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(71) Applicant: **Euroform S.p.A.**
33074 Fontanafredda (PN) (IT)

(72) Inventors:
- **Storti, Giampaolo,**
c/o Euroform
33074 Fontanafredda,
Pordenone (IT)
- **Bettoli, Franco,**
c/o Euroform
33074 Fontanafredda,
Pordenone (IT)

(74) Representative: **Giugni, Valter et al**
Propria S.r.l.
Via della Colonna 35
33170 Pordenone (IT)

(54) **Process for manufacturing engine starting motor shafts**

(57) The present invention refers to a process for manufacturing engine starting motor shafts, comprising the steps of:
- providing a raw workpiece made of a C45EC-grade steel made of a material having a chemical composition comprising the following elements as percentages referred to the total weight of the raw workpiece: from 0.32 to 0.45 weight-percent of C; from 0.73 to 0.80 weight-percent of Mn; from 0 to 0.013 weight-percent of Si; from 0 to 0.10 weight-percent of P; from 0 to 0.10 weight-percent of S;
- submitting said raw steel workpiece to a single cold-forming cycle to produce an intermediate workpiece adapted to undergo subsequent surface machining or chemical-physical finishing treatments.

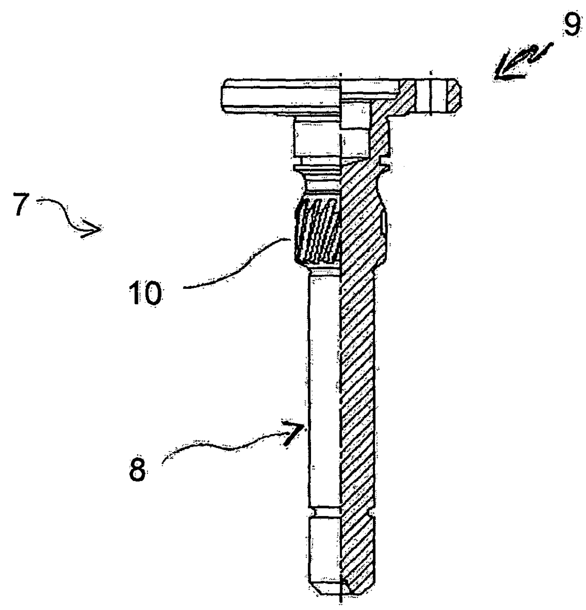

FIG. 3

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Description

Field of the Invention

[0001] The present invention refers to a manufacturing process for the production of engine starting motor shafts for automotive applications. In particular, this process refers to processing a raw steel workpiece, formed of a new mixture of elements and particular mechanical properties, which has been developed to obtain an intermediate workpiece provided with optimal physical properties in view of its being submitted to final processing.

Background of the Invention

[0002] The shafts used in engine starting motors are largely known to be functionally intended to rotatably drive a pinion meshing with the crown gear of an engine to the purpose of starting the engine. In the process, the shaft undergoes a considerable amount of loads and stresses, which it shall be able to withstand without any risk for it to incur such problems as breakdowns or undue strain.

[0003] For such shafts to be adequately reliable in operation, as well as capable of safely withstanding the loads and stresses, which they are usually submitted to, they must first of all be manufactured according to most severe, strict standards with the use of processes and techniques that are adapted to fully meet such manufacturing and operating requirements of the parts concerned.

[0004] Widely known in the art and commonly used in industry are on the other hand manufacturing processes that include turning and cold forming, followed by short machining steps.

[0005] In particular, cold forming typically consists of a sequence of mechanical processing steps performed on a raw workpiece, generally referred to as "billet" in the art. This billet is introduced in a cold-pressing metal-forming apparatus, in which it is subjected to considerable pressing forces that are duly rated so as to gradually deform it in accordance with the desired final configuration and into the desired final shape.

[0006] The above-cited processing steps must be carried out in a very accurate manner if the afore-mentioned ideal mechanical properties are to be reliably obtained. Furthermore, after pressing, the resulting intermediate workpiece must be such as to be adapted to undergo subsequent machining and processing as required to finishing purposes, such as for instance surface rolling for forming the helical gear teeth aimed at meshing with the pinion of the motor, and hardening heat-treatment. It can therefore be most readily appreciated that the cold-forming process has a number of critical aspects or conditions that need be strictly complied with in view of the afore-noted optimization of the mechanical properties and suitability for subsequent processing.

[0007] In other words, the billet shall be provided with such properties as to enable it to be easily processed by cold forming, while preserving a sufficient extent of residual deformability that on the one hand allows rolling to be adequately performed for the helical gear teeth to be properly formed and, on the other hand, ensures high values of strength and toughness to the same gear teeth. In addition, the billet shall be such as to allow for a final hardening heat-treatment to be carried out in order to ensure the proper hardness properties as required by the application.

[0008] For all of the above-mentioned requirements to be able to be duly complied with, the billet is produced using application-standardized materials, and is submitted to certain heat-treatment cycles between a processing step and the next one. In fact, the above-cited materials are represented by particular kinds or grades of steel that - as already explained - are subjected to hardening after cold forming. Generally, such steels have a chemical composition that mainly comprises iron (Fe) with variable amounts of carbon (C) and manganese (Mn) as basic elements thereof, and small amounts of further elements such as phosphorus (P), silicon (Si), sulphur (S), copper (Cu), nickel (Ni), chromium (Cr), as well as impurities of various nature.

[0009] It is also widely known that billets made of steel as described above represent a kind of material that has by now been practically optimized in view of cold forming, but still rather far from being such in view of its suitability to traditional material-removing machining processes such as the afore-mentioned rolling to helical gear teeth forming purposes. In fact, it is as soon as the first forming step is completed - as usually carried out in view of forming the billet into a first rough shape thereof - that the material undergoes a structural transformation, generally referred to as work-hardening in the art, due to which the billet loses a great deal of its deformability properties. It ensues that a further deformation step may quite easily lead to cracks forming in the workpiece or even cause the workpiece to break down, thereby making it fully and absolutely unusable for subsequent pressing or processing steps and - much more than that - by no way fit for application in the ultimate function thereof. Furthermore, also a surface processing step, such as rolling, as finishing would prove fully ineffective due to exactly such excessive hardening of the material.

[0010] In view of doing away with or getting round such a drawback, the process used to process raw steel workpiece, or billets, necessarily involves at least a heat-treatment or annealing step, aimed at nullifying the work-hardening effect, and a surface treatment aimed at optimizing the coefficient of friction and enabling the above-cited rolling step.

[0011] It can therefore be most readily appreciated that currently used processes for manufacturing engine starting motor shafts are particularly delicate on their whole and, in any case, must be interrupted by the introduction of at least a heat-treatment step aimed at nullifying the work-hardening effect brought about by each cold deformation or pressing step.

Summary of the Invention

[0012] The problem of the present invention therefore lies in providing a process for manufacturing engine starting motor shafts, which is effective in enabling the processing steps involved to be simplified and a substantially continuous.
[0013] Said problem, is solved in a process for manufacturing engine starting motor shafts, wherein the deformation steps by cold-forming occur, are performed in a substantially continuous manner.
[0014] Accordingly, it is a first purpose of the present invention to provide a process for manufacturing engine starting motor shafts as recited in the appended claims.
[0015] It is further a second purpose of the present invention to provide a workpiece of semi-processed, material for use in the production of engine starting motor shafts.
[0016] A third purpose of the present invention is then using a steel-based material in the production of engine starting motor shafts.

Brief Description of the Drawings

[0017] Further features and advantages of the present invention will become apparent and be more readily understood from the description of an exemplary embodiment that is given below by way of non-limiting example with reference to the accompanying drawings, in which:

- Figure 1 is a diagrammatical view of the yield-stress curve in a raw steel workpiece of given mechanical properties and given chemical composition, versus the variation in the amount of deformation applied thereonto;

- Figure 2 is a perspective schematical view of the various transformations, which a billet goes through in the process according to the present invention;

- Figure 3 is a partially sectional, side view of a shaft of an engine starting motor.

Detailed Description of the Invention

[0018] The basic idea, which the present invention is founded on, lies in providing a raw steel workpiece, or billet, which is sufficiently soft as to enable it to be processed by cold forming even in a multi-step process, while doing away with any interruption that may be caused by the introduction of heat treatments aimed at nullifying work-hardening effects, and is at the same time such as to ensure that the desired hardness is obtained at the end of the entire cold-forming process, as required in view of the following machining, i.e. turning and rolling steps to be carried out to finishing purposes.
[0019] In other words, extensive experimental test runs have been carried out in an attempt to identify a kind of steel that would exhibit an optimum balance between the initial deformability properties and the final hardness of the workpiece in the light of the overall physical properties, which the final part is required to most desirably comply with for due performance, while doing away with any need for intermediate heat treatments to be carried out during cold forming to compensating purposes.
[0020] To such purpose, a full set of cylindrical billets in a diameter of 20.5 and a length of 40 mm has been produced from a steel grade classified as C45EC according to EN-10263-4 standards. This particular steel grade and the size selected for the billets enable initial hardness and deformability properties conventional in engine starting motor shaft manufacturing industry.
[0021] Starting from the above-mentioned grade of steel, some variations have then been introduced in the chemical composition thereof, as far as the main elements thereof were concerned, so as to ultimately obtain following billets:

- B1 (billet # 1): C = 0.50% - Si = 0.30% - Mn = 0.80%;
- B2 (billet # 2): C = 0.45% - Si = 0.13% - Mn = 0.80%;
- B3 (billet # 3): C = 0.38% - Si = 0.10% - Mn = 0.76%;
- B4 (billet # 4): C = 0.32% - Si = 0.05% - Mn = 0.73%;
- B5 (billet # 5): C = 0.42% - Si = 0.03% - Mn = 0.50%.

[0022] Various chemical compositions have then been submitted to extensive experimental testing - on the basis of thoroughly conventional cylinder forming tests, or forming tests carried out on cylindrical specimens - under application of pre-established reductions in the diameter of the cylinders as commanded by the ultimate product that is to be obtained and, therefore, in accordance with widely known procedures.

[0023] From each extruded cylinder, three specimens, or samples, have then been taken for subsequent compression testing on an AFFRI Testing Machine - Easy Dur testing apparatus. The specimens, in a cylindrical shape and having following dimensions:

- diameter: 10 mm
- length: 10 mm

have been selected under due consideration of also he provisions set forth in this connection in the User's Manual of the testing machine used.

[0024] The extrusion tests have been carried out to embrace various chemical compositions lying in any case within the raw-material provisions set forth for the afore-cited steel grade C45EC. In particular, the tests have been directed at assaying the limits of three basic elements of the alloy as far as the desired properties were concerned, i.e. Carbon (0.42% - 0.50%), Silicon (0.03% - 0.30%), Manganese (0.50% - 0.80%). The test run has been carried out to assess the upper limits of following percentages:

- C = 0.50%;
- Si = 0.30%;
- Mn = 0.80%.

[0025] This kind of alloy has given rise to the formation - on the specimen - of a number of cracks that were fully and clearly visible along the shaft regions that are generally subject to the greatest strains. Subsequent hardness tests have shown that such parameter was clearly too high, with values ranging from 106 and 128 HRB. On their whole, these results have been considered as being the symptom of an excessive strain-hardening of the material.

[0026] A second test run has been carried out to assess the lower limits of the percentage provisions set forth by the applying standards for the considered elements, i.e.:

- C = 0.42%;
- Si = 0.03%;
- Mn = 0.50%.

[0027] With this chemical composition, the surface of the extruded specimens turned out as being free of cracks; the result of the subsequent hardness tests, however, showed much too low a value when compared with the properties that the shaft should be assured with for proper performance under use conditions; in particular the hardness turned out as ranging between 85 and 92 HRB. In addition, machinability has turned out as being inadequate, since subsequent turning - as carried out prior to rolling, i.e. prior to forming the required helical gear teeth - was found to be quite critical. Through a number of various further trial-and-error attempts at properly adjusting the chemical composition (billets 2, 3 and 4), an optimum chemical composition was eventually identified as follows:

- C = 0.32%-0.45%;
- Si ≤ 0.13%;
- Mn = 0.73% - 0.80%;
- P ≤ 0.10%;
- S ≤ 0.10%.

[0028] The alloy turned out as being able to ensure a fully crack-free outer surface, while at the same time ensuring high hardness values (94 - 104 HRB) and - what is to be considered a still greater advantage - a particular evolution pattern for the yield stress, as this shall be illustrated further on.

[0029] Thereupon, compression tests have been carried out on the above-cited specimens taken from the cold-formed material. Also these tests have been carried out on an AFFRI Testing Machine - Easy Dur testing apparatus. Using the operating and control software of the apparatus, it has in this way been possible for the pattern of the stress-strain curves to be evaluated through the Hansel-Spittel rheological model based on following equation:

$$\sigma_f = Ae^{m_1 T}\varepsilon^{m_2}\dot{\varepsilon}^{m_3}e^{\frac{m_4}{\varepsilon}}\left(1+\varepsilon\right)^{m_5 T}e^{m_7\varepsilon}\dot{\varepsilon}^{m_8}T^{m_9}$$

[0030] Tests have been carried out at room temperature under constant strain rate conditions, so that the tests performed in this way would then be comparable with each other. The result of these compression tests has enabled the graph shown in Figure 1 to be worked out and plotted.

[0031] As it can be noticed, the above-cited graph shows the correspondence, i.e. relation existing between the steel-cylinder reduction ratio and the yield stress. The graph appears to be a linear one in a bi-logarithmic representation on a Cartesian coordinate system.

[0032] In order to check the so derived results for reliability, extrusion runs have been simulated using the finite-element simulation programme Forge 2005 3D. It has therefore been possible for process simulations to be carried out by using the material that had been characterized through the compression tests, to then verify whether the simulated process was going to faithfully replicate what was experimentally derived from the tests.

[0033] In particular, the graph in Figure 1 plots the value of the reduction in the diameter of the workpiece or billet (d_0/d) on the abscissa, as against the value of the yield stress (N/mm^2) on the ordinate, or, in other words, the hardness pattern. The value do indicates the initial, i.e. starting diameter of the workpiece prior to a compression force being applied, whereas the value d indicates the extent of variation in diameter reduction as compared with said initial or starting value do. To each value of d_0/d, i.e. for each degree of reduction in diameter brought about by the applied compression, there corresponds a given value of yield stress.

[0034] As it can be noticed, the curve generated in this way therefore describes the characteristics of the evolution pattern of the yield stress increasing in a substantially linear manner that is directly proportional to the decrease, i.e. reduction in the diameter of the workpiece being compressed, on a bi-logarithmic Cartesian plane.

[0035] A corresponding curve has been in this way plotted for each one of the afore-indicated billets. At this point, a comparison has been made to identify which curves, and therefore which billets, were complying with the required characteristics of yield stress for degree of deformation, actually.

[0036] As it can be inferred from the graph of Figure 1, the curve plotting the pattern for the composition according to the present invention appears to fully comply with the desired characteristics.

[0037] It can in fact be noticed how the billet made of a steel comprising C = 0.32 to 0.45%, Si ≤ 0.13%, Mn = 0.73 to 0.80%, P ≤ 0.10%, S ≤ 0.10%, is featuring a tensile stress Rm equal to a maximum value of 550 MPa and a yield stress $Rp_{0.2}$ equal to a maximum value of 460 MPa. Now, these values are exactly the values characterizing the desired product.

[0038] Further experimental testing has been carried out in view of finding out whether there might be other compositions capable of ensuring compliance with the desired requirements. To this purpose, steel compositions around the above-indicated ideal one have been prepared to be assessed in their behaviour both on the afore-noted compression testing apparatus and in the simulation procedure with the afore-described programme for calculating the pattern of the yield point.

[0039] These further tests have led to the definition of a composition of steels comprising following percentages of the afore-cited main elements as referred to the total weight of the billet:

- from 0.32 to 0.45 weight-percent of C;
- from 0.73 to 0.80 weight-percent of Mn;
- from 0 to 0.013 weight-percent of Si;
- from 0 to 0.10 weight-percent of P;
- from 0 to 0.10 weight-percent of S.

[0040] A billet based on a composition as described above has surprisingly turned out as being most effective in complying with the desired physical and mechanical requirements set for the application. In fact, the billet has been found to feature an initial degree of strength (400 MPa), prior to being submitted to cold forming, that is fully adequate in view of ensuring optimum processability, i.e. workability during all steps of the forming process, without incurring the really serious strain-hardening problem. In addition, at the end of the cold forming process, the resulting intermediate product is provided with a strength (720 to 850 MPa) enabling not only rolling to be effectively carried out, but also the workpieces to be optimally heat-treated for hardening in view of them being able to adequately withstand the stresses, which the finished product is bound to sustain, without giving rise to any problem whatsoever.

[0041] Furthermore, the above-described experiments have been successful in showing that the yield stress varies in a linear manner starting from the core of the billet, where it is smaller, and moving towards the surface, where it is greater. Such behaviour is particularly advantageous, since the finished workpiece, i.e. the end product will be exposed to torsional stresses during its use, which are certainly greater on the surface than at its core.

[0042] Therefore, a first object of the present invention is to provide a process for manufacturing engine starting motor shafts, which comprises the steps of:

- providing a billet made of a material based on the chemical composition as

described hereinbefore;

- submitting said billet to a single cold-forming cycle to produce an intermediate workpiece adapted to undergo subsequent surface machining or chemical-physical finishing treatments.

[0043] Preferably, the step calling for submitting the billet to a single forming cycle is carried out in at least two subsequent working passes, in which the billet is gradually deformed into pre-established shapes. More preferably, such working passes are in the number of five and are carried out according to sequences and processes, as well as with the use of equipment as these are fully conventional in the art, so as to gradually form he workpiece into a corresponding number of intermediate shapes, as this is shown in Figure 2.

[0044] For example, starting from a billet 1 having a cylindrical shape, a first pass would produce a first end-side portion 2 having a smaller diameter than a second larger-diameter portion 3. Thereafter, a second pass would modify the second portion 3 into a second end-side portion 4 and two intermediate portions 5 and 6, all of them having diameters differing from each other. In particular, the intermediate portions 5 and 6 and the first end-side portion 2 represent, i.e. form the shank of the yet unfinished starting motor shaft. A third pass would bring about a first partial flattening of the second end-side portion 4 so as to create an outline of the head of the starting motor shaft. A fourth pass would complete the flattening out of the shaft head to thereby allow it to take its final disc-like shape. Finally, the fifth pass would be used to prepare the shaft head for final drilling.

[0045] Such fifth pass would also complete the cold-forming cycle, and the billet, i.e. the raw steel blank, would at this point have been converted into an intermediate workpiece ready for the following machining as provided for to complete production of the starting motor shafts.

[0046] A further object of the present invention is therefore an intermediate workpiece obtainable according to the afore-described process. In particular, said intermediate workpiece is made of a material comprising the afore-indicated chemical composition and featuring a yield stress value that is equal to 720 - 850 MPa, along with an improved machinability ensured by the afore-noted P and S contents.

[0047] The finishing steps, which the intermediate workpiece is adapted to be submitted to, usually include mechanical processing, i.e. machining, such as truing and butting, turning, rolling for forming helical gear teeth; physical processing, such as hardening; along with grinding and drilling.

[0048] Accordingly, a yet further object of the present invention is using the above-described raw steel blank to produce a shaft for engine starting motors.

[0049] With reference to Figure 3, the end product, i.e. a shaft for engine starting motors - as represented in a partially sectional view - is generally indicated at 7. The shaft is made of a material comprising the afore-specified chemical composition. In addition, following hardening the end product will feature a hardness ranging from 520 to 720 HV 10, preferably from 570 to 680 HV 10, and more preferably is 600 and 640 HV 10.

[0050] Furthermore, the shaft 7 comprises a shank portion 8 in a substantially cylindrical general shape, and a head portion 9 in a disc-like general shape. In proximity of said head portion 9, the shank is provided with a helically toothed gear portion 10 adapted to engage a corresponding pinion (not shown) meshing with the crown gear of an engine.

[0051] Fully apparent from the above description is therefore the ability of the present invention to both solve the problems generally encountered in the prior art, as mentioned hereinbefore, and fully comply with the particular needs and requirements as dictated by the industrial application.

[0052] The inventive manufacturing process, the inventive intermediate workpiece, as well as the inventive shaft for engine starting motors shall obviously not be understood as being limited to the above-described embodiment, since it is fully apparent to those skilled in the art that various improvements and modifications may be introduced or added without departing from the scope of the present invention as defined in the appended claims.

[0053] In particular, for example, the actual size selected for the billets may vary as far as both the length and the diameter thereof are concerned, and the ratios of the various elements in the chemical composition of the steel may be adjusted so as to obtain the afore-noted hardness and yield strength properties.

Claims

1. Process for manufacturing engine starting motor shafts, comprising the steps of:

- providing a raw workpiece made of a C45EC-grade steel material having a chemical composition in which the main elements comprise following percentages as referred to the total weight of the raw workpiece: from 0.32 to 0.45 weight-percent of C; from 0.73 to 0.80 weight-percent of Mn; from 0 to 0.013 weight-percent of Si; from 0 to 0.10 weight-percent of P; from 0 to 0.10 weight-percent of S;
- submitting said raw steel workpiece to a single cold-forming cycle to produce an intermediate workpiece adapted to undergo subsequent surface machining or chemical-physical finishing treatments.

2. Process according to claim 1, wherein said step calling for submitting said raw steel workpiece to a single cold-forming cycle is carried out in at least two subsequent working passes, in which the raw workpiece is deformed into pre-established shapes.

3. Process according to claim 2, wherein said working passes are in the number of five and are carried out in a sequence within a single forming cycle, so that:

- the first working pass produces a first end-side portion (2) having a smaller diameter as compared with a second larger-diameter portion (3);
- the second pass modifies the second portion (3) into a second end-side portion (4) and two intermediate portions (5, 6), all of them having diameters differing from each other;
- the third pass brings about a first partial flattening of the second end-side portion (4) so as to outline the head of the starting motor shaft;
- the fourth pass completes the flattening out of the shaft head to thereby allow it to take its final disc-like shape;
- the fifth pass is used to prepare the shaft head for final drilling.

4. Process according to any of the claims 1 to 3, wherein said raw steel workpiece is in a cylindrical shape having a diameter lying anywhere between 12.4 and 49.6 mm, a tensile stress (Rm) equal to a maximum value of 550 MPa and a yield stress ($Rp_{0.2}$) equal to a maximum value of 460 MPa.

5. Process according to any of the claims 1 to 4, further comprising at least one of the following machining steps selected from: truing and butting, turning, rolling for forming helical gear teeth, hardening, grinding and drilling.

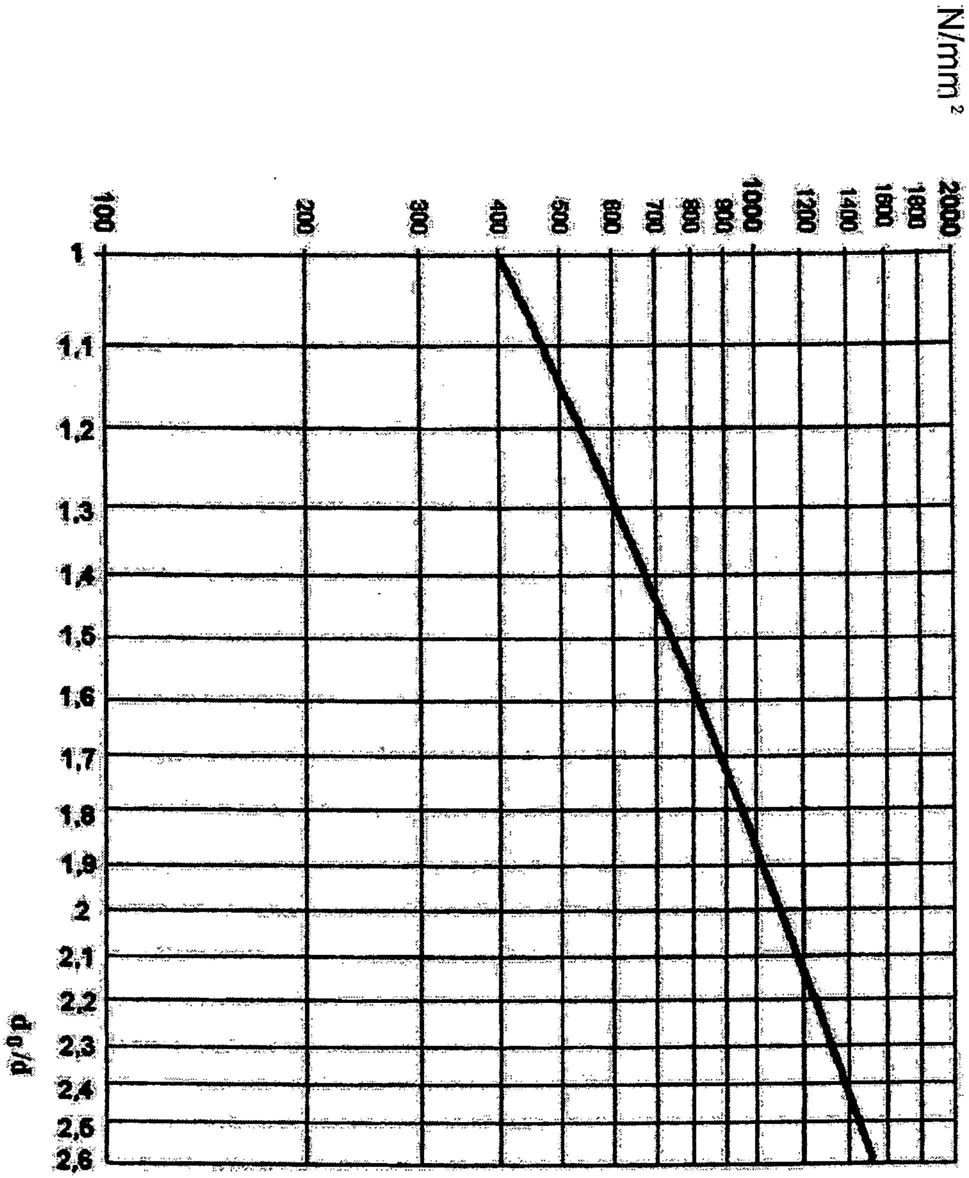
6. Intermediate workpiece obtainable with the process according to any of the claims 1 to 4.

7. Intermediate workpiece according to claim 6, made of a C45EC-grade steel material comprising the following elements in percentages as referred to the total weight of the workpiece: from 0.32 to 0.45 weight-percent of C; from 0.73 to 0.80 weight-percent of Mn; from 0 to 0.013 weight-percent of Si; from 0 to 0.10 weight-percent of P; from 0 to 0.10 weight-percent of S; and featuring a yield stress value ranging from 720 and 850 MPa.

8. Use of a raw workpiece made of a C45EC-grade steel made with a material having a chemical composition comprising as percentages referred to the total weight of the raw workpiece: from 0.32 to 0.45 weight-percent of C; from 0.73 to 0.80 weight-percent of Mn; from 0 to 0.013 weight-percent of Si; from 0 to 0.10 weight-percent of P; from 0 to 0.10 weight-percent of S, for the production of engine starting motor shafts.

9. Engine starting motor shaft obtainable with the process according to any of the claims 1 to 5.

10. Engine starting motor shaft made of a C45EC-grade steel material comprising the following elements as percentages referred to the total weight of the workpiece: from 0.32 to 0.45 weight-percent of C; from 0.73 to 0.80 weight-percent of Mn; from 0 to 0.013 weight-percent of Si; from 0 to 0.10 weight-percent of P; from 0 to 0.10 weight-percent of S; and featuring a yield stress value ranging from 720 and 850 MPa.


N/mm²
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d₀/d

FIG. 1

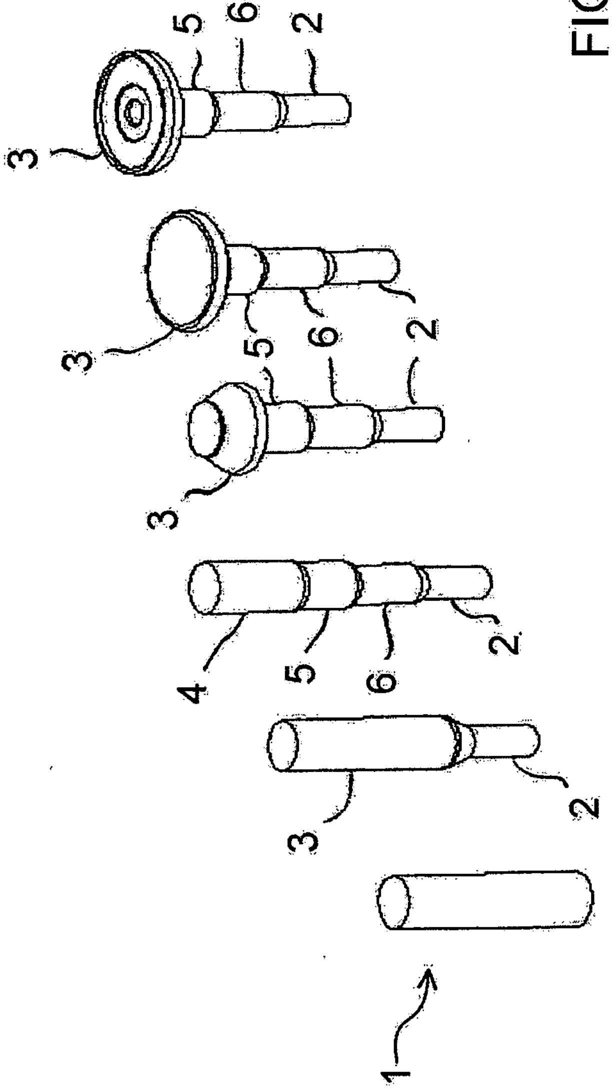

FIG. 2

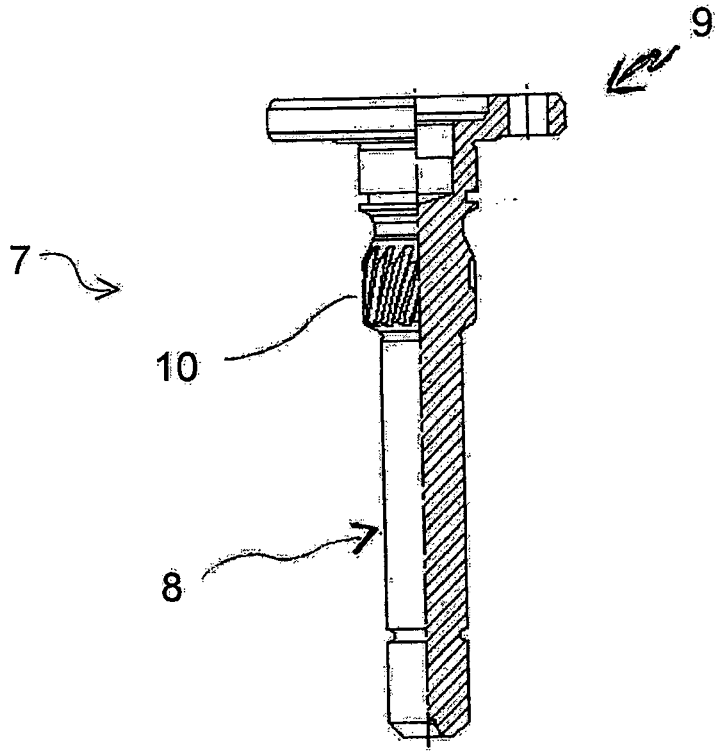

FIG. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 08 42 5239

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	"Material Card Index -Material number 1.1192 - C45EC" WWW.METALLOGRAF.DE/WERKSTOFFKARTEI-ENG/1192/1192.HTM, 2006, - 2006 XP002498407 DE * the whole document *	1-10	INV. C22C38/04 C22C30/00 B21K1/06 B21K1/30 F16H55/06
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	6 October 2008	Chebeleu, Alice

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 08 42 5239

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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