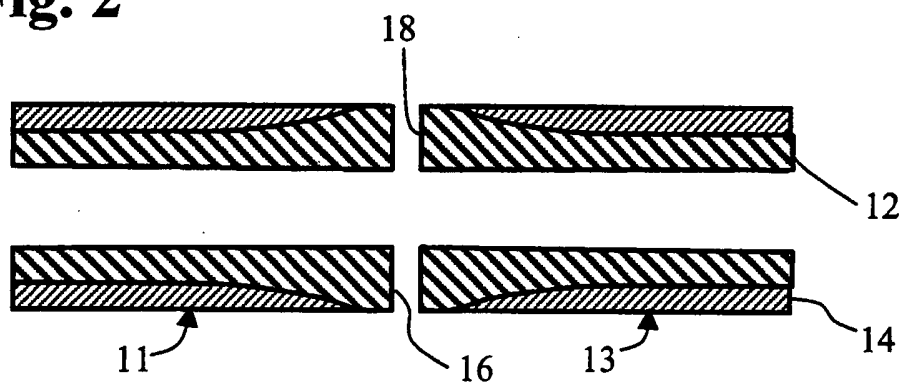
20 27. A process for joining a first pipe and a second pipe, each of said pipes having an outside surface and an inside surface and comprising at least inner and outer layers of thermoplastic materials, the relative thickness of said layers varying along the length of said pipes, the process comprising the steps of

- a) preparing a first mating surface at one end of said first pipe;  
b) preparing a second mating surface at one end of said second pipe;  
c) heating said first and second pipes to at least soften said first and second mating surfaces;  
d) bringing said first and second pipes into abutment at said mating surfaces  
25 to form a joining zone; and  
30 e) cooling said first and second pipes under compression to solidify said joining zone, thereby forming a weld joining said pipes.

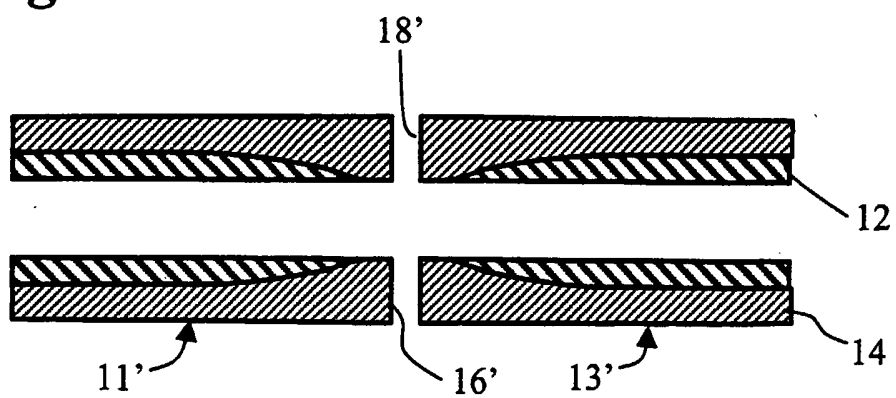
28. A process as recited by claim 27, wherein said relative thickness of said inner and outer layers at said first and second mating surfaces is substantially the same and the thickness of one of the layers predominates.  
35

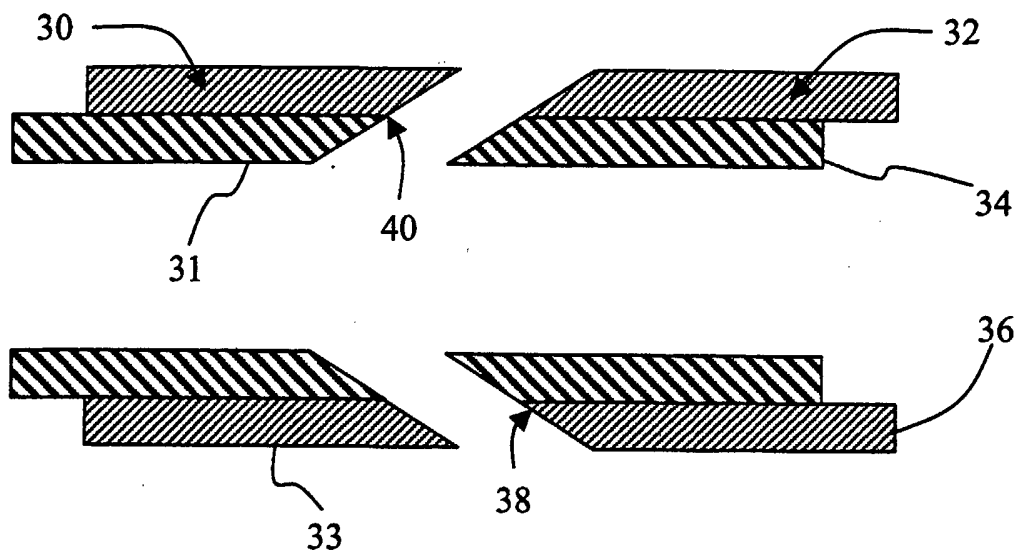
29. For use in joining two multi-layer thermoplastic pipes, each having an outside surface and an inside surface and an inner welding layer with inside and outside diameters and an outside layer, a tubular joint insert having first and  
40

- second end sections, a center section, and first and second transition sections between said end sections and said center section, said end sections having an outside diameter substantially equal to the inside diameter of said inner welding layers, said center section having an outside diameter substantially equal to the outside diameter of said inner welding layers, and being composed of a thermoplastic material chemically compatible with said inner welding layer.
- 5
30. A tubular joint insert as recited by claim 29, said insert having an exterior surface with a plurality of grooves thereon containing a material that absorbs at least one of an electromagnetic induction heating field and optical radiation.
- 10

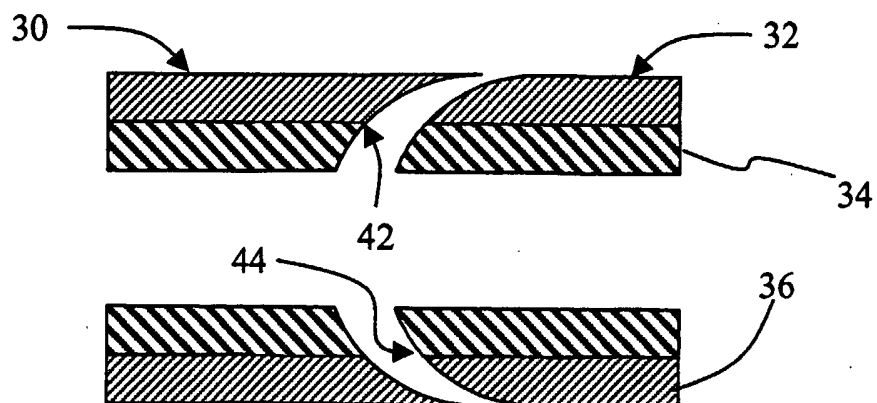
**Fig. 1****Fig. 2**

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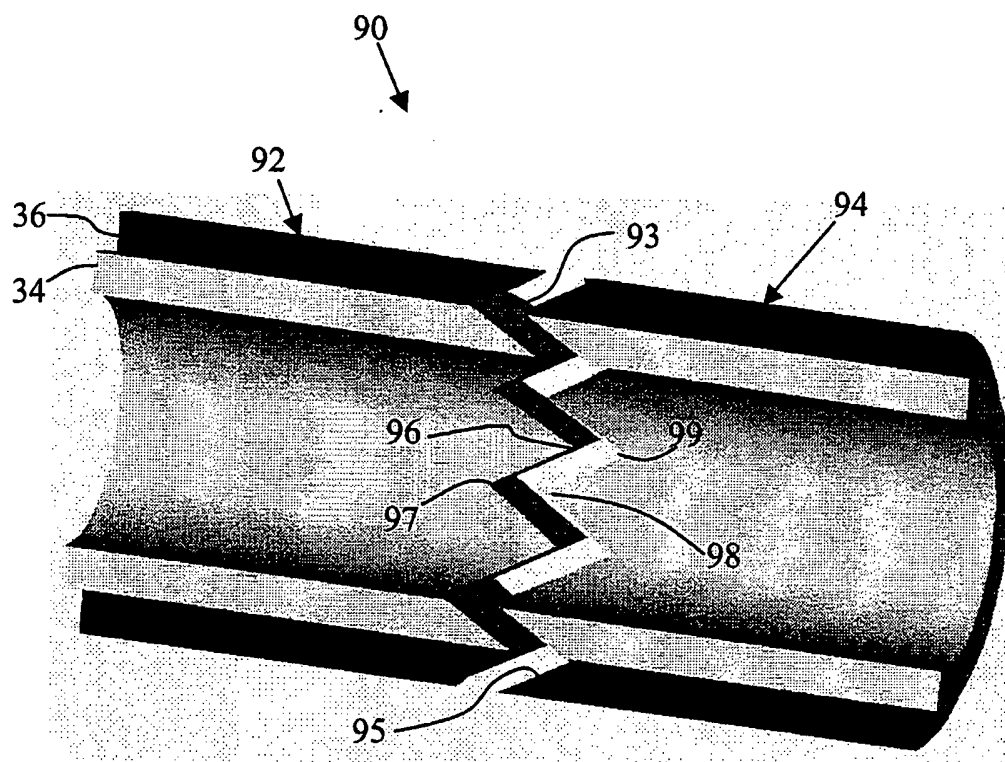
**Fig. 3**

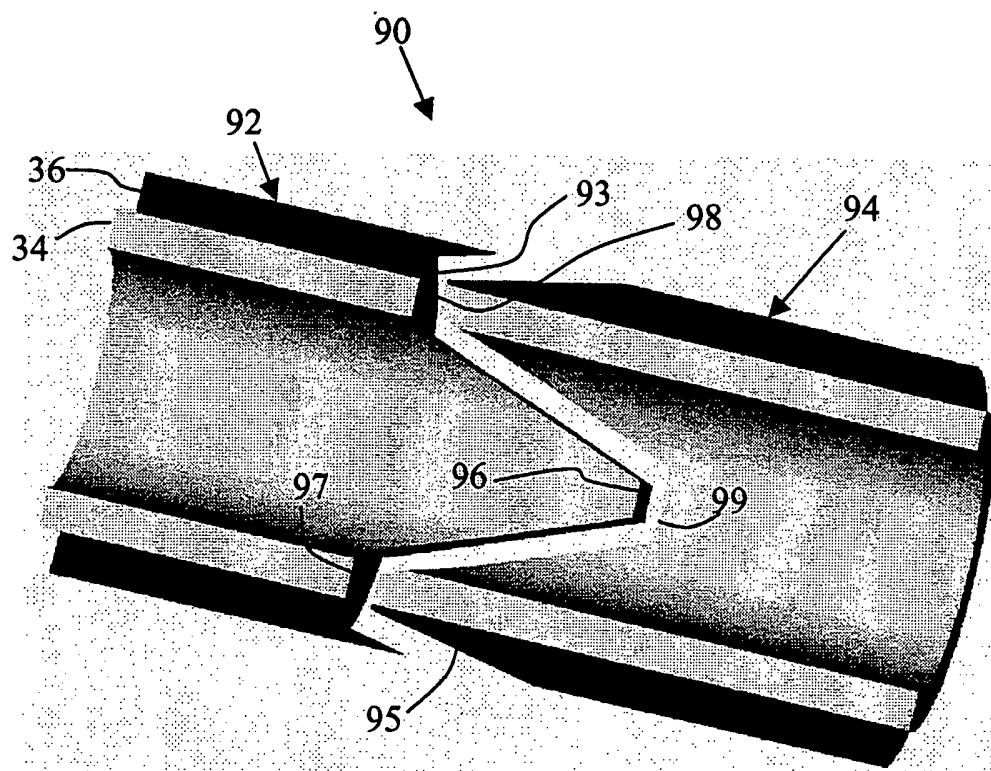
**Fig. 4**

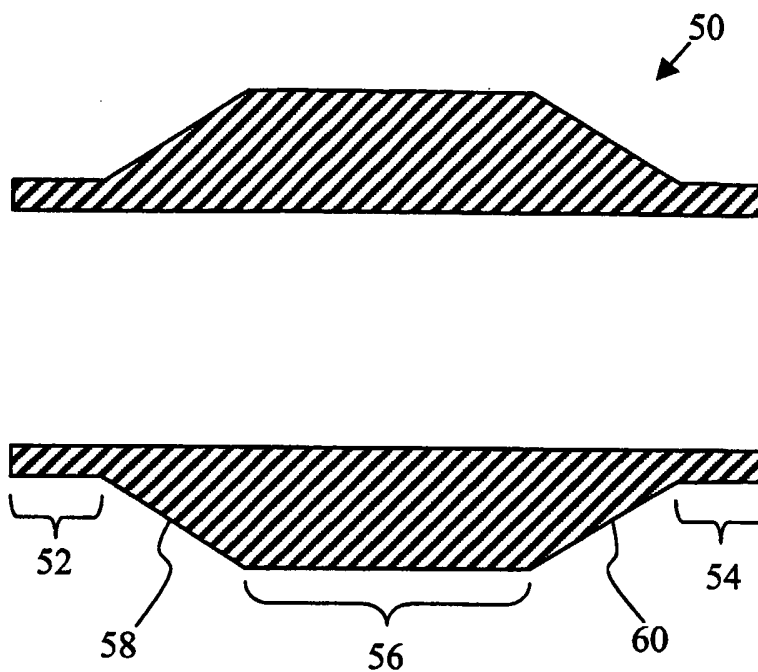
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**Fig. 5**

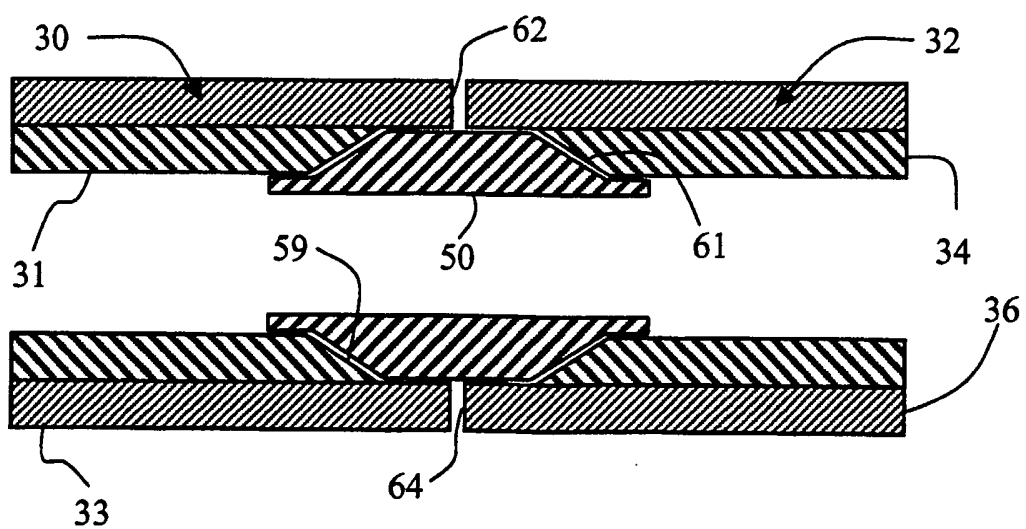
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**Fig. 6a**

**Fig. 6b**

**Fig. 7**

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**Fig. 8**

**Fig. 9**