WARM FORMING OF METAL ALLOYS AT HIGH AND STRETCH RATES

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ABSTRACT

Process for production of metallic components by warm forming of blanks of alloys with superplastic micro-structure, wherein the deforming pressure in the deforming tool is kept at least 20% below the deformation pressure necessary for forging of the respective alloy without superplastic micro-structure, and the expansion rate (ε) of the warm forming is adjusted to a value above 0.1/s, or wherein the expansion of the blank during the warm forming is maintained below 50% of the expansion value achievable by a superplastic deforming and the expansion rate (ε) which is at least the 100 fold of that for superplastic deformation, as well as drive shafts, gears, pinions or profile pans obtainable thereby.
WARM FORMING OF METAL ALLOYS AT HIGH AND STRETCH RATES

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

The invention concerns the process for manufacture of metal components by warm forming of blanks or unfinished parts comprised of alloy with superplastic microstructures, in particular of UHC-steels, Al or Ti alloys with high stretch rates, according to the characteristics as described herein.

[0002] In machine construction or manufacturing systems engineering, as well as in the motor vehicle industry, various shaping processes for the manufacture of complex shaped components of metal are known. These include, among other things, impact extrusion, transverse rolling, bore pressing, rotary swaging, geared tooth rolling, buckling flange tool milling or internal high pressure deformation, as well as forging.

[0004] If these shaping processes were carried out at low temperatures, then in part only a very slow deformation speed can be achieved. If deformation is carried out more rapidly, then the deformation pressures must be raised to very high values, which has undesired consequences in tool pressures and tool costs in general. If the deformation processes in contrast are carried out at high temperature regions, in particular at forging temperatures, then the tool costs increase substantially, since only very expensive high temperature tools, in certain circumstances made of ceramic, can be employed. In certain cases multi-step processes are necessary. Beyond this, the blanks to be deformed are, as a rule, in the absence of precautions, damaged by oxidation. This leads for example to scale formation on steels or to strong oxidation of titanium alloys. Prior to the further processing of the thereby produced components, these must be follow-up processed, at least on their surfaces.

[0005] It is of further significant importance for the economic feasibility of the shaping process that a high degree of deformation corresponding to a high stretch (ε) is realized. Only hereby can complex shaped components be produced by a single deformation step.

[0006] 2. Description of the Related Art

Superplastic metals offer the mechanical engineering and in the motor vehicle industry a high potential to produce components with a high degree of deformation. Superplastic alloys are known for example from FR 274 1360 A1, U.S. Pat. No. 5,672,315, EP I 252 352 A1, or US 2001 020 502.

[0007] The term “superplasticity”, with regard to metals, is understood to mean the capacity to withstand degrees of deformation upon application of a very low yield stress, without lateral contraction and practically no work hardening, which, for materials having normal plasticity is approximately 10 to 40% for, is for superplastic materials several hundred to over 1000%. A fundamental characteristic of the superplastic behavior of materials is the strong dependence of the yield strength on the rate of elongation or, as the case may be, elongation rate (ε).

[0009] Superplastic deformation occurs using time controlled diffusion processes, during which very fine and often also rounded crystallites flow and rotate past each other. Thus, only a very narrow process window of temperature and deformation speed (elongation rate) (ε) is allowed, in order to achieve the elongation values of the superplastic deformation of several 100 to 1000%. Typically herein a higher deformation temperature, above approximately 50% of the melting temperature (in °C), and a very low deformation speed of approximately 10⁻² to 10⁻⁵ s⁻¹, can be mentioned as guide.

[0010] For the aviation and space travel applications superplastic titanium alloys are of particular interest. Herein the titanium alloys TiAl16V4 are deformed at approximately 925° C. and TiAl5Fe2.5 at 870° C. Herein pressures of approximately 10 bar, in certain cases 1 N/mm², are employed. The temperatures necessary for the superplastic deformation necessitate deformation tools with a good creep resistance at high deformation temperatures. Due to the very high reactivity of titanium alloys at high temperatures, the deformation must be carried out in a vacuum or under inert gas. Since the danger of the welding of the work tool to the work piece is very great, the tools must be protected.

[0011] In contrast to the air and space industry, in mechanical engineering and in the motor vehicle industry, mass produced components, in particular of steel, are of great interest. In mass production a very high process speed is of substantial importance, in order to keep the costs for mass production low. The deformation speed of superplastic deformation is, however, in any case, not acceptable for the series production of components.

SUMMARY OF THE INVENTION

[0012] It is thus the task of the invention to provide an economical process for the mass production of highly deformed metal components.

[0013] The task is inventively solved by a process for manufacture of metal components by warm forming of blanks of alloys with superplastic microstructure, wherein the deformation pressure in the deformation tool is kept at least 20% below that of the deformation pressure necessary for forging of the corresponding alloy, and the stretch rate (ε) of the warm forming is adjusted to a value greater than 0.1/s, as well as a process for production of metal components by warm forming of blanks of alloy with superplastic microstructure, wherein the expansion (ε) of the blank during warm forming is carried out below 50% of the expansion value achievable by a superplastic deformation and this carried out at expansion rates (ε) which are at least 100 times that for the superplastic deformation. The deformation pressure is often also referred to as the corresponding yield tension.

[0014] By the inventive process the superplastic microstructure of metallic alloys, is employed in order with, compared to the maximal value of the superplastic deformation, to have high deformation speed with comparatively low stretching. In accordance with the invention the high stretching, which would be possible with deformation in the superplastic region, is inventively surrendered or declined in order to take advantage of a high process speed.

[0015] In general the metal alloys, after their metallurgical manufacturer, are not in the microstructure condition which exhibits superplastic characteristics. Only after a particular
thermo-mechanical processing will a micro structure be formed, which exhibits superplastic characteristics, referred to in the following as “superplastic microstructure”. In order to achieve for example the ultra fine crystallite, for example invar, which are necessary for the superplasticity of UHC-Steels, two phases must be formed, which prevent a nucleation or grain growth. The corresponding phases are ferrite and cementite or other carbon rich phases. In order to adjust this micro structure, first a relatively homogenous material of perlit is produced which is a lamellar mixture of ferrite and cementite. In a second step this perlite structure is converted to the superplastic micro structure, with which the carbonite is present primarily in spheroidal (ball) shape and the ferrite in ultra-fine grain form.

[0016] The inventive process offers therewith the advantage, that for a large number of alloys, in particular of high strength steel, a substantial reduction in the number of deformation steps can be achieved. The deformation can already be carried out in the temperatures average for warm forming. These are temperatures significantly below the forging temperatures of the respective alloys, which in the case of steels could mean the difference between approximately 600 to 900°C and approximately 1200-1400°C. These lower temperatures have a significant advantage for the deformation tools, since in this case, as a rule, working can take place with simpler steel tools and not only with high temperature resistant steels or even ceramic tools.

[0017] The lower temperatures provide, in addition to this, a lower scaling or oxidation of the metal surfaces in the components to be manufactured. Depending upon alloy this can be a very significant advantage.

[0018] As a rule, with the inventive process, even in the case of complex components, no, or at least substantially reduced, stress reducing further process steps are necessary, whereby a improved material utilization results. Likewise, in some cases, a series of deformation processes sequentially following each other can be joined into a single inventive deformation process, the process chain for production of the finished component is in advantageous manner shortened.

[0019] One further advantage of the inventive process lies in the comparatively low deformation pressure in the deformation tool. This leads to substantially improved stamping time of the work tool. Likewise, the space requirement for the deformation apparatus is reduced.

[0020] In accordance with the invention it is provided that the deformation pressure is maintained significantly below that necessary for deformation in the case of forging (of the corresponding alloys) wherein working is conducted explicitly outside of the superplastic region. The temperature of the warm forming corresponds as a rule to the temperature range in which superplasticity is observed, in comparison to which the inventive selected expansion rate is significantly outside of the superplastic region. In accordance with the invention the expansion rate (ε) of the warm forming is adjusted to a value above 0.1/s and deformation pressure in the deformation tool is maintained at least 20% below that of the deformation pressure necessary for forging. The pressure for forging depends upon the corresponding alloy composition, which would exhibit no superplastic micro structure. The temperature and pressure conditions of the forging correspond as a rule to that of warm forming.

[0021] Surprisingly the superplastic micro structure of the alloy can also be deformed with high speed of deformation with comparably low process pressure. Therein the process pressure necessary for deforming is dependent upon the respective alloy, the precise micro structure imparted and in particular also the deformation speed. Process pressure and deformation speed are inverse.

[0022] For UHC-Steels with superplastic micro structure preferably a process pressure below 150 to 180 MPa and a deformation speed expansion rate (ε) above 0.1/s is used. The process pressure deformation is particularly preferably below 100 to 150 MPa. The arrangement of the process can be optimized towards lower process pressure or towards higher deformation speeds. Particularly preferred deformation speeds are above 0.5/s. For Al-alloys with superplastic micro structure, the expansion rate at low temperatures is substantially higher. Preferably here pressures below 80 MPa and expansion rates above 1/s are used.

[0023] In a further inventive embodiment it is envisioned that the expansion of the blank during the warm forming is carried out below 50% of the expansion value achievable by a superplastic deformation and an expansion rate (ε), which is at least the 100 fold of that for the superplastic deformation. Herein it is inventively explicitly declined to take advantage of The high achievable superplastic stretching, in exchange for the benefit of a high expansion rate. This translates to very advantageous short process times. Surprisingly it is possible with the very high expansion rates to achieve a degree of deformation with which also complex component geometries can be achieved. In steels with superplastic micro structure preferably expansion rates, (deformation degrees) are above 100% and particularly preferred in the range of 100 to 500%. The indicated values are understood to be component geometry averaged values. The preferred expansion rates lie in a range of 100 to 1000 fold of the necessary small expansion rates of the superplastic deformation.

[0024] In a particularly preferred embodiment of the inventive process the warm forming occurs in a temperature region, which corresponds to the process window for superplastic deformation. The process window is essentially dictated by the parameters of temperature, expansion and expansion rate. For steels, in particular UHC-steels, the preferred temperature range lies at 600-900°C, and particularly preferably at 750 to 850°C. UHC-steels with Al-outdent above 2% are particularly preferably deformed at 800-950°C. The Al-alloys are preferably deformed in a temperature region of 300 to 400°C.

[0025] Preferably alloys are employed which exhibit for the corresponding superplastic deformation an expansion rate sensitivity (m) above 0.4; particularly preferred are alloys with m greater than 0.7.

[0026] The preferred alloys include those of which the maximal superplastic deformation lies above 500%. Particularly preferred is the employment of alloys with expansions above 800%. Thereby it is ensured that, in the deformation of the blank, expansions in the region of 100 to 400% can be achieved without problems. With these degrees of deformation a very large region of technically relevant components can be covered.

[0027] In a preferred embodiment of the invention the process time of the deformation is adjusted to a value of less
than 10 s. Depending upon selective deformation process the preferred range is between 1 and 5 s. Therein the process parameters of the deformation temperature and process pressure are adjusted or adapted appropriately. Lower deformation times are likewise possible, are however not particularly necessary, since the set-up time for the deformation tool is the speed determining variable of the total process time. The inventive preferred alloys are steel, Al and Ti-alloys.

[0028] Particularly preferred is when the steels are selected from the UHC-steels (ultra high carbon steels). The carbon content of the steels lies therein above 0.9 wt. % and particularly preferably in the range of 1.2 to 2%.

[0029] Particularly suited UHC-steels have the following compositions, wherein the indications are in wt. %:

- [0030] C: 0.9-2.2; Al: 1.5-10; Cr: 0.5-7; Mn 1-10; rest Fe and impurities.
- [0031] C: 0.9-2.2; Al: 1.5-10; Cr: 1-16; Mn 0-2.2; rest Fe and impurities.
- [0032] C: 0.9-2.2; Al: 1.5-10; Cr: 0.25-5; 0.5-5 mo; Mn: 0-2; rest Fe and impurities.
- [0033] C: 0.9-2.2; Al: 1.5-10; Cr: 1-17; Si: 0.5-5%; Mn: 0.2-2; rest Fe and impurities.
- [0034] C: 0.9-2.2; Al: 1.5-10; Cr: 1-7; Si: 0.5-5%; Mn: 0.2-2; rest Fe and impurities.
- [0035] C: 0.9-2.2; Al: 1.5-10; Cr: 1-7; Ni: 0.25-5; Mn: 0.2-2; rest Fe and impurities.
- [0036] C: 0.9-2.2; Al: 1.5-10; Cr: 1-7; Ni: 0.25-5; Mn: 0.2-2; rest Fe and impurities.

[0040] Typical representatives of the corresponding groups are:

- [0041] 1.5 C, 1.5 Al, 7 Cr, 0.5 Mn, rest Fe,
- [0042] 1.5 C, 1.5 Al, 1 Cr, 2 Mo, 0.5 Mn, rest Fe;
- [0043] 1.3 C, 1 Al, 3 Cr, 2 Si, 0.5 Mn, rest Fe;
- [0044] 1.3 C, 1.5 Al, 4 Cr, 1 Ni, 0.5 Mn, rest Fe;
- [0045] 1.3 C, 3 Al, 1.5 Cr, 2 Mn, rest Fe;
- [0046] 1.3 C, 3 Al, 1.5 Cr, 2 Mn, 3 Mn, rest Fe.

[0047] A further suitable UHC-steel comprises, in addition to iron and impurities conventionally accompanying steel, the following alloy components in wt. %:

- [0048] 0.8 to 2.5% C,
- [0049] 0.1 to 0.85 Sn,
- [0050] 3.5 to 15% Al,
- [0051] 0.5 to 4% Cr,
- [0052] 0.01 to 4% Si,
- [0053] up to 4% Ni, Mn, Mo, Nb, Ta, V, and/or W, and up to 2% of Ti, Be and/or Ga.

[0054] Preferred is the selection of Al/C ratio above 2/1. Particularly preferred is when this ratio is greater than 3/1.

[0055] A further advantage is exhibited by the UHC-steels with high Al-content. Therein an Al-content above approximately 5% is to be understood. The presence of Al further suppresses the scaling of the steel. In warm forming with these steels as a rule so little surface oxidation or as the case may be scaling occurs that a surface treatment for prevention of a scaling layer can be omitted. The surfaces obtained after deformating correspond essentially to the usable condition.

[0056] Due to the Al-content the mentioned UHC-steels are not limited to a particular protective or inert atmosphere. The warm forming thus occurs preferably in the presence of air. The deformation of the Ti-alloys is, in comparison, typically carried out under protective or inert gas, and particular Ar.

[0057] As further steel with low carbon content and without Al the following composition can be employed in the inventive process (indications are in wt. %): C 0.05%, Si 1.2%, Mn 2.8%, Cr. 15-23%, Ni: 3-9%, Mo: 1-1.9%, N:0.09-0, 25%, rest Fe and impurities.

[0058] The particularly suited Al or Ti-alloys include the following compositions indicated in wt. %:

- [0059] 70-79 Zn rest Al;
- [0060] 6-8 Al, 4-6 V, rest Ti;
- [0061] 4-6 Al, 2-3 Fe, rest Ti.

[0062] The inventive process is carried out in preferred manner as a near-net-shape process, so that the component after the deformation is in as near a useful state as possible and only in certain cases do certain functional surfaces need follow up or final processing. Further, it is useful to use the process heat of warm forming in order to instill or adjust a suitable micro-structure in the component. Therein the component, after the deformation, is controlled cooled. Steels and Al-alloys thereby hardened in known manner during cooling. Since no further form giving process step follows the warm forming, this manner of proceeding is possible. In comparison thereto, in conventional processes, these processes are unsuited, since for example by machining or boring, are necessarily carried out only on unhardened components; the hardening is carried out subsequent to the final forming by a further thermal process step.

[0063] The preferred process variance of the warm forming include impact extrusion, transverse rolling, bore pressing, rotary swaging, geared tooth rolling, buckling flank tool milling or internal high pressure deformation, as well as forging.

[0064] By the combination of the inventive warm forming with the known forming processes, drive shafts, flow press parts, forged parts, or drop forged puts can be produced, which otherwise are only producible following multiple process steps, with higher equipment or operation costs.

[0065] By the inventive warm flow pressing the most diverse machine components of the machine construction are preferably produced. These include for example gear wheels, pinions, short profile parts and so on.

[0066] In the following the various processes of the warm forming will be described by way of example with reference to a hollow drive shaft.

[0067] A particularly suited processes includes traverse rolling. The known processes are therein essentially adapted to the process parameters of the inventive warm forming. For example, a traverse roller profiling is described in DE 199 05038 A1, in which, in the direction of a work piece...
rotation axis, a movable profiled spike or spur is provided, which exhibits a defined geometry. This is acted upon by a spike pushing device for controlled movement of the spike along the work piece rotation axis with an axial force. The relative movement of the spike is coordinated to the movement of the transverse roller tool. Further, traverse processes are known for example DE10066177, in which a rotation symmetric blank, for example a round rod, is rolled between two or more tools directionally or back and forth so long until the gear structure shaped on the tools is transferred to the covering surface of the blank.

By the inventive warm extrusion pressing solid drive shafts with finished surfaces of exacting sophisticated sauce geometries can be produced. It is also possible to already provide gears on the surfaces. In particular in this process step also multi-gear wheels can be introduced or applied independent of each other. In a subsequent process step the boring out of the solid shaft to form a hollow shaft is necessary.

The transverse rolling of drive shafts of steel can occur in accordance with the inventive process with very productive cycle times of from 1 to 5 s. The temperature of the warm forming makes it possible to deform the steel shafts by means of steel tools. Preferably hollow drive shafts are produced; either from solid shafts with subsequent boring out or from pipes. Therein it is necessary that the inter-contour of the pipe is supported during transverse rolling. It can also occur using mandrels, in particular movable mandrels. On the basis of the low process temperature the mandrels can also be produced from press adapted steels. In comparison to the conventional transverse rolling, substantial thick wall pipes can be employed as starting material. Particularly preferred is an inventive transverse rolling of the entire outer contour of the drive shaft brought into industrially finished condition. The outer contour can, for example, carry gears, which are imparted during warm transverse rolling. In certain cases during transverse rolling it is not the finished surface structure which is introduced or applied to the outer surface of the pipe, but rather in a subsequent process step of warm radial forging. Thereby greater degrees of geometric freedom can be realized in particular in the shaft inter-contour.

For the production of drive shafts with wall thickening reinforcement in the area of the flange, conventionally a combination process of round working and punch working at room temperature is employed. The inventive warm punch working (or axial-radial-deforming) a drive shaft with complex geometric design can be produced in a single process step with high precision. While with a conventional process multi-warming steps are necessary for forming the flange, in certain cases multi-clamping and reducing the long and the short drive shaft is necessary, there can during the inventive warm forming round working/punch working in one process step the entire deformation occur. In certain cases in the same or a subsequent warm forming step gears can also be introduced using suitable tools. The degree of deforming of the inventive process suffices in general to impart upon the drive shaft teeth with the conventional geometry and depth.

In the case of the highest geometrical requirements it can also be useful to impart gears or other surface structures by milling or machining processes, such as turning or milling or by electro-chemical processes such as for example the PECN-process. A rough contour can be provided in any case by the warm forming, thereby substantially reducing the amount of work needed for the finishing or fine processing.

A further process variant is provided by the warm forming internal high pressure deformation. For production of a hollow shaft the starting pipe is subjected to an internal pressure and the material is extruded in the direction of the length of the pipe. During conventional processes for typical drive shafts pressures of up to 10,000 bar are necessary, which does not allow a economical mass production. With the inventive process in contrast it suffices for drive shafts already to have process pressures of 1,000 to 3,000 bar. As a rule gears would have to be introduced using additional process steps.

For the inventive warm forming the known basic processes can also be combined in suitable manner or certain cases can be sequentially carried out. In particular the already deformed components exhibit substantial reserves in ability to stretch, since in each of the inventive deformation steps only a fraction of the maximal possible expansion is carried out. Only after multiple deformation steps is the maximal superplastic deformation achieved. Depending upon the alloy employed, it is necessary to allow process steps to occur immediately after each other, so that no recrystallization of the superplastic micro structure can occur by cooling and reheating.

For example it can be useful first by warm flow deforming from solid shafts, to produce a blank or raw shape of a drive shaft and to deform this by means of warm bore pressing into a hollow shaft with a fine or precise inner and outer contour. Therein in particular the inner-contour can already be a finished contour, whereby an otherwise necessarily expensive or complex or possibly even impossible follow-up processing on the inside can be dispensed with.

Now that the invention has been described, I claim:

1. A process for production of metallic components by warm forming of blanks of alloys with superplastic microstructure, comprising:
   - deforming said blank with a deformation tool, wherein the deformation pressure in the deformation tool is kept at least 20% below the deformation pressure necessary for forging of the respective alloy without superplastic microstructure, and wherein the expansion rate (e) of the warm deforming is adjusted to values above 0.1/s.

2. A process for production of metallic components by warm forming of blanks of alloys with superplastic microstructure, comprising:
   - expanding the blank during warm forming, maintaining expansion below 50% of the expansion value achievable by superplastic deformation, and with an expansion rate (e) which is at least the 100 fold of that for superplastic deformation.

3. A process according to claim 1, wherein the warm forming is carried out a temperature range, which corresponds to the process window of a superplastic deformation.

4. A process according to claim 1, wherein the warm forming occurs within the forging temperature of the alloy.
5. A process according to claim 1, wherein alloys are employed which during existence of a superplastic microstructure exhibit an expansion rate sensitivity (m) above 0.4.

6. A process according to claim 1, wherein an alloy is selected, of which the maximal superplastic expansion lies above 500%.

7. A process according to claim 1, wherein the deformation leads to expansion of the blank in the range of 100 to 400 percent.

8. A process according to claim 1, wherein the warm forming is adjusted to a process time below 10 s.

9. A process according to claim 1, wherein as alloy UHC-Steel is employed, which essentially has the following composition (in wt. %):

   C: 0.9-2.2; Al: 1.5-10; Cr: 0.5-7; Mn 1-10; rest Fe and impurities

   C: 0.9-2.2; Al: 1.5-10; Cr: 1-16; Mn 0-2.2; rest Fe and impurities

   C: 0.9-2.2; Al: 1.5-10; Cr: 0.25-5; 0.5-5 Mo; Mn: 0-2; rest Fe and impurities

   C: 0.9-2.2; Al: 1.5-3; Cr: 1-7; Si: 0.5-5; Mn 0-2.2; rest Fe and impurities

   C: 0.9-2.2; Al: 1.5-10; Cr 1-7; Ni: 0.25-5; Mn 0-2.2; rest Fe and impurities

   0.8 to 2.5 C; 0.1 to 0.85 Sn; 3.5 to 15 Al; 0.5 to 4 Cr; 0.01 to 4 Si; up to 4 Ni, Mn, Mo, Nb, Ta, V, and/or W, and up to 3 of Ti, Be and/or Ga; rest Fe and impurities.

10. A process according to claim 9, wherein the warm forming is carried out in the presence of air.

11. A process according to claim 7, wherein the process heat is employed for a controlled cooling of the component.

12. A process according to claim 7, wherein annealing occurs during cooling.

13. A process according to claim 1, wherein Al-alloys are employed, which essentially exhibit the following composition (in wt. %):

   70-79% Zn, rest Al;
   6-8% Al, 4-6% V, rest Ti;
   4-6% Al, 2-3% Fe, rest Ti.

14. A process according to claim 1, wherein as alloy, a steel with the following composition is selected:

   C<0.5%, Si<1.2%, Mn<2.8%, Cr: 15-23%, Ni: 3-9%, Mo: 1-1.9%, N: 0.09-0.25%, rest Fe and impurities.

15. A process according to claim 1, wherein the warm forming is carried out as extrusion, transverse rolling, bore pressing, round working, mesh rolling, punch forming, go internal high pressure forming or combinations thereof.

16. A process according to claim 1, wherein multi-warm forming steps are carried up sequentially on the same part.

17. Drive shafts, gears, pinions or profile parts obtained by a process for production of metallic components by warm forming of blanks of alloys with superplastic microstructure, comprising:

   deforming said blank with a deformation tool, wherein the deformation pressure in the deformation tool is kept at least 20% below the deformation pressure necessary for forging of the respective alloy without superplastic microstructure, and wherein the expansion rate (ε) of the warm deforming is adjusted to values above 0.1/s.

18. Drive shafts, gears, pinion or profile parts according to claim 17, wherein they are formed of UHC-Steels with a superplastic microstructure.

19. (canceled)