CLAIMS

What is claimed is:

1. A process for the production of a nickel-titanium mill product comprising:

hot forging a nickel-titanium alloy ingot at a temperature greater than or equal to 500°C to produce a nickel-titanium alloy billet;

hot bar rolling the nickel-titanium alloy billet at a temperature greater than or equal to 500°C to produce a nickel-titanium alloy workpiece;

cold drawing the nickel-titanium alloy workpiece at a temperature less than 500°C to produce a nickel-titanium alloy bar; and

hot isostatic pressing the cold worked nickel-titanium alloy bar for at least 0.25 hour in a HIP furnace operating at a temperature in the range of 700°C to 1000°C and a pressure in the range of 3,000 psi to 50,000 psi.

2. The process of claim 1, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 1.0 hour in a HIP furnace operating at a temperature in the range of 800°C to 950°C and a pressure in the range of 10,000 psi to 17,000 psi.

3. The process of claim 1, wherein the hot forging and the hot bar rolling are independently performed at an initial workpiece temperature in the range of 600°C to 900°C.

4. The process of claim 1, wherein the nickel-titanium alloy workpiece is cold drawn at ambient temperature.

5. The process of claim 1, wherein the process produces a bar mill product that meets size and area fraction requirements of ASTM F 2063 – 12.

6. A process for the production of a nickel-titanium mill product comprising:

hot working a nickel-titanium alloy workpiece at a temperature of greater than or equal to 500°C;

cold working the hot worked nickel-titanium alloy workpiece at a temperature less than 500°C; and

hot isostatic pressing the cold worked nickel-titanium alloy workpiece for at least 0.25 hour in a HIP furnace operating at a temperature in the range of 700°C to 1000°C and a pressure in the range of 3,000 psi to 50,000 psi.

7. The process of claim 6, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 1.0 hour in a HIP furnace operating at a temperature in the range of 800°C to 950°C and a pressure in the range of 10,000 psi to 17,000 psi.

8. The process of claim 6, wherein the hot working is performed at an initial workpiece temperature in the range of 600°C to 900°C.

9. The process of claim 6, wherein the nickel-titanium alloy workpiece is cold worked at ambient temperature.

10. The process of claim 6, wherein the process produces a bar mill product that meets size and area fraction requirements of ASTM F 2063 – 12.

11. A process for the production of a nickel-titanium mill product comprising:

cold working a nickel-titanium alloy workpiece at a temperature less than 500°C; and

hot isostatic pressing the cold worked nickel-titanium alloy workpiece.

12. The process of claim 11, wherein the nickel-titanium alloy workpiece is cold worked at a temperature less than 100°C.

13. The process of claim 11, wherein the nickel-titanium alloy workpiece is cold worked at ambient temperature.

14. The process of claim 11, wherein the cold working comprises at least one cold working technique selected from the group consisting of forging, upsetting, drawing, rolling, extruding, pilgering, rocking, swaging, heading, coining, and combinations of any thereof.

15. The process of claim 11, comprising:

cold working the nickel-titanium alloy workpiece in a first cold working operation at ambient temperature;

annealing the cold worked nickel-titanium alloy workpiece;

cold working the nickel-titanium alloy workpiece in a second cold working operation at ambient temperature; and

hot isostatic pressing the twice cold worked nickel-titanium alloy workpiece.

16. The process of claim 15, further comprising, after the second cold working operation and before the hot isostatic pressing, subjecting the nickel-titanium alloy workpiece to:

at least one additional intermediate annealing operation; and

at least one additional cold working operation at ambient temperature.

17. The process of claim 15, wherein the nickel-titanium alloy workpiece is annealed at a temperature in the range of 700°C to 900°C.

18. The process of claim 15, wherein the nickel-titanium alloy workpiece is annealed for at least 20 seconds furnace time.

19. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 0.25 hour in a HIP furnace operating at a temperature in the range of 700°C to 1000°C and a pressure in the range of 3,000 psi to 50,000 psi.

20. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) in a HIP furnace operating at a temperature in the range of 800°C to 1000°C and a pressure in the range of 7,500 psi to 20,000 psi.

21. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) in a HIP furnace operating at a temperature in the range of 800°C to 950°C and a pressure in the range of 10,000 psi to 17,000 psi.

22. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) in a HIP furnace operating at a temperature in the range of 850°C to 900°C and a pressure in the range of 12,000 psi to 15,000 psi.

23. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 2.0 hours in a HIP furnace operating at a temperature in the range of 800°C to 1000°C and a pressure in the range of 7,500 psi to 20,000 psi.

24. The process of claim 11, further comprising hot working the nickel-titanium alloy workpiece before the cold working.

25. The process of claim 24, wherein the hot working is performed at an initial workpiece temperature in the range of 600°C to 900°C.

26. The process of claim 11, wherein the process produces a mill product selected from the group consisting of a billet, a bar, a rod, a wire, a tube, a slab, a plate, and a sheet.

27. The process of claim 11, wherein:

the cold working reduces size and area fraction of non-metallic inclusions in the nickel-titanium alloy workpiece; and

the hot isostatic pressing reduces porosity in the nickel-titanium alloy workpiece.

28. The process of claim 1, wherein the process produces a mill product that meets the size and area fraction requirements of ASTM F 2063 – 12.

CLAIMS

1. A process for the production of a nickel-titanium mill product comprising:

hot forging a nickel-titanium alloy ingot at a temperature greater than or equal to 500°C to produce a nickel-titanium alloy billet;

hot bar rolling the nickel-titanium alloy billet at a temperature greater than or equal to 500°C to produce a nickel-titanium alloy workpiece;

cold drawing the nickel-titanium alloy workpiece at a temperature less than 500°C to produce a nickel-titanium alloy bar; and

hot isostatic pressing the cold worked nickel-titanium alloy bar for at least 0.25 hour in a HIP furnace operating at a temperature in the range of 700°C to 1000°C and a pressure in the range of 3,000 psi to 50,000 psi.

2. The process of claim 1, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 1.0 hour in a HIP furnace operating at a temperature in the range of 800°C to 950°C and a pressure in the range of 10,000 psi to 17,000 psi.

3. The process of claim 1, wherein the hot forging and the hot bar rolling are independently performed at an initial workpiece temperature in the range of 600°C to 900°C.

4. The process of claim 1, wherein the nickel-titanium alloy workpiece is cold drawn at ambient temperature.

5. The process of claim 1, wherein the process produces a bar mill product that meets size and area fraction requirements of ASTM F 2063 – 12.

6. A process for the production of a nickel-titanium mill product comprising:

hot working a nickel-titanium alloy workpiece at a temperature greater than or equal to 500°C;

cold working the hot worked nickel-titanium alloy workpiece at a temperature less than 500°C; and

hot isostatic pressing the cold worked nickel-titanium alloy workpiece for at least 0.25 hour in a HIP furnace operating at a temperature in the range of 700°C to 1000°C and a pressure in the range of 3,000 psi to 50,000 psi.

7. The process of claim 6, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 1.0 hour in a HIP furnace operating at a temperature in the range of 800°C to 950°C and a pressure in the range of 10,000 psi to 17,000 psi.

8. The process of claim 6, wherein the hot working is performed at an initial workpiece temperature in the range of 600°C to 900°C.

9. The process of claim 6, wherein the nickel-titanium alloy workpiece is cold worked at ambient temperature.

10. The process of claim 6, wherein the process produces a bar mill product that meets size and area fraction requirements of ASTM F 2063 – 12.

11. A process for the production of a nickel-titanium mill product comprising:

hot working a nickel-titanium alloy workpiece at a temperature greater than or equal to 500°C;

cold working the hot worked nickel-titanium alloy workpiece at a temperature less than 500°C; and

hot isostatic pressing the cold worked nickel-titanium alloy workpiece.

12. The process of claim 11, wherein the nickel-titanium alloy workpiece is cold worked at a temperature less than 100°C.

13. The process of claim 11, wherein the nickel-titanium alloy workpiece is cold worked at ambient temperature.

14. The process of claim 11, wherein the cold working comprises at least one cold working technique selected from the group consisting of forging, upsetting, drawing, rolling, extruding, pilgering, rocking, swaging, heading, coining, and combinations of any thereof.

15. The process of claim 11, comprising:

cold working the nickel-titanium alloy workpiece in a first cold working operation at ambient temperature;

annealing the cold worked nickel-titanium alloy workpiece;

cold working the nickel-titanium alloy workpiece in a second cold working operation at ambient temperature; and

hot isostatic pressing the twice cold worked nickel-titanium alloy workpiece.

16. The process of claim 15, further comprising, after the second cold working operation and before the hot isostatic pressing, subjecting the nickel-titanium alloy workpiece to:

at least one additional intermediate annealing operation; and

at least one additional cold working operation at ambient temperature.

17. The process of claim 15, wherein the nickel-titanium alloy workpiece is annealed at a temperature in the range of 700°C to 900°C.

18. The process of claim 15, wherein the nickel-titanium alloy workpiece is annealed for at least 20 seconds furnace time.

19. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 0.25 hour in a HIP furnace operating at a temperature in the range of 700°C to 1000°C and a pressure in the range of 3,000 psi to 50,000 psi

20. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) in a HIP furnace operating at a temperature in the range of 800°C to 1000°C and a pressure in the range of 7,500 psi to 20,000 psi.

21. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) in a HIP furnace operating at a temperature in the range of 800°C to 950°C and a pressure in the range of 10,000 psi to 17,000 psi.

22. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) in a HIP furnace operating at a temperature in the range of 850°C to 900°C and a pressure in the range of 12,000 psi to 15,000 psi.

23. The process of claim 11, wherein the nickel-titanium alloy workpiece is hot isostatic pressed (HIP) for at least 2.0 hours in a HIP furnace operating at a temperature in the range of 800°C to 1000°C and a pressure in the range of 7,500 psi to 20,000 psi.

24. The process of claim 11, wherein the hot working is performed at an initial workpiece temperature in the range of 600°C to 900°C.

25. The process of claim 11, wherein the process produces a mill product selected from the group consisting of a billet, a bar, a rod, a wire, a tube, a slab, a plate, and a sheet.

26. The process of claim 11, wherein:

the cold working reduces size and area fraction of non-metallic inclusions in the nickel-titanium alloy workpiece; and

the hot isostatic pressing reduces porosity in the nickel-titanium alloy workpiece.

27. The process of claim 1, wherein the process produces a mill product that meets the size and area fraction requirements of ASTM F 2063 – 12.