

Method of Manufacturing Hot-Worked Elongated Products, in particular Bar or Pipe, from High-Alloy or Hypereutectoid Steel

Description

The invention relates to a process for manufacturing hot-worked elongated products, particularly bars or pipes, from high-alloy or hypereutectoid steel in accordance with the introductory part of the main claim.

High-alloy or hypereutectoid steels, especially anti-friction bearing steels such as 100Cr6, form grain boundary carbides and pearlitic microstructural components when cooled from high temperatures (1100 to 1250°C). These formations impede mechanical workability and hardenability as well as chipless deformation. A spheroidal cementite microstructure suitable for further processing can be achieved only after long annealing processes (spheroidal cementite annealing) of 16 hours or more. Much thought has been given to the question of how to shorten the duration of this soft annealing or replace the treatment altogether.

F. Mladen and E. Hornbogen studied the influence of thermomechanical processing on the mechanical properties of 100Cr6 steel (*Archiv Eisenhuettenwesen* 49 (1978) No. 2, pp. 449 to 453). Austenitizing was carried out at a temperature above the limit temperature for the complete dissolution of Fe_3C , which, given a C content of 0.99 mass shares in percent, is somewhat less than 1100°C. Hot rolling began at 1100°C with simultaneous cooling to 720°C. Cooling from 720°C to ambient temperature was accomplished by means of water quenching. The details of the deformation sequence are not discussed in the article. The thermomechanically treated microstructure displayed such a finely dispersed distribution of carbides that the resolution limits of the optical microscope were reached. The reason

for this improved distribution was the increase in dislocation density and the subgrain boundaries created by dislocations, which resulted in new nucleation sites for the carbides.

A process for producing cylindrical rolled bodies from steel with a carbon mass share of 0.7 to 1.2 in percent is known from DE PS 2361330. In this process, steel wire that has been hot-rolled at 1000° C is rapidly cooled to a temperature that corresponds to its lower pearlite range. The steel wire is then isothermally transformed and brought to a hardness of 50 HRC by cold drawing without intermediate annealing. The rapid cooling of the wire and its subsequent isothermal transformation results in a microstructure of fine-lamellar pearlite. This makes it possible for the wire to be drawn, after being descaled and phosphatized, without any intervening annealing.

The object of the present invention is to indicate an especially economical process for producing hot-worked elongated products, especially bars or tubes, from high-alloy steel or hypereutectoid steel, especially anti-friction bearing steel, in which a microstructure is produced that is extremely well suited, without prior soft annealing, e.g., annealing to spheroidal cementite, for further chipless processing and final heat treatment. A further object is to produce a microstructure that is also suitable, without prior soft annealing, for further metal-cutting processing with a subsequent final heat treatment.

This object is attained by means of the features specified in the characterizing part of Claim 1. Advantageous further developments are the subject of the subclaims.

The coordinated process steps of the invention make it possible to produce the desired microstructure, whereby, in the case of the anti-friction bearing steel, a brinell hardness less than or equal to 280 HB 30, preferably less than 250 HB30, is achieved. This microstructure also makes it possible to feed hot-worked tubes directly to a processing unit, for example, dispensing with soft annealing. The optimized manufacturing process is especially economical, because it omits soft annealing and the transport and work steps associated therewith. The

hot-worked elongated products according to the invention can be processed by cold drawing, cold pilger rolling, cold rolling or cross rolling.

The individual steps that contribute to the success of the process according to the invention are explained in what follows: The first process step, which occurs after the initial deformation and before reheating for subsequent continuous rolling, is a controlled heating or cooling to achieve temperature equalization over the length and circumference of the rolled material, which has various temperatures, whereby the equalization temperature is lower than the preset temperature of the reheating furnace. The purpose of this measure is, first of all, to precisely adjust the temperature of the rolled material, even taking into account the opportunities to regulate temperature in the reheating furnace. Secondly, the measure is intended to achieve the most precise and reproducible conditions possible for the temperature-dependent measurement of wall thickness that takes place before the tube enters the reducing mill. The measure chosen, i.e., heating or cooling, depends on the thickness of the material to be rolled. For example, in the case of a push bench arrangement, the temperatures of thick-walled tubes after the initial deformations of piercing, elongation and striking are above 700°C . In such cases, temperature equalization is achieved by controlled cooling to a preestablished equalization temperature in the range between 650° and 700°C . In thin-walled tubes, which cool very quickly, temperatures are frequently below 650°C . In this case, temperature equalization is achieved by controlled heating to a preestablished equalization temperature in the aforementioned range of 650° to 700°C .

Actual reheating is carried out either to a temperature below A_{c1} but above 650°C , or to a temperature above A_{c1} but below A_{cm} (a = start of carbide resolution region). It is necessary to take into account the well-known fact that the A_{c1} or A_{cm} temperature depends primarily on the carbon content of the material used and on its deformation history. The first temperature range mentioned above corresponds to the second phase region $\gamma + \text{Fe}_3\text{C}$ in the continuous TTT diagram, while the second temperature range corresponds to second phase region $\gamma + \text{Fe}_3\text{C}$.



A further measure in the proposed combination of coordinated process steps relates to the final continuous rolling process, preferably in a stretch reducing mill. Unlike other rolling methods, this rapid continuous rolling offers few opportunities for intervention. It is nonetheless important for the proposed process that, first of all, a minimum partial deformation, expressed as the stretching $R\text{-value} \geq 1.03$, be maintained in the reducing mill per stand and that, secondly, a minimum stretching degree be maintained for the total deformation ≥ 1.5 . In special cases, the total stretching can even be somewhat deeper, i.e.,

≥ 1.4 . In addition, any temperature increase that occurs during rolling due to loss work, or any temperature decrease that results from excessive cooling, should be as small as possible. In all cases, rolling must take place in the given two-phase region, and the rolled material leaving the final stand must have a temperature corresponding to that of the region in question. This means that during the preferred rolling in the $\gamma + \text{Fe}_3\text{C}$ region, the temperature of the rolled material must not exceed A_{cm} . Compliance with this narrow temperature range can be achieved by means of cooling means control; additional heat, in special cases, from an external heating device; and variations in the geometry of the rolls, roll speed and pass reduction. In roller geometry, the pressed length is especially significant.

The process according to the invention is generally applicable for all known tube-making processes that end in a reducing mill with or without draught or in a sizing mill. For example, the process can be used on a continuous tube train, a plug train or an Assel mill. In particular, it is suitable for the push bench method of producing seamless tubes of anti-friction bearing steel. The feedstock for the process according to the invention can be ingot cast material (forged or rolled) or strand cast material (square or round), whereby the strand cast material is deformed and annealed in a known manner prior to rolling. Tests have shown that the process can be used especially advantageously when the chemical analysis of the known anti-friction bearing steel is modified. This relates, firstly, to the sulphur and phosphorous content and, secondly, to the ratio of chromium to carbon. To avoid possible melt-out at the grain boundaries when deformation rates rise, the maximum sulphur and phosphorous contents should each equal 0.005 mass share in percent,



taking into account the ratio of manganese to sulphur due to the suppression of FeS. The melt-out danger results from the high deformation temperatures required during the initial deformation steps, when deformation rates are such as to lead to corresponding temperature increases. For this reason, the deformation rate in the initial deformation steps is selected in such a way that the temperature in the interior of the rolled material, i.e., at the least advantageous point, does not exceed 1170°C. In addition, low S and P contents have an advantageous effect on any subsequent chipless deformation.

With respect to secondary metallurgy, the declining S and P contents are also advantageous in establishing a low oxygen content in the melt, which leads to an improvement of the oxidic purity.

The chromium-to-carbon ratio should be in the range of 1.35 to 1.52, preferably 1.45. The carbon content then equals 0.94 mass share in percent, for example, while the chromium content equals roughly 1.36 mass share in percent. Undesirable carbide banding can be positively influenced via this ratio.

When anti-friction bearing steel is used, the cost advantage that results from omitting soft annealing, which otherwise would be necessary, can be further increased by using a strand cast bar with no predeformation, i.e., in the cast state and without prior heat treatment (diffusion), as the feedstock.

Another improving measure relates to the cooling step that follows the final deformation. After leaving the rolling mill, the rolled material is cooled in resting air or by an air shower to a temperature that corresponds in the TTT diagram to a microstructure located above the martensite point and below the bainite nose. The deformed material is held in this area isothermally for several hours. This method has proved advantageous in the reduction of internal stresses. The step can be carried out by means of a cooling bed covered at a suitable point in a heat-insulating manner,

or by feeding the rolled material to a temperature equalization furnace or tempering furnace.

To dispense with the hardening of individual finished products after machining, it is further proposed that the rolled material, after cooling, be heated to 600° to 700° C, cooled and then tempered at 180° to 210° C. After this, the rolled material has a hardness corresponding to the required final hardness of the finished product.

The proposed new process technology for manufacturing hot-worked elongated products, especially bars or tubes, from anti-friction bearing steel has the following advantages:

- a) Eliminates investment expenditures for a special annealing furnace and operating costs for long-term spheroidal cementite annealing.
- b) Eliminates transport and work steps (annealing, straightening) and thus reduces opportunities for defects, resulting, at shorter operational run times, in more economical hot-worked products or cheaper feedstocks for further deformation steps.
- c) Improves material exploitation by shortening work sequences and attaining low decarburization depths due to omission of oxidizing annealing. This leads to small allowances and thus lower machining volumes and allows customers to retain their gripping clamp dimensions.
- d) Due to the reduced deformation temperature, the rolled material leaving the rolling mill has greater rigidity and becomes sufficiently straight on the cooling bed. Straightening can therefore be omitted, as a rule.
- e) The produced microstructure is markedly fine grained. During heat treatment, this leads to higher and more homogeneous hardness and better toughness. This has a positive effect on the later useful life of the finished product, e.g., roller bearings.

- f) The microstructure achieved through the new process technology can be subjected without additional heat treatment to a cold deformation process, e.g., cold drawing, cold pilger rolling, cold rolling or cross rolling. After stress-relief annealing, cold drawn tubes have the same properties as cold pilger rolled tubes.
- g) Money is saved during melt production due to the reduced S and P contents and the Cr and C contents set at the lower limits. Minimizing carbide banding and improving oxidic purity increases the useful properties of the finished product.

The process according to the invention will be described in greater detail in reference to an example. A hot-worked tube with dimensions of 40.9 mm in external diameter x 4.8 mm in wall thickness is to be produced from 100Cr6 on a tube push bench machine. From a strand cast bar 220 mm in diameter and 11,000 mm in length, feedstock ingots approximately 850 mm in length are cut. The feedstock ingots of 100 Cr6 are in the cast state, i.e., they have not been heat-treated or predeformed. The cut ingots are placed into a rotary hearth furnace and heated to approximately 1140°C. After a total heating time of 150 minutes, the ingots are removed individually from the furnace and, after pressurized water descaling, fed to the piercing press. In the piercing press, the initial deformation into a pierced piece takes place. In this example, the pierced piece has the following dimensions:

Outer diameter	223 mm
Inner diameter	121 mm
Wall thickness	51 mm

This deformation corresponds to a cross-sectional reduction of 29.4% and stretching of = 1.42. In this example, the deformation rate equals 0.45 s⁻¹ and influences the optimal temperature window. After the piercing press, another deformation occurs, namely elongation in a shoulder mill. This deformation produces a shell with an outer diameter of 192 mm, an inner diameter of 112 mm and a wall thickness of 40 mm. The cross-sectional reduction is 30.7% and the stretching



= 1.44. During this deformation, high temperatures arise on the inner surface during rolling. Therefore, special care must be taken to ensure that the temperature on the shell inner surface does not exceed 1170°C . Otherwise, inner surface defects must be expected due to grain boundary melt-out. Changes in roll speed and transport angle can be used as control variables. The third deformation step is striking on the push bench. A push bench billet with an outer diameter of 122.8 mm, an inner diameter of 112 mm and a wall thickness of 5.4 mm is produced as the selected final size. After being pushed through a number of stands, the billet from the bar is detached in a detaching mill in the form of an internal die. The temperature of the billet continues to drop until the extracting duo and reaches, in the described case, a level in the range of 650° to 700°C . After extraction of the push bar, the billet bottom is created. According to the invention, the billet, before entering the reheating device, is subjected to controlled cooling to attain a uniform temperature distribution in the range between 650°C and 700°C . In this case, a temperature of approximately 670°C is striven for. The billets are held for a certain time in a heat-insulating buffer, so that heat can flow from the areas of the billet with a higher temperature to the areas with a lower temperature. The heat insulation ensures that the total level of the billet temperature does not fall below the preset target value. In this example, the temperature of the reheating furnace is set in such a way that a temperature of roughly 740°C is achieved in the deformation material. At this temperature, the billet runs into a stretch reducing mill. This mill comprises a large number of three-roll stands, which are arranged offset by 120° in a roll line. For the selected example with the final dimensions of 40.9×4.8 mm, 29 stands are used. The partial deformation in the base stands equals a cross-sectional reduction of between 7.1 and 8.1%. The total deformation equals 72.7% in keeping with a stretching of 3.66. The deformation conditions are selected (i.e., the pass design and roll speed are chosen and the cooling is adjusted) in such a way as to permit a slight temperature increase to 760°C . This ensures that deformation in the stretch reducing mill takes place completely in the two phase region $+$ Fe_3C . After cooling, tubes of 100Cr6 rolled in this manner have a microstructure that comes near to the spheroidal cementite microstructure. The finely dispersed microstructure consists of



spheroidized cementite with slight pearlite residues. The brinell hardness of the tube produced in this fashion is below 250 HB30. The distribution of hardness values is slight. The microstructure is finer than that achieved by standard spheroidal cementite annealing, as can be seen by comparing Figures 1 and 2.

The tube produced according to the invention can be further processed without additional heat treatment in a chipless or metal-cutting fashion. This processing can consist, for example, of cold drawing. By means of the selected process, which includes

- deliberate temperature control before entry into the reheating furnace
- reduced reheating furnace temperature, compared to the usual method
- rolling in the two-phase region
- omission of spheroidal cementite annealing lasting over 16 hours

a much thinner decarburized layer is obtained, compared to the known prior art. The tube dimensions needed for machining can therefore be reduced. Despite stress-relief annealing after straightening, cold-drawn tubes with microstructure attainable according to the invention have the same properties as cold-pilgered tubes.

To make clear the difference between the new process technology and the known prior art, products of the same final size (40.9 mm outer diameter x 4.8 mm wall thickness) were also rolled of 100Cr6 according to the usual method. The hardness found in these tubes equaled 328 HB30 at a reheating furnace setting of 1000°C. This hardness is so high that spheroidal cementite annealing is required prior to further processing.

In producing thick-walled hot tubes, e.g., 60.3 x 8.0 mm, it is advantageous to control cooling based on the TTT diagram in such a way that an isothermal holding period is introduced above the martensite point, but below the bainite nose. The temperature range is preferably between 240° and 300°C. After a holding period of more than 3.5 hours in this temperature range, cooling to ambient temperature can take place.



THIS SHEET HAS BEEN
REPLACED

Patent Claims:

1. Process for producing a hot-worked elongated product, especially bar or tube, from high alloy or hypereutectoid steel, in which the feed length of selected feedstock heated to deformation temperature is reheated after one or more deformation steps to a temperature below the original deformation temperature and is deformed by continuous rolling in a multi-stand reducing mill to the final size and then cooled in resting air,
characterized by the fact
that after the first deformation steps and before reheating, a uniform temperature distribution is produced, seen over the length and thickness of the intermediate product, by means of controlled heating or cooling to a preestablished temperature within a certain temperature range, and the subsequent reheating is carried out either to a temperature below A_{c1} but above 650°C or to a temperature above A_{c1} but below A_{cmn} in the two-phase region, and the deformation and cooling and, as needed, the additional external heating in the reducing mill are coordinated in such a way that the temperature increase of the rolled material remains small relative to the initial temperature, and the rolled material, during deformation in the reducing mill and upon leaving the roll mill, is located in the two-phase region with respect to temperature, whereby the minimum deformation, expressed as stretching, is ≥ 1.5 for the total deformation and $R\text{-value} \geq 1.03$ for the minimum partial deformation in a single stand of the reducing mill.
2. Process as in Claim 1,
characterized by the fact
that the preestablished temperature for temperature equalization prior to reheating is in the range between 650°C and 700°C .





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3. Process as in Claims 1 and 2,
characterized by the fact
that the reheating of the rolled material is carried out to a temperature in a range above 650°C but below 710°C or in a temperature range greater than 710°C but less than 880°C.
4. Process as in the Claims 1 to 3,
characterized by the fact
that the temperature increase or the temperature decrease of the rolled material in the reducing mill is kept within narrow limits by means of a cooling means control, in special cases, a heat addition by an external heating device, and the variation of roll geometry, roll speed and pass reduction.
5. Process as in the Claims 1 to 4,
characterized by the fact
that when a hypereutectoid steel, especially an anti-friction bearing steel, is used, the maximum respective sulphur and phosphorus contents are 0.005 mass share in percent and a range between 1.35 and 1.52 is selected for the chromium-carbon ratio.
6. Process as in Claim 5,
characterized by the fact
that the Cr/C ratio is preferably 1.45.
7. Process as in one of the Claims 1 to 6,
characterized by the fact
that a strand cast bar without any predeformation, i.e., in the cast state and without prior heat treatment (diffusion annealing), is used as the feedstock.



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8. Process as in the Claims 1 to 7,
characterized by the fact
that the deformation rate in the initial deformation steps before temperature equalization is selected in such a way that the highest temperature in the interior of the rolled material does not exceed 1170°C .
9. Process as in the Claims 1 to 8,
characterized by the fact
that after rolling, the rolled material is cooled to a temperature above the martensite temperature and below the bainite nose (continuous TTT diagram), held for a longer time, and then cooled in the known manner to ambient temperature.
10. Process as in the Claims 1 to 9,
characterized by the fact
that the finished rolled product, after cooling to a temperature between 650° and 700°C , is heated and held for a preestablished time and then cooled again and subsequently tempered at a temperature between 180° and 210°C with subsequent cooling in resting air.