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(54) **PROCESS FOR PRODUCING A TURBINE WHEEL FOR AN EXHAUST GAS TURBOCHARGER**

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(57) **ABSTRACT**

The invention relates to a process for producing a turbine wheel for an exhaust gas turbocharger by metal powder injection molding, which comprises the following steps: (a) provision of a feedstock comprising a metal powder and a binder, (b) provision of a tool which comprises a negative mold of the turbine wheel to be produced for metal powder injection molding of the turbine wheel, (c) introduction of a rotationally symmetrical core comprising a binder into the negative mold of the tool provided in process step (b) and alignment of the core so that it is aligned symmetrically about the axis of rotation of the turbine wheel to be produced, (d) production of a green body by metal powder injection molding of the feedstock provided in process step (a) around the core, (e) carrying out of a binder removal step to remove the binder from the green body in order to obtain a molding in the shape of the turbine wheel, and (f) sintering of the molding.

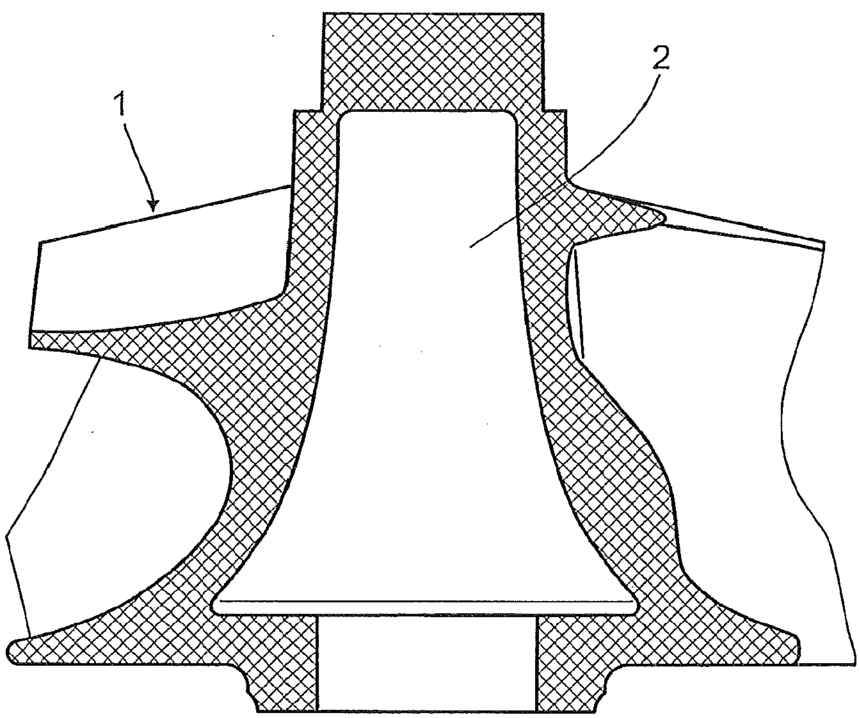
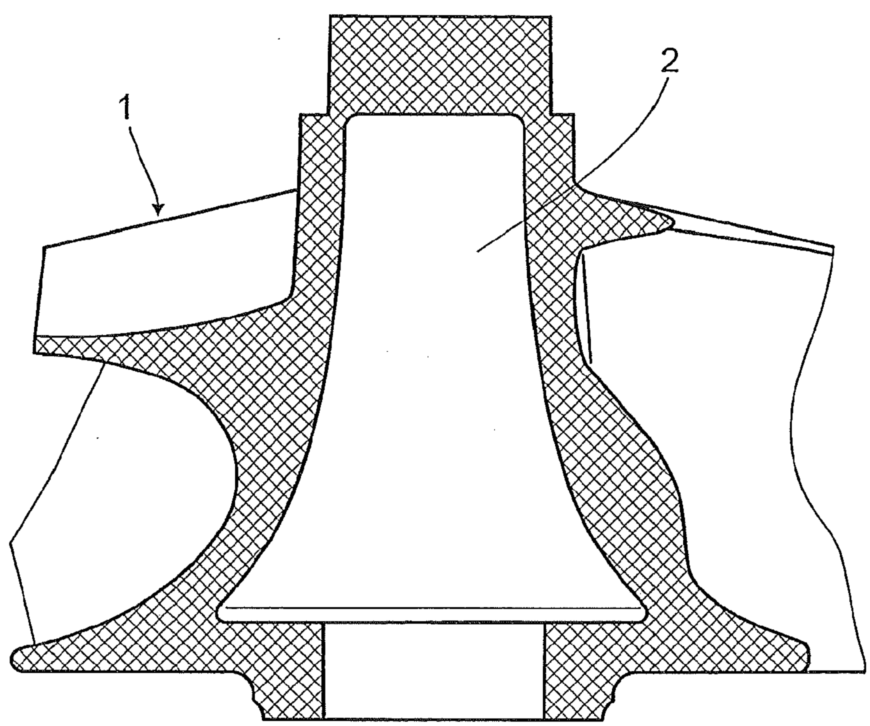


FIG.1



PROCESS FOR PRODUCING A TURBINE WHEEL FOR AN EXHAUST GAS TURBOCHARGER

[0001] The invention relates to a process for producing a reduced-weight turbine wheel for an exhaust gas turbocharger in internal combustion engines by means of metal powder injection molding.

[0002] A turbocharger for an internal combustion engine comprises an exhaust gas turbine which is arranged in the exhaust gas stream of the internal combustion engine and is connected by a shaft to a compressor in the intake tract of the internal combustion engine. The turbine is set into rotation by the exhaust gas stream of the internal combustion engine and drives the compressor wheel. The compressor wheel increases the pressure in the intake tract of the engine so that a larger amount of air goes into the cylinder during the intake phase than in the case of a suction engine. As a result, more oxygen is available for the combustion of a correspondingly greater amount of fuel. The turbine wheel of the "hot" side exposed to the exhaust gas stream, which has a complex geometry, is usually produced from a high-temperature-resistant material by precision casting and connected to the shaft by friction welding. The compressor wheel is installed at the opposite end of the shaft, for example by means of a screw connection. During operation of the turbocharger, extremely high rotational speeds of the shaft together with the two wheels of up to about 300 000 rpm are reached. To achieve a very rapid response of the turbocharger, the inertia of the rotating parts should be very low.

[0003] One document which is concerned with reducing the weight of turbocharger components is the Japanese first publication JP 2007-120409. This document discloses the decoring of a turbine wheel and thus saving of material for reducing the weight. The decored turbine wheel is produced by means of a precision casting process. However, a disadvantage is that the precision casting process described is complicated and expensive.

[0004] Metal powder injection molding (MIM) is known as a process for the mass production of metallic components, in particular for components of this type with close-to-final dimensions. The MIM process allows small to medium-sized parts having a complex shape to be produced inexpensively and automatically in large numbers.

[0005] The MIM process comprises plasticization of metal powders having a spherical or irregular morphology (particle sizes of the powder are generally less than 100 μm) by means of a binder to give a feedstock. Homogenization of the feedstock is carried out in a kneader and the feedstock is subsequently introduced into an injection molding machine. Parts of the binder (for example suitable waxes) are melted in a heated zone to give a melt. A screw then conveys the melt into a dividable too mold. After filling of the mold is complete, the melt resolidifies and makes it possible for the component to be taken from the mold. Removal of the binder is effected by means of a binder removal step preceding sintering. Depending on the binder, the binders are removed from the component in various ways.

[0006] In the case of binder removal, a distinction is generally made between thermal binder removal (melting-out or decomposition of the binder via the gas phase), solvent extraction and catalytic binder removal. The binder removal step is followed by the sintering process in which densification of the component to over 95%, preferably even over 98%, of the theoretical density is achieved by means of diffusion processes.

[0007] The use of metal powder injection molding in the production of exhaust gas turbocharger components has hitherto failed because the process was not sufficiently economical in order to displace the conventional production process of precision casting.

[0008] It is an object of the invention to provide a novel economical process for producing a turbine wheel for an exhaust gas turbocharger of an internal combustion engine, by means of which reduced-weight turbine wheels for exhaust gas turbochargers can be produced in a simple way.

[0009] This object is achieved by a process for producing a turbine wheel for an exhaust gas turbocharger by metal powder injection molding, which comprises the following steps:

- **[0010]** a) provision of a feedstock comprising a metal powder and a binder,
- **[0011]** b) provision of a tool which comprises a negative mold of the turbine wheel to be produced for metal powder injection molding of the turbine wheel,
- **[0012]** c) introduction of a rotationally symmetrical core comprising a binder into the negative mold of the tool provided in process step (b) and alignment of the core so that it is aligned symmetrically about the axis of rotation of the turbine wheel to be produced,
- **[0013]** d) production of a green body by metal powder injection molding of the feedstock provided in process step (a) around the core,
- **[0014]** e) carrying out of a binder removal step to remove the binder from the green body and at the same time to remove the core in order to obtain a molding in the form of the turbine wheel, and
- **[0015]** f) sintering of the molding.

[0016] The process of the invention makes it possible to produce turbine wheels for exhaust gas turbochargers, which have a hollow space of defined internal structure, simply and inexpensively. The internal structure which defines a hollow space is formed by removal of the core in the binder removal step carried out in process step (e). This makes it economical to produce turbine wheels, which have hitherto been manufactured as solid components by means of precision casting, as hollow components in large numbers, as a result of which a significant weight reduction can be achieved in the turbocharger. This weight reduction leads to a more rapid response associated with a lower fuel requirement and an increase in the efficiency of the internal combustion engine and also a considerable saving of material. Furthermore, the process of the invention makes it possible, in contrast to the precision casting process known in the prior art, to produce turbine wheels for exhaust gas turbochargers in a particularly fine design with wall thicknesses in the range from 0.1 to 1 mm.

[0017] For the purposes of the invention, the term "feedstock" generally refers to a composition which comprises a sinterable metal or ceramic powder and a binder and is suitable for use in metal powder injection molding. Such compositions are known to those skilled in the art. The term "metal powder" refers, for the purposes of the invention, to a pulverulent metal or a pulverulent metal alloy or a mixture thereof. As metals which can be comprised in powder form in the feedstock, mention may be made by way of example of iron, cobalt, nickel, chromium, titanium, molybdenum, niobium and aluminum; alloys are, for example, nickel-based alloys or titanium-based alloys. The alloys are preferably nickel-based alloys which can be obtained, for example, under the trade name Inconel® 713; these comprise 74% by weight of nickel, 12.5% by weight of chromium, 4.2% by weight of molybdenum, 2% by weight of niobium, 6% by weight of aluminum, 0.8% by weight of titanium and 0.12% by weight of carbon. Preference is likewise given in the case of the nickel-based alloy to an alloy which can be obtained under the trade name Inconel® 718. This base alloy comprises from 50 to 55% by weight of nickel, from 17 to 21% by weight of chromium, <24% by weight of iron, from 2.8 to 3.3% by weight of molybdenum, from 4.8 to 5.5% by weight of niobium, from 0.2 to 0.8% by weight of aluminum, from 0.7 to 1.1% by weight of titanium and less than 0.08% by weight of carbon. Preference is likewise given in the case of the nickel-based alloy to NIMON IC® 90. NIMONIC 90 comprises less than 0.13% by weight of carbon, from 2 to 3% by weight of titanium, from 1 to 2% by weight of aluminum, less than 1.5% by weight of iron, from 15 to 21% by weight of cobalt, from 18 to 21% by weight of chromium, with the balance being nickel. The nickel-based alloy is more preferably HASTELLOY® X. HASTELLOY® X is an alloy comprising from 0.05 to 0.15% by weight of carbon, less than 0.5% by weight of aluminum, from 0.5 to 2.5% by weight of cobalt, from 8 to 10% by weight of molybdenum, from 17 to 20% by weight of iron, from 20 to 23% by weight of chromium and nickel as balance. A further suitable alloy is an alloy which comprises about 15% by weight of chromium, about 10% by weight of iron, 5% by weight of molybdenum, 2% by weight of titanium, niobium and nickel. The proportion of metal powder in the feedstock can vary over a wide range and is usually from 40 to 70% by volume, preferably from 45 to 60% by volume, based on the feedstock.

[0018] Herein suitable "binders" are in principle all systems which are known from the prior art and are suitable for use in metal powder injection molding. The proportion of binder in the feedstock can vary over a wide range and is usually from 10 to 60% by volume, preferably from 30 to 50% by volume, based on the feedstock. Suitable binders are thermoplastic resins in general, e.g. polystyrene, polypropylene, polyethylene and ethylene-vinyl acetate copolymers. Such binders can be removed from the green body by, for example, heating to temperatures of from 300 to 500° C. over a period of from 3 to 8 hours. Here, the binder is thermally dissociated. Further suitable binders are those which can be removed from the green body by extraction with a solvent. Binders based on polyoxymethylene are likewise suitable and are removed by treatment of the green body in a gaseous, acid-comprising atmosphere. Acids used in these processes are usually protic acids, i.e. acids which on reaction with water are dissociated into a proton (hydrated) and an anion.

[0019] In a preferred embodiment of the invention, the feedstock comprises

[0020] A) from 40 to 90% by volume of a sinterable pulverulent metal or a pulverulent metal alloy or a mixture thereof,

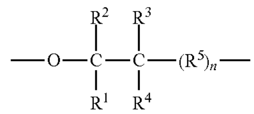
[0021] B) from 10 to 60% by volume of a mixture of

[0022] B1) from 80 to 98% by weight, in particular from 85 to 98% by weight, based on B), of a polyoxymethylene homopolymer or copolymer and

[0023] B2) from 2 to 20% by weight, in particular from 2 to 15% by weight, of a polyolefin or a mixture of polyolefins.

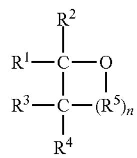
[0024] The polyoxymethylene homopolymers or copolymers are known per se to those skilled in the art and are described in the literature. The homopolymers are generally prepared by polymerization of formaldehyde or trioxane, preferably in the presence of suitable catalysts. Preferred polyoxymethylene copolymers comprise, in addition to the repeating units —OCH_2—, up to 50 mol %, preferably from 0.1 to 20 mol % and particularly preferably from 0.3 to 10 mol %, of repeating units

(I)



where R^1 to R^4 are each, independently of one another, a hydrogen atom, a C_1-C_4-alkyl group or a halogen-substituted alkyl group having from 1 to 4 carbon atoms and R^5 is a CH_2—, —CH_2—O—, a methylene group substituted by C_1-C_4-alkyl or C_1-C_4-haloalkyl or a corresponding oxymethylene group and n is in the range from 0 to 3. These groups can advantageously be introduced into the copolymers by ring opening of cyclic ethers. Preferred cyclic ethers are those of the formula (II)

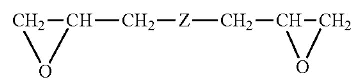
(II)



where R^1 to R^5 and n are as defined above. Purely by way of example, mention may be made of ethylene oxide, 1,2-propylene oxide, 1,2-butylene oxide, 1,3-butylene oxide, 1,3-dioxane, 1,3-dioxolane and dioxepane as cyclic ethers and linear oligoformals or polyformals such as polydioxolane or polydioxepane as copolymers.

[0025] Further polymers suitable as component B1) are oxymethylene terpolymers which are prepared, for example, by reaction of trioxane, one of the cyclic ethers described above and a third monomer, preferably a bifunctional compound of the formula (III)

(III)



where Z is a chemical bond, —O— or —ORO— (R═C_1-C_8-alkylene or C_3-C_8-cycloalkylene). Preferred monomers of this type are ethylene diglycide, diglycidyl ether and diethers of glycidyls and formaldehyde, dioxane or trioxane in a molar ratio of 2:1 and also diethers derived from 2 mol of glycidyl compound and 1 mol of an aliphatic diol having from 2 to 8 carbon atoms, e.g. the diglycidyl ethers of ethylene glycol, 1,4-butanediol, 1,3-butanediol, cyclobutane-1,3-diol, 1,2-propanediol and cyclohexane-1,4-diol, to name only a few examples.

[0026] Processes for preparing the above-described homopolymers and copolymers are known to those skilled in the art and are described in the literature, so that further details are superfluous here. The preferred polyoxymethylene homopolymers and copolymers have melting points of at least 150° C. and molecular weights (weight average) in the range from 5000 to 150 000, preferably from 7000 to 60 000.

[0027] Component B2) comprises polyolefins or mixtures thereof. As polyolefins, mention may be made of those having from 2 to 8 carbon atoms, in particular from 2 to 4 carbon atoms, and also copolymers thereof. Particular preference is given to polyethylene and polypropylene and copolymers thereof, as are known to those skilled in the art and are commercially available, for example under the trade names Lupolen® and Novolen® from BASF SE.

[0028] As component C), the binders used in the process of the invention can comprise from 0 to 6% by volume, preferably from 1 to 5% by volume, of a dispersant. Mention may here be made, purely by way of example, of oligomeric polyethylene oxide having an average molecular weight of from 200 to 600, stearic acid, stearamide, hydroxystearic acid, fatty alcohols, fatty alcohol sulfonates and block copolymers of ethylene oxide and propylene oxide.

[0029] In addition, the binders can further comprise customary additives and processing aids which favorably influence the rheological properties of the mixtures during shaping.

[0030] The feedstock is usually produced by melting the component B), preferably in a twin-screw extruder, at temperatures of preferably from 150 to 220° C., in particular from 170 to 200° C. The metal powder A) is subsequently introduced in the required amount into the melt stream of the binder (component B)) at temperatures in the same range.

[0031] In process step (b) of the process of the invention, a tool which comprises a negative mold of the turbine wheel to be produced is provided. According to the invention, this is suitable for metal powder injection molding of the turbine wheel. Such tools are known to those skilled in the art and do not have to be described in more detail at this point. In general, the tool is a tool which allows cores to be withdrawn.

[0032] After provision of the tool which comprises the negative mold of the turbine wheel to be produced, a rotationally symmetrical core is introduced into the negative mold of the tool in process step (c) of the process of the invention. The rotationally symmetrical core is an auxiliary by means of which a hollow space structure is introduced into the turbine wheel. This core is, according to the invention, aligned in the negative mold in such a way that it is present symmetrically about the axis of rotation of the turbine wheel to be produced. “Symmetrically about the axis of rotation” means that the core is arranged in the negative mold in such a way that it can cause no imbalance in the turbine wheel produced as a result of its alignment. The core comprises the above-defined binder or consists of a binder as defined above, as a result of which it is removed completely from the turbine wheel during production of the turbine wheel after the process of the invention has been carried out and leaves behind a hollow space structure which is arranged symmetrically to the rotation axis. According to a general embodiment of the invention, the core is introduced on a suitable accommodation device into the tool and held in position. The accommodation device can be, for example, a pin or a rod onto which the core is positioned. The binder or constituents of the binder of which the core is composed can then diffuse out of the hollow space which the accommodation device leaves behind in the green body during the binder removal step.

[0033] In process step (d) of the process of the invention, the feedstock provided in process step a) is injected into the negative mold around the core to produce a green body. Conventional screw or piston injection molding machines can be used for carrying out injection molding in process step (d). The shaping of the feedstock is generally carried out at temperatures of from 60 to 200° C. and injection pressures of from 300 to 2000 bar in tools which have a temperature of from 60 to 150° C. This produces a green body which has the structure of the turbine wheel to be produced and comprises the core made from the binder.

[0034] To remove the binder from the feedstock and to remove the core from the green body, the binder removal step, viz. process step (e), is carried out in order to obtain a molding having the shape of the turbine wheel. The binder removal step is carried out as a function of the binder selected. The progress of the binder removal step can be monitored by a person skilled in the art by, for example, determining the weight change of the green body. If the preferred binder comprising the components A), B) and optionally C) is used, the binder removal step is generally carried out at temperatures in the range from 20 to 180° C. for a period of from 0.1 to 24 hours, preferably from 0.5 to 12 hours, in a gaseous acid-comprising atmosphere. Suitable acids for the treatment are inorganic acids which are gaseous at room temperature or at least can be vaporized at the treatment temperature. Hydrogen halides and HNO_3 may be mentioned by way of example. Suitable organic acids are those which have a boiling point of less than 130° C. at atmospheric pressure, for example formic acid, acetic acid or trifluoroacetic acid or mixtures thereof. Further suitable acids are BF_3 and its adducts with organic ethers. The required treatment time depends quite generally on the treatment temperature and the concentration of the acid in the treatment atmosphere. If a carrier gas is used, this is generally passed beforehand through the acid and loaded with the latter. The loaded carrier gas is then brought to the treatment temperature which is advantageously higher than the loading temperature in order to avoid condensation of the acid. The acid is preferably mixed into the carrier gas via a metering device and the mixture is heated to such an extent that the acid can no longer condense.

[0035] The binder removal step can also be carried out, for example, in two stages. The treatment in the first stage is carried out until the polyoxymethylene component B1) of the binder has been removed to an extent of at least 80% by weight, preferably at least 90% by weight. This can easily be recognized from the decrease in weight of the green body. The molding obtained in this way is subsequently heated at from 250 to 500° C., preferably from 350 to 450° C., for from 0.1 to 12 hours, preferably from 0.3 to 6 hours, in order to remove virtually all the remaining binder.

[0036] The molding which has been freed of the binder in the binder removal step can be converted in the usual way into a metallic molding by sintering. During sintering, moldings are densified and shrunk to form components having the final geometric properties. During sintering, the molding accordingly becomes smaller, with the dimensions having to shrink uniformly in all three directions in space. The linear shrinkage is, depending on the binder content, generally from 10% to 20%. Sintering can be carried out under various protective gases or under reduced pressure. Process step (f) is generally carried out at temperatures in the range from 250 to 1500° C. The sintering time is generally in the range from 1 to 12 hours, preferably in the range from 2 to 5 hours. In a preferred embodiment of the invention, a holding device which supports the molding during sintering in order to at least largely prevent distortion of the component is used during sintering in process step (f). In an embodiment of the invention, this holding device is fastened in the form of a mandrel to the component. In a particularly preferred embodiment of the invention, one or more holding devices whose materials composition and wall thickness are matched to the materials composition and wall thickness of the turbine wheel to be produced are used during sintering. This ensures that the molding to be sintered and the corresponding holding device are densified and shrink to the same extent during sintering. To avoid reaction or diffusion between component and holding device during sintering and thus avoid sintering together of component and holding device, one surface of the respective holding device is coated at least in sections. The surface is coated in at least those sections in which the holding device is in contact with the molding to be sintered. The holding device can also be coated on all sides. Of course, the coating used depends on the material or materials composition of the moldings to be sintered. The use of a ceramic coating or a coating of titanium nitrite for the holding device is preferred.

[0037] In a preferred embodiment of the invention, the core introduced in process step (c) comprises the same binder which is comprised in the feedstock. This advantageously ensures that the removal of the core and of the binder comprised in the feedstock can be carried out in an identical process step.

[0038] The size and/or geometry of the rotationally symmetrical core introduced in process step (c) can be varied over wide ranges. In general, the size of the core is selected so that it has a volume which is from about 5 to 60% of the volume of the turbine wheel, preferably from 45 to 55% of the volume of the turbine wheel. The incorporation of the core and the hollow space structure resulting therefrom gives a turbine wheel which can be produced in a simple manner and has a significantly reduced weight compared to the turbine wheels known from the prior art. Furthermore, the process of the invention allows turbine wheels having a lost core to be produced.

[0039] The introduction of the core into the central region of the turbine wheel which has considerable thicknesses and accumulations of mass makes it possible to avoid voids and defects which usually occur. The geometry of the core can be selected by a person skilled in the art as a function of the geometry of the turbine wheel. Cores which have a cone geometry, ball geometry (spherical geometry), elliptical geometry, cylindrical geometry or very generally a rotationally symmetrical geometry are generally suitable. As core, it is also possible, in a preferred embodiment of the invention, to select a core whose geometry approximately reproduces the geometry of the turbine wheel, as a result of which particularly weight-optimized turbine wheels whose wall thicknesses are selected so that they withstand the forces acting on them during operation can be obtained.

[0040] After production of the turbine wheel of the invention, the latter is usually joined by friction welding or direct injection molding to a shaft and subsequently balanced.

[0041] In one embodiment of the invention, the turbine wheel obtained in process step (f) is connected by means of metal injection molding to a shaft in a further process step (g).

[0042] The invention is illustrated by the figures and examples below.

[0043] FIG. **1** shows a sectional view of the turbine wheel **1** for an exhaust gas turbocharger for internal combustion engines.

[0044] The turbine wheel **1** for an exhaust gas turbocharger for internal combustion engines which is shown in FIG. **1** has a hollow space structure **2** which has been created by means of the process of the invention. The hollow space structure is located in the center of the turbine wheel and is symmetrical about the rotational axis of the turbine wheel **1**.

EXAMPLE

[0045] As feedstock, use was made of an injection-moldable pelletized material for producing sintered moldings of a heat-resistant nickel superalloy (DIN 2 4632), which is marketed by BASF SE under the trade name Catamold® N90.

[0046] The feedstock was processed on an Engel ES80/10 thermoplastics injection molding machine.

[0047] The settings on the machine were as follows:

	Barrel temperature			
	Zone 1 160° C.	Zone 2 170° C.	Zone 3 180° C.	Die 190° C.
Tool surface temperature			128° C.	
Rotational speed of screw			50 min^{-1}	
Injection rate			10 cm^3/s	
Maximum injection pressure			2000 bar	
Hold time			3 s	
Banking-up pressure			0 bar	
Cooling time in the tool			30 s	

[0048] Before carrying out injection molding, a core comprising the binder and having a volume of about 6 cm^3 was introduced into the negative mold of the tool.

[0049] Binder removal was carried out at 110° C. in an HNO_3 atmosphere. A Heraeus VT 6060 MU2 binder removal oven having a volume of 50 l and provided with acid introduction at 30 ml/h and a flushing gas flow (nitrogen) of 500 l/h was used for this purpose. The binder removal process was complete after a binder loss of 7.7%, based on the starting weight of the green body, had been achieved.

[0050] Sintering was carried out under a 100% argon atmosphere. The argon used was clean and dry (99.98%, dew point<−80° C.). The sintering cycle was as follows

Room temperature—5 K/min—60° C., hold for 1 h,

600° C.—5 K/min—1325° C., hold for 3 h,

furnace cooling.

[0051] To achieve a very high density of the turbine wheel, the component was held at a temperature of 1185° C. for a period of 4 hours at a pressure of 1000 bar.

[0052] To optimize the strength properties further, a two-step heat treatment was carried out subsequently. In step 1, the turbine wheel was heated under reduced pressure at 1080° C. for a period of 8 h under 900 mbar of argon. In step 2, the workpiece was treated under reduced pressure at 705° C. for 16 h under 900 mbar of argon.

[0053] This gave a turbine wheel which had a volume of 7.5 cm^3 and was one third lighter than a solid turbine wheel.

1-9. (canceled)

10. A process for producing a turbine wheel for an exhaust gas turbocharger by metal powder injection molding, the process comprising:

a) providing a feedstock comprising
  (A) from 40 to 90% by volume of a sinterable pulverent nickel-based alloy or of a titanium-based alloy,
  (B) from 10 to 60% by volume of a mixture of
    (B1) from 80 to 98% by weight of a polyethylene homopolymer or copolymer, and
    (B2) from 2 to 20% by weight of a polyolefin or a mixture of polyolefins as binder, and
  (C) from 0 to 5% by volume of a dispersant;
b) providing a tool which comprises negative mold of the turbine wheel to be produced for metal powder injection molding of the turbine wheel;
c) introducing a rotationally symmetrical core comprising a binder into the negative mold of the tool provided in process step (b) and alignment of the core so that it is aligned symmetrically about the axis of rotation of the turbine wheel to be produced;
d) producing a green body by metal powder injection molding of the feedstock provided in process step (a) around the core;
e) removing the binder and at the same time removing the core in order to obtain a molding in the shape of the turbine wheel; and
f) sintering the molding.

11. The process according to claim **10**, wherein a core comprising the binder which is comprised in the feedstock provided in process step (a) is introduced in process step (c).

12. The process according to claim **10**, wherein the molding is mounted in at least one holding device in process step (f).

13. The process according to claim **10**, wherein the core introduced in process step (c) has a volume from 5 to 60% of the volume of the turbine wheel.

14. The process according to claim **10**, wherein process step (e) is carried out at a temperature in the range from 10 to 180° C.

15. The process according to claim **10**, wherein process step (f) is carried out at a temperature in the range from 250 to 1500° C.

16. A turbine wheel for an exhaust gas turbocharger having a hollow space structure which is symmetrical about the rotational axis of the turbine wheel and has a volume of from 5 to 60% of the volume of the turbine wheel, produced by a process according to claim **10**.

* * * * *