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(54) **METHOD OF THERMOMECHANICAL PROCESSING OF LOW-CARBON BAINITIC STEEL WITH RETAINED AUSTENITE, APPLICATION OF THE STEEL OBTAINED BY THE METHOD**

(57) A method of thermomechanical treatment of bainitic steel with retained austenite carried out by austenitization, hot forging and cooling, characterized by the fact that the initial material with the mass content of individual elements: not more than 0.22% mass. C, not less than 3% mass. Mn, not less than 0.9% mass. Si, not more than 0,8 % mass. Al, not less than 0.1% mass. Mo, not less than 0.03% mass. Ti and not less than 0.03% mass. V, where the minimum total addition of Si and Al is

1.5% mass, and the minimum total addition of Ti and V is 0.1% mass, and the rest is Fe, austenitized at a temperature 1100-1150°C, then hot forged at a temperature 900-980°C during the last deformation step during forging, and then cooled at an average cooling rate of the forging in the range of 50 - 2 °C/s to a temperature 390-410 °C and isothermally held at this temperature for 10-20 min, then cooled in air to room temperature.

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Description

[0001] The subject of the invention is a thermomechanical processing method of low-carbon bainitic steel containing retained austenite, in particular for forgings. High-strength bainitic steel with retained austenite is intended especially for forgings showing increased plasticity and resistance to the development of contact-fatigue defects.

The method of obtaining high-strength bainitic steel containing retained austenite was shown for example in the American application US20210047705A1, in which the range of element content is as follows: C less than 0.4%, Si more than 1%, Mn is in the range of 0.2-1%, Mo is in the range of 0.4-0.8%, Cr is in the range of 0.1-0.9%, expressed in mass %, while the rest of the composition are unavoidable impurities and Fe. Due to the low manganese addition such steel requires a high carbon content and is intended for sheets. High-strength bainitic steel containing retained austenite with increased manganese content has been shown in the Japanese patent JP6765495B2, in which the element content range is as follows: C from 0.1 to 0.4%, Si from 1 to 2%, Mn from 1 to 2.5 %, Cu from 0.25 to 1%, B from 0.0001 to 0.035%, Ni from 0.1 to 1%, expressed in mass %, while the rest of the composition are unavoidable impurities and Fe. Despite increasing the manganese content to the maximum 2.5%, this steel still requires the addition of carbon up to 0.4% and it is also intended for flat products. The method of obtaining high-strength bainitic steel containing retained austenite with an increased manganese content and its thermomechanical processing and heat treatment were shown in a research article (Opiela M., Grajcar A., Pakieta W.: Effect of hot deformation and isothermal holding temperature on retained austenite characteristics in 3 -5% Mn multiphase steels. Bulletin of the Polish Academy of Sciences, 71(2), 2023), in which the range of element content is as follows: 0.18% C, 3.6% Mn, 1.7% Al, 0.2% Si, 0.2% Mo, 0.04% Nb, 0.004% S, 0.008% P. Due to its chemical composition, this steel did not allow obtaining more than 10% of retained austenite in the structure and it is susceptible to the formation of blocky fresh martensite during cooling.

[0002] Due to the increasing requirements concerning plasticity and resistance to the development of contact-fatigue defects in high-strength steels, especially high-strength forgings it is necessary to introduce lath-type retained austenite in the amount $\geq 10\%$ into their structure, which requires the manganese addition as an additional element stabilizing this phase. It is also necessary to carry out the heat treatment process immediately after hot forging (thermomechanical treatment) in order to refine the structure, which leads to an increase of the strength properties. The optimized chemical composition of steel and the combination of thermomechanical and heat treatment will shorten the process, which will reduce production costs and shorten the technological process. The production of elements with larger cross sections such as forgings, additionally requires greater control during the process and less sensitivity of the material to changes in a cooling rate by increasing hardenability in order to obtain homogeneous structure both at the surface and core of the forging.

[0003] In the solutions concerning bainitic steels with retained austenite shown so far, an increased carbon content was used to stabilize the austenite, which allows for the stabilization of the austenite, but decreases the economic indicators of the material and reduces its fracture resistance due to the generation of a large amount of brittle carbides. This necessitates the addition of a high silicon content. The increased carbon content in the alloy allows to obtain a fine-grained bainitic structure containing retained austenite, which however requires a long production process. Plastic deformation (forging or rolling) and heat treatment after reheating were also carried out separately, which resulted in the recrystallization of the structure and the loss of grain refinement effect resulting from previous deformation. Each of the above-mentioned approaches is characterized by disadvantages and/or limitations that increase production costs and/or lead to obtaining reduced mechanical properties of the finished product.

[0004] The subject of the invention is a method of thermomechanical treatment of bainitic steel with retained austenite carried out by austenitization, hot forging and cooling, characterized by the fact that the initial material with the mass content of individual elements: not more than 0.22% mass. C, not less than 3% mass. Mn, not less than 0.9% mass. Si, not more than 0.8 % mass. Al, not less than 0.1% mass. Mo, not less than 0.03% mass. Ti and not less than 0.03% mass. V, where the minimum total addition of Si and Al is 1.5% mass, and the minimum total addition of Ti and V is 0.1% mass, and the rest is Fe, austenitized at a temperature 1100-1150°C, then hot forged at a temperature 900-980°C during the last deformation step during forging, and then cooled at an average cooling rate of the forging in the range of 50 - 2 °C/s to a temperature 390-410 °C and isothermally held at this temperature for 10-20 min, then cooled in air to room temperature. Application of steel obtained by the method according to claim. 1 for the production of forgings.

[0005] The B_s temperature is above 460 °C for isothermal heat treatment, the incubation time of the bainitic transformation is below 10s for the isothermal holding range between 380 and 460°C, the bainitic transformation completion time is below 25 min for the isothermal holding range between 380 and 460 °C, and the M_s temperature is below 400°C. The steel has the following structural composition: less than 3% of fresh blocks of martensite, more than 80% of carbide-free bainite, more than 10% of retained austenite in the form of laths with a thickness of not exceeding 0.6 μm with a weight content of C min. 1.1%.

[0006] Aluminum and silicon added to steel with a total content of at least 1.5% mass prevent the formation of cementite in steel allowing to enrich the austenite in carbon during the isothermal holding process. However, the aluminum content must not exceed 0.8% to not reduce the hardness and strength of the steel. Moreover, the addition of aluminum also

shortens the incubation time and accelerates the bainitic transformation, which is economically beneficial.

[0007] Manganese is used to stabilize the retained austenite and improve the hardenability of steel. Molybdenum is used to increase solid solution strengthening and to improve the hardenability of steel. Increasing the hardenability of steel and, consequently, reducing its sensitivity to the cooling rate due to Mn and Mo is necessary to achieve a uniform bainitic transformation at the surface and in the core after cooling the forging to the isothermal holding temperature.

[0008] The total addition of Ti and V a minimum of 0.1% mass allows to obtain fine austenite grains during the hot forging process and ensures the strengthening of the bainitic ferrite matrix with TiC and VC carbide nanoparticles. It has been experimentally established that the refinement of the austenite grain also increases the resistance to wear processes of bainitic steels. However, maintaining the proportions between the content of molybdenum, titanium and vanadium allows you to control the growth of TiC and VC particles in technological processes.

[0009] The content of alloy additions in the steel according to the invention is set to achieve a specific hardenability and critical temperatures: B_s and M_s , as well as the kinetics of the bainitic transformation, i.e. the incubation time and the completion time of the bainitic transformation. Designing the steel meeting above requirements allows for carrying out the bainitic transformation at a relatively low temperature, which increases the strength properties of the steel and also allows for a shortened isothermal step, which shortens the technological process and reduces its costs.

[0010] Cooling the steel which is the subject of the invention, after the forging process to the temperature in a range of 390-410°C allows the formation of fine fine-lath bainite and stabilization of more than 10% of retained austenite in less than 15 min., which allows the reduction or elimination of the presence of blocks of fresh martensite in the microstructure.

[0011] Meeting the assumptions defined previously, is a specific technical solution, which is an example of the solution according to the invention.

[0012] The key structural constituent of steel is ductile retained austenite with optimal stability, determined by the carbon content of min. 1.1% weight, which prevents the initiation and development of microcracks during cyclic service conditions and/or may be transformed into martensite (TRIP effect), which causes a gradual strengthening of the forging surface. The structure of multiphase steel according to the invention ensures increased durability of high-strength forgings.

[0013] The chemical composition of the steel according to the invention allows obtaining retained austenite in the structure with the following parameters:

- carbon content min. 1.1% weight
- volume fraction min. 10%; the rest is bainite
- uniform distribution in the structure both at the surface and in the core of the forging in the form of laths with a thickness of less than 0.6 μm .

[0014] The solution according to the invention is explained in more detail in the examples of implementation.

[0015] An ingot with a chemical composition of 0.17C-3.1Mn-1.0Si-0.55Al-0.22Mo-0.034Ti-0.073V with a cross-section of 100x100mm and a mass of 100 kg was produced using a vacuum furnace in an argon atmosphere. Then, the ingot was initially forged into a rod with a diameter of 80 mm. The forging process was preceded by austenitizing of the ingot in a furnace at 1150°C for 60 min; the same austenitizing parameters were used during the next hot forging cycle. Hot forging was carried out in a press in two deformation steps at the following temperatures: 1100°C (I) and 980°C (II). The forging obtained in this way was cooled in air to the temperature of 400°C and heat treated for 10 minutes. Then, the forging was cooled in air to the room temperature.

[0016] The chemical composition of multiphase steel (% mass) according to the invention is shown in Table 1.

Table 1

Melt	C	Mn	Si	Al.	Mo	Ti	V	P max	S max
S837	0.17	3.1	1.0	0.55	0.22	0.034	0.073	0.015	0.013

[0017] The mechanical properties are shown in Table 2.

Table 2

Melt	YS, MPa	UTS MPa	TEI, %	HV10
5837	760	1030	16	380

[0018] Fig. 1 shows DCCT and DTTT diagrams for steel according to the invention from the melt named as 5837. The DCCT diagram indicates that cooling after plastic deformation to 390-410°C at a rate in the range of 50 - 2 °C/s allows avoiding phase transformations, which is important in the case of bainitic steels, and the M_s temperature is 382 °C. The

DTTT diagram shows that for the isothermal holding temperature range between 380 and 460°C, the incubation time of the bainitic transformation is below 5 s and the transformation is completed within 25 min, which results in a hardness higher than 370 HV. Fig. 2 shows a scheme of thermomechanical processing of a steel forging according to the invention, consisting of hot forging with finishing deformation temperature of 980 °C, cooling at an average rate in the range of 50 - 2 °C/s to a temperature of 400 °C and held the steel at this temperature for 10 min and finally cooled in air to the room temperature. Fig. 3 shows the microstructure of the steel according to the invention obtained using scanning electron microscope at magnification of 10,000×.

10 **Claims**

1. A method of thermomechanical treatment of bainitic steel with retained austenite carried out by austenitization, hot forging and cooling, **characterized by** the fact that the initial material with the mass content of individual elements: not more than 0.22% mass. C, not less than 3% mass. Mn, not less than 0.9% mass. Si, not more than 0,8 % mass. Al, not less than 0.1% mass. Mo, not less than 0.03% mass. Ti and not less than 0.03% mass. V, where the minimum total addition of Si and Al is 1.5% mass, and the minimum total addition of Ti and V is 0.1% mass, and the rest is Fe, austenitized at a temperature 1100-1150°C, then hot forged at a temperature 900-980°C during the last deformation step during forging, and then cooled at an average cooling rate of the forging in the range of 50 - 2 °C/s to a temperature 390-410 °C and isothermally held at this temperature for 10-20 min, then cooled in air to room temperature.

2. Application of steel obtained by the method according to claim. 1 for the production of forgings.

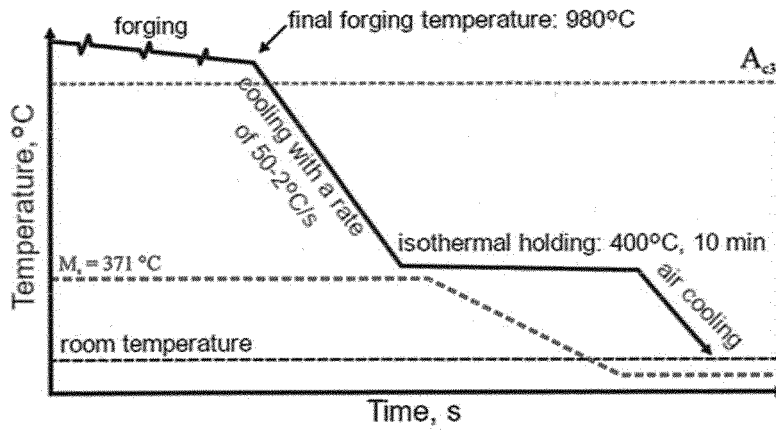


Fig. 2

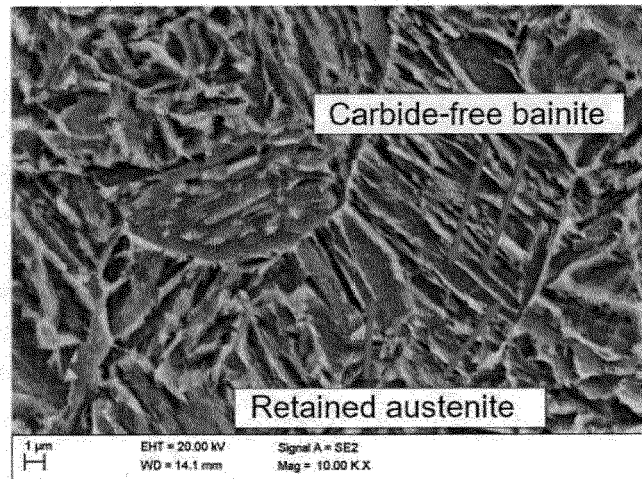


Fig. 3

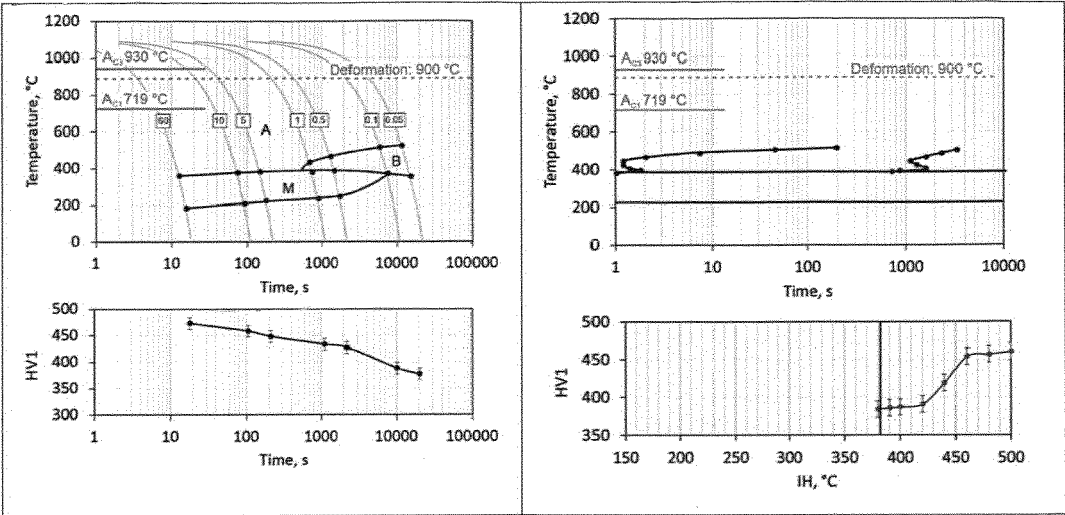


Fig. 1



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Application Number
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 5 June 2024	Examiner Abrasonis, Gintautas
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EUROPEAN SEARCH REPORT

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Place of search		Date of completion of the search	Examiner
The Hague		5 June 2024	Abrasonis, Gintautas
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