others. Indeed, in some modes of operation a single chamber can be used to perform both immersion and curing under pressure.

[0026] Such an apparatus provides the flexibility to treat unique and different objects in contrast to the apparatus of the art which have been designed to process a single article, such as, wound glass fibre packages or sheet paper.

[0027] The favoured thermoplastics of the invention are polycapralactones which are, of course, well recognised polyesters, see e.g US 2007/0111037 and US 5,977,203, with a wide range of applications, and are produced by companies such as Perstop.

[0028] It is a first object of the present invention is to provide improved methods for infusing three dimensional printed, free form fabricated or additive manufactured objects.

[0029] It is a separate and yet further object to identify functional polymers which are safer and have greater versatility for use with said method, and to provide stronger and / or better finished objects infused by said polymers.

[0030] It is yet a further and independent object to provide improved apparatus for the automated infusion of three dimensional printed, free form fabricated or additive manufactured objects.

BRIEF SUMMARY OF THE DISCLOSURE

[0031] In accordance with a first aspect of the present invention there is provided a method of infusing, infiltrating or impregnating a three dimensional printed, free-form fabricated or additive manufactured object comprising pores or voids in or between particles or sheets of material from which the object is manufactured characterised in that the object is infused with a thermoplastics material which is a linear or branched semi-crystalline aliphatic polyester with a melting point between 40 °C and 65 °C and a solidification / crystalisation point between 20 °C and 40 °C and which is introduced under controlled conditions of temperature and pressure, and wherein the thermoplastics is caused to penetrate the object by immersing the object in the thermoplastics and controlling the frequency and amplitude of pressure oscillation to ensure sufficient infusion into the object to at least partially fill the pores or voids and bond particles or sheets of material from which the object is manufactured.

[0041] The object may then be presented for inspection, the temperature dropped from the second temperature (T2) to a third handlable temperature (T3), intermediate between the first and second viscosity lowering temperatures (T1 and T2), and if required, surplus material can be removed using a novel thermoplastic removal device.

[0042] Finally the object is tempered under positive pressure (P2) by moving between one or more further intermediate temperatures (T4 and T5) to control crystalinity.

[0043] In accordance with a second aspect of the present invention there is provided an apparatus (10), for post treating three dimensional printed, free-form fabricated or additive manufactured objects (100), comprising:

a) an infusion chamber (12), in which the object to be infused ~~with a thermoplastics (110)~~ is infused with a thermoplastics (110) material which is a linear or branched semi-crystalline aliphatic polyester with a melting point between 40 °C and 65 °C and a solidification / crystalisation point between 20 °C and 40 °C;

b) a reservoir (14) which, in use, is filled with the thermoplastics;

c) a curing chamber (16) for heating and curing the object; and

d) a controller (18) for controlling the operative functions of the apparatus~~;~~ including controlling frequency and amplitude of pressure oscillation.

~~characterised in that the reservoir comprises a heating means (20) and sensors (22, 26, 28) such that the thermoplastics can be melted within defined parameters of temperature (T) and the controller enables the sequential steps of infusion and curing in the apparatus.~~

[0044] In accordance with a third aspect of the present invention there is provided ~~an apparatus (10), for post treating three dimensional printed, free-form fabricated or additive manufactured objects (100), comprising:~~

~~a. an infusion chamber (12), in which the object to be infused with a thermoplastics (110) is infused;~~

~~b. a reservoir (14) which in use is filled with the thermoplastics;~~

~~c. a curing chamber (16) for heating and curing the object; and~~

~~d. a controller (18) for controlling the operative functions of the apparatus;~~

~~characterised in that at least one chamber is constructed such that reactions can be conducted under both negative pressure (P1) and positive pressure (P2/P3).~~ a three dimensional printed, free-form fabricated or additive manufactured object (100) infused with a linear or branched semi-crystalline aliphatic polyester thermoplastic with a melting point between 40 °C and 65 °C and a solidification/crystallisation point of between 20 °C and 40 °C such that pores or voids in or between particles or sheets of material from which the object is manufactured are penetrated by at least 10%.

[0045] In the apparatus of both the second and third aspects there are a number of common features.

[0046] In one embodiment it is preferred that the curing chamber has associated therewith a vacuum pump and one or more of at least one heat sensor(s), pressure sensor(s) and / or level sensor(s).

[0047] By "associated therewith", and as will be apparent from Fig 3 (step 7), it will be apparent that when curing is under pressure, the infusion chamber may also serve as the curing chamber.

[0048] Prefererably the apparatus further comprises a platform, container or arm for supporting the object and a compressor to pressurise the infusion chamber and assist other operative functions.

[0049] More preferably the apparatus also comprises heat means associated with one or more of the infusion chamber and curing chamber.

[0050] In a preferred embodiment a lid seals the reaction chamber and provides support for the platform and the apparatus further comprises a viewing window and one or more fans.

[0051] Preferred thermoplastics for use with said method of the invention, are a linear or branched semi-crystalline aliphatic polyester thermoplastics with a melting point between 40 °C and 65 °C and a solidification/crystallisation point of between 20 °C and 40 °C.

[0052] Preferably the functional polymer is a polycaprolactone. Most preferably it is a polyol, more preferably still a diol, triol, or tetrol.

[0053] The polycaprolactone may have a molecular weight of from between 2000 to 100,000.

[0054] In accordance with a forth aspect of the invention there is provided a three dimensional printed, free-form fabricated or additive manufactured object (100) infused with a linear or branched semi-crystalline aliphatic polyester thermoplastic with a melting point between 40 °C and 65 °C and a solidification/crystallisation point of between 20 °C and 40 °C such that pores or voids in or between particles

CLAIMS

1. A method of infusing, infiltrating or impregnating a three dimensional printed, free-form fabricated or additive manufactured object comprising pores or voids in or between particles or sheets of material from which the object is manufactured characterised in that the object is infused with a thermoplastics material which is a linear or branched semi-crystalline aliphatic polyester with a melting point between 40 °C and 65 °C and a solidification / crystalisation point between 20 °C and 40 °C and which is introduced under controlled conditions of temperature and pressure, and wherein the thermoplastics is caused to penetrate the object by immersing the object in the thermoplastics and controlling the frequency and amplitude of pressure oscillation to ensure sufficient infusion into the object to at least partially fill the pores or voids and bond particles or sheets of material from which the object is manufactured.

2. A method as claimed in claim 1 wherein the pressure is oscillated between negative or atmospheric pressure and positive pressures including over pressure.

3. A method as claimed in claim 1 or 2 wherein the particles or sheets of material have been deposited in layers.

4. A method as claimed in claim 3 wherein the sheets of material comprise paper, plastic, or fabric.

5. A method as claimed in claim 1 wherein the particles from which the object is manufactured comprise a colour absorbent or colour coatable material.

6. A method as claimed in claim 5 wherein the colour absorbent or colour coatable particles comprise plaster or plastics.

7. A method as claimed in claim 6 wherein the plaster further comprises a solvent based co-polymer.

8. A method as claimed in claim 7 wherein the solvent based co-polymer is polyvinyl acetate (PVA).

9. A method as claimed in claim 1 wherein the particles or sheets are coloured.

~~10. A method as claimed in any of the preceding claims wherein the thermoplastics is a linear or branched semi-crystalline aliphatic polyester with a melting point between 40 °C and 65 °C and a solidification / crystalisation point between 20 °C and 40 °C.~~

~~11.~~10. ~~A~~ A method as claimed in claim 1~~10~~ wherein the thermoplastics is a caprolactone or a blend comprising one or more caprolactones.

~~12.~~11. A method as claimed in claim ~~10 or 11~~1 or 10 wherein prior to infusion of the thermoplastics the object is heated to a first temperature (T1) and held at negative pressure (P1) to drive off water and or other volatiles from the pores or voids.

~~13.~~12. A method as claimed in claim ~~10, 11 or 12~~1, 10 or 11 wherein the object is immersed in the thermoplastics and taken to a second viscosity lowering temperature (T2) of from 90 °C to 220 °C under a vaccum (P1) or atmospheric pressure (P0).

~~14.~~13. A method as claimed in claim 12~~13~~ wherein when the second temperature (T2) is reached, the infusion process begins.

~~15.~~14. A method as claimed in claim 13~~14~~ wherein, to drain the thermoplastics, the second viscosity lowering temperature (T2) is maintained, and the thermoplastics is drained under a positive pressure (P2/P3).

~~16.~~15. A method as claimed in claim 14~~15~~ wherein the object is moved through various orientations at the second viscosity lowering temperature (T2) to displace thermoplastics material (46).

~~17.~~16. A method as claimed in claim 14~~15~~ wherein the object is presented for inspection, the temperature is dropped from the second viscosity lowering temperature (T2) to a third handlable temperature (T3), intermediate between the first and second viscosity lowering temperatures (T1 and T2), and if required, material can be removed using a thermoplastic removal device (46).

~~18.~~17. A method as claimed in any of the preceding claims wherein the object is tempered to control recrystalisation of the thermoplastic.

~~19.~~18. A method as claimed in claim 17~~18~~ wherein tempering comprises adjusting the temperature such that the object is taken to one or more further intermediate temperatures (T4 and T5) under positive pressure (P2/P3).

~~20.~~19. An apparatus (10), for treating three dimensional printed, free-form fabricated or additive manufactured objects (100), comprising:

a) an infusion chamber (12), in which the object to be infused ~~with a thermoplastics (110)~~ is infused with a thermoplastics (110) material which is a linear or branched semi-crystalline aliphatic polyester with a melting point between 40 °C and 65 °C and a solidification / crystalisation point between 20 °C and 40 °C;

b) a reservoir (14) which, in use, is filled with the thermoplastics;

c) a curing chamber (16) for heating and curing the object; and

d) a controller (18) for controlling the operative functions of the apparatus including controlling frequency and amplitude of pressure oscillation;

~~characterised in that the reservoir comprises a heating means (20) and sensors (22, 26, 28) such that the thermoplastics can be melted within defined parameters of temperature (T) and the controller enables the sequential steps of infusion and curing in the apparatus~~.

~~21.~~20. An apparatus (10) as claimed in claim 19 wherein the reservoir comprises a heating means (20) and sensors (22, 26, 28) such that the thermoplastics can be melted within defined parameters of temperature (T) and the controller enables the sequential steps of infusion and curing in the apparatus , ~~for treating three dimensional printed, free-form fabricated or additive manufactured objects (100), comprising:~~

~~a) an infusion chamber (12), in which the object to be infused with a thermoplastics (110) is infused;~~

~~b) a reservoir (14) which, in use, is filled with the thermoplastics;~~

~~c) a curing chamber (16) for heating and curing the object; and~~

~~d) a controller (18) for controlling the operative functions of the apparatus;~~

~~characterised in that~~ and/or at least one chamber is constructed such that reactions can be conducted under both negative pressure (P1) and positive pressure (P2/P3).

~~22.~~21. An apparatus as claimed in claim 19 or 20 ~~or 21~~ wherein the curing chamber (16) or the infusion chamber (12) has associated therewith a vacuum pump (24) allowing temperature to be controlled at reduced or elevated pressures and comprises one or more of at least one heat sensor(s) (22), pressure sensor(s) (26) and / or level sensor(s) (28).

~~23. An apparatus as claimed in claim 20, 21 or 22 wherein the curing chamber (16) or the infusion chamber (12) comprises one or more of at least one heat sensor(s) (22), pressure sensor(s) (26) and / or level sensor(s) (28).~~

~~24.~~22. An apparatus as claimed in any of claims ~~20 to 23~~19 to 21 further comprising a platform, container or arm (30) for supporting the object.

~~25.~~23. An apparatus as claimed in any of claims 19 to 22~~20 to 24~~ further comprising a compressor (32) to pressurise the infusion chamber and assist other operative functions, such as, pneumatic control of a door (36), lid (34), ball valve (44), reservoir (14), infusion chamber (12) and material removal device (46).

~~26.~~24. An apparatus as claimed in any of claims 19 to 23 ~~20 to 25~~ further comprising heat means (20) associated with one or more of the infusion chamber (12) and curing chamber (16).

~~27.~~25. An apparatus as claimed in claim 22~~24~~ further comprising a lid (34) which seals the reaction chamber and provides support for the platform (30).

~~28.~~26. An apparatus as claimed in any of claims 19 to 25 ~~20 to 27~~ further comprising a viewing window and door (36).

~~29.~~27. An apparatus as claimed in any of claims 19 to 26 ~~20 to 28~~ further comprising one or more fans (38).

~~30.~~28. A three dimensional printed, free-form fabricated or additive manufactured object (100) infused with a linear or branched semi-crystalline aliphatic polyester thermoplastic with a melting point between 40 °C and 65 °C and a solidification/crystallisation point of between 20 °C and 40 °C such that pores or voids in or between particles or sheets of material from which the object is manufactured are penetrated by at least 10%.

~~31.~~29. A three dimensional printed, free-form fabricated or additive manufactured object (100) infused with a linear or branched semi-crystalline aliphatic polyester thermoplastic as claimed in claim 28~~30~~ wherein the thermoplastics is or comprises a polycaprolactone.

~~32.~~30. A three dimensional printed, free-form fabricated or additive manufactured object (100) infused with a linear or branched semi-crystalline aliphatic polyester thermoplastic as claimed in claim 29~~31~~ wherein the polycaprolactone is a polyol.

~~33.~~31. A three dimensional printed, free-form fabricated or additive manufactured object (100) infused with a linear or branched semi-crystalline aliphatic polyester thermoplastic as claimed in claim 30~~32~~ wherein the polyol is a diol, triol, or tetrol.

~~34.~~32. A three dimensional printed, free-form fabricated or additive manufactured object (100) infused with a linear or branched semi-crystalline aliphatic polyester thermoplastic as claimed in any of claims 28-31 ~~30-33~~ wherein the polycaprolactone has a molecular weight of from 2000 to 100,000.