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(54) **METHOD FOR PRODUCING AN ELONGATED HOLLOW BODY CONSISTING OF STEEL AND HAVING A POLYGONAL, IN PARTICULAR SQUARE OR RECTANGULAR, CROSS-SECTION**

VERFAHREN ZUR HERSTELLUNG EINES LÄNGLICHEN HOHLKÖRPERS AUS STAHL MIT EINEM MEHRECKIGEN, INSBESONDERE QUADRATISCHEM ODER RECHTECKIGEM, QUERSCHNITT

PROCÉDÉ DE PRODUCTION DE CORPS CREUX ALLONGÉ COMPORTANT DE L'ACIER ET AYANT UNE SECTION TRANSVERSALE POLYGONALE, EN PARTICULIER CARRÉE OU RECTANGULAIRE

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Description

[0001] The invention relates to a method for producing a non-destructively tested elongated hollow body consisting of steel and having a polygonal, in particular square or rectangular, cross-section, in which an intermediate hollow body having a round cross-section is produced in each case from a flat pre-material or an intermediate hollow body having a round cross-section is produced from a block-shaped pre-material, whereby the intermediate hollow body is cooled or quenched with partial or full phase transformation.

[0002] It is generally known that for decades hot-finished circular, square or rectangular and elongate hollow profiles consisting of steel have been used in the steel industry. The fields of application include the modern steel architecture in structural engineering, bridge construction, industrial construction, sports facilities construction, mechanical engineering, construction of agricultural devices and conveyor systems, shipbuilding and fairground ride construction for fairs. The hot-finished hollow profiles pass through a heating process in a final production step e.g. in normalising temperature range at approximately 850 to 1050°C. Square or rectangular hollow profiles achieve wall thicknesses of up to approximately 30 mm and outer dimensions in the range of 40 x 40 mm to 400 x 400 mm or 50 x 30 mm to 500 x 300 mm respectively. Typical lengths of the profiles are 12 m or 16 m. The materials used include general structural steels, high-strength fine-grained structural steels and special grades as well as non-weldable grades corresponding to the desired intended purposes. Hot-finished, square or rectangular hollow profiles are characterised by smaller corner radii than in the case of cold-finished profiles and thus have larger cross-sectional areas. Therefore, a higher load can be accommodated with identical profile dimensions.

[0003] German laid open document DE 2 348 152 and US patent 3,779,817 disclose a method for producing elongate hollow bodies consisting of steel and having a polygonal cross-section. In this method, a hollow steel pipe having a substantially round cross-section is hot-rolled and is then austenitised in a gas-heated oven with an excess of air and above an Ac3 temperature of the steel in question. The austenitising temperature is preferably between 871 and 954°C. Then, quenching occurs in water to a temperature of less than 93°C and then heating occurs to a tempering temperature which is above a stress-relief annealing temperature and below an Ac1 temperature of the steel in question. Preferably, the tempering temperature is between 621 and 663°C. Then, the steel pipe is tempered at this temperature and is rolled out within the tempering temperature range to the desired polygonal cross-sectional shape, in particular to that of a rounded rectangle and is then cooled in air. The hollow bodies produced according to this method are intended to be free of surface defects, such as e.g. buckling, and to have high yield stresses, distinctive notch impact strength and strain properties as a result of the quenching and tempering steps. A suitable pre-material for the method is a Si-Al-killed steel having approximately 0.2% carbon, 1.45% Mn and 0.06% V steel, which is martensitic and has good weldability.

[0004] Further German laid open document DE 197 03 586 and US patent 5,802,903 show a method for producing elongated hollow steel bodies having a polygonal cross-section. Starting from a flat pre-material an intermediate hollow body having a polygonal cross-section is obtained by squeeze-moulding and welding. The intermediate hollow body has a curvature radius in its edge region being larger than the respective curvature radius of the final elongate hollow steel body having a polygonal cross-section. Afterwards the intermediate hollow body is heated in an oven and is finally rolled. During final-rolling the curvature radii are decreased to reach the desired shape of the final elongate hollow steel body having a polygonal cross-section.

[0005] Moreover the European patent EP 0 485 572 discloses a method for producing a seamless steel pipe having a round cross-section. This method describes producing an intermediate hollow body having a round cross-section from a round block-shaped pre-material. A testing apparatus is arranged at a suitable position, especially between a rolling mill and a cooling bed, within the production line in order to test the pipe for dimensional changes or flaws. The achieved testing results are used to provide control information for the production method. The testing apparatus has a source/detector apparatus using a penetrative source of radiation, e.g. X-ray or gamma ray beam, for non-destructive testing.

[0006] In addition German laid open document DE 10 2012 006 472 teaches the production of welded steel pipes having a round cross-section from a flat pre-material. This flat pre-material undergoes a non-destructive control via ultrasound or eddy current testing before U-/O-forming and welding. In particular homogeneity of material properties is continuously or discontinuously obtained to provide control information for the production method.

[0007] In general, non-destructive testing, in particular ultrasonic testing for defects, in particular laminar imperfections and inclusions, of hollow bodies consisting of steel and having a square or rectangular cross-section is not possible. Nowadays, hollow bodies consisting of steel and having a polygonal, in particular square or rectangular, cross-section are rolled and heat-treated in various steps. In addition, concavities, convexities, twisting and deviations in squareness and straightness occur owing to a separate heat-treatment step.

[0008] The object of the invention is to provide a method for producing an elongated hollow body consisting of steel and having a polygonal, in particular square or rectangular, cross-section which is characterised by produced hollow bodies having increased dimensional stability, in particular narrow dimension tolerances. The hollow bodies are heat-treated and tested in a non-destructive manner.

[0009] The object is achieved by a method having the features of claim 1. Advantageous embodiments of the invention

are described in dependent claims 2 to 18.

[0010] In accordance with the invention, in the case of a method for producing an elongated hollow body consisting of steel and having a polygonal, in particular square or rectangular, cross-section, in which an intermediate hollow body having a round cross-section is produced from a flat pre-material or an intermediate hollow body having a round cross-section is produced from a block-shaped pre-material whereby the intermediate hollow body is cooled or quenched with partial or full phase transformation, the intermediate hollow body is tested by at least one non-destructive testing method selected from eddy current testing of surfaces, ultrasonic testing of surfaces, ultrasonic testing for laminar imperfections and other defects in a wall volume, magnetic particle testing for local testing of the surface or combinations thereof preferably at lower temperatures, especially at room temperature, and the intermediate hollow body is final-shaped to form a final hollow body having a polygonal, in particular square or rectangular, cross-section, by amending the average wall thickness of the intermediate hollow body by less than 10%, preferably less than 5%, compared with the wall thickness of the final hollow body, the intermediate hollow body is final-heat-treated immediately prior to the final-shaping of the intermediate hollow bodies or the hollow body produced by final-shaping is final-heat-treated during the final-shaping, whereby the method relies on the non-destructive testing results of the intermediate hollow body for the final hollow body, a simplification in the non-destructive testing is achieved by virtue of the fact that the intermediate hollow body having the round cross-section, is tested in a non-destructive manner prior to the final-shaping. During the final-shaping, a logarithmic reduction $\ln(CO/C1)$ of a starting periphery $C0$ of the intermediate hollow body occurs during an in particular multi-stage shaping to a final periphery of the hollow body in a range between 0 and 0.3, wherein an extension of the hollow body outweighs an increase in the wall thickness. The shaping speed is between about 0.2 and 5 m/s, preferably between about 0.5 and 5 m/s. The final-shaping of the intermediate hollow body is more or less a thermo-mechanical shaping step, in particular a drawing or stretching or pressing, especially a roll-drawing or roll-stretching or roll-pressing.

[0011] In conjunction with the present invention the term "without intended change" in the feature "the intermediate hollow body is final-shaped without intended change of the wall thickness of the intermediate hollow body to form a final hollow body" is to be understood that the average wall thickness of the intermediate hollow body is amended (reduced or increased) by less than 10%, preferably less than 5%, compared with the wall thickness of the hollow body having a polygonal, in particular square or rectangular, cross-section. The wall thickness is to be understood as an average wall thickness.

[0012] Also in conjunction with the present invention, non-destructive testing is understood to mean at least one of the following testing methods or combinations thereof. The non-destructive testing occurs prior to or after a heat treatment (e.g. quenching, normalising, soft annealing) of the hollow body.

- eddy current testing of surfaces, typical minimum defect depth for reliable recognition approximately 0.2 mm or 5% of the wall thickness of the hollow body, whichever value is higher; for wall thicknesses of less than or equal to 15 mm, defects on the outer surface and also on the inner surface of the hollow body are recognised whereas for wall thicknesses of greater than 15 mm only defects on the outer surface of the hollow body are recognised;
- ultrasonic testing of surfaces (inner and outer), typical minimum defect depth for reliable recognition approximately 0.3 mm or 5% of the wall thickness of the hollow body, whichever value is higher in the longitudinal direction, tangential direction and oblique direction. Typically, a test frequency for ultrasonic testing methods is in the range of 2-25 MHz;
- ultrasonic testing for laminar imperfections and other defects in a wall volume using reflection/reference defects (e.g. flat bottom bores) having a minimum size of the reference surface of approximately at least 1 mm;
- magnetic particle testing for local testing of the surface of a hollow body, a pipe inside and outside surface as well as end faces, edges of a polygonal structure and its corners and end faces. Local magnetic particle testing can also take place on the final hollow product. Preferably the non-destructive testing of the intermediate hollow body is an eddy current testing or ultrasonic testing or a combination hereof.

[0013] Also in conjunction with the present invention, the term "immediately" in the feature "under final-heat-treating of the intermediate hollow body immediately prior to the final-shaping" is understood to mean that the time frame between the final-heat-treating and the final-shaping is less than 5 minutes, preferably less than 60 seconds.

[0014] Further in conjunction with the present invention the term "room temperature" in the feature "the intermediate hollow body is at room temperature for the non-destructive testing" is understood to mean a temperature of the intermediate hollow body that is between 5 °C to 60 °C.

[0015] In a particularly advantageous manner, provision is made in the method in accordance with the invention that the non-destructive testing of the intermediate hollow body is carried out after the intermediate heat treatment of the intermediate hollow body or prior to the final-shaping of the intermediate hollow body to control if requirements of customers for the final hollow body-product are met. Accordingly the final hollow body having a polygonal, in particular square or rectangular, cross-section, will not be tested any more. The core idea of the invention is to rely on non-

destructive testing results before final-shaping in order to meet the customers' demands. Additionally, non-destructive testing takes place on the seamless or the welded intermediate hollow body prior to the intermediate or final heat treatment of the intermediate hollow body or on the flat pre-material for a welded intermediate body. Optionally additionally non-destructive testing takes place on the hollow body after final-shaping externally in the region of its corners and/or ends. The non-destructive testing for defects in the wall of the intermediate hollow body, e.g. for laminar imperfections, can be effected with conventional ultrasonic testing facilities using typical testing standards for hollow bodies having a circular cross-section. When testing flat pre-material, testing is effected in this initial state by means of conventional ultrasonic testing facilities more typically used for this semi-finished product. Since the ultimate shaping of the intermediate hollow body having a round cross-section to form a hollow body having a polygonal cross-section is effected within a provided heat treatment step, very narrow dimension tolerances can be maintained for the hollow body. Depending upon the desired properties of the hollow body having a polygonal cross-section, heat treatments such as cooling with water, oil or polymers also take place after austenitising the intermediate hollow body prior to ultrasonic testing. The final-heat treatment (e.g. tempering, normalising, age hardening or dual-phase annealing) is effected during or immediately prior to the final-shaping to form a hollow body consisting of steel and having a polygonal, in particular square or rectangular, cross-section. As a basic condition for all final-heat treatments, it is applicable that reheating the intermediate hollow body to the predefined temperature range, in order to achieve the desired mechanical properties, lasts for at least 1 minute per mm of wall thickness and at the most 6 minutes per mm of wall thickness if heated in an oven using inductive heating lower times can be used.

[0016] With reference to an additional and optional intermediate heat treatment of the intermediate hollow body in terms of a pre-normalising step, provision is preferably made that the intermediate hollow body is intermediately heat treated prior to the final-shaping, in particular by heating above an Ac3 temperature of the corresponding steel in order to austenitise and subsequently cool the intermediate hollow body prior to the final-shaping. Preferably, heating to an Ac3 temperature of the corresponding steel + 20 Kelvin, preferably to 870 to 980°C, maintaining said temperature for at least 5 minutes, and cooling with water, oil or polymers prior to the final-shaping are provided. By way of this cooling step, diffusion processes in the intermediate hollow body are minimised or avoided. In a particularly advantageous manner, a subsequent final-heat treatment is in the form of tempering at a temperature between 580°C and Ac1 - 20 Kelvin with this temperature being maintained for between 5 and 60 minutes, which is performed immediately prior to the final-shaping or with the final-shaping of the intermediate hollow body in a common step.

[0017] The temperatures Ac1 and Ac3 are defined as follows on the basis of generally known equations adapted by appropriate trials:

$$Ac1 = 734.2 - 13.9*\%Mn + 22.2*\%Si + 23.3*\%Cr - 14.4*\%Ni$$

$$Ac3 = 960.3 - 254.4*\%C^{1/2} - 14.2*\%Ni + 51.7*\%Si$$

[0018] Preferably, as an alternative final-heat treatment, provision is made that the hollow body is final-heat treated in the form of normalising at a temperature of at least Ac3 + 20 Kelvin with this temperature being maintained for at least 5 minutes.

[0019] With respect to age hardening of the hollow bodies, provision is preferably made that the hollow body is final-heat-treated in the form of age hardening at a temperature of less than Ac1 and with a tolerance of +/- 30 Kelvin with this temperature being maintained for 10 to 60 minutes. This particular age hardening temperature is dependent upon the type of age hardening.

[0020] With respect to dual-phase annealing of the hollow bodies, provision is preferably made that the hollow body is final-heat treated in the form of dual-phase annealing at a temperature between Ac1 and Ac3 and with this temperature being maintained for 5 to 60 minutes. The obtained dual-phase microstructure can consist of combinations of ferrite, perlite, bainite, residual austenite and martensite.

[0021] In an advantageous manner, provision is made that the non-destructive testing is effected as eddy current testing or ultrasonic testing or as a combination thereof. Defects in the surface of the seamless or welded intermediate hollow body or of the flat pre-material can be detected by the eddy current testing and defects in the wall of the seamless or welded intermediate hollow body or of the flat pre-material can be detected by the ultrasonic testing.

[0022] Provision is preferably made that the final hollow body having rounded corners is tested externally in a non-destructive manner, in particular by means of magnetic particle testing, after the final production step in the region of its corners and/or ends.

[0023] In a particularly advantageous manner, the method can begin with shaping, in particular bending and/or rolling, the flat pre-material to form a slotted hollow body having adjoining abutment ends, and welding the abutment ends to form a welded intermediate hollow body having a round cross-section, or with shaping, in particular rolling, the block-

shaped pre-material to form a seamless intermediate hollow body having a round cross-section. Depending upon the subsequent field of application, known steels are used in this case. The flat pre-material in the form of strips or sheets can be cold-shaped or hot-shaped.

5 [0024] With reference to the known shaping of seamless intermediate hollow bodies from a block-shaped pre-material, a combination of separate or integrated shaping steps is used, such as piercing, reducing the wall thickness and stretching, optionally flattening the surface and optionally rolling to size to a defined outer diameter prior to or in combination with a heat treatment. Internal tools are used for piercing, reducing the wall thickness and flattening. Rolling to size occurs without an internal tool. A logarithmic surface reduction $\ln(D0/(2*S1))$ over the entire shaping of the block-shaped pre-material with a diameter D0 to form intermediate hollow bodies having a round cross-section with a wall thickness S1 is preferably between 0.6 and 4.0.

10 [0025] Provision is preferably made that the intermediate hollow body is final-shaped immediately after the final-heat treatment at a temperature between 550°C and Ac1 - 20 Kelvin or at a temperature of at least Ac3 + 20 Kelvin and thus in the temperature ranges of hardening or normalising.

15 [0026] The present invention is particularly suitable for producing hollow bodies, in particular hollow profiles, having a polygonal, in particular square or rectangular, cross-section having rounded corners which are then used in the steel industry, in particular for cranes, in mechanical engineering, offshore applications, deep sea applications and wind turbines as well as for components subjected to high levels of vibration.

20 [0027] By using the present method in accordance with the invention, a rectangular final hollow body was produced experimentally from steel grade API 5L X70Q having the dimensions 200 mm x 140 mm and a wall thickness of 6.3 mm. After rolling an intermediate hollow body having a circular cross-section, austenitising (heating to and maintaining at a temperature of greater than Ac3) was performed, followed by quenching. Then, ultrasonic testing of the intermediate hollow body having a round cross-section was performed. Then, simultaneous final-shaping and tempering were performed at a tempering temperature of 550 to 750°C. The then measured tolerances met the specifications from standard EN 10210-2:2006. Also, no cracks occurred in the corners of the hollow body. Corresponding magnetic particle testing was performed. The following mechanical properties were achieved: yield point Rt0.5 > 485 MPa, tensile strength > 570 MPa, notch impact strength > 150 J/cm² at -40°C and hardness < 240HV10. Typical lengths of the hollow bodies, in particular hollow profiles, are 12 m or 16 m.

25 [0028] Also, in accordance with the present method in accordance with the invention, a square hollow body, in particular a hollow profile, was produced experimentally from steel grade S355G15+N pursuant to EN 10225:2009 having the dimensions 160 mm x 160 mm and a wall thickness of 10 mm. After producing the intermediate hollow body, ultrasonic testing was performed. Then, the intermediate hollow body was final-shaped into its ultimate dimensions at a normalising temperature between 880 and 960°C. The then measured tolerances met the specifications from standard EN 10210-2:2006. Also, no cracks occurred in the corners of the hollow profile. Corresponding magnetic particle testing was performed. The mechanical properties met the specification from standard EN 10225:2009.

30 [0029] In order to be able to perform the final-shaping, in particular final-rolling, during the heat treatment, the device for final-shaping, in particular final-rolling, is to be arranged immediately downstream of the heat treatment oven in the normal product sequence.

35 [0030] The production method in accordance with the invention will be described in more detail hereinafter with the aid of exemplified embodiments illustrated in a drawing in which:

40 Figure 1 shows a process flow chart of an exemplified embodiment.

[0031] In a first process sub-variation hereof, initially a flat pre-material 1a is tested in a non-destructive manner by means of a non-destructive testing device 3a. Then, a slotted hollow body having adjoining abutment ends is produced from the flat pre-material 1a by shaping, in particular bending and/or rolling. Then, the abutment ends are welded to form a welded intermediate hollow body having a round cross-section 2b. Alternatively to the non-destructive testing device 3a for the flat pre-material 1a or in addition thereto this intermediate hollow body 2b can be tested in a non-destructive manner by means of an alternative or additional non-destructive testing device 3a.

45 [0032] In a second process sub-variation hereof, starting from a block-shaped pre-material 1b, a seamless intermediate hollow body having a round cross-section 2c is produced from a block-shaped pre-material 1b. Shaping, in particular rolling, is used as the production method. This seamless intermediate hollow body having a round cross-section 2c is tested in a non-destructive manner by means of a non-destructive testing device 3a.

50 [0033] The then available intermediate hollow bodies having a round cross-section 2b, 2c are subjected to an intermediate heat treatment depending upon the respective material. This intermediate heat treatment consists of intermediate heating of the intermediate hollow body 2b, 2c in an intermediate heating oven 4a and subsequent cooling of the intermediate hollow body 2b, 2c in an intermediate cooling path 4b prior to the final-shaping to form an intermediate hollow body having a round cross-section with intermediate heat treatment 2b', 2c'. Alternatively to the above-described non-destructive testing devices 3a or in addition thereto, the intermediate hollow body having a round cross-section 2b, 2c can be tested in a non-destructive manner before the intermediate heat treatment 2b', 2c' by means of an alternative or additional non-destructive testing device 3a. Therefore, the non-destructive testing takes place after the intermediate

shaping and prior to the final-shaping by means of one or a plurality of non-destructive testing devices 3a at different positions during the production process.

[0034] Then, the intermediate hollow bodies 2b' or 2c' are subjected to a final-heat treatment in a final-heating oven 5a and a final-shaping device 5b in order to obtain a hollow body 6 having a polygonal, in particular square or rectangular, cross-section. Alternatively, the final-heat treatment and final-shaping can be performed in a common step.

[0035] Finally, the final hollow body 6 is externally tested in the region of its corners, edges and/or ends using a non-destructive final testing device 7, in particular a magnetic particle testing device.

List of reference numerals

[0036]

- 1a Flat pre-material
- 1b Block-shaped pre-material
- 2b Welded intermediate hollow body having a round cross-section
- 2c Seamless intermediate hollow body having a round cross-section
- 2b' Welded intermediate hollow body having a round cross-section with intermediate heat treatment
- 2c' Seamless intermediate hollow body having a round cross-section with intermediate heat treatment
- 3a Non-destructive testing device
- 4a Intermediate heating oven
- 4b Intermediate cooling path
- 5a Final-heating oven
- 5b Final-shaping device
- 6 Hollow body having a polygonal cross-section
- 7 Non-destructive final testing device

Claims

1. Method for producing an elongate hollow body consisting of steel and having a polygonal cross-section, comprising the following steps:

producing an intermediate hollow body having a round cross-section from a flat pre-material or from a block-shaped pre-material, whereby the intermediate hollow body is cooled or quenched with partial or full phase transformation,
 testing the intermediate hollow body by at least one non-destructive testing method selected from eddy current testing of surfaces, ultrasonic testing of surfaces, ultrasonic testing for laminar imperfections and other defects in a wall volume, magnetic particle testing for local testing of the surface or combinations thereof,
 final-shaping to form a final hollow body having a polygonal, in particular square or rectangular, cross-section, by amending the average wall thickness of the intermediate hollow body by less than 10 %, preferably less than 5 %, compared with the wall thickness of the final hollow body,
 final-heat treating the intermediate hollow body immediately prior to the final-shaping or final-heat treatment and final-shaping the intermediate hollow body in a common step, relying on the non-destructive testing results of the intermediate hollow body for the final hollow body.

2. Method as claimed in claim 1, **characterised in that** the non-destructive testing is an eddy current testing or ultrasonic testing or a combination hereof.

3. Method as claimed in claim 1 or 2, **characterised in that** the intermediate hollow body is at room temperature for the non-destructive testing, whereby room temperature is defined from 5 °C to 60 °C.

4. Method as claimed in any one of claims 1 to 3, **characterised in that** the final-shaping of the intermediate hollow body is a drawing or stretching or pressing, especially a roll-drawing or a roll-stretching or a roll-pressing.

5. Method as claimed in claim 4, **characterised in that** the final-shaping of the intermediate hollow body amends the wall thickness of the intermediate hollow body by less than 10%, preferably less than 5%, compared with the wall thickness of the hollow body having a polygonal, in particular square or rectangular, cross-section.

6. Method as claimed in any one of claims 1 to 5, **characterised in that** the intermediate hollow body having a round cross-section is produced from a block-shaped pre-material.
- 5 7. Method as claimed in any one of the claims 1 to 6, **characterised by** an intermediate heat treatment of the intermediate hollow body prior to the final-shaping, in particular heating above an Ac3 temperature of the corresponding steel for austenitisation, and then cooling or quenching the intermediate hollow body prior to the final-shaping.
- 10 8. Method as claimed in claim 7, **characterised by** heating to an Ac3 temperature of the corresponding steel + 20 Kelvin, preferably to 870 to 980°C, maintaining said temperature for at least 5 minutes, and cooling with water, oil or polymers.
- 15 9. Method as claimed in claim 7 or 8, **characterised by** a final-heat treatment in the form of tempering at a temperature between 550°C and Ac1 - 20 Kelvin, with this temperature being maintained between 5 and 60 minutes.
- 20 10. Method as claimed in claim 1, **characterised by** a final-heat treatment in the form of normalising at a temperature of at least Ac3 + 20 Kelvin, with this temperature being maintained for at least 5 minutes.
11. Method as claimed in claim 1, **characterised by** a final-heat treatment in the form of age hardening at a temperature of less than Ac1 and with a tolerance of +/- 30 Kelvin, with this temperature being maintained for 10 to 60 minutes.
- 25 12. Method as claimed in claim 1, **characterised by** a final-heat treatment in the form of dual-phase annealing at a temperature of between Ac1 and Ac3, with this temperature being maintained for 5 to 60 minutes.
13. Method as claimed in any one of claims 1 to 12, **characterised by** external non-destructive final testing, in particular magnetic particle testing, of the final hollow body in the region of its corners, edges and/or ends.
- 30 14. Method as claimed in any one of claims 1 to 13, **characterized by** shaping, in particular rolling, the block-shaped pre-material to form a seamless intermediate hollow body.
15. Method as claimed in any one of claims 1 to 14, **characterised by** non-destructive testing of the flat pre-material prior to the production of the intermediate hollow body.
- 35 16. Method as claimed in any one of claims 1 to 13 or 15, **characterised by** shaping, in particular bending and/or rolling, the flat pre-material to form a slotted hollow body having adjoining abutment ends and welding the abutment ends to form a welded intermediate hollow body.
17. Method as claimed in any one of claims 1 to 16, **characterised by** non-destructive testing of the intermediate hollow body prior to the final-shaping of the intermediate hollow body and optionally additionally prior to the intermediate heating treatment of the intermediate hollow body.
- 40 18. Method as claimed in any one of claims 1 to 17, **characterised by** final-shaping of the intermediate hollow body immediately after the final-heat treatment at a temperature between 550°C and Ac1 - 20 Kelvin or at a temperature of at least Ac3 + 20 Kelvin.

45 **Patentansprüche**

1. Verfahren zur Herstellung eines langgestreckten Hohlkörpers, der aus Stahl besteht und einen polygonalen Querschnitt aufweist, umfassend die folgenden Schritte:
- 50 Herstellen eines Zwischenprodukt-Hohlkörpers mit einem runden Querschnitt aus einem flachen Vormaterial oder aus einem blockförmigen Vormaterial, wobei der Zwischenprodukt-Hohlkörper mit teilweiser oder vollständiger Phasenumwandlung abgekühlt oder abgeschreckt wird,
- 55 Prüfen des Zwischenprodukt-Hohlkörpers durch wenigstens ein zerstörungsfreies Prüfverfahren ausgewählt aus Wirbelstromprüfung von Oberflächen, Ultraschallprüfung von Oberflächen, Ultraschallprüfung auf laminare Fehler und andere Defekte in einem Wandvolumen, Magnetpartikelprüfung zur lokalen Prüfung der Oberfläche oder Kombinationen davon,
- Endformen, um einen fertigen Hohlkörper mit einem polygonalen, insbesondere quadratischen oder rechtecki-

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gen, Querschnitt zu bilden, durch Verändern der mittleren Wanddicke des Zwischenprodukt-Hohlkörpers um weniger als 10 %, vorzugsweise weniger als 5 %, im Vergleich zu der Wanddicke des fertigen Hohlkörpers, abhängig von den Ergebnissen der zerstörungsfreien Prüfung des Zwischenprodukt-Hohlkörpers End-Wärmebehandeln des Zwischenprodukt-Hohlkörpers unmittelbar vor dem Endformen oder End-Wärmebehandeln und Endformen des Zwischenprodukt-Hohlkörpers in einem gemeinsamen Schritt für den fertigen Hohlkörper.

- 5 2. Verfahren gemäß Anspruch 1, **dadurch gekennzeichnet, dass** die zerstörungsfreie Prüfung eine Wirbelstromprüfung oder Ultraschallprüfung oder eine Kombination davon ist.
- 10 3. Verfahren gemäß Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** der Zwischenprodukt-Hohlkörper für die zerstörungsfreie Prüfung bei Raumtemperatur vorliegt, wobei Raumtemperatur als von 5 °C bis 60 °C definiert ist.
- 15 4. Verfahren gemäß einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** das Endformen des Zwischenprodukt-Hohlkörpers ein Ziehen oder Strecken oder Pressen ist, insbesondere ein Walzenziehen oder ein Walzenstrecken oder ein Walzenpressen.
- 20 5. Verfahren gemäß Anspruch 4, **dadurch gekennzeichnet, dass** das Endformen des Zwischenprodukt-Hohlkörpers die Wanddicke des Zwischenprodukt-Hohlkörpers um weniger als 10 %, vorzugsweise weniger als 5 %, im Vergleich zu der Wanddicke des Hohlkörpers mit einem polygonalen, insbesondere quadratischen oder rechteckigen, Querschnitt verändert.
- 25 6. Verfahren gemäß einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** der Zwischenprodukt-Hohlkörper, der einen runden Querschnitt aufweist, aus einem blockförmigen Vormaterial hergestellt wird.
- 30 7. Verfahren gemäß einem der Ansprüche 1 bis 6, **gekennzeichnet durch** eine Zwischen-Wärmebehandlung des Zwischenprodukt-Hohlkörpers vor dem Endformen, insbesondere Erhitzen auf über eine Ac3-Temperatur des entsprechenden Stahls zur Austenitisierung, und dann Abkühlen oder Abschrecken des Zwischenprodukt-Hohlkörpers vor dem Endformen.
- 35 8. Verfahren gemäß Anspruch 7, **gekennzeichnet durch** Erhitzen auf eine Ac3-Temperatur des entsprechenden Stahls + 20 Kelvin, vorzugsweise auf 870 bis 980 °C, Halten der Temperatur für wenigstens 5 Minuten und Abkühlen mit Wasser, Öl oder Polymeren.
- 40 9. Verfahren gemäß Anspruch 7 oder 8, **gekennzeichnet durch** eine End-Wärmebehandlung in der Form von Tempern bei einer Temperatur zwischen 550 °C und Ac1 - 20 Kelvin, wobei diese Temperatur zwischen 5 und 60 Minuten gehalten wird.
- 45 10. Verfahren gemäß Anspruch 1, **gekennzeichnet durch** eine End-Wärmebehandlung in der Form von Normalisieren bei einer Temperatur von wenigstens Ac3 + 20 Kelvin, wobei diese Temperatur für wenigstens 5 Minuten gehalten wird.
- 50 11. Verfahren gemäß Anspruch 1, **gekennzeichnet durch** eine End-Wärmebehandlung in der Form von Alterungshärten bei einer Temperatur von weniger als Ac1 mit einer Toleranz von +/- 30 Kelvin, wobei diese Temperatur für 10 bis 60 Minuten gehalten wird.
- 55 12. Verfahren gemäß Anspruch 1, **gekennzeichnet durch** eine End-Wärmebehandlung in der Form von Zweiphasentempnern bei einer Temperatur von zwischen Ac1 und Ac3, wobei diese Temperatur für 5 bis 60 Minuten gehalten wird.
13. Verfahren gemäß einem der Ansprüche 1 bis 12, **gekennzeichnet durch** externe zerstörungsfreie Endprüfung, insbesondere Magnetpartikelprüfung, des fertigen Hohlkörpers in dem Bereich seiner Ecken, Kanten und/oder Enden.
14. Verfahren gemäß einem der Ansprüche 1 bis 13, **gekennzeichnet durch** Formgebung, insbesondere Walzen, des blockförmigen Vormaterials, um einen nahtlosen Zwischenprodukt-Hohlkörper zu bilden.
15. Verfahren gemäß einem der Ansprüche 1 bis 14, **gekennzeichnet durch** zerstörungsfreie Prüfung des flachen Vormaterials vor dem Erzeugen des Zwischenprodukt-Hohlkörpers.

16. Verfahren gemäß einem der Ansprüche 1 bis 13 oder 15, **gekennzeichnet durch** Formgebung, insbesondere Biegen und/oder Walzen, des flachen Vormaterials, um einen geschlitzten Hohlkörper mit benachbarten anstoßenden Enden zu bilden, und Schweißen der anstoßenden Enden, um einen geschweißten Zwischenprodukt-Hohlkörper zu bilden.

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17. Verfahren gemäß einem der Ansprüche 1 bis 16, **gekennzeichnet durch** zerstörungsfreie Prüfung des Zwischenprodukt-Hohlkörpers vor dem Endformen des Zwischenprodukt-Hohlkörpers und gegebenenfalls vor der Zwischenwärmebehandlung des Zwischenprodukt-Hohlkörpers.

18. Verfahren gemäß einem der Ansprüche 1 bis 17, **gekennzeichnet durch** Endformen des Zwischenprodukt-Hohlkörpers unmittelbar nach der End-Wärmebehandlung bei einer Temperatur zwischen 550 °C und Ac1 - 20 Kelvin oder einer Temperatur von wenigstens Ac3 + 20 Kelvin.

15 Revendications

1. Procédé de production d'un corps creux allongé composé d'acier et ayant une section transversale polygonale, comprenant les étapes suivantes :

20 production d'un corps creux intermédiaire ayant une section transversale ronde à partir d'un pré-matériau plat ou à partir d'un pré-matériau en forme de bloc, le corps creux intermédiaire étant refroidi ou trempé avec changement de phase partiel ou complet, contrôle du corps creux intermédiaire par au moins une méthode de contrôle non destructif choisie parmi le contrôle par courants de Foucault de surfaces, le contrôle par ultrasons de surfaces, le contrôle par ultrasons d'imperfections laminaires et d'autres défauts dans un volume de paroi, le contrôle par particules magnétiques pour le contrôle local de la surface, ou les combinaisons de ceux-ci, façonnage final pour former un corps creux final ayant une section transversale polygonale, en particulier carrée ou rectangulaire, avec modification de l'épaisseur moyenne de paroi du corps creux intermédiaire de moins de 10 %, de préférence moins de 5 %, par rapport à l'épaisseur de paroi du corps creux final, traitement thermique final du corps creux intermédiaire juste avant le façonnage final ou traitement thermique final et façonnage final du corps creux intermédiaire dans une étape commune, reposant sur les résultats de contrôle non destructif du corps creux intermédiaire pour le corps creux final.

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2. Procédé selon la revendication 1, **caractérisé en ce que** le contrôle non destructif est un contrôle par courants de Foucault ou un contrôle par ultrasons ou une combinaison de ceux-ci.

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3. Procédé selon la revendication 1 ou 2, **caractérisé en ce que** le corps creux intermédiaire est à température ambiante pour le contrôle non destructif, la température ambiante étant définie de 5 °C à 60 °C.

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4. Procédé selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que** le façonnage final du corps creux intermédiaire est un emboutissage ou un étirage ou un pressage, en particulier un emboutissage par cylindres ou un étirage par cylindres ou un pressage par cylindres.

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5. Procédé selon la revendication 4, **caractérisé en ce que** le façonnage final du corps creux intermédiaire modifie l'épaisseur de paroi du corps creux intermédiaire de moins de 10 %, de préférence moins de 5 %, par rapport à l'épaisseur de paroi du corps creux ayant une section transversale polygonale, en particulier carrée ou rectangulaire.

6. Procédé selon l'une quelconque des revendications 1 à 5, **caractérisé en ce que** le corps creux intermédiaire ayant une section transversale ronde est produit à partir d'un pré-matériau en forme de bloc.

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7. Procédé selon l'une quelconque des revendications 1 à 6, **caractérisé par** un traitement thermique intermédiaire du corps creux intermédiaire avant le façonnage final, en particulier un chauffage au-dessus d'une température Ac3 de l'acier correspondant pour austénitisation, puis un refroidissement ou une trempe du corps creux intermédiaire avant le façonnage final.

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8. Procédé selon la revendication 7, **caractérisé par** un chauffage jusqu'à une température Ac3 de l'acier correspondant + 20 kelvins, de préférence jusqu'à 870 à 980 °C, le maintien de ladite température pendant au moins 5 minutes, et un refroidissement avec de l'eau, de l'huile ou des polymères.

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9. Procédé selon la revendication 7 ou 8, **caractérisé par** un traitement thermique final sous la forme d'un revenu à une température comprise entre 550 °C et Ac1 - 20 kelvins, cette température étant maintenue entre 5 et 60 minutes.
- 5 10. Procédé selon la revendication 1, **caractérisé par** un traitement thermique final sous la forme d'une normalisation à une température d'au moins Ac3 + 20 kelvins, cette température étant maintenue pendant au moins 5 minutes.
- 10 11. Procédé selon la revendication 1, **caractérisé par** un traitement thermique final sous la forme d'un durcissement par vieillissement à une température inférieure à Ac1 et avec une tolérance de ± 30 kelvins, cette température étant maintenue pendant 10 à 60 minutes.
- 15 12. Procédé selon la revendication 1, **caractérisé par** un traitement thermique final sous la forme d'un recuit à double phase à une température comprise entre Ac1 et Ac3, cette température étant maintenue pendant 5 à 60 minutes.
- 20 13. Procédé selon l'une quelconque des revendications 1 à 12, **caractérisé par** un contrôle non destructif final externe, en particulier un contrôle par particules magnétiques, du corps creux final dans la région de ses coins, bords et/ou extrémités.
- 25 14. Procédé selon l'une quelconque des revendications 1 à 13, **caractérisé par** le façonnage, en particulier le laminage, du pré-matériau en forme de bloc pour former un corps creux intermédiaire sans soudure.
- 30 15. Procédé selon l'une quelconque des revendications 1 à 14, **caractérisé par** le contrôle non destructif du pré-matériau plat avant la production du corps creux intermédiaire.
- 35 16. Procédé selon l'une quelconque des revendications 1 à 13 ou 15, **caractérisé par** le façonnage, en particulier le cintrage et/ou le laminage, du pré-matériau plat pour former un corps creux fendu ayant des extrémités d'aboutement contiguës et le soudage des extrémités d'aboutement pour former un corps creux intermédiaire soudé.
- 40 17. Procédé selon l'une quelconque des revendications 1 à 16, **caractérisé par** le contrôle non destructif du corps creux intermédiaire avant le façonnage final du corps creux intermédiaire et éventuellement aussi avant le traitement thermique intermédiaire du corps creux intermédiaire.
- 45 50 55 18. Procédé selon l'une quelconque des revendications 1 à 17, **caractérisé par** le façonnage final du corps creux intermédiaire juste après le traitement thermique final à une température comprise entre 550 °C et Ac1 - 20 kelvins ou à une température d'au moins Ac3 + 20 kelvins.

REFERENCES CITED IN THE DESCRIPTION

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